Coastal Resilience Center of Excellence
Research Lead

based at

The University of North Carolina at Chapel Hill

YEAR 3 ANNUAL REPORT

Reporting Period:
July 1, 2017 – June 30, 2018
Award Number 2015-ST-061-ND0001-01

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Theme 3: Disaster Dynamics

Theme 4: Education and Workforce Development

Appendices

DHS S&T Coastal Resilience Center of Excellence

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Year 3 Annual Report

July 1, 2017 – June 30, 2018

I. INTRODUCTION AND CENTER OVERVIEW

This report provides a description of the activities and accomplishments of the Coastal Resilience Center of Excellence (CRC) that occurred during Year 3 of the Center's operations, covering the reporting period July 1, 2017, to June 30, 2018.

Report Structure

The first section of this annual performance report summarizes the administrative/management structure of the CRC, followed by a description of selected activities that were undertaken at the Center level during Year 3, including summaries of a few of the supplemental studies carried out by the CRC, a description of ongoing program activity, and several CRC-hosted events.

Following the summary is a section containing individual progress reports from each of the CRC PIs. The CRC provided a template to help PIs write an overarching report that stretched back to the beginning of their projects (January 1, 2016), and allowed PIs to describe in detail their research and education activities; progress in achieving project milestones; efforts towards transition of project outputs; interactions with end-users and stakeholders; and student activity. In addition, the template included a customized chart for each PI to report on project metrics for Year 3. These metrics are reported in the aggregate to DHS OUP each calendar year.

Finally, this report includes three appendices: Appendix A contains reports submitted by student recipients of CRC's Science and Engineering Workforce Development Grant; Appendix B contains material that supplements the reports of several individual PIs; and Appendix C contains a list of journal articles, conference papers, and other documents produced by PIs with support from CRC.

CRC Project Composition

At the beginning of the reporting period, CRC managed a total of 22 projects carried out by partners from 21 universities, colleges and three private-sector firms located in 12 U.S. states and one U.S. territory. Seven projects focused on enhancing and institutionalizing education and workforce development programs at partner institutions; of these partners, four are classified as

Minority Serving Institutions (MSIs). The remaining 15 CRC projects focused primarily on research in coastal hazards modeling, planning, and social and behavioral sciences. Prior to and following the Center's Biennial Review, the CRC's project portfolio was modified by termination of seven projects, including five research and two education projects. Additional information about the Biennial Review can be found in the following section.

All but one of the education projects were initially planned as five-year projects, and all initial research projects were two-year projects. Project funding through Year 3 was administered in three phases covering the following periods:

- Year 1: January 1, 2016, through June 30, 2016
- Year 2: July 1, 2016, through June 30, 2017
- Year 3:
    - July 1, 2017, through December 31, 2017, with a no-cost extension to June 30, 2018 (research projects)
    - July 1, 2017 through June 30, 2018 (education projects)

All Research Project PIs were provided the opportunity to work through to the end of Year 3, including the no-cost extension period to June 30, 2018, regardless of their scheduled or actual end-dates.

Summary Statistics

Between July 1, 2017, and June 30, 2018, PIs at the CRC made steady progress on their projects, as demonstrated by the following aggregated figures:

- PIs taught approximately **60 courses** to **830 students** across seven campuses, including class offerings in multiple categories, such as majors, minors, concentrations, certificate programs, seminars, and electives.

- Students were involved in more than **50 internships** related to Homeland Security.

- **33** students received **Homeland Security-related degrees**, including 15 at the graduate-level.

- **14** students secured **employment in Homeland Security**-related fields.

- **73** journal articles were submitted and/or published.

- PIs gave more than **159** project-related **presentations** in a variety of settings, including professional conferences, visiting lecture series, panel discussions and outreach events, among others.

- Center partners reported more than **$1.5 million in leveraged support** and nearly **$7.5 million in non-OUP funding**. Funding came from a variety of sources, such as government agencies, foundations and internal institutional programs.

CRC Administration and Management

The structure and associated roles and responsibilities of the CRC remained largely unchanged from the original organization chart established in Year 1, with the notable exception that Thomas Richardson took on the role of Executive Director, and Jessica Southwell was hired as Project Manager for the Hurricane Matthew Disaster Recovery and Resilience Initiative (HMDDRI) (see Figure 1). These changes were implemented to enable Director Gavin Smith to continue applying a significant portion of his effort to leading HMDRRI, with the goal of assisting six communities in eastern North Carolina recover from the impacts of Hurricane Matthew.

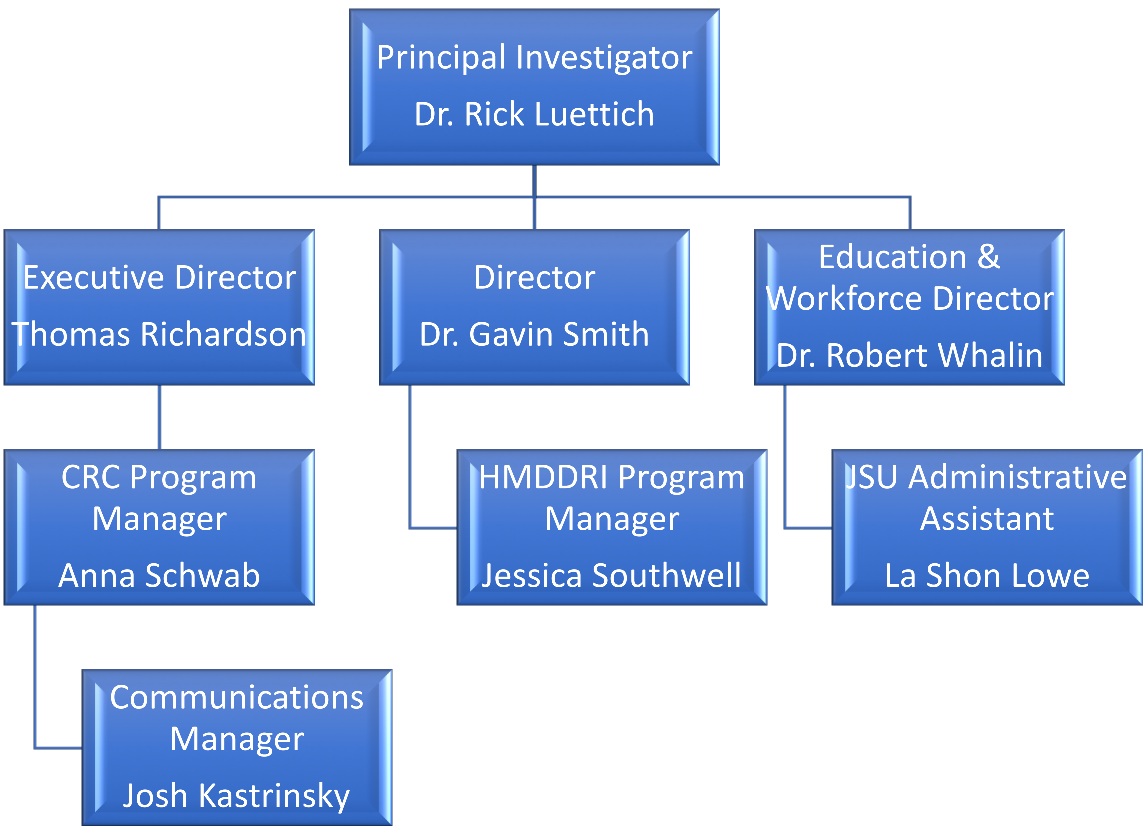


Figure 1: The CRC organizational chart

Frequent communication among members of the CRC management team continued to be an essential mechanism for ensuring coordination and integration during Year 3. Weekly meetings were held every Monday morning with Center management and staff. A running chronological narrative for each issue and task was captured, listed, and assigned to a member of Center management for implementation. Monthly Center conference calls with PIs and Advisory Board members continue to be used to discuss business matters, plans and upcoming events, and address questions. The Coastal Resilience Center email listserv was used throughout Year 3 to send messages regarding important management issues, as well as information of general interest. Subscribers to the CRC listserv included PIs, Center management, Advisory Board members, and the DHS Program Manager.

CRC Communications

The CRC communicates information about its projects, events, successes and interactions with end users through the following:

- News posts placed on the CRC website
- Blog posts from students and PIs
- Electronic newsletter issued 10 times a year
- Social media (Twitter and Facebook)
- Videos produced by CRC and in partnership with other groups
- Media interviews about CRC projects and expertise regarding current events

The CRC newsletter has about 1,600 recipients; social media posts reach an audience of about 1,700 users, totaling about 32,000 impressions per month for CRC posts. The CRC website receives an average of about 1,750 unique visitors per month.

Unified Business Center

Essential support functions during Year 3 were provided by the Renaissance Computing Institute's Unified Business Center (UBC), including: assistance with grant management, financial administration, human resources, travel, event planning, purchasing, and other administrative functions. The UBC also continued to provide pre- and post-award administrative services, including developing, executing, and managing subcontracts.

CRC Advisory Board

Many members of the CRC Advisory Board who served during Years 1 and 2 continued to be involved in the Center through Year 3 as well. Board members have helped the Center by reviewing and providing feedback on overall Center activities, evaluating current projects, and helping to place graduate students in internships and careers. Board members also help to identify transition partners, and to serve as subject matter experts as needed.

The primary mechanism for transmitting Board recommendations was the closed-door session immediately following the Center's Annual Meeting, as well as through separate communications with individual Board members.

The following members served on the CRC Advisory Board during Year 3:

- **Norma Anderson,** Founder, The William Averette Anderson Fund (BAF) for Hazard & Disaster Mitigation Education and Research
- **Doug Bellomo,** Institute for Water Resources, US Army Corps of Engineers
- **Chad Berginnis**, Executive Director, Association of State Floodplain Managers
- **Curtis Charles,** Vice President for Research, Development, and Innovation, RLM Communications

- **Dr. John Cooper, Jr.,** Associate Professor of Practice, Landscape Architecture and Urban Planning Department, Texas A&M University
- **Dr. Reginald DesRoches**, Dean's Professor and Chair, Civil and Environmental Engineering, Georgia Institute of Technology
- **Dr. Billy Edge,** Professor of Civil, Construction, and Environmental Engineering, North Carolina State University
- **Dr. Gerald Galloway**, Glenn L. Martin Institute Professor of Engineering, University of Maryland
- **Dr. Diana Harrington**, Distinguished Professor of Finance, Babson College
- **Dr. William Hooke,** Senior Policy Fellow and Director of Policy Programs, American Meteorological Society
- **Dr. Gary LaFree**, Director, National Consortium for the Study of Terrorism and Responses to Terrorism (START)
- **Dr. James Martin**, Professor and Chair of Civil Engineering, Clemson University
- **Dr. Jae Park**, Recovery and Hazard Mitigation, AECOM
- **Dr. John Pine**, Director, Research Institute for Environment, Energy & Economics, Appalachian State University
- **Anthony Pratt,** Shoreline and Waterway Administrator, State of Delaware
- **Dr. Linda Rimer**, Region IV Liaison for Climate Resilience, U.S. Environmental Protection Agency
- **Ellis Stanley**, Executive Vice President, Hammerman & Gainer International and former General Manager, City of Los Angeles Emergency Preparedness Department
- **Dr. Lee Weishar,** Senior Scientist, Woods Hole Group, Inc.

II. CENTER-LEVEL ACTIVITIES

Over the course of Year 3, the CRC administrative and management team carried out multiple activities on behalf of the Center, as summarized below.

Biennial Review

The Office of University Programs (OUP) conducts Biennial Reviews of DHS Centers of Excellence throughout the performance period of their cooperative agreement grants with DHS. The purpose of the CRC's Biennial Review was to assist OUP in evaluating the COE's research and education portfolio at the project level. OUP uses the results of the review to determine which projects should continue to be funded and to develop recommendations for future directions of research and education for the Center. Three projects were eliminated prior to the Biennial Review based on results of the Center's Second Annual Program Review meeting, during which the Federal Board of Directors reviewed all CRC projects.

The Biennial Review involved two phases:

- **Phase I - Scientific Quality Letter Review**. OUP held the letter review from August 14-September 9, 2017, to assess the scientific quality and merit of each project. The review was held virtually with multiple subject matter experts from academia, government and the private sector. Beginning in Year 2, the CRC provided substantial input to Phase I of the biennial review process, which involved developing and submitting written materials about each project. CRC provided extensive guidance to PIs to assist them in preparing their Phase

I review materials, which included a two-page Project Summary, a Literature Review, an NSF Biosketch, a Stakeholder Point of Contact List and additional information to help the reviewers evaluate the projects' scientific quality or educational merit.

Phase I resulted in the elimination of four projects.

- **Phase II - Mission Relevancy Federal Board of Directors Review**. OUP held the in-person Phase II of the Biennial Review on December 12-13, 2017, in Arlington, Va. (Phase II was originally scheduled for October 2017, however, hurricanes Harvey, Irma and Maria made it impossible for reviewers, the Center and the OUP program manager to participate at that time due to active disaster operations). The purpose of Phase II was to assess the relevance of each project to DHS mission requirements.

  During Phase II, members of the CRC management team and support staff presented information about each active project, as well as an overview of the CRC and its organizational structure, management processes, communications, integration of research and education, external leveraging, and CRC's draft sustainability plan. Twenty-two Federal Board of Director reviewers participated from DHS (FEMA, USCG, NPPD, Policy and S&T) and NOAA, USACE, and NIST.

Biennial Review Outcomes

In addition to identifying projects to be discontinued, the Biennial Review identified projects that the Federal Board of Directors considered essential to meeting their mission requirements. OUP received substantial input from the Federal Board of Directors on how to transition the outcomes of these projects into use by either government or the communities they serve. Based on these inputs and inputs from the S&T Flood APEX Program, the Center was authorized to develop new two-year work plans structured to enable transition.

CRC Annual Meeting

The third annual CRC meeting was held February 28-March 2, 2018, at the Center's main offices in Chapel Hill, NC. While the preceding annual meeting held in 2017 focused nearly exclusively on preparations for the Biennial Review, the annual meeting held during Year 3 provided the opportunity to discuss and reflect upon the Biennial Review process and outcomes.

More than 80 attendees participated in the event, including the CRC management and support team (6); 30 Principal Investigators; 11 CRC Advisory Board members; 14 students (UNC-CH, NCSU, LSU, and JSU); 12 DHS personnel, support staff, and federal Board of Directors; and 10 invited guests, including faculty and students from the University of the District of Columbia, Tiffin University, and others. Over the course of the two-day meeting, PIs presented on progress made to date, as indicated by milestone accomplishments and funding expenditures. During their presentations, research PIs identified committed customers within the Homeland Security Enterprise (HSE), and outlined plans to get their research products into actual use. Education PIs focused on how their projects' course content is kept current, their level of engagement with HSE professionals, and plans for courses to continue post-project.

In addition to PI presentations, the annual meeting agenda included an overview of several Center-lead initiatives, a summary of the Biennial review, and discussions about the CRC's draft business strategy and sustainability of ADCIRC/CERA. The discussions were carried into the closed-door Advisory Board meeting.

CRC Sustainability Plan Development

In anticipation of the need to become a self-sustaining enterprise by the end of CRC's grant performance period in 2020, Center leadership worked with a business development expert at the UNC-CH Business School throughout Year 2, and continued the effort to develop and refine the Center's approach to sustainability during Year 3.

Following the initial four-month assessment of the CRC and its prospects for sustainability, the CRC team, with guidance from the business development expert, came to the following conclusions, which form the core of the Center's draft sustainability strategy:

- Focus: identify/define a "system" within which CRC can add most value
- Join a "Tribe": participate in existing platforms/networks
- Invest: Dedicate personnel to build partnerships and market expertise and tools/products

In addition to developing a general framework for sustainability, the CRC management team focused specifically on progress toward support, maintenance and growth of ADCIRC, using a two-pronged approach:

- ADCIRC for Real-Time Decision Support during major coastal storm events; and
- Bootcamp

Usage of the ADCIRC Surge Guidance System (ASGS) and the CERA web portal has grown substantially, particularly during the 2017 hurricane season, when there was a breakthrough of acceptance and attention as ASGS and CERA supported several state and federal agencies. Next steps include developing financially sustainable revenue streams, including plans for O&M costs, and potential expansion of ASGS/CERA services to include post-storm damage assessment.

Since 2010, attendance at the annual ADCIRC Bootcamp has grown both in the number of participants, along with the cost of attendance. The annual ADCIRC event may provide some level of sustainability through ongoing outreach and training.

CRC management presented the assessment of CRC's sustainability potential and the progress toward ADCIRC sustainability during the CRC Biennial Review in December 2017. The presentation was well received by the review board.

Supplemental Studies

During Year 3, the CRC continued to provide services and expertise to several major studies that fall outside of the core project base. These studies included support to the DHS Flood Apex Program, the Hurricane Matthew Disaster Recovery and Resilience Initiative, and completion of the Resilient Design Education Project, among others. These programs are summarized below, with additional information found on the CRC website.

DHS Flood Apex Program

Research Review Board

The multidisciplinary Flood Apex Research Review Board was established formally in November 2015 by the CRC with 13 members from academia, DHS subject matter experts (e.g., FEMA), other federal, regional, state and local experts, professional organizations, and the private sector. The Research Review Board serves as an expert panel whose responsibilities include:

- Help the DHS Flood Apex Program Manager refine the concept, requirements, and target users of the Program;
- Provide input on existing and developing systems, methods, and data sources;
- Provide advice on gaps in knowledge, data, and technology;
- Review draft products and publications;
- Identify transition pathways to help ensure end-products are useable for target users, particularly as they may have differing levels of capability and capacity

Two more members joined in January 2017, bringing the total to 15 plus the 2 ex-officio members (Smith and Luettich). In April 2018, the Board was reconstituted. Nine members whose original 2-year terms had expired were asked to serve an additional year, and 7 new members were added.

The Board first met informally via webinar in September 2015. Since formal establishment, it has met 9 times (5 via webinar and 4 in person). During Year 3, the CRC organized and managed the following meetings:

- August 24, 2017 – virtual meeting by webinar
- December 18-19, 2017 – in person meeting, Arlington, VA
- April 19, 2018 – orientation for new Board members by webinar
- May 8, 2018 – virtual meeting by webinar

Hurricane Floyd/Hurricane Matthew Empirical Disaster Resilience Study

The purpose of the Hurricane Floyd/Hurricane Matthew study is to improve the understanding of the impacts of state and local level mitigation actions intended to enhance community resiliency, support effective and equitable recovery, and reduce flood fatalities and losses by examining the post-Hurricane Floyd mitigation actions in North Carolina and the consequences of those actions as they relate to Hurricane Matthew, which affected many of the same areas. The study is being conducted by AECOM under subcontract to the CRC. During the first half of Year 3, there were multiple revisions to the subcontract SOW due to a variety of reasons, including data availability. Good progress was made during the second half of Year 3, but work on the subcontract had to be suspended at the end of Year 3 awaiting carryover funding approval from DHS. Work will be completed in Year 4.

Flood Analytics Colloquium

Under the auspices of the DHS Flood Apex program, CRC and the Renaissance Computing Institute (RENCI) planned and co-hosted the "Rethinking Flood Analytics Colloquium." Lead by CRC PI Dr. Sandra Knight (UMD), the invitation-only colloquium brought together thought leaders from many disciplines to explore innovative and disruptive approaches to flood prediction and impact analytics.

More than 50 people attended the Colloquium. Objectives were to convene a multi-disciplinary group of technical specialists and end-users to reimagine flood analytics; and to capture the challenges and gaps in a Proceedings to help shape a coordinated research agenda for flood analytics. Invitees included a select group of innovative data, modeling and analytics experts - both within and outside the flood risk community - and visionary decision-makers that are preparing for the escalating impacts associated with floods.

A report titled "Rethinking Flood Analytics: Proceedings from the 2017 Flood Analytics Colloquium" was produced following the event, and can be found on the CRC website.

HMDRRI

The **Hurricane Matthew Disaster Recovery and Resilience Initiative** (HMDRRI) involves engagement of faculty and students as well as professional planning experts in addressing community and state-level needs associated with recovery from Hurricane Matthew. The initiative's objectives are to:

1. Serve as point of contact for UNC faculty, students and staff to help the state address a range of policy and technical issues as identified.
2. Engage with select communities to assist them identify local needs and help them develop post-disaster recovery plans.

During Year 3, Initiative faculty, staff and students worked with six eastern North Carolina communities - Fair Bluff, Seven Springs, Windsor, Kinston, Lumberton and Princeville. The Initiative worked to assess needs, coordinate resources across multiple levels of administration and develop reports that include HomePlace documents (proposed design standards for rebuilt/retrofitted homes) and open space plans for communities thinking through what to do with the open space created following the buyout and demolition of flood-prone homes.

In August 2017, the Initiative held a five-day Community Design Workshop in Princeville, to design a plan for a more flood-resilient future. The event brought together teams of land use planners, engineers, architects and landscape architects to collaborate with local, state and federal officials to develop three scenarios for a new 52-acre tract of land.

The Initiative is currently finishing plans for each community, including flood retrofit studies of downtown Fair Bluff, Windsor and Seven Springs; land suitability analyses and additional analysis for policies and projects to make communities and neighborhoods more resilient toward future threats. More information about the Initiative, including community-specific news and documents, can be found on the CRC website.

Resilient Design Education Project

During Year 2, DHS S&T provided funding for a CRC study led by Director Gavin Smith and faculty at the Department of City and Regional Planning at UNC-CH. The study aimed to understand how universities throughout the country and across different disciplines teach resilient design. With research assistance provided by graduate students in the CRC's Science and Engineering Workforce Development grant programs, the study involved a review of existing college and university education programs in planning, architecture, landscape architecture, building sciences and engineering that incorporate design approaches to address natural hazards, disasters and climate change adaptation into the curriculum. The study received guidance and feedback from an advisory board made up of academics, private sector industry groups, professional associations and government agency representatives.

The research methodology included a literature review and internet search of institutions and programs involved in the area of resilient design; semi-structured telephone interviews with 16 identified academics and practitioners; and case studies of universities and college programs that show innovation in teaching resilient design. During CRC Year 2, the research team completed approximately six case studies, and developed a list of recurring themes emanating from interviews conducted to date. During Year 3 the research team completed all scheduled interviews, finalized case studies and wrote the final report, which describes the current state-of-the-art in resilient design education, identifies best practices and discusses some of the obstacles and barriers to teaching resilient design. The report will be made available on the CRC website.

CRC Events and Programs

In addition to participating in the Biennial Review, hosting the third annual meeting, and conducting supplemental studies, the Center continued to manage, support, and participate in several established programs that have proven highly successful over the past three years. These programs, described below and in more detail on the CRC website, include: ADCIRC Week and Bootcamp; RETALK, SUMREX, the DHS Summer Research Team Program for Minority Serving Institutions; the PIRE program; and the Career Development and Workforce Development grant programs. Additionally, the CRC planned and hosted two major on-site events during Year 3; helped organize the HBCU Flood and Hurricane meeting held in Jackson, MS; and participated heavily in planning and executing the COE-sponsored Summit in Arlington, VA.

ADCIRC Week 2018

Coastal modelers and decision-makers gathered on April 9-13, 2018, to teach, learn, discuss, plan and build capacity for a tool that provides decision support for hazards like storm inundation during tropical and extratropical cyclones as part of ADCIRC Week 2018. ADCIRC Week, a gathering of professionals, academics, students and officials, was held at the National Oceanic and Atmospheric Administration Center for Weather and Climate Prediction in College Park, Md. The event includes two major sections – the ADCIRC Boot Camp training event and the ADCIRC Users Meeting. More information can be found on the CRC website.

RETALK

The Research Talk program, or *RETALK*, began in Year 1, and involves research PIs delivering an in-person talk to students at a CRC education partner. The talk may be a lecture, seminar or other type of presentation where visiting PI's discuss the details of their research projects as they relate to courses taught at the host institution. Guest speakers may also engage the students in new and different ways of thinking about resilience issues by exposing them to expanded scientific or technical concepts. During Year 3, CRC Director Dr. Gavin Smith gave a RETALK lecture for students attending class at LSU taught by CRC partners Jeff Carney and Robert Twilley.

SUMREX: Summer Research Experience

Every summer since the CRC began operations, select students have benefited from participation in the CRC's summer exchange program. The SUMmer Research Experience, known as SUMREX, is a unique program developed by the CRC. Student support is provided through the project budgets of individual Research PIs.

Through the program, students enrolled in CRC-supported courses at partner universities are hosted by CRC research PIs for several weeks in the summer, where the students receive intensive training, research experience, and mentoring in their chosen fields of study.

During the summer of 2018, student exchanges included:

- DaChawn Kincaid, an undergraduate student at Tougaloo College, visited Old Dominion University.
- Two graduate students from University of Puerto Rico-Mayaguez - Bryan Marrero and Jorge Hernandez – interned at Oregon State University where they worked with PI Dr. Dan Cox to in OSU's wave lab.

Stories of SUMREX students narrated in their own words are shared in the CRC News section and on the Students page of the CRC website.

DHS Summer Research Team Program for Minority Serving Institutions

Two researchers from Norfolk State University (NSU) received continuation funding from the U.S. Department of Homeland Security (DHS) Summer Research Team (SRT) Program, which aims to increase and enhance the scientific leadership at Minority-Serving Institutions (MSIs) in research areas that support the mission and goals of DHS. During their second summer of funded collaboration, Drs. Camellia Okpodu and Bernadette Holmes worked with CRC partners at Old Dominion University, to further advance their study of impacts from and opinions about sea-level rise and other environmental factors faced by minority populations in the Hampton Roads region of Virginia.

NSF PIRE Program

During Year 3, CRC partners continued to be engaged in the National Science Foundation (NSF) Partnerships for International Research and Education program (PIRE) through an award made to Texas A&M University at Galveston. In particular, the program provided a rich summer research experience for Sabrina Welch, a doctoral student in coastal engineering at Jackson State University. She had the opportunity to travel to The Netherlands where she spent two weeks collecting data, interviewing practicing engineers, and touring coastal flood mitigation structures in support of her research as part of the ongoing PIRE project, "Coastal Flood Risk Reduction Program."

Career Development and Workforce Development Grants

With funding from the DHS Office of University Programs, CRC and its predecessor, the CHC, have sponsored a total of four fellowships at UNC-CH through the DHS Career Development Grant (CDG) and the Science and Engineering Workforce Development Grant (WFD). The following update shows where these former students are now.

The first CDG recipient, Lea Sabbag, graduated with a Master's in City and Regional Planning from UNC-CH in Spring 2016 after fulfilling her CDG requirements. She is currently employed full-time at the NC Division of Emergency Management.

Ms. Ashton Rohmer completed the requirements for the CDG program upon graduating from UNC-CH with a Master's in City and Regional Planning in the Spring of 2017. Ms. Rohmer now works with ASI Government as a consultant in support of the National Flood Insurance Program.

With funding from the DHS OUP Science and Engineering Workforce Development grant, two students from UNC-CH - Colleen Durfee and Darien Williams – graduated with master's degrees in City and Regional Planning in Spring, 2018. During the fall and spring semesters, both WFD students worked on the CRC-funded Resilient Design Education Study, a research project lead by CRC Director, Dr. Gavin Smith. They both served as interns during the summer term and into the fall semester on the Hurricane Matthew Recovery and Resilience Initiative, a program funded by the NC Division of Emergency Management and UNC to help six communities in eastern North Carolina recover from Hurricane Matthew.

Mr. Williams is continuing his resilience studies by pursuing a Ph. D in Urban Studies and Planning at the Massachusetts Institute of Technology, where he has secured a position as a research assistant for a project relating to infrastructure resilience in the northeastern United States. He also plans to engage in pre-dissertation work relating to elevation and hazard vulnerability in black communities.

Ms. Durfee has secured a position as the Planning and Zoning Administrator for the City of University City, Missouri. She plans to apply the knowledge and skills she has gained through her experiences as a WFD student to ensuring University City's community facilities, assets, and infrastructure are not prone to degradation from environmental hazards, including extreme heat, winter storms, tornados, and flooding.

Mr. Williams and Ms. Durfee's WFD final reports are included in Appendix B of this report.

HBCU Flood and Hurricane Meeting

With support from DHS OUP, the CRC hosted the Historically Black College and Universities (HBCU) Flood and Hurricane Meeting on August 3-4, 2017. The event was held at the CRC partner Tougaloo College. U.S. Rep. Bennie Thompson was the keynote speaker for the meeting, which addressed the question "*What are the unique contributions HBCU's can make to improve community resilience to floods and hurricanes, and what needs to be done to make this happen?*" The meeting was attended by more than 45 individuals representing 21 HBCUs from 10 states and the District of Columbia. Breakout groups developed several recommendations that have been distilled into action items for implementation.

COE Summit

Following several months of intense planning, organizing and coordinating, on May 30-31, 2018, CRC researchers, staff and students joined 10 other Department of Homeland Security Centers of Excellence (COE) at George Mason University's Arlington, Va., campus, to co-host the 2018 COE Summit, a showcase of the tools and products of center research and education projects. The theme of the event was "University Research and Development to Protect the Homeland." CRC had a prominent role in panels covering "Natural and Man-Made Disasters" and "The 2017 Hurricane Season: Lessons in Resilience." These included discussion of the successes of ADCIRC and CERA in the past few hurricane seasons and the Hurricane Matthew Disaster Recovery and Resilience Initiative.

CRC also had two students, Rowshon Jadid of North Carolina State University and Catherine Nowakowski from the University of Rhode Island, present their research in the student poster showcase.

2017 Hurricane Season

The 2017 hurricane season brought several opportunities for demonstration of CRC tools and expertise. During Hurricane Harvey:

- CRC staff performed approximately 100 ADCIRC storm surge model forecasts during Hurricane Harvey at the Texas Advanced Computing Center at the University of Texas.

- CRC co-PI Dr. Clint Dawson and Dr. Gordon Wells of the University of Texas-Austin were embedded during Harvey at Texas State Emergency Operations Center and interpreted ADCIRC storm surge forecasts for pre- and post-storm planning and response at the Texas EOC.

- ADCIRC storm surge forecasts helped to position rescue and recovery resources in advance of Harvey, execute pre-landfall search-and-clear operations and make preliminary damage assessments in Texas.

The website coastalemergency.org (now cera.coastalrisk.live), which is managed by CRC researchers at Louisiana State University, experienced record usage during hurricanes Harvey and Irma in August and September 2017. The website, which uses ADCIRC to project storm surge and other data on a map overlay for public consumption, recorded 201,000 page views during the week of Sept. 4-11, with a peak of 97,000 page views on Sept. 9. The website typically attracts a few hundred page views per week with a peak of tens of thousands of views per week during previous storm events.

During the season, CRC researchers appeared in more than 70 publications, including The Wall Street Journal, the Associated Press, The New York Times, CBS, CNN, The Guardian, BBC World Service and National Public Radio.

More stories about student work and PI accomplishments, awards and presentations can be found on the CRC news page, media appearances list, project profiles and newsletters.

III. PROJECT REPORTS

The CRC research portfolio spans three research themes: 1) Coastal Infrastructure Resilience projects focus on ways to quantify vulnerability and robustness and on developing tools to assist practitioners. 2)Projects in the Building Resilient Communities theme focus on decision-making processes to include evaluating insurance; planning for hazard mitigation, disaster recovery, and future climate trend adaptation; developing indicators and metrics to measure disaster recovery outcomes; and creating tools to convey findings. 3) The Disaster Dynamics-themed projects emphasize advancing computer modeling capabilities for predicting storm surge, waves, and flooding associated with severe weather events along the U.S. East and Gulf Coasts and communicating the results of these predictions to improve coastal resilience.

Through the fourth theme, CRC addresses education and workforce development by formulating and delivering resilience-oriented undergraduate and graduate courses, concentrations, minors, certificates, and training, with strong emphasis on Minority Serving Institutions. Focus areas in education include coastal and computational engineering, computer science and engineering, social science, coastal infrastructure, disaster science, and natural hazards resilience.

Performance reports for each CRC project are in the section below, organized by theme.
All of the PIs were encouraged to take a retrospective look back to the beginning of their projects while developing their Year 3 reports, with a focus on the cumulative progress made to date. Final reports were submitted for those projects that will not continue into Year 4, as indicated in the list of project titles below.

Theme: Coastal Infrastructure Resilience

Cox; van de Lindt: *Experimental and Numerical Study to Improve Damage and Loss Estimation Due to Overland Wave and Surge Hazards on Near-Coast Structures*

Bennett; Gabr: *Establishment of a Remote Sensing Based Monitoring Program for Performance Health Assessment of the Sacramento Delta* (Final Report)

Wallace: *Community Supply Resiliency-COMSURE* (Final Report)

Theme: Building Resilient Communities

Berke: *Local Planning Networks and Neighborhood Vulnerability Indicators*

Prochaska: *Communicating risk to motivate individual action*

Horney: *Implementing the Disaster Recovery Tracking Tool* (Final Report)

Davidson: *An Interdisciplinary Approach to Household Strengthening and Insurance Decisions* (Final Report)

Opaluch: *Overcoming barriers to motivate community action to enhance resilience* (Final Report)

Yusuf: *Stakeholder/End User Engagement Support of Two CRC Projects (Former project title: A Tool to Measure Community Stress to Support Disaster Resilience Planning)* (Final Report)

Theme: Disaster Dynamics

Blanton: *A multi-tiered ADCIRC-based storm surge and wave prediction system*

Dietrich: *Improving the Efficiency of Wave and Surge Models via Adaptive Mesh Resolution*

Hagen; Medeiros: *Development of an Optimized Hurricane Storm Surge - Wave Model for the Northern Gulf of Mexico for use with the ADCIRC Surge Guidance System*

Ginis; Huang: *Modeling the combined coastal and inland hazards from high-impact hypothetical hurricanes*

Resio: *The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency*

Twilley: *Integrated Approaches to Creating Community Resilience Designs in a Changing Climate*

Theme: Education

Chen/Faik: *Preparing Tomorrow's Minority Task Force in Coastal Resilience through Interdisciplinary Education, Research, and Curriculum Development*

Laiju: *Institutionalization, Expansion, and Enhancement of Interdisciplinary Minor: Disaster and Coastal Studies*

Pagan-Trinidad: *Education for Improving Resiliency of Coastal Infrastructure*

Smith: *Expanding Coastal Resilience Education at UNC - University of North Carolina*

Whalin: *PhD in Engineering (Coastal/Computational) at an HBCU - Jackson State University*

Keim: *Disaster Science and Management Program at LSU* (Final Report)

Knight: *Development and Testing of a Project Management Curriculum for Emergency Managers* (Final Report)

Theme 1

Coastal Infrastructure Resilience

COX, OSU
Van de LINDT, CSU
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Experimental and Numerical Study to Improve Damage and Loss Estimation due to Overland Wave and Surge Hazards on Near-Coast Structures

Principal Investigator Name/Institution:
Dr. Daniel Cox, Professor, Oregon State University
Dr. John van de Lindt, Professor, Colorado State University

Co-Principal Investigators and Other Partners/Institutions:
Bill Coulbourne, Applied Technology Council
Chris Jones, consulting coastal engineer

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description ("elevator speech"):

This project will develop an accurate method to determine damage to buildings subjected to extreme surge/wave forces during hurricanes. The methodology will use large-scale hydraulic model testing combined with numerical simulations to improve existing risk software used by DHS/FEMA and to advance risk-based design methodologies to enhance coastal infrastructure resilience. The method will be consistent with other multi-hazard frameworks such as earthquake and wind engineering

Summary Abstract:

This project focuses on Theme 1 – Coastal Infrastructure Resilience; Topic 1a – Coastal Infrastructure Planning and Design. As building stakeholders seek to mitigate damage, risk to property and structure loss it is becoming apparent that exiting design methodologies such as those outlined in the FEMA Coastal Construction Manual are inadequate to incorporate the range of building types, storm conditions, and potential for resulting damage. More effective decision support tools such as FEMA's HAZUS-MH rely on a framework of multi-hazard fragility curves to relate the hazard and affected buildings to compute/predict an expected level of damage and subsequent losses. Although there have been significant advances in this correlation for wind earthquake loading and some preliminary work for tsunamis, the coastal surge and wave response of structures remains poorly defined, primarily due to a lack of large-scale data and the complexity of the fluid/structure interaction modeling. This project will significantly improve HAZUS input fragilities for surge and wave through a robust experimental and numerical study of the interaction of surge and waves with near-coast structures. The overall goal of this project is to develop accurate fragilities for near-coastal structures against overland surge and wave forces for input to HAZUS-MH such that they can be used in a design framework consistent with the risk-based methods used in wind and earthquake engineering We outline these specific

objectives to be completed in two years in order to provide (1) improved accuracy for surge and wave analysis in HAZUS-MH; and (2) innovative advances in risk-informed design methodologies to enhance coastal infrastructure resilience:

- ***Objective 1:*** Quantify wave forces on near-coast structures for a range of surge levels based on a mid-scale hydraulic model test program, and develop new predictive equations for horizontal and vertical forces.
- ***Objective 2:*** Develop the conditional probabilities (fragilities) for exceeding key thresholds which will be linked to damage levels available in HAZUS-MH.
- ***Objective 3:*** Illustrate next-generation risk-informed design for near-coast structures that have been shown to be vulnerable to hurricane surge and waves using the fragilities developed in (2). This will improve the ability of building occupants to return following the hurricane thereby improving the resiliency of the community.

This project will have a direct impact on estimating probable damage and loss of existing coastal infrastructure by providing improved load-response relationships to HAZUS-MH for surge and wave and develop a risk-informed framework for future engineering design of near-coast structures. While beyond the scope of this study, the results could also help improve the potential designs associated with the retrofit of existing structures funded through FEMA hazard mitigation grant programs and the implementation of improved coastal building codes.

PROJECT NARRATIVE:

1. <u>Research Need:</u>

Hurricanes Sandy in 2012, Ike in 2008, and Katrina and Rita in 2005 have underscored the significant and growing risk to coastal communities due to surge and wave hazards. Hurricane-induced economic losses in the United States have increased steadily over the past 60 years and are now $35.8 billion *annually*. Approximately 50 percent of the U.S. population lives within 50 miles of a coastline, and the physical infrastructure to support this population was estimated in the 1990s to be over $3 trillion in the Gulf and Atlantic regions. These problems are compounded by global climate change resulting in increased sea levels and increases in the intensity and frequency of extreme windstorms. The overall vision for this project is to support the broader vision of the CRC to increase the resilience of near-coast structures to coastal hazards. Resilience is the ability of a system to absorb and recover from a sudden disturbance.

Our project is linked to "Mission 5: Ensuring Resilience to Disasters" as listed in the DHS Strategic Plan Fiscal Years 2012 – 2016. Goal 5.1 is to Mitigate Hazards by "strengthening the capacity at all levels of society to withstand threats and hazards." Moreover, Objective 5.1.2 Mitigate Risk to Communities will "improve community capacity to withstand disasters by mitigating known and anticipated threads and hazards." Our project will link directly to Goal 5.1 and Objective 5.1.2 by understanding the damage to the built environment as a result of coastal hazards produced by hurricanes and other coastal windstorms. The overall aim of the DHS CRC is to improve the Nation's ability to safeguard people, infrastructure and economies from catastrophic coastal disasters. By improving FEMA's (HAZUS-MH) ability to predict damage and loss estimates due to waves and surge and developing a framework for new design methodologies for near-coast structures, this project will enhance the resilience of the Nation's coastal infrastructure to hurricane and other coastal hazards. By improving the predictions of damage and loss, we will be better positioned to anticipate and manage cascading consequences and interactions between infrastructure and hazards. This project will help reduce losses from hurricanes in the United States. and will assist FEMA's mission in the National Windstorm Impact Reduction Program and the National Flood Insurance Program by improving damage and loss assessment tools consistent with FEMA's program for HAZUS modernization.

2. History:

Task 1.1 Experimental Design. We developed wave/surge boundary conditions; bathymetry; specimen design and placement; test matrix and protocols.

Task 1.2 Physical Model Testing. We conducted the physical model tests at the Hinsdale Wave Research Laboratory at Oregon State University. The test program included specimen construction, instrumentation setup, data acquisition, demobilization, and data QA/QC and data archive.

Task 2.1 Numerical Modeling. We developed a numerical model of archetype coastal residential structures and verified the structural model using existing experimental data.

Task 2.2 Fragility Formulation. We developed initial fragility limit states, producing fragility surfaces that can relate hurricane surge level and wave conditions to the expected building damage. These are intended to be used within DHS/FEMA's HAZUS.

3. Results:

The experimental work was completed successfully and fluid/structure interaction models validated and documented in several archival papers with peer review/feedback. A methodology was developed to combine a state-of-the-science numerical model with an array of surge and wave conditions to develop fragility surfaces. End user outreach was undertaken with the FEMA HAZUS group and plans to discuss implementation of the sample fragilities, as well as plans for additional fragilities discussed.

4. End Users and Transition Partners:

We have had the following people involved in the End-User Transition:

- FEMA HQ
- HAZUS Program Manager, FEMA HQ Risk Management Directorate
- Risk Analyst, FEMA Region VIII
- FEMA Building Science Division
- Chad Berginnis, ASFPM Executive Director and CRC Advisory Board Member

End User Meeting #1: Denver, CO. FEMA Region VIII (April 25, 2017). The meeting took place with Cox, van de Lindt and two end users, HAZUS Program Manager, FEMA HQ Risk Management Directorate, Actuarial and Catastrophic Modeling Branch, and Risk Analyst, FEMA Region VIII. Cox and van de Lindt presented their project results and discuss possible implementations

End User Meeting #2: Washington DC. FEMA HQ (May 19, 2017). The meeting was organized by FEMA HQ. Cox and van de Lindt gave a one-hour presentation on the project to approximately 20 FEMA staff at the meeting and an addition 20 people participating via webinar. Question and answer session followed the presentation. A working lunch continued the discussion with about 3 FEMA personnel.

5. Project Impact:

The real-world impact when the new fragilities are implemented in the HAZUS update over the next several years will be the ability to include more accurate loss estimation for near coastal structures. To this point in time loss estimates in HAZUS do not account for the wave climate for near coastal structures and have used flood fragilities. This is particularly critical for elevated coastal structures whose structural failure may occur as a result of wave action under and at the bottom of the structure.

6. Student involvement and awards:

Year 1: We hosted two SUMEX students from University of Puerto Rico - Mayaguez, Diego Delgado and Kevin Cueto. Kevin and Diego were on the Oregon State University campus from June 18, 2016, to August 5, 2017. Both students participated in an undergraduate research program with 9 other students and completed a project report and presentation on August 4. Kevin is currently enrolled as an MS student at UPR-M. Diego has applied to graduate school at the Univ. Cantabria in Spain.

In Year 2, Dr. Cox visited the Univ. Puerto Rico – Mayaguez. Dr. Cox visit Puerto Rico from March 5 to March 9, 2017, at the invitation of Professors Ismael Pagan and Ricardo Lopez. On March 7, Dr. Cox visited the campus of the University of Puerto Rico Mayaguez campus, met with faculty in civil engineering and marine sciences, met with students, toured the facilities, and gave a seminar on coastal hazards engineering and resilience. On March 8 and 9, Dr. Cox attended the research symposium organized by Profs. Pagan and Lopez in San Juan. Dr. Cox met with engineering practitioners from Puerto Rico and researchers from the USACE. Dr. Cox gave a keynote presentation on this research project.

In Year 2, we hosted two SUMEX students from UPR-M**,** Hector Colon and Peter Rivera. Hector and Peter were on the Oregon State University campus from June 18, 2017, to August 12, 2017. Both students are participating in an undergraduate research program with 17 other students and will complete a project report and presentation on August 9. Both students gave presentations of their project at the International Conference on Coastal Engineering (ICCE) in Baltimore in August 2018.

In Year 3, hosted two SUMREX student from UPR-M, Bryan Acevedo-Adames and Jorge Santiago Hernández. Bryan and Jorge were on the Oregon State University campus from June

17, 2018, to August 17, 2018. Both students are participating in an undergraduate research program with several other students and will complete a project report.

Degrees Obtained

Trung Quang Do, Ph.D., Civil Engineering

7. Interactions with education projects:

We have worked with a total of 6 SUMREX students, 2 each summer and all from the University of Puerto Rico – Mayaguez. We visited UPR-M once during this project in Year 2.

8. Publications:

1. Do, T., van de Lindt, J., Cox, D. "Hurricane Surge-Wave Building Fragility Methodology for Use with HAZUS-MH," (submitted 2018)
2. Tomiczek, T., Wyman, A., Park, H., Cox, D.T. "Application and Modification of Goda's Formulae to Estimate Horizontal and Vertical Forces on Elevated Coastal Structures. Part 1: Nonbreaking Waves," *Coastal Engineering* (re-submitted 2018)
3. Park, H., Do, T., Tomiczek, T., Cox, D.T., van de Lindt, J.W. (2018) "Numerical Modeling of Non-breaking, Impulsive Breaking, and Broken Wave Interaction with Elevated Coastal Structures: Laboratory Validation and Inter-Model Comparisons," *Ocean Engineering*, 158, 15, 78-98. doi: 10.1016/j.oceaneng.2018.03.088
4. Tomiczek, T., Park, H., Cox, D.T., van de Lindt, J.W., Lomonaco, P. (2017) "Experimental Modeling of Horizontal and Vertical Wave Forces on an Elevated Coastal Structure," *Coastal Engineering*, 128, 58-74.
5. Do, Trung, van de Lindt, J., Cox, D.T. (2016) "Performance-Based Design Methodology for Inundated Elevated Coastal Structures Subjected to Wave Load Engineering Structures," *Engineering Structures*, 117, 250 – 262.

REPORTS

6. William Short. *A laboratory study of horizontal and vertical regular wave forces on an elevated structure*. (2016). MS Thesis, Oregon State University.

7. Benjamin Hunter. *Exceedance Probabilities of Hurricane Wave Forces on Elevated Structures*. (2016). MS Thesis, Oregon State University.

CONFERENCE PAPERS

8. Park, H., Do, T., Tomiczek, T., Cox, D., van de Lindt, J.W. (2018) "Laboratory Validation and Inter-Model Comparisons of Non-breaking, Impulsive Breaking, and Broken Wave Interaction with Elevated Coastal Structures using IHFOAM and FLUENT," *International Conference on Coastal Engineering*, ASCE.

9. Lomonaco, P., P. Arduino, A. Barbosa, D. Cox, T. Do, M. Eberhard, M. Motley, K. Shekhar, T. Tomiczek, H. Park, J. W. van de Lindt, A. Winter "Experimental Modeling of Wave Forces and Hydrodynamics on Elevated Coastal Structures Subject to Waves, Surge or Tsunamis: The Effect of Breaking, Shielding and Debris, *International Conference on Coastal Engineering*, ASCE.

10. Tomiczek, T., Wyman, A., Park, H., Cox, D.T. (2018) "Application and modification of Goda Formulae for Non-impulsive Wave Forces on Elevated Coastal Structures," *International Conference on Coastal Engineering*, ASCE.

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
n/a			

Table 2A: Documenting External Funding

Title	**PI**	**Total Amount**	**Source**
n/a			

Table 2B: Documenting Leveraged Support

Description (e.g., free office space; portion of university indirects returned to project; university-provided student support)	**Estimated Total Value**
n/a	

Table 3: Performance Metrics:

COX/van de LINDT PERFORMANCE METRICS

Metric	Year 1 (1/1/16 – 6/30/16)	Year 2 (7/1/16 – 6/30/17)	Year 3 (7/1/17- 6/30/18)
HS-related internships (number)			
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	0	0	0
Graduate students provided tuition/fee support (number)	2	2	2
Graduate students provided stipends (number)	0	2	2
Undergraduates who received HS-related degrees (number)	0	0	0
Graduate students who received HS-related degrees (number)	0	0	0
Graduates who obtained HS-related employment (number)	0	0	0
SUMREX program students hosted (number)	2	2	2
Lectures/presentations/seminars at Center partners (number)	0	3	0
DHS MSI Summer Research Teams hosted (number)	0	0	0
Journal articles submitted (number)	0	2	2
Journal articles published (number)	0	2	0
Conference presentations made (number)	0	1	2
Other presentations, interviews, etc. (number)	0	0	2
Patent applications filed (number)	0	0	0
Patents awarded (number)	0	0	0
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	0	0
Requests for assistance/advice from other agencies or governments (number)	0	0	0
Total milestones for reporting period (research activity/milestone)*	4	5	4
Accomplished fully (research activity/milestone)	0	2	3
Accomplished partially (research activity/milestone)	4	3	1
Not accomplished (research activity/milestone)	0	0	0

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Task 3: Performance-Based Wave-Surge Design for Near-Coast Structures (CSU/OSU) -- A performance-based design example for a representative archetype near-coast structures will be conducted to illustrate the new methodology for engineering practice	12/31/2017	100%	
Design and construction of retrofitted specimens at OSU	6/30/2018	0%	Funds for this time period were not secured in time to reserve wave basin time. Testing was undertaken on an existing specimen at large scale to examine scaling approaches.
Application of validated numerical model for scale model design and development of fragilities for retrofitted specimens use in year 4 and 5	6/30/2018	50%	These have been developed but not validated experimentally. The submitted scope of year 4 and 5 changed slightly after discussion with FEMA HAZUS end-user group.
Meeting with FEMA in either Washington D.C. with invitation/participation by Region VIII (HAZUS leads), or meeting at Region VIII with Washington D.C. participants.	6/30/2018	100%	This was an on-line meeting organized by DHS.
Research Milestones			
Progress Report 9: Performance-Based Wave-Surge Design for Near-Coast Structures	12/31/2017	100%	

Final Report submission: Synthesis of Progress Reports with overall project summary and recommendations.	6/30/2018	100%	
Progress reporting in the form of a journal paper documenting the scale specimen design method which is an area lacking in near coast structural modeling that can benefit HAZUS fragility development substantially.	6/30/2018	100%	Submitted 8/1/2018
Progress reporting in the form of two journal papers explaining (1) the modeling methodology for scale wood modeling; and (2) the resulting fragilities for HAZUS.	6/30/2018	50%	Load cell issue on scale model. Finalizing in early Fall.

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Develop written report and final presentation to FEMA officials, HAZUS User Group and CRC	12/31/2017	100%	
Submit written report and present at annual meeting or other specified time.	12/31/2017	100%	
Present additional/new scope at CRC Annual Meeting	3/1/18	100%	
Document feedback from FEMA regarding adoption of new fragilities	6/30/18	100%	
Transition Milestones			

New fragilities are implemented into IN-CORE by the National Center for Supercomputing Application (IN-CORE development/programmers)	12/31/2017	100%	They are available and were provided, but IN-CORE development is not at the point that it can use the fragilities – it is close. They will be applied when it is ready.
FEMA agrees to use new fragilities in HAZUS update	12/31/2017	50%	Good discussion with FEMA and research team is waiting for additional feedback from FEMA on data sharing and their study areas for coordination.
Conference presentation at domestic conference	6/30/18	100%	

BENNETT – RPI
GABR - NCSU
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Establishment of a Remote Sensing Based Monitoring Program for Performance Health Assessment of the Sacramento Delta

Principal Investigator Name/Institution: Victoria Bennett, Rensselaer Polytechnic Institute

Co-Principal Investigators and Other Partners/Institutions:

- Tarek Abdoun, RPI
- Mourad Zeghal, RPI
- Mohammed Gabr, NCSU
- Brina Montoya, NCSU
- NASA/Jet Propulsion Laboratory
- Joel Dudas, Department of Water Resources, Sacramento, CA
- USACE, Vicksburg, MS

Project Start and End Dates: 1/1/2016 – 6/30/2018

Short Project Description ("elevator speech"):

As climate change progresses in the form of continuous land subsidence and rising sea level, the integrity and reliability of flood-control infrastructure have become ever more essential components to homeland security. This project employed a sensor-based (remote sensing with in-ground instrumentation for validation) and model-aided approach to provide engineers and decision makers with systematic tools to assess the health and provide early warning of deteriorating levee systems. The modeling tool integrated the use of measured data with the concept of performance limit states to effectively achieve a performance-based, network-level health assessment of the levee system. An artificial neural network tool, labeled Risk Estimator for Earth Structures (REES), was developed for the transition of the research findings to the end users.

Summary Abstract:

The integrity and reliability of levee systems are essential components of homeland safety and security. The integrity of the levees is not limited to the flood defense aspect, it also contributes to the preservation of water resources, as in the case of the California Delta levees. The distributed levee systems are, however, aging, and their structural health are deteriorating. Assessing the health, predicting the performance, and implementing countermeasures to sustain such performance are challenging tasks for aged civil infrastructure in view of the complexity of

the associated processes of long-term degradation and wear. A validated remote sensing-based approach coupled with analyses to place the monitored data in context of performance parameters is used herein to assess the health of the spatially distributed levee system. This project highlighted the potential of a remote sensing-based monitoring system and health assessment tools that could enable early identification and warning of vulnerable levee or dam sections and enabling prioritized repair work. This project validated the use of satellite imagery to detect rate of deformation of a levee section on Sherman Island, California. Such data were then implemented in a numerical model for estimating the probability of exceeding a performance limit state. This probability provides an indication of the likelihood of damage and the extent of performance failure. The concept of limit state was also used to assess the performance of the Princeville levee, located in the city of Princeville, North Carolina, under the effect of repeated rise and fall of water levels, representing severe storm cycles. Results showed that the increase of storm cycles leads to an increase in probability of exceeding a given performance limit state by several orders of magnitude. While the stability factor of safety obtained from traditional limit equilibrium approach is unaffected by the number of storm cycles. Finally, an artificial neural network tool labeled Risk Estimator for Earth Structures (REES) was developed to facilitate the transition of the research findings to the end users.

REPORT NARRATIVE

1. Research Need:

Work in this project employed remote sensing (with in-ground instrumentation for validation) and a modeling-aided approach to provide engineers and decision makers with systematic tools to predict performance aspects and assess the health and condition of deteriorating levees. The modeling tool integrated the use of measured data with the concept of performance limit states to effectively achieve a performance-based assessment of the levee system condition and predict future response under severe storm events.

2. Project History:

The primary objective of this project was to establish a remote sensing-based monitoring program for the performance-based health assessment of a Sacramento Delta levee on Sherman Island. To this end, the satellite images and in-ground GPS sensors were used for displacement measurements of a levee section in the first phase of this project. The study levee section is part of the Whale's Mouth on Sherman Island. This levee was modeled using the large deformation option of the finite element program Plaxis 2D. The model was used to establish the deterministic performance response under maximum water level loading and to investigate the effect of peat decomposition on the deformation response of the levee section. The modeling results were guided and calibrated by the remote sensing data.

The concept of performance limit states was utilized in the second phase of this project to assess quantitatively the functionality of the levee section under severe storm loading events. The probability of exceeding a prescribed limit state is defined based on the strain or hydraulic gradient levels in potential emerging failure zones. The variation in strength properties and hydraulic conductivity of the levee embankment, as well as the rate of rising water level and duration of flooding, may lead to the progression of the distress state from a low probability of exceeding adequate functionality to the probability of imminent failure. The displacement data collected during these loading and unloading events were used to establish the levee condition assessment on the basis of the performance limit states. An artificial neural network tool labeled Risk Estimator for Earth Structures (REES) was developed for the transition of the research findings to the end users. REES can assess the probability of exceeding a limit state without the need to conduct advanced numerical modeling. It is important to note that the parameter needed for training the REES tool should be the shear strain at key locations within the earth structure (such as the toe of the levee). The scaled conjugate gradient backpropagation training function was implemented in MATLAB to train the REES tool and the modified approach led to lower mean square error.

In the third phase of the project, the concept of limit states was applied to assess the performance of the Princeville levee under the effect of repeated rise and fall of water levels, representing severe storm cycles. These storms were the representative hurricanes Floyd and Matthew. The Princeville levee system is located on the western, southwestern, and northern sides of the Town of Princeville, North Carolina. Results showed that the increase of storm cycles leads to an increase in the probability of exceeding a given limit state by several orders of magnitude. While the stability factor of safety obtained from the conventional limit equilibrium approach is unaffected by the number of storm cycles. The application of the proposed approach to the Princeville levee demonstrated its usefulness for predicting the levee performance under future severe storms.

3. Results:

The work conducted in this project includes the integration of a remote-sensing monitoring program and numerical modeling for the development of a protocol for assessing the integrity of levees. The Sherman Island levee section, within the California Delta region, is used as a catalyst for the development of the proposed technology. Data (from literature and discussion with end users) show the Sherman Island site to be underlain by highly fibrous peat. As shown in Figure 1, satellite images and in-ground GPS sensors were used to collect displacement measurements at the study levee section. These measurements were used for the calibration of a numerical model, using the finite element program Plaxis 2D, with large deformation mesh updating. A fine 15-nodal element was used with the domain having 1961 elements and 15,975 nodes. The locations of three Global Navigation Satellite System (GNSS) in situ stations (GNSS-1, 2 and 3) are shown in Figure 1. Points A and B along the levee landslide side slope are used to compare the data from the numerical model with monitored GNSS records. Flow and deformations boundary conditions were assigned appropriately.

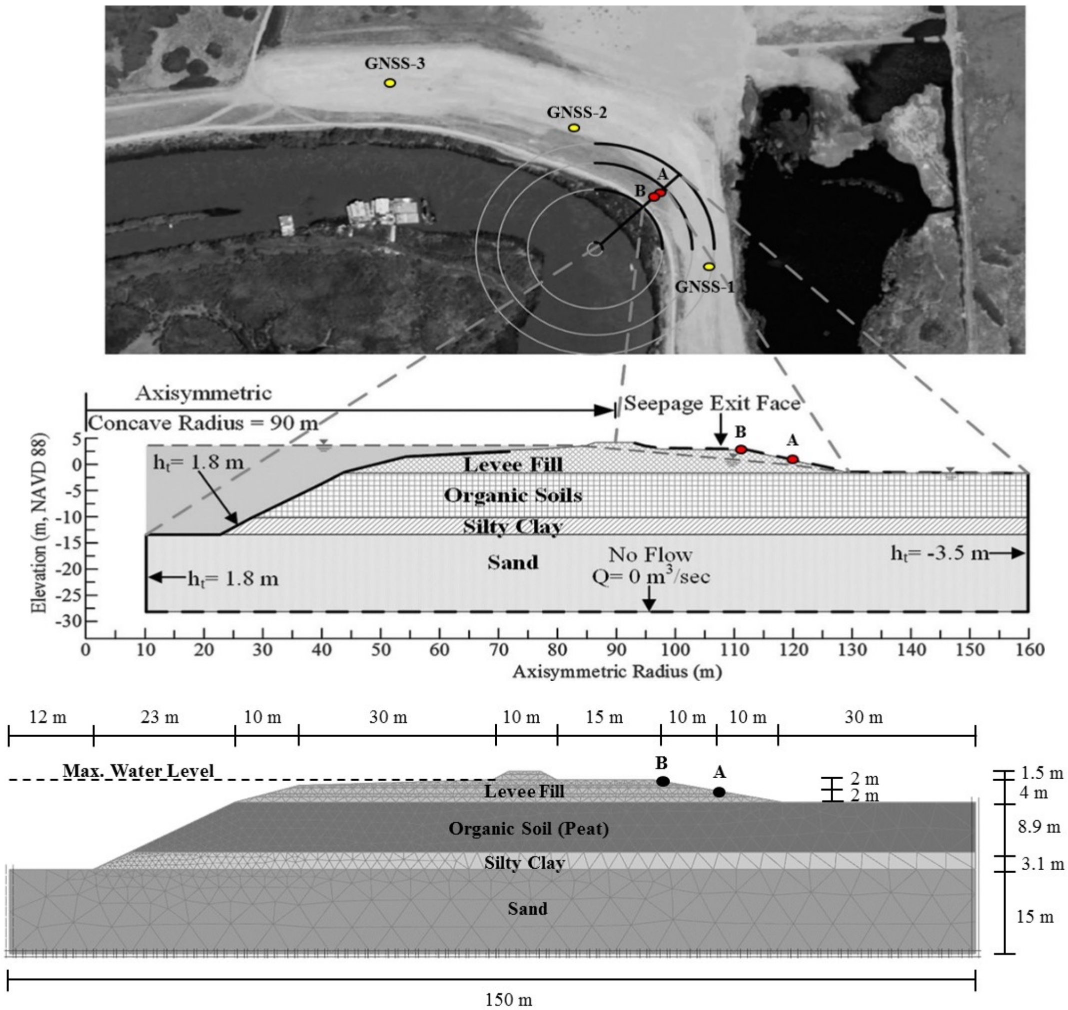


Figure 1. Finite element Plaxis 2D levee mesh and boundary conditions.

Results for vertical displacement (negative sign means settlement downwards) versus time for fibrous peat are shown in Figure 2 for locations A and B on the levee section (designated on Figure 1). These locations were chosen to allow for the model calibration with the available GNSS-1 and GNSS-2 remote sensing records for the Sherman Island levee. These GNSS data were for a one-year period from 4/1/2015 up to 4/1/2016. In this case, the rate of deformation with time show a relatively close trend as the model results falls between the range of measured deformation at points A and B. The GNSS data showed an average of 0.13 m of deformation per year compared to the computed 0.095 per year computed for location A. The rates between the model results and location B were not in agreement but the monitored points are located on the landside side slope; a location consistent with "point A."

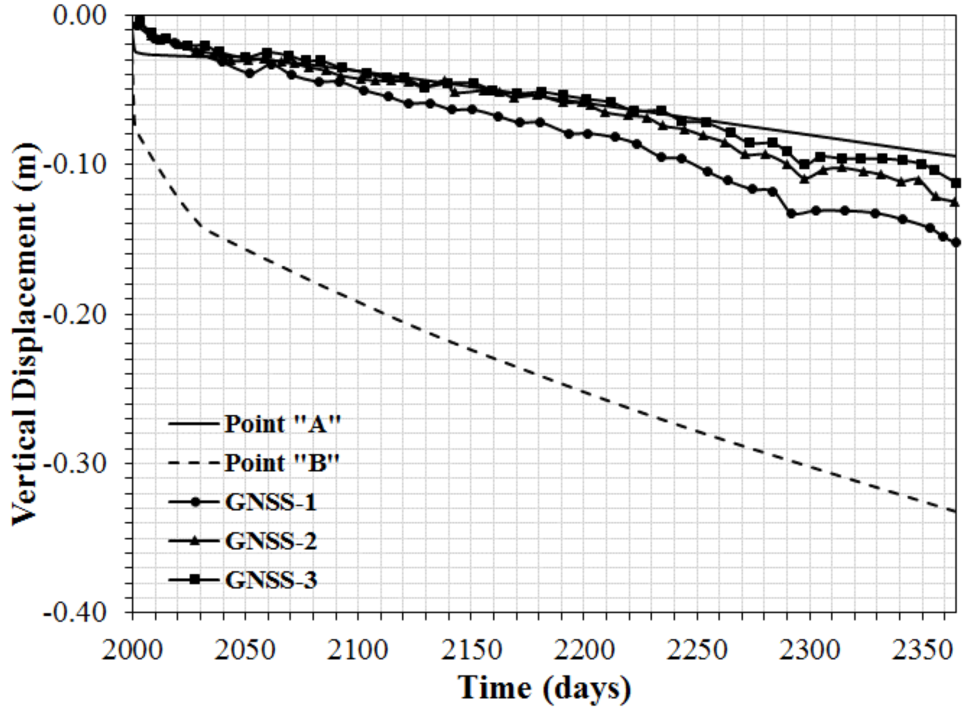


Figure 2. Displacement with time for fibrous peat versus measured data.

The data from the numerical model were used to establish fragility curves providing the probability of exceeding performance limit states including the influence of the peat layer decomposition/aging with time. Peats with three degrees of decomposition, from fibrous (H1-H3) to hemic (H4-H7) to amorphous (H8-H10), were modeled and the corresponding deformation aspects are shown in Figure 3 at 10,000 days for the presumed three-peat decomposition ranges. It is important to note that the Sherman Island levees have been constructed around 1870's. This implies around 147 years of peat layer decomposition for these levees (~50,000 days). Figure 3 shows higher deformation especially at toe location for fibrous (H1-H3) peat compared to H4-H7 and H8-H10 peats. As the peat decomposition level increases, the deformation values decrease as the peat layer experiences less compression with time. Figure 4 shows the fragility curves for the three modeled peat decomposition ranges. In this case, fragility is defined as the probability of exceeding a given limit state, given the decomposition rate of the peat layer with time. It should be noted that LS3 is corresponding to the critical condition, defined as exceeding shear strain of 5% or higher at the landside toe area; an indication of excessive deformation and potentially failure.

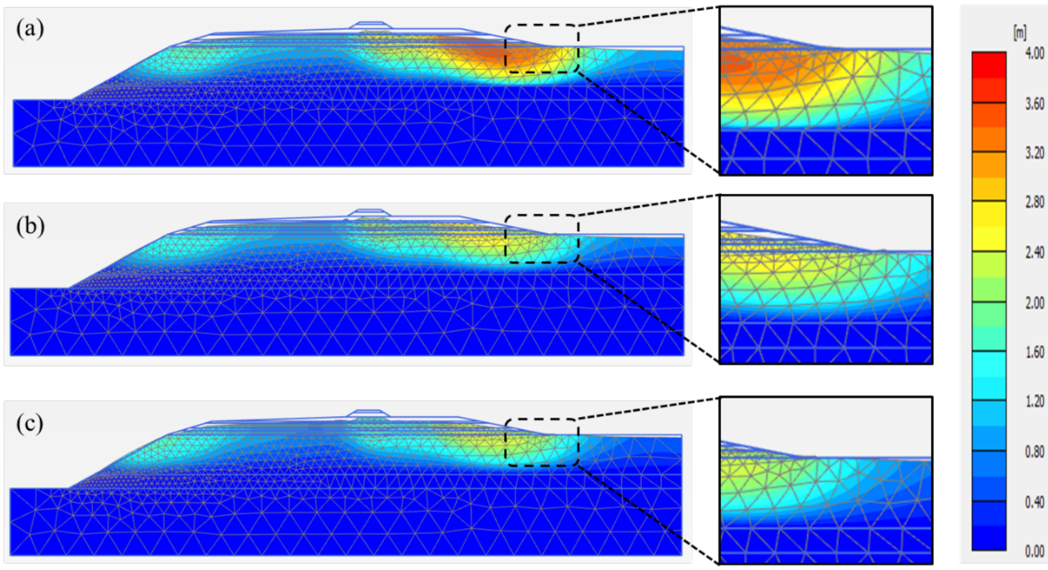
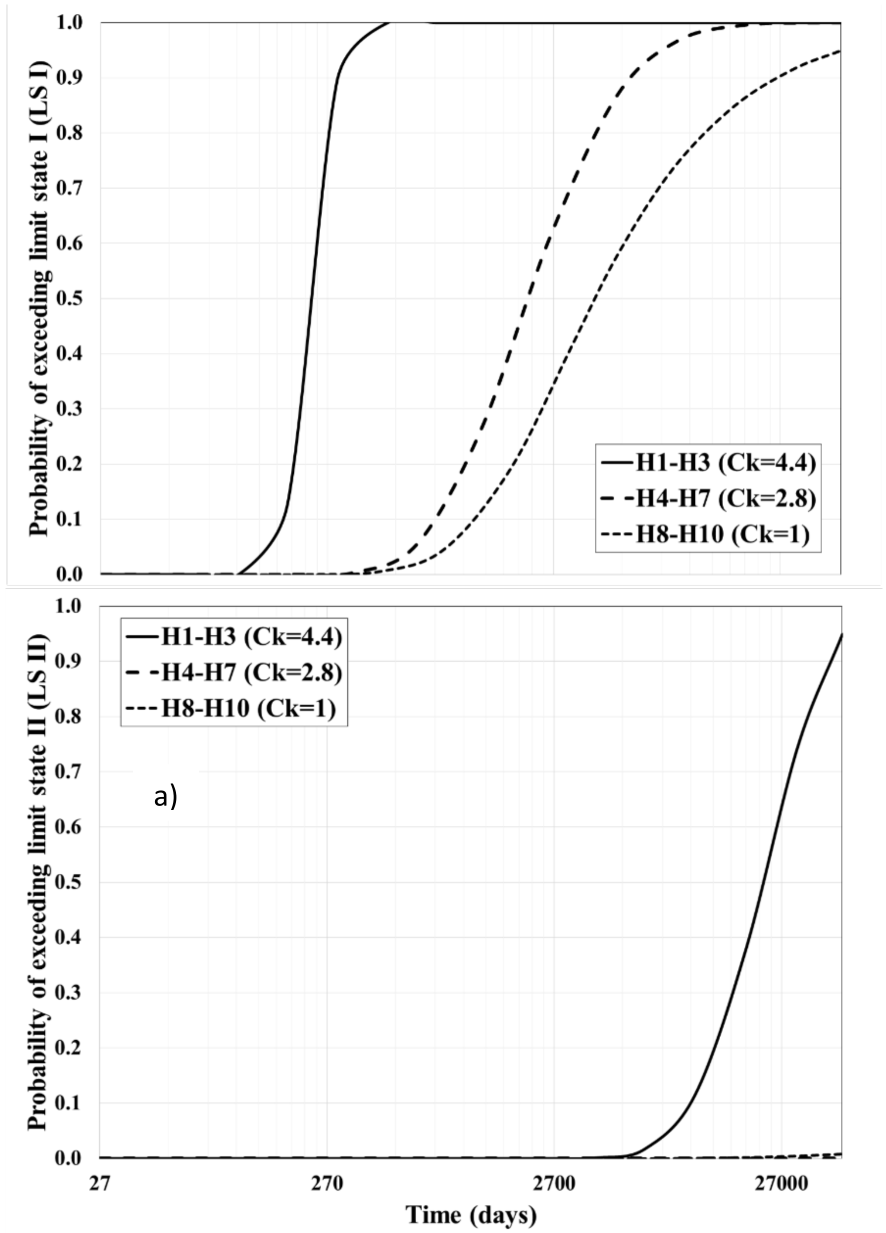


Figure 3. Deformation of levee for a) H1-H3 peat b) H4-H7 peat c) H8-H10 peat at 10,000 days.

As shown in Figure 4, for fibrous (H1-H3) peat, shear strain exceeds a value of 1% (corresponding to LS1) at approximately 270 days. Probability of exceeding LS2 increases around 9100 days when shear strain reaches 2.6% and the probability of exceedance keeps increasing to reach 95% at 50,000 days. For (H4-H7), it takes 10,000 days to reach 100% probability of exceeding LS1 as the shear strain trend for this case does not exceed the 1% value until 1800 days. The assumption of amorphous peat (H8-H10) properties leads to more time (around 300,000 days) to yield an indication of 100% probability of exceedance. The probability of exceeding LS2 for both H4-H7 and H8-H10 peat is very low as the shear strain values are below 3% (LS2) by 50,000 days. Within the context of the modeling, the use of H1-H3 peat (Fibrous) yielded a shear strain value around 3.2% at 50,000 days which corresponds to the lifetime of the Sherman Island levee (Figure 4). This value of shear strain corresponds to 100% probability of exceeding LS1. As peat ages with time, more shear strain will be developed causing the probability of exceeding LS2 to increase as well and therefore increases the vulnerability of the levee and its susceptibility to failure (reaching LS3) under extreme flood events. It is important however to mention that several factors still need to be investigated for more detailed analyses and representative results. These include the time needed in the field for peat to decompose, as the decomposition rate is influenced by temperature, aerobic and anaerobic activity, pH, etc. These analyses nonetheless demonstrate the value of condition assessment of levee health to place its vitality in the context of potential damage to be caused by impending severe weather events.



a

b

Figure 4. Probability of exceedance: a) LS1 and b) LS2 for shear strain for peat with different degrees of decomposition.

The performance limit state or strain-based approach was also used to assess the probability of exceeding performance limit states of the Princeville levee, North Carolina, due to the effect of repeated rise and fall of water levels, representing severe storm cycles. The Princeville levee system is located on the western, southwestern, and northern sides of the Town of Princeville, North Carolina. The levee was constructed as a flood defense structure for the town which was established in 1865 by freed slaves (and originally named Freedom

Hill). The geometry, soil layers, and finite-element mesh of the analyzed Princeville levee section are shown in Figure 5. In a feasibility study, the US Army Corps of Engineers identified the levee section at Station 32+00 as a "critical" since it was overtopped by flooding associated with Hurricane Floyd in 1999 (USACE, 2015). Another major flood event following Hurricane Matthew in 2016 occurred at this levee. Although this time the levee was not overtopped, as was the case following Hurricane Floyd, the town was flooded with 10 ft of water primarily from the ends of the levee system and from an un-gated culvert running underneath the embankment.

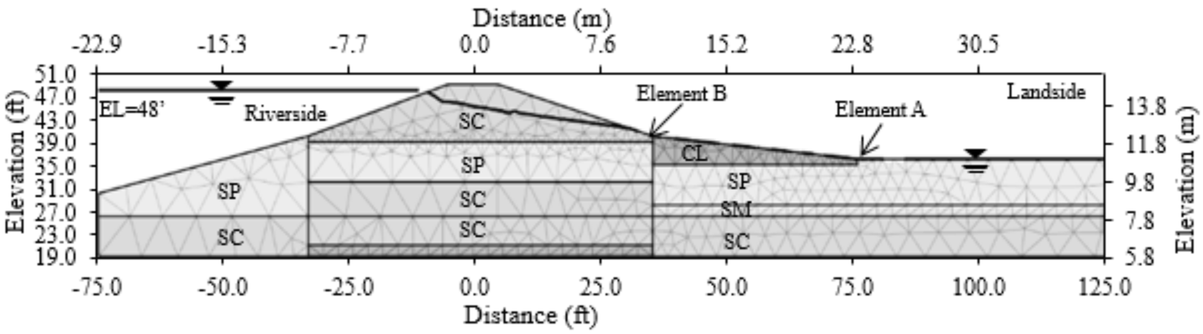


Figure 5. Princeville levee: geometry and discretized mesh.

The Princeville levee was analyzed using a strain-based approach through numerical analyses, strength reduction method (SRM), and the traditional limit equilibrium method (LEM). Four cycles of water level rise and fall, representative of hydrographs observed during Hurricane Floyd and Hurricane Matthew were applied to the levee. The strain-based approach considered the uncertainty of the permeability of the foundation layer and considered the permeability as random variable. The probability of exceeding a given limit state was determined considering 1 and 2 standard deviations (SD) and is presented in Figure 6 as a function of the number of loading cycles. Approximately 68.2% of a given property values are within +/- one SD of the mean and 95.4% are within +/- two SD of the mean value. The probability of exceeding LS1 was near unity in all cases, and therefore is not shown here. The probability of exceeding limit state value is very small after 1 cycle for 1 SD variation, and is not shown in Figure . The FS obtained from the LEM and SRM for the design flood scenario after each storm cycle is shown in Figure . Results indicated that the probability of exceeding a given limit state is increased by 1 to 3 orders of magnitude as the number of storm cycles is increased from 1 to 4 due to the accumulation of shear strain after each storm cycle. The increase in the degree of uncertainty (represented by assuming 1SD versus 2SD in the distribution of the foundation layer permeability) related to permeability of the SP soil layer (Figure 5) also leads to an increase in probability of exceeding a given limit state by 1 to 8 orders of magnitude, depending on the number of storm cycles. If both the loading history and the degree of uncertainty in permeability are considered, this increase would be more significant. For instance, the probability of exceeding LS3 is 1 in 10,000,000 after 4 storm cycles considering 1 SD variability in SP layer permeability. This value is increased to 1 in 20 considering 2 SD variability in SP layer permeability. The deterministic FS remains as 1.61 from the LEM in this case. In parallel, the FS obtained from SRM remains unchanged after 2 cycles. However, it drops from 1.60 to 1.51 after 3 storm cycles (corresponding to a 5.6% decrease) due to the change in the location of the critical slip surface after 2 storm cycles.

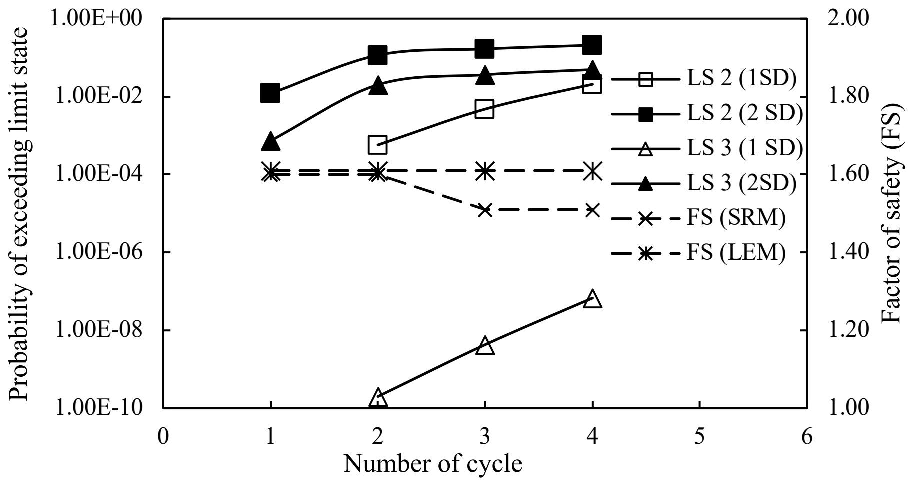


Figure 6. Variation of probability of exceeding limit state and factor of safety with number of storm cycle.

The flood event related to Hurricane Floyd caused more than $6 million in property damage. The Federal Emergency Management Agency (FEMA) allocated $26 million to the town to rebuild after Floyd's floodwaters receded. Figure 7 shows the probability of exceeding LS3 for the Princeville levee, plotted against risk criteria for traditional civil facilities; the risk criteria were presented by Baecher and Christian (2003). A value for 2 SD variation in the permeability of the SP layer was assumed. The probability of exceedance was plotted against the property damage value ($6 million) as a consequence, as was the case following Hurricane Floyd. Figure shows the probability of exceeding LS3 transitioning from 'acceptable' region after 1 storm cycle into the 'unacceptable' region after 4 cycles. Thus, using the proposed approach developed herein, the characterization of the damage level and the associated probability of occurrence allow for forecasting the consequences of future damage and therefore assist in informing decisions regarding rehabilitation and retrofitting expenditures for mitigating future risk.

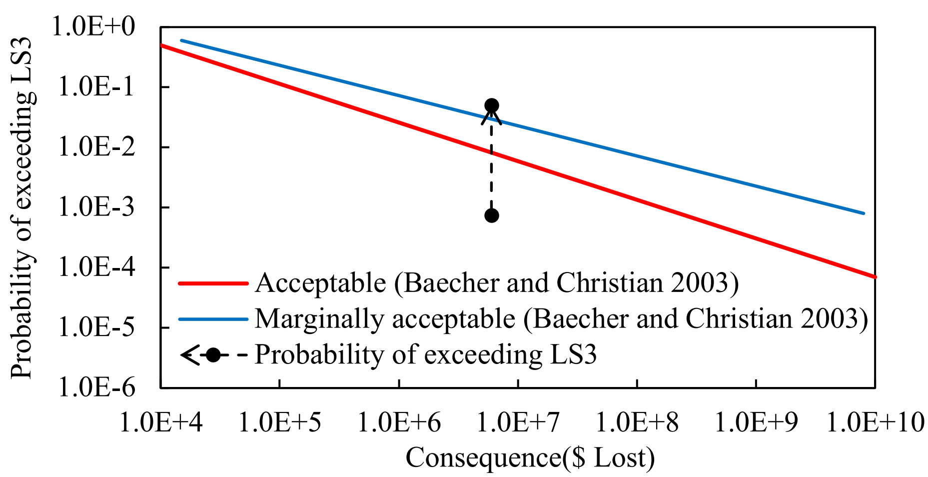


Figure 7. Probability of exceeding LS3 versus consequence curve showing the effect of

load history on risk evaluation associated with slope failure.

Risk Estimator for Embankment Structures "REES" tool development

REES was developed based on the Artificial Neural Network (ANN) platform to assess the probability of exceeding a limit state without the need to conduct advanced numerical modeling. A graphical user interface (GUI) tool was developed to implement the ANN model and allows for a user-friendly approach for estimating the probabilities of exceeding a given limit states. ***REES*** provides the probability of exceeding the three predefined limit states. Using the probability of exceeding LS III (the ultimate limit state) risk in terms of failure consequence as a function of fatality rates with distance away from the embankment structure is estimated using peak breach discharge (cfs) and 10-year discharge (cfs) values from the FEMA loss of life risk sheet (FEMA risk tool, 2008). However, the risk can be estimated in terms of economics and loss of functionality of critical infrastructure if the "impact" data downstream are available. A user manual was developed to guide the user through operating the tool with examples.

4. End Users and Transition Partners:

The work in this project was focused on developing an innovative platform for monitoring and condition assessment of the California Delta levees. A levee on Sherman Island was used for this purpose. The proposed approach couples the concept of strain-based limit states (LS) with data collection from remote sensing efforts to identify the levees' weak sections and possible impending failure modes. The modeling of the levee sections provides condition assessment of their current state and provides the context through which the monitoring data are viewed to discern gradual and abrupt condition changes. The end users include the following:

i. California's Department of Water Resources (DWR);
ii. US Army Corps of Engineers (USACE);
iii. Federal Emergency Management Agency (FEMA);
iv. US Bureau of Reclamation (USBR); and
v. Levee Safety Boards.

Joel Dudas, Senior Engineer with California's DWR FloodSAFE Environmental Stewardship and Statewide Resources Office; the Technical Director of USACE Engineer Research and Development Center (ERDC), and the Senior Program Manager at USACE – Risk Management Center, consult with the research team throughout the project and serve as ambassadors for the transition to practice. Joel Dudas is also an incident responder with DWR. Joel McElroy, Superintendent with Reclamation District #341, is responsible for bimonthly levee inspections and is a first responder for levee breaches on Sherman Island. John Paasch, Program Manager for the Delta Flood Emergency Preparedness, Response and Recovery Program, will link our project to others in DWR Emergency Management and California Emergency Management Agency (CalEMA) (http://www.water.ca.gov/floodmgmt/hafoo/fob/dfeprrp/). Jim Murphy, Head of Levee Condition Assessment Division of Risk Assessment, Mapping and Planning Partners (RAMPP), will help bring the project outcomes from FEMA Region IX to other critical coastal areas such as Louisiana (Region VI) and New York / New Jersey (Region II).

5. Project Impact:

Flood protection infrastructure, such as earthen levees and dams, play a significant role of protecting critical infrastructure during extreme flood events. These levees and dams experience large and rapid fluctuations of water level during extreme flood events. Such events cause major distress to these earth structures and may lead to breaching failure. The failure of such systems can have monumental repercussions, sometimes with dramatic consequences on human life, property and the country's economy. The failure of levees during Hurricane Katrina in 2005 is a highly illustrative example of the criticality of these systems. But this distributed system of national flood-control infrastructure is aging, and its structural health is deteriorating. Assessing the health, predicting the failure, and implementing countermeasures are challenging tasks for any civil infrastructure in view of the complexity of the associated processes of long-term environmental degradation and wear. To efficiently maintain this infrastructure, managing engineers should have access to fully automated programs to continuously monitor, assess the health, and adaptively upgrade these systems. A validated remote sensing-based (i.e., satellite or airborne radar) approach coupled with analyses to place the monitored data in context of performance parameters provides significant impact to sustain the functionality of such a spatially distributed system. This innovative approach serves to identify weak sections and impending failures and can be used as a tool to prioritize maintenance and upgrade efforts on a system level rather than manual inspection of each levee. This project demonstrated the coupling of remote sensing-based monitoring data with analyses and modeling to develop health assessment tools that can enable early identification and warning of vulnerable levee or dam sections enabling prioritized repair work. The advantages of using the concept of performance limit states are demonstrated to quantitatively assess the damage level that a levee system experiences under severe storm loading events. The characterization of the damage level and the associated probability of occurrence allow for the performance of the risk assessment in which the consequences of the damage on the protected assets can be included in the analyses. As such, an informed decision regarding rehabilitation and retrofitting expenditures can be made. An artificial neural network tool labeled Risk Estimator for Earth Structures (REES) was developed as a part of this project which presents a robust and user-friendly way for geotechnical engineers to estimate probabilities of exceeding performance limit states for embankment structures.

6. Student involvement and activities:

- Students involved in research:
  - Amr Helal, Ph.D.-Level Research Assistant, NCSU
  - Rowshon Jadid, Ph.D.-Level Research Assistant, NSCU
  - Chung Nguyen, Ph.D.-Level Research Assistant, RPI

- Degrees attained:
  - Amr Helal, PhD, Civil Engineering (Geotechnical), NCSU - Degree Awarded December 2017

- Chung Nguyen, PhD, Civil Engineering (Geotechnical), RPI – Degree Awarded August 2018

- Awards:
    - Rowshon Jadid, ***Student Paper Competition Winner***, Dam Safety 2018, Seattle, Washington.
    - Rowshon Jadid, ***Best Oral Presentation,*** 4th Annual Symposium on Geotechnical Engineering by G-I GSO at NCSU 2018.

- Publications:

"***Monitoring and Modeling of Peat Decomposition in Sacramento Delta Levees***" Amr Helal, Victoria Bennett, Mo Gabr, Roy Borden and Tarek Abdoun. Geotechnical Frontiers 2017, Orlando, Florida.

"Deformation Monitoring for the Assessment of Sacramento Delta Levee Performance" Victoria Bennett, Cathleen Jones, David Bekaert, Jason Bond, Amr Helal, Joel Dudas, Mohammed Gabr, Tarek Abdoun. Geo-Risk 2017 (Geotechnical risk from theory to practice), Denver, Colorado.

"Use of remote-sensing deformation monitoring for the assessment of levee section performance limit state" Victoria Bennett, Chung Nguyen, Tarek Abdoun, Amr Helal, Mohammed Gabr, Cathleen Jones, David Bekaert, Joel Dudas. Proceedings of the 19^{th} International Conference on Soil Mechanics and Geotechnical Engineering, Seoul 2017.

"Analysis of Earth Embankment Structures using Performance-based Probabilistic Approach including the Development of Artificial Neural Network Tool" Amr Helal. PhD dissertation, Civil Engineering Department, North Carolina State University, June 2017.

"Deformation-based versus Limit Equilibrium Analyses to Assess the Effect of Repeated Rise and Fall of Water Level on the Stability of Princeville Levee" Rowshon Jadid, Brina Montoya, Victoria Bennett, and Mo Gabr. Dam Safety 2018, Seattle, Washington.

"Effects of Load History on Seepage-Induced Deformation and Associated Performance in Terms of Probability of Exceeding Limit States - Case Study of Princeville Levee" Rowshon Jadid, Brina Montoya, Victoria Bennett, and Mo Gabr. Geo-Congress 2019, Philadelphia, Pennsylvania. (under review)

- Poster:

"Strain-Based Approach versus Limit Equilibrium Analyses: Assessing the Effect of Hydraulic Loading History on the Stability of Princeville Levee" Rowshon Jadid. DHS COE Summit 2018, Arlington, Virginia.

7. Interactions with education projects: Not applicable to this project since the limited budget did not include allowance for a meaningful interaction.

8. Publications

"***Monitoring and Modeling of Peat Decomposition in Sacramento Delta Levees***" Amr Helal, Victoria Bennett, Mo Gabr, Roy Borden and Tarek Abdoun. Geotechnical Frontiers 2017, Orlando, Florida.

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"Effects of Load History on Seepage-Induced Deformation and Associated Performance in Terms of Probability of Exceeding Limit States - Case Study of Princeville Levee" Rowshon Jadid, Brina Montoya, Victoria Bennett, and Mo Gabr. Geo-Congress 2019, Philadelphia, Pennsylvania. (under review)

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
REES "Risk Estimator for Embankment Structures"	Software	June 2018	Federal Agencies looking for an expedient means to assess performance of levees and earth dams

Table 2A: Documenting External Funding

Title	**PI**	**Total Amount**	**Source**
Establishment of Sensor Driven and Model Based Health Assessment for Flood Control Systems	Tarek Abdoun	$61,595	US Army Engineer Research Development Center
New Faculty Startup Funds	Victoria Bennett	$241,500	Rensselaer Polytechnic Institute

10% of annual year salary and associated fringe benefits	Victoria Bennett	$11,780	Rensselaer Polytechnic Institute

Table 2B: Documenting Leveraged Support

Description	Estimated Total Value
Spare GPS equipment available from JPL to maintain instrumentation installed in Sherman Island setback levee.	$34,500
Field instrumentation recovered from V-Line Levee site in New Orleans	$25,000

Table 3: Performance Metrics:

BENNETT-GABR PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17- 6/30/18)
HS-related internships (number)			
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)			
Graduate students provided tuition/fee support (number)	2	3	
Graduate students provided stipends (number)	2	3	
Undergraduates who received HS-related degrees (number)			
Graduate students who received HS-related degrees (number)		2	
Graduates who obtained HS-related employment (number)			
SUMREX program students hosted (number)			
Lectures/presentations/seminars at Center partners (number)	1	1	2
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)		0	
Journal articles published (number)			
Conference presentations made (number)	2	3	2
Other presentations, interviews, etc. (number)	1	3	
Patent applications filed (number)			
Patents awarded (number)			
Trademarks/copyrights filed (number)			
Requests for assistance/advice from DHS agencies (number)			
Requests for assistance/advice from other agencies or governments (number)	4	2	2
Total milestones for reporting period (number)	3	3	3
Accomplished fully (number)	3	2 (REES being updated)	3
Accomplished partially (number)		1	
Not Accomplished (number)	0	0	0

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Task d. Probability of Exceeding Limit State and Uncertainty	6/30/2017	100%	
Task e. Field Comparison	12/31/2017	100%	
Research Milestones			
Establishment of Levee Section fragility in terms of probability of exceedance versus flood cycle and level	6/30/2017	100%	
Establish the coupled model-monitored data approach as a means to identify vulnerabilities of the levee section studied herein.	12/31/2017	100%	

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Submit a Journal paper documenting the findings of the 2-year study	12/31/2017	50%	Delay in calibrated model of levee section with accurate numerical description of section response shifted timeline in paper submission
Transition Milestones			
Successful demonstration of the coupled model-monitored data for identifying vulnerabilities of the levee section with variation in reservoir level and number of flood cycles	12/31/2017	100%	

WALLACE, RPI
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Community Supply Resiliency (COMSURE)

Principal Investigator Name/Institution: William A. Wallace, Yamada Corporation Professor, Industrial & Systems Engineering (ISE), Rensselaer Polytechnic Institute (RPI)

Co-Principal Investigators and Other Partners/Institutions: John Mitchell, Professor, Mathematical Sciences, RPI; Thomas Sharkey, Associate Professor, ISE, RPI; Richard Little, Research Scholar, ISE, RPI

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description ("elevator speech"): The resilience of a coastal community to an extreme event depends upon the resilience of its critical infrastructures, one of which is the system of supply chains that provide the goods and services that make a community livable – Community Supply Resiliency (COMSURE).

Summary Abstract: The capability of communities to withstand and recover from the disruptions of extreme events will determine, to a large extent, the degree to which the social, economic, and psychological impacts of these events can be reduced. It is well recognized that civil infrastructures (e.g., transportation, power, water supply and sewerage, and communications) are critical to the wellbeing of a community; our past work has focused on these systems. However, it is the social infrastructures (e.g., emergency response, banking, and food, fuel, and pharmaceutical distribution) that play a crucial role in societal functioning; the availability of these systems following an extreme event is a key element in determining the resilience of a community. Therefore, the objective of the proposed research is to better understand, describe, and portray the supply chains that provide the goods and services needed to respond to and recover from an extreme event, such as a hurricane impacting a coastal community. With this knowledge, models and algorithms will be developed to support emergency management in planning, community development, training and education, thereby enhancing overall community resilience.

PROJECT NARRATIVE:

1. Research Need: Infrastructure restoration is one of the most difficult challenges that must be addressed during a disaster and emergency managers are faced with many decisions during preparation, response, and recovery from extreme events such as hurricanes. Implementation of these decisions involves actors from both the public and private sectors who normally don't work and train together for such rare events, which can hinder their effective collaboration when the event actually occurs. Computer-based simulation tools such as COMSURE can be used for education and training to construct and display multiple scenarios that can raise the

awareness of public officials and corporate managers to the interdependent complexity of hazard events. This training and preparedness aid for response and recovery from extreme events is also less costly and more time-efficient than drills or full-scale exercises. At the present time, there are no such training aids that account for the interdependencies that exist between civil and social infrastructures which are readily available to the practitioner community. COMSURE has established that these linkages exist and has developed algorithms that can translate this research into a readily deployable education and training tool for practitioners that will make the nation and its critical infrastructures more resilient in the face of multiple hazards.

The results of this research contribute directly toward the achievement of Goal 5.4: Enable Rapid Recovery: "Ensure continuity and restoration of essential services and functions; and support and enable communities to rebuild stronger, smarter, and safer" as noted in *The 2014 Quadrennial Homeland Security Review* under Mission 5: Strengthen National Preparedness and Resilience.

2. History: Our previous work on the restoration of critical civil infrastructure systems focused on network models of the integrated restoration assignment and scheduling of multiple interdependent infrastructure systems. The research was expanded to include: (1) network models of social infrastructure systems, (2) a damage assessment model, and (3) a disruption of services model. An artificial community (CLARC) was developed for the purpose of research, education, and training. In addition to the contribution to knowledge in the form of theses and scholarly articles, an innovative suite of decision technologies, MUNICIPAL/CRISIS/COMSURE, has been developed. Its development and ongoing assessment were accomplished in partnership with the emergency management department of New Hanover County, NC. A stakeholders' workshop was held to provide guidance for the integration of the MUNICIPAL model with DHS's SUMMIT toolkit. Based upon the information from that workshop, a SUMMIT-compatible version of MUNICIPAL was completed with user documentation and delivered to Sandia National Labs in Livermore, California in May 2015. COMSURE, the current iteration of this work, is based on extensive interaction with the convenience store, pharmaceutical, and banking industries and provides: (1) the theoretical foundations for COMSURE, (2) an artificial community (CLARC) for experimentation and elaboration, and (3) a partnership with Healthcare Ready in Washington, DC to specifically assess the impacts of extreme events such as Hurricanes Harvey and Maria on the pharmaceutical and medical device supply chains.

   The focus on community supply resilience required the development of models of the supply chains that provide goods and services for social infrastructures. The construction of such models entailed data collection on-site at a coastal community facing a hazard – in our case, hurricanes. The result is GIS visualizations of the supply chains for review by both the provider of the critical good and emergency management. For example, the supply chain for the fuel distribution system for gasoline for New Hanover County would be shown in a GIS map for review. These supply chain models are then integrated with those of the social and civil interdependent infrastructure systems developed in past research. These new mathematical formulations have been incorporated into an interdependent integrated network design and scheduling framework. Using these mathematical representations, we modeled: (1) relationships between supply chains and support infrastructure networks that influence supply chain operations, such as power, communications, and transportation; and (2) interactions among emergency managers and infrastructure managers in the context of coordination and information sharing in determining mitigation and restoration activities. These formulations coupled with models of damage and disruption of services, databases and a GIS interface form the basis for the COMSURE model. The project provided funding for a graduate student to participate both in the data collection and the modeling activities. The graduate student drew heavily upon recently completed doctoral research on the modeling of social infrastructures.

Primary Steps Taken To Carry Out The Project

MUNICIPAL was developed to assist state, county, and local emergency managers, as well as managers of public and private infrastructure systems, in preparing for a hurricane or other extreme event leading to the loss of infrastructure services. New Hanover County, North Carolina was selected as an ideal prototypical location to develop and test MUNICIPAL. It is located in southeastern North Carolina at the confluence of the Cape Fear River and the Atlantic Ocean and has had a long history of hurricanes and tropical storms. New Hanover County is 849.5 km^2 (328 square miles) in area and had an estimated population of 209,234 in 2012. It is home to the City of Wilmington, the International Port of Wilmington, Wilmington International Airport, the University of North Carolina at Wilmington, Cape Fear Community College, and the New Hanover Regional Medical Center which serves southeastern North Carolina and northeast South Carolina. Public safety services are provided by New Hanover County and the City of Wilmington within their respective jurisdictions. New Hanover County Emergency Management (NHCEM) coordinates disaster response during emergencies. The five infrastructure systems modeled in MUNICIPAL are managed by a mix of public and private entities within the boundaries of New Hanover County and City of Wilmington.

The COMSURE effort required outreach to a new community of stakeholders engaged in the provision of critical commercial and other "social" infrastructure services.

Commercial Service Providers (requests for information on the impacts of Hurricane Matthew and other storms)
Grocery Chains – Food Lion, Lowes Food, Harris Teeter
Drug Chains – Walgreens, CVS, Rite Aid, Healthcare Ready, Southeastern Health
Banks – Wells Fargo, Bank of America, Sun Trust
Convenience Stores – Circle K (Kangaroo Express), National Association of Convenience Stores

North Carolina Emergency Management (requests for information on the impacts of Hurricane Matthew; possible demonstrations to potential users of the technology)
City of Lumberton – Bill French
Cumberland County – Randy Beeman
Johnson County - Kim Robertson
Nash County – Brent Fisher
Pitt County - Allen Everette
Robeson County - Stephanie Chavis

Scotland County - Roylin Hammond
Wayne County - Mel Powers

Problems Or Challenges During The Project

As the model development and initial assessment phases in New Hanover County proceeded, two data-related complications became apparent. The first was that it was time consuming and expensive to collect data on the design and content of multiple infrastructure systems as well as on historic damage and disruption scenarios for those systems. It took approximately two years to organize the original infrastructure dataset for New Hanover County and even after this time, it was still difficult to validate the accuracy of the composite data due to inconsistent formats and the reluctance of many private and public organizations to supply complete datasets. The second complication was the realization that the release of vulnerability data on actual infrastructure systems in academic papers or public reports could raise legitimate security concerns. Of the two issues, the latter was more problematic.

Data on the location and vulnerability of critical infrastructure components is considered critical infrastructure information, and its handling and dissemination is subject to DHS regulations. Despite no single piece of data being subject to these provisions, the sum of the parts created security concerns and the data was deemed not publishable. This created two problems. It greatly restricted the ability of the research team to discuss the model and its capabilities in open sessions and present results in academic and technical journals and perhaps more importantly, it limited the use of the models to New Hanover County. If MUNICIPAL and its related models were to achieve their desired potential as a planning and educational tool, it would have to operate with a dataset that did not have these security concerns nor require two years of data collection to build a new dataset for each area under study.

To overcome these obstacles, the research team created an artificial community called CLARC (Customizable Artificial Community) to support further development and validation activities. This robust and sharable dataset can support additional infrastructure and emergency management research without compromising potentially sensitive information regarding the location and/or vulnerabilities of actual infrastructure. The development of the CLARC dataset is discussed in "CLARC: An Artificial Community for Modeling the Effects of Extreme Hazard Events on Interdependent Civil and Social Infrastructure Systems" which is currently under review by the *Journal of Infrastructure Systems.*

In preparation for validating the COMSURE algorithms at the locations of potential partners, the research team needed a method to quickly develop an accurate dataset of critical commercial facilities. Working from the websites of major commercial chains and independent search engines, the team was able to compile an inventory of banks, supermarkets, convenience stores, pharmacies, and other commercial operations near or within a zip code or major landmark. The street addresses were convertible to GPS coordinates using Google Maps and could be digitally plotted on base maps. The resultant mapping was also valuable for observing how multiple suppliers of the same service tend to group together in shopping plazas or at highway intersections. This empirical knowledge was used to populate the artificial community CLARC with commercial facilities.

3. Results: The research outcomes for Community Supply Resiliency (COMSURE) are as follows:

- A dataset that describes the supply chains for goods and services critical to the response and recovery of a coastal community subject to a hazard, e.g. a hurricane. Recognizing security considerations, the results of this effort were used in augmenting the data in CLARC, our artificial community, to include these supply chains.
- Visual and mathematical representations of the supply chains that form the basis for COMSURE.
- The results of this effort have been described in "Modeling the Recovery of Critical Commercial Services and their Interdependencies on Civil Infrastructures" which is currently under review by *The International Journal of Critical Infrastructures."*
- The research team has also developed a deeper understanding of the implications for community resilience that are created by the interdependencies between civil and social infrastructures, particularly in the areas of food, fuel, and pharmaceuticals. This understanding will underpin continuing research in this relatively unexamined area.

End Users and Transition Partners:

We envision the end users for our research to be local emergency managers, DHS analysts tasked with providing guidance on policies that effect community resilience to extreme events, and educators who wish to incorporate computer-aided decision support tools into their curricula. Data on the supply chains for the goods and services provided by social infrastructures has been compiled based on the attributes of several coastal communities in North Carolina as well as Puerto Rico. This information has been incorporated into the CLARC dataset for research and analysis purposes. We have met with representatives of DHS's Office of Cyber & Infrastructure Analysis and presented our decision support tool MUNICIPAL for their review.

MUNICIPAL has been integrated into the U.S. Department of Homeland Security (DHS) Standard Unified Modeling, Mapping & Integration Toolkit (SUMMIT). SUMMIT is a software toolkit that enables the emergency management community to access integrated suites of modeling tools and data sources for planning, exercises, or operational response. Making the decision support technology compliant with SUMMIT will enable emergency managers to use the planning and training capabilities of SUMMIT in concert with the modeling and simulation capabilities of MUNICIPAL. Integration with SUMMIT databases will also help to reduce the data collection burden mentioned earlier.

Additional funding to carry on this research was sought from various sponsors as shown below:

Title	Submitted to	Date	Outcome
MUNICIPAL+4: A Stakeholder-Guided Educational and Training Tool to Improve Decision-Making for Critical Infrastructure	NOAA	July 2015	Not Selected

Subject to Extreme Weather Events and Storm Surge			
Demonstration and Deployment of Education and Training Technology for the Restoration of Critical Infrastructure Following Extreme Weather Events	Critical Infrastructure Resilience Institute (CIRI)	October 2016	Not Selected
Deployment of MUNICIPAL: An Education and Training Technology for the Restoration of Critical Infrastructure Following Extreme Events	DHS	May 2017	Not Selected
Determining the Impacts of Interdependent Infrastructure Failures on the Production and Supply of Pharmaceuticals and Medical Devices Following Hurricane Maria	NSF	May 2018	Not Selected

Project Impact:

The MUNICIPAL/COMSURE technology has three potential levels of application that could be utilized by different cohorts of the EM community.

- An educational application designed for university-level curricula in emergency management that would make use of the CLARC community dataset
- A training application designed for working professionals in emergency management that would make use of the existing technology coupled with the HSIP Gold dataset specific to the location in question
- A field application to be used as a real-time decision-support tool in an actual emergency; it would also utilize the HSIP Gold dataset

All of these applications would produce usable tools for the education and practitioner communities. The educational tool would make students more familiar with the complex interactions that occur between civil and social interdependent systems; the training tool would supplement or replace costly "boots on the ground" field exercises; and the decision-support tool would increase understanding of the important role of service restoration priorities in designing effective response and restoration activities.

Overall, the work completed to date validates the previously developed algorithms and their applicability to critical commercial services as well as civil infrastructures. It also affirms the important role of the Emergency Manager as the sole owner of the "Big Picture" of how the various systems interact and the importance of restoration priorities in designing the most effective response and recovery program for these interdependent systems.

Although the research necessary to develop and deploy MUNICIPAL/COMSURE has been completed, this technology is not readily usable by the practitioner community. If additional funding were available, this research could be translated into a readily deployable education and training tool for practitioners that will make the nation and its critical infrastructures more resilient in the face of multiple hazards. The full impact of this research is in its application; without the funding to build workable tools based on the research, its full potential for education, training, and real-time decision support will never be realized.

Student involvement and awards:

Over the lifetime of the project, the following students were involved:

Ryan A. Loggins, Ph.D. awarded 2015, RPI Department of Industrial and Systems Engineering
Aaron Rowen, Ph.D. candidate, RPI Department of Industrial and Systems Engineering
Ni Ni, Ph.D. candidate, RPI Department of Industrial and Systems Engineering

> Loggins, R. A., & Wallace, W. A. (2015). Rapid Assessment of Hurricane Damage and Disruption to Interdependent Civil Infrastructures Systems. *J. Infrastruct. Syst.*, doi: http://dx.doi.org/10.1061/(ASCE)IS.1943-555X.0000249.
>
> Loggins, R. A. (2015). Improving the Resilience of Social Infrastructure Systems to an Extreme Event. Ph.D. Thesis. Troy, NY: Rensselaer Polytechnic Institute.
>
> Loggins, R.A., W.A. Wallace, and B. Cavdaroglu. (2013). "MUNICIPAL: A Decision Technology for the Restoration of Critical Infrastructures," in Proceedings of the 2013 Industrial and Systems Engineering Research Conference, A. Krishnamurthy and W.K.V. Chan, eds.

Interactions with education projects: A formal "Request for Input" entitled "Adapting a Computer-aided Emergency Management Research Tool for Educational Purposes" was sent to CRC educational partners. No interest was expressed in incorporating the technology into existing curricula.

Publications: Provide a comprehensive list of your CRC-funded publications that have already been published or accepted for publication. Make sure citations are complete and in the accepted format for your discipline.

Ni Ni, R. Little, T. Sharkey, and W. Wallace. "Modeling the Recovery of Critical Commercial Services and their Interdependencies on Civil Infrastructures." *International Journal of Critical Infrastructure Systems.* (in review).

Little, R., R. Loggins, J. Mitchell, T. Sharkey, and W. Wallace. "CLARC: An Artificial Community for Modeling the Effects of Extreme Hazard Events on Interdependent Civil and Social Infrastructure Systems." *Journal of Infrastructure Systems*. (in review).

Loggins, R., R. Little, J. Mitchell, T. Sharkey, and W. Wallace. "CRISIS: A Tool for Modeling the Restoration of Interdependent Civil and Social Infrastructure Systems Following an Extreme Event," *Natural Hazards Review.* (in review).

Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
N/A			

Table 2A: Documenting External Funding

Title	**PI**	**Total Amount**	**Source**
NONE			

Table 2B: Documenting Leveraged Support

Description (e.g., free office space; portion of university indirects returned to project; university-provided student support)	**Estimated Total Value**
Free office space	**$2,000**
Visiting Scholar's time	**$ 9,600**

Table 3: Performance Metrics:

WALLACE PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17-6/30/18)
HS-related internships (number)	--		
Undergraduates provided tuition/fee support (number)	--		
Undergraduate students provided stipends (number)	--		
Graduate students provided tuition/fee support (number)	--		
Graduate students provided stipends (number)	1	2	1
Undergraduates who received HS-related degrees (number)	--		
Graduate students who received HS-related degrees (number)	--		
Graduates who obtained HS-related employment (number)	--		
SUMREX program students hosted (number)	--		
Lectures/presentations/seminars at Center partners (number)	1	1	1
DHS MSI Summer Research Teams hosted (number)	--		
Journal articles submitted (number)	--	1	3
Journal articles published (number)	--		
Conference presentations made (number)	--	3	
Other presentations, interviews, etc. (number)	2	1	1
Patent applications filed (number)	--		
Patents awarded (number)	--		
Trademarks/copyrights filed (number)	--		
Requests for assistance/advice from DHS agencies (number)	1		
Requests for assistance/advice from other Federal agencies or state/local governments (number)	1	1	
Total milestones for reporting period (number)	3		
Accomplished fully (number)	2	2	2
Accomplished partially (number)	1	0	
Not accomplished (number)	0	0	

Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Assessment of results of analysis	8/1/17	100%	
Adjust models based on assessment	9/1/17	100%	
Format data for decision support tool	9/1/17	100%	
Research Milestones			
Paper on COMSURE	10/1/17	100%	
Formal Knowledge Report	12/15/17	100%	

Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Data formats and visuals for decision support tool	9/1/17	100%	
Meet with representatives of the Association for Convenience & Fuel Retailing and Healthcare Ready, an association that focuses on the preparation of healthcare supply chains for natural and manmade disasters.	10/1/17	100%	

Meet with representatives of the International Association of Emergency Managers	10/1/17	100%	
Transition Milestones			
Formal Knowledge report	12/15/17	100%	
Paper on assessment of COMSURE	10/1/17	100%	

Theme 2

Building Resilient Communities

BERKE- TAMU
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Local Planning Networks and Neighborhood Vulnerability Indicators

Principal Investigator Name/Institution: Philip Berke, Texas A&M

Co-Principal Investigators and Other Partners/Institutions:

- Jaimie Masterson, Texas A&M;
- Galen Newman, Texas A&M;
- Walter Peacock, Texas A&M

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description (“elevator speech”):

A primary objective is to develop a tool and user guidelines to assist local planners and emergency managers to integrate hazard mitigation into planning in all relevant sectors of urban development. Failure to coordinate networks of plans can significantly compound the growing risks to disaster events. Development and validation of the tool requires testing in communities to assess how well networks of local plans (land use, hazard mitigation, economic development, transportation) integrate mitigation practices that govern development in hazard areas.

Summary Abstract:

We apply a *Plan Integration for Resilience Scorecard* (PIRS) in six US coastal cities. Our research objectives are twofold: (1) to evaluate the degree to which hazards mitigation is integrated throughout network of plans in different geographic areas exposed to hazards; and (2) to evaluate the degree to which the network of plans recognizes and targets areas where the built environment is vulnerable to hazards. We find that plan integration scores vary widely across the cities, and that some plans actually increase vulnerability in hazard zones. Policies also frequently support mitigation in areas with low vulnerability, rather than in areas with high vulnerability.

We engaged three additional communities to translate PIRS to planning practice. In partnering with local officials, we adapted PIRS to fit mitigation planning practice through the lens of local practitioners. Our aim is to improve the capability of local partners to self-evaluate their own networks of plans. We found that PIRS generates information to improve hazard planning by allowing planners to identify conflicts between plans, assess whether plans target areas that are most vulnerable, and better inform decision makers about opportunities to mainstream mitigation into multiple sectors of planning.

We developed a *PIRS Guidebook* for practitioners, and training materials (scoring tool, video of lectures, ppt slides) to guide local application of PIRS that are publicly available [see, mitigationguide.org]. We gave five webinars to national and state audiences, eight presentations at national conferences, and generated three funded proposals that showcase PIRS (two from NSF at $2.2 million and one from the Texas One Gulf Program at $90,000).

REPORT NARRATIVE:

1. Research Need:

Fragmentation and poor integration among the diverse range of sectors of planning has led to siloes in which mitigation planning is isolated from other planning. Hazard mitigation specialists have long been concerned about the implications of lack of integration of mitigation across local planning sectors, which can significantly compound future risks. Failure to coordinate integration of multiple planning activities that govern land use in hazard areas has become a national policy concern. This was acknowledged by the Federal Emergency Management Agency director Craig Fugate's call in 2010 for more integration of hazard mitigation efforts into all types of local planning and more cooperation between emergency managers and planners (Fugate 2010). Although Fugate's observation was made nearly a decade ago, recent DHS funded research substantiates its relevance (Berke et al. 2012, Lyles and Berke 2014).

Berke, P. R., Smith, G., & Lyles, W. (2012). Planning for resiliency: evaluation of state hazard mitigation plans under the Disaster Mitigation Act. Natural Hazards Review, 13, 139–150.

Fugate, W. C. (2010). "Integrating Hazards into Local Planning," Foreword to Hazard Mitigation: Integrating Best Practices into Planning, James Schwab, editor, Planning Advisory Service Report 560, American Planning Association, Chicago, IL, 2010: iii-iv).

Lyles, W., Berke, P., and Smith, G. (2014). "A Comparison of Local Hazard Mitigation Plans in Six States, USA." Landscape and Urban Planning 122: 89–99. https://doi.org/10.1016/j.landurb plan.2013.11.010.

2. Project History:

We reviewed the literature in hazard mitigation planning to identify how mitigation can be supported thorough different types of local planning activities (economic development, land use, capital improvement programs, environment) that influence land use and development patterns in hazard areas. We then developed a conceptual framework to guide development of a *Plan Integration for Resilience Scorecard* (PIRS). The scorecard includes two sets of geospatial indicators to measure the level of: 1) integration of hazard mitigation policies in a local network of plans in different geographic areas; and 2) social and physical vulnerability in different geographic areas. Next, we systematically applied PIRS in six demonstration coastal communities to evaluate the level of integration that local plans support mitigation, and the degree to which the network of plans prioritize vulnerability reduction in different geographic areas. Finally, we engaged three additional communities to translate PIRS to planning practice. We developed training materials to guide local application of PIRS.

3. Results:

Research. Two core sets of findings are derived to date from our research. For *physical vulnerability* to the built environment, we find that plan integration scores vary widely across cities, and that some plans actually increase vulnerability in hazard zones. Policies also frequently support mitigation in areas with low vulnerability, rather than in areas with high vulnerability. For *social vulnerability*, we find that local plans are not fully integrated and do not always address the areas where marginalized populations are most vulnerable; moreover, some plans actually actively increase vulnerability in neighborhoods with the most marginalized populations.

Community engagement. We created a Plan Integration for Resilience Scorecard (PIRS) derived from research in six communities (see, mitigationguide.org). The research-driven scorecard was converted into a user-friendly tool that enables local officials to self-evaluate their community's network of plans. We produced a *Plan Integration for Resilience Scorecard Guidebook* that provides end users the opportunity to identify when and where their community plans are in conflict, as well as how well they target different geographic areas of the community that are most vulnerable. The new knowledge generated by application of PIRS allows local officials to engage the whole community regarding 'missed opportunities' to strengthen local hazard mitigation planning, and to improve the integration, consistency, and responsiveness of their networks of plans. We completed a collaborative effort with local officials in Norfolk, VA and we are currently working with Nashua, NH and League City, TX. Norfolk actually revised its plans as a result of application of PIRS.

Webinars.

- Model Forest Policy Program, September 2016
- Planning Information Exchange (PIE) of the Association of Floodplain Managers and the American Planning Association, October 2017
- FEMA PrepTalk, January 2018
- FEMA-Community Planning and Capacity Building (CPCB), June 2018
- Louisiana Sea Grant Program, July 2018

Targeted Outreach.

- American Planning Association- Hazard Mitigation and Disaster Recovery Division Newsletter, 2016
- National Planning Conference, Hazard Mitigation and Disaster Recovery Division Meeting, Phoenix, April 2016
- National Hurricane Conference, New Orleans, March 2017
- National Planning Conference, New York City, May 2017
- Association of State Floodplain Mangers Regional Conference, New Jersey, June 2017
- Natural Hazards Workshop, Broomfield, July 2017
- Texas Sea Grant Program, College Station, February 2018
- National Hurricane Conference, Orlando, April 2018

Leveraging for additional funded projects.

- Berke received funding for two NSF proposals (NSF RAPID, $200,000 2017-18, and NSF CRISP $2 million 2019-23) in which PIRS has a central role.
- Berke leveraged another NSF project ($200,000 2016-2020) under the Partnerships for International Research & Education (NSF-PIRE) that supported three doctoral students to apply the PIRS in three different cities in the Netherlands.
- Berke received funding ($90,000 2018-19) from the Texas One Gulf program to apply PIRS to communities recovering from Hurricane Harvey.

4. End Users and Transition Partners:

We are engaging end-users through creation of a National Advisory Committee, direct contact with FEMA officials, and involvement of local government staff in the demonstration communities.

We have recruited and convened a National Advisory Committee to strengthen partnerships and collaborations with the practice community and to ensure the applicability of the scorecard for mitigation practitioners. Members include key leaders in the practice community:

- Chad Berginnis, Director, Association of State Floodplain Managers
- Nat'l Coordinator for Community Recovery Planning & Branch Chief for Community Planning and Capacity Building of the Interagency Coord. Div.,FEMA
- Jennifer Ellison, Community Development Coordinator, City of Urbandale, Iowa
- Allison Hardin, Urban Planner, City of Myrtle Beach, SC
- Barry Hokanson, Director, Hazard Mitigation and Disaster Recovery Division of the American Planning Association & Mitigation Planner, PLN Associates
- Darrin Punchard, Mitigation Planner, Hawksley Consulting
- Gavin Smith, Exec. Director, Coastal Resilience Center, University North Carolina

The Committee met about every 4-months via teleconference with project investigators during a two-year period. Committee members offered guidance in the development of the PIRS tool, assisted with dissemination of project results, and provided oversight and strategic advice to the research and translational activities. The Committee also served to enhance communication between the project researchers and the practice community.

FEMA is the primary end user for this project. Our primary point of contact at FEMA has also serves on our National Advisory Committee. We also kept in regular communication with our OUP Program Manager (Eleanore Hajian) about progress of this study through emails, conference calls, and preparation of a brief research summary report.

Finally, our engagement efforts focused on local officials in multiple cities. It is the local community where all aspects of planning come together. We engage local agency staff charged with responsibilities for planning. Local officials that have been engaged include, for example, emergency management, resilience officers, land use planning, economic development, and environmental conservation. These end users are typically charged with preparing, updating and reviewing the diversity of local plans that influence land use and development in hazardous areas.

By the end of the project period in June 2018, we have initiated multiple potential engagement projects in communities. We completed a successful 12-month engagement effort with Norfolk, VA. We initiated work in Nashua, NH in Spring 2018 in partnership with NIST focused on integrating PIRS with the NIST *Community Resilience Planning Guide* in Nashua, NH. We plan to continue this collaboration with NIST in several additional communities over the next two years with DHS support. We also are doing long-term engagement work with League City, TX where we are applying PIRS in a Hurricane Harvey disaster recovery planning effort.

5. Project Impact:

Summary of Impacts
As noted, we developed the PIRS tool to enable local officials to self-evaluate their local networks of plans. We also prepared a guidebook for training local officials on PIRS. Application of PIRS has had multiple impacts: raised knowledge and capacity of local officials to better support mitigation; provided a fact base that has been used to revise plan policies to improve integration of plans; improved land use regulatory practices and standards to be consistent with plan revisions and to better integrate mitigation into urban development projects.

We completed a collaborative effort with local officials in Norfolk, VA in applying PIRS. Norfolk actually revised its plans as a result of application of PIRS and has revised its development ordinances to be consistent with the network of plans. In collaboration with NIST, we are currently working with Nashua, NH in combining efforts to jointly apply PIRS with the NIST *Community Resilience Planning Guide*. We also are working with League City, Texas, in applying PIRS in assisting them preparing post-Harvey recovery plans, and to extend PIRS to include an evaluation component that assess the degree of integration of local networks of plans with land use regulations in different geographic areas.

Detailed review of impacts:
In our work in applying the scorecard in the three demonstration communities we tracked four types of impacts likely to occur at different stages of the plan review and implementation process:

Impact #1: Changes in knowledge by urban planners, emergency managers and stakeholders about roles of alternative plans and how they can be better integrated to increase support for mitigation, reduce duplication of effort, and more efficiently use limited resources.

Impact #2: Revision and better integration of vulnerability reduction into a community's general plan, hazard mitigation plan, and other local plans.

Impact #3: Revision of a range of development policy tools that influence land use and development in hazard areas to be consistent with the revisions of plans. Examples of policies include development regulations (e.g., zoning and subdivision ordinances), incentives (density bonuses, property tax breaks), land acquisition strategies, and design and location of capital improvement projects (transportation, water, sewer).

Impact #4: Changes in vulnerability outcomes that limit or prevent new development (and population) in hazard areas, or reduce vulnerability of existing development (and population) in hazard areas in different geographic areas.

Impact #1 (change in knowledge of planners and stakeholders) begins soon after (1-3 months) a community starts to apply the scorecard. This impact indicates that plan review is not just about the scores. Based on our work with the demonstration communities to date, we are finding that a valuable contribution resulting from application of the scorecard is a collaborative process that yields information about how specific policies that influence public and private land use and investments within a plan and the network of plans. Application of the scorecard provides a deeper understanding and comprehensive assessment of how multiple plans, that may not directly address hazard mitigation, are conclusively linked to mitigation and disaster loss.

For example, the City of Nashua saw the scorecard as so valuable they developed an interactive web-mapping tool to score plans. Stakeholders are able to log in to the mapping website to understand the integration of their network of plans. Additionally, Nashua planners felt some policies were unclear. Going forward, the city will use the scorecard process to update their hazard mitigation plan and draft a new comprehensive plan, with clearer policies that incorporate hazard exposures. This knowledge, along with Resilience Dialogues recommendations and HAZUS analysis are being fully integrated into the new hazard mitigation plan updates.

Examples of comments by local officials in the demonstration communities indicate the high value they place in gaining a better understanding of their networks of plans through application of the scorecard:

- "We wanted to see the effect of all our policies on flood resilience because we had never taken such a comprehensive look our policies before. It was also an opportunity to see how different plans stacked up, particularly because we had not previously evaluated the hazard mitigation plan side by side with other community plans." –City of Norfolk;
- "We were very intrigued by the spatiality of our policies and hadn't thought about our policies spatially before. This was important to us because our Vision2100 document specifically designates areas of flood protection and retreat." –City of Norfolk;
- "We utilized this to update our comprehensive plan and zoning ordinances" –League City;
- "It is important for practice that you are tracing back to the policy." –League City
    - "The Resilience Scorecard was a great tool to allow us to evaluate our existing plans and policies against the backdrop of resilience. Perhaps most revealing were not inconsistencies in our plans, but that we had not fully incorporated all our policies and actions aimed at resilience into our most important policy document, our

comprehensive plan. Following our participation in scoring Norfolk's plan, we undertook a major plan amendment to more fully incorporate our Hazard Mitigation Plan as a key element in our comprehensive plan. As we kick off the drafting of our next comprehensive plan later this year, we plan to revisit our scores from the Resilience Scorecard to better guide future development and investments that will maximize our opportunities to transform Norfolk into a resilient waterfront community." – George Homewood, FAICP, CFM, Planning Director

Examples of comments from the 40-member stakeholder meeting during an interactive activity we conducted in June, describe the "Aha" moments various departments and agencies had in Nashua:

- "This policy recommends increasing development in the floodplain. Clearly we want to encourage development in the Mill Yard District, but not in floodplain." –City of Nashua stakeholder
- "Many of the policies are too vague and need to be more targeted." (the scorecard reveals weak policies that could more specifically speak to hazards, vulnerability, and actionable policy tools) –City of Nashua stakeholder
- "We are required to create a consolidated housing plan for HUD. We see that vulnerable groups are identical to the SoVI census tract that are most vulnerable and the plan scorecard results." –City of Nashua stakeholder
- "We need to update our masterplan to address hazards." –City of Nashua stakeholder
- "Drainage capacity can only be done to a certain extent. We need to address open space in flood-prone areas and regulations on development at the same time." –City of Nashua stakeholder
- "We need to look at areas not developed. The city needs to decide about how to develop the parcels in the floodplain." –City of Nashua stakeholder

Impact #2 (change in plans) and Impact #3 (change in regulatory and investment policies) will likely occur in the mid-term (3-12 months) after completion of our engagement efforts in the demonstration communities this summer 2018. We will document these changes up to the summer 2018, and continue to track changes if funding for this project is extended. To date, change in plans and policies have included amendments to several components of planning documents of the City of Norfolk. Staff planners indicate that applying the scorecard produced several benefits: a) the most comprehensive examination (but not time consuming) of the level of integration among different plans they had ever undertaken; b) allowed them to evaluate the degree to which policies from multiple plans decrease (or actually increased) vulnerability in different geographic areas of the city; and c) the new information supported deeper and more inclusive conversations about different stakeholder interests regarding the impacts of specific policies.

Action by the City of Norfolk was recently taken based largely on results of the scorecard evaluation process. On June 22, 2017 the planning staff presented a document to the Norfolk Planning Commission Public Hearing that details policy amendments across various plans. Following are examples of needed actions under two broad headings that are included in the public hearing document (see attached Planning Commission Public Hearing document):

- The scorecard tool revealed weaknesses and inconsistencies throughout plans. Examples of improving plan integration include:
  a. Pg. 1: Land use, transportation, and facility location elements in the comprehensive plan (plaNorfolk 20130) need to be amended to incorporate resilience plan proposals (Vision 2100).
  b. Pg. 2: Amend comprehensive plan (plaNorfolk 20130) to incorporate specific design criteria for public facilities in the resilience plan (Vision 2100).
  c. Pg. 4: Revise land sales and acquisition policies in the affordable housing plan to be consistent with resilience plan (Vision 2100).
  d. Pg. 4: Update zoning regulations to be consistent with resilience plan land use strategies that vary across different geographic areas (red, yellow, green and purple districts, see pp. 10-11).
  e. Pg. 5: Location criteria for community facilities within the comprehensive plan did not account for resilience policies and metrics discussed in the resilience plan.
  f. Pg. 5: Incorporate resilience policies in Vison 2100 into the capital improvement projects to determine major roadway improvements, rail, ferries, etc. (p. 5)
  g. Pg. 5: Use Vision 2100 as a guide when reviewing development proposals and budgets for capital improvements.

- Norfolk planning staff indicates they had not previously reviewed or evaluated the hazard mitigation plan. They have not consulted the hazard mitigation plan in the preparation of all other plans adopted by the city. They indicate that the scorecard provided a methodological tool to guide integration of the mitigation plan across other plans, and to make the mitigation plan better. Examples of integration of the mitigation plan identified on the attached Planning Commission Public Hearing document include:
  h. Pg. 2: Amend the comprehensive plan (plaNorfolk 20130) to incorporate actions in the hazard mitigation plan (Hampton Roads Mitigation Plan).
  i. Pg. 5: Integrate the mitigation plan and resilience plan (Vision 2100) guides to evaluate options to future development proposals.
  j. Pg. 7: Hazard mitigation plan contains policy actions that should more clearly specify "appropriate strategies to mitigate the impact of flooding to existing flood-prone structures." The resilience plan could be used to improve the mitigation plan, for example, since the resilience plan includes flood maps of locations of such structures, which can provide the basis for formulating more spatially specific policies in the mitigation plan.
- Norfolk planning staff indicates they had not considered the policies impacts in socially vulnerable areas. For instance the scorecard:
  k. Revealed the quantity of policies in more socially vulnerable districts. The city stated they see now they should include additional policies for socially vulnerable planning districts.
  l. Revealed socially vulnerable districts in upland areas are the same locations they are incentivizing for sea level rise retreat. Planners had conversations about the

"new gentrification" that might occur displacing socially vulnerable populations by wealthier residents that are seeking homes outside of hazard zones.

Impact #4 (change in vulnerability outcomes) will likely be evident in the long-term (>2 years), but we will track any change outcomes during the duration of this study.

6. Student involvement and awards:

Three doctoral students (Matt Malecha, Malini Roy, Siyu Yu) at Texas A&M are employed on this project. They are all applying and extending PIRS in various forms for their dissertation research. Each has conducted international field research in applying PIRS in three cities in the Netherlands under a NSF funded project. Two of the students have completed all course, exams and are working on their dissertations with expected date of graduation May 2019.

- Matt Malecha:

International Research Fellowship, National Science Foundation Partnerships for International Research & Education (NSF-PIRE), 2016. Research focused on application of PIRS in Rotterdam, Netherlands.

Spatially Evaluating a Network of Plans and Flood Vulnerability Using a Plan Integration for Resilience Scorecard: A Case Study in Feijenoord District, Rotterdam, the Netherlands, 57th Association of Collegiate Schools of Planning (ACSP) Annual Conference, October 12-15, Denver, Colorado

Resiliency through Plan Integration, Avoiding Disasters Conference: How to Reduce Impacts from the Next Big Storm, April 26-27, Rice University, Houston, Texas

- Malini Roy:

Roy, Malini. NSF-PIRE Research Seminar Presentation. "Planning for Future Flood Scenarios: Adapting Plan Integration for Resilience Scorecard in Dordrecht, Netherlands," May 25, 2018, Vrije Universiteit Amsterdam, Netherlands.

International Research Fellowship, National Science Foundation Partnerships for International Research & Education (NSF-PIRE), 2016. Research focused of application of PIRS in Dordrecht, Netherlands.

- Siyu Yu:

Jesus Hinojosa Endowed Urban Planning Scholarship, Texas A&M University, 2018. Scholarship based on application of PIRS Nijmegen, Netherlands.

International Research Fellowship, National Science Foundation Partnerships for International Research & Education (NSF-PIRE), 2017. Research focused on application of PIRS Nijmegen, Netherlands.

Urban and Regional Science Doctoral Departmental Scholarship, Texas A&M University, 2014-2017.

College of Architecture Research Colloquium Lecture Series, Texas A&M University on Dec 8th, 2017."Making Room for the River: Applying a Plan Integration for Resilience Scorecard to a Network of Plans in Nijmegen, Netherlands"

Publications with students as lead- or co-authors:

Berke P., **Malecha M., Yu S.**, Lee J., Masterson J. (2018). Plan Integration Scorecard for Resilience: Evaluating Networks of Plans in Six US Coastal Cities, *Journal of Environmental Planning and Management*, DOI:10.1080/09640568.2018.1453354.

Malecha, M., Brand, A., & Berke, P. (2018). Spatially evaluating a network of plans and flood vulnerability using a Plan Integration for Resilience Scorecard: A case study in Feijenoord District, Rotterdam, the Netherlands. *Land Use Policy, 78*, 147-157. DOI: 10.1016/j.landusepol.201

Masterson, J., Berke, P., **Malecha, M.**, Yu, S., Lee, J., & Thapa, J. (2017) Plan integration for resilience scorecard: How to spatially evaluate networks of plans to reduce hazard vulnerability. College Station, Texas: Institute for Sustainable Communities, College of Architecture, Texas A&M. http://mitigationguide.org/wpcontent/uploads/2013/01/Scorecard_3Oct2017.pdf.

7. Interactions with education projects:

Berke. P. *Mitigation Planning for Resilient Cities. Coastal Resilience Center ReTalk Webinar*, March 8, 2018. Johnson C Smith University, Charlotte, NC

8. Publications:

Berke, P., Malecha, M., Yu, S. and Masterson, J. 2018. Plan integration for resilience scorecard: Evaluating networks of plans in six US coastal cities. *Journal of Environmental Planning and Management* (online): https://doi.org/10.1080/09640568.2018.1453354.

Malecha, M.L., Brand, A.D., & Berke, P.R. 2018. Spatially evaluating a network of plans and flood vulnerability using a plan integration for resilience scorecard: A case study in Feijenoord District, Rotterdam, the Netherlands. *Land Use Policy* 78: 147-157.

Two papers under review, and two papers are currently in preparation related to application of PIRS.

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type (e.g., software, guidance document)	Delivery Date	Recipient or End User
Plan Integration for Resilience Scorecard Guidebook	Guidance document	2017	FEMA staff that focus on hazard mitigation. State and local officials directly active in hazard mitigation, or indirectly though planning activities that govern development and land use in hazard areas. Professional practice associations like Assoc. of State Floodplain Managers, Am Planning Assoc. Hazard Mitigation and Disaster Recovery Division, Natural Hazard Mitigation Assoc., Nat'l Emergency Man. Assoc.
Berke, P., Malecha, M., Yu, S. and Masterson, J. 2018. Plan integration for resilience scorecard: Evaluating networks of plans in six US coastal cities. *Journal of Environmental Planning and Management* (online): https://doi.org/10.1080/09640568.2018.1453354.	Peer reviewed outlet		researchers
Malecha, M.L., Brand, A.D., & Berke, P.R. 2018. Spatially evaluating a network of plans and flood vulnerability using a plan integration for resilience scorecard: A case study in Feijenoord District,	Peer reviewed outlet		researchers

Rotterdam, the Netherlands. *Land Use Policy* 78: 147-157.			

Table 2A: Documenting External Funding

Title	PI	Total Amount	Source
Inter-organizational Dynamics in Human Systems that Govern Interdependent Infrastructure Systems under Urban Flooding	**Berke, co-PI**	**$200,000**	**NSF RAPID**
Anatomy of Coupled Human-Infrastructure Systems Resilience to Urban Flooding: Integrated Assessment of Social, Institutional Planning, and Physical Networks	**Berke, Co-PI**	**$2 million**	**NSF CRISP**
Coastal Flood Risk Reduction Program: Integrated, Multi-scale Approaches for Understanding How to Reduce Vulnerability to Damaging Events	**Berke**	**$200,000**	**NSF PIRE**
Application of PIRS During Post-disaster Recovery after Hurricane Harvey	**Berke**	**$90,000**	Texas One Gulf program

Table 2B: Documenting Leveraged Support

Description	Estimated Total Value
Indirect	**$10,000**

Table 3: Performance Metrics:

BERKE PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 2** (7/1/17- 6/30/18)
HS-related internships (number)	0	0	0
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	0	0	0
Graduate students provided tuition/fee support (number)	2	2	2
Graduate students provided stipends (number)	3	3	3
Undergraduates who received HS-related degrees (number)	0	0	0
Graduate students who received HS-related degrees (number)	0		0
Graduates who obtained HS-related employment (number)	0		0
SUMREX program students hosted (number)	0	0	0
Lectures/presentations/seminars at Center partners (number)	0	3	
DHS MSI Summer Research Teams hosted (number)	0	0	
Journal articles submitted (number)	0	2	2
Journal articles published (number)	0	0	2
Conference presentations made (number)	3	5	2
Other presentations, interviews, etc. (number), webinars	1	6	2
Patent applications filed (number)	0	0	0
Patents awarded (number)	0	0	0
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number) (FEMA, NIST)	0	1	2
Requests for assistance/advice from other agencies or governments number)	0	9	3
Total milestones for reporting period (number)	2	2	
Accomplished fully (number)	2	1	4
Accomplished partially (number)		1	1
Not accomplished (number)			

10. Year 3 Research Activity and Milestone Achievement.

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Complete evaluations of networks of plans and community hazard vulnerability in 6 additional local governments.	5/30/17	100	
Complete data analysis to determine how well a network of plans support mitigation, and how well they are spatially correlated with variation of social and physical vulnerability.	6/30/17	100	
Complete assessment of impacts of local government application of the plan integration tool based on one or more sources of information: 1) anecdotes that represent end user assessments of proposed changes that will be taken; 2) actual policy changes in plans, regulations, and public investment strategies; and, 3)if possible, measurable changes in vulnerability	5/18/18	100	
Research Milestones			
Submit a manuscript for publication to a refereed journal.	10/30/17	100	
Compile a report that documents impacts of application of the plan	6/30/18	100	

integration tool that are accomplished by the end of the project			

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Further test the plan integration for resilience scorecard in 6 additional communities that agree to have their plans assessed; and inform communities of results.	6/30/17	95	All plans are examined in the 6 communities. We have not informed them of the results. We decided that it would best only inform community officials in those communities where we had significant engagement and developed trust (Norfolk has been informed and Nashua will be informed once we complete our engagement work there about 9/30/18.
Complete preparations for a workshop with hazard mitigation practitioners to review tool in partnership with the Hazard Mitigation and Disaster Recovery Planning Division of the American Planning Association.	7/30/2017	100	
Transition Milestones			
Conduct workshop with hazard mitigation practitioners to review tool in partnership with	7/30/17	100	

the Hazard Mitigation and Disaster Recovery Planning Division at the American Planning Association Conference, and review tool at the Hazards Workshop in Broomfield, CO.			
Place final plan integration assessment tool on website [mitigationguide.org] with examples that demonstrate application of the tool.	6/30/18	100	

PROCHASKA, URI
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Communicating risk to motivate individual action

Principal Investigator Name/Institution: Dr. James O. Prochaska, Cancer Prevention Research Center (CPRC), URI

Co-Principal Investigators and Other Partners/Institutions: Dr. Andrea Paiva, CPRC, URI, Pam Rubinoff, CRC, URI.

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description ("elevator speech"):

Communicates risk to motivate action by tailoring communication to diverse populations. Participants receive individualized feedback via online coaching based on their readiness to take action and tailored text messages, thereby encouraging them to move forward in the behavior change process to prepare and mitigate impacts of coastal storms.

Summary Abstract:
Efforts to communicate disaster preparedness and risk messages lead to increased public awareness. However, FEMA surveys indicate that the public today is little more prepared to respond to a disaster than it was several years ago. This conundrum reflects the axiom in the science of behavior change that increasing awareness can start the change process, but cannot sustain it; reflecting a disconnect between theory and practice. This project used behavior change psychology to define and include specific achievable actions in tailored feedback delivered both online and through text messages to reach 3,000+ people from coastal states. Despite the very small percentage of our sample who completed the follow-up (9.6%), among those people not yet prepared at baseline, 38% of participants took action by the end of the study. Additionally, 74% of participants who were already prepared at baseline remained prepared at follow-up. These results were 19 times greater (38%) than the secular trends and were comparable to the mean of 42% success rates we have found across 14 different risk behaviors that we treated for the first times with TTM-tailored interventions. Given all of these results, we now predict that our success rates in our proposed preparedness project will be about 20 times greater than secular trends and plan to test this hypothesis in a proof of concept project in the upcoming year.

PROJECT NARRATIVE:

1. Research Need:

This project has supported DHS in improving its national mission to safeguard people, infrastructure, and economies from catastrophic coastal natural disasters. This research met DHS priorities by strengthening national preparedness and improving the resilience of coastal communities in the face of coastal storm hazards; consistent with NOAA's coastal missions and programs as well. As such, this research addresses Presidential Policy Directive 8, which calls for increasing our level of National Preparedness by preventing, mitigating, responding to, and recovering from the hazards that pose the greatest risk. This project is specifically tied to strategic priority 1 of the 2014-2018 DHS strategic plan. More specifically we are responding to objective 1.3 aimed at increasing disaster awareness and action. Additionally, this project addresses QHSR Mission 5 (Strengthen National Preparedness and Resilience), which helps develop tools to enhance citizen preparedness, specifically Goal 5.1, Enhance National Preparedness supports efforts to "Empower individuals and communities to strengthen and sustain their own preparedness…build a collective understanding of their risks, the resources available to assist their preparations, and their roles and responsibilities in the event of a disaster." Hurricanes account for 10 of the top 15 most expensive natural disasters in the United States, including the top 3 (NOAA, 2014).

2. History:

This project began in January 2016 with the development of an online program, including writing tailored feedback and tailored text messages that are delivered to participants based on their responses to an empirically tested and validated disaster preparedness assessment. This phase included meetings with stakeholders and possible end-users, like FEMA. Once the program was developed and tested, we recruited 3,043 participants from five states (RI, MA, CT, AL, and FL). We experienced delays in recruiting due heavily to budget limitations and by generating leveraged funds we were able to resolve the issue. We were able to complete the baseline data collection rapidly and were able to increase our baseline recruitment from 1,000 participants to over 3,000 participants. During this time, due to our close discussions and collaborations with FEMA and with leveraged funds we were able to also have an investigator who spent more time engaging end users.

Through 2017, participants received tailored text messages and the project team analyzed the baseline data and presented this in a webinar. Once enough time had passed, the team began the data collection for the follow-up so to be able to evaluate the results of the program and subsequent text messages. All 3,043 participants were contacted by the survey company to participate in the follow-up program and assessment. Very early on in this process, it became apparent that the survey company was struggling to engage participants for the follow-up. Our project team pushed their team to offer more incentives, send more engaging emails to retain participants, and also sent emails from the project email address and offered entry into a large lottery as an incentive to participate. We realized after these efforts did not succeed that the survey company that we ended up choosing, based on their lower cost, did not have experience with engaging their participants at a follow-up time point. They had estimated a 30-35% retention rate, which would have given us 1000 participants at follow-up. Unfortunately, despite our efforts, we ended up with only 9.6% retention at follow-up. Though results are promising, this has prompted us to change our survey company for a proof of concept project if allowed in Year 4.

3. Results:

The low costs allowed us to generate a large sample of 3,043 for three New England states (Connecticut, Massachusetts and Rhode Island) and two southeast Gulf States (Alabama and Florida). The baseline data were excellent and revealed interesting regional differences in distributions across stages of change. Table 1 shows that the New England region had twice as many people in the Precontemplation stage who were not ready to take action on becoming prepared for natural disasters compared to the Southeast region.

Table 1. Stage of Change by Region

		New England (n= 860)		South East (n= 2,177)		X^2	*p*
		n	%	n	%		
Baseline Stage – Disaster	Precontemplation	164	19.1	187	8.6	140.39	**<.001**
	Contemplation	213	24.8	332	15.3		
	Preparation	206	24	541	24.9		
	Action	145	16.9	636	29.2		
	Maintenance	132	15.3	481	22.1		

The New England region also had 56% more people than the southeast region in the Contemplation stage, who are characterized by deep doubts that taking such actions are worth the costs and efforts. Such doubts could lead the majority of contemplators to delay taking action. In the southeast region, on the other hand, almost 60% of respondents reported they had taken effective action in the past six months (29.2%) or were maintaining that action for more than six months (22.1%). Results on other key behavior change constructs (Pros, Cons and Confidence) support the validity of our stages of change findings. Figure 1 shows that across both regions, people in the pre-action stages evaluated the cons (e.g., time, cost, hassle) as significantly greater than the pros (e.g., increasing the safety to family by preparedness to evacuate and the ability to cope of remaining at home). People in the Action or Maintenance stages (A/M) had the appropriate pattern with the pros outweighing the cons. Those in the A/M had significantly higher pros than those in the pre-action stages and lower cons. Similarly, those in pre-action stages had significantly lower confidence or self-efficacy that they could take action and maintain the action than those in A/M. The practical importance of differences on these TTM constructs is that our computer tailored interventions (CTIs), including tailored digital texting were designed to increase the pros of changing, decrease the cons and increase self-efficacy in people in specific pre-action stages of change.

As discussed in the history section above, the follow-up retention rate was much lower than expected and yielded follow-up data on 293 participants (9.6%). Despite the very small percentage of our sample who completed the follow-up, we were able to analyze the data from both those participants who were in the pre-action stages (no yet prepared) at baseline (N=166) and those who were prepared at baseline (in Action or Maintenance) (N=127).

Pre-action at baseline sample results: Among this sample, 38% of participants moved to the Action or Maintenance stages. In our original proposal, we predicted that our tailored intervention would produce results at least 10 times greater than the national secular trends of 2% action taken per year. Our results were 19 times greater than the secular trends.

Action/Maintenance at baseline sample results: Our hope is that our tailored interventions keep participants prepared. We found that 74% of these participants remained in the Action/Maintenance stages at follow-up.

Results by region: Comparison of these results by region indicated that 47.8% of those in the South East region took action compared to 17% in the New England region. This was expected given that the participants in the Southeast were more prepared at baseline.

4. End Users and Transition Partners:

One major end-user continues to be FEMA's Individual and Community Preparedness Division, working through Senior Advisor Jacqueline Snelling. Our major goal is to help solve the problem that FEMA has of striving to surpass the rate of 2% increases annually in the U.S. population's preparedness for natural disasters. Our initial goal was to produce preparedness rates that are 10 times the current national benchmark of 2% increases per year. Our preliminary outcomes indicate that we are likely to produce 20 times the 2% benchmark. Other target end users are organizations that require staffing during emergencies. These include government emergency response (e.g. FEMA, RIEMA); health-related organizations (e.g., CVS Health); South County Health System serving Rhode Island coastal communities; trade organizations that represent a broad range of companies (e.g., Insurance Institute for Business and Home Safety); and NGOs (e.g., the Red Cross). Such organizations suggest that organizational staff need to have their personal/family preparedness strategies attended to so that they can be relied upon by their organizations when emergency strikes. Tailoring interventions for individual preparedness behavior change in these organizations will increase the effectiveness of staff preparedness as well as organizational effectiveness to support community preparedness.

a. How did you transition your results?
b. Describe how end-users are using the results.

Both of these are in process – during Year 4 – part of the process for transitioning is completing the proof of concept and then we will continue to work with our end users to disseminate the program. Ultimately, our specific tools include reliable content that use valid measures of key constructs that produce progress at each stage of change. These measures are applied to tailor the online and texting communications that can motivate and guide at risk participants through the stages with the goal of taking actions that match FEMA's criterion of household preparedness for severe storm disasters. These evidence-based tools and products can be delivered via alternative pathways. A national employer, like CVS Health, home-based in Rhode Island, could deliver it to employees that already receive digital communications for their company. DHS could apply the same approach from their employee population that ironically and reportedly are not adequately prepared for disasters. There is the potential for DHS to model institutes at NIH that make evidence-based risk reduction programs available to the public via the Internet. Implementation by end-users will require both the URI developed content and a software delivery platform that includes algorithms for tailored feedback to participants. We would make our content program available to these organizations and will work with interested end-users to understand their technical capacities and identify options for online delivery of the program. If preferred, we could facilitate collaboration with Pro-Change Behavior Systems Inc., a company that we have contracted with multiple times to provide technical capacity for helping organizations deliver the online program including, texting communications.

5. Project Impact:

This project developed and tested state of-the-science and innovative disaster preparedness communication intervention program. Addressing Topic 2c (Communicating Risk to Motivate Action), it identified and used messages that motivate individuals and groups to prepare in advance for disasters, and to take action when disasters threaten. Participants were linked to key information sources, such as the National Oceanic and Atmospheric Administration (NOAA), FEMA, and the project's recent Waves of Change (RIClimatechange.org) website, which is organized to help visitors move through the stages of behavior change. This project took it one step further and provided information by text messaging in addition to the online program to increase efficacy of behavior change.

This computer tailored intervention identified resident's readiness to prepare for such disasters and provide them with the tools, education, and behavior change strategies that empower them to take action on this important issue. In doing so, we focused on, and worked closely with key members of the community, including governmental agencies, nongovernment organizations, and the private sector. Our innovative reliance on digital communications included texting, is directly related to FEMA Administrator Fugate's interest in the use of texting and other digital modalities to communicate information that can reach at-risk populations and increase their preparedness and mitigation behaviors (Haldeman, 2013).

Based on our Year 03 preliminary results, we expect that our completed Proof of Concept work in Y04 will represent a breakthrough in the percentage of at-risk populations that progress through the stages of change and take action that meets FEMA's criteria for household preparedness. We expect that our breakthrough percentage of 38% taking action will be 19 times greater than the 2% that currently take action in a year. These outcomes will support a new best practice of applying digital technologies to deliver tailored online and texting programs for entire at-risk populations ranging from those who are not ready to take action (Precontemplation) through those who are ready to take more immediate action to meet FEMA's criteria for household preparedness. Such breakthroughs would represent major advances in both technologies and capabilities.

6. Student involvement and awards:
   One graduate student in year 1

7. Interactions with education projects: None

8. Publications: Mundorf, N., Redding, C.A., Prochaska, J.O., **Paiva, A.L.,** & Rubinoff, P. (2018). Resilience and thriving in spite of disasters: A stages of change approach. In A. Fekete & F. Fiedrich (Eds.), *Urban disaster resilience and security: Addressing risks in*

societies (pp. 383–396). Springer International Publishing. doi: 10.1007/978-3-319-68606-6_22

Once the proof of concept project has been completed, the data from both the preliminary and proof of concept projects will be turned into a manuscript for publication.

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
Expertise on the FEMA Household Survey	Survey	November 2016 and April 2017	FEMA
Results	Report	My 2018	FEMA and other end users
Intervention Program	Software	Expected Y04	DHS

Table 2A: Documenting External Funding

Title	**PI**	**Total Amount**	**Source**
Rhode Island Science and Technology Advisory Council Collaborative Research Grant	Prochaska	$100,000	NSF

Table 2B: Documenting Leveraged Support

Description	**Estimated Total Value**
Foundation funding for Pro-Change software	$30,000
Indirect funds were used to allow Pam Rubinoff to connect with end users	$9,000
Free support staff office	$7,000

Table 3: Performance Metrics:

PROCHASKA PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17-6/30/18)
HS-related internships (number)			
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)			
Graduate students provided tuition/fee support (number)	1		
Graduate students provided stipends (number)			
Undergraduates who received HS-related degrees (number)			
Graduate students who received HS-related degrees (number)			
Graduates who obtained HS-related employment (number)			
SUMREX program students hosted (number)			
Lectures/presentations/seminars at Center partners (number)	2	2	
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)			
Journal articles published (number)			
Conference presentations made (number)			
Other presentations, interviews, etc. (number)			
Patent applications filed (number)			
Patents awarded (number)			
Trademarks/copyrights filed (number)			
Requests for assistance/advice from DHS agencies (number)	2	2	
Requests for assistance/advice from other agencies or governments (number)			
Total milestones for reporting period (number)	4	5	
Accomplished fully (number)	4	3	
Accomplished partially (number)	4	2	
Not accomplished (number)			

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Deliver Internet CTI and first 12 months of text messaging with frequency tailored to stage.	11/30/2017	100%	
Research Milestones			
Analyze and report data on 12 month outcomes of 3,000 coastal residents recruited into the study	12/31/2017	100%	Retention at follow-up was small (see narrative above), but all analyses have been completed

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Ongoing collaborative conference calls with End-user Team	7/1/2017 – 6/30/2018	100%	
Analyze and report data on 12 month outcomes of 3000 coastal residents	7/1/2017 – 6/30/2018	100%	
Webinar/presentation at meeting (e.g. ASFPM meeting) of results and application to future efforts using CTI as a communication tool for disaster preparedness.	7/1/2017 – 6/30/2018	100%	
Transition Milestones			
Completed one collaborative conference call with End-user Team	10/31/17	100%	
Webinar completed with representation from local, state, federal agencies in emergency management and coastal planning	12/31/2017	100%	
Dissemination to networks of emergency managers and coastal planners.	6/30/2018	0%	Due to the unanticipated issues with recruiting the follow-up data, we have not yet begun dissemination. This is

			expected to be completed during Y04/Y05 if accepted.
Having an organization or community actually adopt use of the tool	12/31/2017	0%	Due to the unanticipated issues with recruiting the follow-up data, we have not yet begun dissemination. This is expected to be completed during Y04/Y05 if accepted.

DAVIDSON, U-DEL
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: An Interdisciplinary Approach to Household Strengthening and Insurance Decisions

Principal Investigator Name/Institution:
Rachel Davidson, Professor, Civil Engineering, University of Delaware

Co-Principal Investigators and Other Partners/Institutions:

- Jamie Kruse, Professor, Economics, East Carolina University
- Linda Nozick, Professor, Civil Engineering, Cornell University
- Joseph Trainor, Associate Professor, Public Policy, University of Delaware

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description ("elevator speech"):

This interdisciplinary project improved a developing tool to help agencies explore the potential effects of policies related to household hurricane risk reduction. The project specifically focused on better understanding the factors that influence homeowner insurance purchase and retrofit decision-making. The tools and policy briefs created are useful to other researchers working with same goal of supporting the development of policies that lead to household hurricane risk reduction.

Summary Abstract:

Two primary mechanisms to manage natural disaster risk— insurance and retrofit—are presently underutilized, suggesting a need to better understand how homeowners make retrofit and insurance purchase decisions. Future programs and policies intended to reduce coastal natural disaster risk will be more effective if designed to align with how homeowners actually make these choices.

This project helped advance understanding of (1) homeowner insurance purchase and retrofit decision-making and (2) the role it plays within the larger insurer-government-homeowner system of managing natural disaster risk. We leveraged two products from a NIST-funded research project we undertook recently—phone survey data and a holistic framework comprised of interacting mathematical models of hurricane risk, and homeowner and insurer decision-making that can help policy makers consider how specific policy alternatives might affect different stakeholder groups.

The support from this funding led to the following: (1) Improved scientific understanding of insurance and retrofit decisions; (2) advances in modeling of those decisions; (3) improvements

in the broader mathematical framework and policy tool; (4) improved alignment in the tools' design based on end users' concerns. Specifically, we created the following tangible products: (1) A discrete choice model that describes homeowner insurance purchase decisions; (2) two versions of discrete choice models that describe retrofit decisions; (3) policy briefs on insurance purchase decisions, and on the impact of low cost loans, grants, and insurance premium reductions on homeowner retrofit decisions; and (4) an analysis of the role of prior hurricane experience and risk perception on protective action decisions using the theory of planned behavior.

PROJECT NARRATIVE:

1. Research Need:

   In the DHS strategic plan for 2012-2016, *Ensuring Resilience to Disasters* is presented as one of the Department's five missions, and within that mission, one of the nine objectives is to *improve individual, family, and community preparedness* (Objective 5.2). This project directly supported that objective by providing insights into how homeowners make preparedness decisions, what influences their decisions, and how their actions affect the ability of the overall community system to manage coastal risk. One of the nine performance measures highlighted for that mission is to increase the percentage of households that have taken steps to be prepared in the event of a disaster. Improved understanding of how homeowners decide whether or not to undertake such steps is critical to achieving that goal, and this project aimed to help provide that required insight. Further, the NFIP is administered by FEMA within the Department of Homeland Security. Better understanding of the policies that increase acceptance of NFIP provisions and premiums can help support the goal of providing flood insurance at risk-based rates yet address concerns of affordability.

2. Project History:

   This project utilized existing data to improve our understanding of homeowner decisions and to advance a policy decision tool. The initial proposal called for the creation of a number of statistical models and analyses. Initial feedback from reviewers suggested that while the models were of interest and the insights they were designed to develop were of importance, that alone they would not be sufficient to meet the needs of our end users. Over the course of the first two years we focused on three major types of activities: (1) development of the statistical models as promised; (2) integration of the models into the broader decision framework/tool; (3) exploring a number of potential products that would better transition the research results for our partners.

   In terms of the first two task above we delivered as promised on the statistical models and integrated the results of that work into the broader framework. The third set of activities proved more difficult in that different stakeholders expressed alternate visions for how they would have liked to see the tool develop and be applied, many of which would have required resources far beyond that which were available in the current support. For example, some would have liked us to expand the model beyond hurricanes to other hazards; some asked for a broader set of mitigation and/or preparedness activities to be included; others wanted the working prototype expanded to a larger region; others still wanted the model to include a broader set of economic concerns. While the tool has the potential to integrate these desires, they represented improvements well beyond what we were able to deliver within the scope of this funding. As an interim translation step we provided policy briefs to explain the practical insights from our statistical analyses. We also developed an oral presentation that was delivered to our partners focused on these insights. Finally, we have used the information we gathered from this initial feedback to help guide our continuing development of these tools through other sources. In short, we are taking these lessons forward in hopes that we can develop some of the elements and return when what we have is closer to what is desired.

3. Results:

The details of our scientific research can be found in the publications and documents listed below. Here we have provided a high-level summary of the insights from our analyses. While some of these suggestions might require further analysis and direct implementation will require consideration of a broader set of issues, we propose the following for consideration:

- Premium and deductible are important factors that can be used to predict insurance penetration rates for a region. The results indicate that although homeowners do respond to insurance pricing (premiums and deductibles) they are not highly sensitive to the tradeoff between premium and deductible. Understanding homeowners' relative sensitivity to premiums and deductibles may help to identify premium and deductible combinations that help increase penetration, reduce risk, but not significantly affect insurance profitability.
- Since higher income is shown to be associated with increased insurance purchase, our work provides additional evidence that affordability is an important factor in determining insurance purchase. It is critical to continue exploring affordability and policies that will facilitate risk reduction.
- Given the apparent relationship between insurance purchase and number and recentness of previous hazard experiences, especially for people with damage, one might consider broadly marketing insurance products in a region recently exposed to an event in order to increase penetration.
- Given that prior retrofit actions to strengthen the home are significant predictors of insurance purchase, one might consider programs that link information about one risk reduction method with the other. For example, insurance companies might provide information on retrofitting and/or greater incentives to homeowners that retrofit.
- Government programs designed to increase retrofits that reduce flood and wind damage will be most effective dollar for dollar if incentives are in the form or grants.
- Information and incentive programs should be offered within the first year after a hurricane and be targeted at property relatively close to the coast.
- Government could target information towards first time homebuyers in order to encourage risk reducing retrofits.

Additional detail on these findings and their limits can be found in the following products:

- Published two journal papers, plus one in draft form (see Section 8).

- Three more journal papers would not have been possible without this project, though they were not directly funded by it (see Section 8).
- Conference presentations
  - Society for Risk Analysis Annual Meeting in 2016 (homeowner insurance purchase decision)
  - Society for Risk Analysis Annual Meeting in 2017 (homeowner retrofit decisions).
  - Natural Hazards Workshop poster in 2017
  - Panel presentation at 2018 Natural Hazards Workshop on Private financing of hazard risk
- Theses and dissertations
  - Slotter R. (2018) Hurricane Mitigation Decision-Making an Application of the Theory of Planned Behavior. Masters Thesis. University of Delaware.
  - Jasour, Z. (2017) Homeowner Decisions to Retrofit to Reduce Hurricane-Induced Wind and Flood Damage. Masters Thesis. University of Delaware.
  - Wang, D. (expected 12/18) A Computational Framework to Support Government Decision-making in Regional Natural Disaster Risk Management. PhD dissertation. University of Delaware.
- Policy briefs
  - *Factors that affect homeowner retrofit decisions to reduce wind and flood damage*, R. A. Davidson, J. E. Trainor, J. B. Kruse and L. K. Nozick
  - *Factors that affect if homeowners purchase flood and wind insurance*, R. A. Davidson, J. B. Kruse, L. K. Nozick and J. E. Trainor

4. <u>End Users and Transition Partners:</u>

Five primary end users were involved in this project, representing both the mitigation and preparedness directorates of FEMA, state floodplain managers, and the NIST Community Resilience group (Table 1). As Acting Division Director of the Risk Analysis Division, one of the three main divisions of the FEMA Mitigation Directorate, one stakeholder focused on identifying hazards, assessing vulnerabilities, and developing strategies to manage the risks associated with natural hazards in communities. In the FEMA Individual and Community Preparedness Division, a stakeholder works to promote preparedness and mitigation activities as adjustments to risk. Chad Berginnis represents the 17,000 members of the ASFPM, an organization dedicated to reducing flood losses nationwide. As a member of the Applied Economics Office and the NIST Community Resilience Group, a stakeholder works on economic analysis of individual and community resilience. Steve Cauffman is lead for Disaster Resilience at NIST. We had multiple conversations with these partners before and during the project through a combination of in-person meetings, conference calls, and email exchanges. Through these interactions we gained a good understanding of the challenges they face and how we can support their efforts to meet those challenges. In our previous NIST-funded research project, we worked with a reinsurance industry representative to gain input from that perspective.

Table 1. Primary end users involved in project

Name	Title	Organization	Role in project
	Acting Division Director	FEMA Federal Insurance and Mitigation Administration, Risk Analysis Division	Advisory Panel
	Senior Policy Advisor	FEMA Individual and Community Preparedness Division, National Preparedness Directorate	Advisory Panel
Chad Berginnis	Executive Director	Association of State Floodplain Managers (ASFPM)	Advisory Panel
	Research Economist	NIST Applied Economics Office/ Community Resilience Group	Advisory Panel
	Lead for Disaster Resilience	Materials and Structural Systems Division	Advisory Panel

5. Project Impact.

Our efforts for this project focused on developing mathematical and statistical tools to support mitigation and insurance decision making. Over the course of the effort it has become clear that a greater distance between the stated goals and the desires of our end users existed than we initially appreciated. We proposed to develop the analysis but users were more focused on what we called future tools. Through engagement and the conversations with our stakeholders we modified our initial approach several times over the course of this project. These interactions have led to important changes to our presentation of the results. We held briefings and developed summary briefs to explain our findings. These products have had modest direct impact on those that have reviewed the policy briefs and participated in our advisory meetings by informing them about the comparative performance of several incentives for mitigation. Given how recently the results were generated, they have not yet led to direct programmatic or policy changes, however our stakeholders were engaged and interested in the implications of the data and results for their programs. As a result of this interest we are hopeful it will inform decisions. It should also be noted that one important tangible gain has been modifications to our scientific approach to the problem in ways that have affected future directions for this work based on the needs and concerns of the stakeholders. We intend to continue developing these tools past the end of the project closing and are actively developing analyses and future modifications to the way our framework is designed to improve usability. For example, we are exploring affordability and considering a broader range of mitigation programs that might be included in the framework. Although beyond this effort's scope, we also have plans to convene a meeting of mitigation specialists to explore new direction in incentives and policy/programs for mitigation. This work has helped us to better align our approach with end user needs and as a result will serve as an important foundation for the next iteration of the project.

6. Student involvement and awards:

- Ms. Zeinab Yahyazadeh Jasour, Dept. of Civil and Environmental Engineering, University of Delaware, M.S. received August 2017. Ms. Jasour wrote a Master's thesis based on this project. She is first author on a journal paper in the *ASCE Journal of Infrastructure Systems*. She began a Ph.D. program at the University of Maryland in September 2017. She was fully funded by this grant.

- Ms. Dong Wang, Dept. of Civil and Environmental Engineering, University of Delaware, Ph.D. expected December 2018. Ms. Wang wrote a chapter of her dissertation based on this project. She is first author on a journal paper in the *Natural Hazards*. The rest of her dissertation involves research that would not be possible without the work funded by this grant (see win-win paper Section 8). She was partially funded by this grant and partially by an NSF grant.

- Ms. Royan Chen, School of Civil and Environmental Engineering, Cornell University. While an MS student, she performed some data analysis on the data generated through the survey. Her work informed some of the later data analysis on this project. She is currently a Ph.D. student at Cornell. She was funded by this grant.

- Dr. Esther Chiew, School of Civil and Environmental Engineering, Cornell University. She is a post-doc and has developed a series of statistical models on household retrofit choice behavior. She is currently writing a journal paper on this work which we expect to submit by the end of this summer. She was funded by this grant although the grant did not fund collection of the data she analyzed.

- Ms. Rachel Slotter, School of Public Policy and Administration, University of Delaware, Masters 2018. Ms. Slotter's time was not funded by this grant, but her research focused on the analysis using the theory of planned behavior and was directly supported by the work of the summer interns (Section 7).

7. Interactions with education projects:

In the Summer of 2016, we hosted two 8-week summer interns from our CRC partner, Tougaloo College, at the Disaster Research Center at the University of Delaware. The students are Irenia Ball and Taralyn Rowell, both African American Female Seniors. While at UD they contributed to this project by reviewing extant insurance literature and developing an inventory of mitigation programs currently being offered by states. These students also visited the Delaware Legislature, with a group of non-profit leaders in Wilmington, and the State Emergency Management Agency. They also interacted more generally with UD social science and engineering students and faculty interested in disaster studies. We were able to bring the second student by identifying supplemental funds from the University of Delaware to support her. These efforts provided material support to a thesis and developing scholarly publication focused on homeowner intentions to mitigate that were developed at DRC.

8. Publications:

Journal papers

Wang, D., Davidson, R. A., Trainor, J. E., Nozick, L. K., and Kruse, J. 2017. Homeowner purchase of insurance for hurricane-induced wind and flood damage. *Natural Hazards* 88, 221–245.

Jasour, Z., Davidson, R., Trainor, J., Kruse, J., and Nozick, L. 2018. Homeowner decisions to retrofit to reduce hurricane-induced wind and flood damage. *Journal of Infrastructure Systems*, in press.

Chiew, E. Nozick, L., Davidson, R., Trainor, J., and Kruse, J. The effect of grants on hurricane retrofit decisions by homeowners. To be submitted August 2018.

The following papers were not directly funded by this project, but they were only possible because of the research conducted under this grant. Thus, the center grant is acknowledged in each of these papers.

Wang, D., Davidson, R., Nozick, L., Trainor, J., and Kruse, J., A computational framework to support government policy-making for hurricane risk management. To be submitted to *Natural Hazards Review* August 2018. This paper is a modified version of the proposed system win-win paper. It directly makes use of the statistical models developed in this project.

Xu, K., Nozick, L., Kruse, J., Davidson, R., Trainor, J. Dynamic modeling of competition in the natural hazard catastrophe loss insurance market with explicit consideration of homeowner financed mitigation. To be submitted August 2018. This paper directly makes use of the statistical models developed in this project.

Robinson, C., Davidson, R. A., Trainor, J. E., Kruse, J. L., and Nozick, L. K. 2018. Homeowner acceptance of voluntary property acquisition offers. *International Journal of Disaster Risk Reduction* 31, 234-242. This paper relies on the same dataset and use similar modeling approaches as the research in this project.

Theses and dissertations

Jasour, Z. (2017) Homeowner Decisions to Retrofit to Reduce Hurricane-Induced Wind and Flood Damage. Masters Thesis. University of Delaware. (fully funded by this grant)

Slotter R. (2018) Hurricane Mitigation Decision-Making an Application of the Theory of Planned Behavior. Masters Thesis. University of Delaware. (not directly funded by this grant, but related to it and relying on intern work funded by this grant)

Wang, D. (expected 12/18) A Computational Framework to Support Government Decision-making in Regional Natural Disaster Risk Management. PhD dissertation. University of Delaware. (partially funded by this grant)

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
Factors that affect homeowner retrofit decisions to reduce wind and flood damage	Policy brief	9/17	Open Access, Advisory Panel
Factors that affect if homeowners purchase flood and wind insurance	Policy brief	1/18	Open Access, Advisory Panel
Homeowner purchase of insurance for hurricane-induced wind and flood damage	Journal paper and dissertation chapter	11/16	Scientific Community
Homeowner decisions to retrofit to reduce hurricane-induced wind and flood damage	Journal paper and M.S. thesis	8/17	Scientific Community
An Interdisciplinary Approach to Household Strengthening and Insurance Decisions: Results	PowerPoint Results Briefing		End User Advisory panel
Hurricane Mitigation Decision-Making an Application of the Theory of Planned Behavior	Master’s thesis		Scientific Community
The effect of grants on hurricane retrofit decisions by homeowners	Draft journal paper	8/31/18	Scientific Community

Table 2A: Documenting External Funding

Title	PI	Total Amount	Source
Collaborative Research: An Interdisciplinary Approach to Modeling Multiple Stakeholder Decision-making to Reduce Regional Natural Disaster Risk, National Science Foundation	Davidson	$306,555	NSF
Modeling natural disaster risk management: A stakeholder perspective	Davidson	$797,000	NIST

Table 2B: Documenting Leveraged Support

Description	Estimated Total Value
DRC support of interns	$1,000
UDEL School of Public Policy and Administration support of interns	$1,000
UDEL Vice Provost of Diversity support of interns	$3,000
Support of undergraduate researcher through McNair Scholars program and UDEL summer scholars program	Approx. $5,000

Table 3: Performance Metrics:

DAVIDSON PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17-6/30/18)
HS-related internships (number)	0	0	0
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	2	0	0
Graduate students provided tuition/fee support (number)	2	2	1
Graduate students provided stipends (number)	2	2	1
Undergraduates who received HS-related degrees (number)	0	0	1
Graduate students who received HS-related degrees (number)	0	1	1
Graduates who obtained HS-related employment (number)	0	1	
SUMREX program students hosted (number)	2	0	0
Lectures/presentations/seminars at Center partners (number)	0	0	0
DHS MSI Summer Research Teams hosted (number)	0	0	0
Journal articles submitted (number)	1	1	1
Journal articles published (number)	0	1	2
Conference presentations made (number)	0	0	2
Other presentations, interviews, etc. (number)	0	0	1
Patent applications filed (number)	0	0	0
Patents awarded (number)	0	0	0
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	0	
Requests for assistance/advice from other agencies or governments (number)	0	0	
Total milestones for reporting period (number)	1	3	
Accomplished fully (number)	1	2	
Accomplished partially (number)	0	1	
Not accomplished (number)	0	0	

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Write journal paper about homeowner hurricane-related retrofit decision-making, including consideration of incentives	8/17	100%	
Research Milestones			
Submit manuscript to peer-reviewed journal about homeowner hurricane-related retrofit decision-making for protection against both wind and flood damage, including consideration of incentives.	8/17	100%	

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Group conference call with research team and all end user partners to present progress and get input	7/17	100%	
Write Retrofit incentives policy brief	12/17	100%	
Transition Milestones			
System win-win paper	12/17	100%	A somewhat modified version of this was completed 8/18. Will be submitted for journal publication 8/18.
Policy Brief: Homeowner purchase of insurance for hurricane-induced wind and flood damage	7/17	100%	

Policy Brief: Factors that affect homeowner retrofit decisions to reduce wind and flood damage	12/17	100%	
Policy Brief: Hurricane experience and risk perception policy brief	10/17	90%	Completed in form of MS thesis. In process of being edited into a publication.

HORNEY, TAMU
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Implementing the Disaster Recovery Tracking Tool

Principal Investigator Name/Institution: Jennifer Horney, Associate Professor, Texas A&M University Health Science Center School of Public Health, Department of Epidemiology and Biostatistics

Co-Principal Investigators and Other Partners/Institutions: Phil Berke, Professor, Texas A&M University, College of Architecture, Department of Landscape Architecture and Urban Planning

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description ("elevator speech')

Valid and reliable quantitative and qualitative measures of community disaster recovery are needed in order to be able to track recovery in different geographic locations, from different types of disasters, and over time. The Disaster Recovery Tracking Tool is a web-based tool that enables end users (e.g., planners, emergency managers, long-term recovery committees) to track the progress and quality of post-disaster recovery by comparing baseline and post-disaster data.

Summary Abstract:

Without monitoring recovery and comparing post-recovery status with pre-disaster benchmarks, it is difficult for communities to assess whether or not they are achieving a quality recovery, improving disaster resilience, or building back better. The Disaster Recovery Tracking Tool provides a framework for end users (e.g., planners, emergency managers, long-term recovery committees) to track progress on metrics of disaster recovery. The metrics were identified and content validated through a literature review, recovery plan review, case studies, focus groups, key informant interviews, and pilot tests with communities impacted by Hurricane Sandy. The metrics include both quantitative and qualitative measures of recovery organized in four themes and ten focus areas. Practitioners using this tool can compare pre- and post-disaster status using baseline and current data. Reports generated by the tool can provide end users with a useful means of prioritizing recovery goals and activities and identifying elements important to include in recovery planning, potentially making recovery more effective and efficient and communities more resilient.

PROJECT NARRATIVE

1. Research Need:

This project contributed to Goal 5.4 of the Department of Homeland Security's Strategic Plan (FY 2014-18) by providing an online tool to measure and monitor post-disaster changes in habitability, the environment, the economy, and geography that emerge from the recovery process.

2. Project History

The Disaster Recovery Tracking Tool was first released in open Beta form in 2016. The completed website was made available for public access in the summer of 2017. An initial horizon scan of similar web-based tools dedicated to disaster recovery tracking and pre-disaster recovery planning revealed that this product was uniquely positioned. Horizon scans performed in the fall of 2016 by 3 undergraduate honors marketing teams at Texas A&M University similarly yielded no significant competitors; however, similar products were later identified.

End user outcomes included completed data sets from recovery for at least two pilot communities in Texas identified by Dr. Cooper and Ms. Masterson of Texas Target Communities. Representatives of Bastrop County, Texas and Liberty County, Texas agreed to serve as pilot communities to evaluate the Disaster Recovery Tracking Tool. However, we were unable to collect evaluation data from pilot communities, as communities engaged in nearly continuous response to multiple disasters over the grant period. Therefore, opportunities for alternative research milestones were pursued.

Potential applications and opportunities to leverage the Tool were discussed previously with a Project Manager at the U.S. Coast Guard R&D Center in March 2016. However, the Coast Guard's Office of Research, Development, Test and Evaluation, located at Headquarters in Washington, DC, determined that the Tool would not be appropriate to meet established needs.

Lisa Schiavinato, Director of Extension at California Sea Grant, provided a connection to an affiliated extension agent for advisement on natural resource data sources. We also worked with Oil Spill Science Outreach and Extension Specialists at Texas Sea Grant College Program to determine whether the Disaster Recovery Tracking Tool could be used to measure recovery progress in oil spill-affected communities. Potential applications for the Tool were also discussed with Alabama Sea Grant. A conference call with a stakeholder at the NOAA Disaster Response Center in Mobile, AL was held to determine where integration/support would possible.

Working with the Department of Homeland Security Coastal Resilience Center of Excellence and the Office of the Assistant Secretary for Preparedness at the Department of Health and Human Services in December 2016, a project proposal to deploy the Disaster Recovery Tracking Tool in several communities in North Carolina affected by Hurricane Matthew was developed. To maximize the impact of available resources given the urgent needs of local practitioners, the deployment of the proposed project was delayed indefinitely.

A meeting was held with stakeholders from FEMA's Community Planning and Capacity Building Division in January 2018. Items discussed included planning capabilities and interests of researchers at Texas A&M University, as well as best practices for recovery- and resilience-related planning, capacity building, and workshops.

Guidance was provided from the Texas A&M Engineering Extension Service (TEEX) to develop a Disaster Recovery Tracking Tool training course targeted to local government officials, city and county planners, and other community stakeholders. A course design document was drafted and reviewed by TEEX; however, time constraints imposed by Hurricane Harvey response activities restricted further course development. The utility of the Tool to TEEX was subsequently reduced following the adoption of a new disaster inventory system by FEMA and continued collaboration ceased in January 2018.

3. Results:

Working with pilot partners (local planners and emergency managers in two Texas jurisdictions), we expected to determine the validity, timeliness, and completeness of the recovery data entered into the tool.

End user capabilities needed: 1) A commitment by end users to engage throughout the life of the project. End user problems addressed: 1) Lack of ability to measure and document different aspects of the recovery process to a) characterize recovery (e.g. through longitudinal metrics or metrics that address unique community factors); b) detect problems with recovery (e.g., housing recovery is lagging or businesses are slow to re-open in the downtown business district); and c) improve future recovery and progress towards resilience / building back better; 2) Lack of ability to compare recovery from different types of events over time to identify similarities, difference, and lessons learned; 3) Lack of end user capacity to develop recovery plans (and in particular, high-quality recovery plans) or improve / revise existing pre-disaster recovery plans.

To enhance the usefulness of the tool for local and federal end-users, the needs, insights, and expertise of FEMA partners were incorporated throughout the decision-making process. Lisa Stillwell, a research software developer at RENCI, provided technical assistance during the development of the Disaster Recovery Tracking Tool. The results of this assistance include an improved user interface, the inclusion of additional tracking functions, and a greater number of automatically-populated metrics. In response to end-user feedback generated using surveys and key informant interviews, the number of metrics that are automatically populated from publicly available datasets was increased from 17 to 39.

Recognizing the need for a rapid means of assessment for time- and resource-limited end-users, a concise metric checklist was created. The checklist was smaller (15-18 metrics) and geared towards a concrete outcome – a draft of a pre-disaster recovery plan, something that many communities need / want but may not have the planning capacity to develop.

In February 2018, a stakeholder inquired about the utility of the disaster recovery metrics for the U.S. Virgin Islands Department of Health’s health and social services recovery surveillance efforts. The potential uses were discussed via email and a conference call, following which a sample user account was provided for demonstration purposes. Subsequent application of the Tool was hindered by a lack of regular data collected on an annual basis for the region (e.g., U.S. Census data).

A request for information describing the purpose and potential applications of the Tool was received in February 2018 from the nonprofit Rebuild North Bay Foundation, which was established to assist in the rebuilding efforts of the fire-affected Counties of Napa, Lake, Mendocino and Sonoma, California. This request was fulfilled and additional assistance was offered.

In April 2018, a graduate student researcher at the University of Connecticut expressed interest in leveraging the Tool to investigate ongoing recovery efforts in Puerto Rico. Unfortunately, the publicly available datasets used to automatically populate the Tool's metrics contain sparse information about Puerto Rico. A document describing the disaster recovery metrics and associated data sources was provided along with links to federal data repositories. Additional assistance and information were offered.

4. End Users and Transition Partners:

The Disaster Recovery Tracking Tool (trackyourrecovery.org) currently has over 730 registered users. These include Federal (EPA, FEMA, NOAA (ERMA), Small Business Administration, US Air Force Academy, Cooperation for National and Community Service); Regional (FEMA Regions 2, 6, and 8); Local Governments; Ga. Tech University; National Non-Profits (Red Cross, Natural Resources Defense Council); Other Non-Profits (SeaPlan.org); and private consultants. Additional end users include: 1) Municipal- and county-level planners, emergency managers, and members of long-term recovery committees; 2) FEMA national and regional-level recovery division staff (Region 6; Region 2; Region 2, Hazard Mitigation Division); 3) Department of Health and Human Services, Assistant Secretary for Preparedness, Office of Emergency Management, Recovery; 4) Los Angeles County Emergency Management (John Chung, Emergency Planner); 5) Department of Homeland Security S&T Flood APEX

The research team also worked with the Federal (FEMA) and Regional (FEMA 2, 6 and 8) end users to determine additional ways in which collected data may be used (e.g., to develop a checklist to assist in the development of a fact base of a recovery plan). To promote the checklist and other findings and tools, we also linked with the American Planning Association's Post-Disaster Recovery Section (James Schwab),the new Hazard Mitigation and Recovery Planning APA Division (Gavin Smith), and the Community Resilience Planning Guide for Buildings and Infrastructure developed by NIST (Walt Peacock at Texas A&M HRRC is a Co-PI of NIST). We had a conference calls with Larissa Graham, Oil Spill Science Extension Specialist with the Mississippi-Alabama Sea Grant Consortium, in April and May of 2017 and contacted the Extension Director of Sea Grant California to request a conference call to discuss the Tool.

A DEMO session of the Tool, called Can We Measure Successful Disaster Recovery? at the National Association of County and City Health Officials Annual Preparedness Summit in April, 2016 was attended by 67 federal, state, and local public health and emergency management staff. In the same month, a case study of measuring disaster recovery in six Texas communities was described in an oral presentation at the Texas Public Health Association Annual Conference and a poster presentation at the Texas A&M Public Health Week Delta Omega Student Poster Contest. A discussion of the Tool during the 2016 NACCHO Preparedness Summit by Natalie Grant, Program Analyst at ASPR, was recorded and featured in the NACCHO Podcast Series (http://naccho.libsyn.com/disaster-recovery-tracking-tool-with-natalie-grant). The Tool was also mentioned during a presentation given at the 2018 NACCHO Preparedness Summit by representatives of the Public Health Commission Office of Public Health Preparedness and the Del Valle Institute for Emergency Preparedness (https://delvalle.bphc.org/pluginfile.php/3215/mod_wiki/attachments/2/NACCHO%202018%20Recovery%20Presentation.pdf).

- The following organizations placed the Disaster Recovery Tracking Tool link on their respective websites:
  - Association of Schools and Programs of Public Health (https://www.aspph.org/texas-am-faculty-receives-funding-from-both-the-national-academies-and-homeland-security-for-disaster-recovery-research/)
  - Coastal Resilience Center (http://coastalresiliencecenter.unc.edu/crc-project-tracks-long-term-recovery-in-communities/)
  - Institute for Sustainable Communities at Texas A&M University (http://ifsc.tamu.edu/Discovery/Health-and-Environment)
  - Texas Sea Grant College Program (http://texasseagrant.org/programs/community-resilience-collaborative/crc-online-resources/)
  - Federal Emergency Management Agency (FEMA)
  - North Carolina Planning Journal
  - Office of the Assistant Secretary for Preparedness and Response (ASPR) Technical Resources, Assistance Center, and Information Exchange (TRACIE) – Technical Resources (https://asprtracie.hhs.gov/technical-resources/resource/2092/disaster-recovery-tracking-tool-measuring-recovery-through-healthy-community-indicators)
  - Texas A&M Foundation

- The Disaster Recovery Tracking Tool was referenced as a resource in the following publications:
  - Texas A&M College of Architecture's ArchOne electronic newsletter (https://one.arch.tamu.edu/news/2016/2/24/prof-evaluate-effects-vulnerability/)
  - Texas A&M Health Science Center's Vital Record (https://vitalrecord.tamhsc.edu/developing-systematic-ways-of-measuring-disaster-recovery-process/)
  - Texas A&M School of Public Health's annual magazine (https://sph.tamhsc.edu/communications/docs/public-health-magazine-2016.pdf)
  - *Emergency Preparedness and Recovery: A Toolkit for Rural Communities*, a guidance document developed by the Texas Chapter of the American Planning Association and Texas Public Health Association (https://docs.wixstatic.com/ugd/c536a4_5fd232d359f54b3ea96e505c3d84308c.pdf).
  - *Resources for Building Resilience in the Puget Sound Region, WA,* proceedings of the Puget Sound Knowledge Exchange: Resources for Building Resilience Workshop co-hosted by the Resilient America Roundtable and the Puget Sound Regional Council (https://sites.nationalacademies.org/cs/groups/pgasite/documents/webpage/pga_185859.pdf)
  - Texas Public Health Journal Supplement Spring 2018, titled *Planners4Health: A Renaissance between Planning and Public Health to Confront Disasters in Rural Areas*

(https://www.txplanning.org/media/files/files/bfa1cf8e/apa-tpha-supplemental-journal-edition-final2.pdf)

5. Project Impact:

The National Disaster Recovery Framework (NDRF) calls for communities to develop tools and indicators that can be used to assess progress toward achieving established goals, objectives, or milestones. The Disaster Recovery Tracking Tool provides an accessible means for resource-limited end users to readily measure and evaluate progress over time. The validated metrics that comprise the Tool's tracking function were developed in accordance with the Recovery Support Functions and Recovery Mission Area Core Capabilities that are defined in the NDRF. The Disaster Recovery Tracking Tool facilitates data collection and management, allowing systematic measurement of the disaster recovery process in various locations, across events, and over time.

The NDRF further recommends that measures of recovery be developed in tandem with pre- and post-disaster planning functions and activities. Data collected for the 84 recovery metrics may be used to guide the development of a recovery plan element as part of a larger plan, or the development of a stand-alone recovery plan. Results may also contribute to increases in the number and improvements in the quality of pre-disaster recovery plans. For example, one of the primary indicators of a high-quality plan is a strong community fact base. It often difficult for smaller communities with limited capacity for recovery planning to develop a robust fact base focused appropriately on high-priority issues. The integration of recovery metrics in community plans and planning processes can aid decision makers in identifying resilience-building opportunities and developing evidence-based policies and priorities. For this purpose, a recovery planning checklist based on the Disaster Recovery Tracking Tool's metrics has been drafted. This resource can be leveraged by practitioners to update plans or begin the process of developing a fact base for a pre-disaster recovery plan.

6. Student involvement:
    - In the fall of 2016, undergraduate students of the Mayes Business School at Texas A&M University were recruited to assist in the completion of a horizon scan and the development of draft marketing materials, training module, and user guide.

- Degrees attained
    - Caroline Dwyer, Masters of Urban Planning
    - Bhagath Chirra, Masters of Public Health in Epidemiology
    - Katy Stone, Masters of Public Health in Epidemiology

- Awards, publications, posters, presentations (*indicates student)
    - Kirsch, K., Sullivan, E., Horney, J., and Goidel, K. (2018, July). Are slow-onset disasters well represented in hazard mitigation plans? Poster presentation at the 43rd Annual Natural Hazards Research and Applications Workshop, Broomfield, CO.

- Kirsch, K. (accepted for publication). Session summary. Equitable and resilient design: Past and present infrastructure challenges. Proceedings of the 43rd Annual Natural Hazards Research and Applications Workshop, Broomfield, CO.
- Horney JA, Dwyer C*, Chirra B*, McCarthy K, Shafer J, Smith G. (2018) Measuring successful disaster recovery. *International Journal of Mass Emergencies and Disasters*. 36(1): 1-22.
- Horney JA, Dwyer C*, Aminto M*, Berke P, Smith G. (2017) Developing indicators to measure post-disaster community recovery. *Disasters*. 41(1):124-149. DOI: 10.1111.disa.12190.
- Kirsch, K., & Masterson, J. (2017, September). Tool for tracking an equitable recovery [Blog post]. Retrieved from http://disasterphilanthropy.org/blog/hurricanes-typhoons/tool-tracking-equitable-recovery/
- Kirsch, K. R., & Horney, J. (2017). Steps toward recovery: A tool for disaster recovery planning, management, and tracking. *Carolina Planning Journal, 42*, 104-109.
- Chirra, B., & Horney, J. (2016, April). Measuring disaster recovery: A case study of six communities in Texas. Poster presentation at the 11th Annual Dr. Jean Brender Delta Omega Research Symposium and Student Poster Contest, Texas A&M University School of Public Health, College Station, TX.
    i. Awarded Third Place in Dr. Jean Brender Student Research Poster Contest
- Chirra, B., & Horney, J. (2016, April). Measuring disaster recovery: A case study of six communities in Texas, United States. Oral presentation at the Texas Public Health Association's 92nd Annual Education Conference, Galveston, TX

7. Interactions with education projects:

We supported the successful application of Dr. Sonia Gilkey from Texas A&M Kingsville, a minority serving institute in Texas, to the U.S. Department of Homeland Security (DHS) Summer Research Team Program for Minority Serving Institutions. Although Dr. Gilkey and her student were selected to participate in the program, they subsequently declined to participate due to a scheduling conflict.

8. Publications:
    a. Horney, J., Dwyer, C., Chirra, B., McCarthy, K., Shafer, J., & Smith, G. (2018). Measuring successful disaster recovery. *International Journal of Mass Emergencies and Disasters, 36*(1), 1-22.
    b. Kirsch, K., & Horney, J. (2017). Steps toward recovery: A tool for disaster recovery planning, management, and tracking. Carolina Planning Journal, 42, 104-109.
    c. Horney, J., Dwyer, C., Aminto, M., Berke, P., & Smith, G. (2017). Developing indicators to measure post-disaster community recovery in the United States. Disasters, 41, 124-149. DOI: 10.1111/disa.12190

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
Are slow-onset disasters well represented in hazard mitigation plans?	Poster Presentation	July 2018	43rd Annual Natural Hazards Research and Applications Workshop, Broomfield, CO
Disaster preparedness and public health challenges	Panel Presentation	December 2017	National Institutes of Environmental Health Sciences Superfund Research Program Annual Meeting, Philadelphia, PA
Training Module	Guidance Document	June 2017	Local government officials, city and county planners, and other community stakeholders or web users
User Guide	Guidance Document	June 2017	Local government officials, city and county planners, and other community stakeholders or web users
Draft TEEX Disaster Recovery Tracking Tool Course	Course Document	June 2017	Local government officials, city and county planners, and other community stakeholders
Trackyourrecovery.org	Conference DEMO Session	April 2016	Various; 67 attendees from federal, state, and local NACCHO Public Health Preparedness Summit, Dallas, TX
Measuring successful disaster recovery: A case study of six communities in Texas, United States.	Oral Presentation	April 2016	Texas Public Health Association's 92nd Annual Education Conference, Galveston, TX
Measuring successful disaster recovery: A case study of six communities in Texas.	Poster Presentation	April 2016	11th Annual Dr. Jean Brender Delta Omega Research Symposium and Student Poster Contest, Texas A&M University School of Public Health, College Station, TX

Table 2A: Documenting External Funding

Title	**PI**	**Total Amount**	**Source**
NA			

Table 2B: Documenting Leveraged Support

Description	**Estimated Total Value**
NA	

Table 3: Performance Metrics:

HORNEY – PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17- 6/30/18)
HS-related internships (number)	0	0	0
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	0	0	0
Graduate students provided tuition/fee support (number)	0	1	0
Graduate students provided stipends (number)	1	1	0
Undergraduates who received HS-related degrees (number)	0	0	0
Graduate students who received HS-related degrees (number)	0	1	0
Graduates who obtained HS-related employment (number)	1	0	0
SUMREX program students hosted (number)	0	0	0
Lectures/presentations/seminars at Center partners (number)	0	0	0
DHS MSI Summer Research Teams hosted (number)	0	0	0
Journal articles submitted (number)	1	1	1
Journal articles published (number)	1	1	1
Conference presentations made (number)	3	0	2
Other presentations, interviews, etc. (number)	4	7	3
Patent applications filed (number)	0	0	0
Patents awarded (number)	0	0	0
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	1	3	2
Requests for assistance/advice from other agencies or governments (number)	3	2	2
Total milestones for reporting period (number)	3		
Accomplished fully (number)	3		
Accomplished partially (number)	0		
Not accomplished (number)	0		

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Track reach of website, marketing materials, requests for information, usage of tool	12/31/17	100%	
Research Milestones			
Final marketing materials, training module, and user guide	8/31/17	100%	

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Track reach of website, marketing materials, requests for information, usage of training, user guide and tool	12/31/2017	100%	
Transition Milestones			
Post final marketing, training, and user guide materials online	6/30/17	100%	
Release of updated version of the Disaster Recovery Tracking Tool website	12/31/17	100%	

OPALUCH, URI
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Overcoming Barriers to Motivate Community Action to Enhance Resilience

Principal Investigator Name/Institution: James Opaluch; Univ. of Rhode Island

Co-Principal Investigators and Other Partners/Institutions: Austin Becker, Marine Affairs, Univ. of Rhode Island, Dawn Kotowicz, Donald Robadue, and Pamela Rubinoff, Coastal Resources Center, Univ. of Rhode Island

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description ("elevator speech"):

This project is designed to improve our understanding of how to overcome the "adaptation deficit" (Burton, 2004) within the context of community preparedness for coastal storm hazards. To do so, we adopt a social science-based framework of the stages of behavior change to identify key barriers to progress through the stages and to design interventions to overcome these barriers. Our approach employs the following methods: (1) group decision processes, (2) individual interviews, (3) a retrospective review of public dialog and (4) policy simulation exercises.

Summary Abstract:

The goal of this research is to improve our understanding of how we can increase "whole community" preparedness for coastal storm hazards. To do so, we apply insights from social science models of behavior change to help better understand how to increase the adoption of protective actions by individuals and communities.

Our project combines the following methods for identifying these barriers and designing interventions:

(1) Observe group decision processes,
(2) Carry out semi-structured interviews of stakeholders,
(3) Carry out a retrospective analysis of news reports and policy actions associated with storm events,
(4) Text effectiveness of interventions, and refine in response to what we learn

The primary project output is a report that provides recommendations for policy actions that show potential to increase the adaptation rate for protective actions by individuals and communities. These recommendations will be targeted to specific DHS programs, and tailored to specific stages of behavior change

PROJECT NARRATIVE:

1. Research Need:

This research contributes to DHS programs by helping to improve the resilience of communities that face risks from coastal storm hazards. It is widely recognized that national preparedness for hazards is not simply the responsibility of the government, but rather preparedness is a responsibility that is shared by everyone—including citizens, the private sector, and communities (e.g., Department of Homeland Security, 2014; National Academy of Sciences, 2012). Yet recent studies have shown that individual preparedness has remained largely unchanged for at least a decade (e.g., FEMA, 2014).

Our project seeks to identifying the barriers that have impeded "whole community" preparedness, and to design interventions to help overcome those barriers. This research embodies the September 15, 2015 Executive Order "Using Behavioral Science Insights to Better Serve the American People" which encourages agencies to conduct behavioral research to "… review elements of their policies and programs that are designed to encourage or make it easier for Americans to take specific actions …" (White House, 2015).

The Behavioral Science literature demonstrates that simply providing information is not generally an effective means of bringing about behavior change (e.g., Velicer et al, 1998; Stern, 2000; Scott, 2002; Moser and Ekstrom, 2010), Rather, increasing the adoption rate of behaviors to mitigate storm effects is challenging (Kesete et al. 2014; Carson et al., 2013; Moser and Ekstrom, 2010). We adopt the lessons of theories of behavior change, that recognize the need for carefully planned and well-designed interventions that are tailored to the specific needs of various groups in order to help to expedite change (e.g., Velicer et al. 1998; Moser and Ekstrom, 2014; Lindell and Perry, 2012).

A key lesson of this scientific literature is that behavior change is not an event, but rather is a process that occurs over a series of stages. The most effective behavior-change programs will identify the specific barriers that impede progress through the various stages, and will apply interventions that are tailored to overcome these specific barriers.

The project outcomes also include development and testing of policy simulation tools, such as storm impact visualizations, that can be used to help improve decision making by helping end users better understanding the consequences action (or inaction). Our current project will test the potential of these policy simulation tools to help overcome barriers to increasing the adoption rate of protective actions. Note that development of some of the policy simulation tools are part of leveraged activities led by Dr. Austin Becker, and are being tested in this project, as discussed below.

Consistent with the spirit of the DHS "Whole Community" approach, we will disseminate project-related information as widely as possible. We will also transmit information to representatives of the private sector, and to federal, state, local government officials by leveraging ongoing planning activities in which project co-PIs routinely participate.

2. <u>History:</u>

In the first calendar year of the project, our goal was to participate in, and observe various group decision processes on coastal storm hazards with a goal of listening to the "conversation" about storm preparedness among various stakeholder groups, including federal, state and local government officials, representatives of NGOS and other interest groups (e.g., builder associations), as well as private citizens. A list of events in which we participated during year 1 is attached as Appendix I to this document. Note that we actually began this activity before funding of the project officially started, and continued to attend events as they were scheduled through June 2017.

As part of these events, we noted key points that participants made regarding barriers that impede Whole Community preparedness, and developed hypotheses on the kinds of interventions that could help overcome these barriers. Phase II of the project began in June 2016, which involved carrying out a series of one-on-one and small group interviews to serve as follow up to get more information on the barriers and interventions we heard in the group meetings. All participants in the interviews were assured that we would not release the name of those who participated in interviews, so confidentially precludes us from listing interviews. However, we carried out a total of 18 interviews with representatives of the same categories of stakeholder groups indicated above.

Starting in Summer 2017, we carried out a thorough analysis of news reports and policy actions regarding specific storm events. The goal here is to obtain information from print media to supplement what we heard orally in group meetings and individual interviews, and to document the institutional memory that has been accumulating over time in key organizations with respect to their understanding and use of putting science to action and into policy.

Specifically, this analysis describes the findings gathered from the following methods of analysis: (1) an aggregate timeline of hazard events, studies, and plans and policies; (2) a database of RI Coastal Resource Management Council (CRMC) permits with illustrations, both geographically and over time by number and type of ascent to document coastal hazards policy implementation by the CRMC; (3) a social network map documenting RI engagement regarding resilience policy among state organizations and with stakeholders; and (4) vignettes describing selected cases of locations or policies significant to resilience policy in RI to provide context for connections between each of the products described above and to assist in identifying the "semantic language" in print and in speech used to describe barriers to action to enhance resilience.

The final phase of the project was to incorporate interventions into regional storm hazard planning processes, to test the effectiveness of interventions to the extent feasible, and to refine interventions in response to what we learned during testing. Several of the activities reported below involved supplementary funding that leveraged DHS Center activities.

This phase of the research included (1) advancing methods for creating data-driven visualizations of storm damages to help stakeholders better envision the consequences of storms, (2) carrying out a pilot survey to provide a preliminary test of the effectiveness of these storm visualizations, (3) creating a resilience planning exercise for port stakeholders, (4) carrying out a survey of 22 medium- and high-use ports of the USACE North Atlantic Division to assess level of agreement on the barriers to coastal hazard adaptation, (5) creating a decision support tool to help communities better understand the consequences of actions to mitigate storm hazards (e.g., comparing flood and erosion control using sea walls vs. living shorelines)

3. Results:

Below is a listing of project results, outputs and outcomes, including a short explanation of each. The major project output is a report that provides details on each of these, that we provide as a separate stand-alone document.

(1) Listing of key barriers and interventions.

This project outcome lists the key barriers to adaption and the interventions that we have identified, with short explanations of each. Here we list each, but without substantive discussion.

1. Many community members do not see coastal storm hazards as high priories. Potential storm hazards are not viewed as urgent enough to command attention, as stakeholder have other items on their minds that they view as more urgent.
2. Related to item 1 above, storm hazards are often viewed as "theoretical" to respondents, and not "real" enough to command their attention adequately to motivate action until it is too late.
3. Opportunity: The immediate aftermath of storms has been described as the "window of opportunity" to elicit adaptation actions on the part of stakeholders. This is a time when storm hazards have people's attention, and are recognized as "real" hazards. Furthermore, in many cases repairs are needed, and it is less costly and more less of an inconvenience to take many of the actions necessary prepare for future storms. In an extreme case, if a building is totally destroyed, it needs to be rebuilt. This is the time to build a structure that is more storm resistant, or relocated further from storm hazards.
4. Barrier related to item 3 above: In the immediate aftermath of a storm people want to be life "back to normal" as quickly as possible. In some cases, building permits are needed to carry out repairs, and permits often are expedited if the structure is to be rebuilt exactly as it was before (Note, however, that in some cases if damage is greater than a stated percentage of the value of the structure, repairs are required to meet updated building codes, that often require a greater level of storm resistance).

   As a consequence, many community members may miss the opportunity provided by the immediate aftermath of a storm.

5. Intervention related to item 4 above: The immediate aftermath of a storm may be an opportunity to take action to increase preparedness for the next storm, but it is *not* the correct time to plan for future preparedness. Plans must be in place ahead of the storm, and rebuilding should be expedited when property owners are taking steps to improve storm resistance (including relocation).

   Property owners are not aware of property-specific storm hazard vulnerabilities they face, what actions to take, or even how to go about learning about how to improve preparedness. It is currently too inconvenient for many property owners to get this information, and as a consequence they do not seek out this information. Especially during the so-called "window of opportunity" in the immediate aftermath of a storm.

   Intervention:

- Develop free or required storm preparedness audits which provide property owners with information on their specific vulnerabilities, and how to go about addressing these vulnerabilities.
- Homeowners who take actions recommended in storm vulnerability audits might obtain tax credits, insurance discounts, cost sharing, and/or other financial inducements to take actions to reduce vulnerability. Certain actions might be required in order to get insurance, or insurance companies might finance actions that are paid back as part of annual insurance premiums.
- Permits required to repair after storm damage might be expedited, or permits might be denied altogether unless high priority recommendations from audits are undertaken.

(2) Aggregate timeline of hazard events, studies, and plans and policies:

This product documents the institutional memory that has been accumulating over time in key organizations with respect to their understanding and use of putting science to action and into policy. As indicate above, this product includes the following: (1) an aggregate timeline of hazard events, studies, and plans and policies; (2) a database of RI Coastal Resource Management Council (CRMC) permits with illustrations, both geographically and over time by number and type of ascent to document coastal hazards policy implementation by the CRMC; (3) a social network map documenting RI engagement regarding resilience policy among state organizations and with stakeholders; and (4) vignettes describing selected cases of locations or policies significant to resilience policy in RI to provide context for connections between each of the products described above and to assist in identifying the "semantic language" in print and in speech used to describe barriers to action to enhance resilience.

An Excel workbook includes a chronological listing the set of documents and resources collected for the timeline provide the basis for understanding many of the federal, state, and municipal planning and decision-making responses along with hazard events. Many of the studies collected for the hazard events and hazards studies timelines have informed the construction of aggregate timeline inclusive of hazard plans and policies. The initial test of Timeline JS revealed that customized programming would have been required to accommodate the full layers of content so that outlet for the information was set aside.

Public information and policy accompany the unfolding of storm events and other processes such as shore erosion and accretion and runoff from storms. The bibliography of over 1,000 entries includes pure hazard studies, mixed documents with some technical analysis and planning or policy recommendations, and adapted legislation and regulation. Entries range from National Weather Service's coverage of a flood in March 1936 resulting from melting of larger than normal snowmelt combined with rainfall that affected all of New England to an article in ricentral.com (a collection of media coverage for six Southern Rhode Island newspapers) of a planning board discussion about Transportation Improvement Program (TIP) application priorities. The review of policy covers federal, state and municipal planning and decision-making responses aligned with storm events and studies.

(3) Barriers to Port Preparedness

This research effort provides empirical data supporting the notion that a void in leadership serves as a significant barrier to resilience planning, at least in the case of the Port of Providence (Rhode Island, USA). The project proposes a definition of leadership within the context of port resilience, and identifies commonalities and differences in port stakeholder perceptions regarding port leadership in adaptation to flooding hazards.

First, the research activity participated in workshop of stakeholders in port resilience planning, and participants in the workshop were recruited to complete an online survey. The goal of the survey was to compare perceptions of different stakeholders regarding leadership responsibility. The results of this survey were used as a starting point in conducting personal interviews with representatives of the organizations identified as having leadership responsibility. This study finds stakeholder perceptions of leadership responsibility contribute to an institutional void, in which it is unclear who is responsible and who should pay for resilience investment. This research emphasizes the need for pre-planning dialogue to develop consensus and build momentum for resilience investment strategies. The specific findings are outlined below.

Survey findings:

Stakeholders see a collaborative effort as responsible to implement resilience strategies and believe planning should begin now. But the survey indicated that this is no clear consensus among respondents on who is responsible for providing leadership. Private sector respondents indicated that public leadership is required, while representative of the public sector indicated the business community should take the lead.

Private and public stakeholders also disagreed on who should pay for specific resilience actions. Over 50% of the private sector respondents felt that they had little or even no financial responsibility for resilience investments and the majority felt that state and federal governments were the most responsible. Public sector respondents, on the other hand, tended to favor more of a shared approach. This might take the form of public/private partnerships, for example, or other strategies that involve private sector funding for resilience.

Interview Findings:

We conducted interviews with seven of the nine organizations most frequently mentioned as having leadership responsibility in the online survey. Interview results showed that six of the seven interviewees stated that their organization is (or should be) a leader in resilience implementation. But they also indicated barriers that limit their ability to implement resilience planning. Three main barriers that limit the ability to provide leadership are (1) lack of expertise, (2) lack of jurisdiction or mandate, and (3) lack of resources. Also, many of those who perceived of themselves in a leadership role, indicated they should be a partner or supporter, not as the "main" leader. The interviews also found that there is a need for dialogue among all stakeholders to help motivate organizations into a leadership role.

(4) Agreement on barriers to port adaptation to storm hazards

This research component employs a cultural consensus model (CCM) to assess the level of agreement among stakeholders

For the analysis, the researchers will use a cultural consensus model (CCM) to assess the three studies groups level of agreement on the barriers to climate change adaptation within the larger context of the port community's resilience.

Climate change investigations stress how decision-making barriers slow the development and implementation of needed adaptation strategies (Moser and Ekstrom, 2010). Although planning for adaptation is more prevalent today than 10 years ago (Becker et al., 2011), overall, the implementation of risk adaptation measures is still scarce (Moser and Ekstrom, 2010, Biesbroek, 2011). Ports and critical coastal infrastructures are already being damaged by heavy rains, storms, sea level rise (SLR), and extreme heat damage (Melillo et al., 2014). It is imperative that as natural, unpredictable threats increase, our ability to strategically plan and respond to these threats is not challenged by not being informed, nor addressing the barriers to adaptation. In order to assist the Department of Homeland Security and other decision makers, to understand and prepare for coastal storm hazards and increase the port community's resilience, we propose an assessment of the decision-makers' barriers to climate change adaptation by surveying port directors/managers, safety officers and environmental risk officers in 22 medium and high-use ports of the USACE North Atlantic Division. For the analysis, the researchers will use a cultural consensus model (CCM) to assess the three studies groups level of agreement on the barriers to climate change adaptation within the larger context of the port community's resilience.

(5) Use of Visualizations to Motivate Storm Adaptation

As indicated above, an important barrier taking protective actions the fact that many stakeholders view storm hazards as "theoretical", and not of immediate priority. Visualizations have been shown to play an important role in making seemingly abstract risks like future sea level rise seem tangible in relevant local contexts (Sheppard, 2015). We find that visualizations of storm damages have become an important part of engaging the public and communicating risks, and are often used in combination with other exhibits and interactions in workshop processes (e.g., Becker 2016). Visualizations of damages in the stakeholders' own community can help communicate risks by demonstrating that "it can happen here" (Sheppard, Shaw, Flanders, & Burch, 2008).

At the same time, concerns have been raised regarding some effects of visualizations. For instance, compelling visualizations of sea level may cause people to focus on their exposure to that risk and discount other risks that are more difficult to model and visualize (e.g., wind, precipitation) (Moser & Dilling, 2011). Visualizations have also been criticized for potentially overstating the resolution and certainty of predictions (Kostelnick et al., 2013).

Given these concerns, the project tested the effects of visualizations to determine whether these phenomena are taking place, and, whether visualizations are in and of themselves having positive effects on overcoming barriers to community preparedness.

Findings

Among key findings regarding the perceptions of visualizations are results that specifically relate to overcoming barriers. Evaluations of effects on risk perception suggest that individuals are more likely to discount highly personal risks (e.g., effects to their individual property) as opposed to risks that impact communities more generally (e.g., depictions of adjacent communities or publicly recognizable locations). Results also suggest that disbelief and discounting increases as scenarios diverge from what audiences already expect.

This research also finds that both experts and the public expect that historic storms are the most robust basis for projections of future inundation. This is potentially problematic in situations where probabilities of higher impact storm events are increasing, for example where a 100-year historic storm might now be more like a 20-year storm. This suggests that visualizations might be effective by indicating impacts of likely future storms. Providing this context will signal credibility by acknowledging existing expectations and may thus increase acceptance of the projections together.

Other results suggest that concerns over misleading characteristics of 3d visualizations may be over-stated. The use of these visualizations in risk communication has been limited by concerns that by being detailed and evocative, they overstate the certainty of a risk and therefore be misleading. These and other effects suggest that modest, semi-realistic visualizations may be able to combine the positive orienting effects of 3d visualizations without diminishing authority to the point that they are ineffective.

This research strongly suggests that overcoming barriers to improved risk communication hinges on understanding audience expectations and avoiding "fear appeals" that emphasize extreme scenarios or that seek to shock audiences. This research reinforces these findings that the ineffectiveness of fear appeals potentially introduces problems where probabilities of storms are increasing. These tools will maximize engagement and acceptance, and thus aid in overcoming barriers.

Impacts

4. <u>End Users and Transition Partners:</u>

Models and Visualizations:

The project created visualizations that contribute to planning for coastal hazards. The visualizations have received a great deal of attention, and have been used, or will be used, as part of the following planning processes:

Rhode Island Coastal Beach Special Area Management Plan (RI Beach SAMP):

- Matunuck (South Kingstown) Rhode Island
- Misquamicut (Westerly) Rhode Island
- Charlestown Rhode Island
- Warwick, Rhode Island
- Barrington, Rhode Island (in progress)
- Warren, Rhode Island (in progress)
- Bristol, Rhode Island (in progress)

Federal Emergency Management Agency Integrated Emergency Management Course (FEMA IEMC), June 2017:

- Pawtucket Rhode Island (maps)
- Providence Rhode Island (community wide 3d)
- Middletown Rhode Island (community wide 3d)
- Westerly Rhode Island (community wide 3d)

Port Planning for the following entities:

- Port of Providence, Providence Rhode Island
- Port of Davisville, Rhode Island (in development)
- Port of Galilee, Rhode Island

Analysis of 25-Year History of Coastal Management in Rhode Island:

The project developed an analysis of news media, government reports, legislative actions, coastal management permits and other public documents to provide an analysis that compiles: (1) an aggregate timeline of hazard events, studies, and plans and policies; (2) a database of RI Coastal Resource Management Council (CRMC) permits with illustrations, both geographically and over time by number and type of ascent to document coastal hazards policy implementation by the CRMC; (3) a social network map documenting RI engagement regarding resilience policy among state organizations and with stakeholders; and (4) vignettes describing selected cases of locations or policies significant to resilience policy in RI to provide context for connections between each of the products described above and to assist in identifying the "semantic language" in print and in speech used to describe barriers to action to enhance resilience.

The information presented here has been requested by end users to provide documentation of the institutional memory that has been accumulating over time in these organizations with respect to their understanding and use of putting science to action and into policy. A final version of the technical report will be provided to the CRMC taking into account a selection of additional information to complement the findings and recommendations of the Shoreline Change SAMP.

Adaptation Strategies:

Cape Cod Commission will use project-generated data to develop a decision support tool to help government officials and private parties better understand the intended and unintended consequences of different strategies to adapt to coastal flooding and other coastal storm hazards. Adaptation strategies include actions such as the following:

- Beach Nourishment
- Artificial Sand Dunes and Dune Nourishment,
- Salt marsh creation and restoration on coastal beaches
- Planting Vegetation to Reduce Erosion and Storm Damage,
- Living Shoreline
- Sand fencing
- Seawall
- Rip Rap
- Managed Realignment
- Coastal Setbacks
- Elevating and relocating buildings

5. Project Impact:

The outputs from this work have supported resilience and risk communication efforts in 14 specific communities, and across the State of Rhode Island, this has included the training of emergency managers and first responders in collaboration with the Rhode Island Emergency Management Agency and the Coastal Resources Management Council. Visualizations were created for the Beach Special Area Management Plan (Beach SAMP) to be used in local public engagement processes in Matunuck, Misquamicut (Westerly) Warwick, Charlestown, Barrington, Bristol, and Warren Rhode Island. These visualizations have become essential parts of the engagement processes conducted by the SAMP. Integration of visualizations into the SAMP process suggests that there are some issues surrounding the depiction of specific damages to individual structures. To the extent that there are no regulatory structures or means to address the specific impacts or vulnerabilities revealed there is discomfort with their publication or distribution. These experiences lend credence to the approach of placing emphasis on qualitative impacts identified by stakeholders: identifying specific concerns that are relevant and actionable. Additional collaborators include: University of Rhode Island, Coastal Resilience Center (CRC) and the State of Rhode Island, Coastal Resources Management Council (CRMC).

Hazard impact models and visualizations were deployed to support a Federal Emergency Management Agency Integrated Emergency Management Course (FEMA IEMC) in collaboration with the Rhode Island Emergency Management Agency, RIEMA. These included visualizations of Westerly, Providence, Middletown, and Pawtucket Rhode Island, and statewide assessment of damages. Additional support was provided by the Department of Homeland Security Office of Cyber and Information Security (DHS OCIS). Deployment included developing time incremented hazard impact models including qualitative impacts, and matching time incremented visualizations of inundation. The process of integrating the time incremented model into an existing simulation exercise made it immediately clear that many of the resources used in these kinds of training exercises (e.g. impacts derived from historic storms) were not well synchronized with the unfolding of the simulated storm. The use of the time incremented simulation made it possible to understand not only what happened, but when impacts occurred relative to other events. Given the significance of access to remote barrier islands for purposes for evacuation and the effects of wind on transportation, the timing of these effects has significant impact on response.

We have compiled a large database information from print media, government reports, legislative actions, etc. The product is a document that includes the following: (1) an aggregate timeline of hazard events, studies, and plans and policies; (2) a database of RI Coastal Resource Management Council (CRMC) permits with illustrations, both geographically and over time by number and type of ascent to document coastal hazards policy implementation by the CRMC; (3) a social network map documenting RI engagement regarding resilience policy among state organizations and with stakeholders; and (4) vignettes describing selected cases of locations or policies significant to resilience policy in RI to provide context for connections between each of the products described above and to assist in identifying the "semantic language" in print and in speech used to describe barriers to action to enhance resilience.

We have developed data and methods for assessing different coastal management adaptation strategies, such as building sea walls, living shorelines, beach nourishment, etc. This information is in the process of being incorporated into a decision support system being developed by Cape Cod Commission. The goal of this system is to serve as an education tool, to help inform communities, government officials and private parties of the likely intended and unintended impacts of these adaptation strategies.

6. Student involvement and awards:

In the spring 2017 semester we ran a Capstone Class with 27 students in the Department of Environmental and Natural Resource Economics. The Capstone is a senior-level class, in which students carry out a detailed case study of direct policy significance applying the methods that they learned throughout their undergraduate careers.

This Capstone focused on the issue of improving storm resilience in coastal communities, with a case study of Misquamicut, Rhode Island. Misquamicut is an excellent case study, as it is coastal beach community that is extremely vulnerable to inundation by coastal storms, and as has a repeated history of hurricane devastation including the Great New England Hurricane of 1938, Hurricanes Carol in 1954, Gloria in 1985, Bob in 1991, Irene in 2011 and most recently Sandy in 2012.

The Capstone project was coordinated with Capstone classes in the Ocean Engineering Department and the Landscape Architecture Department to create an interdisciplinary collaboration that focused on increasing the resilience of Misquamicut to coastal storm hazards. The students in the three Capstone classes met periodically throughout the semester, and shared research plans, project data and research findings. At the end of the semester the students from the three Capstone classes hosted an event with public presentations of their findings to a set of "whole community" end users.

The Ocean Engineering Capstone project analyzed potential physical damages to properties in Misquamicut for scenarios of varying hurricane intensity and sea level rise. Landscape Architecture students created different designs for communities to improve storm resilience. Environmental Economics students in our Capstone carried out three sets of analyses:

(1) A cost-benefit analysis of alternative structural solutions, including shoreline armoring, beach renourishment, elevating structures and retreat from hazard zones;
(2) A housing value assessment to see whether coastal storm threats are reflected in housing prices;
(3) A survey of the local public on risk attitudes and willingness to take protective actions.

The survey was used as a pilot test of the effectiveness of storm visualizations. Roughly 110 respondents were assigned to two groups: a treatment group that was shown visuals of storm impacts and a control group that was not shown visuals. Aggregate survey responses were compared across the control and treatment group to test the hypothesis that visualizations of storm impacts affected the respondents' perceived risk of coastal storms, and to compare stated intentions to take protective actions with vs without storm visualizations. We found that the visualizations show promise in preparing communities to adapt to storm hazards, both in terms of an increased perception of storm risks, and in terms of a stated willingness to take protective actions.

7. <u>Interactions with education projects</u>:

We have funded Courtney Hill from Tougaloo College to serve as a summer intern for our project. The goal of the internship is to expose Courtney to rich and varied educational experience centered on adaptation to coastal hazards. The primary project-related activity is participating in our retrospective review and timeline of community response to storm events by analyzing the content of various types of reports, data bases, interviews and news coverage of coastal hazards. This activity will develop a timeline of coastal storms and associated community response to provide a longer terms perspective on barriers to adaptation and potential interventions. This review will utilize state agency permit data; reports of state and local policy responses; content analysis of newspaper coverage of post-storm events; and identification of patterns of decision making. The findings will be reported in the form of a timeline of events and associated responses. The student intern will participate in team meetings, and have the opportunity to engage in other coastal resilience meetings and activities of the URI-CRC project.

8. Publications:

Becker, A., (2016). “Findings from a port vulnerability assessment.” Dept. of Homeland Security Center of Excellence for Coastal Resilience and University of North Carolina Maritime Risk Symposium University of North Carolina, Chapel Hill, North Carolina, Nov. 14-15, 2016, scheduled. (I).

Becker, A, (2016). “Adapting ports to climate change: Providence (RI) Case Study,” AIVP Ports and Cities Conference, Netherlands, Oct 10-12, scheduled.(I)

Becker, A., (2016). “Inspiring leadership for Adaptation,” North American Symposium on Climate Adaptation, New York, New York. Aug. 16-18, scheduled. (I)

Becker, A., (2016). “Inspiring resilience thinking for seaport systems.” Transportation Research Board Conference for Committee on Maritime Transportation System (CMTS), National Academy of Sciences, Washington, DC, June 21-22, scheduled.

Becker, A, (2016). “Adapting ports to climate change: Providence (RI) Case Study,” Adaptation Futures 2016, Rotterdam, Netherlands May 11-13.

Becker, A., (2016). “Inspiring resilience thinking for seaport systems.” Green Ports for Blue Waters Conference, University of Rhode Island April 4-5, (I)

Green, W., Becker, A., (2016). “Built environments and rising seas: Service learning recommendations for the future of the Port of Galilee.” A presentation of student work resulting from a course on resilient planning, policy, and design. Keeping History Above Water Conference, Newport, Rhode Island, April 10-13 .

Becker, A. (2016). “Hurricane Resilience and Impacts to Seaport Supply Chains.” Invited Speaker for the 2016 Stu Clark Speaker Series at the University of Manitoba. March 4 (I,E)

McIntosh, R.*, Becker, A. (2016). “Towards a Comparative Index of Seaport Climate-Risk: Development of Indicators from Open Data.” Poster presentation at American Geophysical Union 2016 Ocean Sciences Meeting, New Orleans, LA, Feb. 21-26.

Kretsch, E.*, Becker, A. (2016). “Leadership and Responsibility for Long-term Hurricane Resilience: Stakeholder Perceptions in the Port of Providence, RI.” Social Coast Conference. Charleston, SC, Feb. 11.

Becker, A., Burroughs, R. (2016). “More holistic planning for long-term coastal resilience? Port of Providence Demonstration Project.” Social Coast Conference. Charleston, SC, Feb. 10.

Becker, Austin, Pamela Matson, Martin Fischer, and Michael D. Mastrandrea, Forthcoming. “Towards Seaport Resilience for Climate Change Adaptation: Stakeholder Perceptions of Hurricane Impacts in Gulfport (MS) and Providence (RI)” *Progress in Planning*. Status: Accepted for Publication. Anticipated Publication Date November 2017.

Zhang, H., Ng, A., Becker, A. (In Press), “Institutional Barriers in Adaptation to Climate Change at Ports, Regions, and Supply Chains.” North American Symposium on Climate Adaptation, New York, New York. Aug. 16-18, 2016. (Refereed Conference Paper)

Touzinsky, K, Rosati, J., Fox-Lent, C., Becker, A., Luscher, A., 2016. “Advancing Coastal Systems Resilience Research: Improving Quantification Tools through Community Feedback” *Shore and Beach* Vol. 84 No. 4 · November 2016.

Kuffner, A. (2016, November 20, 2016). Rising Seas, Rising Stakes. Providence Journal.

Spaulding, M. L., Grilli, A., Damon, C., Crean, T., Fugate, G., Oakley, B., & Stempel, P. (2016). Stormtools: Coastal Environmental Risk Index (CERI). Journal of Marine Science and Engineering, 4(3).

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Witkop, R., Stempel, P., Becker, A., (2017). "Coupling local scale, high resolution, qualitative data to interface with numerical storm models." Poster Presentation. American Geophysical Union Annual Conference, New Orleans, LA. December 12.

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9. Tables:
   Table 1: Documenting CRC Research Product Delivery
   Table 2A: Documenting External Funding
   Table 2B: Documenting Leveraged Support
   Table 3: Performance Metrics

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type (e.g., software, guidance document)	Delivery Date	Recipient or End User
Decision Support System for Coastal Hazard Mitigation Actions	Data and Software to Integrate into Decision Support Tool	April 2018	Cape Cod Commission
Data-Driven Visualizations of Storm Impacts	Images to Communicate Storm Impacts	June 2017	Federal Emergency Management Agency Integrated Emergency Management Course (FEMA IEMC) in collaboration with the Rhode Island Emergency Management Agency, RIEMA.

Table 2A: Documenting External Funding

Title	PI	Total Amount	Source
Assessing Coastal Hazard Mitigation Strategies	James Opaluch	$75,000	Cape Cod Commission

Table 2B: Documenting Leveraged Support

Description (e.g., free office space; portion of university indirects returned to project; university-provided student support)	**Estimated Total Value**

Table 3: Performance Metrics: OPALUCH

Metric	Year 1 (1/1/16 – 6/30/16)	Year 2 (7/1/16 – 6/30/17)	Year 3 (7/1/17- 6/30/18)
HS-related internships (number)			1
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)			
Graduate students provided tuition/fee support (number)			
Graduate students provided stipends (number)		1	
Undergraduates who received HS-related degrees (number)			
Graduate students who received HS-related degrees (number)			
Graduates who obtained HS-related employment (number)			
SUMREX program students hosted (number)		1	1
Lectures/presentations/seminars at Center partners (number)	2	3	
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)	2	9	6
Journal articles published (number)		3	3
Conference presentations made (number)	13	18	7
Other presentations, interviews, etc. (number)	5	4	4
Patent applications filed (number)			
Patents awarded (number)			
Trademarks/copyrights filed (number)			
Requests for assistance/advice from DHS agencies (number)	2		
Requests for assistance/advice from other agencies or governments (number)	5		
Total milestones for reporting period (number)	26	38	22
Accomplished fully (number)	20	36	22
Accomplished partially (number)	6	2	0
Not accomplished (number)		0	0

1. <u>Year 3 Research Activity and Milestone Achievement:</u>

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Group Decision Processes	9/30/2017	100%	
Pretest and Revise Policy Simulation Tools	12/31/2017	100%	
<u>Research Milestone</u>			
Updated List of Barriers and Interventions for Behavior Change	9/30/2016	100%	
Draft Policy Simulation Tools (updated quarterly)	10/1/2017 & 12/31/2017	100%	

2. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Continue updates/newsletter and/or periodic virtual meetings to remain fully connected with the end-users.	12.31/2017	100%	
Barriers and Interventions for Actions to Mitigate Storm Damages	12/31/2017	100%	
Design, Pretest and Revise Policy Simulation Tools	12/31/2017	100%	
Organize a Northeast / Mid-Atlantic regional workshop to demonstrate, train and utilize the tools that have been developed. Logistics and resource support for this workshop will be coordinated with the Transition Director, Tom Richardson as appropriate.	Fall 2017	100%	
End of period report out to end-users	Dec 31, 2017	100%	
Transition Milestone			
Training workshop for DHS, NOAA/NWS and RI stakeholders.	July 2017	100%	

Appendix A Summary of Group Decision Meetings[1]

Meetings to Date

1. Rhode Island Legislative Commission on Economic Impacts of Sea Level Rise and Coastal Flooding. (September 24, 2015) Legislative Hearings on economic threats of sea level rise and coastal flooding.
2. Rhode Island Legislative Commission on Economic Impacts of Sea Level Rise and Coastal Flooding. (Oct 15, 2015) Legislative Hearings on economic threats of sea level rise and coastal flooding.
3. Municipal Adaptation Work Session, New Shoreham. (Oct 22, 2015). Purpose: Assist communities to understand exposure to coastal storm hazards, plan for action to reduce risk and implement plans. Increase awareness of tools, planning requirements and adaptation strategies.
4. Municipal Adaptation Work Session, Westerly. (Oct 29, 2015) Purpose: Assist communities to understand exposure to coastal storm hazards, plan for action to reduce risk and implement plans. Purpose: Assist communities to understand exposure to coastal storm hazards, plan for action to reduce risk and implement plans. Increase awareness of tools, planning requirements and adaptation strategies.
5. Municipal Adaptation Work Session, Charlestown. (Oct 29,2015) Purpose: Assist communities to understand exposure to coastal storm hazards, plan for action to reduce risk and implement plans. Purpose: Assist communities to understand exposure to coastal storm hazards, plan for action to reduce risk and implement plans. Increase awareness of tools, planning requirements and adaptation strategies.
6. Municipal Adaptation Work Session, North Kingstown. (Nov 11, 2015) Purpose: Assist communities to understand exposure to coastal storm hazards, plan for action to reduce risk and implement plans. Purpose: Assist communities to understand exposure to coastal storm hazards, plan for action to reduce risk and implement plans. Increase awareness of tools, planning requirements and adaptation strategies.
7. Rhode Island Legislative Commission on Economic Impacts of Sea Level Rise and Coastal Flooding (Nov 19, 2015) Legislative Hearings on economic threats of sea level rise and coastal flooding.
8. Rhode Island Legislative Commission on Economic Impacts of Sea Level Rise and Coastal Flooding. (December 17, 2015) Legislative Hearings on economic threats of sea level rise and coastal flooding.
9. Town of South Kingstown, Municipal Adaptation Work Session. (January 20 2015) Purpose: Assist communities to understand exposure to coastal storm hazards, plan for action to reduce risk and implement plans. Increase awareness of tools, planning requirements and adaptation strategies.
10. Rhode Island Legislative Commission on Economic Impacts of Sea Level Rise and Coastal Flooding. (January 21, 2016) Legislative Hearings on economic threats of sea level rise and coastal flooding.
11. #ResilientPVD Community Workshop. A team of experts from around the country come to Providence for three days of charrettes, workshops, and community meetings to explore how Providence's infrastructure, buildings, and neighborhoods can prepare for the impacts climate change. (February 1- 3, 20016)
12. Beach SAMP meeting, Meeting of State and Town leaders to discuss adaptation to sea level rise and coastal flooding threats. (February 4, 2016)
13. Meeting of Community Leaders to Discuss historic and potential future impacts of coastal flooding, and actions to mitigate impacts. (February 16, 2016)

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[1] Note that some of these meetings are periodic events that involve attending multiple meetings.

14. Rhode Island Legislative Commission on Economic Impacts of Sea Level Rise and Coastal Flooding. Legislative Hearings on economic threats of sea level rise and coastal flooding. (February 25 2016)
15. BeachSAMP meeting. Meeting of State and Town leaders to discuss adaptation to sea level rise and coastal flooding threats. (April 6, 2016)
16. ANNUAL RIFMA CONFERENCE - "Incentivizing Actionable Resilience to Flooding" - Join floodplain management and hazard mitigation professionals as we explore implementation tools and techniques, and share experiences and lessons learned from the past to improve resiliency in the present and future. (April 7, 2016)
17. Keeping History Above Water Conference, Newport, RI. One of the first national conversations to focus on the increasing and varied risks posed by sea level rise to historic coastal communities and their built environments. This is not a conference about climate change, but about what preservationists, engineers, city planners, legislators, insurers, historic home owners and other decision makers need to know about climate change—sea level rise in particular—and what can be done to protect historic buildings, landscapes and neighborhoods from the increasing threat of inundation. (April 10-13, 2016)
18. RI Silver Jackets (RIEMA, Cranston) - Meeting of Interagency coalition to reduce flood risk. State-led teams, implementation of USACE National Flood Risk Program (April 14, 2016)
19. DC DHS Presentation and discussion with DHS HQ and others on how to link with their efforts. (April 14, 2016)
20. RI Coastal Erosion Control Workshop (April 21, 2016) http://www.crmc.ri.gov/news/pdf/2016_0421_Workshop_Flyer.pdf
21. Meeting with and presentation by Chris Landsea, NOAA's Joint Hurricane Testbed Director/Science and Operations Officer at the National Hurricane Center. Discussion of all three URI projects funded by DHS, and lecture "Inside the Eye: Improving Hurricane Forecasts". (May 3, 2016)
22. BEACHSAMP Stakeholder Meeting with presentation from Michael Oppenheimer, speaking about climate change and the IPCC. (May 3, 2016)
23. Estuarine and Coastal Modeling Conference (ECM14) at URI - Rick Luettich (UNC lead) will be a keynote, Meeting with Rick Luttich with our team and other key users, including Coast Guard, and possibly other DHS leaders. (June 12-15, 2016)
24. New England Climate Adaptation, Preparedness, and Resilience seminar - Organized by DHS Infrastructure Protection, EPA, FEMA, NOAA, NH Department of Safety. First in a series of New England seminars. (May 24 – 25, 2016)
25. Preparedness Conference (CCRI) - Series of presentations, trainings, and exhibits. http://www.riema.ri.gov/resources/government/prepare/preparednessconference/index.php (August 10-11, 2016)
26. RI Shoreline Change Special Area Management Plan Meeting, (August 25, 2016)
27. Presentations on Misquamicut Storm Vulnerability. Presentations by Rhode Island Officials to Capstone Classes. (Feb 3, 2017)
28. Coastal Storm Vulnerability Case Study. Misquamicut beach storm vulnerability site visit to led by RI Coastal Resources Management Council. (Feb 3, 2017).
29. Rhode Island Association of Emergency Managers (RIAEM) - Monthly meetings of local emergency managers, Red Cross, RIEMA, and Dept of Health. Identify tangible and useable products. Obtain feedback on prototypes of hazard management tools.

30. RI Annual Conference on Building Flood Resilience, (April 6, 2017)
31. Improving Resilience to Coastal Storms: Misquamicut Capstone Presentations, Reporting of findings of Capstone Classes to Stakeholder Groups. (May 5, 2017).
32. RI Executive Climate Change Coordinating Council Meeting, Council created by RI Legislation to coordinate planning for climate change impacts into the duties of all state agencies. (June 14, 2017)
33. FEMA Integrated Emergency Management Course/Community Specific Public officials and other leaders are placed in a realistic simulation of a hurricane disaster scenario to enhance storm preparedness. (June 19–22, 2017).

YUSUF-ODU
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Stakeholder/End User Engagement Support of Two CRC Projects (Former project title: A Tool to Measure Community Stress to Support Disaster Resilience Planning)

Principal Investigator Name/Institution: Wie Yusuf, School of Public Service, Strome College of Business, Old Dominion University

Co-Principal Investigators and Other Partners/Institutions:

- Larry Atkinson, Slover Professor and Eminent Scholar, Department of Ocean Earth & Atmospheric Sciences, College of Sciences, Old Dominion University
- Joshua Behr, Research Associate Professor, Virginia Modeling, Analysis, and Simulation Center (VMASC), Old Dominion University
- Michelle Covi, Assistant Professor of Practice, Department of Ocean Earth & Atmospheric Sciences, College of Sciences, Old Dominion University and Virginia Sea Grant Extension

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description ("elevator speech"):

This project supported several Coastal Resilience Center (CRC) research and education projects, building on the project team's expertise in stakeholder engagement, leveraging information already collected from initial case studies, and utilizing existing connections to stakeholders and possible end users in the Hampton Roads region. Specifically, this included (1) organizing a panel for the Maritime Risk Symposium that addresses "Integrating Maritime and Costal Resilience;" (2) supporting stakeholder engagement and end user translation efforts of '*The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency'* project*;* (3) participating in a collaborative research project studying socio-ecological resilience with a team from Norfolk State University (NSU), a minority-serving institution, as part of the DHS Summer Research Team Program; and (4) hosting a summer research intern from Tougaloo College, a minority-serving institution. Overall, the project team engaged with the CRC and its projects by assisting with communications and engagement efforts and providing linkages between CRC research and education projects and Hampton Roads resilience initiatives.

Summary Abstract:

The objective of this project is to provide stakeholder and end user engagement in support of CRC research and education projects, building on the ODU team's expertise in stakeholder engagement and utilizing existing connections to stakeholders and potential end-users in Hampton Roads. The project team co-organized (with the U.S. Coast Guard) the panel titled "Integrating Maritime and Coastal Resilience" held at the November 2016 Maritime Risk Symposium. This panel included Jim Redick (Director of Norfolk Emergency Management),

RADM Ann Phillips (U.S. Navy, ret.), Kit Chope (Vice President for Sustainability, Port of Virginia), and CAPT Richard Wester (Commander, U.S. Coast Guard Sector Hampton Roads). We supported stakeholder engagement efforts of 'The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency' project (PI: Don Resio) by hosting a Hampton Roads Adaptation Forum on the topic of Sea Level Rise and Flooding Science and a web-based hydro-surge flood modeling focus group with local government stakeholders. We participated in collaborative research on socio-ecological resilience with faculty and students from Norfolk State University (a minority serving institution) as part of the DHS Summer Research Team Program. In summer 2018 we hosted a SUMREX student from Tougaloo College. The student worked with faculty to define resilience and engaged various stakeholders and potential end-users by participating in training, workshops, and events. Across these activities, we connected CRC partners with stakeholders and end-users, including managers and planners from local governments, regional organizations, state agencies, federal and DoD agencies, and non-profits.

PROJECT NARRATIVE:

1. Research Need:

This project meets the Homeland Security needs for stakeholder and end user engagement in two CRC projects. Our efforts focused on engaging with federal, state and local government stakeholders and facilitating end user translation of project deliverables and products. In addition, our project supports building coastal resilience and enhancing homeland security in the coastal region, specifically integrating maritime and port issues with coastal resilience issues. By connecting stakeholders in maritime and port sectors with stakeholders in emergency management and resilience, our project supports Homeland Security needs related to risk and improving coastal resilience. These issues have been brought to a wider audience through our support of the Maritime Risk Symposium; the visibility of such issues and their connectivity to other related risk and resilience concerns have been advanced by this project. Through *'The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency'* project, our engagement efforts with planning- and management-level stakeholders in Hampton Roads addresses the Homeland Security research need related to modeling and decision making that incorporate different risks and that are more strongly connected to the needs of end-users. Since end-users can provide input into development, such as specifying the use of modeling information or what risks to incorporate into the models, they are more invested in using the models, which through participation are better tailored to their needs. We also supported Homeland Security efforts to better involve faculty and students from minority-serving institutions in the research and practice of coastal resilience. Through the collaborative research project with faculty and students from Norfolk State University and through the SUMREX student internship, we are building an interdisciplinary community of scholars that have diverse backgrounds and perspectives.

2. History:

Year 1 (January 1, 2016 – June 30, 2016)

During Year 1, this project shifted in focus to support stake holder engagement activities within the DHS Coastal Resilience Center of Excellence (CRC). The original project involved development of a Hazards Stress Test Tool (HSTT) that supports coordinated actions in all risk management and mitigation phases involving collaboration between federal, state, local, tribal, and private sector partners. It addresses the nexus of risk assessments, land use and hazard mitigation plans under climate change. "**Community stress" (CS)** preconditions the capability "to **prevent, protect against, mitigate, respond to, and recover from the threats and hazards that pose the greatest risk." CS is a proxy for this capability. CS has not been systematically integrated in disaster risk assessments. Significant knowledge gaps in the probability density functions (PDF) of local sea level (LSL) rise and extreme events make rigorous assessment of costs and benefits impossible, leading planners to make decisions based on somewhat arbitrary assumptions. Interdependencies among services, infrastructure, buildings, areas, and social fabric are not always considered. The processes in the coupled natural-human system that translate hazards into disasters are not yet fully understood.**

We began work on HSTT development by engaging with use case stakeholders and other potential end users of the HSTT. Beginning January 2016, the ODU project team began working with potential use case stakeholders to identify relevant use cases for the HSTT. We identified three potential groups of use case stakeholders and met with each group to discuss their planning information needs and identify appropriate use cases. We identified the following use cases:

1. **Rural use case**: Gloucester County, VA. January 27 meeting with Brian Lewis, Director of Engineering; Garrey Curry, Assistant County Manager; and Anne Ducey-Ortiz, Director of Planning and Zoning.
2. **Urban use case**: City of Norfolk, VA. February 3 meeting with Jeremy Sharpe, Long-range Planner and lead of Norfolk 2100 project; Paula Shea, Principal Planner; Katerina Oscarson, Resiliency Office; Bobby Tajan, Floodplain Manager; Pam Myers, AmeriCorps resilience intern; Justin Burns, AmeriCorps resilience intern.
3. **Regional use case:** Hampton Roads Planning District Commission (HRPDC) and the Regional Emergency Management lead on regional mitigation planning. February 4 meeting with Ben McFarlane (HRPDC planner); Erin Sutton, Emergency Management Director for the City of Virginia Beach.

We met with use case stakeholders to identify their needs, constraints, and capacity to utilize the HSTT in their planning processes. Our discussions were structured around answering the following questions:

1. What planning processes are you currently engaged in to reduce flood and/or hazards risk?
2. The hazard stress test tool is a decision support tool that provides information about how the resources, characteristics, and capacities of your community interact to affect resilience to hazards. Can you describe how this information feeds into these planning processes?
3. What factors or characteristics of communities can affect how resilient a community can be to floods and hazards?
4. What is the status and/or timeline of these planning process?

Several key themes arose from our discussion with the use case stakeholders:

1. Moving beyond hazards
   - The stakeholders believe that there is existing knowledge about hazards. Most plans also rely on HAZUS to identify hazards and vulnerabilities. In many cases, use of HAZUS for planning is mandated. Additional information and models about hazards are not useful. Long-range planners want to focus on 'opportunities' and want to frame the issue away from hazards towards possibilities. They are interested in a tool that not only included the negatives and gaps, but also characteristics, assets, resources and capabilities that enhance or contribute to increased resilience.
   - Questions the stakeholders need help with are related to hazards but on a broader level: Where to build? If you need to rebuild, what is the best plan? How to inform a long-term recovery plan? How to inform the capital budgeting process and zoning decisions. How to decide funding priorities?
2. Utility beyond planning and plans:
   - The plans (floodplain management plan, hazard mitigation plan, emergency management/response plan) are perceived as end outcomes, with the outcome being to 'check the box' that the plans have been developed. These plans are reviewed, but various other decisions such as land use decisions (i.e. where to develop- where to bring in water and sewer, zoning and rezoning) are often made independent of these plans.
   - Taking plans to the next step requires supporting the implementation phase. Implementation requires information about how different decisions involve different trade-offs, e.g. (re)zoning decisions may involve trade-offs regarding economic activity, livability, resilience. Planners need tools to help communicate these trade-offs to officials who make the decisions. Both Gloucester and Norfolk stakeholders raised the importance of linking plans to capital budgeting. One stakeholder noted: "The usefulness is in the implementation of the plan. Not as part of the development of the plan."
   - In terms of mitigation strategies and actions included in the plans, there is a gap in how to prioritize projects for implementation. Stakeholders do not have metrics, tools, process, or frameworks to compare different mitigation strategies or to rank them.

From the meetings with use case stakeholders, we found that the HSTT project, as originally proposed, did not meet end user needs and would not gain traction within the end user community as a decision support tool. We concluded that the project direction should be altered to produce a decision support framework that supports not only planning, but the integration of planning within a broader decision-making context including implementation and funding.

Given this conclusion, remaining funding for this project was repurposed with approval from DHS to support stake holder engagement with the Coastal Resilience Center, leveraging our connections to various stakeholder groups including planners, policy makers and decision makers, non-profit and outreach organizations, and resident groups.

Year 2 (July 1, 2016 – June 30, 2017)
For Year 2, we supported two CRC projects, building on our expertise in stakeholder engagement and utilizing existing connections to stakeholders and potential end-users in Hampton Roads. First, we hosted a Hampton Roads Adaptation Forum on the topic of Sea Level Rise and Flooding Science, in support of stakeholder engagement efforts of 'The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency' project (PI: Don Resio). Second, we co-organized a panel for the Maritime Risk Symposium that addressed "Integrating Maritime and Coastal Resilience." For both projects, we connected our CRC partners with stakeholders and potential end-users, including managers and planners from local governments (e.g., in emergency management, coastal planning), regional organizations (e.g., Hampton Roads Planning District Commission, Hampton Roads Sanitation District), state agencies (e.g., Virginia Department of Emergency Management, Port of Virginia), federal and DoD agencies (e.g., Coast Guard, Navy, NOAA, National Weather Service), and non-profits (e.g., Chesapeake Bay Foundation, Wetlands Watch). We also conducted regular and periodic engagement events The ODU team also represented the CRC in a collaborative project with faculty and students from Norfolk State University (NSU, a minority serving institution) as part of the DHS Summer Research Team Program. The NSU-ODU research team studied socio-ecological resilience using the case study of communities in Portsmouth, Virginia.

The July 2016 Hampton Roads Adaptation Forum focused on the topic of Sea Level Rise and Flooding Science. Dr. Don Resio presented on 'Risk and Extreme Events' included participation by the following end-users as presenters:

- *NOAA National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS)*
- *NOAA National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS)*
- *Senior Hydrologist, National Weather Service, Wakefield Office*
- *Coastal Hazards Specialist, NOAA Office for Coastal Management*

In addition to the federal end users, over 80 state and local stakeholders and end-users attended the Hampton Roads Adaptation Forum to hear from Don Resio and ask questions about Don Resio on his presentation 'Risk of Extreme Events.'

In October 2016, Dr. Wie Yusuf provided a lecture at Johnson C. Smith University in Charlotte, NC as part of RETALK. Her talk was titled 'Lessons Learned the Hard Way and Tales of Engagement… 5 Things You Need to Know About Stakeholder Engagement.'

In November 2016, the ODU team hosted Dr. Rachel Davidson (Univ. of Delaware) to present a lecture as part of the Center for Coastal and Physical Oceanography (CCPO)/ODU Resilience Collaborative (ODU-RC) Seminar Series. Her seminar title was 'An Integrated Scenario Ensemble-based Hurricane Evacuation Modeling Framework.'

In March 2017, the ODU team hosted Dr. Billy Sweet (NOAA National Ocean Service). Dr. Sweet gave a lecture titled **'Trends, Patterns and Scenario-based Projections of Relative Sea**

Level and Tidal Flood Frequencies along the US East Coast' as part of the CCPO/ODU-RC Seminar Series.

In April 2017, the ODU team sent Dr. Joshua Behr to present a lecture to the Disaster Research Center at the University of Delaware, titled Vulnerable Populations under Risk for Severe Storm Events. Special emphasis in seminar meetings focused on collaborative graduate student research. The sharing of regional data and maps followed this visit.

The ODU team also represented the CRC in an interdisciplinary, multi-institution collaborative project with faculty and students from Norfolk State University (NSU, a minority serving institution) as part of the DHS Summer Research Team Program. The NSU-ODU collaborative project, titled 'A Systems Approach: Developing Cross-Site Multiple Drivers to Understand Climate Change, Sea-level Rise and Coastal Flooding for an African American Community in Portsmouth, VA' involved studying socio-ecological resilience using the case study of communities in Portsmouth, Virginia.

NSU team:

- Dr. Camellia Okpodu, Professor of Biology
- Dr. Bernadette Holmes, Professor of Sociology and Criminal Justice
- Raisa Barrera, Graduating Senior, Biology
- Mikel Johnson, Rising Senior, Sociology
- Bryan Clayborne, Rising Senior, Sociology

ODU team:

- Dr. Wie Yusuf, School of Public Service
- Dr. Michelle Covi, Ocean, Earth & Atmospheric Science and Virginia Sea Grant
- Dr. Joshua Behr, Virginia Modeling, Analysis and Simulation Center,
- Dr. Larry Atkinson, Ocean, Earth & Atmospheric Sciences
- Dr. Gail Nicula, School of Public Service
- Donta Council, Doctoral student, Public Administration and Policy
- Isaiah Amos, Master's students, Ecological Sciences

<u>Year 3 (July 1, 2017 – June 30, 2018)</u>

Year 3 involved wrapping up the NSU-ODU collaborative research project and continuing to support stakeholder and end user engagement for 'The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency' project (PI: Don Resio). We conducted a focus group involving staff of local governments in Hampton Roads. We also hosted a SUMREX student for 6 weeks. The student studies regional resilience under the supervision of Dr. Joshua Behr and his research team.

In July 2018, the undergraduate and graduate students involved in the NSU-ODU collaborative research project presented their research results.


(The NSU-ODU research team)

In October 2017, we hosted a Hydro-Surge Flood Modeling Focus Group to support end user engagement for Dr. Don Resio's project. The synchronous web-based focus group was intended to discuss local government's needs for flood modeling and to provide input and feedback to Dr. Resio's team. Staff from local government agencies in Virginia Beach, Chesapeake, Norfolk, and Portsmouth participated in the focus group.

In February 2018, Drs. Wie Yusuf, Michelle Covi and Gail Nicula attended the Social Coast Forum and hosted a workshop based on our stakeholder engagement work to an audience that included potential end users from NOAA, Sea Grant, Association of State Floodplain Managers, EPA, FEMA, and others. In March 2018, Dr. Wie Yusuf provided the same workshop as a virtual RETALK to Johnson C. Smith University students titled 'Applying ASERT Tools for Addressing Coastal Resilience.'

(RETALK Presentation by Dr. Wie Yusuf to Johnson C. Smith University students)

In April 2018 Donta Council (ODU doctoral student involved in the project) was the guest speaker at Tougaloo College's Interdisciplinary Minor Disaster Coastal Studies Research Symposium. He presented on 'Understanding Decision Making and Risk Perceptions of Sea Level Rise and Flooding.'

In summer 2018, we hosted a SUMREX student from Tougaloo College, DaChawn Kincaid, for 6 weeks (May 14, 2018 through June 22, 2018). DaChawn worked with an Dr. Joshua Behr's research team (Dr. Jose Padilla and Dr. Erika Frydenlund) from the Virginia Modeling, Analysis, and Simulation Center (VMASC) on a project focused on characterizing regional resilience.

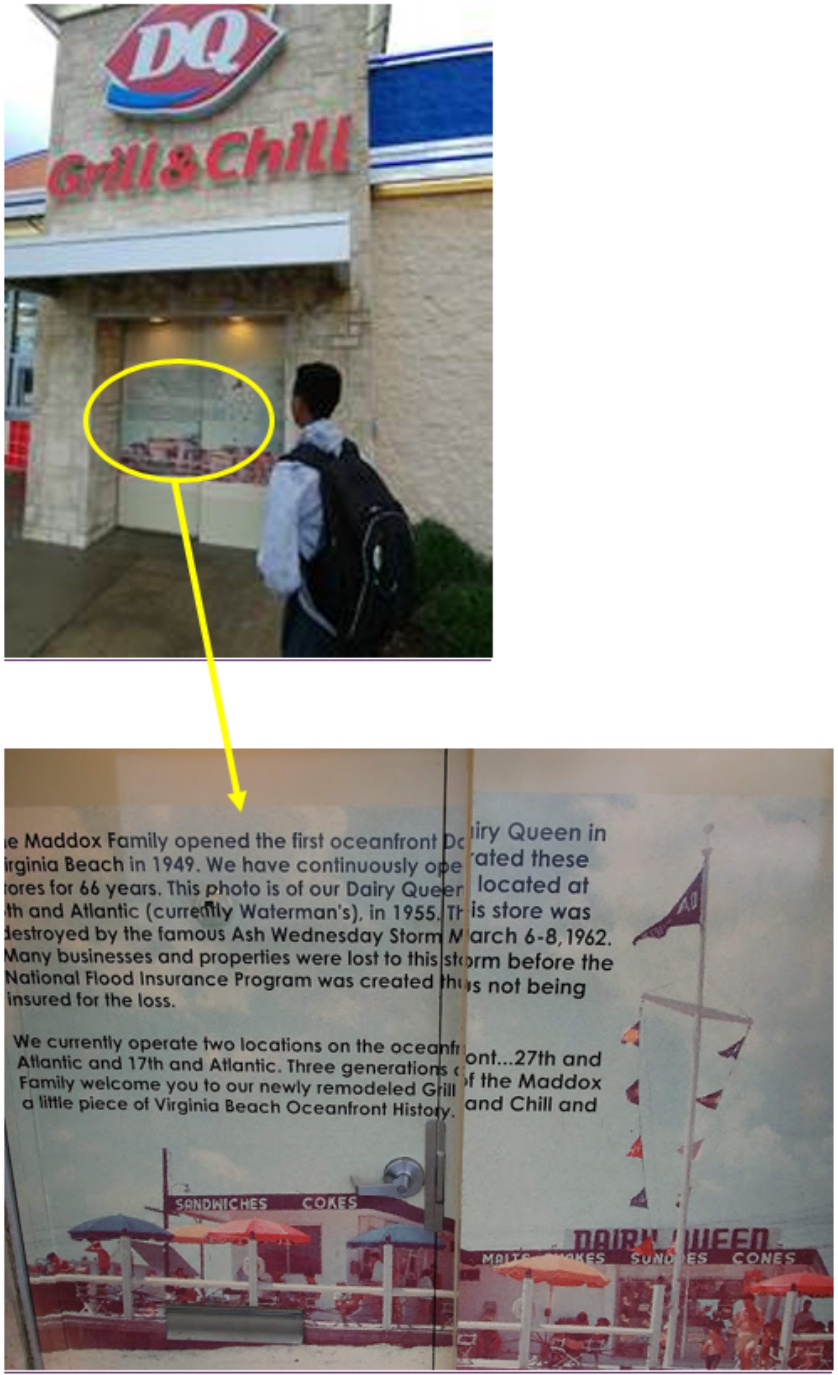
Project description:
This project focuses on characterizing, categorizing, and measurement of the broad concept of resilience. The concept of resilience is used in our discourse in many different contexts and is necessarily far-reaching. It may refer to culture, perceptions, behavior, physical assets and infrastructure, communication protocols, and public and private delivery of services, as well as system of these systems, among others. In addition, implicit is that the considered asset or system is resilient *to* some force, whether this force is either steady or dynamic over time, or whether is it a sudden puncturing of the equilibrium of normalcy. These forces may be in the form of changing natural systems, human migration, displacement and upheaval, severe weather events, and intentional human-induced immediate shocks to an asset or system. Our understanding and treatment of resiliency has implications for public policy, shapes culture, informs engineering, enlightens homeland security, and promotes humanity.

Over the 6 weeks, DaChawn worked with the VMASC project team to characterize resilience as a concept, and develop typologies of resilience. DaChawn also participated in several activities and events where he engaged with various resilience stakeholders. These experiences include:

- Observer at the Homeland Security Planners Course conducted by the Joint Forces Staff College/National Defense University and hosted by ODU
- Note taker and participant at the RISE Coastal Community Resilience Challenge (https://riseresilience.org/rise-resilience-challenge/) and the MIT SOLVE Coastal Communities Challenge (https://solve.mit.edu/challenges/coastal-communities)
- Coastal Resilience Tournament for the Lower Virginia Peninsula hosted by the Virginia Silver Jackets

DaChawn's reflections about his research experience are available on the project's website: https://sites.wp.odu.edu/odudhscrcproject/

(DaChawn Kincaid and Dr. Joshua Behr)



(DaChawn Kincaid during coastal shoreline visit, at location where business was destroyed by the 1962 Ash Wednesday Storm, prior to the NFIP)

(DaChawn Kincaid taking notes during the RISE Coastal Community Resilience Challenge)

3. Results:

Project outcomes:

(a) Connections to end users
Introduced port, maritime and emergency management stakeholders and end users into CRC activities via the Maritime Risk Symposium.
Hosted live and virtual stakeholder engagement forums for Don Resio to present his research to and solicit feedback from potential end users.

(b) Support of 2 Coastal Resilience Center projects.
Organized a panel for the Maritime Risk Symposium that addresses "Integrating Maritime and Costal Resilience" for November 2016.
Supported stakeholder engagement and end user efforts of '*The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency' project through connecting Don Resio to the Hampton Roads Adaptation Forum.*

(c) Collaborative research project on socio-ecological resilience
Participated in interdisciplinary, multi-institutional research project (NSU and ODU) that included faculty, and undergraduate and graduate students. This project built an interdisciplinary community of scholars.

(d) Support for CRC educational projects
Participated in RETALK and hosted a SUMREX student.

(e) Participation in Coastal Resilience Center activities and engage with CRC and projects.

4. End Users and Transition Partners:

The ODU team has a long and successful track record of working closely with stakeholders in the co-design of research and the co-creation of practice-relevant knowledge. This "tried-and-true" approach was used in the project to engage stakeholders and potential end users.

Outside partners and organizations include:

- Hampton Roads Sea Level Rise Preparedness and Resilience Intergovernmental Planning Pilot Project which includes a range of federal agencies involved in a whole-of-community and whole-of-government approach to resilience. Larry Atkinson, Michelle Covi, and Wie Yusuf were actively involved in the Pilot Project and served on the Science, Citizen Engagement, and Land Use Planning working groups, respectively.
- Hampton Roads Sea Level Rise/Flooding and Adaptation Forum organized by Michelle Covi, Larry Atkinson and the HRPDC provides quarterly stakeholder forums that engage government and private sector actors from planning, emergency management, public works, etc.
- Hampton Roads Planning District Commission, the MPO-equivalent for the Hampton Roads region has strong connections with the project team.
- 17 urban and rural municipalities in the Hampton Roads region including the City of Norfolk, City of Virginia Beach, City of Portsmouth, and Gloucester County.
- Hampton Roads All Hazards Committee and local emergency management

Through the Maritime Risk Symposium, the following end-users directly participated as panelists:

- Jim Redick, Director of Emergency Management, City of Norfolk, VA.
- RADM Ann Phillips, U.S. Navy (Ret.)
- Kit Chope, Vice President, Sustainability, The Port of Virginia
- CAPT Richard Wester, Commander, U.S. Coast Guard Sector Hampton Roads

We co-organized the panel with LCDR Blair Sweigart, Operations Research Analyst, U.S. Coast Guard.

During the panel, the end-users highlighted challenges faced by the Hampton Roads region in terms of coastal and maritime issues. They also discussed some of the Hampton Roads resilience projects they have been involved in, including the Intergovernmental Pilot Project, and the partnerships they have participated in to build coastal and maritime resilience. By connecting stakeholders in maritime and port sectors with stakeholders in emergency management and resilience, the project supported efforts to address risk and improve coastal resilience in an integrated way. By bringing these issues to a wider audience through the Maritime Risk Symposium, the project increased the visibility of such issues and their connectivity to other related risk and resilience concerns.

The July 2016 Hampton Roads Adaptation Forum on the topic of Sea Level Rise and Flooding Science included participation by the following end-users as presenters:

- NOAA National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS)
- NOAA National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS)
- Senior Hydrologist, National Weather Service, Wakefield Office

- Coastal Hazards Specialist, NOAA Office for Coastal Management

Over 80 stakeholders and end-users attended the Hampton Roads Adaptation Forum to hear from Don Resio and ask questions about Don Resio on 'Risk of Extreme Events.' End users (and their organizations) included:

Michael	Anaya	City of Chesapeake Planning Department
Josh	Balisteri	Ecology and Environment
		USGS
Don	Berchoff	True Weather Solutions
Charles	Bodnar	City of Virginia Beach, DPW-Engineering
Justin	Burris	City of Norfolk
Shanda	Davenport	City of Virginia Beach
Stephen	DeVilbiss	DEQ
Gina	DiCicco	Virginia Department of Conservation and Recreation
Robin	Dunbar	Elizabeth River Project
Christy	Everett	Chesapeake Bay Foundation
		USACE, Norfolk District
Gregory	Haugan	Northumberland Assoc for Progressive Stewardship
Gayle	Hicks	City of Hampton
John	Horne	James City County
Shereen	Hughes	Wetlands Watch
Kim	Hummel	Isle of Wight County
Caleb	Hurst	Clark Nexsen
		NOAA Coastal Storms Program
Whitney	Katchmark	HRPDC
Heather	Kerkering	MARACOOS
Scott	Kudlas	DEQ
Ronald	Lovell	Hampton Roads REALTORS® Association
Tavorise	Marks	VDEM
Robert	Martz	Hampton Roads Sanitation District
Elizabeth	Mayo	Verizon Wireless
Ben	McFarlane	HRPDC
Tom	McNeilen	McNeilen and Associates
		US Navy
Mohammad	Shar	City of Newport News
David	She	ASCE
Mark	Slauter	VDEM
Brian	Swets	City of Portsmouth
Dave	Pryor	Clark Nexsen
Brian	Batten	Dewberry
Jenny	Reitz	HRSD
		NOAA/ Chesapeake Bay

(Note: This is not a complete list of attendees)

More information about the Hampton Roads Adaptation Forum is available here: https://sites.wp.odu.edu/HRAdaptationForum/the-latest-in-sea-level-rise-and-flooding-science/

In October 2017 the ODU team conducted a web-based Hydro-Surge Flood Modeling Focus Group that included the following end users in local emergency management, stormwater engineering and floodplain management:

- Greg Johnson, City of Virginia Beach
- Shanda Davenport, City of Virginia Beach
- Jim Reddick, City Norfolk
- Kyle Spencer, City of Norfolk
- Deva Borah, City of Chesapeake
- Brian Swets, City of Portsmouth
- Meg Pittenger, City of Portsmouth

The involvement of end-users in this project facilitated flood modeling that incorporates different risks and that are more strongly connected to the needs of end users.

In November 2016, the ODU team hosted Dr. Rachel Davidson (Univ. of Delaware) to present a lecture as part of the Center for Coastal and Physical Oceanography (CCPO)/ODU Resilience Collaborative (ODU-RC) Seminar Series. Her seminar title was 'An Integrated Scenario Ensemble-based Hurricane Evacuation Modeling Framework.'

In March 2017, the ODU team hosted Dr. Billy Sweet (NOAA National Ocean Service). Dr. Sweet gave a lecture titled **'Trends, Patterns and Scenario-based Projections of Relative Sea Level and Tidal Flood Frequencies along the US East Coast' as part of the CCPO/ODU-RC Seminar Series.**

End-users attending the seminars by Dr. Davidson and Dr. Sweet included regional planners from the Hampton Roads Planning District Commission, City of Virginia Beach, and City of Portsmouth. The seminars were open to the public and also available via WebEx. Recordings of the lectures are available here: http://vs.odu.edu/kvs/interface/?cid=201530_CCPOSeminarSeriesVS_96096

Following the seminar by Dr. Sweet, we hosted a 3-hour Roundtable Discussion for end-users to have a technical discussion with Dr. Sweet and the ODU research team about the needs of regional stakeholders with respect to nuisance and recurrent flooding and similar topics of interest. Representatives from the Hampton Roads Planning District Commission, National Weather Service, and local cities participated in the Roundtable Discussion.

For the NSU-ODU collaborative research project, we connected with end-users from the City of Portsmouth (Meg Pittinger, Environmental Manager and Brian Swets, Planning

Administrator) to ensure that our research is relevant to the needs of the city and the communities served.

For the SUMREX internship, the student engaged with various stakeholders including those from nonprofit organizations, businesses, local government emergency management, US Coast Guard, Navy, Customs and Border Patrol, Virginia Defense Force.

5. Project Impact:

The focus of our efforts was on engaging stakeholders and involving potential end users in CRC projects. For 'The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency' project, the involvement of end-users facilitated flood modeling that incorporates different risks and that are more strongly connected to the needs of end users. Since end-users can provide input into development, such as by specifying how they would use modeling information or what risks they want incorporated into the models, they are more invested in using the models that they will be better tailored to their needs.

Through our panel at the Maritime Risk Symposium, we introduced port, maritime and emergency management stakeholders and end users into CRC activities. By connecting stakeholders in maritime and port sectors with stakeholders in emergency management and resilience, we were able to support efforts to address risk and improve coastal resilience in an integrated way. By bringing these issues to a wider audience through the Maritime Risk Symposium, we raised the visibility of such issues and their connectivity to other related risk and resilience concerns.

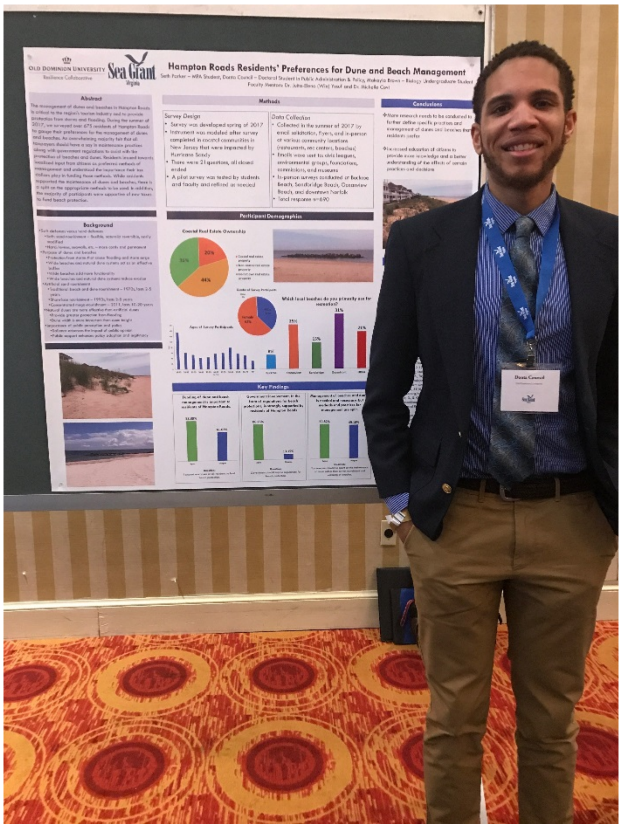
Through the NSU-ODU collaborative research project and the SUMREX student internship, we involved faculty and students from minority-serving institutions in the research and practice of coastal resilience. As a result, we built an interdisciplinary community of scholars that have diverse backgrounds and perspectives.

6. Student involvement and awards:
    - Three NSU undergraduate students participated in the NSU-ODU collaborative research project. The students presented their research on July 28, 2017. A recording of the complete presentation is available at: http://vs.odu.edu/kvs/interface/?cid=201620_ResilienceCollaborativeVS_90690
    - Individual student presentations:
        - Raisa Barrera (http://www.kaltura.com/tiny/mulfo)
        - Bryan Clayborne (http://www.kaltura.com/tiny/ofk1f)
        - Mikel Johnson (http://www.kaltura.com/tiny/lgl7g)

- Two ODU graduate students participated in the NSU-ODU collaborative research project. The students presented their research on July 28, 2017.
    - Donta Council, Doctoral student, Public Administration and Policy – 'Sea Level Rise, Perceptions, and Adaption Responses of Residents in Portsmouth, VA' (http://www.kaltura.com/tiny/ld4jv)

– Isaiah Amos, Master’s student, Ecological Sciences – ‘Micropropagation of Salt Tolerant Ornamentals and Grasses in Flood Prone Locales’ (http://www.kaltura.com/tiny/pzsid)

Donta Council is a BAF Fellow (associated with the William Averette Anderson Fund) and is program chair of the BAF Fellows Executive Committee. He is also an SREB Scholar. Donta presented his research on ‘Hampton Roads’ Residents Preferences for Dune and Beach Management’ at the Virginia Sea Grant Graduate Symposium in February 2018.



(Donta Council presented his poster at the Virginia Sea Grant Graduate Symposium)

One undergraduate student from Tougaloo College, DaChawn Kincaid, participated in the SUMREX program at ODU. DaChawn, a rising junior, is majoring in Sociology and plans to minor in Disaster Coastal Studies. DaChawn’s reflections on his summer experience is available at: https://sites.wp.odu.edu/odudhscrcproject/2018/06/27/sumrex9/

7. Interactions with education projects:

- Dr. Wie Yusuf gave RETALK presentations for Johnson C. Smith University students titled ‘‘Lessons Learned the Hard Way and Tales of Engagement… 5 Things You Need to Know About Stakeholder Engagement’ (October 2016) and ‘Applying ASERT Tools for Addressing Coastal Resilience’ (March 2018).

- Graduate student Donta Council was guest speaker at Tougaloo College's Interdisciplinary Minor Disaster Coastal Studies Research Symposium. His presentation was on 'Understanding Decision Making and Risk Perceptions of Sea Level Rise and Flooding.'
- From May 14, 2018 through June 22, 2018 we hosted a SUMREX student from Tougaloo College.

8. Publications: n/a

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type (e.g., software, guidance document)	Delivery Date	Recipient or End User
N/A			

Table 2A: Documenting External Funding

Title	PI	Total Amount	Source
Assessing Current and Future Risk Posed to Structural Assets at Norfolk International Terminal South Stemming from Sea Level Rise and Severe Storm Inundation	Behr	$68,000	Commonwealth of Virginia (Port of Virginia)
Assessment of Tourism Industry Resilience	Yusuf & Covi	$30,000	Commonwealth Center for Recurrent Flooding Resiliency
Hampton Roads Adaptation Forum	Covi	$15,000	NOAA
Virginia Sea Grant Climate Adaptation and Resilience Program	Covi & Yusuf	$113,228	Virginia Sea Grant
Community Engagement in Virginia Beach	Covi & Yusuf	$32,760	City of Virginia Beach
Tourism Resilience Workshops	Covi & Yusuf	$28,235	Commonwealth Center for Recurrent Flooding Resiliency
Flooding Risk Communications Best Practices and Demonstration Project	Covi & Yusuf	$39,000	Commonwealth Center for Recurrent Flooding Resiliency

Factors that Influence Flood Mitigation Behaviors in Portsmouth, VA	Covi & Yusuf	$6,000	Virginia Environmental Endowment

Table 2B: Documenting Leveraged Support

Description (e.g., free office space; portion of university indirects returned to project; university-provided student support)	**Estimated Total Value**
Office and meeting space, telecommunication services	$7,000
Guest speakers and engagement events (CCPO/ODU-RC Speaker Series, Roundtable discussions)	$4,500
Hampton Roads Adaptation Forum corporate support	$3,000
Outreach support through Virginia Sea Grant Climate Adaptation and Resilience Program	$6,000
Student hours	$3,000

Table 3: Performance Metrics:

YUSUF PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	Year 3 (7/1/17- 6/30/18)
HS-related internships (number)	0	0	0
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	0	0	0
Graduate students provided tuition/fee support (number)	0	0	0
Graduate students provided stipends (number)	0	2	0
Undergraduates who received HS-related degrees (number)	0	0	0
Graduate students who received HS-related degrees (number)	0	0	0
Graduates who obtained HS-related employment (number)	0	0	0
SUMREX program students hosted (number)	0	0	1
Lectures/presentations/seminars at Center partners (number)	0	1	1
DHS MSI Summer Research Teams hosted (number)	0	2	0
Journal articles submitted (number)	0	0	0
Journal articles published (number)	0	0	0
Conference presentations made (number)	0	0	1
Other presentations, interviews, etc. (number)	0	0	1
Patent applications filed (number)	0	0	0
Patents awarded (number)	0	0	0
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	1	0
Requests for assistance/advice from other agencies or governments (number)		5	5
Total milestones for reporting period (number)	0	17	13
Accomplished fully (number)	0	15	11
Accomplished partially (number)		2	2
Not accomplished (number)		0	0

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Continued participation in CRC activities	June 2018	100%	
Participate in CRC annual meeting	February 2018	100%	
Summer Research Team (SRT) for Minority Serving Institutions			
Present research findings to ODU and NSU community, and end-users	July 2017	100%	
Conclude multi-institutional research project with Norfolk State University (NSU)	July 2017	100%	
Research report to ORNL, CRC	September 2017	100%	
Present and publish research results	June 2018	0%	NSU team awarded follow on funding to complete the project. Presentations and publications are on hold until the follow-on research is completed.
SUMREX Student			
Arrange SUMREX experience with Tougaloo College PI Dr. Laiju	April 2018	100%	
Identify research project and faculty mentor for SUMREX student	April 2018	100%	
Arrange travel and housing logistics for SUMREX student	April 2018	100%	
Research Milestones			
Host SUMREX student	July 2018	100%	
Conclude SRT research collaboration and reporting	September 2017	100%	

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Stakeholder engagement and end user translation efforts of '*The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency' project.*			
Organize and host stakeholder and end user forums for model utility and application	January 2018	100%	
Develop template of vulnerability analysis	April 2018	0%	Activity put on hold pending DHS review and waiting on information from PI Don Resio
Organize and host stakeholder and end user forums for feedback on vulnerability analysis template	May 2018	0%	Activity put on hold pending DHS review and waiting on information from PI Don Resio
Transition Milestones			
Host stakeholder and end user forums for '*The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency' project*	July2018	50%	Only one forum was hosted. Additional forum put on hold pending DHS review and information from PI Don Resio

Theme 3

Disaster Dynamics

BLANTON – UNC/RENCI
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: A multi-tiered ADCIRC-based storm surge and wave prediction system

Principal Investigator Name/Institution: Brian Blanton, Renaissance Computing Institute, UNC-Chapel Hill

Co-Principal Investigators and Other Partners/Institutions:

- Rick Luettich, Institute of Marine Sciences, UNC-Chapel Hill, co-PI
- Jason Fleming, Seahorse Coastal Consulting, ASGS developer, ADCIRC Bootcamp organizer
- Crystal Fulcher, Institute of Marine Sciences, UNC-Chapel Hill, ADCIRC grid development
- Jess Smith, Master's student, UNC-Chapel Hill, Department of Marine Sciences. (100%, as of May 1, 2017)

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description ("elevator speech"): Decision makers need critical and helpful information delivered on time and in formats that are easily understandable. This is particularly true with dangerous and destructive natural hazards such as hurricanes and the resulting wind, storm surge, and wave impacts. Late and/or incomprehensible information is useless. This DHS CRC project is about reducing the time needed to deliver hazard information to end users by using advanced models for storm surge, very high-performance computing resources, and education and training of end-users interested in using these state-of-the-art models and tools.

Summary Abstract: This project enhances and extends a multi-tiered, ADCIRC-based storm surge and wave prediction system covering the US East Coast with highest resolution in North Carolina (NC). The overall objective is to provide real-time guidance information for active tropical cyclones impacting US coastal waters. The primary computational tool is the ADCIRC storm surge, tide, and wind wave model, in both its direct application and as it is used within the ADCIRC Surge Guidance System (ASGS). ASGS provides fully dynamic, deterministic, highly accurate ADCIRC-based storm surge and wave predictions ~1-2 hrs following the release of meteorological forecasts.

PROJECT NARRATIVE:

1. Research Need:

Our research and application activities in this project directly address many of the goals of Mission 5, which is to *Strengthen National Preparedness and Resilience*. Over the course of the previous DHS/CHC and CRC projects, we have extended the reach of ADCIRC-based coastal hazards assessment capabilities by improving the model's physics, output product and format options, web-based accessibility, and techniques that can "accelerate" the availability of ADCIRC results. These extensions and enhancements are essential in aiding decision makers in both pre- and post-disaster efforts and will continue to leverage experiences with end users such as coastal emergency managers, FEMA coastal risk groups, and the US Coast Guard (Goals 5.1-5.4). This project forms the core of CRC modeling activities that are advancing the awareness of, and familiarity with, ADCIRC-based research and applications in North Carolina, with broad applicability to other states and regions, as well as other hazards. This CRC project will *advance* these efforts and provide DHS and the ADCIRC community with new capabilities for both real-time decision-making information and educational tools (Goals 5.1, 5.3). A better understanding of storm impacts on coastal environments is essential to reducing risks, both now and in the future (Goals 5.2, 5.3). This includes better, more accurate, and more timely predictions (Goal 5.3) of natural hazards to enhance pre- and post-storm emergency response activities (Goal 5.3). Our education and end-user training activities such as the ADCIRC Boot Camp and Users Group Meeting enable users to develop information for decision-makers and thus enhance preparedness (Goal 5.1) to storm surge hazards and risks.

2. History:

From the outset, this project has built upon prior work in the DHS CHC, with two main threads of activity: **operation** of the ADCIRC Surge Guidance System (ASGS) for computing real-time storm surge predictions; and **research** into statistical approaches for storm surge estimation and hurricane track probabilities.

The development, application, and operation of the ASGS by J. Fleming of Seahorse Coastal Consulting (SCC) has continued, attracting more users that need to provide real-time storm surge results to end users and decision makers further down the line. The ASGS-related activities included the holding of the ADCIRC Boot Camp and Users Group meetings. These events are one of the key transition points for users of ADCIRC and ASGS to get up to date on recent advances, learn about the research and applications of other users, and to educate and train new users (the primary target of the Boot Camps).

The 2017 Atlantic Hurricane season proved to be very active, with Hurricanes Harvey, Irma, and Maria causing substantial damage and losses in the southeast US and Caribbean Islands. The ASGS system provided high-resolution guidance information to end-users, including the US Coast Guard, FEMA, local emergency management groups, and the National Hurricane Center. We have seen large growth in the accesses to the nc-cera.renci.org website, which has motivated a major investment in new hardware to support the ASGS/CERA system (noted below in the leveraging section) and performance analyses of the web site infrastructure. We are now better prepared, with more robust hardware and software, for the 2018 season.

Research has focused on statistical approaches for storm surge prediction using pre-existing ADCIRC data sets and for developing probabilistic hurricane tracks based on prior errors in hurricane track and intensity predictions. Regarding storm surge predictions, the original concept was to use the large dataset of ADCIRC simulations for the recent coastal flood insurance study in North Carolina and implement the response surface method detailed in Taflanidis et al (2013)♣. We implemented this method and developed a web-based "dashboard" (Figure 1) for accessing the approach (http://dashboards.renci.org:3000). We have noted in prior progress reports that the appropriate sampling of the hurricane parameter distributions is critical to the effective use of a response surface approach, and that the random sampling of the landfall location in the North Carolina FEMA dataset causes significant interpolation issues. As a result, we computed a new data set with even distribution sampling, but on a coarser ADCIRC grid, resulting in a dataset with about 10,000 simulations.

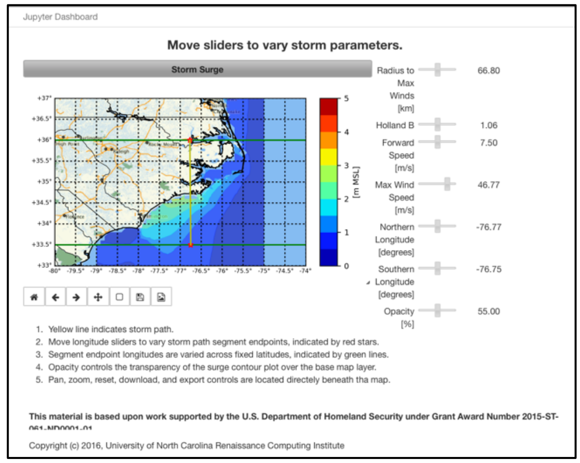


Figure 1: ADCIRC Lite Dashboard

The hurricane track probability research has focused on development of tracks that represent uncertainty in the near-term evolution of the storm. Led by a Master's student Jessica Smith, tools have been developed that generate a suite of storm tracks, given a forecast from the NHC, that could be used in the ASGS system to provide its ensemble members. Ms. Smith's Master's thesis will be submitted to the Journal of Marine Science and Engineering Special Issue on Coastal Hazards Related to Water, guest edited by Rick Luettich.

One of the main conferences in the coastal hazards community is the American Meteorological Society's Annual Meeting, typically in January or February. This project participated in the AMS's 16th Symposium on the Coastal Environment, with the following research and applications presentations:

- Probabilistic Track Generation for Hurricane Storm Surge Estimates. **Jessica L Smith**, Univ. of North Carolina, Chapel Hill, NC; and B. Blanton and R. Luettich.
- Assimilation of Observed Water Levels into Storm Surge Model Predictions. **Taylor Asher**, Univ. of North Carolina, Chapel Hill, NC; and R. Luettich, J. G. Fleming, and B. Blanton.
- The ADCIRC Surge Guidance System for Coastal Zone Decision Support. **Jason G. Fleming**, Seahorse Coastal Consulting, Morehead City, NC; and R. Luettich, M. E. Agnew, C. Kaiser, N. Dill, and Z. Cobell.

Finally, as the 2018 Atlantic Hurricane season approached, we spent the last six months of the Y3 period preparing for an active tropical season. In addition to the ASGS training activities at

♣ Taflanidis et al, (2013). Rapid assessment of wave and surge risk during landfalling hurricanes: Probabilistic approach, *Journal of Waterway, Port, Coastal, and Ocean Engineering*, **139,** 171–182.)

the 2018 Boot Camp, we have: 1) deployed ASGS onto different computer systems that will help increase computing capacity if needed; and 2) installed and configured 4 new computer servers at RENCI to support CERA-related activities.

3. Results:

The ASGS-related aspects of this project have several important results and outcomes. Most prominently is the impact that ASGS-driven storm surge and wave guidance products have had on decision-makers. Over the past 3 years, J. Fleming has conducted training classes, hands-on tutorials, and similar engagements with end-users and decision makers who use ADCIRC/ASGS/CERA-related products. The ADCIRC Boot Camps have attracted increasing numbers of participants over the past three years. Course offerings have also been extended into areas such as ADCIRC grid development and visualization approaches and tools, and ASGS for emergency managers and decision makers (which focuses more on how to interpret the graphical output of the system, as opposed to running the ASGS software itself).

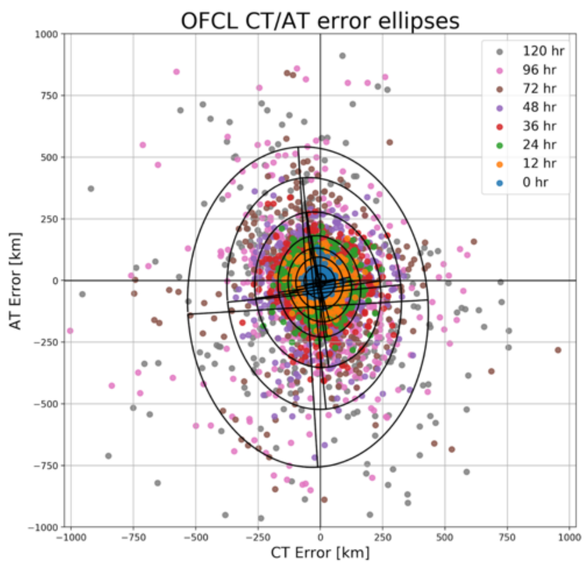


Figure 2. ATE/CTE error ellipses over the period 2011-2015. Major and minor ellipse axes show the variance in the along- and cross-track directions. The center of each ellipse is the mean error for that time level. The color dots are the individual errors for each time level.

The probabilistic track statistical research has resulted in an improved understanding of the level at which hurricane forecast track error distributions need to be sampled to achieve a specified level of along-shore "accuracy" in a probabilistic assessment of predicted storm surge levels. This work extends that of Davis et al (2011)♥ by including intensity as a variable through the maximum wind speed. The number of tracks needed is a function of several factors, including the time to landfall (longer time to landfall requires more tracks, due to the inherent uncertainty in track direction) and the storm's radius (larger storms need fewer tracks to resolve along-coast spacing). We do not yet have a fully developed expression for estimating the needed number of tracks based on a specific storm's characteristics. That is a future activity. The statistical analysis of the NHC's OFCL (official) forecast error data shows several interesting features. Table 1 reports the mean and standard deviations of the OFCL errors over the 2011-2015 Atlantic hurricane seasons. The error components are the along- and cross-track errors (ATE and CTE) and the error in the forecast maximum wind speed (Vmax), for the usual forecast lead times of 0, 12, 24, 36, 48, 72, 96, and 120 hours. Regarding the spatial error (ATE and CTE), there is an increasingly negative error in both components, indicating that forecast storm centers slide behind and to the left of the verified best-track locations. In other words, the forecast storms are increasingly slower and "to the left" of the true storm centers. This can be

♥ Davis et al. (2010). Toward the probabilistic simulation of storm surge and inundation in a limited-resource environment, *Monthly Weather Review*, 138/7, pp. 2953-2974.

more easily seen in Figure 2, which shows the corresponding error ellipses. In this context, the ellipse axes correspond to the +/- 1 std dev of the error, which is how the NHC defines their cone of uncertainty. The Vmax data shows that the forecast maximum wind speed error does not have an obvious trend toward *increasing* errors. If anything, its magnitude gets smaller as the lead time increases, although the *variance* does increase in the first 48 hours, then flattens out beyond that. The importance of this is not particularly clear and may not be statistically significant.

Table 1 Forecast errors for NHC OFCL forecasts, over the period 2011-2015.

	Mean			Std. Deviation		
Time	ATE	CTE	Vmax	ATE	CTE	Vmax
[hr]	[km]	[km]	[m/s]	[km]	[km]	[m/s]
0	-0.5	0.4	-0.8	17.9	14.2	1.9
12	-9.6	-3.4	-0.7	44.1	40.3	3.9
24	-20.9	-6.0	-0.7	70.0	61.2	5.6
36	-32.1	-7.2	-0.5	99.7	84.5	7.0
48	-44.5	-11.4	-0.4	140.6	113.6	8.1
72	-72.1	-22.8	-0.6	206.0	180.9	9.7
96	-98.5	-47.0	-0.1	306.0	252.3	10.0
120	-176.8	-65.7	0.5	399.2	352.8	9.5

This dataset consists of storm surge levels for a population of probable hurricanes, with cyclone parameters determined using a joint probability approach to sample distributions of the observed parameters (radius to maximum winds, central pressure deficit, etc). For the FEMA study, the computational load was substantially reduced by randomly sampling the landfall location of the cyclones. For the intended purposes of the FEMA coastal flood insurance study, this is appropriate because, for larger storms that contribute more to low-frequency water levels (such as the 1% or 0.5% annual exceedance levels), the storms' radii are large enough to fill in unevenness in landfall location. However, for general interpolation problems, where it is necessary to compute a weighted response from a set of "nearest" neighbors, the interpolated results can be unexpected.

4. <u>End Users and Transition Partners:</u>

End users and decision makers have been substantially involved in the ASGS-related activities led by J. Fleming. Below, we list the key partners, with additional information on these and other contacts provided in an Appendix.

- NWS Morehead City, North Carolina Weather Forecast Office, coordinator for storm surge activities for the entire NWS
- Ignacio Harrouch, Director of Operations, Louisiana Coastal Protection and Restoration Authority (CPRA)
- New Orleans District of US Army Corps of Engineers
- Tom Langan, NC Division of Emergency Management
- Lora Eddy, The Nature Conservancy
- NWS Warning Coordination Meteorologists in Houston and Corpus Christi

- FEMA HQ
- US Coast Guard search-and-rescue (SAROPS)
- NOAA Coast Survey Development Lab
- Gordon Wells, UT Center for Space Research

Organizations that have participated in transition activities include:

- South Florida Water Management District, at their request.
- North Carolina Association of Flood Plain Managers, Atlantic Beach, NC, Apr 2017.
- NC Division of Emergency Management, routine/frequent interactions
- North Carolina Beach Inlet and Waterway Association, Wrightsville Beach, NC, Nov 2017.
- Corpus Christi National Weather Forecast Office, Jan 2018.
- Harte Research Institute (HRI) at Texas A&M, Corpus Christi, TX, Jan 2018.
- Seattle District of the US Army Corps of Engineers, Jun 2018.

Transition of technical and operational outcomes occur routinely by email and listserv activity, as well as by presentations on the state of ASGS at AMS, the ADCIRC Boot Camp and Users Group meetings, and continuous outreach and "marketing" by J. Fleming. He has also traveled extensively to end-user locations to provide training, tutorials, and hands-on activities, and frequently holds virtual meetings with end users, decision makers, scientists and researchers to convey and discuss ASGS results and capabilities. Transition of the probabilistic track research has been primarily through posters and presentations at the AMS annual meetings by Ms. Jessica Smith. We are currently working on turning the research software into more general user-friendly python code to be hosted in GitHub.

As a last example of end user connections, RENCI, IMS, SCC, and CRC PI Dietrich have had many discussions with the North Carolina Department of Emergency Management (NC-DEM) about how ADCIRC products and related CRC-funded activities could be used by them in their flood forecasting framework. NC-DEM is led by John Dorman, with whom RENCI and IMS conducted the recent coastal Flood Insurance Study statistical analysis for updating the North Carolina digital flood insurance rate maps. Tom Landon, the engineering supervisor for the Risk management Section of NC-DEM, has been our primary contact throughout the years. While there has always been much interest on the state's part for leveraging our activities, specific funding mechanisms have not been clear, until recently. The state would like real-time guidance information and ensemble specification beyond what is currently available in the ASGS implementation for North Carolina. They also would like the Enhanced Resolution product (developed at CRC PI Dietrich and his Master's student N. Tull at NCSU) available in real-time. We are currently (July 2018) working through the final stages of this contract, which specifies a per-storm-event cost for ASGS simulations and provides support for implementing the Enhanced Resolution product in the ASGS workflow. In anticipation of this contract for ASGS services, we have installed and tested the ASGS system with the high-resolution North Carolina grid on a commercial High-Performance-Computing (HPC) provider called Penguin Computing. This represents the first commercial contract-for-services for ASGS outputs that will support both CRC and SCC time and effort.

5. Project Impact:

As detailed above, there are several aspects to this ADCIRC-based CRC project. At the technical/operational level, we continue to develop and extend the ASGS forecasting framework, the primary activity of Seahorse Coastal Consulting. Dr. Fleming has also developed extensive curricula for education and training activities for ADCIRC and ASGS, and these have been used at recent ADCIRC Annual Meetings and Boot Camps. Dozens of graduate students, post-docs, and early career professionals attended the 2017 and 2018 Boot Camps (Figure 3) in Norwood, MA and College Park, MD. This constitutes a broad group of "end-users" of the software and technology developed, maintained, and supported by DHS via this project.

Figure 3. Dr. J. Fleming (Seahorse Coastal Consulting) conducting a training session at the 2018 ADCIRC Boot Camp.

Coastal decision-makers are using ASGS/ADCIRC results much more frequently, as evidenced by the transition and outreach activities described in the accompanying appendix and below. We highlight a few of these interactions here.

- **June 2016**, J. Fleming visited the **Texas Department of Emergency Management** (TDEM), National Weather Service (NWS) Regional Operations Center (ROC), and NWS West Gulf River Forecast Center (WGRFC) at the Texas State Operations Center (SOC) in Austin, Texas. TDEM expressed particular interest in the high-resolution model guidance available from ADCIRC/ASGS, and this group uses ADCIRC results more routinely in their decision-making framework more often. CRC PI Clint Dawson also participated in this interaction.
- **November 2017**, J. Fleming held a virtual meeting with **NWS Warning Coordination Meteorologists in Houston and Corpus Christi** including John Metz, MIC Tom Johnstone, and Dan Reilly to review ADCIRC wind and storm surge performance during Harvey. They described their success in validating the guidance after the storm with measured data and their interests in future capabilities.
- **January 2018**, J. Fleming Site visit to **Coast Guard Sector Houston-Galveston** in Houston, Texas to discuss the use and value of ADCIRC model guidance to the Coast Guard in general and Sector Houston-Galveston in particular. One specific outcome of this meeting was that the value of ADCIRC guidance to the US Coast Guard is exclusively focused on consequences for search-and- rescue and oil/chemical spills.

- **April 2018**, J. Fleming and C. Kaiser (a CRC PI and developer of the CERA system) visited with stakeholders at **FEMA HQ** to discuss the use of ADCIRC guidance during the 2017 hurricane season and ways to make direct connections between technical ADCIRC experts and FEMA stakeholders in future hurricane seasons.

6. Student involvement and awards:

This project involved two Master's-level students in ADCIRC-related research and applications. Mr. Stephen Kreller, a student at LSU of CRC-funded Barry Keim, visited RENCI in the summer of 2017 to learn about the ADCIRC model, how to run it and analyze its output, and how to more generally carry research computations. This was done through SUMREX funding. He returned to LSU and has continued to use ADCIRC in his research into storm surge impacts on the Louisiana coast. Ms. Jessica Smith, a Master's student in the Department of Marine Sciences at UNC-Chapel Hill of Rick Luettich, was supported by this CRC project. She conducted research into computing probabilistic hurricane tracks for potential use in ASGS or other applications where uncertainty in hurricane path/intensity and resulting storm surge needs to be accounted for. During her research, she presented results in the American Meteorological Society's annual meetings, in both 2017 and 2018. She successfully defended her Master's thesis in December 2017, entitled "Probabilistic Hurricane Track Generation for Storm Surge Prediction".

- Smith, J. December 2017. Probabilistic Hurricane Track Generation for Storm Surge Prediction. Master's Thesis, UNC-Chapel Hill, Department of Marine Sciences.
- Smith, J., Blanton. B., and Luettich, R. 2018. Probabilistic Hurricane Track Generation for Storm Surge Prediction. Presented at the American Meteorological Society 2018, Austin, TX.

7. Interactions with education projects:

This project has not directly engaged with CRC Education projects. However, we have worked with several graduate students, and we consider the ADCIRC/ASGS Boot Camp and Users Group meeting venues as critical points of education, outreach, training, and transition. In addition to extending the reach of ADCIRC and ASGS through this project's end users and forums such as the ADCIRC Annual meeting and Boot camps, one key to long-term development and sustainability of these activities is to engage with future researchers and end-users at the educational level. Indeed, this is a core part of the RENCI mission, and RENCI enthusiastically participates in these opportunities with DHS/CRC. In the summer of 2017, RENCI hosted a summer internship in conducting coastal hazards research with ADCIRC. This included in-depth experiences that range from setting up ADCIRC, high-performance computing, and statistical methods for risk assessment. Through the DHS Summer Research Team Program for Minority Serving Institutions, Dr. Anton Bezuglov and undergraduate student Reinaldo Santiago from Benedict College in Columbia, South Carolina, spent the 2016 summer at RENCI. Dr. Bezuglov is a computer scientist with expertise in "expert systems", a branch of artificial intelligence research targeted at emulating the human decision-making process. He and Mr. Santiago were in residence at RENCI to implement an artificial neural network for storm surge prediction using the same ADCIRC storm surge database used for the ADCIRC_Lite response surface research. This complemented and extended our current knowledge about rapid forecasting methods. Drs. Bezuglov and Blanton have continued to work on machine learning techniques as applied to hurricane-related problems, with a change in focus to hurricane track simulations to be consistent with the probabilistic track research described above. The goal is to conduct enough background research to pursue new funding opportunities.

8. Publications:

- Thomas, A., J. Dietrich, T. Asher, M. Bell, B. Blanton, J. Copeland, A. Cox, C. Dawson, J. Fleming, and R. Luettich (2018). Influence of Storm Timing and Forward Speed on Tides and Storm Surge during Hurricane Matthew (2016). Submitted to *Ocean Modelling*.
- Smith, J. December (2017). Probabilistic Hurricane Track Generation for Storm Surge Prediction. Master's Thesis, UNC-Chapel Hill, Department of Marine Sciences.

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
ASGS	Software	ongoing	ADCIRC forecasting and real-time users
ASGS	Training, tutorials	ongoing	ADCIRC/ASGS operators, end-users/decision-makers

Table 2A: Documenting External Funding

Title	**PI**	**Total Amount**	**Source**
Real Time ADCIRC Model Guidance for Louisiana CPRA (cooperative Contract to SCC)	J. Fleming	$45,000	LACPR
Coupling the National Water Model to the Coastal Ocean for Predicting Water Hazards	B. Blanton	$890,000	NOAA/IOOS

Table 2B: Documenting Leveraged Support

This project, as in several DHS-funded projects in the previous Center of Excellence, is based at the Renaissance Computing Institute (RENCI), a long-term partner with Rick Luettich, DHS, FEMA, and Seahorse Coastal Consulting. RENCI has provided substantial cyberinfrastructure resources to previous DHS projects involving ADCIRC, including high-performance computing resources, data storage and data management resources, and data servers for delivering and making available ADCIRC/ASGS output to the end user community. RENCI will continue to provide this level of service and support for this new project at no direct cost. We estimate that, at a minimum, this leverage is $75,000 per year, when considering the level of computation involved, storage requirements for the large volume of data, and the personnel involved in maintaining the compute resources and helping debug ASGS runtime issues when they arise. In this year 3 period, RENCI also purchased the hardware noted above to update the CERA-related servers at RENCI. External contributions to ASGS/SCC are estimated by considering support for Users Group and Boot Camp events, travel support to certain meetings from non-CRC sources, and internal SCC travel funding.

Description	Estimated Total Value
Recurring technical/infrastructure support @ RENCI (computer support, compute/storage resources, hardware installation/support) @ 75,000/yr	$225,000
RENCI hardware investment for CERA website infrastructure	$35,000
External contributions to SCC/ASGS activities	$150,000
Total:	$410,000

Table 3: Performance Metrics:

BLANTON PERFORMANCE METRICS

Metric	Year 1 (1/1/16 – 6/30/16)	Year 2 (7/1/16 – 6/30/17)	Year 3 (7/1/17- 6/30/18)
HS-related internships (number)	0	0	0
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	0	0	0
Graduate students provided tuition/fee support (number)	1	1	1
Graduate students provided stipends (number)	1	1	1
Undergraduates who received HS-related degrees (number)	0	0	0
Graduate students who received HS-related degrees (number)	0	0	1
Graduates who obtained HS-related employment (number)	0	0	0
SUMREX program students hosted (number)	0	1	0
Lectures/presentations/seminars at Center partners (number)	1	0	1
DHS MSI Summer Research Teams hosted (number)	1	0	0
Journal articles submitted (number)	0	0	0
Journal articles published (number)	0	0	0
Conference presentations made (number)	2	2	2
Other presentations, interviews, etc. (number)	0	2	4
Patent applications filed (number)	0	0	0
Patents awarded (number)	0	0	0
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	0	0
Requests for assistance/advice from other agencies or governments (number)	0	0	0
Total milestones for reporting period (number)	7	7	5
Accomplished fully (number)	2	2	5
Accomplished partially (number)	3	3	0
Not accomplished (number)	2	2	0

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Complete probabilistic track generator implementation	12/31/2017	100	
Continue operation of ASGS at RENCI	On-going	100	
Test new ASGS features and deployment of the NOAA HSOFS grid at RENCI	12/31/2017	100	
Research Milestones			
Status report on ASGS system upgrades and initial tests with new grid	12/31/2017	100	
Report on probabilistic track generator implementation and initial results (J. Smith's Master's Defense)	12/31/2017	100	
ASGS for NC ready for 2018 Atlantic Hurricane season	01/05/2018	100	

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Attend 2018 American Meteorological Society meeting to present ensemble method development and results	Jan 2018	100	
Develop material on ASGS enhancements and status for ADCIRC user community	3/31/2018	100	
Aide NOAA/CSDL in deploying ASGS prior to the 2018 hurricane season	5/31/2018	100	
Transition Milestones			
Report/presentation on ASGS enhancements and features to ADCIRC User's Group and Boot Camps	April 2018	100	
J. Smith's Master's Thesis on probabilistic hurricane track generation	31/12/2018	100	

DIETRICH, NCSU
DAWSON, UT-AUSTIN
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title:

Improving the Efficiency of Wave and Surge Models via Adaptive Mesh Resolution

Principal Investigator Name/Institution:

Joel Casey Dietrich, Assistant Professor, North Carolina State University

Co-Principal Investigators and Other Partners/Institutions:

Clint Dawson, Professor, University of Texas at Austin

Project Start and End Dates:

1/1/2016 – 6/30-2018

Short Project Description:

Coastal communities rely on predictions of waves and flooding caused by storms. Computational models are essential for making these predictions, but they can be costly. A typical prediction can require hundreds or even thousands of computational cores in a supercomputer, and several hours of wall-clock time. In this project, we will improve the performance of a widely-used, predictive model. Its representation of the coastal environment will adapt during the storm, to better utilize the computing resources and ultimately provide a faster prediction. This speed-up will benefit coastal communities, including emergency managers, who will have more time to make decisions during the storm event. It will also benefit long-range planners, such as flood mappers, who will be able to consider larger, more-accurate models in the same amount of time.

Summary Abstract:

Storm-induced waves and flooding can be predicted using computational models such as the ADCIRC+SWAN modeling system, which has been used by DHS and its constituent agencies for mapping of floodplain flood risk and forecasting of storm surge and inundation. This modeling system has been shown to be efficient in parallel computing environments. It is implemented on static meshes and with a static parallelization, and thus it does not evolve as a storm approaches and inundates a coastal region. This implementation can be inefficient when large portions of the mesh remain dry during the simulation.

In this project, we are optimizing the parallel implementation of ADCIRC by using a large-scale adaptivity, in which a mesh will be refined by incorporating entire portions of another, higher-resolution mesh. Instead of subdividing an individual element, we are increasing resolution by adding elements from a pre-existing mesh that has been well-validated. This procedure leverages the existing suites of meshes for the same geographic region. The adapted mesh is rebalanced among the computational cores so that geographic regions with increased resolution are not concentrated on a disproportionally-small number of cores, and so that the time spent on inactive regions is minimized. These technologies will decrease the computational cost and better utilize the available resources.

This project is developing technologies to improve the efficiency of ADCIRC simulations, thus allowing for more model runs in ensemble-based design applications, and for faster simulations in time-sensitive applications such as operational forecasting. These outcomes will increase the accuracy of flood risk products used in building design and the establishment of flood insurance rates, and thus lessen the impact of a disaster. These outcomes will also improve the communication and understanding of potential hazards.

PROJECT NARRATIVE:

1. Research Need:

The goal of this research project is to speed up the ADvanced CIRCulation (ADCIRC) and Simulating WAves Nearshore (SWAN) models. The tightly-coupled ADCIRC+SWAN modeling system is used extensively by DHS and its constituent agencies for the prediction of storm-induced waves and flooding. We are improving the efficiency of the modeling system, and thus reducing its computational cost. This work is relevant to the DHS mission to ensure resilience to disasters, as articulated in its Strategic Plan and Quadrennial Review, specifically its Goals 5.1 (Objectives 5.1.1 and 5.1.2) to reduce vulnerability and mitigate risks associated with natural hazards, and its Goal 5.3 (Objective 5.3.1) to provide timely and accurate information during a storm event. The efficiency improvements in this project will allow for more model simulations in ensemble-based design applications, which will increase the accuracy of flood risk products used in building design and the establishment of flood insurance rates, and thus lessen the impact of a disaster. The efficiency improvements in this project will also allow for faster simulations in time-sensitive applications such as operational forecasting, and thus improve the communication and understanding of potential hazards.

This project will benefit DHS and the Homeland Security Enterprise in two ways: a more-efficient ADCIRC model will allow for more model runs in ensemble-based design application, and for faster simulations in time-sensitive applications such as operational forecasting. In its development of Flood Insurance Rate Maps (FIRMs), FEMA will benefit because the probabilistic framework requires a large number of simulations, which will now require fewer computational resources, and thus the studies can be completed in a shorter time and/or consider a larger suite of storms. We are working with several FEMA engineers, with whom we are sharing research progress and receiving feedback on future directions. In their use of flood predictions provided in real-time by the ADCIRC community, state-level emergency managers will benefit because by now having more time to consider the forecast guidance in their decision-making. We are working with partners at the Texas State Operations Center and NC Emergency Management. We also have partners in the USACE, NOAA, and academia, as described below.

2. Project History:

This project is developing technologies to improve the efficiencies of the ADCIRC modeling system in parallel computing environments. ADCIRC utilizes an unstructured mesh, which is a highly-flexible, multi-scale representation of the coastal environment. This project is developing automated routines for an adaptive, multi-resolution approach to employ high-resolution, unstructured meshes for storm surge applications, and it is developing automated routines for the efficient re-balancing of the computational workload via parallelized domain decomposition.

Over two decades of performing storm surge hindcasting and analysis, and through the efforts of dozens of researchers in academia, government and industry, the ADCIRC community has developed extensive high-resolution models of the Gulf and Eastern Coasts of the U.S. These region-specific models have been developed to analyze storms impacting, e.g. Texas, Upper Texas-Louisiana, the Northern Gulf of Mexico, the Carolinas, the Northeast-New England region, etc. In most cases, these models are too expensive to be of use in storm surge forecasting, which requires simulations to be performed in typically 1-1.5 hours; however, the resolution within these models could provide much more accurate predictions of storm surge for use by emergency managers. This motivated our research on "adaptive mesh resolution." The idea behind this approach is simple on the surface: use a less refined mesh when the storm is still far from land and/or the track is still uncertain, then, at some intermediate point of the calculation, stop the run, interpolate the solution onto a higher resolution mesh, and finish the simulation on this mesh. The expected outcome of this work is to provide a solution with comparable accuracy to a high-resolution simulation in much less computing time.

The first milestone in this project was to develop a fast interpolation routine that could read ADCIRC hotstart files and interpolate the results from one mesh to another. This led to the development of the beta version of the software program ADCIRpolate. The next milestone was to test the algorithm on some simple test problems. This was completed in the first year of the project. The third milestone was to extend the entire process to handle floodplain regions, which has been challenging and took several iterations until we came up with a solution. We have made substantial progress in the past year to the point where we have been able to perform a complete simulation of Hurricane Harvey, starting with coarser resolution in the Texas floodplains and running for about 1 day of simulation, then interpolating onto a higher-resolution mesh (developed specifically for hurricanes impacting Texas) for the remainder of the simulation.

The other component of this research project has been the treatment of dry regions within our high-resolution meshes. These meshes have evolved to have millions of elements in overland floodplains, so that ADCIRC can push floodwaters into these regions during the storm. However, when these regions are dry, either before / after the storm or when the storm is far away, then there is nothing for ADCIRC to compute. For the computational cores assigned to these dry regions, there is nothing to do, and thus these resources are wasted. This motivated our research on “dynamic load balancing.” The idea behind this research is to better distribute the dry regions, so that they are contained on only a few cores. Then more of the cores will be available to compute the flooding in wet regions. This technology will adapt during the storm, as regions become wet and then dry again. By better distributing the workload over the cores, ADCIRC will become more efficient for simulations of flooding into overland regions.

The first milestone in this project was to modify the existing code in ADCIRC for its domain decomposition. A new routine was added to its source code to perform the domain decomposition at the start of the simulation, so each computational core is now responsible for developing its own set of input files. This new routine can also be called periodically during the simulation, to re-perform the domain decomposition, and thus re-balance the workload among the cores. The second milestone was to test this new routine on simple test problems. In our initial tests, the efficiency gain was about 25 percent. These milestones were completed in the first year of the project. However, while working with collaborators at the University of Notre Dame, we determined that this new routine would not scale, i.e., the efficiency would not increase for larger problems on larger numbers of cores. Thus our third milestone was to rewrite this routine to use the Zoltan library for adaptive domain decomposition. This library can control how computational points are migrated between neighboring sub-domains, instead of starting each decomposition from scratch. This implementation has provided further speed-ups in the wall-clock time. We have made substantial progress in the past year, to where now the dynamic load balancing is being tested on realistic domains for realistic storms.

3. <u>Results</u>:

Our joint research in adaptive mesh resolution and dynamic load balancing has led to a set of outcomes and findings that will improve the efficiency of ADCIRC simulations.

The final results of the adaptive mesh resolution research can be summarized as follows. The outcomes of the research include the software ADCIRpolate, which uses many of the interpolation routines in the open-source Earth System Modeling Framework (ESMF). ADCIRpolate reads an ADCIRC hotstart file generated on one mesh (call it Mesh 1), and interpolates it onto another mesh (call it Mesh 2). If Mesh 1 and Mesh 2 cover the exact same domains, this process is straightforward. The difficulty in our project is that Mesh 1 and Mesh 2 may differ substantially, especially in floodplain areas. This required developing some extensions of the ESMF software to handle extrapolation and wetting and drying, and to make some modifications to the hostart capability of ADCIRC, which historically has been based on simply hot-starting a calculation on the same mesh/domain. Some of these modifications are still undergoing debugging and testing. However, during the past six months, we have been able to perform a complete simulation of Hurricane Harvey using this process, described below.

Hurricane Harvey proved to be a great test case for our project and for CRC-related research in general. It developed over the southwestern Gulf of Mexico during the week of August 20th, 2018. On August 23-24 it quickly developed from a tropical storm to a Category 4 hurricane. It made its first landfall on August 25th near Port Aransas, TX, causing extensive damage to the coastal bend region. During this time period, we worked extensively with Jason Fleming and Carola Kaiser through the CRC, our project transition partners Gordon Wells at the Texas State

Operations Center and a stakeholder at the NOAA West Gulf River Forecast Center, and the Texas Advanced Computing Center (TACC), to operate the ADCIRC Surge Guidance System (ASGS). We generated real-time storm surge forecasts on two models with different resolutions, the recently developed NOAA Hurricane Storm Surge Forecasting on Demand System (HSOFS), which covers the entire Gulf and Eastern Coasts of the U.S., and a mesh (Texas 35h) developed specifically for Texas hurricanes, with higher resolution in the Texas floodplains. The Texas 35h results were used extensively in the Texas State Operations Center to make decisions regarding transportation, staging, evacuations, etc. Overall the ASGS performed admirably on all storms during the 2017 hurricane season.

Hurricane Harvey provided a great test case for adaptive mesh refinement. Using the best track hurricane wind information, we begin the calculation on the HSOFS mesh during the first 1-1.5 days of the storm. At that point the track was pretty well established, so we use ADCIRpolate to interpolate the results from HSOFS to the Texas 35h mesh and complete the simulation. We observed essentially no difference in the maximum water levels produced by the interpolation vs. performing the simulation entirely on the finer mesh. This result was presented at the CRC 2018 Annual Review. ADCIRpolate only takes a few minutes to do the interpolation, therefore this approach could provide substantial savings in computation time, though a complete analysis of the approach is ongoing.

After the simulation has been interpolated and continued on the high-resolution mesh, it will need to be smarter about how it handles the dry regions, which may make up half of the computational domain. Thus we have also focused our research on dynamic load balancing. For this part of our research, the outcome has been the implementation of a capability within ADCIRC to re-decompose the computational workload at selected points during the simulation. The first iteration of this implementation was within the existing ADCIRC code, by switching it to rely on the parallel version of the METIS domain decomposition library. The ADCIRC pre-processor was integrated within the regular code. The simulation is now started with the global input files, which are then localized by each core before they start their time-stepping. Then the re-decomposition was performed by writing and reading information from the hotstart files. When an imbalance was detected, the simulation would write its information to a hotstart file, close a lot of its computations, perform the re-decomposition, and then read information from the hotstart file. In this way, the information was 'migrated' between neighboring sub-domains, but by writing and reading information from the disk.

This implementation used a lot of the existing structures and routines within ADCIRC, and it was promising on small test problems. We have been testing on an idealized, rectangular domain, in which the bathymetry is varied from about 4 m below sea level to about 2 m above sea level. In this domain, about one-third of the area is dry, and about one-half of the computational points are dry. By forcing a 1-m tide at the ocean boundary, we can cause a lot of wetting and drying during the simulation, and thus test our dynamic load balancing. These tests were promising. When the simulation was performed on small numbers of cores, say 16 to 48, the speed-ups were 25 to 30 percent, which would be a significant improvement in accuracy. However, when the simulation was performed on a large number of cores, say 96 cores, then the simulation would slow down. This loss in efficiency was due to the combined effects of writing/reading information from the hotstart files, as well as the increased costs associated with putting less than 1000 mesh vertices on a core. These behaviors were also seen in tests on realistic domains. We ran a simulation of Hurricane Irene on the high-resolution mesh to describe coastal North Carolina, which contains the floodplains surrounding Pamlico Sound, over which the storm moved and caused a lot of flooding. For tests on small numbers of cores, the speed-ups were again about 20 to 25 percent, but for tests on large numbers of cores, the speed-ups were minimal. This initial implementation has provided a lot of the framework for the dynamic load balancing, but its reliance on external hotstart files was a limitation.

In the past year, and working with collaborators at the University of Notre Dame, we have updated the framework to instead use the Zoltan library. This library was developed at the Sandia National Laboratories, is open source, and can automate the migration of simulation information through the network to neighboring sub-domains. By integrating this library within the ADCIRC code, we can now pass information without writing and reading it from the hotstart files. The simulation can proceed without having to restart so completely. This capability has been tested on the idealized, rectangular domain described above, and it has proven to scale efficiently to large numbers of cores and configurations. We are now testing it on realistic domains for tidal simulations, and the capability is continuing to scale efficiently. When this capability is implemented within ADCIRC and released to the community, it has the potential for a significant speed-up of our simulations of coastal flooding. Our ongoing research is focused on a complete analysis and testing of this dynamic load balancing.

To summarize our findings:

- We developed ADCIRpolate, a parallel software tool that interpolates/extrapolates ADCIRC hot start data from one mesh to another. It is an open source tool that will be transitioned to the ASGS, to our partners and to the ADCIRC community at large. The tool has been demonstrated to work on examples without and with floodplains, and it has been applied to Hurricane Harvey and shown to be effective.
- We implemented a dynamic load balancing within ADCIRC, first by using the existing routines and framework, and then by integrating the Zoltan library. This capability has been demonstrated to work on idealized and realistic examples for tide-driven flooding, and it is being tested now for storm-driven flooding on large domains.

4. <u>End Users and Transition Partners</u>:

The proposed enhancements to efficiency will benefit all model users, including several DHS agencies with missions related to coastal flooding. In its development of Flood Insurance Rate Maps (FIRMs), FEMA will benefit because the probabilistic guidance requires a large number of deterministic simulations, and the approach described in this project will require fewer computational resources. For example, if a flood mapping study would see an efficiency gain of, say, 10 percent, then the study could be completed in a shorter time. Alternatively, that efficiency gain could be reinvested into increasing the mesh resolution and/or considering a larger suite of storms, and thus increasing the accuracy of the model results. At FEMA, multiple stakeholders are participating as transition partners. The project will also help to speed the delivery of projected flood inundation levels associated with coastal storms, thereby assisting FEMA as well as state and local emergency managers to plan for coastal evacuations and deployment of resources and personnel. In addition, the Coast Guard will benefit from faster guidance about waves and surge and therefore be able to make operational decisions about the possible relocation of assets in advance of an oncoming storm. The project personnel will continue to work with the transition team to identify additional end-users in these and other DHS constituent agencies.

With the Texas State Operations Center, the project personnel are working with **Gordon Wells** and **Teresa Howard** to transition the analysis products that are used for guidance by the emergency management leadership. They have worked with forecast guidance for the Texas coastline in previous seasons and are supportive of the proposed work. This partnership is important because it connects the products with end users at the state and local levels.

The proposed work will also benefit ADCIRC model users at other federal agencies. With the USACE Engineer Research and Development Center, the NOAA NCEP, and the NOAA West Gulf River Forecast Center, multiple stakeholders are participating as transition partners. For partners who are focused on operational modeling with ADCIRC, these activities are taking the form of guidance about development with the goal of transitioning products to their work in the long term.

The project personnel also work closely to transition the project outcomes to the ADCIRC modeling community. These transition activities are connected with **Jason Fleming** and **Carola Kaiser**, who are key members of the Coastal Emergency Risks Assessment (CERA) group. They operate the forecasting systems for regions along the U.S. Gulf and Atlantic coasts, and they visualize and communicate the forecast guidance via a Google Maps application. Dr. Fleming also manages the software repository for the development of ADCIRC. The project personnel are working with these partners to ensure that the new modeling technologies can be incorporated within the forecasting system and the release version of ADCIRC.

During this project year, the research team facilitated the transfer of research products to these transition partners via two methods:

- Progress reports via videoconference, during which the research team shared interim results from our activities, and our transition partners provided guidance about future directions. Their feedback and suggestions are valuable as we move our research products into something useful for production.
- We are working with Jason Fleming to transition a static load balancing into the ADCIRC version used for forecasting in North Carolina, so it can benefit from a gain in efficiency. The latest development version of ADCIRC was modified so its static domain decomposition will account for the relative costs of dry and wet computational points. Preliminary tests, even with this most-basic of changes, have shown a speed-up of 10-20 percent compared to the existing release version of ADCIRC. We continue to work on more-sophisticated methods that will offer enhanced efficiency gains.
- Over the next year, ADCIRpolate will be transitioned into the ASGS with the help of Jason Fleming. We will work with Fleming on automating ADCIRpolate within the ASGS and developing a beta version of the software for the 2019 hurricane season.

Thus, we are working with our transition partners, and information is flowing in both directions. They have identified some future directions for our research, and we are sharing our technologies with them. The project technologies will be shared as they become available, and our transition partners will be trained and then test the technologies for applications ranging from operational forecasting to engineering design. The technologies developed in this project will also be released to the ADCIRC modeling community. This work will require the development of extensive documentation and example files, which will be hosted online, and the integration of the software into the release version of ADCIRC.

The following testimonial is from Gordon Wells about the use of ADCIRC forecasts in the Texas State Operations Center during Harvey:

> *"In the Texas State Operations Center, where state and federal agencies coordinate the response to major disasters, ASGS web services and data products were used extensively during Tropical Storm Cindy and Hurricane Harvey, as well as for Hurricane Irma. As TS Cindy approached the Upper Texas Gulf Coast in late June, the Texas Department of Transportation (TXDOT) used ASGS forecasts available from the CERA website to monitor safe operation of the Bolivar Ferry system between Galveston Island and Bolivar Peninsula. Although the storm tide began to approach the 5-foot AMSL elevation limit on June 20-21, the ASGS forecasts showed that the limit would not be exceeded, and TXDOT management decided to continue ferry operations without interruption. Access to the ferry service allowed a Texas Army National Guard motorized company to stage from Galveston Island while assisting search-and-clear activities on Bolivar Peninsula rather than redeploying through Houston across to the eastern side of the peninsula, which would have required several hours in transit. Both TXDOT and the Texas Military Department expressed their satisfaction with the use of ASGS predictive services during TS Cindy that led them to make more effective decisions during the state's response.*
>
> *"In late August, as Hurricane Harvey rapidly intensified off the Coastal Bend of Texas in late August, ASGS forecasts were again used by TXDOT to determine the timing of causeway closures to North Padre and Mustang islands, the cessation of ferry operations at Port Aransas and the continuation of swing-gate operations along the Intracoastal Waterway. Texas Task Force 1 search-and-rescue coordinators and the Texas Army National Guard used ASGS predictions of the maximum storm surge elevations to plan rapid re-entry operations into the impact region. The Texas Department of Public Safety used the ASGS forecasts to determine whether their offices and staging areas in Corpus Christi were on safe ground as well as the locations of emergency communications facilities. For several days following the initial landfall, as Harvey lingered along the Texas coastline, several state agencies and the state mass care coordinator used the forecast wind speed time series feature of the CERA web service to determine when it would be safe to move high-profile vehicles into and from damaged coastal towns.*
>
> *"As field operations were winding down for Hurricane Harvey, FEMA strike team coordinators in the State Operations Center were preparing to depart for Florida and the arrival of Hurricane Irma. Impressed with the Harvey guidance products, several FEMA personnel regularly checked the ASGS forecast for the Florida Keys*

> *using the CERA web service. Initial concerns were focused on Key West, but ASGS correctly predicted the maximum impacts would occur about 10 miles to the east in the area of Cudjoe Key."*

The following testimonial is from the NOAA West Gulf River Forecast Center about the use of ADCIRC forecasts at the West Gulf River Forecast Center during Harvey:

> *During Harvey while at the Texas State Operations Center ADCIRC was used within the final 12 hours and after land fall to monitor the impact that the rapid intensification would have on the localized inundation along all of the Gulf Coast. By displaying accurately where surge inundation was occurring down at the local (street) level, key decisions for response were being made by multiple agencies particularly along the bays. The particular area the ADCIRC results were proven extremely useful was the funneling of water into the Lavaca Bay and other parts of Matagorda Bay. One particular issue was transferring search and rescue equipment and personnel from Rockport area (landfall location) up into Houston (severe flooding). The surge itself along with the surge preventing river flooding from draining was making several roads along the coast impassable. This made moving this equipment and personnel a challenge because time was of the essence, and turning around to find a route around the flooding would have taken hours. Working in conjunction with Texas Task Force 1 (search and rescue team) we developed a route around the flooding area. This rerouting saved a lot of time that would have been lost if these vehicles attempted to find their own path and were forced to turn around several times.*
>
> *The accuracy level that ADCIRC provides from surge inundation allows the response and recovery effort on a local scale to be performed more efficiently than ever before and undoubtedly is vital to the decisions emergency managers must make as a tropical system impacts their jurisdiction.*

5. <u>Project Impact</u>:

This project is developing technologies to improve the efficiencies of the ADCIRC modeling system in parallel computing environments. It is developing automated routines for an adaptive, multi-resolution approach to employ high-resolution, unstructured meshes for storm surge applications, and it is developing automated routines for the efficient re-balancing of the computational workload via parallelized domain decomposition.

The initial motivation for adaptive mesh refinement was to speed up the forecast capabilities of ADCIRC and improve the ASGS. Over the next year, we will work with Jason Fleming and other ASGS developers to incorporate ADCIRpolate into the ASGS as a beta version for the 2019 hurricane season. The adaptive capability has also motivated future ADCIRC-related projects within the CRC. Our next phase will be to develop capability to interpolate HSOFS results onto a number of ADCIRC models of Texas, the Northern Gulf, the Carolinas, and the Northeast/New England. In addition, there are extensions of this work beyond hurricane forecasting. We also could substantially speed up post-storm analysis and scenario analysis by allowing for the use of high-resolution meshes targeted to specific regions and specific locations, but also allowing for pre-storm tidal spin-up and storm initiation to be executed on a coarser mesh.

The capability for dynamic load balancing has the potential to benefit all ADCIRC simulations, including the real-time forecasting in the ASGS. These routines better utilize the available computing resources by ensuring that every core is busy during the entire simulation. One benefit of these new routines is that they will be blind to the user; the workload will be rebalanced automatically, without requiring input from the user. Thus it will not be necessary for users to know Zoltan or the other mechanics of the domain decomposition. The efficiency gains will be shared by all users. These new routines will be shared (with extensive documentation and examples) with the ADCIRC modeling community, including the ASGS.

6. Student involvement and awards:

At NC State, this project has supported one graduate student: Ajimon Thomas, who is working toward a PhD in coastal engineering. He has focused on a high-resolution hindcast for Hurricane Matthew along the U.S. Atlantic coast; this hindcast will be used as a test case for both the adaptive mesh resolution and dynamic load balancing.

At UT Austin, graduate student Ardavan Behnia was involved in the project. He developed the first version of the ADCIRpolate software and performed initial testing during the first 1.5 years of the project. He received an MS degree in Computational Science, Engineering and Mathematics, but then left graduate school for personal reasons. After his departure, two research scientists took over the project, Ali Samii and Jennifer Proft.

This project has supported the following student-led publications:

- A Thomas*, JC Dietrich, TG Asher, M Bell, BO Blanton, JH Copeland, AT Cox, CN Dawson, JG Fleming, RA Luettich (2018). "Influence of Storm Timing and Forward Speed on Tide-Surge Interactions during Hurricane Matthew." *Ocean Modelling*, to be submitted.
- R Cyriac*, JC Dietrich, JG Fleming, BO Blanton, C Kaiser, CN Dawson, RA Luettich (2018). "Variability in Coastal Flooding Predictions due to Forecast Errors during Hurricane Arthur." *Coastal Engineering*, 137(1), 59-78.

and the following student-led conference presentations:

- A Thomas*, JC Dietrich, TG Asher, BO Blanton, AT Cox, CN Dawson, JG Fleming, RA Luettich. "High-Resolution Modeling of Surge during Hurricane Matthew." *15th Estuarine and Coastal Modeling Conference*, Seattle, Washington, 25 June 2018.
- A Thomas*, JC Dietrich, JG Fleming, BO Blanton, T Asher, RA Luettich. "High-Resolution Modeling of Surge during Hurricane Matthew." *ADCIRC Users Group Meeting*, NOAA Center for Weather and Climate Prediction, College Park, Maryland, 13 April 2018.
- A Thomas*, JC Dietrich, RA Luettich, JG Fleming, BO Blanton, TG Asher, SC Hagen, MV Bilskie, P Bacopoulos. "Hindcasts of Winds and Surge during Hurricane Matthew (2016): Balancing Large-Domain Coverage and Localized Accuracy." *ADCIRC Users Group Meeting*, Norwood, Massachusetts, 4-5 May 2017.

and the following student-led conference posters:

- A Thomas*, JC Dietrich, JG Fleming, BO Blanton, T Asher, RA Luettich. "High-Resolution Modelling of Surge during Hurricane Matthew (2016)." *Graduate Student Research Symposium*, North Carolina State University, 21 March 2018.
- A Thomas*, JC Dietrich, JG Fleming, BO Blanton, T Asher, RA Luettich. "High-Resolution Modelling of Surge during Hurricane Matthew (2016)." *Environmental, Water Resources, and Coastal Engineering Research Symposium*, North Carolina State University, 02 March 2018.
  - Honorable Mention

7. <u>Interactions with education projects</u>:

This project has initiated involvement with the CRC's MSI education partners in several ways. PI Dietrich has visited both Jackson State University (JSU, in 4 May 2016) and Johnson C. Smith University (JCSU, in 31 March 2017) to present seminars about current research in storm surge modeling and forecasting. These seminars were attended by a combination of students and faculty members at each institution. The first half of the seminar was a summary of the last decade of PI Dietrich's research, with a focus on storm surge modeling along the northern Gulf coast, and with an emphasis on experiences in graduate school and beyond. The second half of the seminar was an introduction to and preliminary results from this CRC project. The seminars were well-received with many questions from the audience. The presentations have been archived on PI Dietrich's institutional web site, and notice of the seminars were shared with CRC leadership.

PI Dietrich also hosted a visit from JCSU students on 14 June 2017. The JCSU students visited NC State for a day, met with PI Dietrich and his graduate students, and learned more about their recent research in modeling of coastal hazards. Because the JCSU students have backgrounds in computer science and engineering, much of the discussion during their visit was focused on the applications of computational techniques and models into our research program. PI Dietrich invited several faculty members from inside his department to meet the JCSU students and describe their research, too. Hopefully this interaction will be another building block to connect JCSU students with research at NC State.

Co-PI Dawson at UT Austin hosted summer intern Xuesheng Qian from Jackson State University during the summer of 2016 through the CRC SUMREX program. Qian learned how to run the SWAN+ADCIRC model on the HPC machines at UT Austin, how to use the Surface Water Modeling System to generate/modify finite element meshes and data used in the models, how wind files are generated and used, and worked with Dawson and JSU researcher Bruce Ebersole to run the model for storms in the Texas Gulf Coast area.

8. <u>Publications</u>:

This project has supported the following student-led publications:

- A Thomas*, JC Dietrich, TG Asher, M Bell, BO Blanton, JH Copeland, AT Cox, CN Dawson, JG Fleming, RA Luettich (2018). "Influence of Storm Timing and Forward

Speed on Tide-Surge Interactions during Hurricane Matthew." *Ocean Modelling*, to be submitted.

- R Cyriac*, JC Dietrich, JG Fleming, BO Blanton, C Kaiser, CN Dawson, RA Luettich (2018). "Variability in Coastal Flooding Predictions due to Forecast Errors during Hurricane Arthur." *Coastal Engineering*, 137(1), 59-78.

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	**Product Type** (e.g., software, guidance document)	**Delivery Date**	**Recipient or End User**
ADCIRC forecast guidance for Texas	guidance	June-Nov 2017	G Wells and T Howard, Texas State Operations Center
ADCIRpolate	software	2019	J Fleming, Seahorse Coastal Consulting

Table 2A: Documenting External Funding

Title	**PI**	**Total Amount**	**Source**

Table 2B: Documenting Leveraged Support

Description	**Estimated Total Value**
NSF XSEDE allocation of 330K node-hours at UT-Austin and 1.1M CPU-hours at SDSC	$127,333.08
NSF XSEDE allocation of 6.6M CPU-hours combined for supercomputers at UT-Austin and SDSC	$282,311.86

Table 3: Performance Metrics:

DIETRICH-DAWSON PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17-6/30/18)
HS-related internships (number)	0	0	0
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	0	0	0
Graduate students provided tuition/fee support (number)	3	2	2
Graduate students provided stipends (number)	3	2	2
Undergraduates who received HS-related degrees (number)	0	0	0
Graduate students who received HS-related degrees (number)	0	0	1
Graduates who obtained HS-related employment (number)	0	0	0
SUMREX program students hosted (number)	1	0	0
Lectures/presentations/seminars at Center partners (number)	1	1	0
DHS MSI Summer Research Teams hosted (number)	0	1	0
Journal articles submitted (number)	0	0	1
Journal articles published (number)	0	0	1
Conference presentations made (number)	2	4	3
Other presentations, interviews, etc. (number)	1	4	11
Patent applications filed (number)	0	0	0
Patents awarded (number)	0	0	0
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	1	0
Requests for assistance/advice from other agencies or governments (number)	0	1	3
Total milestones for reporting period (number)	6	7	8
Accomplished fully (number)	6	3	3
Accomplished partially (number)	0	2	5
Not accomplished (number)	0	2	0

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Extension of ADCIRpolate to incorporate floodplains and wet/dry regions	12/2017	100	
Testing of ADCIRpolate and ADCIRC for a hurricane scenario	02/2018	100	
Dynamic load balancing for an adaptive ADCIRC simulation	03/2018	50	We are progressing on both technologies (adaptive mesh resolution, dynamic load balancing), but their development has been more involved (and thus slower) than we expected. We are working to combine the two technologies to meet these completion dates.
Demonstration of adaptive approach with segments of target mesh	04/2018	50	Same.
Combined simulation with dynamic load balancing and adaptivity	06/2018	50	Same.
Refining and streamlining the technologies for widespread release	06/2018	50	Same.

Research Milestones			
Gave several interviews to local news media on storm surge forecasting during Hurricane Harvey	08/2017	100	
Online documentation for new technologies	03/2018	50	These milestones are all related to documentation of project technologies, which we are writing as we continue to develop them.
Submission of manuscript about adaptive approach	06/2018	50	Same.
Transfer of technologies to ADCIRC modeling community	06/2018	50	Same.

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Integration of mesh adaptivity technology into official ASGS	06/2018	50	This activity will be completed within the next year.
Integration of project software into release version of ADCIRC	06/2018	50	Same.

Transition Milestones			
Quarterly progress updates, feedback from transition partners	09/2017 12/2017	100	
Documentation and examples on online Web site	03/2018	50	These milestones are all related to documentation of project technologies, which we are writing as we continue to develop them.
Testing of mesh adaptivity technology with J Fleming and C Kaiser	03/2018	50	Same.
Release of software to transition partners, training with examples	03/2018	50	Same.

HAGEN, LSU
MEDEIROS, UCF
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Development of an optimized tide and hurricane storm surge model for the northern Gulf of Mexico (MS, AL, FL) for use with the ADCIRC Surge Guidance System.

Principal Investigator Name/Institution: Scott C. Hagen, Professor. Louisiana State University, Department of Civil & Environmental Engineering / Center for Computation & Technology.

Co-Principal Investigators and Other Partners/Institutions: Stephen C. Medeiros, Research Assistant Professor. University of Central Florida, Civil, Environmental & Construction Engineering Department.

Project Start and End Dates: 1/1/2016 – 6/30/2018

Short Project Description ("elevator speech"):

This study developed a semi-automated mesh de-refinement method designed to optimize a research grade tide, wind-wave, and hurricane storm surge model for use in real-time surge guidance operations. The resulting model includes advanced terrain characterization and is capable of producing accurate predictions within the ADCIRC Surge Guidance System (ASGS) forecast time frames.

Summary Abstract:

This project advanced state-of-the-art model development by introducing novel terrain analysis techniques and lidar-based surface roughness parameterization at the regional scale. These advanced techniques were used to develop intelligent, stable, and semi- automated mesh de-refinement methods for optimizing a research grade (i.e., high resolution) storm surge model to reduce computational time to the point where it can be run within reasonable real-time forecast time frames (e.g., ~1-2 hrs). We used a protocol based on emphasizing hydraulically significant embankment or valley features to optimize a research grade model of the MS, AL, and FL Panhandle. Since the purpose of ASGS is the provision of real-time hazard guidance, we emphasized the accurate capture of the timing and magnitude of maximum water levels. This was achieved by employing mesh development techniques such as: running preliminary simulations to define active floodplain and removing unnecessary elements (relevant because the research grade model was developed to accommodate up to two meters of sea level rise); employing accelerated element relaxation moving outward from significant vertical features; and enforcing stricter criteria for vertical feature inclusion (especially for channels). Objective error metrics were used to assess model performance. The final outcome/deliverable will be an accurate, optimized hurricane storm surge model of the northern Gulf of Mexico (MS, AL, & FL Panhandle) that is suitable for use with the ASGS. In addition, this high resolution

ADCIRC+SWAN model can serve as a benchmark for validating future versions that may incorporate less resolution or smaller regional focus.

1. Research Need:

This project is directly relevant to the Homeland Security Enterprise, in particular the stated mission to "Strengthen National Preparedness and Resilience." In the 2014 Quadrennial Homeland Security Review, two out of the three examples used to illustrate evolving threats and hazards since the 2010 review are directly related to this project. The Deepwater Horizon Oil Spill is relevant both scientifically and geographically; the end result of this project will be an immediately applicable tool if such an event were to occur in the future.

Furthermore, Hurricane Sandy is exactly the type of hazard scenario the ASGS and the NGOM model is designed to simulate. Our project enables DHS / FEMA to determine hazard risk by simulating the effects of synthetic or historic storms under various scenarios such as including existing conditions, infrastructure enhancements/degradations and sea level rise. This directly impacts the resiliency of the United States by enabling government agencies to develop planned mitigation strategies, adopt relevant disaster-resistant building codes and educate their citizens on the specific preparedness measures necessary for the storm surge hazard. In addition, this project contributes to near real-time storm surge hazard impact forecasts for storms in progress that inform communities in the impact zone. This directly enhances the preparedness of the United States by enabling the pre-staging of required life-sustaining commodities for post-storm delivery into affected areas, assembly of incident response teams including the incident command hierarchy as well as search and rescue teams for deployment within the stated goal of 12 hours post-storm.

2. Project History:

This project proceeded more or less as planned with some unforeseen administrative delays. The development of the NGOM forecast grade model proceeded according to schedule with the model becoming active for the 2018 hurricane season. All that remains is full integration of its results into CERA.

The expansion of the lidar-based surface roughness to the regional scale was hampered by the amount of data to process. The problems scaling the surface roughness parameter computations to model scale proved to be difficult on many fronts (compute, storage, spatial registration of results). To address this problem, Dr. Medeiros invested in lidar processing software (LAStools) in order to use its tools on some of the more routine lidar data processing tasks such as projecting, clipping, tiling, boundary shapefile production and point height computations. This has greatly sped up the progress of this aspect of the work. Dr. Medeiros also hired an established undergraduate research assistant, Alex Rodriguez, to work on the lidar data processing pipeline for 30 hours per week during the summer semester and plans to continue through Performance Period 3. To date, this has already accelerated the progress of the work. Lastly, Dr. Medeiros is planning to invest in additional compute allocation from the STOKES HPC at UCF in order to speed up the production of surface roughness parameters for the model domain.

One of the major successes of the project was the SUMREX program. In the summers of 2016 and 2017 we were able to host 3 students (two from UPRM and one from Jackson State). The students benefitted significantly from the experience and the student from 2016 earned an NSF Graduate Research Fellowship and is currently pursuing his PhD at LSU under the direction of Dr. Hagen. The administrative tasks associated with implementing SUMREX program were much more complex than anticipated. Issues regarding payment of travel funds and stipend resulted in Dr. Medeiros spending an inordinate amount of time on this, thus delaying the research milestone associated with submission of a journal paper on the lidar surface roughness parameterization. Also, due to delays in the issuance of Performance Period 2 funds, Dr. Medeiros temporarily funded the SUMREX program from his research balance account in order to mitigate the financial burden on the student from UPRM. All issues were resolved and we expect the process to go much smoother in summer 2019 and onward.

3. Results:

The project achieved its primary goal of creating a forecast grade surge and wave model of the Northern Gulf of Mexico, specifically the Florida panhandle, Mississippi, and Alabama. The primary driver of this was the ability to modify what is recognized as the best research grade ADCIRC+SWAN model of the region to optimize run times. As of 2018, the model is running in an ASGS instance producing results automatically each time a relevant storm advisory is issued.

This project also significantly advanced the parameterization of surface roughness using lidar data. Future storm surge modeling efforts nationwide will be enhanced by the big data methods and workflows developed during this project.

4. End Users and Transition Partners:

- Jerrick Saquibal, Northwest Florida Water Management District. Dr. Medeiros contacted him prior to CAT 1 Hurricane Hermine Landfall. Provided link to CERA and sample images from NGOM3 via email. Received positive feedback on the CERA product. Dr. Medeiros followed up with him regarding a possible CERA tutorial for NWFWMD staff. Mr. Saquibal was interested and also suggested two people from FDEM and FDOT that might be interested as well. To help facilitate this, Dr. Medeiros has tested the existing CERA tutorial on the CERA website by having 2 undergraduate research assistants go through it and provide feedback. We also had the 2017 SUMREX students run through the tutorial and provide feedback as well. We assimilated all feedback and produced a revised tutorial in early 2018. Mr. Saquibal continues to look forward to high resolution surge forecasts for the Florida Panhandle and Big Bend regions, as well as the value-added lidar products.
- NOAA Northern Gulf of Mexico Sentinel Site Cooperative (NGOM SSC). Team has remained in constant contact with stakeholders at NGOM SSC regarding the value of accurate coastal hydrodynamic modeling to the NGOM SSC mission. This partnership had been leveraged into a funded NOAA project. We anticipate presenting the CERA tutorial (once finalized in conjunction with Carola Kaiser) to the NGOM SSC as well as their invitees.

5. Project Impact:

Our project produced an accurate, optimized hurricane storm surge model of the NGOM that is suitable for use with the ASGS and CERA. This will enable ASGS and CERA to provide emergency management personnel in the region with the highest resolution, most accurate storm surge forecasts for real-time tropical cyclones as they approach. In turn, this will facilitate more efficient evacuation and better prediction of post-storm emergency resource needs.

The submission and subsequent publication of the surface roughness parameterization and mesh optimization method papers (in preparation) in high-impact journals will validate the research pathways and document their acceptance by successful peer review. By achieving these milestones, the incorporation of this optimized model into ASGS will be justifiable by any measure and DHS S&T will have independent documentation in support of it. The incorporation of the optimized model into ASGS provided a major advance towards a readily adoptable means for conveying the model results to the public in a meaningful way (CERA).

Lastly, the impact of the SUMREX program needs little explanation other than stating the facts. Our pilot program in the summer of 2016 was a resounding success as the student, Felix Santiago of UPRM, had an outstanding experience and was able to leverage his participation into a PhD opportunity at LSU, which will be funded in part by an NSF Graduate Research Fellowship award (Drs. Hagen and Medeiros both provided letters of recommendation). Furthermore, the program was expanded to two students in 2017: Sabrina Welch of Jackson State University and Diego Delgado of UPRM. This impact of this program will be qualified, talented, and motivated students that will remain in this field either through advanced study or industry practice.

6. Student involvement and awards:

Alex Rodriguez, UCF Undergraduate Research Assistant. Major: Industrial Engineering and Management Systems. Presented poster at UCF Showcase of Undergraduate Research regarding the lidar data processing for surface roughness parameters. Co-Author on peer-reviewed IEEE paper (in preparation.)

7. Interactions with education projects:

This reporting period contains the 2016 (student: Felix Santiago, UPRM) and the 2017 SUMREX (students: Sabrina Welch, Jackson State University and Diego Delgado, UPRM). The students spent the first 3 weeks at UCF and the second 3 weeks at LSU.

At UCF, the students began with a pre-test consisting of basic linear algebra and numerical methods problems designed to assess their level of competence in these topics and gage the need for further explanation on these topics. During the experience, the students engaged with Dr. Talea Mayo for assistance with the mathematical aspects of the pre-test. The pre-test also required the students to read a research paper in JGR-Oceans written by the LSU-UCF team, highlighting both concepts they did not understand as well as concepts that they were interested in. For the remainder of the UCF phase of the SUMREX, the students worked closely with Dr. Medeiros to learn the SMS software for ADCIRC mesh development (temporary software licenses provided at no cost by Alan Zundel of Aquaveo). They went through tutorials from past ADCIRC boot camps, working through the examples. They then used their knowledge to implement and run desktop ADCIRC tide simulations on an existing WNAT mesh in SMS. Dr. Medeiros also took the students into the field on the UCF campus where they learned the basics of RTK-GPS topographic surveying, field methods for determining Manning's n bottom friction coefficients and effective aerodynamic roughness length by measuring the height, canopy width and other dimensions of trees and above-ground obstructions. Lastly, the 2017 students engaged with Dr. Thomas Wahl to discuss sea level rise, appropriate model scales, and how ADCIRC (or surge model output in general) is used by downstream researchers and policy makers. The students were given 3 questions to ponder after Dr. Wahl's presentation and given three days to develop responses.

- How can ADCIRC be used to identify and quantify non-linear interaction between different sea level components?
- How could you implement sea level rise in an ADCIRC model? Be specific.
- For which spatial scales is ADCIRC most suitable and why?

For the second three weeks, the students transitioned to LSU and began working with Dr. Matthew Bilskie to build on their ADCIRC knowledge by conducting storm surge simulations. The students attended three virtual trainings entitled "Introduction to Linux" and High Performance Computer (HPC) User Environment Part 1 and Part 2". These trainings were provided by LSU HPC. They also simulated several hurricanes using a coarse ADCIRC model on both their workstations and on the LSU HPC and document the difference in run-time. They learned how to generate presentation and publication quality graphics of storm surge model output using the FigureGen software program (developed by J. Casey Dietrich, NC State University, CRC PI). On the last day of the program each student gave a presentation outlining their overall summer research tasks and experience with SUMREX.

8. Publications.

Tahsin, S., S.C. Medeiros, A. Singh, M. Hooshyar (2017), "Optical Cloud Pixel Recovery via Machine Learning", *Remote Sensing*, Vol. 9 (6), doi:10.3390/rs9060527..

Tahsin, S., S.C. Medeiros, A. Singh (2016). "Resilience of coastal wetlands to extreme hydrologic events in Apalachicola Bay." Geophysical Research Letters, Vol. 43, doi: 10.1002/2016GL069594.

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type (e.g., software, guidance document)	Delivery Date	Recipient or End User
CERA Video Tutorial	YouTube Video	02/28/2018	We were asked to withhold public release pending an upgrade to CERA

Table 2A: Documenting External Funding

Title	PI	Total Amount	Source

Table 2B: Documenting Leveraged Support

Description	Estimated Total Value
STOKES HPC at UCF	**$10,000**
Queenbee2 HPC at LONI	**$50,000**
Stampede2 at TACC (via XSEDE)	**$25,000**

Table 3: Performance Metrics:

HAGEN-MEDEIROS PERFORMANCE METRICS

Metric	Year 1 (1/1/16 – 6/30/16)	Year 2 (7/1/16 – 6/30/17)	Year 3 (7/1/17- 6/30/18)
HS-related internships (number)			
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)		1	1
Graduate students provided tuition/fee support (number)	1	1	
Graduate students provided stipends (number)	1	1	
Undergraduates who received HS-related degrees (number)			
Graduate students who received HS-related degrees (number)			
Graduates who obtained HS-related employment (number)			
SUMREX program students hosted (number)	1	2	
Lectures/presentations/seminars at Center partners (number)			
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)			
Journal articles published (number)	1	1	
Conference presentations made (number)			1
Other presentations, interviews, etc. (number)	8	10	1
Patent applications filed (number)			
Patents awarded (number)			
Trademarks/copyrights filed (number)			
Requests for assistance/advice from DHS agencies (number)		1	
Requests for assistance/advice from other agencies or governments (number)		2	
Total milestones for reporting period (number)	3	4	
Accomplished fully (number)	0	5*	3
Accomplished partially (number)	3	2	3
Not accomplished (number)	0		

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Develop scalable data processing pipeline for lidar-based surface roughness parameterization	06/30/2016	100%	
Finalize, validate and test NGOM forecast grade model and get running inside of ASGS	06/20/2018	100%	
Research Milestones			
Submit a manuscript on Regional Scale Lidar Surface Roughness	06/30/2016	80%	Efforts directed towards engaging with end users regarding NGOM model's integration into ASGS and CERA. Expect completion by 12/31/2018.
Submit manuscript on mesh optimization	6/30/2017	60%	Efforts were directed towards getting model for hurricane season 2018. Expected Completion 12/31/2018.

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Develop transfer protocol for NGOM model to ASGS including file naming convention, file compression, security keys, model update schedule, ADCIRC version control, etc.	07/31/2016	100%	
Participate in workshop (in-person or virtual) to discuss possible improvements to the interface at http://cera.cct.lsu.edu to facilitate both end-user experience and model output integration pipeline	03/31/2017	100%	
Transition Milestone			
Prototype integration of NGOM ADCIRC model output into CERA	06/30/2016	100%	
Refined transition goals and plan with end user input	06/30/2016	100%	
Implementation of preliminary optimized NGOM model in ASGS. Enables us to deliver surge imagery to NGOM Sentinel Site Cooperative and NWFWMD via email. This preliminary implementation sets up ASGS to automatically execute simulations of our optimized NGOM model using latest NHC storm tracks.	08/31/2016	100%	.
Full integration of NGOM ADCIRC model output into CERA. Enables NGOM Sentinel Site Cooperative and NWFWMD to view current surge forecasts on CERA. These surge forecasts will be generated by ASGS using the preliminary optimized NGOM ADCIRC model and latest NHC storm tracks.	05/31/2017	95%	Technical difficulties, high demand, and security issues at CERA have prevented full scale testing of automatic output integration of our results.

GINIS, URI
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title:

Modeling the combined coastal and inland hazards from high-impact hurricanes

Principal Investigator Name/Institution:
Isaac Ginis, Graduate School of Oceanography, University of Rhode Island

Co-Principal Investigators and Other Partners/Institutions:
David Ullman, Graduate School of Oceanography, University of Rhode Island
Tetsu Hara, Graduate School of Oceanography, University of Rhode Island
Chris Kincaid, Graduate School of Oceanography, University of Rhode Island
Lewis Rothstein, Graduate School of Oceanography, University of Rhode Island
Wenrui Huang, Department of Civil and Environmental Engineering, Florida State University
Austen Becker, Department of Marine Affairs, University of Rhode Island
Pam Rubinoff, Coastal Resources Center, University of Rhode Island
Reza Hashemi, Ocean Engineering, University of Rhode Island

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description ("elevator speech"):

This project advances modeling capabilities to assess and predict the impacts of landfalling hurricanes and nor'easters on critical infrastructure and communities in the Northeastern United States. The primary focus is on combined multiple hazard impacts, including coastal flooding due to storm surge and inland flooding due to rainfall. This project will allow DHS and other agencies to better understand the consequences of hazards associated with extreme weather in specific regions and to better prepare coastal communities for future risks.

Abstract:

This project is developing a modeling system to predict the consequences of coastal and inland hazards associated with high-impact landfalling hurricanes and nor'easters with complex storm characteristics in order to prepare coastal communities in the Northeast for future risks. Our modeling approach adds new capabilities to the real-time ADCIRC-SWAN system, such as improved surface wind modeling near the coast and over land, coupling effects of storm surge and waves, inland flooding from rainfall, incorporation of vulnerability data collected from emergency managers, and 3D visualization of hazard impacts. The ADCIRC mesh is highly refined in order to properly resolve the complicated coastal geometry of the New England coast including narrow inlets and salt ponds. The computational domain boundaries over land are reconfigured to allow river inflows from the major rivers for combined inland and coastal flood

modeling. Coupling of the storm surge and wave models include a sea state dependent drag coefficient and air-sea flux budgets. The Precipitation-Runoff Modeling System (PRMS) is applied to simulate rainfall runoff for all major rivers in southern New England. River flows are used as upland boundary inputs for ADCIRC to simulate the effects of rainfall runoff on coastal flooding. The Regional Ocean Modeling System (ROMS) model is used to investigate the effects of 2D vs. 3D on storm surge predictions and environmental impacts of hurricanes on estuarine systems. The prediction system includes 3D visualization and impact assessment tools to provide specific actionable outputs that are relevant to emergency and facility managers. Geographic points representing specific vulnerabilities are indexed directly into multiple nodes of ADCIRC and detailed 3D visualizations of critical infrastructure such as buildings, bridges and wastewater treatment plants allow for rapid impact assessment by the users.

PROJECT NARRATIVE

1. **Research Need**:

This project will assist DHS agencies such as FEMA and USCG to better understand the consequences of simultaneous coastal and inland hazards associated with landfalling hurricanes and nor'easters. Comprehensive ensemble modeling of the combined coastal and inland flooding and wave effects has not been previously considered. FEMA Region 1, a region that experiences infrequent but extremely severe hurricanes, currently lacks high-resolution storm surge models, relying primarily on SLOSH and other low-to-medium-resolution storm surge models for the area. In addition to storm surge, landfalling hurricanes and nor'easters in the Northeastern United States often cause extreme rainfall runoff and floods in coastal rivers, extreme waves during the hurricane often cause severe erosion in beaches and coastal roadways, and strong wave forces can cause damage to coastal and waterfront structures. The New England states of Connecticut, Rhode Island and Massachusetts are especially vulnerable to inland flooding since the rivers are relatively short and high-river discharge can coincide with coastal storm surge during extreme wind and rain events. This project will advance modeling capabilities of combined coastal and inland flooding in order to better prepare coastal communities in the Northeast for future risks from extreme weather. This research meets DHS priorities by strengthening national preparedness and improving the resilience of coastal communities in the face of coastal storm hazards. As such, this research addresses Presidential Policy Directive 8, which calls for increasing our level of National Preparedness by preventing, mitigating, responding to, and recovering from the hazards that pose the greatest risk.

2. **History**:

During the first three years of this project a multi-model framework was built, including state-of-the-art atmosphere, wave, ocean, and hydrology models in the southern New England. Major milestones include new capabilities and improvements to the ADCIRC-SWAN system, such as improved surface wind modeling near the coast and over land, coupling of storm surges and waves, and inland flooding from rainfall. The ADCIRC mesh has been highly refined in order to properly resolve the complicated coastal geometry of the New England coast including narrow inlets and salt ponds. Coupling of the storm surge and wave models include a sea state dependent drag coefficient and air-sea flux budgets. We have developed a new hurricane boundary layer (HBL) model for more accurate prediction of the surface winds near shore and over land during hurricane landfall. The Precipitation-Runoff Modeling System (PRMS) has been configured for several watersheds in Rhode Island and applied to simulate rainfall runoff for all major rivers. We have implemented the Regional Ocean Modeling System (ROMS) model and investigated the effects of 2D vs. 3D configurations on storm surge predictions and explored longer term impacts of hurricanes on estuarine systems. A 3D version of ROMS was used to track water masses of ecological and economic significance, particularly offshore nutrient sources and industrial chemical spills, and to quantify the erosion, transport and re-deposition of sediment in Narragansett Bay after hurricane landfall. The developed multi-model framework includes impact analysis and 3D visualizations of critical infrastructure such as buildings, bridges and wastewater treatment plants to provide specific actionable outputs that are relevant to emergency and facility managers. Our major transition effort involved collaboration with NOAA's National Weather Service Office, the DHS Office of Cyber and Infrastructure Analysis, FEMA Region 1, and Rhode Island Emergency Management Agency (RIEMA) to create a hypothetical high-impact scenario, "Hurricane Rhody" that was used to support a FEMA Integrated Emergency Management Course conducted by the Emergency Management Institute and RIEMA in Cranston, RI June of 2017. More than 160 participants attended the training course from state agencies, municipalities, non-profit organizations and FEMA Region 1.

This project is clearly compute-intensive and the primary challenge has been the availability of adequate computer resources. It has been addressed by our partners at the Coastal Resilience Center who provided access for our team to the computer cluster and data storage at the Renaissance Computing Institute (RENCI) at the University of North Carolina at Chapel Hill.

3. **Results**:

This project has advanced the state-of-the-art in coupled models for simulating the physics of atmosphere/ocean/estuarine/watershed processes during extreme weather events and their impacts on critical infrastructure. Here we briefly summarize our results, including primary outcomes and products. Details of the project activities and results are provided in Appendix.

We implemented the ADCIRC-SWAN modeling system for storm surge predictions in the Southern New England region and made several advancements to improve its performance. The ADCIRC mesh has been highly refined in order to properly resolve the complicated coastal geometry of the New England coast including narrow inlets and salt ponds. The Precipitation-Runoff Modeling System (PRMS) has been configured for several watersheds and major rivers in Rhode Island and applied to simulate rainfall runoff during historic and hypothetical hurricanes in New England. The computational domain boundaries of ADCIRC and PRMS are configured to allow river inflows from the major rivers for combined inland and coastal flood modeling.

We employed the Regional Ocean Modeling System (ROMS) model and investigated the effects of 2D vs. 3D on storm surge predictions. Using ROMS we explored longer term impacts of how tropical cyclones impact estuarine systems. We focused on tracking water masses of ecological and economic significance in Narragansett Bay – particularly offshore nutrient sources and industrial chemical spills. We showed that baroclinic effects are the dominant contributor to the non-tidal storm response and in developing modeling tools that accurately represent the longer-term impacts of a tropical cyclone it is not sufficient to rely on vertically integrated storm-surge models. We conducted a modeling study to quantify the erosion, transport and re-deposition of sediment in Narragansett Bay during and after the passage of a hurricane for the purpose of understanding the redistribution of potentially harmful pollutants from locations that are known to contain those contaminants to other, relatively contaminant-free locations.

We investigated the sensitivity of tropical cyclone wave simulations in the open ocean to different spatial resolutions using two wave models, WW3 and SWAN. We found that model errors in maximum wave predictions can be significant with coarser resolutions under a small and fast-moving storm.

We investigated the sea state dependent drag coefficient (C_d) in shallow water under hurricane wind conditions, by extending the approach of Reichl et al. (2014) that was developed for deep water. It is found that as water depth decreases, the sea state dependence of drag coefficient is enhanced. Also, the median value of C_d is gradually reduced at all wind speed with decreasing depth, compared to that in the deep water. In shallow waters, opposing swell can introduce large variability of C_d at lower (10-20m/s) wind speed.

We developed a hurricane boundary layer (HBL) model that utilizes the physical balances in the dynamic equations to determine how the near surface winds respond to local variability in the surface conditions (primarily topography and surface roughness) during hurricane landfall. Parametric wind models commonly used in storm surge modeling are typically too simplistic and are not capable of properly representing the changes in the wind structure when the hurricane moves from sea to land. The HBL model software infrastructure enables to run high-resolution wind simulations in a real time forecast mode.

In parallel with the development of high-resolution hazard models we have been developing innovative impact and visualization methods. While methods for creating aggregate hazard impact models based on statistically derived damage curves are well established (e.g., HAZUS), methods for creating highly granular impact models of individual infrastructure points that take advantage of the high-resolution and time-incremented aspects of the physical models have not been considered in the past. In our approach geographic points representing specific vulnerabilities are indexed directly into multiple nodes of ADCIRC and detailed 3D visualizations of critical infrastructure such as buildings, bridges and wastewater treatment plants allow for rapid impact assessment by the users. We enlisted local facility managers and other decision makers in the development a “concern thresholds database” that includes the concerns of specific facility managers as quantifiable thresholds that tie these concerns back to the hazard models. This allowed us to extend impact modeling to facilities for which there are not existing damage functions (e.g., effects of communications outages resulting from a wind-damaged cell tower).

Our team collaborated with NOAA’s National Weather Service Office, the DHS Office of Cyber and Infrastructure Analysis, FEMA Region 1, and Rhode Island Emergency Management Agency (RIEMA) to create a hypothetical high-impact scenario, “Hurricane Rhody” that was used to support a FEMA Integrated Emergency Management Course (IEMC) conducted by the Emergency Management Institute (EMI) and RIEMA on June 19-22, 2017. The four-day exercise which was attended by more than 160 emergency managers from Rhode Island municipalities, state agencies, and nonprofit organizations focused on the response and identifying key actions taken before, during, and after a hurricane. We developed the training material and 3D impact visualizations for use in the exercise. Outcomes from the course provided RIEMA with an opportunity to enhance overall preparedness, while actively testing modeling outputs during various parts of the course. RIEMA will use the developed materials for further trainings and exercises to update state preparedness to new threat standards.

4. **End Users and Transition Partners**:

Rhode Island Emergency Management Agency (RIEMA) and FEMA Emergency Management Institute (EMI)

1) The URI team provided modeling products and collaborated with Rhode Island Emergency Management Agency (RIEMA) and the Emergency Management Institute (EMI) to conduct an Integrated Emergency Management Course (IEMC) as part of a statewide preparedness exercise on June 19 – 22, 2017. The four-day exercise focused on the response to hurricane scenarios while identifying key actions taken before, during, and after a hurricane. Outcomes from the course provided RIEMA with an opportunity to enhance overall preparedness, while actively testing modeling outputs during various parts of the course. In this effort, the URI team worked closely with Stephen Conard at RIEMA, multiple stakeholders at EMI, and multiple stakeholders at the DHS Office of Cyber and Infrastructure Analysis in developing the impact analysis on critical infrastructures in Rhode Island. Stephen Conard, Training & Exercise Specialist, stated: "The information and modeling provided by URI will be used within RIEMA sponsored trainings and exercises to update the scientific data and modeling used. Also, RIEMA can use this information within the State Emergency Operations Center for catastrophic planning. The information given from URI can also be used in long-term planning to deal with the effects that sea level rise plays on 21 of RI's 39 communities."

2) Graduate student Bobby Witkop received a summer internship from RIEMA and was authorized to interview critical facility managers in Westerly, RI after he underwent background checks. RIEMA's personnel involved in this effort included Peter Gaynor – Director, Mark Bennett - Critical Infrastructure/Key Resources Coordinator, Tom Guethlein - Acting Associate Director of Program Operations at Rhode Island's Department of Human Services, and Tara Chicharro - Internship coordinator. Bobby Witkop created a database of 11 critical facilities in Westerly based on damage assessment from hypothetical Hurricane Rhody.

FEMA Region 1

Hurricane Program Manager, implemented the Hurricane Rhody scenario developed by our team into HVX decision support tool administered by FEMA for the Integrated Emergency Management Course on June 19 – 22, 2017.

NOAA NWS, Taunton, MA

Meteorologist-in-Charge and Hurricane Program Leader used the Hurricane Rhody scenario and output from the URI hurricane boundary layer model wind simulations to develop tropical storm advisories and hazard graphics for the weather briefings during the Integrated Emergency Management Course on June 19 – 22, 2017.

<u>NOAA/NWS/NCEP Environmental Modeling Center</u>
The URI team conducted an evaluation of the new operational (ST4) version of the WAVEWATCH 3 wave model in hurricane conditions and shared the results with the NCEP wave modeling group and during the WW3 developer meetings and provided recommendations to adjust/recalibrate the source terms in the WW3 wave action equations.

<u>DHS Office of Cyber and Infrastructure Analysis</u>
Senior Analyst conducted analysis of the impact of Hurricane Rhody on critical infrastructure for the Integrated Emergency Management Course on June 19 – 22, 2017 based on hazard model output provided by the URI team.

<u>RI Flood Mitigation Association</u>
We participated in the RI Flood Mitigation Association Annual Meetings to network with state emergency managers. Presentations of model outputs provided our team with feedback from local end users. These inputs have been incorporated into the model and outputs as feasible.

<u>RI Coastal and Resources Management Council</u>
We coordinated with this state regulatory agency on modeling and visualizations as a tool for planning, response and permitting. Discussions on integrating the models and programs (i.e. Shoreline Change Special Area Management Plan) are underway. This coordination also provides an example of how to link with 33 coastal states as well as NOAA's Office of Coastal Resources Management.

<u>RI Environmental Management Agency</u>
Efforts have been made to transfer technological advances and multi-modeling tools to those relevant RI management agencies that are tasked with protecting RI marine resources. We organized a meeting with RI EMA that included DHS team members Chris Kincaid, David Ullman and Lew Rothstein, along with Jim Boyd, (Coastal Policy Analyst, RI CRMC), David Beutel, (Aquaculture Coordinator, RI CRMC) and Conor McManus (RI DEM, Fisheries Management Section). Also present were Professors Dale Levitt and Scott Rutherford, researchers from Roger Williams University with extensive experience with RI Shellfishing activities, communities, outreach, and research. The outcome of the meeting was the consensus agreement that our DHS-funded modeling tools on the mobilization and transport of hazardous materials from the urban source regions in the north, through the sensitive and valuable fisheries resource regions of the mid-lower estuary, should be developed into planning and training activities.

5. **<u>Project Impact</u>**:
The unique aspect of this project is the employment a multi-model approach to characterizing and improving simulations of hurricane winds, waves, storm surge and inland flooding in coastal

regions combined with innovative hazard impact modeling and visualization methods. Below we list specific project's outcomes:

5.1 The project advanced current technologies and capabilities by developing end-to-end model simulations capable of representing extreme hurricane events from the open ocean, onto the shelf, through coastal estuaries and tributaries, and into coastal watersheds based on multiple, independent models that contributed to an ensemble of model solutions for DHS stakeholders in the southern New England region.

5.2 The project conducted detailed assessment of the performance of state-of-the-art coastal circulation, watershed rainfall and river flood models in representing the hurricane and other extreme weather hazards in the Rhode Island region.

5.3 The project conducted detailed assessment of the performance of two ocean surface wave models, WW3 and SWAN under hurricane forcing and communicated the results to operational wave modeling centers.

5.4 The project created a physically plausible hypothetical worst-case scenario (low probability, high impact), Hurricane Rhody, by combining multiple hazard impacts, including coastal flooding due to storm surge and inland flooding due to rainfall, based on a combination of historical storm elements.

5.5 The project developed multi-model strategies and methodologies for testing the benefits and unintended consequences of utilizing engineered structures (hurricane barriers) under a range of storm characteristics, and conducted detailed evaluations of the Fox Point Hurricane Barrier in Rhode Island.

5.6 The project transitioned the results from the physical modeling scenarios to DHS end users that helped to inform the impact on infrastructure and losses and the associated challenges in managing multiple threats with limited resources, and used this as a pilot for other emergency preparedness and response trainings.

5.7 The project designed a computationally efficient framework that combines multi-model ensemble output with interactive 3D visualization tools for training and real-time hazard impact analyses. These products are a substantial advancement of the existing tools that will maximize the utility of outputs from complex numerical models. They are produced in forms that are most useful for emergency managers, first responders, and other professionals from all levels of government and the private sector.

5.8 By contributing models and outputs (visualizations and impact scenarios) to RIEMA/FEMA training for their Integrated Emergency Management Course, the trainees of the statewide preparedness exercise are able to envision (and practice) and respond to "exercises that update our materials to current threat standards, instead of slightly outdated, unrealistic thresholds that growth has easily surpassed." (Stephen Conard, RIEMA). These materials are being considered for more trainings and exercises in the state and the Northeast region.

6. **Student involvement and awards**:

1. Involvement in Research

1) Xuanyu Chen, a PhD student at the Graduate School of Oceanography, focused her work on evaluation and improvements of the wave models WW3 and SWAN in hurricane conditions and investigated the sea state dependent drag coefficient in shallow waters during hurricane landfall.
2) Catherine Nowakowski, an MS student at the Graduate School of Oceanography, focused her work on advancing modeling of surface winds during hurricane landfall for predicting storm impacts.
3) Megan Layman, a MO student at the Graduate School of Oceanography, developed an ArcGIS interface for ADCIRC model output and analyzed coastal inundation from historic and hypothetical hurricanes that made landfall in the southern New England and the impact on critical infrastructure using E-911 classifications.
4) Peter Stempel, a PhD student at the Department of Marine Affairs, focused his work on developing techniques to integrate qualitative data into hazard models and produce 3D visualizations of model outputs.
5) Robert Witkop, a MS student at the Department of Marine Affairs, developed a methodology to collect qualitative data from emergency managers in a format that could then be integrated with the drivers that can be modeled (e.g., wind, wave, surge, flooding). He served as an intern in RIEMA's critical infrastructure program intern and conducted storm vulnerability analysis for 11 critical facilities in Westerly, RI.
6) Xiahui Zhou, a PhD student at the Graduate School of Oceanography, conducted a modeling study to quantify the erosion, transport and re-deposition of sediment in Narragansett Bay during and after the passage of a hurricane for the purpose of understanding the redistribution of potentially harmful pollutants from locations that are known to contain those contaminants to other, relatively contaminant-free locations.
7) Kevin Rosa, a PhD student at the Graduate School of Oceanography, focused his work on impacts of tropical cyclones on estuarine systems. He investigated water masses of ecological and economic significance in Narragansett Bay – particularly offshore nutrient sources and industrial chemical spills during and after the passage of a hurricane.

2. Degrees attained by students

1) Peter Stempel earned a PhD in Marine Affairs, 2014 – 2018, Dissertation title: *Depicting the consequences of storm surge and sea level rise: risk communication opportunities and ethics.*
2) Robert "Bobby" Witkop earned a Master of Marine Affairs, 2016 – 2018, Thesis title: *Developing Consequence Thresholds for Storm Impact Models: Case Study of Westerly, Rhode Island*

3. Student awards, publications, posters, presentations, etc.

<u>Student awards:</u>
- Propeller Club Scholarship awarded to Peter Stempel (2017)
- Graduate Student Research and Scholarship Excellence Award in Social Sciences, Arts, and Humanities, awarded to Peter Stempel (2018)
- Best poster award of the URI Graduate Conference awarded to Kevin Rosa (2018)

Student presentations (students indicated by *):

Stempel, P.*, Becker, A., (Accepted). "Effects of localization on perceptions of storm surge risk depicted in model driven semi-realistic visualizations." International Conference on Sustainable Development, NY, NY. September 26-28, 2018.

Chen, X. *, I. Ginis and T. Hara (2018). "Sea-State Dependent Drag Coefficient in Shallow Waters Under Tropical Cyclones", 21st Conference on Air-Sea Interaction, June 18 https://ams.confex.com/ams/23BLT21ASI/meetingapp.cgi/Paper/345222

Chen, X.*, T. Hara, and I. Ginis (2018). "Sea-state dependent air-sea momentum flux in a shallow water under a tropical cyclone", Ocean Sciences Meeting, February 14 https://agu.confex.com/agu/os18/meetingapp.cgi/Paper/303041

Ginis, I., C. Nowakowski*, and K. Gao (2018). "A Hurricane Boundary Layer Model for Simulating Surface Winds during Hurricane Landfall", 33rd Conference on Hurricanes and Tropical Meteorology, April 18, https://ams.confex.com/ams/33HURRICANE/webprogram/Paper339799.html

Ginis, I., D. Ullman, T. Hara, C. Kincaid, K. Rosa*, X. Chen*, B. Thomas, A. Becker, P. Stempel*, R. Witkop*, P. Rubinoff, W. Huang, M. Orr, R. Thomas, R. Thompson, M. Belk, P. Morey, and S. Conard (2018). "Advancing Modeling Capabilities and Impact Analysis Tools to Improve Preparedness for Major Hurricane Hazard Events", 98th AMS Annual Meeting, January 11, https://ams.confex.com/ams/98Annual/webprogram/Paper336049.html

Nowakowski, C.* and I. Ginis I. (2018): Advancing modeling of surface winds during hurricane landfall for predicting storm impacts, DHS Centers of Excellence Summit, May 30-31, 2018 https://cina.gmu.edu/coe-summit-2018/

Witkop, R.*, Becker, A., Stempel, P.*, (2018). "Incorporating facility manager knowledge into storm impact models: A case study of critical facilities in Westerly, Rhode Island," Rhode Island Floodplain Managers Association, Smithfield, RI, April 5.

Rosa, K.*, Kincaid, C. (2018). "Transporting Nutrients Northward from Rhode Island Sound Bottom Water to the Upper Narragansett Bay Euphotic Zone", RI C-AIM/RI NSF EPSCoR Symposium. Kingston, RI, April 9.

Rosa, K., Kincaid, C., Ullman, D., and Ginis, I. (2017). Hurricane Rhody: How does Rhode Island Fare Against Hypothetical Superstorm?. URI Graduate Conference. Kingston, RI. 8 April.

Rosa, K. *, Kincaid, C., Ullman, D., and Ginis, I. (2017). "Baroclinic Model of Narragansett Bay Post-Storm Shelf-Estuary Exchange", Estuary Research Workshop: Limiting Factors Beyond Nitrogen. Narragansett, RI. September 13.

Ginis, I., D. Ullman, T. Hara, C. Kincaid, L. Rothstein, W. Hwang, B. Thomas, X. Chen*, K. Rosa*, A. Becker, P. Stempel*, R. Witkop*, P. Rubinoff (2017). "Developing a mul.-model ensemble system for assessing hurricane hazards and impacts", URI Coastal Resilience Science and Engineering Workshop, December 4.

Ullman, D., I. Ginis, W. Hwang, P. Stempel*, T. Hara, C. Kincaid, L. Rothstein, P. Rubinoff, B. Thomas, X. Chen*, K. Rosa* (2017). "Assessing the Mul-ple Impacts of Extreme Hurricanes in Southern New England", URI Coastal Resilience Science and Engineering Workshop, December 4.

Witkop, R.*, Stempel, P.*, Becker, A., (2017). "Coupling local scale, high resolution, qualitative data to interface with numerical storm models", American Geophysical Union Annual Conference, New Orleans, LA. Dec. 12.

Stempel, P.* (2016). "Data Driven Visualization", Estuarine and Coastal Modeling Conference 2016, Narragansett, RI, June 14-15.

<u>Student publications:</u>

Witkop, R.*, Stempel, P.*, Becker, A.. Incorporating critical facility managers' knowledge into hazard impact models: A case study of Westerly, Rhode Island. *Frontiers in Citizen Science: Reducing Risk and Building Resilience to Natural Hazards. To be submitted.*

Stempel, P.*, Becker, A., (*In Prep*). Visualizations out of context. Implications of using simulation-based 3d hazard visualizations.

Stempel, P.*, Ginis, I., Ullman, D. S., Becker, A., Witkop, R.*, 2018: Real-Time Chronological Hazard Impact Modeling. *Journal of Marine Science and Engineering. To be submitted.*

Spaulding, M. L., Grilli, A., Damon, C., Crean, T., Fugate, G., Oakley, B., & Stempel, P.*, (2016). "Stormtools: Coastal Environmental Risk Index (CERI)." *Journal of Marine Science and Engineering*, 4(3).

Chen, X. *, I. Ginis, T. Hara: Sensitivity of Offshore Tropical Cyclone Wave Simulation to Spatial Resolution in Wave Models, Journal of Marine Science and Engineering, to be submitted.

<u>Other student press</u>

Disaster visualization work of Peter Stempel featured on front page of *Providence Journal*, (Nov. 27, 2016), "Rising seas, rising stakes, R.I. researchers project future flooding." Online at http://www.providencejournal.com/news/20161127/rising-seas-rising-stakes-ri-researchers-project-future-flooding

Peter Stempel featured in URI *Big Thinkers* (2016), "CELS grad student innovates ways to visualize climate change." Online at http://web.uri.edu/cels/cels-grad-student-innovates-ways-to-visualize-climate-change/.

Interactions with education projects:

Our team hosted two undergraduate summer interns from Tougaloo College in 2017. We took advantage of an opportunity presented when Tougaloo College approached us with the need to place students.

This project motivated a new URI-GSO minor (PODS-Proficiency in Ocean Data Science), a 4-course sequence with a capstone internship. The program involves all DHS Faculty PI's, with the fourth, or capstone course covering the multi-model hurricane-surge approach developed on this project. All courses and the PODS minor approved by general education and curriculum affairs committees and URI Faculty Senate.

Results from this research project have been used in class teaching and student's course projects in URI's large general education courses The Ocean Planet, OCG 110, Fall, 2016 and General Oceanography, OCG 301, Fall, 2016 and 2017.

Results from this research project have been used in class teaching and student's course projects at FSU: CWR4201, Hydraulic Engineering I, Fall, 2016, 20 students and a course project for CWR4201, Hydraulic Engineering I, Spring, 2017, 23 students

7. **Publications:**

Aijaz, S., M. Ghantous, A. Babanin, I. Ginis, B. Thomas. and G. Wake 2017: Nonbreaking wave-induced mixing in upper ocean during tropical cyclones using coupled hurricane-ocean-wave modeling. J. Geophys. Res. Oceans., 122, 3939-3963.

Blair, A., I. Ginis, T. Hara, and E. Ulhorn, 2017: Impact of Langmuir turbulence on upper ocean response to Hurricane Edouard: Model and Observations, J. Geophys. Res., 122, 9712–9724, http://DOI: 10.1002/2017JC012956.

Chen, X., I. Ginis, T. Hara, 2018: Sensitivity of Offshore Tropical Cyclone Wave Simulation to Spatial Resolution in Wave Models, Journal of Marine Science and Engineering, to be submitted.

Gao K, and I. Ginis, 2018: On the characteristics of roll vortices under a moving hurricane boundary layer, J. Atmos. Sci., 75, 2589-2598. https://doi.org/10.1175/JAS-D-17-0363.1

Gao, K., I. Ginis, J.D. Doyle, Y. Jin, 2017: Effect of boundary layer roll vortices on the development of the axisymmetric tropical cyclone J. Atmos. Sci. DOI: 10.1175/JAS-D-16-0222.1

Gao, K. and I. Ginis, 2016: On the Equilibrium-State Roll Vortices and Their Effects in the Hurricane Boundary Layer. J. Atmos. Sci., 73, 1205-1221.

Fei T., Q. Shen, W. Huang, I. Ginis, and Y. Cai, 2017: Characteristics of river flood and storm surge interactions in a tidal river in Rhode Island, USA, Procedia IUTAM, 25, 60-64, DOI: 10.1016/j.piutam.2017.09.009

Fei, T., W. Huang, and I. Ginis, 2017: Hydrological modeling of storm runoff in Taunton river basin by HEC-HMS and PRMS models, Natural Hazards, https://doi.org/10.1007/s11069-017-3121-y.

Fei Teng, Wenrui Huang, Yi Cai, Chunmiao Zheng, Songbing Zou, 2018. Application of PRMS hydrological model to simulate rainfall runoff in Zamaske-Yingluoxia Subbasin of the Heihe River Basin. Journal of Water, Accepted.

Fei T., W. Huang, I. Ginis, D. Ullman, Y. Cai, 2017. Integrated rainfall runoff and river hydrodynamic modeling for flood analysis in Woonasquatucket river basin. J. Frontiers of Civil and Structure Engineering, to be submitted November 2017.

Liu, Q., L. M. Rothstein, Y. Luo, D. S. Ullman, and D. L. Codiga, 2016. Dynamics of the periphery current in Rhode Island Sound, Ocean Modelling, 105, 13-24. DOI: 10.1016/j.ocemod.2016.07.001

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8. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type	Delivery Date	Recipient or End User
Hurricane Rhody scenario	Digital track files and model output	May 2017	NOAA NWS, Taunton FEMA Region 1, Boston
WAVEWATCH III	Hurricane Evaluation Analysis	July 2016	NOAA NCEP
Hurricane Rhody impact analysis	Damage spread sheets	April 2016	EMI, RIEMA
Hurricane Rhody visualizations	3D graphics	May 2017	EMI, RIEMA
Hurricane Rhody Master Scenario List (MSEL)	Digital tables aligning with storm timing	June 2017	EMI, RIEMA
WAVEWATCH III	Analysis of hurricane waves	February 2017	NOAA NCEP

Table 2A: Documenting External Funding

External Funding			
Title	PI	Total Amount	Source
Improving NOAA's HWRF Prediction System through New Advancements in the Ocean Model Component and Air-Sea-Wave Coupling	Ginis	$260,000	NOAA
GFDN operational tropical cyclone model maintenance and support	Ginis	$134,000	Navy

Advancing tropical cyclone models through explicit representation of boundary layer roll vortices	Ginis	$260,000	ONR-Navy
Langmuir turbulence under tropical cyclones	Hara, Ginis	$376,000	NSF
Airflow separations over wind waves and their impact on air-sea momentum flux	Hara	$355,000	NSF
4D physical models of migrating mid-ocean ridges: Implications for shallow mantle flow	Kincaid	$357,000	NSF
Collaborative Research: 3D Dynamics of buoyant diapirs in subduction zones	Kincaid	$442,000	NSF
NOAA/RISG: Quahog Larval Dispersion and Settlement in Narragansett Bay	Kincaid Ullman	$199,000	RI Sea Grant/NOAA
Authentic Data and Visualization Experiences and Necessary Training (ADVENT): An undergraduate model for recruiting students to STEM careers in the U.S. Navy	Pockalny Kincaid	$750,000	ONR-Navy
Rhode Island Sound as a Potential Source of HAB Toxins for Narragansett Bay	Ullman	$140,000	RI Sea Grant
MARACOOS: Preparing for a Changing Mid-Atlantic	Ullman	$75,000	NOAA, Rutgers Subcontract
Optimizing Seaweed and Shellfish Integrated Multi-Trophic Aquaculture: Developing a Spatially Explicit	Humphries, Ullman, Kincaid,	$300,000	NOAA

Ecosystem Model	Thornber		
Summer Undergraduate Research Fellowship in Oceanography (2 students from Tougaloo)	Rubinoff	$12,000	NSF

Table 2B: Documenting Leveraged Support

Description	Estimated Annual Value
Returned Indirect Cost [1]	$10,000
Graduate Student tuition	$30,000
Microsoft Azure Research Award, a one-year grant that allows our project to utilize cloud computing technology.	$20,000
Support for graduate students Peter Stemple and Robert Witkop from URI Coastal Institute and RI Sea Grant	$40,000
Support for graduate students Kevin Rosa and Xuanyu Chen from State Funded TA's.	$40,000

[1] The University of Rhode Island's Coastal Institute (CI) has generously agreed to return 66% of their share of indirect cost return back to the project. The CI obtains 17% of the indirect cost, so roughly 11.3% of indirect cost is being returned to the project.

Table 3: Performance Metrics:

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17- 6/30/18)
HS-related internships (number)	0	0	0
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	0	0	0
Graduate students provided tuition/fee support (number)	2	3	3
Graduate students provided stipends (number)	2	3	3
Undergraduates who received HS-related degrees (number)	0	0	0
Graduate students who received HS-related degrees (number)	0	0	0
Graduates who obtained HS-related employment (number)	0	0	0
SUMREX program students hosted (number)	0	2	2
Lectures/presentations/seminars at Center partners (number)	1	3	2
DHS MSI Summer Research Teams hosted (number)	0	0	0
Journal articles submitted (number)	2	7	6
Journal articles published (number)	7	8	9
Conference presentations made (number)	15	14	15
Other presentations, interviews, etc. (number)	12	22	17
Patent applications filed (number)	0	0	0
Patents awarded (number)	0	0	0
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	3	5
Requests for assistance/advice from other agencies or governments (number)	5	13	12
Total milestones for reporting period (number)	11	21	19
Accomplished fully (number)	9	17	19
Accomplished partially (number)	2	4	0
Not accomplished (number)	0	0	0

12. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/2017 – 6/30/2018

Research Activity	Proposed Completion Date	% Complete	Explanation of why activity / milestone was not reached, and when completion is expected
Investigate the impact of wave coupling on simulated coastal ocean flooding. Implemented the URI air-sea coupling module (ASCM) into the ADCIRC/SWAN model.	12/31/2017	100%	
Set up the river flood model and provided time series of flow and water levels at RI rivers as boundary conditions for ADCIRC and tested its performance in historic hurricanes.	12/31/2017	100%	
Simulated the impact of hypothetical Hurricane 'Rhody' on coastal and inland flooding and compared it to the historical events.	12/31/2017	100%	
Refined ADCIRC mesh to provide uniformly high resolution (30 m minimum cell size) over Narragansett Bay and the adjacent southern New England shelf. Continue to work on improvements of the ocean circulation/storm surge and hydrological models and investigate the impact of opening or closing the Fox Point Hurricane Barrier on the magnitude of flooding in the Providence area.	12/31/2017	100%	
Conducted tests of mesh nesting capabilities in ROMS, for use in DHS simulations. Focus on defining benefits of enhanced resolution in the most sensitive regions of the estuary (e.g. Port of Providence, Fox Point	11/30/2017	100%	

Hurricane Barrier, etc.).			
Developing total storm impacts through multi-model approach: preliminary simulations of after hurricane environmental impacts. Fate/impacts of a) chemical releases from Port of b) mobilized debris.	12/31/2017	a. 100% b. 100%	This activity has been added in the course of the project based on feedback from end users. Summary provided in Appendix
Ran ROMS tests of key differences in 2D versus 3D predictions for transport of chemical fields and debris for Hurricanes Carol and Bob.	11/30/2017	100%	
Improved computational efficiency and software infrastructure of the Hurricane Boundary Layer model	6/30/2018	100%	
Implemented ADCIRC on Microsoft Cloud Computing Platform, Azure.	6/30/2018	100%	
Investigated the role of hurricanes on shelf-estuary exchange in Narragansett Bay using ROMS and observations during Hurricane Floyd.	6/30/2018	100%	
Conducted a modeling study to quantify the erosion, transport and re-deposition of sediment in Narragansett Bay during and after the passage of a hurricane for the purpose of understanding the redistribution of potentially harmful pollutants.	6/30/2018	100%	

Investigated the sensitivity of tropical cyclone wave simulations in the open ocean to different spatial resolutions using WW3 and SWAN.	6/30/2018	100%	
Investigated the sea state dependent drag coefficient in shallow water under hurricane wind conditions.	6/30/2018	100%	
Implemented and tested the Precipitation-Runoff Modeling System (PRMS) in Blackstone River Basin.	6/30/2018	100%	
Collected new data regarding local concerns of facility managers and other decision makers in Rhode Island and integrated as ADCIRC flood model output.	6/30/2018	100%	

Research Milestone			
All research milestones associated with the research activities described above have been achieved. Details are provided in Appendix to this report.		100%	Summary is provided in Appendix.

13. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Generated model output in a digital format compatible with FEMA Hazus and other software.	8/01/2017	100%	
Training workshop for DHS, DEM, NOAA/NWS and other end users.	11/31/2017	100%	

Transition the results to end users, and tailor output from our model simulations to the software tools they routinely use.	12/31/2017	100%	
Provided model output to the project led by James Opaluch for examining the variable response of counties, communities, firms and individuals to different hurricane impact scenarios and analysis of the most significant barriers to adoption of hazard mitigation behaviors by different interest groups for different decisions.	8/01/2017	100%	
Transitioned the wave coupling methodology developed during this project to NOAA NCEP/EMC, including wave coupling module for NWS operational models and documentation.	12/31/2017	100%	
Transition Milestones			
Organized Workshop with RIDEM and other end users, October 10, 2017.			
Organized a breakout session "Assessing the Impact of Extreme Hurricanes in Rhode Island" at RI Preparedness Conference. August 9, 2017.			
Joint URI-RIEMA presentation at the New England Weather Conference: Ready for Hurricane Rhody? FOXBORO, MA, November 4, 2017 http://www.providencejournal.com/news/20171104/weather-conference-asks-are-we-ready-for-hurricane-rhody			
Three presentations at the URI Coastal Resilience Science and Engineering Workshop, December 4, 2017.			
Multiple interviews to state and local media about the project.			
Attended and presented at ADCIRC Week, session: ADCIRC for Decision Makers, College Park, MD, April 11, 2018			
Attended and presented at the DHS Centers of Excellence Summit, Arlington VA, May 30-31, 2018			

RESIO – UNF
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency

Principal Investigator Name/Institution: Donald T. Resio, Ph.D., University of North Florida

Co-Principal Investigators and Other Partners/Institutions: Dr. John Atkinson, ARCADIS, and Bruce Ebersole, Jackson State University.

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description: Rising sea level and growing coastal populations increasingly threaten lives and livelihood of those living along coasts and the environment in which they live. Planning decisions for a range of timescales must be based on accurate information on hazards and risks; however, the present state of the art does not include critically important combined hydrologic-surge sources of flooding. This project will focus on the development of a methodology for incorporating these interactions in a statistically and physically appropriate manner into FEMA's operational coastal modeling systems.

Summary Abstract: The primary objectives of this project have been 1) to develop a statistical method for including rainfall-runoff effects into FEMA-JPM studies and 2) to develop a stable, adaptable numerical scheme to combine hydrologic and surge models into a common executable system, and 3) to produce a preliminary evaluation of the impacts of combining these effects into improved estimates of flooding hazards. Ancillary goals that were important to work on this project were 1) to ensure involvement of students into studies of coastal resilience and 2) to coordinate our work with potential end-users and collaborators. Some primary accomplishments on this project include an improved understanding of the role of natural structure in flooding hazards and the identification/development of analysis tools to utilize this information in combined hydrologic-surge flooding. Also, during this project, all graduate students in the Coastal Program at UNF participated in a forensics study of the impact of Hurricane Matthew, which provided an excellent motivation for students to understand the importance of hurricane impacts in terms of dune breaching relative to their location within a half-completed beach-fill project in Jax Beach. The final report accompanying this Year 3 Performance Report provides information on changes in flooding patterns and depths for a range of storm tracks and rainfall rates, along with conclusions concerning a statistical approach that appears to offer a flexible basis for conducting FEMA RiskMap studies within reasonable computer resources.

PROJECT NARRATIVE:

1. Research Need: Rainfall and coastal tributaries/rivers greatly affect inundation patterns and levels throughout the U.S. East and Gulf coasts. Present coastal flood maps neglect hydrologic-

surge interactions, significantly underestimating the extent and magnitude of hazards and risks in essentially all major urbanized areas and underestimating actuarial insurance costs; therefore, improved quantification of this compound flooding is essential to establishing clear guidelines for coastal resilience. The research needed to accomplish this task consists of two major elements 1) improving the statistical treatment of combined hydrologic-surge flooding and 2) developing stable, efficient and accurate numerical methods for coupling hydrologic and surge models into a common numerical framework. The fundamental problem in achieving this goal is to retain accuracy and stability in the numerical code while still allowing all necessary computer simulations to be completed within an acceptable level of computer resources. It is well recognized that existing RiskMap studies require many extensive, time-consuming model simulations in order to obtain estimates of flooding hazards in coastal areas. The number of simulations needed for this purpose has been shown to be directly related to the number of different parameters required to represent the phenomena responsible for causing the flooding. If rainfall, antecedent conditions, and river/tributary discharges were added to this list in a fashion that required execution of both the surge model and coupled hydrologic model in a simplistic manner, this could increase the number of simulations needed by more than an order of magnitude. The results shown in the accompanying report suggest that this may not be necessary.

2. History:
   - Primary steps taken to carry out the project

     Year 1

     i. obtain river discharge and rainfall data for statistical analysis
     ii. form user group for project communication
     iii. obtain gridded bathymetry-topography of study area for ADCIRC model, wind fields for simulations for the study area
     iv. obtain hydrologic models (HEC-RAS and SWAT) for hydrologic testing

     Year 2

     v. Develop statistical characterization of rainfall patterns relative to the deterministic PHRaM algorithm
     vi. Perform sequence of tests of different methods of coupling a modified SWAT model to the ADCIRC model
     vii. Characterize the rainfall and James River discharge statistics

     Year 3

     viii. Choose a set of storm tracks and rainfall patterns to test sensitivity of response to variations in the hydrologic variables and utilize a response function to examine the sensitivity of flood levels to these variations
     ix. Provide skype briefing on statistical methods to user group
     x. Write final report

   - Major project milestones
     i. Data acquisition
     ii. Statistical characterization of rainfall patterns, amounts and variability
     iii. Three stages of model coupling tests
     iv. Definition of test cases for demonstration of modeling system and sensitivities to rainfall and James River discharge
     v. Presentation to user group and obtain feedback

- Problems or challenges that arose, how they impacted progress, and the action taken to address them.
    i. Insufficient radar data available for entire study time period forced a greater reliance on meteorological station data and multivariate analyses of the intrinsic rainfall patterns in time and space.
    ii. The lack of readily available open-source hydrologic models for the area of application made it necessary to borrow parts of the SWAT model approach (basin-scale) and implement a gradually varied flow (GVF) approximation on the hydrologic-surge model interface. This did not affect water levels much on the surge side in areas which opened into broad, deep water bodies but definitely had important effects in rivers and on the hydrologic side of the boundary in our model tests.
    iii. A problem that emerged during our interactions with hydrologic groups is the tremendous inertia in the hydrologic modeling systems. The amount of site-specific tuning and event specific tuning makes the users very reluctant to consider changing to a different model than the one they are presently using. This issue was beyond the scope of our project but definitely will need to be solved either by making a "universal" coupling system or by choosing a "universal" hydrologic model to couple with ADCIRC. Clearly, the latter of these two choices is preferred for RiskMap applications.

3. <u>Results:</u>

    i. Our final results suggest that it is indeed possible to avoid an overly large increase in the number of computer simulations using methods investigated during this project; however, these findings could be site specific and additional tests at other sites are recommended.
    ii. The characterization of rainfall characteristics in terms of mean function have only begun to receive the level of analysis and local modification needed to ensure that they can be used along all East and Gulf Coast areas to set insurance rates in this area.
    iii. Given the results of our set of simulations, it is very appropriate that the continuation of this effort with focus on different accuracies of hydrologic model combinations with ADCIRC, using different types of boundary conditions at their intersection.
    iv. An important part of the work involved in the investigation into different types of statistical techniques that could be considered for RiskMap applications. In particular, Resio et al. (2017) showed the importance of allowing the physical influence of natural structure to influence statistical analyses.

4. <u>End Users and Transition Partners:</u>

    i. Coastal communities that need accurate information for their planning
    ii. FEMA managers since they can justify raising rates to cover costs. Since the estimated risk, with combined effects neglected, greatly

underestimates the rates and the distribution of flooding problems over the entire flooding range from nuisance to extreme disasters.

iii. Coast Guard, USACE and other first responders who could obtain improved estimates of expected locations of flooding and preposition materials that have a high likelihood of being needed in the immediate, critical post-storm interval.

- Organizations/agencies or other partners that participated in transition planning and implementation and the role they played.

  i. Agency

  FEMA HQ
  FEMA Region I
  FEMA Region II
  FEMA Region III
  FEMA Region IV
  FEMA Region VI
  US Coast Guard
  USACE
  NOAA

  ii. These individuals were assembled into a review team by Mr. Ebersole (JSU) and interacted with him to provide feedback to the overall team.

  iii. A number of collaborators such as Larry Atkinson and Michelle Covi from Old Dominion University worked with us to appreciate special considerations for the study area.

- Transition

  i. Via the final report accompanying the Performance Report and from the journal publication on the role of natural structure in statistics.

- How end-users are using the results

  i. Presently used only as a building block to move to a more formalized system for coupling surges and hydrologic flooding into a unified statistical analysis. The current coupling method should be adaptable to any hydrologic model linked with the ADCIRC model; however, the applications in developing a production version for a hydrologic-surge system is not complete.

  ii. Concepts from the statistical methods developed as part of this study are currently being adapted to the application of coupled tide-surge statistics in the New York City appeal to FEMA. This is potentially an important adaptation to the previously proposed method that provides both reduced numbers of simulations required and more accurate results.

5. Project Impact:
    - The overall impact is the enhanced ability to analyze the structure of coupled interactions in numerical modeling systems which could become an enabler for the production of significantly more accurate hazard and risk estimates in coastal areas. This is a necessary step toward making the risks represent the actual expected economic losses in coastal areas.

6. Student involvement and awards:
    - Students involved in research, including research assistants or other student participants.
        i. A mandatory class for all graduate and selected undergraduate students on the topic of damages caused by Hurricane Matthew along the coast in the three coastal counties in the vicinity of Jacksonville. The class covered all aspects of flooding and wave induced damage in this tri-county area and presented their findings at a special, well attended, session at the annual American Shore and Beach Preservation Association in Ft Lauderdale in 2017. We have also designed a special Risk Assessment course to teach students new statistical tools that are needed for quantifying coastal resilience.
        ii. Amanda Tritinger is working on a new class of model which incorporates the vertical structure of currents into a model such as ADCIRC. She is the first author on a recently submitted manuscript on this topic to the Journal of Geophysical Research (JGR).

    - Degrees attained by students supported through your project.
        i. Nikole Ward who was funded for one semester under this DHS project was awarded her MS in Civil Engineering and is now in the UNF-UF Ph.D. program working on the topic of an improved representation of beach recovery following storm.
    - Student awards, publications, posters, presentations, etc.
        i. Amanda Tritinger gave a presentation in Liverpool, England in September 2017 on the topic of her recently submitted JGR paper.
        ii. Amanda Tritinger received the Coasts Oceans Ports and Rivers Institute (COPRI) award for the best student poster at the 2017 national convention.
        iii. Nikole Ward received the COPRI award for best student poster at the 2018 national convention.

7. Interactions with education projects:
    i. Rudy Bartels, Ph.D. candidate at LSU, spent 4 weeks at UNF working with Dr. Resio on multivariate analyses of climate data.
    ii. Dr. Resio gave a lecture in 2017 on "The Effect of Natural Structure on Storm Surge Probabilities" at LSU.

8. Publications

i. Resio, D.T., T.G. Asher, J.L Irish, 2017. The Effects of Natural Structure on estimated tropical cyclone surge extremes. *Nat Hazards,* **88,** 1609-1637.

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type (e.g., software, guidance document)	Delivery Date	Recipient or End User
Analysis of effects of natural structure on coastal flooding hazards	Journal Publication	3/2017	Scientific community and users of hazard information in coastal areas
Two-way coupling method for hydrologic-surge modeling	Software	10/2017	Modelers and developers of the next-generation modeling system
Integration of hydrologic and surge modeling and preliminary assessment of options	Report	7/2018	DHS and all agencies involved in CRC activities

Table 2A: Documenting External Funding

Title	PI	Total Amount	Source
Coupled Rain-Surge Flooding in the Upper Barataria Basin	Resio	$60,000	Louisiana Water Institute
Guidelines to Electric Power Research Institute for	Resio	$30,000	EPRI
Development of Combined Storm Surge and Rainfall-Hydrologic Modeling for the coast of Louisiana	Resio	$60,000	Louisiana RESTORE funding

Table 2B: Documenting Leveraged Support

Description (e.g., free office space; portion of university indirects returned to project; university-provided student support)	**Estimated Total Value**
UNF student support for Matthew forensics study	$30,000
UNF Taylor Engineering Research Institute contribution to project	$50,000

Table 3: Performance Metrics:

RESIO PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17- 6/30/18)
HS-related internships (number)			
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)			
Graduate students provided tuition/fee support (number)	1		
Graduate students provided stipends (number)	1	2	1
Undergraduates who received HS-related degrees (number)			
Graduate students who received HS-related degrees (number)			
Graduates who obtained HS-related employment (number)	2		
SUMREX program students hosted (number)		1	
Lectures/presentations/seminars at Center partners (number)	1	1	1
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)	1	1	1
Journal articles published and Book Chapters (number)	1	1	
Conference presentations made (number)		1	1
Other presentations, interviews, etc. (number)	1		1
Patent applications filed (number)			
Patents awarded (number)			
Trademarks/copyrights filed (number)			
Requests for assistance/advice from DHS agencies (number)	1	1	
Requests for assistance/advice from other agencies or governments (number)	1	1	
Total milestones for reporting period (number)	3	2	2
Accomplished fully (number)	1	5	1
Accomplished partially (number)	2	6	1
Not accomplished (number)			

10. Year 3 Research Activity and Milestone Achievement:

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Analysis of Coupled Flooding Statistics and Modeling Boundary Conditions	7/2018	100%	Rainfall report was included within the final report
Research into the effects of natural structure on statistical processes critical to coastal hazards	12/2016	100%	Published in 2017
Research Milestones			
Rainfall-Hydrology-Statistics and Modeling Integration Report	2/2017	100% (7/2017)	It was late but was reached
Journal Publication	12/2016	100%	Accepted before12/2016 but published in early 2017

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Presentation of teleconference to collaborators and end-users	2017	100%	
Final report on statistical-modeling approach to combining hydrologic and surge driven flooding in the Tidewater Virginia area	2017	100%	
Technical Guidelines for FEMA application of coupled hydrologic-surge modeling for coastal flooding hazards	No date proposed		This was intended as an ultimate goal but was not given a completion date, since it depended on many factors that had to be better understood during the research
Transition Milestones			
Application of Methodology to an area of interest	No date proposed	100%	An application of the modeling system to show statistically relevant impacts which could be quantified was completed as intended; however, a complete JPM study is well beyond the scope and resources of the current project, so this should be recognized as a demonstration of what can be done, not a full JPM application.

TWILLEY, LSU
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Integrated Modeling Approaches with Application to Pre- and Post-Disaster Planning for Creating More Resilient Communities

Principal Investigator Name/Institution:
Robert R. Twilley, Louisiana Sea Grant/Oceanography & Coastal Science, LSU

Co-Principal Investigators and Other Partners/Institutions:
Jeff Carney, Coastal Sustainability Studio (CSS), LSU
Traci Birch, Coastal Sustainability Studio (CSS), LSU
Carola Kaiser, Center for Computation and Technology (CCT), LSU
Brant Mitchell, Stephenson Disaster Management Institute (SDMI), LSU

Project Start and End Dates: 1/1/2016 – 6/30-2018

Short Project Description:

Communities can improve their ability to reduce repetitive losses associated with flooding from coastal storms by improving how flood risks are incorporated in mitigation planning immediately following an event. Post-disaster recovery planning can be a driving force behind mitigation and recovery planning that will improve public safety and economic recovery.

Summary Abstract:

We propose that an integration of coastal modeling tools linked to innovative design/planning approaches, together with effective outreach to both emergency managers and land use planners is needed to provide crucial community-level data for effective pre- and post-disaster planning. Beyond large-scale models or those that only demonstrate one aspect of hazard impact (e.g. storm surge), communities need clear guidance on exactly which vulnerable infrastructure and populations may be threatened and/or protected (pre-disaster planning and rapid response), and accurate post-event impact in order to make crucial land use and redevelopment decisions quickly. The ability to leverage this type of community-specific data provides the opportunity to avoid loss and rebuild for maximum future risk reduction. The trans-disciplinary LSU partnership builds on the strengths of several research centers and outreach institutions that incorporate science of coastal flooding with new techniques in community resilience planning. This collaborative effort provided transformational products to vulnerable communities to actively address improved flood prediction, protection, and response. We incorporated established modeling outputs into a new consequence model showing how flood risk (both from storms and SLR) will impact people, industry, and infrastructure. This much needed information was used to enhance pre- and post-disaster planning efforts. Louisiana Sea Grant, SDMI and CSS engaged federal, state and local planners and emergency managers to

incorporate these products into planning efforts. Beyond the targeted work being undertaken with established partner community(ies), the products were leveraged to develop integrated approaches for university-based design studio courses and design/outreach entities addressing these issues. The products and concepts developed from this project demonstrated utility during Louisiana 2016 Flood and hurricane season of 2017 (Hurricanes Harvey, Irma and Maria).

PROJECT NARRATIVE:

1. Research Need:

This project responds to the HSE problems defined by the need to assess future coastal flood risks and to create more flood resilient communities in the future. Our project proposes novel techniques to allow vulnerable communities to plan, react, and recover more quickly and effectively in areas facing repetitive disturbance. The goals of the program are to improve emergency response with regard to protecting vulnerable infrastructure and populations, and to reduce repetitive loss by providing accurate impact data to community planners in the immediate aftermath of an event. This program focuses on significant reduction in risk with the use of high-fidelity storm surge data and impact scenario viewers during the pre-disaster planning and rapid reaction to storms, and accurate information useful to post-disaster recovery planning. The transition of these models is proposed in a community design format with local planners in a 'Resilience Institute'. The proposed project solidly supports the mission and goals of the DHS Strategic Plan QHSR. In particular, the proposal supports DHS's Mission 5 (Strengthen National Preparedness and Resilience) to create tools and partnerships that ensure effective, unified planning and response operations in the during extreme weather events.

2. History:

The Mississippi River Delta (MRD), like most deltaic coasts around the world, have rates of sea level rise plus high rates of deltaic subsidence that amplify the risks to coastal flooding today that represents what most other coastal cities will experience in future decades. The persistent impacts of relative sea level rise together with natural hazards such as hurricanes severely threatened infrastructure that is critical to the livelihood and economic well-being of Louisiana and the nation. The seafood industry, energy sector, and shipping/navigation industries in this coastal region represent some of the most significant contributions to the national economies of the USA. Given that many of these industries are fixed to coastal locations, there is limited capacity for the business community and workforce to migrate inland even under scenarios of increased future flooding risk. This fixed location is typical of many industries that are located in coastal regions that have access to marine transportation and unique natural resources. These industries located along coastal regions are also made up of small towns, rural areas, and major cities – all of which are vital to the workforce and service industries of these industries, but who struggle to become more resilient in the face of rising seas and storminess. With accelerated sea level rise and natural hazard impacts projected over the next century, subsequent disruptions to business, critical infrastructure, and individuals will challenge the ability of coastal communities and industries to meet increasing demand for goods and services to supply the nation's economy. Therefore, it is critical that vulnerable coastal communities and industries have access to quality information and processes that protect assets and reduce the cycle of repetitive loss. This includes a range of strategies, from improved predictive capabilities and communications that guide strategic protection of assets and populations during an event to coordinated plans that improve the quality and efficiency of recovery. Simply put, the driving forces behind hazard response and recovery planning are public safety and economic recovery.

Recognizing the need for community-level hazard impact models, LSU, in collaboration with UNC, developed a high-accuracy tool that presents storm surge modeling forecasts and real-time surge information in an effective, user-friendly, and visually appealing way. This tool, known as Coastal Emergency Risk Assessment (CERA), has been a critical and important first step in the process of real-time forecasting and an essential precondition for conveying accurate information to industry and community leaders. CERA provides 3-5 ensemble runs during an active tropical storm for each advisory, based upon information on track conditions provided by the NOAA National Hurricane Center (NHC). CERA has added features, which have been used such as during Joaquin and Hurricane Isaac, to provide flood projections based on modifications of the NHC forecasted track – including runs within the eastern and western boundaries of the NHC central track. In addition, modifications in wind speed have been included, along with these multiple tracks, to give emergency managers a glimpse of 'what if' scenarios of hurricane track forecasts. While CERA provides high-resolution detail of storm surge, it does not link this information to industry, infrastructure, or vulnerable populations.

We propose that an integration of coastal modeling tools linked to innovative design/planning approaches, together with effective outreach to both emergency managers and land use planners is needed to provide crucial community-level data for effective pre- and post-disaster planning. Beyond large-scale models or those that only demonstrate one aspect of hazard impact (e.g. storm surge), communities need clear guidance on exactly which vulnerable infrastructure and populations may be threatened and/or protected (pre-disaster planning and rapid response), and accurate post-event impact in order to make crucial land use and redevelopment decisions quickly. The ability to leverage this type of community-specific data provides the opportunity to avoid loss and rebuild for maximum future risk reduction.

We developed a unique collaboration among three LSU research centers (Coastal Sustainability Studio (CSS) and Stephenson Disaster Management Institute (SDMI)) and a research and outreach organization (Louisiana Sea Grant College Program (LSG)) to develop pre- and post-disaster planning and adaptation tools for coastal communities to increase resilience. These efforts are designed to enable vulnerable communities to plan, react, and recover more quickly and effectively in areas facing repetitive disturbance. The goals of the program are to improve emergency response with regard to protecting vulnerable infrastructure and populations, and to reduce repetitive loss by providing accurate impact data to community planners in the immediate aftermath of an event. This program focuses on significant reduction in risk with the use of high-fidelity storm surge data and impact scenario viewers during the pre-disaster planning and rapid reaction to storms, and accurate information useful to post-disaster recovery planning. Together this group will provide (1) planning tools that visualize aggregated risks to include hurricane force winds, storm surge, and inland flooding along with vulnerable populations based on socio-economic status; (2) modeling and visualization tools to communicate flood risks during a tropical cyclone event by identifying vulnerable populations and structures that are susceptible to storm surge; (3) provide post-landfall search and rescue grid system with prioritization based on socio-economic vulnerabilities; (4) develop methodology for helping community planning departments and recovery planning teams effectively utilize and implement changes to their built environment through effective resilience based planning. User groups and Sea Grant outreach program were organized to facilitate awareness of products generated from this project, with focus on how to communicate vulnerable infrastructure and populations to regional planners. The trans-disciplinary LSU partnership builds on the strengths of each research center and outreach institution, and developed transformational products to vulnerable communities to actively address improved flood prediction, protection, and response.

We incorporated established modeling outputs into a new consequence model showing how flood risk (both from storms and SLR) will impact people, industry, and infrastructure. This much-needed information can be used to enhance pre- and post-disaster planning efforts. Louisiana Sea Grant and CSS engaged federal, state and local planners and emergency managers to incorporate these products into planning efforts. The new model, known as the Coastal Emergency Risk Assessment (CERA) Planning tool, incorporated many NOAA and other federal products (e.g., NOAA National Ocean Service, NOAA's River Forecast Centers, NOAA's National Centers for Environmental Information (NCEI), NOAA's Weather Prediction Center, and the NOAA National shoreline data, along with USGS, and USACE) to inform local consequence model results. User groups and Sea Grant outreach program are able to facilitate awareness of products generated from this project, with focus on how to communicate vulnerable infrastructure and populations to regional planners (with research funding from Sea Grant to enhance how flood risk is communicated to public).

The CERA visualization system and the website itself provide enhancements to DHS' mitigation programs and community preparedness plans, as well as a pathway to improved timely and accurate information to the public during hurricane threats. This tool has been modified using the results of a focus group described below to incorporate attributes across the landscape that will be vulnerable under different hurricane scenarios utilizing hindcasts of real storms in the region. Hurricane Isaac was used to test the ability of CERA Planning to capture those attributes of infrastructure that advisory panels recommended are needed by planners and emergency managers as critical to the resiliency of communities during extreme weather events. The CERA Planning tool has been utilized in design studios in Architecture at LSU to initiate the process of building approaches towards a Resilience Institute. The CERA Planning tool has been developed as partial support of graduate students in Stephenson Disaster Management Institute.

3. <u>Results:</u>

This project, starting with the establishment of a focus group of federal, state and local planners and emergency managers, evaluated what variables should be tracked in terms of consequences of storm surge to people, homes, and infrastructure to assist them in making critical decisions during and immediately following storm events. A list of end users involved in this process are listed in the transition section below. This aggressive outreach component was established to ensure local, state and federal planners and emergency mangers were aware of this project and its potential to influence their decision-making and planning processes. The project team has completed several outreach opportunities that include the State of Louisiana American Planning Association (APA), the Louisiana Emergency Preparedness Association's (LEPA) general session and the National Homeland Security Conference. In addition, direct outreach with several federal agencies to include FEMA Region VI, U.S. Coast Guard, DHS Protective Services and the National Communication Center have also taken place. The Focus Group took place on September 21, 2016, with initial focus towards Louisiana and Region VI. **A**dditional users such as the National Communications Center were involved for input to continue to provide situational awareness for all communications infrastructure during tropical cyclones and U.S. Coast Guard – Sector New Orleans.

The first phases of developing CERA Planning was to modify a 143,000-point infrastructure database for the State of Louisiana and historical storms to determine effectiveness of consequences to inform planning process. A FEMA's Hazard Mitigation Grant Program to GOHSEP funded GIS Hazard Mitigation project to accomplish the following:

1) the collection of 6-inch high resolution imagery for the entire state; and
2) collection of critical infrastructures for all 64 parishes;
3) additional imagery consisting of 4-inch resolution for all cities in the state with a population of at least 10,000 and 3-inch resolution for the metropolitan areas of New Orleans and Baton Rouge was also captured in 2014.

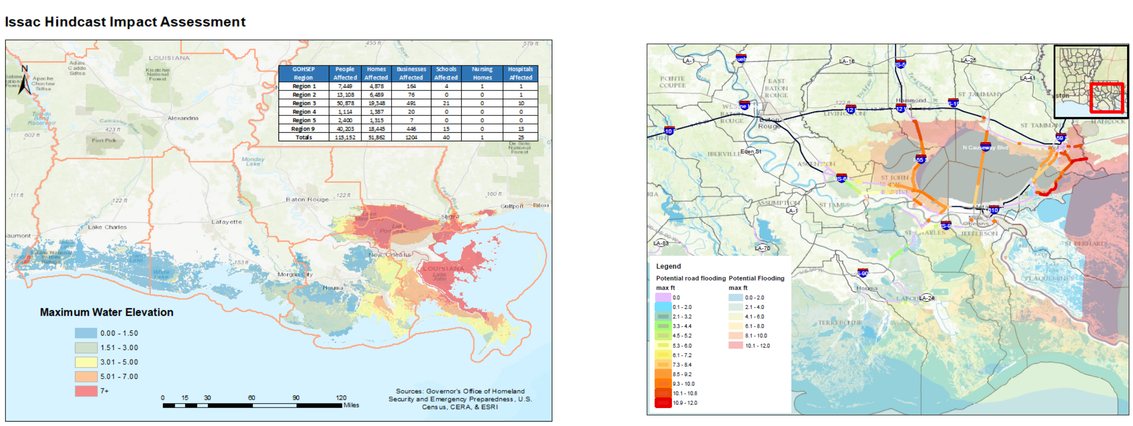
The LSU team worked with the State to first develop the state's 144k point infrastructure database as the basis on which to build the consequence model. Additional work was performed with individual agencies such as DHS Protective Service and USCG District 8 on refining additional infrastructure requirements. Critical infrastructure from the data base was shared with a focus group agreed to focus discussion on what would be best approach in developing critical infrastructure for the CERA Planning tool, using initial data sets that were identified for consequence model. The focus group recommended that available parcel data and building footprints data be added to the consequence model. The also emphasized that critical to the locals would be the status of water utilities, sewer treatment plants and any surge that would disrupt their operations. Without the ability to provide potable water, a community has little ability to recover and sustain their populations following a major disturbance. The focus group continued to develop critical infrastructure from the FEMA data set that would address the following groups:

Safety: Nursing homes/hospitals, Fire/police (Brant has this)
Water: Drinking water and sewerage infrastructure
Energy: pipelines and energy generation (yet there was issue of this information being made public)
Accessibility: airports, roads, ports, rail, evacuation routes – and in particular major roads and evacuation routes with elevations/flood depths/topo maps so emergency managers can get from point A to point B.
Telecommunications: telephone and cable.

The development of CERA Planning first utilized a consequence model developed at SDMI that is based on social vulnerability of communities along coastal Louisiana. This consequence model was designed and built as an automated model in ArcGIS to interpret outputs of CERA to analyze the consequences of expected storm surge. The consequence model has roots in emergency management, serving during Hurricane Isaac to understand decision making process when storm surge results were provided to state and parish government officials. Output from

CERA was placed in hindcast on critical infrastructure and business assets that were threatened from flooding to understand potential impacts to LaPlace and other local communities (Figure 1). The process of exporting CERA website information to consequence analysis of SDMI in hindcast of storm surge predictions help to focus conversations on vulnerability of community operations and recovery to flooding. Cyberinfrastructure was developed to transfer information from CERA to Consequence Model (GIS platforms) to expand the utility of products associated with critical infrastructure along the coast. Along with this effort was a build out the Storm Surge Vulnerability Index for at risk parishes, such as Vermillion and Camaron parishes. Again, the idea was to 'distill' the 144k data set on critical infrastructure to set of criteria that would define community vulnerability during an event that would utilize information from CERA to help decision making based on flood predictions and potential infrastructure damage. This vulnerability and mapping exercise, again using both Storm Surge Vulnerability Index maps of parishes in southwest Louisiana, and hindcast consequence maps of Hurricane Isaac, were outputs used by emergency managers for Federal, State and Local governments to help identify the critical infrastructure that should help lead a planning tool.

A second approach to developing CERA Planning was to incorporate results of the SDMI consequence model directly into CERA. Rather than exporting CERA output into a GIS consequence model, the project moved to using the discussion of critical infrastructure with the SDMI consequence model dealing with emergency operations to focus on infrastructure during the recovery phase that planners should pay particular attention during mitigation strategies to reduce repetitive losses. This modeling process involved loading selective datasets from the FEMA data set described above (the 144k data points of infrastructure sponsored by FEMA grant) directly into CERA. A hindcast storm run for Hurricane Isaac 2012 on the latest ADCIRC mesh for Louisiana (2017, collaboration with Center for Coastal Resiliency@ LSU, Scott Hagen) was developed with several of the critical infrastructure attributes described above (SWEAT). An example of such a mapping exercise developed using CERA directly to demonstrate CERA Planning is shown in Figure 2.



GOHSEP Region	People Affected	Homes Affected	Businesses Affected	Schools Affected	Nursing Homes	Hospitals Affected
Region 1	7,449	4,878	164	4	1	1
Region 2	13,108	6,489	76	0	0	1
Region 3	50,878	19,348	491	21	0	10
Region 4	1,114	1,387	20	0	0	0
Region 5	2,400	1,315	7	0	0	0
Region 9	40,203	18,445	446	15	0	13
Totals	115,152	51,862	1204	40	1	25

Figure 1. Maps based on consequence modeling using CERA hindcast of Hurricane Isaac to determine how information on flooding of critical infrastructure would assist with emergency operations that identify vulnerability of community operations following storm impacts. (left panel) Statewide assessment by region of people, homes, hospitals and businesses affected. (right panel) Highways in the Lake Pontchartrain area impacted by Hurricane Isaac.

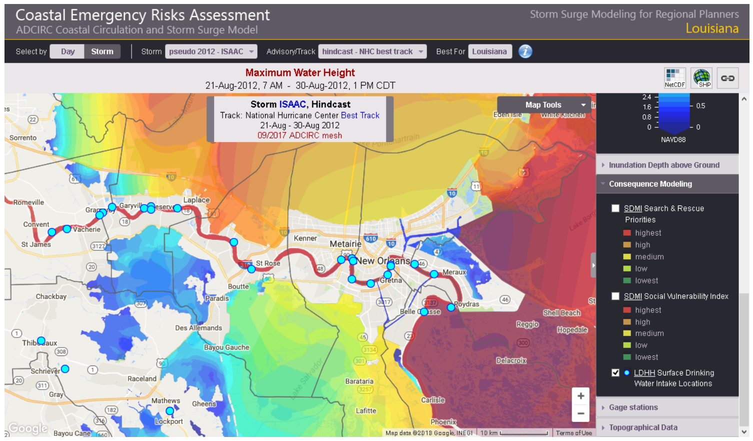


Figure 2. Hindcast of Hurricane Isaac with critical infrastructure using water intake locations to define community vulnerability during a storm surge event.

The CERA Planning tool (Figure 3) is based on cyberinfrastructure scripts that incorporate information on critical infrastructure and transferring infrastructure data to GIS platforms that is defined as the original Consequence Model of this CRC project. The output of this hindcast of Hurricane Isaac and other vulnerability scenarios of southwest parishes, user groups help to define the transition from vulnerabilities based on emergency management to discussion of how to mitigate future losses with better design. Based on discussions with advisory groups, critical infrastructure was slowly imported directly into CERA website that were focus of interactions with planning community. Model integration between the consequence model data inventory and the CERA storm surge visualizations were tested using hindcasts of Hurricane Isaac. Linkages were also proposed with HAZUS, but not implemented in this study. Two courses in Architecture have been taught engaging the CERA tools from this grant to test feasibility of infrastructure selected to planning designs, but have yet to be implemented fully as a course focus due to lack of tool completion in time for use in course development. Part of the delay in sequencing various components of this project was the requests during the 2016 and 2017 Louisiana and Texas floods in which an exercise for the Governor and Unified Command Group requested scenarios developed using ADCIRC and the Consequence Model (see impact section below). These products actually accelerated completion of partnerships with GOHSEP and the LA National Guard as part of the hurricane planning exercise by developing products for the 2017 hurricane season.

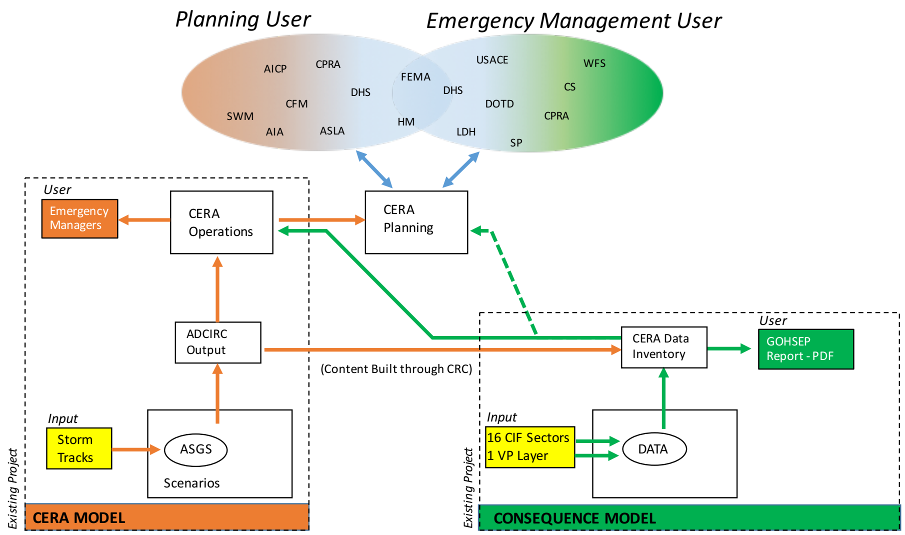


Figure 3. Diagram demonstrating the integration of information on consequence model and content provided by CERA Model using ADCIRC simulations of storm surge during extreme weather events as planning tools for both emergency managers and planners.

4. <u>End Users and Transition Partners:</u>

This project, starting with the establishment of a focus group of federal, state and local planners and emergency managers, assisted in determining what variables should be tracked in terms of consequences of storm surge to people, homes, and infrastructure to assist them in making critical decisions during and immediately following storm events. These end users continue to provide contacts to transition information into the proper combination of consequence modeling into the CERA Planning tool.

- Federal Emergency Management Agency (FEMA) - Federal Preparedness Coordinator
- Federal Emergency Management Agency – Region VI Hurricane Program Manager
- Department of Homeland Security (DHS) Federal Protective Services - Protective Service Advisor
- National Weather Service (NWS) – Slidell/New Orleans Forecasting Office
- Louisiana Governor's Office of Homeland Security and Emergency Preparedness (GOHSEP) – Deputy Director for Preparedness, Response and Interoperability
- Louisiana Coastal Protection and Restoration Authority (CPRA) – Michael Ellis, Executive Director
- Louisiana Department of Wildlife and Fisheries (LDWF) – Patrick Banks, Deputy Director
- Louisiana Office of Community Development (OCD) – Pat Forbes, Secretary
- Louisiana National Guard, - MAJ Robert Fudge
- US Coast Guard – Sector New Orleans - Port Security Specialist
- Local Planners –
  - Bob Rivers, Planning Director – City of New Orleans
  - Louisette Scott, Planning Director – City of Mandeville, LA

- Chris Pulaski, Planning Director – Terrebonne Parish, LA
    - Doug Burguires, Assistant Planning Director, Lake Charles, LA
    - Jennifer Gerbasi, Terrebonne Parish Recovery Planner
    - Frank Duke, Director – East Baton Rouge Parish Planning Commission
    - Lynne Dupont, GIS Coordinator – New Orleans Regional Planning Commission
    - Jamie Setze, Director – Capital Area Planning Commission
  - Emergency Managers –
    - Dev Jani, Deputy Directory – City of New Orleans
    - Dexter Accardo, Director - St. Tammany Parish OHSEP
    - John Rahaim, Director – St. Bernard Parish
    - Earl Eues, Director, Terrebonne Parish
  - Sea Grant Agent - Kevin Savoie, Camaron Parish
  - National Sea Grant Office

5. Project Impact:

This project, starting with the establishment of a focus group of federal, state and local planners and emergency managers, will determine what variables should be tracked in terms of consequences of storm surge to people, homes, and infrastructure to assist them in making critical decisions during and immediately following storm events. Each of the agencies described above have been involved in the development of CERA and its use during several recent hurricane events, such as Hurricane Isaac. These agencies made commitments through attendance at workshops dedicated to training on CERA products, and technology updates prior to hurricane season, that continue the partnerships that exist to efforts by CERA and SDMI to provide emergency management quality information during storm events. In addition, SDMI has established relationships with local partner communities that served as case studies for the Consequence Model production and targeted planning efforts. There was an attempt during the program to integrate these two advisory groups, first responders and community planners, to help in the transition of CERA into a planning tool. However, the development of Consequence Model by SDMI and the CERA model with Sea Grant continued to evolve in separate advisory circles. In addition, the planning community with Coastal Sustainability Studio, while helpful at the initial stages of defining critical infrastructure for post-mitigation planning, stayed focus on issues that evolved from Louisiana Floods of 2017 and did not connect with the CERA Planning tool development.

Tool development for Consequence Model and the CERA Planning tool did develop and produced several products in software development, data management protocols using critical infrastructure data sets, and vulnerability indices that are representative of the technical developments of this project (Figure 3). The use of Hurricane Isaac hindcast as a focal point of how Consequence Model and CERA Planning could exchange information and provide different outputs of critical infrastructure vulnerability was very effective during the project (Figures 1 and 2). These products allowed for internal development of information that could be shared with user groups, such as SDMI continued discussions with emergency managers, and presentation on importance of planning to the annual conference of Louisiana Emergency Preparedness Association (LEPA). In addition, products of Consequence Model and CERA

Planning were used in studios in Architecture at LSU to foster adaptations of flood risk into community planning. In addition, products of CERA Planning and Consequence Model were used in sophomore course in 'Ecosystem Design', which was part of a new minor in Delta Sustainability developed at LSU. Material from CERA Planning were also used to help frame some of the training for new members of Governor Coastal Commission on Restoration and Protection during January 2018 session. The mapping exercises of flood risks and critical infrastructure using Hurricane Isaac continued to have impact on training of emergency management, but has only limited impact on training of planning professions to support post-event mitigation techniques.

It was anticipated that CERA-Planning would be tested by professional planners, planning directors, and professional organizations at Louisiana Emergency Preparedness Association (LEPA) Conference in May 2018. The original concept was that this exercise would improve the integration of SWEAT infrastructure into the hindcast of Hurricane Isaac as prototype of CERA-Planning to be presented to planners. However, in spring 2018, it was decided that CERA Planning should focus on DHS sectors as guide to interact with planning tools that would help with mitigation efforts following major flood events. Discussion with NIST and FEMA, along with DHS leadership, focused CERA Planning on moving from state efforts in planning to more case studies using developed planning guides that are being incorporated at the federal level. Conference calls and webinar with NIST was organized during spring and summer 2018 to initiate the utility of CERA Planning into those techniques and guidelines. In addition, efforts have been initiated, at the request of FEMA, to test the application of CERA Planning with the mitigation planning guidelines that are being developed at Texas A&M by Dr. Phil Burke. Both of these efforts are in the stage of identifying coastal communities in Louisiana to apply the NIST and TAMU techniques, and test the application of CERA Planning to those case studies.

A final component of the Consequence Model was the development of a localized Storm Surge Social Vulnerability Index (SSVI). Portions of this tool were developed for Vermillion Parish, and expanded to other parishes in southwest Louisiana. SSVI includes a base map in which vulnerable populations are geographically identified, along with socio-economic data (include age, gender, income, and education etc.), housing characteristics, proximity to hospitals, fire stations, police stations to evaluate safety factors. The data is aggregated to determine overall vulnerability, and along with real time storm surge information is designed to improve disaster response operations such as targeted evacuations and search and rescue. Post-storm, the SSVI will assist emergency managers and planners in analyzing impacts to industry, infrastructure, and social systems, and provide critical information necessary for recovery and adaptation planning. The SSVI was used to help with initial stages of what critical infrastructure should be considered by working groups and in discussions with planning professionals. But the development of SSVI as a component of CERA Planning was not pursued based on feedback from CRC advisory comments and leadership discussions.

The Louisiana Flood of 2016 and Hurricane Season of 2017 captured the efforts of CERA Planning tool and discussion of how to use storm surge information in real time extreme flood events. There was discussion of importance in regional watershed planning associated with flood events during 2016 in Lafayette and greater Baton Rouge area in Louisiana. Several of the Principle Investigators of this project were involved with providing guidance to recovery plans associated with the 2016 Louisiana Flood. This included the development of strategies to link flood modeling and assessment with visualization tools such as CERA to guide recovery efforts. Robert Twilley was on planning team for Flood Symposium held on 7 Dec 2016 in Lafayette, LA. LSU CSS played a significant role in advising local planning commissions and professionals on mitigation strategies following the 2016 Flood. In addition, LSU CSS was recipient of large National Academy of Science grant to develop mitigation strategies to inland flooding as part of coastal resilience. These guidelines and grant opportunities are associated with this ability to apply storm surge models to mitigation planning strategies.

In addition, Consequence Model and CERA were active during Hurricane Harvey. Figure 4 shows some of the infrastructure vulnerability mapping provided by Consequence Model as to assets potentially threatened in Louisiana during the event. There were follow up site visits in Texas during January 2018:

- Coast Guard Sector Houston-Galveston gathered information about operational need for an organized GIS database of vulnerable coastal infrastructure including tanks and pipelines
- Rice University is building a database of Above Ground Storage Tanks (ASTs). The response of institutions in Texas to improving the integration critical infrastructure with storm surge modeling techniques captures the learning from CERA/ASGS operations and CERA Planning during Hurricane Harvey.

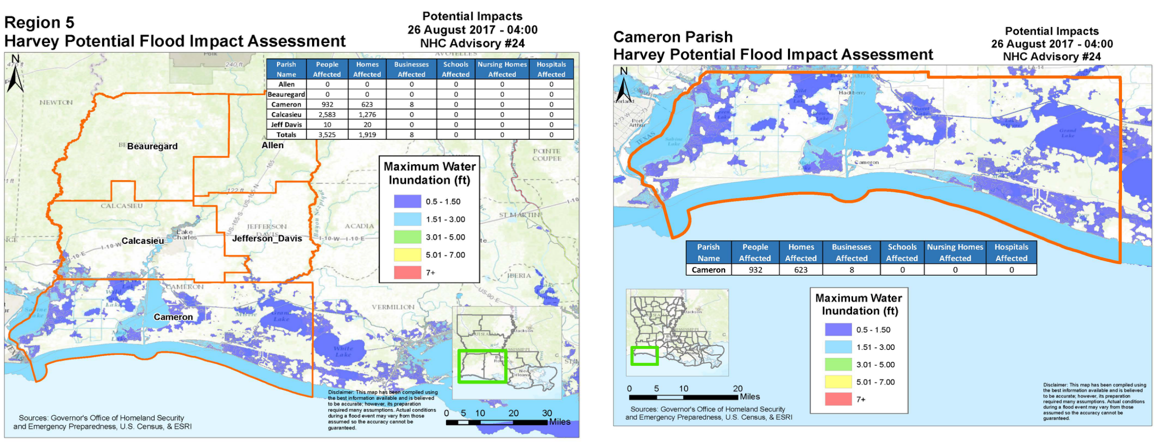


Figure 4. Pre-landfall estimates of potential impacts from flooding at regional and parish level associated with Hurricane Harvey in 2018. These predictions are based on CERA output being transferred to Consequence Model developed during this CRC project.

Tool development in this CRC project was very effective in transitioning two separate analysis of flood prediction and flood consequences into a more holistic approach. Two separate approaches in developing CERA and developing Consequence Model was finally integrated into a system of priority infrastructure and planning initiatives to develop a CERA Planning tool that is capable of providing insights during mitigation planning exercises following a major storm event (transition from pre to post disturbance utility). However, the application of this new tool was not realized during this CRC project. The change in strategy from continued developing of local planning guidelines, to using present guidelines that are emerging at the national level (and part of the DHS responsibility) is a much-improved approach to testing the utility of CRA Planning tool. This strategy will include the following.

1. Utilize discussions with CRC leadership to determine how the outcomes of consequence model and CERA Planning tool can be integrated into existing systems and training opportunities to improve planning actions creating more resilient communities such as those created by NIST Community Resilience program.
2. Collaborating with the APEX group would be helpful to the continued development of CERA Planning to make sure the selection of infrastructure used in model results has utility to those engaged in post-disturbance needs.
3. Using CERA-Planning to inform other tool development programs on what specific information may be most effective in changing the perspective of planning process. CERA Planning is a tool that is testing a variety of techniques to be more effective in communicating the risk of flooding on planning decisions.

6. Student involvement and awards:
   - A graduate research assistantship was funded on this project that was used to support Nick Robles. His contributions to the project was programming scripts that developed the Consequence Model, including programming to exchange information from CERA into GIS platforms to map flooding exposure and the location of key assets and critical infrastructure. His programming also supported the access of critical infrastructure assets from data bases into CERA to help develop CERA Planning tool.
   - Nick Robles completed the requirements for a Masters of Science
   - Undergraduate interns were supported in the LSU Coastal Sustainability Studio to assist with collecting and organizing GIS information on the 2016 Louisiana Flood.

7. Interactions with education projects: Describe your involvement with CRC's education partners over the life of your project, including student interns hosted at your institution, lectures and other activities conducted at partner institutions, etc.

   - The CERA Planning Tool was presented on a zoom conference in Computer Science at Johnson C Smith University (RETALK) on February 22, 2018. In addition, Jeff Carney of LSU CSS participated in lectures at UNC involving course in Mitigation Community Planning, led by Dr. Gavin Smith.
   - Dr. Twilley gave a guest lecture on coastal resilience of Mississippi River Delta at UNC Institute of Marine Science, hosted by Dr. Mike Piehler.

8. Publications:

   N/A

9. Tables:

Table 1: Documenting CRC Research Project Product Delivery

Product Name	Product Type (e.g., software, guidance document)	Delivery Date	Recipient or End User
CERA Planning Web Site	Software	March 2018	Used to inform how storm surge exposure can be incorporated into NIST Community Resilience products
Python script for Consequence Model	Software	June 2017	Emergency Management Agencies such as LA GOHSEP (Governor's Office of Homeland Security and Emergency Preparedness)
Analysis of FEMA data set	Data platform – Statistical software	December 2016	Emergency Management Agencies such as LA GOHSEP (Governor's Office of Homeland Security and Emergency Preparedness)
Advisory Group Report	Guidance document	June 2017	Louisiana Planning Association to guide discussion of CERA Planning Tool
Consequence mapping script	Software	March 2018	Emergency Management Agencies such as LA GOHSEP (Governor's Office of Homeland Security and Emergency Preparedness)
Storm Surge Vulnerability Index (SSVI)	Software	June 2017	Emergency Management Agencies such as LA GOHSEP (Governor's Office of Homeland Security and Emergency Preparedness)

Table 2A: Documenting External Funding

Title	PI	Total Amount	Source
Improved Algorithms for Computing Storm Surge (STORM) (NSF)	Hartmut Kaiser	$206,560	National Science Foundation
Coastal SEES Project on Accelerated Flood Risk with Delta Degradation	Robert Twilley	$298,683	National Science Foundation
Port Resilience Index (NOAA)	Robert Twilley	$20,000	NOAA

Louisiana Community Resilience Institute I, II & III (Kresge, Sea Grant)	Jeff Carney	$50,000	KRESGE

Table 2B: Documenting Leveraged Support

Description (e.g., free office space; portion of university indirect returned to project; university-provided student support)	**Estimated Total Value**
Free Office Space	$28,000
Portion of university indirect returned to project	$26,480
Reduced rates on high performance computing	$25,000
Support of ASGS development by Louisiana Sea Grant	$75,000

Table 3: Performance Metrics:

TWILLEY PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17-6/30/18)
HS-related internships (number)			
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)	1	1	1
Graduate students provided tuition/fee support (number)	1	1	1
Graduate students provided stipends (number)	1	1	1
Undergraduates who received HS-related degrees (number)			
Graduate students who received HS-related degrees (number)			
Graduates who obtained HS-related employment (number)			
SUMREX program students hosted (number)			
Lectures/presentations/seminars at Center partners (number)	1	2	3
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)			
Journal articles published (number)			
Conference presentations made (number)	5	3	3
Other presentations, interviews, etc. (number)	6	2	3
Patent applications filed (number)			
Patents awarded (number)			
Trademarks/copyrights filed (number)			
Requests for assistance/advice from DHS agencies (number)	7	6	11
Requests for assistance/advice from other Federal agencies or state/local governments (number)	5	4	3
Total milestones for reporting period (number)	8		
Accomplished fully (number)	3		
Accomplished partially (number)	5		
Not accomplished (number)	0		

10. Year 3 Research Activity and Milestone Achievement.

Research Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Research Activities	Proposed Completion Date	% Completed	Explanation of why activity/ milestone was not reached
Determine which variables in the Louisiana model are available for other coastal states.	Dec 2017	100 %	
Build automation and integration between the Consequence Model and CERA website.	Mar 2018	100%	
Research Milestones			
Validate SSVI with operational data from historical storms	Dec 2017	100%	
Develop process to create the SSVI for other coastal parishes	Mar 2018	100%	

11. Year 3 Transition Activity and Milestone Status:

Transition Activities and Milestones: Final Status as of 2018
Reporting Period 7/1/2017 – 6/30/2018

Transition Activities	Proposed completion date	% completed	Explanation of why activity / milestone was not reached
Integrate CERA modeling and visualization tools that define how CERA consequence tool can improve regional planning	Mar 2018	100%	
Development of an annual Resilience Institute designed to connect decision makers in small coastal communities with planning and technical resources for resilient development. Integrate this effort with flood response programs to Louisiana 2016 flood	June 2018	25%	Resilience Institute format with selected mayors was performed; and planning for resilient development were performed as part of Louisiana 2016 flood; but the CERA Planning tool was not developed sufficient as utility to these institute and planning activities.
Discuss with NOAA and FEMA on how to utilize the feedback from user groups and operational exercises with GOHSEP on how to expand the utility	June 2018	100%	Discussions moved forward with how CERA Planning can be incorporated into the NIST Community Resilience program.

of products on regional and national level			Plans were developed to establish case study with community in coastal Louisiana (see explanation for not completing workshop at LEMA).
Discuss with leadership of APA how to utilize community resilience workshop products on regional and national level	Mar 2018	100%	
Host workshop at LEMA annual meeting in May 2018 that trains hazard mitigation planning on use of tool for flood vulnerability	June 2018	0%	Decisions were made to move the focus of CERA Planning from state level emergency management conference to case study of coastal community using NIST Community Resilience planning tools.
Transition Milestones			
Produce and test integrated design and planning strategies for risk prone coastal communities	June 2018	25%	CERA Planning tool is being coordinated with case study of coastal community using NIST Community Resilience planning tools.
Produce guidelines on an annual Resilience Institute that describes how CERA, with integrated consequence modeling tools, can be used as planning and technical resource for resilient development for FEMA and GOHSEP (LA Governor's Office of Homeland Security and Emergency Preparedness). CERA uses standardized interfaces for web mapping and data distribution; updates will continue to work with clients and provide data via export functions in the CERA interface (export buttons), OpenDap data distribution services or FTP data services to ensure that our clients can benefit from our results.	June 2018	75%	CERA Planning tool is being coordinated with case study of coastal community using NIST Community Resilience planning tools. Using this federal planning document together with storm surge exposure from CERA Planning, a more national technical resource will be formulated. CERA and Consequence Model were used during Hurricane Harvey as example of model development utility; CERA interface with other utility by clients was expanded during the 2017 Hurricane Season

Theme 4

Education and Workforce Development

FAIK, JCSU
DHS COASTAL RESILIENCE CENTER
EDUCATION PROJECT
FINAL/YEAR 3 REPORT TEMPLATE

Project Title:

Preparing Tomorrow's Minority Task Force in Coastal Resilience through Interdisciplinary Education, Research, and Curriculum Development.

Principal Investigator Name/Institution:

PI, Dr. Ahmed Faik, Johnson C. Smith University

Other Partners/Institutions:

UNC-Chapel Hill, UNC-Charlotte, and Jackson State University (major partners)

Project Start and End Dates:

July 1, 2017 – June 30, 2018

Short Project Description:

We focus on the integrative, interdisciplinary nature of real-world problems and strive to bridge traditional academic programs to develop solutions to coastal resilience and its related problems facing our nation. The proposed program will build an undergraduate education framework to prepare tomorrow's minority task force in coastal resilience (approximately 80% of students are minorities), which presents tailored courses in coastal resilience, applied research experience, knowledge transfer activities, scientific seminars, and summer camps.

PROJECT NARRATIVE:

1. Introduction and project overview:

   Given the national need to prepare future coastal resilience professionals with educational and research experience, this proposed program supports a critical mission. Most existing coastal resilience related curriculum currently either target graduate programs or vocational education. We developed an undergraduate education framework that meets the needs and standards for excellence in undergraduate education.

   The project was designed around the following aims:

   1) **Goal 1**: Develop a curriculum to prepare undergraduate students for careers in coastal resilience;
   2) **Goal 2**: Create partnerships to conduct applied research in the area of coastal resilience;
   3) **Goal 3**: Create ongoing opportunities for the transfer of skills, knowledge, people and ideas between JCSU and the community at large.

   To help reach the above-mentioned goals, we defined the following processes:

1) **Process 1**: Develop four new courses to educate students with demonstrated interests and aptitudes in coastal resilience study;
2) **Process 2**: Design and deploy interdisciplinary coastal resilience seminar series;
3) **Process 3**: Establish and develop Faculty/Student research collaborations in coastal resilience;
4) **Process 4**: Design and offer a 1-week summer research camp to expose and increase the awareness of undergraduate students in coastal resilience study.
5) **Process 5**: Design and offer a 4-week summer research project to expose and increase the awareness of undergraduate students in coastal resilience study.

2. Project History:

1) **Process 1**: Three courses related to the DHS CRC program (Data Mining, Introduction to Geographic Information System (GIS), Risk Analysis and Management) were developed. Two of these three courses (Introduction to Geographic Information System (GIS), Risk Analysis and Management) were also taught. The third course (Data Mining) was given a code and added to the catalog. We are planning on having the two above-mentioned courses (Introduction to Geographic Information System (GIS), Risk Analysis and Management) added to the catalog as well. We are also planning on developing, teaching and adding to the catalog a fourth course (Technology in Emergency Management).
2) **Process 2**: We developed, added to the curriculum of the department major and presented 2 seminar series. In these seminar series we had five professors from different universities, who are involved in research related to the DHS CRC program, give presentations about their corresponding topics of research.
3) **Process 3**: two faculty members in our computer science department developed and conducted faculty/student CRC-related research during the Spring 2018 semester.
4) **Process 4**: One group of 20 students conducted a one-week summer research camp supervised by two faculty members from our Computer Science and Engineering department.
5) **Process 5**: Three groups of 4 students each conducted 4-weeks summer research project, each of which were supervised by one faculty member from our Computer Science and Engineering department.

3. Results.

1) Three courses were developed (Data Mining, Introduction to Geographic Information System (GIS) and Risk Analysis and Management), and taught during the regular academic semesters. The students who attended and passed the courses received credit as part of their required credit for their majors.
2) The students who attended and completed the requirements for the seminar series received credit as part of their required credit for their majors.
3) Students who participated in the research projects during the Spring 2018 semester gained valuable experience in topics related to the DHS mission. Additionally, those students, who conducted the research, will have the opportunity to present their findings in future conferences.
4) The students who attended both, the 1-week summer research camp as well as the 4-week summer research project, conducted intensive research related to the DHS CRC program. All the students presented their work at the end of their research period to several faculty

members from the STEM College. Additionally, those students, who conducted the research, will have the opportunity to present their findings in future conferences.

4. Students:

   All the students in our Computer Science and Engineering department, and therefore all the students who attended the courses, the seminars and the research projects that were funded by the DHS grant were undergraduate students.

   How many graduated during your project?

   None.

   Approximately how many are employed in the Homeland Security Enterprise?

   We don't know yet if any of our graduates applied or is currently employed in the Homeland Security Enterprise.

5. Institutionalization: *Describe how your project will be institutionalized beyond CRC funding.*

   - *What will be the sources of ongoing support?*
     Other grants available in the STEM college listed in table 2.
   - *Where in your institution will your project be maintained?*
     The project will be maintained in our STEM College.
   - *Who will be involved in sustaining your project?*
     Some of the faculty members of our Computer Science and Engineering department as well as one or two faculty members of the Natural Sciences and Mathematics (NSM) department will be involved in sustaining the project. Mostly the same faculty members who were involved in the project in the past year, plus one or two others.

6. Interactions with research projects:

   Five professors from different universities, who are involved in research related to the DHS CRC program, gave presentations about their corresponding topics of research.
   The summer research camp and projects that were conducted in the summer of 2018 were centered around Coastal Resilience subjects.

7. Publications:

   Ying Bai & Hang Chen, "Build an Optimal Evacuation Contraflow Model for Natural Disasters by Using Fuzzy Inference System", to be appeared on Proceedings of the 2018 IEEE International Conference on Fuzzy System, July 8-13, Rio de Janeiro, Brazil, 2018.

8. Lessons Learned:

   What would you do the same and why?

   We would develop and implement the courses, seminars and research projects in very much the same way.

What changes would you make and why?

We would try to connect and collaborate more with end users, faculty members of outside education institutions who are conducting research related to the DHS CRC program as well as with other experts in research fields related to the DHS CRC program.

9. Tables:

Table 1: Documenting CRC Education Project Courses and Enrollments

Courses Developed and Taught by Johnson C Smith University under Project DHS CRC				
Course		Developed (D), Revised (R), and/or Taught (T), by Project Year		
Number	Title	1	2	3
CSC432	Data Mining	D, T	T	R, T
	Offering: Elective (E), Concentration (C), Minor (M)	E	E	E
	Enrollment	12	8	10
CSE439A	**Introduction to Geographic Information System (GIS)**			D, T
	Offering: Elective (E), Concentration (C), Minor (M)	-	-	E
	Enrollment	-	-	10
CSE439B	Risk Analysis and Management		D, T	
	Offering: Elective (E), Concentration (C), Minor (M)	E	E	E
	Enrollment		10	
CSC210	Career Prep I		D	T
	Offering: Elective (E), Concentration (C), Minor (M)			C
	Enrollment			16
CSC211	Career Prep II		D	T
	Offering: Elective (E), Concentration (C), Minor (M)			C
	Enrollment			19

Table 2: Documenting External Funding and Leveraged Support

2A: External Funding			
Title	PI	Total Amount	Source
Minority Science and Engineering Improvement Program (MSIEP): Embedding Active and Experiential Learning and Entrepreneurial Thinking into Computer Science and Engineering Education	Dr. Suryadip Chakraborty	$736,286	Department of Education
ASPIRE: Ambassador Scholarship Program in Research and Education	Dr. Dawn McNair	$598,500	National Science Foundation
The Virginia-North Carolina Louis Stokes Alliance for Minority Participation program (VA-NC Alliance)	Dr. Sunil Gupta	$297,220	National Science Foundation
Innovating the Research Educational Experiences	Dr. Tracy Brown-Fox	$399,911	National Science Foundation

2B: Leveraged Support	
Description	Estimated Annual Value

Table 3: Performance Metrics:

Hang Chen, JCSU

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17 – 6/30/18)
HS-related internships (number)	1	1	0
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	37	47	40
Graduate students provided tuition/fee support (number)	0	0	0
Graduate students provided stipends (number)	0	0	0
Undergraduates who received HS-related degrees (number)	9	20	7
Graduate students who received HS-related degrees (number)	0	0	0
Certificates awarded (number)	0	0	0
Graduates who obtained HS-related employment (number)	3	0	0
Lectures/presentations/seminars at Center partners (number)	0	0	0
DHS MSI Summer Research Teams hosted (number)	0	0	0
Journal articles submitted (number)	1	1	1
Journal articles published (number)	0	0	1
Conference presentations made (number)	0	2	0
Other presentations, interviews, etc. (number)	0	0	0
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	0	0
Requests for assistance/advice from other agencies or governments (number)	0	0	0
Total milestones for reporting period (number)	7	6	0
Accomplished fully (number)	4	6	0
Accomplished partially (number)	3	0	0
Not accomplished (number)	0	0	0

10. Year 3 Education Activity and Milestone Achievement:

Education Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/17 – 6/30/18			
Education Activities	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
Taught 2 new 3-credit hour courses	5/30/2018	100%	
Taught 2 new 1-credit hour seminar series	5/30/2018	100%	
Conducted 2 spring semester research projects	5/30/2018	100%	
Conducted 4-week summer research camp	6/30/2018	100%	
Conducted 3 parallel 1-week summer research projects	6/30/2018	100%	
Education Milestones			
New course being developed and will be taught next academic year	5/30/2018	100%	
20 students completed the 2 new courses	5/30/2018	100%	
8 students completed the spring semester research project	5/30/2018	100%	
20 students completed the 1-week summer research camp	6/30/2018	100%	
12 students completed the 4-weeks summer research project	6/30/2018	100%	

11. Year 3 Transition Activity and Milestone Achievement:

Transition Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/2017 – 6/30/2018			
Transition Activity	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
The students who participated in the research projects will be available for employment in the greater Homeland Security enterprise.	06/30/2018		
Dissemination of the undergraduate education and research education framework and results.	06/30/2018		
Develop the collaboration with research partners.	06/30/2018		
Transition Milestone			
Graduates are employed in greater HS enterprise or continued graduate school enrollment	06/30/2019	In progress	We will track our graduates to monitor their future applications and employments
Conference presentation and publications of the project results.	06/30/2019	In progress	We are planning on sending our students who attended our research projects to conferences to present their research findings

LAIJU: TOUGALOO COLLEGE
DHS COASTAL RESILIENCE CENTER
EDUCATION PROJECT
FINAL/YEAR 3 REPORTS (1/1/2016 – 6/30/18)

Project Title: Institutionalization, Expansion, and Enhancement of Interdisciplinary Minor: Disaster and Coastal Studies

Principal Investigator / Institution: Meherun Laiju, Ph. D. Associate Professor and Chair, Sociology Department; Tougaloo College

Other Education Participants/Partners: Interdisciplinary collaboration within Tougaloo College (Mass-Communication, Physics, Political Science, Psychology, and Sociology, Department's faculty members)

Project Start and End Dates: January 1, 2016 – June 30, 2018

<u>Short Project Description ("elevator speech"):</u>

To diversify the Department of Homeland Security's (DHS) workforce and help Tougaloo College's new career pathway curriculum, the current project took several initiatives to institutionalize an Interdisciplinary Minor Disaster Coastal Studies (DCS), established under the auspice of Department of Homeland Security's Coastal Hazards Center. Initiatives, such as course modification, collaboration with other departments, and a multidisciplinary professional certificate program at the undergraduate level were developed. This certificate program has been approved to be launched for Fall 2018. Also, to strengthen community resilience during natural and man-made disasters, the project undertook Neighborhood Outreach initiatives and, in collaboration with Mississippi Emergency Management Agency (MEMA), conducted neighborhood training to train first responders.

PROJECT NARRATIVE:

1. <u>Introduction and project overview:</u>
The education project, Interdisciplinary Minor: Disaster Coastal Studies (DCS), addresses the acute underrepresentation of minorities in the Science, Technology, Engineering, and Mathematics areas (STEM). The project goal is to diversify the future DHS and S&T related workforce by training underrepresented minorities, mirroring some of the more vulnerable population impacted by disaster scenarios. The DCS curriculum allows students to develop skills and knowledge and provides an opportunity to be trained in interdisciplinary fields across academic divisions (Natural & Social Science). The curriculum helps create a pipeline of underrepresented minority students with interdisciplinary skills, incorporating a Social Science focus that is marketable in the field of disaster and emergency planning, management, response, and recovery. In addition to coursework that addresses the legal, economic, and public health aspects of natural disasters, practical skills—such as student internships with emergency management agencies, Geographical Information System (GIS) training, and FEMA's Independent Study (IS) training—are incorporated into the coursework. The Project also provides students the opportunity to participate in faculty lead research in the field of community

preparedness to enhance community resilience. Students present their research findings in the field of disaster preparedness and recovery at the annual, yearend symposium—attended by various stakeholders including students, faculty, staff, administration, program partners, homeland security related organizations, and community members. Additionally, the pilot program neighborhood outreach initiative, in collaboration with MEMA, offered opportunities for community leaders and interested citizens to be trained as first responders. The neighborhood training initiative addresses Homeland Security's Post–Katrina Emergency Reform Act of 2006—building resilient communities as a part of national preparedness.

2. History:
This project took initiatives to institutionalize, expand, and enhance the Interdisciplinary Minor: Disaster and Coastal Studies implemented during the Coastal Hazards Center of Excellence-Education (2008-2015). The minor consisted of six courses, including forty (40) hours of field placement (internship) with local, state, federal, and NGO'S which deal with emergency management. Faculty members from Sociology, Psychology, Physics, Political Science departments, and the Jackson Heart Study collaborated to teach and modify courses, which includes adding GIS component and FEMA's Independent Study (IS) Training. The minor provides students an opportunity to be trained in interdisciplinary fields across academic divisions (Natural Science and Social Science), which is uncommon in small historically black colleges. Students pursuing the minor also participate in faculty lead research in the field of community preparedness to enhance community resilience. Students receive training in the critical needs area through education, participating in research and field experience by completing an internship with local emergency management agencies. The exposure helps students acquire highly portable skills necessary to succeed in high impact careers, thus creating a more diverse future workforce. Furthermore, the project addresses the acute underrepresentation of African American minorities in the Science, Technology, Engineering and Mathematics (STEM) areas. During the Spring 2016 academic session, an advisory committee was put together. The committee members assisted in the designing the credit-bearing, multidisciplinary certificate program and neighborhood training. The objective of the certificate program is to diversify and develop a skilled workforce for DHS, national, and local emergency management agencies. The committee members met at least once a semester—most correspondence and meetings being conducted by email and phone. The participants and their roles are included in the following table:

End User	Agency/Employer	Project Role
Dr. Nicole Cathy	Political Science; TC	Coordinator
Dr. George Humphrey, CFM	Director (grants)MEMA	DCS Instructor, Place Intern
Mr. John Brown	Regional Manager; Red Cross	Serve on panel, place Intern
Ms. Loretta Thorpe, MEP	Bureau Director-Training State Training Officer, Office of Preparedness, MEMA	Serve on panel, Place Interns, & neighborhood training coordinator
Mr. Jesse Murphree	Emergency Preparedness Training Officer, MEMA	Conduct the neighborhood training

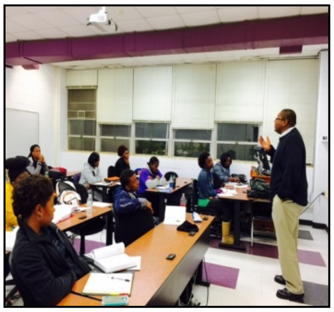
Ms. Marsha Manuel	Grant Director, MS office of Homeland Security	Serve on panel, Intern placement
Colonel Donnell Berry	MS State Trooper	Serve on panel
Mr. Ricky Moore	Director, Hinds County Emergency Management	Serve on Panel
Mr. Warren D. Miller	President, Mississippi Voluntary Organizations Active in Disaster(VOAD)	Serve on Panel, Intern Placement
Phyllis Parker	Director, Woodhaven Homeowners Association	Serve on Panel
Mr. Anderson	Pastor, United Methodist Church	Serve on Panel
Dr. Shaila Khan	Psychology Department, TC	DCS Instructor &Mentor student research
Dr. Santanu Banerjee	Physics Department, TC	DCS Instructor &Mentor student research

The advisory committee helped design a twelve credit-hour multidisciplinary DCS certification. The curriculum incorporates existing DCS minor courses along with modified elective courses from Psychology, Sociology, Mass-Communication, Political Science, and the Natural Sciences. The minor was approved by the board in spring 2018 and will be rolled-out in fall 2018. The objectives of the DCS certificate is to prepare undergraduates with knowledge and skills to work in the public sector (federal, state, county, or city), private sector, or graduate programs in a variety of fields—including disaster management, public policy, public health, social work etc. The DCS certificate addresses the demand of the United States Department of Homeland Security, local, and state government needs for trained professionals in the area of disaster management, and diversifies the future DHS workforce. The neighborhood outreach initiative in collaboration with Mississippi Emergency Management Agency (MEMA) helps to develop a working relation with the local community. The certificate program also offers opportunities for community leaders and interested citizens to be trained as first responders, which will help in preparing resilient communities. The DCS certificate provides students with a multidisciplinary perspective to show the nature of disasters, organizational issues inherent in management and planning, skills in GIS, and internships with end users. The major challenge encountered by the project has been developing the certificate program. Several times, the delivery method has been changed for the certificate program. Initially, a non-credit bearing certificate program was commenced by the Tougaloo College Continuing Education Program for the community at large. A change of administration (Provost) between Fall 2015 and Spring 2016 led to the administration decision to phase out the continuing Education Department and created a problem for the proposed certificate program. By March 2016, it was decided that the certificate program will be offered by the Sociology Department in collaboration with the Political Science Department. Dr. Nicole Cathy, assistant professor of the Political Science Department, is assigned as a coordinator. We have contacted the local emergency management agencies and setup an advisory board to assist us in designing the certificate program. Unfortunately, we had to face another unanticipated challenge. In the Fall 2016, the new administration focused on restructuring the general education (common core) curriculum. The new curriculum reduces the general education requirements from 60 to 40 (credits hours) and plans to add professional certifications in different fields—career pathway initiatives. The consensus was professional certificates will provide an option for students who want to join into workforce immediately after completing their undergraduate degree. We saw this is an opportunity to institutionalize the existing DCS minor within the college curriculum. Using advisory committee members input, collaboration between different departments, and by modifying the minor's courses, a newly designed multidisciplinary professional certification will be offered in Fall 2018.The professional certifications will prepare students for emergency management related workforce. The change in administration and their new initiatives put us slightly behind schedule to develop and launch the proposed certificate program. The change in administration and their new initiatives put us slightly behind schedule to develop and launch the proposed certificate program. Even though I had to deal with uncertainty but at end these challenges benefitted the outcome of the project.

Outreach Initiatives. Collaboration with MEMA

GIS Training

Students collecting data at Harris County, TX



MEMA personnel teaching

Jackson Mayor visiting DCS class

3. Results:

The project (January 2016 – June 2018) delivered15courses, revised 6courses, enrolled 139 students, placed 25 research internships, had 27 merit awards, graduated 11 students with Disaster Coastal Study minor, and supported 2 faculty members' research projects. The offered courses also served as electives towards graduation for many students. 9 students presented at Mississippi Academy of Science (MAS) conferences and 3 (students guided by faculty) abstracts were published in MAS journal. DCS students also participated at TCMC (Tougaloo and Mississippi College) undergraduate research symposium. Each academic year, the project organized Disaster Coastal Studies Research Symposium. In this symposium the guest speaker from UNC- Chapel Hill, and Old Dominion University shared their ongoing research project with the DCS students. 4students participated in SUMERX program and did the summer internships at University of Delaware Disaster Research Center, University of Rode Island, and Old Dominion University. Faculty members teaching the minor courses invited experts in the field as guest speakers. The goal was to help students develop an understanding of the relevance of the course in daily settings. To sustain and institutionalize the Interdisciplinary Minor, Disaster Coastal Studies, it was modified and made into a 12 credit hour Multidiscipline, Certificate program Disaster Coastal Studies. The Certificate program received all the necessary approval and will be offered from fall 2018.

DCS Research Group

2018

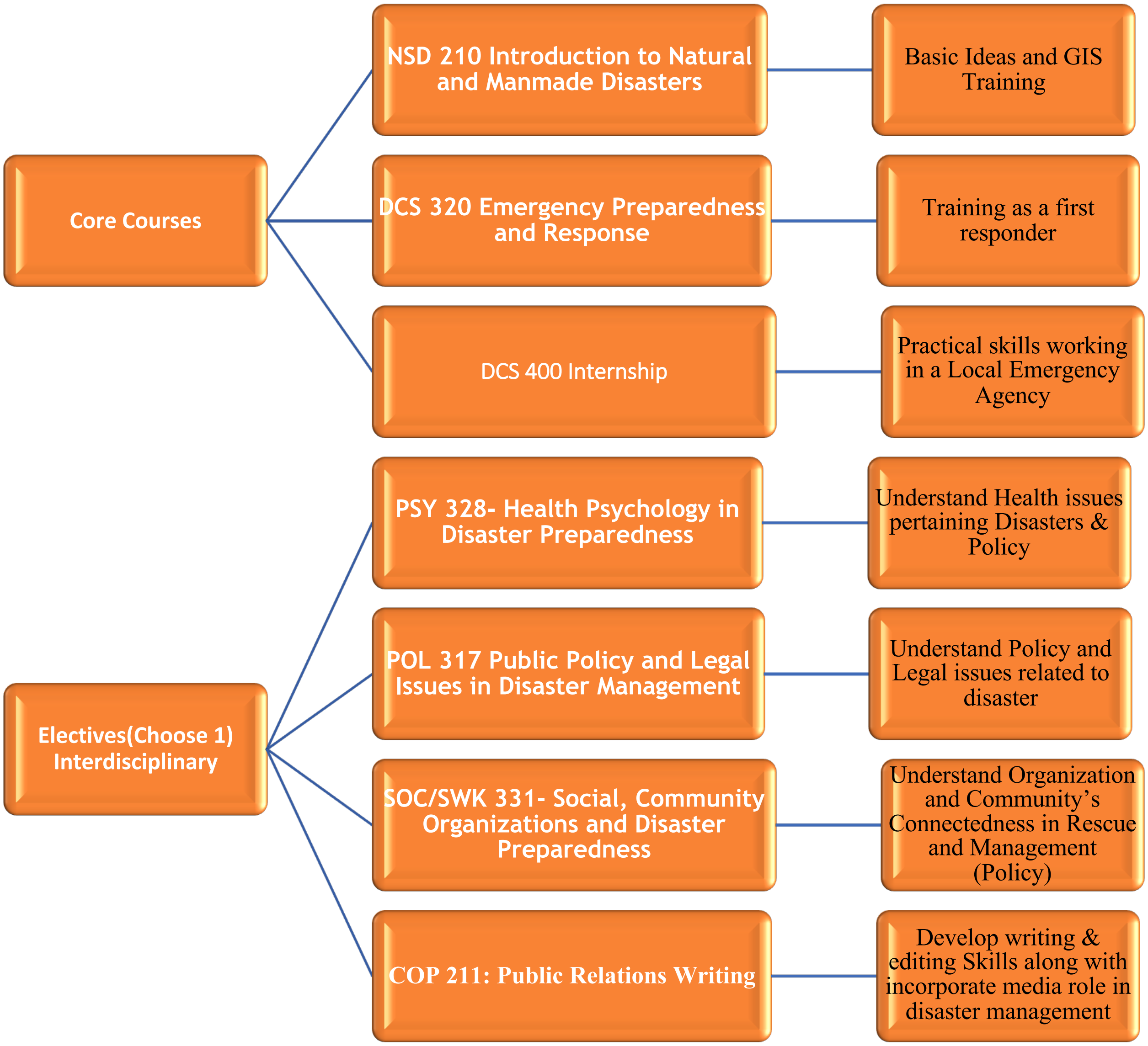
2017

 2016

4. Students:
   Tougaloo College is a Historically Black undergraduate institution, 99% of the student body is African-American and are full-time students. From January 2016 to June 2018, 11 students graduated with DCS minor — 3 males and 8 females. 6 are attending graduate schools, 4 applied for jobs with emergency management agencies, and 1 is working with a VOAD (a voluntary agency).

5. Institutionalization:
   To institutionalize the DCS minor, years 1-3 took steps such as collaborating with different disciplines, modifying courses, incorporating elective courses from other disciplines, and designing a curriculum. The new curriculum replaced the DCS minor as a multidisciplinary certificate program. The program will be rolled out in Fall 2018, and is expected to be a self-sustaining program. To make a self-sustaining program, the twelve credit-hour certification curriculum incorporates the existing elective courses from different disciplines (see following table). The three core courses, *DCS 201: Intro to Natural Disaster* course was adopted by the Natural Science and co-listed (NSD 201) as an elective offered by the division. Mississippi Emergency Management Agency (MEMA) personnel currently teach DCS *320: Emergency Preparedness and Response* as an adjunct faculty. Academic Affairs agreed to pay adjunct salary if the enrollment in the course is 8-10students after (2020). The same holds true for the Internship course (*DCS 400).* Beginning fall 2018, College will offer Bachelor of Social Work (BSW) as a degree granting program and the DCS certification is included within the BSW degree program as an option of specialization. In the next two years (2018-20), the project will take initiatives such as continuing with the existing end-users, establishing collaboration with FEMA and other private agencies which deal with emergency management, placing interns into private emergency management organizations, inviting personnel to class as field experts, and inviting local public and private emergency management agencies to participate in the Tougaloo College job fair to help DCS graduates' recruitment. I am expecting that these initiatives will help strengthen to sustain the certificate program beyond 2020. The certificate will be part of Tougaloo College's path to career program.

Design of the Certificate Curriculum



6. <u>Interactions with research projects:</u>

The Interdisciplinary Minor: Disaster Coastal Studies hosts a research symposium each academic year to showcase students' activities. Dr. Gavin Smith of University of North Carolina - Chapel Hill shared his research project with the students in 2017, and Dante Council, a Ph.D. student from Old Dominion University, shared his work in progress at the 2018 symposiums. Through the SUMERX program, students pursuing the minor attended University of Delaware's Disaster Research Center, University of Rhode Island, and Old Dominion University. Student Irenia Ball, attended University of Delaware's Disaster Research Center completed her senior paper that focused on natural disaster preparedness. Her abstract was published in Mississippi Academy of Science (MAS) journal.

SUMERX Interns

2018

2017

2016

Symposium Lecturers---UNC Chapel Hill & Old Dominion

7. <u>Publications:</u>

Mage, D. Reed, S. Hokins, A. Mangum, C. & Banerjee, S. (2018) Using Arc GIS to Map Disaster Effects on Mississippi, abstract published in *The journal of Mississippi Academy of Sciences (*ISSN 0076-9436) vol 63, 1 February edition

Bryant, J. Hill, C. Bibbs, M. Boler, D. & Khan, S. (2018)*Role of Effective Communication in Disaster Preparedness,* abstract published in *The journal of Mississippi Academy of Sciences (*ISSN 0076-9436) vol 63, 1 February edition

Ball, I & Laiju, M. (2017) Socio-demographic Characteristics and Natural Disaster Preparedness among Mississippi Residence, abstract published in *The journal of Mississippi Academy of Sciences (*ISSN 0076-9436) April edition.

<u>Presentations</u>:

Laiju, M. (2016) *Natural Disaster and Child Trafficking,* Mellon Fellowship

Laiju, M. (2017) *A Global Issue: Natural, Manmade Disaster, and Exploitation of Children,* Pardee RAND Faculty Leaders Fellowship, manuscript under review.

Laiju, M. & Banerjee, S. (2017) *Innovative Interdisciplinary Undergraduate Curriculum in Homeland Security at a HBCU*, Presented at the 10th Anniversary Homeland Defense & Security Education Summit on March 23, 2017

Laiju, M. (2018) *Social Impact of Natural and Manmade Disasters***.** developed this course

DCS Symposium

2018

2017

2016

MAS Conference

2017

2018

8. Lessons Learned:
   I would keep the education component as it is. However, given the chance I would include a summer program such as offering a workshop (in collaboration with local emergency management agencies) for the surrounding community and STEM education courses (resilience related) for the high school and community college students. These would have helped the program as well the college in recruiting students.

9. Tables:

Table 1: Documenting CRC Education Project Courses and Enrollments

Courses Developed and Taught by Tougaloo College under Project Interdisciplinary Minor: Disaster Coastal Studies (DCS) **Period (January 2016 – June 2018)**				
Course		**Developed (D), Revised (R), and/or Taught (T), by Project Year**		
No.	**Title**	**1**	**2**	**3**
DCS 201	**Introduction to Natural & Manmade Disaster**	**-**	**R, T**	**T**
	Elective (E), Concentration (C), Minor (M)		**M**	**M**
	Enrollment	*****	**10**	**10**
***Offer in fall semester**				
DCS 211	**Public Health Issues in Disaster Preparedness**	**T**	**T**	**T, R**
	Elective (E), Concentration (C), Minor (M)		**M**	**M**
	Enrollment	**1****	**8**	**11**
****Schedule to offer in fall; 2016 spring offered as an independent study for a graduating Senior with DCS minor**				
DCS 301	**Political & Legal Issues in Disaster Preparedness**	**T**	**T**	**T, R**
	Elective (E), Concentration (C), Minor (M)	**M**	**M**	**M**
	Enrollment	**14**	**10**	**8**
DCS 320	**Emergency Preparedness Response & Planning.**	**T**	**R, T**	**T**
	Elective (E), Concentration (C), Minor (M)	**M**	**M**	**M**

	Enrollment	**16**	**5**	**11**
DCS 314	**Economic Aspects of Disaster.**		**T**	**T, R**
	Elective (E), Concentration (C), Minor (M)		**E**	**E**
	Enrollment		**13**	**7**
DCS 311	**Psychological Dimension of Disaster**	**-**	**-**	**R**
	Elective (E), Concentration (C), Minor (M)		**E**	**E**
	Enrollment	*** ****		
***** offer one elective in fall for each academic year**				
DCS 400	**Internship**	**T**	**T**	********
	Elective (E), Concentration (C), Minor (M)	**M**	**M**	
	Enrollment	**7**	**8**	**-**
******offer only to students graduating with minor & completion of other requirements**				

Table 2: Documenting External Funding and Leveraged Support

2A: External Funding

Title	PI	Total Amount	Source
Natural Disaster & Child Trafficking	M. Laiju	$4,000.00	Andrew Mellon Foundation
A Global Issue: Natural, Manmade Disaster, and Exploitation of Children	M. Laiju	$4,000.00	Pardee RAND Fellowship

2B: Leveraged Support

Description	Estimated Annual Value
Class room space and computer lab for GIS Training, space for hosting Symposium	$15,000
Portion of university indirect returned to project	$10,000
25% release time for PI	$11,000

Table 3: Performance Metrics:

LAIJU PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17— 6/30/18)
HS-related internships (number)	7	8	0
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)	15	17	20
Graduate students provided tuition/fee support (number)	NA	NA	NA
Graduate students provided stipends (number)	NA	NA	NA
Undergraduates who received HS-related degrees (number)	3	5	4
Graduate students who received HS-related degrees (number)	NA	NA	NA
Certificates awarded (number)	NA	NA	NA
Graduates who obtained HS-related employment (number)			0
Lectures/presentations/seminars at Center partners (number)	1	1	1
DHS MSI Summer Research Teams hosted (number)	0	0	0
Journal articles submitted (number)	0	0	0
Journal articles published (number)	0	0	3
Conference presentations made (number)	1	4	6
Other presentations, interviews, etc. (number)	10	12	14
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	2	1	1
Requests for assistance/advice from other agencies or governments (number)	5	2	2
Total milestones for reporting period (number)	7	7	7
Accomplished fully (number)	4	5	6
Accomplished partially (number)	3	1	1
Not accomplished (number)	-	1	-

10. Year 3 Education Activity and Milestone Achievement:

Education Activities and Milestones: Final Status as of 2018
LAIJU

Reporting Period 7/1/17 – 6/30/18			
Education Activities	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
Analyze the neighborhood outreach initiative survey to enhance future training	July 2017	100%	
Offer 3 courses for DCS minor	August 20017	100%	
Select new students for research and training (GIS & Survey Construction and Analysis)	August 2017	100%	
Test the validity & reliability of the questionnaire (based on theoretical construct) (pre-test)	September 2017	100%	
Submit the proposed work plan to Institutional Review Board (IRB) for permission to collect data;	September 2017	100%	
Seek faculty approval for the professional certificate program	October 2017	100%	
Student/Faculty/staff certified training in GIS	October 2017	100%	
Neighborhood Outreach Training	November 2017	0%	MEMA emergency training Personal was busy due to inclement weather condition
Collect data	December 2017	100%	
Promote the new certificate program	November & December 2017	0%	Received the board approval in April 2018

Offer 3 courses for the minor	January 2018	75%	Internship course was not offered; after completing the core requirements students enroll in this course; current DCS minors are interested in the certificate program, so they plan to take the course next year.
Tentative: launch certificate program	January 2018	0%	Explained
Select and place intern students to end – user hosting organizations	February 2018	0%	Course was not offered
DCS Research Project students participate at MAS	February 2018	100%	
Host DCS Research Symposium	April 2018	100%	
Education Milestones	**Completion Date**		
Students working in GIS project& risk identification and perception awareness project present at Mississippi Academy of Science (MAS) conference	March 2018	100%	
Intern and DCS minor students present at DCS Symposium, MAS & TCMC Undergraduate Research Symposium	February &April 2018	100%	
Invite CRC partners & end-user agency personnel as guest speaker	April 2018	100%	
Expecting 4 students graduate with DCS minor Encourage graduates to attend graduate program at CRC Institute /seek employment at end-user agencies	May 2018	100%	
Send 2 students to CRC partner /end - user institute for summer internship	June 2018	100%	

11. Year 3 Transition Activity and Milestone Achievement:

Transition Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/2017 – 6/30/2018			
Transition Activity	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
Recruit end-users to provide internships (Research Students)	July 2017	100%	
Recruit end-users to provide internships (course)	January 2018	0%	The course was not offered; due to change in certificate program; launch in Fall of 2018
Recruitment for Certificate Program	January 2018	0%	The certificate program received the necessary approval in March 2018
Transition Milestone			
Internships at end-user organizations	June 2018	60%	Only for research students; Internship course was not offered
Initiative to Increase enrollment in DCS minor	July 2017	100%	

Disaster Coastal Studies Minor Student Tracking January 2016 – June 2018							
Year	**Student Enroll in Courses**	**Students in Research Project**	**Total Students**	**Declared Minor**	**Internship /End-User**	**Graduate with minor**	**Job/ Grad. Prog.**
2015-16	38	8	46	7	6	1	
2016-17	54	8	62	9	8	5	3 applying at MEMA
2017-18	47	8	55	10	6	4	

PAGAN/LÓPEZ - UPRM
DHS COASTAL RESILIENCE CENTER
EDUCATION PROJECT
YEAR 3 REPORT TEMPLATE

Project Title: Education for Improving Resilience of Coastal Infrastructure

Principal Investigator Name/Institution: Ismael Pagán-Trinidad (PI), Ricardo R. López (Co-PI); Department of Civil Engineering, University of Puerto Rico at Mayagüez, Mayagüez, Puerto Rico

Other Partners/Institutions: ERDC-US Army Corp of Engineers, PR Emergency Management Agency, FEMA, PR Department of Natural Resources, Association of Professional Engineers of PR, UPRM partners (Marine Science Department, Sea Grant Program, CariCOOS NOAA project, Transportation Technology Transfer Center, Civil Infrastructure Research Center); NOAA (National Weather Service), INESI ("Instituto Nacional de Energía y Sostenibilidad Isleña" = National Institute on Energy and Island Sustainability), CRB (Community Resilient Building).

Project Start and End Dates: January 1, 2016 to June 30, 2018

Short Project Description ("elevator speech"):

This project helped educate the community by transferring state of practice knowledge to stakeholders (students, faculty, professionals, first responders, and workforce) through formal (curriculum, internships, student projects, undergraduate research) and informal (workshops, seminars, lectures, short courses, webinars) learning experiences. It served as a vehicle to engage the community as a whole to understand and learn its members' roles and responsibilities in providing resilient coastal infrastructure systems. The project helped the community understand better various stages in coastal infrastructure hazard prevention, preparedness, response, recovery, and mitigation. The focus was to understand the natural phenomenology, the engineering methodologies to address the level of risk the infrastructure is exposed to, the engineering methodologies and technology to analyze and predict the level of resistance and vulnerability the infrastructure and community is exposed to, the sustainable and resilient alternative available at the state of practice or state of art to cope with risks and vulnerabilities. The project helped motivated students and professionals into CRI careers and practice.

PROJECT NARRATIVE:

1. Introduction and project overview:

The main goal of this project is to develop and offer formal and informal education through courses, workshops, seminars, lectures, and other educational means leading to advance knowledge on the state of practice on the Resiliency of Coastal Infrastructure (RCI) of the built and natural environment. This initiative aims at creating a Certificate in Resiliency of Coastal Infrastructure. The focus of the project is to provide students and faculty, professionals and homeland security personnel, and affected citizens with capabilities to assess the effects of natural hazards on coastal infrastructure, the conditions of existing structures, and rehabilitation alternatives to mitigate future damage and potential risks. The educational content is focused on pre-incidents, incidents and post-incidents. New courses and revisions of existing course were evaluated in Civil Engineering and related disciplines dealing with estimates of causes and effects of coastal flooding, storm surge, ocean waves, tsunami loads, earthquake effects, and strong winds. Instruction was alternatively offered in the form of conferences, workshops, and lectures. Lecturers and experts from CRC, ERDC, FEMA, and other partners were invited to participate. State of practice technology is a priority, e.g., FEMA P646 publication for tsunami load estimates. The National Infrastructure Protection Plan and state infrastructure protection programs and plans are addressed. Results of recent research work by UPRM, ERDC, and other CRC partner investigators regarding flood, wave, earthquake and tsunami, and hurricane wind effects on structures are incorporated. Being a small and fully developed island, Puerto Rico offers the ideal setting to assess lessons learned of the effect of natural hazards on built and natural infrastructure including housing, commercial, industrial, institutional, transportation, communication systems, and others.

Most recent Hurricane Irma and María experiences on the devastation over Puerto Rico will continue to be evaluated and the lessons learned will be incorporated in presentations, curriculum contents, and guidelines. The principal investigators will continue participating in various working teams, forums and meetings addressing building a resilient community in Puerto Rico for the future. At present time the PI's are involved with various initiatives, for example, Resilient Puerto Rico, ReImagine Puerto Rico, and others. All communities in Puerto Rico have been left overexposed to major damages and recovery challenges which require strong capacity building from the engineering perspective. The Island continues to present more catastrophic settings from overdeveloped and exposed urban and rural communities, more vulnerable zones (flood prone, weak soils and landslides, hurricane wind exposure), highly concentrated and poorly planned urban communities, stressful tradeoff between urban development and natural ecosystems development and conservation, extreme economic development constraints and suboptimal first responders resources (e.g. funding, equipment, capabilities, training, and others) make the Island educational settings most challenging. All this setting will be available for first hand assessment and evaluation from the educational and research perspective.

Puerto Rico will be in a continuous development process focusing on providing a more resilient community, infrastructure, families, and individual. The project collects, disseminates and exposes new knowledge and lessons learned from our past and expected natural events causing damages to the community.

This program has also the goal to facilitate internships at CRC universities performing research in CRI and in government agencies and industry dealing with coastal hazards. Being a minority serving institution (MSI) with a high women's participation (near 1/3 in Civil Engineering) it is also our goal to create and capacitate minority Hispanic students, faculty, professionals, and affected citizens to warranty up to date level of competency in Coastal Resilient Infrastructure to this part of the community. Our MSI University has been providing well qualified Hispanic Engineers to US for many years and benefits from the opportunity to collaborate with DHS and the community it serves.

2. History:

The project began by kicking off various activities to meet, engage and commit partners and constituents who can collaborate within and outside the university. Strategic alliances with partners were focused on collaborative educational efforts. Students and faculty were targeted to participate in formal and informal courses in order to develop leadership and start a pipeline toward terminal degrees and labor force in the homeland security enterprise. Priority topics were defined from the civil infrastructure perspective as geotechnical, transportation, water, power, communication, and other built infrastructure exposed to coastal wind, earthquake and water forces on built infrastructure.

Faculty was engaged by developing formal and informal courses, undergraduate research and graduate theses. Students were allocated in summer educational internships experiences like SUMREX at CRC partner institutions and the ERDC-UPRM ERIP at the US Army Corp of Engineers national laboratories.

A series of workshops, conferences, lectures, trainings, short courses and other activities on relevant coastal topics were developed and offered with the participation of students, faculty, professionals, government officials and the community. Over a thousand mentors, faculty, lecturers, students, invited speakers, professionals and general public participated.

The third year was particularly special for the occurrence and devastation of Hurricanes Irma and María, two Category 5 hurricanes that not only surpassed any projection we had learned and experienced in the past, but also devastated the island's coastal and upland built and natural infrastructure. Despite the major institutional operational and administrative disruptor and interruptions, the PI's were able to provide real time adaptation to pursue the project goals and objectives. They engaged in preparedness, response, damage assessment, recovery, and adaptation educational and advisory activities to support the reconstruction of Puerto Rico. All of a sudden the resilience of all the built and natural infrastructure in Puerto Rico shifted to one of the first priorities be federal, state, and municipal governments, industry, non-for profit organizations and the general public in Puerto Rico and abroad. In addition the project continued offering formal and informal educational activities, through workshops, lectures, undergraduate research, graduate theses, formal course offering, and meetings. A new generation of "Conversatories" were offered where experts, partners, government officials, the university and general communities, and the press gathered to openly discuss the impacts of and lessons learned from the hurricanes on the built and natural infrastructure, the economic development, the environment quality, and the integrity and the social wellbeing of the community in Puerto Rico. The PI's actively participated in various forums, field reconnaissance, presentations, community and press advise, meetings, and many other initiatives not only to help recover community from the University perspective but also to help educate the community and capture the lessons learned after the hurricanes.

The following main outcomes can be identified from the project up to date:

1. UPRM administrations has identified as a primary university strategic challenge the needs to become a leader to provide the appropriate educational and research

elements necessary to warranty the resilience and sustainability of the built and natural environment in Puerto Rico.

2. The PI's and the associated faculty were invited to participate with leadership roles in various initiatives to identify and develop ideas, opportunities, and priorities for the reconstruction project through capacity building, analyses and design of reconstruction projects, and new educational ideas and projects for Puerto Rico.
3. New funding sources were identified to lever and sustain resilience initiatives.

3. <u>Results:</u>

<u>Courses:</u>

a. Special Courses: Ten different existing formal courses were offered to undergraduate and graduate students. Nine of those courses were offered in civil engineering and marine science with the assignment of special engineering problems and research topics. Since the strategy in the project was to engage students and faculty, it was found that a "learn by doing" approach was followed by identifying interesting and priority themes and assigning formal independent study course in a wide variety of modes depending on which mode applied better. Topics were assigned in a variety themes including wind, water, and earthquake forces on structures, coastal erosion, floodplain and ocean modeling, prediction of hurricane tracks, coastal transportation infrastructure, coastal geotechnical hazards, and many others.

Approximately 120 students were formally registered in one of various special or regular courses at UPRM during the past 2 ½ years:

The following shows a list of special courses:

Course	No.	Title
INCI 4998	3	Undergraduate Research
INCI 5995	4	Special Topics (undergraduate in civil engineering)
INCI 5996	1	Special Problems (undergraduate in civil engineering)
INCI 6995	4	Special Problems (graduate in civil engineering)
INCI 6065	1	Engineering Project (Master of Engineering Project)
INCI 6066	4	Research Thesis (Master of Science)
INCI 8999	3	Doctoral Research and Thesis
CIMA 8999	1	Doctoral research and Dissertation (Marine Science)
CIMA 6999	1	MS Research and Thesis (Marine Science)
Total	22	

b. New courses: Two new course were developed, one was offered through the Special Topics mode and the second one was developed and is being videotaped with the intention of being distributed to a broader audience:

INCI 6997	7	Special Topics (Graduate in civil engineering): "Rehabilitation of Coastal Structures"
INCI 6XXX	N/A	"Resilience and Reliability of Coastal Infrastructure"
INCI 5XXX/6XXX	N/A	Others are under development

c. Capstone course: Seven Coastal Comprehensive Urban Development hypothetical projects with real constraints were assigned to senior civil engineering students to develop (analyzed and designed) multidisciplinary solutions during three consecutive semesters with the participation of a total of 88 undergraduate students, five faculties, five graduate students, and the participation of various guest speakers and lecturers on coastal engineering, resilient design and sustainability topics. The proposed sites are exposed to multi-hazards, namely: earthquakes; tsunamis; riverine and urban floods; coastal floods caused by storm surge, waves, tides, and winter ocean swells; soil liquefaction; corrosive environment; extreme hurricane winds; and localized sporadic twisters. Projects required to satisfy multiple objectives in function of economic development, environmental quality and compliance, social wellbeing and social satisfaction, construction sustainability, and resilient design against coastal hazards. Students formed companies, were trained by faculty and external professionals, worked in teams, and developed the whole design process, namely: Feasibility analyses, conceptual design, preliminary design, final design, project management, permit requirements, and oral and verbal presentations. This experience exposed our graduating students to mature the concept of coastal resilient systems, motivated some to go to graduate school, and directed others to participate in reconstruction activities in PR after Hurricanes Irma and María.

INCI 4950	88	Integrated Civil Engineering Project (Mayagüez Bay Urban Development Cluster)

<u>Faculty:</u>

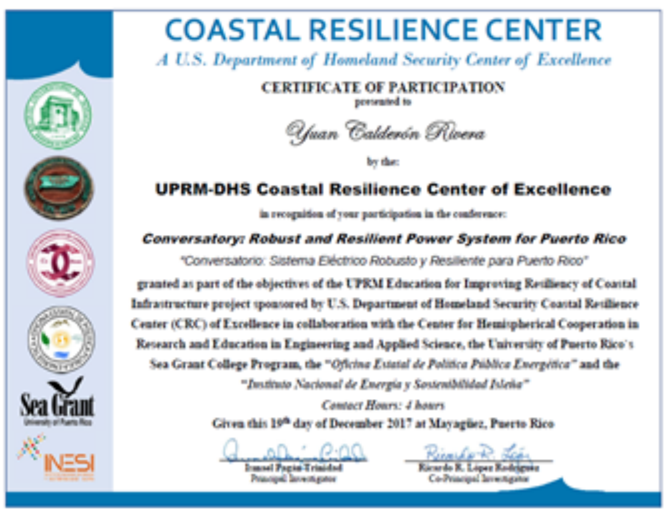
The project directly sponsored part of the time and effort of only the two co-pi's. However, a significant leverage was achieved with the engagement of many professors who were assigned to supervise courses through which students were exposed to civil engineering and coastal engineering topics and experiences. Others participated either as lecturers, collaborators, and participants in field reconnaissance after the hurricane.

An estimated 26 faculties participated in various modes of teaching, learning and research activities. Faculty were assigned a total of 12 different courses which were repeated during four different semesters. Some like theses and dissertations were continuous until graduation, but others like Undergraduate research and Special Problem courses were repeatedly taught every semester. Engaged faculty supervised approximately 118 student-semester for four semesters and three summers, for an average of about 40 students/year.

Four “Conversatories” were coordinated with two faculties who direct COHEMIS office in Campus. One faculty from Geology, three from Electrical and Computer Engineering , one from Industrial Engineering, and two from Marine Science Departments participated in the conversatories”. These served either to engage new faculty or to share and collaborate with the work they have been doing in community resilience after the hurricane.

Certificates:

Over 800 participants and trainers were exposed to activities sponsored by the project including lectures, short courses, workshops, regular and special courses, conferences and the capstone course. An estimated 3137 person-hour of contact time of training are estimated for the audience. Formal and special curriculum courses are not included here. Each 3 credit-hour regular course requires 45 hour-semester of contact time, while a 3 credit-hour special course requires 135 hour-semester of research or working time.



Example of Certificate

Example of Conversatory.

4. <u>Students</u>:

In addition to the number of students who participated as audiences in various lectures, conferences, "conversatories," and other activities, a total of approximately 118 student-semester for four semesters and three summers, for an average of about 40 students/year were registered in formal and special courses.

Six students finished their BSCE or MSCE degrees. Out of these, two finished their MS, and one of the two (Félix Santiago) entered the PhD Program in Coastal Engineering at LSU under Dr. Scott Hagen. The other four finished their BSCE. Three of them were admitted to Master Programs as a transition to eventually pursuing a PhD. One (Diego Delgado) will be studying in Spain, another (Peter Rivera) at UPRM. Both will follow coastal engineering related studies. The third student (Gabriela Buono) finished with outstanding qualifications her BSCE.

Various students who participated in the project received various recognitions:

1. **Gabriela Buono:** Graduated from the CE program in June 2018 and shared with another student the <u>**Department Honor Medal as the best CE department student**</u>. She also won the Dwight D. Eisenhower Fellowship awarded by the Federal Highway Administration during her senior year and worked a project entitled ***"Scouring Impacts in Bridges at River Mouth: Puerto Rico Case Study of Victor Rojas Avenue Bridge")*** which derived from her participation in our CRC project.

She was hired by Dewberry and Davis Company and she is working with site development applying all the principles she learned in her Capstone Course.

2. **Felix Santiago:** Graduated from the CE Program in the option of Environmental Engineering in June 2017. He is currently studying a PhD in Civil and Environmental Engineering at LSU at Baton Rouge (Coastal Engineering) and won the prestigious **NSF Graduate Fellowship**.

3. **Juan Gonzalez-Lopez:** PhD, worked as a university post doc and **was sponsored through a one year project under the PI's BAA grant by ERDC through one of our projects** to complete the study entitled "***Updating and Improving a High Resolution Finite Element Mesh for Storm Surge and Hurricane Wave Modeling in Puerto Rico".*** Currently working as Physical Oceanographer/Modeler with Wood plc, based on Dartmouth, Nova Scotia, Canada since August 2017.

4. **Giovanni Seijo:** Participated as undergraduate student with Dr. González's project, graduated from Physics at UPRM in June 2017, and **currently pursuing doctoral studies** at City University New York (CUNY, Earth & Environmental Sciences).

5. **Peter Rivera:** Graduated from the CE program in June 2018 and was **admitted to the ME department at UPRM** to study materials related to coastal engineering. He is aiming at pursuing a PhD in coastal engineering after he will finish his MS degree.

6. **Diego Delgado:** Graduated from the CE program in June 2018 and was **admitted to pursue a MS degree in a Coastal Engineering Program** in Coasts and Ports at the Cantabria University, Santander, and City, Spain.

7. **Efrain Ramos:** Ongoing MS student in Environmental Engineering at UPRM who participated with the ERDC-UPRM Internship Program at the Coastal and Hydraulic Laboratory (CHL). Responding to our leverage initiatives of the project with our partners he was one of five students sponsored by ERDC to participate in the Summer Internship at CHL under the supervision of Norberto Nadal to study the prediction of hurricane tracks in the Atlantic Ocean. Consequently, **he adopted his internship Scope of Work as his MS Thesis topic, his sponsor was appointed ever since through the project as Adjunct Professor at UPRM, his thesis project was sponsored by ERDC to work at UPRM, and he was hired by the CHL to work as a full time employee in September 2016** while he continues working in his thesis.

8. **Daniel Martínez:** A graduate student in Mechanical Engineering with option in Coastal Engineering, participated in an internship with our partner at the ERDC. He was hired by the ITL laboratory at ERDC in Nov. 2017.

9. **Alexander Molano:** MS Graduate Student in CE program in the option of Transportation Engineering, began as an undergraduate student in the program, participated in undergraduate research in the project with topic "Resilient Coastal Transportation Infrastructure", **coauthored various local and international**

presentations with the PI's and collaborators. **Molano received the Dwight D Eisenhower during Spring 2018.**

10. **Angel Alicea:** PhD student planning to graduate by December 2018. He already has an offer to teach Structures in the new Civil Engineering Program for the Interamerican University of Puerto Rico. **He won the Dwight D. Eisenhower fellowship sponsored by the Federal Highway Administration for year 2016-2017.** Alicea worked in a project entitled ***"Implementation of Innovating Structural Health Monitoring Techniques to a Highway Bridge" as part of his PhD thesis*** which is of high priority in coastal seismic regions. His PhD thesis is entitled ***"Dynamic Identification and Non-Linear Modeling for the Structural Health assessment of Aged Coastal Infrastructure".***

11. **Héctor Colón:** An undergraduate student who participated in the **SUMREX** at OSU under Dr. Dan Cox in Summer 2017. **His summer internship research work entitled *"Numerical Modelling of Tsunami Inundation Considering the presence of Offshore Islands and Barrier Reefs"* was approved to be presented in 36th International Conference on Coastal Engineering to be celebrated in Baltimore, MD from July 30th to August 3, 2018.**

5. Institutionalization:

Department and Deanship: Commitment to Resilient Infrastructure as an emerging strategic area at the department, deanship and Campus levels

UPRM created the Mitigation Committee: Faculty called to engage and and participate in after Hurricane María mitigation and recovery projects

Research/Education: Various proposals on research and curriculum development on the topic of resilient infrastructure are under consideration which will leverage and support the mission and vision of the project.

- Proposal with Dr. Zachary Grasley, Director of the Center for Infrastructure Renewal at Texas A&M University: **NSF Planning Grant: Engineering Research Center for Hurricane Resistant Coastal-Community Neighborhoods (HuReCaNe) through Reimagined House Construction"**, June 2018.

- **Proposal with:** Dr. Dan Cox, Professor, Civil and Constr. Engineering, Oregon State University: Director Cascadia Lifelines Program, and Assoc. Director Center for Risk-Based Community Resilience Planning, **NSF Planning Grant: Engineering Research Center for Adaptive and Resilient Coastal Infrastructure (CARCI), June 2018.**

- **Proposal to: RAND Corporation PR - "Proposal HSOAC FFRDC Task Order - Expert Analysis of FEMA Cost Estimate Development process and validation for FEMA-4339-DR-PR and FEMA-4340-DR-VI (Hurricane Maria) Remediation / Reconstruction", July 2018.**

- Proposal to NSF: A partnership with various institutions led by the civil Engineering Department faculty including the Co-PI's **- "Building Capacity: Collaborative Research: Resilient Infrastructure and Sustainability Education: Undergraduate Program (RISE-UP)", March 6, 2018.**

Continue partnering with other institutions: Various initiatives are under development (see previous section) with partner institutions like: Cornell University, UPR-Rio Piedras, UPR-Ponce, Catholic University of Puerto Rico, Government agencies, Communities, Professionals related to building capacity and launching new educational strategies and activities. New collaboration is under negotiation with the US Army Corp of Engineers Research and Development Office on engineering and scientific coastal resilience advances and lessons learned after Hurricanes Irma and María.

Increase participation: Increase in faculty and students participation in coastal projects/theses/undergraduate research

Stakeholders: Continue strengthen collaboration and engagement with stakeholders on homeland enterprises.

a. Where in your institution will your project be maintained?
   At the Civil Infrastructure Research Center under the Department of Civil and Surveying Engineering

b. Who will be involved in sustaining your project?
   The PI and the Co-PI will be the main responsible persons. Other faculty will be assigned leadership roles in future activities.

6. Interactions with research projects:

a. **SUMREX** participation has been successful for 2016, 2017, and 2018. In 2017 opportunities were communicated by researchers from two institutions. Oregon State University (Dr. Dan Cox and Dr. John van de Lindt – two opportunities), and University of Central Florida/Louisiana State University (Dr. Stephen Medeiros/Dr. Scott Hagen- one opportunity). These initiatives were coordinated with Researchers during CRC meetings. Advertisements were posted including all requirements at the university. Interested students presented their credentials and we evaluated if students qualified. Students who qualified were advised to apply and referred directly to Research PI's for their evaluation. Two students were admitted at OSU (working at the O.H. Hinsdale Wave Research Laboratory (HWRL)) and one student was admitted to UCF/LSU (working on the ADCIRC model (setup and parameterization) and how to run simulations on a high-performance computing cluster). In 2016 SUMREX students were

Kevin Cueto and Diego Delgado at OSU and Felix Santiago at UCF/LSU. Felix has now started to study his PhD at LSU starting in January 2018, thanks in part to being awarded an NSF Graduate Fellowship to pursue the PhD, and to his research at UCF, LSU, and at UPRM with Dr. Walter Silva. The students selected for SUMREX in 2017 were Peter Rivera and Hector Colón to attend OSU and Diego Delgado will attend UCF/LSU. In 2018 two opportunities were communicated by Oregon State University (Dr. Dan Cox and Dr. John van de Lindt. The students selected for this Summer following the same procedure as in 2017, were Brian Acevedo and Jorge Santiago. Both are currently in the middle of the internship. In summary, UPRM students participated in 8 SUMREX internships for the 3 years.

b. **ReTALK** program at UPRM by CRC researchers was initiated with the visit of Dr. Dan Cox of OSU in March of 2017. Dr. Cox gave lectures at UPRM and at San Juan Professional Engineers Association. In Mayagüez, he also met with students and professors. Both his presentations were well attended. Other talks at UPRM given by distinguished researchers were offered by Mr. Ernesto Díaz, president of PR Climate Change Council and Director of the PR Coastal Zone Management Program at the Department of Natural and Environmental Resources Agency, by Mr. Ron Eguchi, president of ImageCat in California who was invited by the Earthquake Engineering Institute UPRM student chapter, and by Mr. José Sanchez, director of the Coastal and Hydraulic Laboratory of the US ARMY Corps of Engineers in Vicksburg, MISS.

c. **Conference Lessons Learned and Best Practices: Resilience of Coastal Infrastructure** was a 2-day conference held in San Juan organized by our project with the cooperation of the Sea Grant Program, PR Engineers Association, Dept. of Natural and Environmental Resources, and the sponsorship of the US Army Corps of Engineers, who provided travel expenses for 9 researchers who shared their expertise with local researchers from UPRM and Dr. Cox from OSU.

d. **After Hurricane María** Profs I. Pagán and R. López of UPRM gave a talk on Dr. Gavin Smith's course at University of North Carolina describing the observed damage in Puerto Rico after Hurricane María. Dr. Smith visited Puerto Rico on 2 occasions for meetings at FEMA, at UPR School of Planning, and with Profs Pagán and López, to discuss several possibilities of helping FEMA with improving resilience in PR. Dr Smith and Prof. Pagán gave presentations at the Conference organized by the UPR Graduate School of Planning.

e. A **Series of Conferences ("Conversatories") on the Impacts of Hurricane María in Puerto Rico** was organized in partnership with CoHemis (Center for Hemispheric Cooperation in Science and Engineering at UPRM), Sea Grant and other collaborators and were held in the Auditorium of the Civil Engineering Building of UPRM. The topics covered were: (1) Impact of María on the Coasts of PR, (2) Impact on the Power System, (3) Impact on Telecommunications, and (4) Impact on the Infrastructure. A total of 16 presenters representing academia (8), the community (3), Professionals (3) and Government (2) discussed the impact from their points of view, made recommendations, and answered questions from the audience. These conversatories were attended by 618 persons.

7. Publications:

a. Robert W. Whalin, Ismael Pagán-Trinidad, Evelyn Villanueva and David Pittman, "A Quarter Century of Resounding Success for a University/Federal Laboratory Partnership", Proceedings, 123rd ASEE Annual Conference and Exposition, Vol 1, presented June 27 2016 in New Orleans, LA. ISBN: 978-1-5108-3480-4

b. Ismael Pagán-Trinidad and Ricardo R. López, editors, Digital proceedings of Conference **"Lessons Learned and Best Practices: Resilience of Coastal Infrastructure"** , organized by the project, 2017, can be found in the link http://engineering.uprm.edu/inci/?page_id=3522

c. Morales-Velez, A. C., and Hughes, K.S., "Comprehensive Hurricane María Mass Wasting Inventory and Improved Frequency Ratio Landslide Hazard Mapping", Revista Dimension Year 32, Vol 1, 2018

d. Aponte Bermúdez, Luis D., "Huracán María,: Sinopsis y Análisis Preliminar del Impacto en la Infraestructura de Puerto Rico", Revista Dimensión Year 32, Vol 1, 2018

e. Martínez-Cruzado, José A. Huerta-López, Carlos I. Martínez-Pagán, Jaffet, Santana Torres, Erick X,and Hernández-Ramírez, Francisco J., "Destrozos, Recuperación, y Planes en la Red Sísmica de Movimiento Fuerte a Raíz de los Huracanes Irma y María", Revista Dimensión, Year 32, Vol 1, 2018

f. Acosta, Felipe J, Esquilín-Mangual, Omar, Wood, Stephanie G., Long, Wendy R. and Valdés, Didier, Lessons Learned from the Evaluation of Concrete Pole Failures Following Hurricane María, Revista Dimension Year 32, Vol 1, 2018

The following two presentations were given by Dr. Ricardo López at the World Engineering Conference on Disaster Risk Reduction. More information at http://www.wfeo.org/events/world-engineering-conference-disaster-risk-reduction-wecdrr-2016/

g. Ismael Pagán-Trinidad, Ricardo López-Rodríguez, Agustín Rullán, Oscar Perales-Pérez, John Fernández-Van Cleve, "THE ROLE OF UNIVERSITIES ON DISASTER RISK REDUCTION IN THE COMMUNITY: UPRM CASE STUDY", World Engineering Conference on Disaster Risk Reduction, Peruvian Association of Professional Engineers, Lima Perú, December 5-6, 2016.

h. López-Rodríguez, Ricardo R., Pagán-Trinidad, Ismael, "Structural Vulnerability to Natural Hazards in Puerto Rico", World Engineering Conference on Disaster Risk Reduction, Peruvian Association of Professional Engineers, Lima Perú, December 5-6, 2016.

Presentations on Impact of Hurricane Maria on Infrastructure

i. Ismael Pagán-Trinidad, Ricardo López-Rodríguez, “Overview of the Impact of Hurricane María in Puerto Rico”, Presented at UNC-Chapel Hill, Graduate Resilience Certificate, by invitation from Dr. Gavin Smith, Feb 28, 2018

j. Ismael Pagán-Trinidad, Ricardo López-Rodríguez, “Education for Improvement of Coastal Infrastructure in PR”, CRC First Annual Meeting, UNC Chapel Hill, March 2-3, 2016.

k. Ismael Pagán-Trinidad, Ricardo López-Rodríguez, “Education for Improvement of Coastal Infrastructure in PR”, CRC Second Annual Meeting, UNC Chapel Hill, Feb 1-3, 2017.

l. Ismael Pagán-Trinidad, Ricardo López-Rodríguez, “Education for Improvement of Coastal Infrastructure in PR”, CRC Third Annual Meeting, UNC Chapel Hill, Feb 28 - March 1, 2018.

m. Ismael Pagán-Trinidad, Ricardo López-Rodríguez, “Education, Resilience and the Built Environment: Impacts and Some Lessons Learned on Infrastructure for Improvement of Coastal Infrastructure in PR”, Symposium: Planning and Resilient Recovery in Puerto Rico, Graduate School of Planning - University of Puerto Rico – Río Piedras, May 18-19, 2018

n. Benjamín Colucci Ríos (Presenter), Alexander Molano Santiago, Ismael Pagán Trinidad and Didier. M Valdés Díaz. Impact of Extreme Climate in Coastal Transportation Civil Infrastructure in the Caribbean, World Engineering Forums November 26 to December 2, 2017, Rome, Italy

o. Benjamín Colucci Ríos (Presenter) and Alexander Molano Santiago, Impact of Hurricane Maria on Puerto Rico’s Transportation Infrastructure: Lessons Learned, 97th Transportation Research Board Annual Meeting, AHB55 Committee, *Work Zone Traffic Control Committee Meeting,* January 9, 2018.

p. Benjamín Colucci Ríos (Presenter) and Alexander Molano Santiago, Impacto del Huracán María en la infraestructura de transportación de Puerto Rico (Impact of Hurricane María in Puerto Rico’s Transportation Infrastructure), 4th Conversatorio para un Puerto Rico Resiliente. February 20, 2018

q. Benjamín Colucci Ríos (Presenter), Alexander Molano Santiago and Joel F. Alvarado López, El impacto del Huracán María en la infraestructura de transporte de Puerto Rico: Lecciones aprendidas (The Impact of Hurricane Maria in Puerto Rico’s Transportation Infrastructure: Lessons Learned), Mega Viernes Civil 2018: Resiliencia Aplicada, College of Engineers and Surveyors of Puerto Rico, San Juan, April 6, 2018

r. Benjamín Colucci Ríos (Presenter), Alexander Molano Santiago, Luis Sevillano García, Launelly M. Rosado Rosa and Joel F. Alvarado López, Transportation Engineering Innovation Spearheading the Economic Development of Puerto Rico after an

Extreme Natural Disaster, XXX Congress of Engineering and Surveying, COINAR 2018, San Juan, April 17, 2018.

8. <u>Lessons Learned:</u>

- It requires vision, courage and passion to make significant contributions to society. But vision is what really drives the others. A main lesson we learned is that opportunities come after leaders. One highlight we can identify is that this project was given an opportunity and it succeed thanks to the intervention of Dr. Robert Whalin, who invited us to participate. Thanks to him, the UNC PI's, and the DHS; hundreds of people (ranging from professionals, faculties, students, government officials, and the community citizens) have benefitted from the contributions made through the project. Lesson learned: It has been worth it!

- We understand the project has been very successful in integrating several partners to deliver quality courses, seminars and conferences. In essence, would do substantially the same. There are more opportunities available to partner with other groups than our possibilities as a small education project.

- Because of the interaction with several groups after Hurricanes Irma and María, we now know several key players that can be brought early into the project. Also because of the hurricanes, we were able to focus on particular problems observed that had huge consequences in the recuperation. Some of those problems were the lack of resilient electrical power system, the damage caused by storm surge on the coast, the lack of potable water, problems with sanitary plants, lack of reliable communication system (both public and private), and several structural failures that could have been avoided with better compliance with modern building codes.

- We have learned that capacity building must be audience type oriented. Being our expertise engineering, it must be our priority to engage, commit, and disseminate information with the engineering background. However, building resilience in the community from the infrastructure perspective requires a diverse multisector and multidisciplinary approach. For that reason, we have engaged and plan to continue engaging experts from diverse backgrounds and expertise.

9. Tables:

Table 1: Documenting CRC Education Project Courses and Enrollments

Courses Developed and Taught by University of Puerto Rico Mayaguez under Project **Education for Improving Resiliency of Coastal Infrastructure**					
Course		Developed (D), Revised (R), and/or Taught (T), by Project Year			
Number	Title	1	2	3	
INCI6997 **INCI5995**	*"Rehabilitation of Coastal Structures (under development)"*- **Guevara** **Dual codes for graduate and undergraduate**		D	T	
Offering: Elective (E), Concentration (C), Minor (M)		-	E	E	
Enrollment		-	-	7	
INCI6XXX **INCI5XXX**	*"Resilience and Reliability of Coastal Infrastructures (under development)"*- **Saffar**		D	R	
Offering: Elective (E), Concentration (C), Minor (M)		-	E	E	
Enrollment		-	-	-	
INCI6995	**CE Special Problems (Graduate):** • *"A Novel Boussinesq -Type Numerical Wave Model Development" - IPT* • *"Stochastic Simulation of Tropical Cyclones for the Quantification of Uncertainty Associated with Storm Recurrence and Intensity: Phase II" - IPT* • *"Analysis of a Ring Levee Breach Using Adaptive Hydraulic" - IPT* • *"US Army Improved Ribbon Bridge" - IPT* • *Feasibility of Using the Weather Research and Forecasting Model (WRF)*	T T T	T T T T T		

	as forcing to the Advanced Circulation Model (ADCIRC) - IPT ● *"Assessment of Existing Tropical Cyclone Vortex Models for the Development of Wind and Pressure Profiles and Fields"*			T	
Offering: Elective (E), Concentration (C), Minor (M)		E/C	E/C	C	
Enrollment		3	5	1	
INCI5996	CE Special Problems (Project) ● *"Impact of Projected Sea Water Rise on Coastal Infrastructures" - IPT* *"Ship Simulation Study"- IPT* ● *"Utilities and Building Inventory For Resiliency Analyses at the Mayagüez Municipality Coastal Zone" - Dr. Ricardo Ramos*	T	T T		
Offering: Elective (E), Concentration (C), Minor (M)		E	E		
Enrollment		1	4		
INCI6066	***MS-Thesis*** ● *"Structural Effects of Tsunami Loads on Coastal Infrastructure," by Kevin Cueto (Ricardo Lopez)* ● *"Computation of Gradually Varied Flow in Channel Networks with Hydraulic Structures" by Felix Santiago (Walter Silva)* ● *"Cost analysis of the alternatives to mitigate damage to the infrastructure in Rincon" by Francisco Villafañe (Luis Aponte)* ● *"Stochastic Simulation of Tropical Cyclones for Quantification of Uncertainty Associated with Storm Recurrence and Intensity" by Efrain Ramos (Norberto Nadal)*	D	D D T T	T T T T	
Offering: Elective (E), Concentration (C), Minor (M)			C	C	
Enrollment		1	4	4	
INCI6065	***Master of Engineering Project***				

	Structural Analysis of Common Coastal Structures found on the West Coast of Puerto Rico using FEMA P-646 by Jorge Romeu		D	T	
Offering: Elective (E), Concentration (C), Minor (M)			C	C	
Enrollment			1	1	
INCI8999	*PhD Dissertation* • *"Resistencia a Cargas de Tsunami de Estructuras Críticas en el Norte de Puerto Rico" (Resistance to Tsunami Loads of Critical Structures in the North of PR) by Johnny Rosario* • *"Variation of the nonlinear dynamic response of three-dimensional buildings of reinforced concrete considering the directionality of seismic accelerations" by Juan Rodríguez* • *"Dynamic Identification and Nonlinear Modeling for the Structural Health Assessment of Aged Coastal Infrastructure in Puerto Rico" by Angel Alicea*	D	D D T	T T T	
Offering: Elective (E), Concentration (C), Minor (M)			C	C	
Enrollment			3	3	
INCI4950	***Civil Engineering Integrated Design Project - Capstone Course***		T	T	
Offering: Elective (E), Concentration (C), Minor (M)			C	C	
Enrollment			45	43	
CIMA8999	***Marine Science PhD Dissertation***		D	D	
Offering: Elective (E), Concentration (C), Minor (M)			C	C	
Enrollment			1	1	
CIMA6999	***Marine Science Master Thesis***		D	D	
Offering: Elective (E), Concentration (C), Minor (M)			C	C	

Enrollment		1	1	
INCI4998 *Civil Engineering Undergraduate Research*		T	T	
Offering: Elective (E), Concentration (C), Minor (M)		C	C	
Enrollment		1	1	

Table 2: Documenting External Funding and Leveraged Support

2A: External Funding

Title	PI	Total Amount	Source
Stochastic Simulation of Tropical Cyclones for Quantification of Uncertainty Associated with Storm Recurrence and Intensity (Efrain Ramos)	Ismael Pagán Trinidad	$22K Summer-Fall 2016	CHL-ERDC-US ARMY Corps of Engineers
Hydro Model Validation and Surge/Wave Grid Development -Puerto Rico and Virgin Islands (Felix Santiago, Giovanni Seijo)	Juan Gonzalez (as Co-PI of a broader BAA with the ERDC)	$36K Fall 2016 - Spring 2017	CHL-ERDC-US ARMY Corps of Engineers
“Houston Ship Channel Ship Simulation Study”- Gabriela Buono	Ismael Pagan Trinidad	$7267, Allen Hammack Summer-Fall 2017	CHL-ERDC-US ARMY Corps of Engineers
“Feasibility of using the Weather Research and Forecasting Model (WRF) as forcing for the Advanced Circulation Model (ADCIRC)”, Nelson Cordero “Evaluating simulation runs techniques using the Weather Research and Forecasting Model (WRF) capabilities”, Nelson Cordero	Ismael Pagan Trinidad	$36903 Summer-Fall 2017	CHL-ERDC-US ARMY Corps of Engineers (three different task orders)

"Assessment of Existing Tropical Cyclone Vortex Models for the Development of Wind and Pressure Profiles and Fields"; Nelson Cordero			
"Physical Model Testing of Improved Ribbon Bridge",Kevin Cueto Alvarado	Ismael Pagan Trinidad	$8364, Dr. Matt Malej, Summer-Fall 2017	GSL--ERDC-US ARMY Corps of Engineers

2B: Leveraged Support

Description	Estimated Annual Value (Mostly In-Kind)
UPRM Release Load - 2 CE Researchers worked on CRC project (Pagán 6 crs. ; López 6 crs)	$55,000 years 2 and 3
Venue and promotion for the "Lessons Learned and Best Practices in Resiliency of Coastal Infrastructure" at PR CIAPR, Hato Rey Puerto Rico	$1,000
ERDC support to participant speakers at "Lessons Learned and Best Practices Conference in Puerto Rico" Other speakers at the Conference @500/participants)	$45,000 $6000
Sea Grant Program Collaboration - Promotional materials, arts, announcements	$2,000
COHEMIS-Collaboration, Coordination of conversatories, promotional material, personnel time)	$5000
Transportation Technology Transfer Program -Promotion	$500
Dr. Dan Cox - Oregon State University - RETALK Program	$1,000
UPRM Release Load - 3 CE Faculties worked on CRC research and teaching topics (Guevara-1 cr. ; Saffar-4 crs ; Ramos - 2 crs, Colucci - 2 crs	$40,000
Coastal Hydraulic Lab (ERDC) speaker on National Coastal Research and Development	$2,000
PR Climate Change Change Speaker - 6 hours	$2000
Conversatories - Speakers 16 @$500	$8000

Table 3: Performance Metrics

Pagan Education Project Metrics

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17— 6/30/18)
HS-related internships (number)	10	16	9
Undergraduates provided tuition/fee support (number)		1	
Undergraduate students provided stipends (number)		2	1
Graduate students provided tuition/fee support (number)	5	9	5
Graduate students provided stipends (number)	6	9	4
Undergraduates who received HS-related degrees (number)		N/A	2
Graduate students who received HS-related degrees (number)		N/A	2
Certificates awarded (number)		245	800
Graduates who obtained HS-related employment (number)		2	1
Lectures/presentations/seminars at Center partners (number)		1	2
DHS MSI Summer Research Teams hosted (number)		N/A	N/A
Journal articles submitted (number)	1	0	4
Journal articles published (number)	1	0	4
Conference presentations made (number)	2	31	23
Other presentations, interviews, etc. (number)	2	8	5
Trademarks/copyrights filed (number)		0	0
Requests for assistance/advice from DHS agencies (number)			
Requests for assistance/advice from other Federal agencies or state/local governments (number)	5		4
Total milestones for reporting period (number)		2	7
Accomplished fully (number)	2	2	7
Accomplished partially (number)		N/A	
Not accomplished (number)		N/A	

10. Year 3 Education Activity and Milestone Achievement:

Education Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/17 – 6/30/18			
Education Activities	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
1. Assessment and Rehabilitation of Coastal Infrastructure course for students and professionals	Dec 2017	100	100 (Guevara)
2._ Outreach high school students and faculty	May 2018	50	Schools schedule and availability within their schedule highly limited because of school closures, class delays, and priority to school's agenda.
3. Expand scope of offerings (workshops, seminars, lectures)	Dec 2017	100	100
4. Offer first train the trainer workshop	June 2018	100	
5. Launch project web page-engine to access repository and web navigation on educational RCI issues	Dec 2017	80	Web page ready. Needs to be uploaded. Documentation copy-rights screening.
Education Milestones			
1.Expand the Educational Community in RCI (Metric: List participants and sectors)	June 2018	100	100
2.Create a Community of Minority Educational Leaders in RCI (Metric: Number of women and Latin-Americans engage as leaders)	June 2018	100	100
3. Provide second round of certificates (Metric: Number of certificates)	June 2018	100	100

11. Year 3 Transition Activity and Milestone Achievement:

Transition Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/2017 – 6/30/2018			
Transition Activity	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
1. Provide second round of certificates	June 2018	100	
2. Engage second formal course on Assessment and rehabilitation on Coastal Infrastructure	Dec 2017	100	
3. Increase /expand seminars/lectures	June 2018	100	
4. Offer second annual local workshop/conference	June 2018	100	
5. Offer first Train the Trainer workshop	June 2018	100	Workshop on Flood Mapping
6. Provide access to RCI literature, guidelines, and websites	Dec 2017	80	Web page ready. Needs to be uploaded. Documentation copy-rights screening.
Transition Milestone			
1. Offer second new formal course (Metric: Contents learned)	June 2018	100	
2. Provide second round of certificates(Metric: No. and distribution of certificates given)	June 2018	100	

3.Create pipeline for precollege students to engineering programs engaged in CRI activities (Metric: No. of students pursuing engineering careers with HLS aspirations)	June 2018	100	
4. Develop RCI leaders (Metric: Distribution of certificates of trainees granted)	June 2018	100	

SMITH, UNC-CH
DHS COASTAL RESILIENCE CENTER
EDUCATION PROJECT
YEAR 3 REPORT
July 1, 2017 – June 30, 2018

Project Title: Expanding Coastal Resilience Education at UNC - University of North Carolina

Principal Investigator Name/Institution:
Gavin Smith, Research Professor, Department of City and Regional Planning
Rick Luettich, Professor, Department of Marine Sciences, University of North Carolina at Chapel Hill

Other Partners/Institutions:
UNC partners include: Departments of City and Regional Planning, Geological Sciences, Law School, Curriculum for the Environment and Ecology, of Marine Sciences, Center for Public Service. North Carolina State University partners include the Departments of Landscape Architecture and Architecture in the College of Design. State partners include the North Carolina Division of Emergency Management and North Carolina Governor's Office. Federal partners include FEMA's Community Planning and Capacity Building team. Additional local partners include: local officials and residents in the towns of Princeville, Windsor, Kinston, Seven Springs, Lumberton and Fair Bluff, North Carolina (communities represent many of the most hard-hit locations following Hurricane Matthew that possess limited capacity to recover).

Project Start and End Dates: 1/1/2016—6/30/2020

Short Project Description ("elevator speech"):

UNC has expanded its capabilities in Coastal Resilience by developing a graduate certificate program in Natural Hazards Resilience and by hiring a tenure track faculty member in the area of Coastal Natural Hazards and Climate Science.

The 10-hour certificate program focuses on the nexus between the physical science underlying natural hazards phenomena and the policies, programs, and plans needed to help societies manage their effects and increase resilience. Key themes explored include the role of planning, governance, and the connectivity between natural hazards, disasters, and climate change adaptation.

The certificate program has further expanded through a partnership with the North Carolina Division of Emergency Management following Hurricane Matthew. At the request of the Director of NCEM and support from the Governor's Office, Dr. Smith created the Hurricane Matthew Disaster Recovery and Resilience Initiative (HMDRRI). HMDRRI is designed to assist 6 heavily impacted communities following Hurricane Matthew, which struck North Carolina in the Fall of 2016. The HMDRRI provides a rare opportunity for students and faculty to engage with seasoned practitioners and local jurisdictions in post-disaster recovery operations following Hurricane Matthew and subsequent events.

PROJECT NARRATIVE:

1. Introduction and project overview:

The study of natural hazards resilience, including those hazards exacerbated by a changing climate, and the translation of these findings to practice is becoming increasingly important as disaster losses continue to rise at an exponential rate in the United States and across the world. The Department of Homeland Security's Science and Technology Directorate, Office of University Programs, the National Science Foundation, and the National Academy of Sciences have all expressed their concerns about this growing trend. A common refrain among all groups is the need to educate the next generation of natural hazards scholars and practitioners as the field is greying and is less diverse than the population as a whole.

The 10-hour certificate program based at UNC offers a recognized value in the field as evidenced by an increased emphasis on professional training and certification among individuals and organizations. The activities also align with Quadrennial Homeland Security Report Goal 1.3 (manage risks to critical infrastructure), Mission 5 (ensuring resilience to disasters) and all of its associated goals (mitigate hazards, enhance preparedness, ensure effective emergency response, and rapid recovery). The certificate program is building important capacity by attracting and training the next generation of natural hazards scholars and practitioners. The value of the program is evident in the fact that all graduates of the program have gone on to work in the field or are pursuing further educational opportunities focused on natural hazards, disasters and climate change adaptation.

Coupling the certificate program with the university's national recognition for academic excellence is intended to provide a multi-disciplinary pool of graduate students with a unique learning opportunity, sense of community, and highly competitive set of skills and knowledge base that blends what we know about natural hazards and disasters with climate change (including adaptation). This is being further supplemented by the research and engagement opportunities offered to students through initiatives like that found in the Hurricane Matthew Disaster Recovery and Resilience Initiative (HMDRRI). Additional opportunities are being explored through post-Hurricane Florence work and informed by the recently completed study by the PI and Dr. Mai Nguyen that assessed the state of disaster resilient design curricula in the United States and offered specific recommendations on how to improve it.

2. History:

Natural Hazards Resilience Certificate Program
The Graduate Certificate Program in Natural Hazards Resilience was approved by UNC-CH in the fall of 2015. Although the process of getting approval was lengthy and challenging, the certificate program has proven to be very successful as indicated by increased enrollment, growing interest expressed by new students entering graduate programs at a variety of departments at UNC, and the increase in the number of students achieving the certificate within the two-year timeframe.

Students must apply to the certificate program. Upon acceptance, students are required to take and pass 10 credit hours, including three core courses (Planning for Natural Hazards and Climate Change Adaptation (3 credits); Survey of Natural Hazards and Disasters (3 credits); and Natural Hazards Resilience Speakers Series Course (1 credit). The remaining 3 credit hours are acquired through approved elective courses in a wide variety of disciplines, including geography, geology, marine science, law, public administration, and social work, among others. Students are strongly encouraged to gain experience through summer internships and/or fieldwork.

The Natural Hazards Resilience Speaker Series was launched as part of the certificate program in the Spring semester of 2016, and has proven to be very popular as evidenced by growing enrollment each time it is offered, including attendance by students and others who are not seeking the certificate. The talks have centered on topics related to natural hazards resilience, but each invited speaker has brought their own unique perspective and experiences to the classroom. In the most recent speaker series offering, topics of discussion included the impacts of Hurricane Maria in Puerto Rico; a professional photographer's perspective on art and disaster; creating wildfire resilient communities; and disaster recovery in a small town, among others. The highlight of the Spring 2018 speaker series was a visit to UNC's campus by FEMA Administrator Brock Long. Administrator Long spoke about lessons learned from the 2017 hurricane season and offered a vision for emergency management moving forward. The Administrator's talk, which was followed by a Q&A session, was attended by students, faculty, community members, and local and state elected officials. Former FEMA Administrator Craig Fugate also spoke in the previous year's class.

New Faculty Hire in Marine Science

In 2015, Dr. Wei Mei was hired at the UNC Department of Marine Sciences as a tenure track faculty member. Dr. Wei, whose specialty is in climate and coastal hazards, conducts internationally recognized research that is closely aligned with the CRC. Specifically, he studies tropical cyclones with a focus on interactions with the ocean and climate control, and is also interested in atmospheric, ocean and climate dynamics, and climate variability, extremes and change. During years 2-5 of the CRC grant, 1/3 of the faculty position is funded by DHS through the CRC; 1/3 funding is provided by the UNC Vice Chancellor for Research; and 1/3 comes from the College of Arts & Sciences.

Hurricane Matthew Disaster Recovery and Resilience Initiative

Following Hurricane Matthew, which heavily impacted much of the eastern portion of the state in 2016, the NC Division of Emergency Management and the Governor's Office requested assistance from Dr. Gavin Smith to serve as a Senior Recovery Advisor and Chief of the Hurricane Matthew Disaster Recovery and Resilience Initiative (HMDRRI). This role involved advising the North Carolina Division of Emergency Management (NCEM), the Governor, and members of his cabinet on a range of disaster recovery policy issues. Key issues included helping the state develop a disaster recovery housing strategy, advising the state on the allocation and coordination of funding, the identification of unmet local needs, and developing strategies focused on assisting local governments and disaster survivors to recover from one of the worst disasters in the state's history. Emphasis was placed on providing assistance not typically addressed by FEMA or state agencies. Based on meetings with local officials to identify unmet needs, the HMDRRI team focused on helping communities with a number of activities. These included: 1) identifying what could be done with the open space following the acquisition and demolition of flood-prone homes; 2) conducting land suitability analyses to identify areas outside the floodplain, but within each town's boundaries where replacement housing could be built (thereby reducing the loss of tax base); 3) designing several housing replacement design plans; 4) conducting a housing study to assess housing needs by type, cost and location; 5) conducting studies assessing possible floodproofing strategies in historic downtowns; and 6) developing disaster recovery plans. In addition, the HMDRRI team led the 5-day Princeville Design Workshop, which involved collaborating with the North Carolina Division of Emergency Management, the North Carolina State University College of Design, over 20 state and federal agencies, local officials, and the residents of Princeville, North Carolina, the oldest African American community in the United States. Emphasis was placed on creating design options for a 52-acre site outside the floodplain adjacent to the town limits to relocate critical public facilities, construct new replacement housing, and explore the creation of a visitor's center.

NCSU Design Week

Under the auspices of HMDRRI, in the Fall of 2017 the North Carolina State University College of Design held Design Week in which teams made up of UNC Department of City and Regional Planning students along with students from the Departments of Architecture and Landscape Architecture at North Carolina State University's College of Design developed design-based solutions for 4 of the 6 HMDRRI communities. In total, more than 30 students participated in the design competition. Students met with officials in their respective communities, developed proposed solutions and presented their findings to a panel of NCSU and UNC faculty as well as representatives from the communities. The winning project sought to inform how communities slated for the purchase and demolition of their homes could be relocated as a group, thereby maintaining a sense of community. The project has resulted in influencing how the expenditure of several hundred million dollars in post-disaster aid may be allocated. The results have also helped to inform the development of a relocation strategy implemented by the HMDRRI team in the 6 communities.

Homeplace: Conversation Guides for Six Communities Rebuilding from Hurricane Matthew

In 2017, the Coastal Dynamics Design Lab at North Carolina State University College of Design led the development of conversation guides to assist flood survivors by providing easy-to-understand technical assistance addressing typical post-disaster issues. The *Homeplace* documents provide residents of the six HMDRRI communities with a menu of high-quality, community-specific designs and strategies that consider broader regional infrastructures, development patterns, and population trends. The ultimate goal is to build the local capacity of North Carolina's flood-prone communities, providing them with design, planning, and policy strategies and tools to promote the long-term function, health, and vitality of their residents and neighborhoods. Specific guidance emphasized how to use the open space created following the acquisition of flood-prone homes (e.g., pocket parks, greenways, community gardens, public spaces) and creating eight replacement housing prototype designs that reflected the local vernacular of impacted communities. The recommendations in each of the six community-specific guides are currently being woven into the communities' recovery plans.

Disasters Design Education in the United States: Current and Emerging Curricula in Colleges and Universities

Under a 2016 federal action in the Obama administration that recognized the role of resilient design education to promote a resilient future, CRC, led by Dr. Gavin Smith and Dr. Mai Nguyen conducted a study of resilient design education in the United States. The project included a literature review and landscape survey by the CRC to establish the current state-of-the-art in the science and education of resilient design. The research involved an extensive internet search of resilient design curricula, key informant interviews with experts, consultation with a review committee, and case studies of resilient design education programs. The study examined five design-based disciplines, including architecture, building sciences, engineering, landscape architecture, and planning.

The study found that resilient design is a small but rapidly growing field, with several universities and colleges creating degrees, minors and certificate programs focusing on the subject. However, the findings also indicate that many programs remain focused on one element of resilient design instead of encouraging interdisciplinary approaches. The report identified several goals to improve the availability of interdisciplinary resilient design education in the United States. Resilient Design Education Goals include:

- Improve institutional commitment from colleges and universities across disciplines and departments.
- Develop new curricula models and organizational structures to emphasize opportunities for research and engagement, beyond classroom learning.
- Build interdisciplinary teams with a mix of faculty, practitioners and policy-makers to teach and mentor students.
- Emphasize field and studio-based projects for a “learning by doing” approach to foster innovation, room to fail, and the ability to fix problems.
- Create flexible and responsive curricula for post-disaster situations, which provide many learning opportunities and opportunities for field work.
- Seek out national, state, and local stakeholders that could serve as ongoing “clients” or sounding board for curriculum content and products developed by students and faculty.

The findings of this study will be incorporated into ongoing efforts to improve the Graduate Certificate in Natural Hazards Resilience. For instance, FEMA’s Higher Education Program has funded the development of a new 3 credit hour course in Disaster Resilient Design to be created by Dr. Smith that will be added as an elective in the certificate program in 2019.

3. <u>Results:</u>

The following courses were developed and have been delivered as part of the natural hazards resilience certificate program:

Natural Hazards Resilience Certificate Course Delivery

Semester	Course Title	Course #	Student Enrollment
Spring 2015	Special Topics Seminar	(PL 90)	5
Fall 2015	Planning for Natural Hazards and Climate Change Adaptation	(PL 755)	8
Spring 2016	Natural Hazards Resilience Speaker Series	(PL 754)	14
Spring 2016	Survey of Natural Hazards and Disasters	(PL756)	9
Spring 2016	Independent Study	(PL 896)	1
Fall 2016	Planning for Natural Hazards and Climate Change Adaptation	(PL 755)	20
Spring 2017	Natural Hazards Resilience Speaker Series	(PL 754)	31
Spring 2017	Masters (non-thesis)	(PL 992)	4
Summer 2017	Masters (non-thesis)	(PL 992)	1
Fall 2017	Survey of Natural Hazards and Disasters	(PL756)	26
Spring 2018	Natural Hazards Resilience Speaker Series	(PL 754)	28
Spring 2018	Masters (non-thesis)	(PL 992)	3
Fall 2018	Planning for Natural Hazards and Climate Change Adaptation	(PL 755)	40

Class enrollment has continued to grow steadily since the first courses were taught in 2015 as the importance of hazards resilience and climate change adaptation is becoming more apparent.

- Three-credit hour classes have enrolled up to 40 students, which is among the largest of all DCRP classes.
- The Speaker Series course has more than doubled in size from 14 to 31 students.

In terms of student recruitment to the University, over the past two years the Department of City and Regional Planning has experienced increasing numbers of student applicants who express interest in a focus on natural hazards, including pursuit of the certificate.

In addition to the core classes required by the certificate program, Dr. Smith has provided students with multiple out-of-class enrichment activities, including field trips to disaster-impacted areas of the state; visits to communities that have been successful in mitigating flood hazards; and visits to the NCEM Emergency Operations Center. Dr. Smith has served on the committees of approximately twenty-eight students, including seven Ph.D. candidates. Dr. Smith has also mentored over twenty students throughout their academic careers in planning for resilience, has procured several internships, and has been instrumental in placing graduates in disaster-resilience related jobs.

Dr. Smith has also procured financial support for 27 students through various sources including the DHS Career Development Grant, the DHS Science and Engineering Workforce Development grant, and research assistantships on a variety of projects related to natural hazards and disasters, including work generated by HMDRRI.

4. Students:

The certificate program is designed to serve enrolled graduate students and is not available to practicing professionals located outside the university. The certificate program is open to master's and Ph.D. students from all departments at UNC-CH that have identified an advisor in their home department that is willing to work with the head of the certificate program or an advisor that is actively participating in the certificate program. Students are primarily enrolled at UNC-CH, although students from NC State and Duke Universities have also taken courses and earned the certificate.

Based on the high demand among employers for recent graduates who have studied with faculty associated with the Coastal Resilience Center and the former Coastal Hazards Center, the certificate program has provided a significant enhancement to participating students' graduate education and competitiveness in the job market. Our first Certificate recipient was hired by the State of North Carolina Division of Emergency Management where she is deeply involved in post-Hurricane Matthew disaster housing issues. Twenty-three students (21 masters students and 2 Ph.D. candidates) were hired to assist HMDRRI efforts during the summer of 2017, including 8 from North Carolina State University and one recent Duke University graduate. In the Fall of 2017, one certificate student began a year-long post-graduate fellowship at Oak Ridge National Labs.

CRC's four Workforce Development grant recipients have also found post-graduation positions. Former WFD students have gone on to work in a number of places, including the North Carolina Division of Emergency Management, pursuing a Ph.D. at MIT (focused on planning for natural hazards and climate change adaptation), a FEMA contractor, and as a planner in Saint Louis working on floodplain management issues. These students' final reports are in Appendix A of the Center report.

5. Institutionalization:

The certificate program was not developed as a source of revenue generation. However, now that the program is well established within the University, we are exploring the creation of a permanent faculty position in the Department of City and Regional Planning or at another university that will allow for the teaching of the courses as part of the responsibilities of the faculty position. The faculty position in the Department of Marine Sciences will be fully funded by UNC after the CRC's 5-year lifetime to provide a long-term programmatic contribution to the HS enterprise.

6. Interactions with research projects:

Seven researchers from across CRC have been invited to speak in each of the three core courses in the graduate certificate program. This has provided an opportunity for PI's to discuss their CRC-funded research and its connectivity to classroom materials. PI's have also served on guest panels that review student presentations and group projects. It is estimated that at least one CRC-affiliated PI or student will speak in each of the three certificate program classes in a given year. The Speaker Series course has also provided an opportunity for invited speakers to deliver lectures to students enrolled in the class, as well as the larger UNC-CH community. Some presentations have involved serving on a panel with other PI's, members of our Advisory Board, and DHS component agency officials. This is intended to expose students to the issues and connections that span research and practice (a key theme of the certificate program).

Student internships are encouraged and serve as an elective in the certificate program. The PI has actively solicited internship opportunities with research partners and practicing professionals working closely with the student to ascertain their interests. In addition, the PI regularly assesses the needs of potential employers.
The Disaster Resilient Design Curricula study findings are being incorporated into Certificate class lectures and a new 3-credit course titled Disaster Resilient Design will be developed in year 2019. The costs associated with course development will be funded by FEMA.

7. Publications (Years 1-3):

Journal Articles

Horney, Jennifer, Carolina Dwyer, Bhagath Chirra, Kerry McCarthy, Jennifer Shafer and Gavin Smith. 2018. Measuring Successful Disaster Recovery, *International Journal of Mass Emergencies and Disasters* 36(1): 1-22.

Gavin Smith, Lea Sabbag and Ashton Rohmer. 2018. A Comparative Analysis of the Roles Governors Play in Disaster Recovery, *Risk, Hazards & Crisis in Public Policy*. 9(2): 205-243. DOI: 10.1002/rhc3.12133.

Smith, Gavin. 2016. Remembrances of the Past, Concerns for the Future, and the Potential Resilience of a Small Coastal Town, *Southern Cultures*. Summer: 64-87.

Horney, Jennifer, Caroline Dwyer, Meghan Aminto, Phil Berke and Gavin Smith. 2016. Developing Indicators to Measure Post-Disaster Community Recovery, Disasters 41(1): 124-149.

Lyles, Ward, Philip Berke and Gavin Smith. 2015. Local Plan Implementation: Assessing Conformance and Influence of Local Plans in the United States, Environment and Planning B: Planning and Design.

Book Chapters

Smith, Gavin. "The Role of States in Disaster Recovery: An Analysis of Engagement, Collaboration, and Capacity Building." 2018. In Building Community Resilience to Disasters: The Handbook of Planning for Disaster Resilience, Routledge Press.

Smith, Gavin, Amanda Martin and Dennis Wenger. "Disaster Recovery in an Era of Climate Change: The Unrealized Promise of Institutional Resilience." 2017. In Handbook of Disaster Research, Second Edition, Eds. Havidan Rodriguez, Joseph Trainor and William Donner. New York: Springer.

Smith, Gavin. "Pre- and Post-Disaster Conditions, their Implications, and the Role of Planning for Housing Recovery." 2017. Chapter 18, pp. 277-292. In Coming Home After Disaster: Multiple Dimensions of Housing Recovery, Eds. Ann-Margaret Esnard and Alka Sapat. Boca Raton, Florida" CRC Press.

Smith, Gavin. "Planning for Sustainable and Disaster Resilient Communities." 2015. Chapter 9, pp. 249-279. In Hazards Analysis: Reducing the Impact of Disasters, Ed. John Pine (2nd edition). Boca Raton, Florida: CRC Press.

Smith, Gavin. "Creating Disaster Resilient Communities: A New Hazards Risk Management Framework." 2015. Chapter 10, pp. 281-308. In Hazards Analysis: Reducing the Impact of Disasters, Ed. John Pine. (2nd edition). Boca Raton, Florida: CRC Press.

Note: Publications involved working with CRC PI's Jen Horney and Phil Berke as well as CRC students Lea Sabbag and Ashton Rohmer (WFD grant recipients) and Ph.D. candidates Ward Lyles and Amanda Martin.

8. Lessons Learned:

Key lessons that involve doing things the same way include: 1) The value of combining classroom lectures with field-based learning; 2) Inviting a multidisciplinary range of practitioners and policymakers, scholars, and others to meet and talk with students (to include asking speakers to discuss their own personal lessons that positioned them to succeed in the field); 3) Requiring group projects, to include analysis, presenting information to instructor and invited guests, and writing papers and reports summarizing the findings. Taken in total, this approach has led to what I believe to be a successful teaching method that blends research findings, theory, and practice in a highly applied, multi-disciplinary field.

Key lessons that involve doing things a different way include: 1) identifying another department that is more vested/interested in the certificate program, to include the provision of financial and faculty support. The Department of City and Regional Planning, while a great fit given the caliber of students interested in the topical area (and my own training) has not been very supportive of the certificate in terms of committing financial resources to address some or all of my time, even though the program has proven to be a vital recruitment tool for prospective students, and recent classes are among the largest in the department (to include drawing students from a number of other departments as well as students from North Carolina State University and Duke University) . If I had to do it over again, I would seek out a more supportive department at UNC or another university.

9. Tables:

Table 1: Documenting CRC Education Project Courses and Enrollments

Courses Developed and Taught by University of North Carolina under Project Expanding Coastal Resilience Education at UNC						
Course		Developed (D), Revised (R), and/or Taught (T), by Project Year				
Number	Title	1	2	3	4	5
PLAN 755	Planning for Natural Hazards and Climate Change Adaptation	T	T	T		
	Offering: Elective (E), Concentration (C), Minor (M)	C	C	C		
	Enrollment	8	20	40		
PLAN 754	Speaker Series	T	T	T		
	Offering: Elective (E), Concentration (C), Minor (M)	C	C	C		
	Enrollment	14	31	28		
PLAN 756	Survey of Natural Hazards and Disasters	T	T	T		
	Offering: Elective (E), Concentration (C), Minor (M)	C	C	C		
	Enrollment	9	15	26		

Table 2: Documenting External Funding and Leveraged Support

2A: External Funding			
Title	PI	Total Amount	Source
HMDRRI	Smith	$100,000	UNC Collaboratory
HMDRRI	Smith	$340,602	UNC Collaboratory
HMDRRI	Smith	$251,797	State of NC Legislative Appropriation
HMDRRI	Smith	$274,364	NC Division of Emergency Management
HMDRRI	Smith	$72,483	NC Division of Emergency Management
Hurricane Matthew Disaster Recovery and Resilience Initiative Student Support.	Smith	$25,000	North Carolina Community Foundation
Resilient Design Education Study	Smith	$49,954	Department of Homeland Security
The Role of the State in Disaster Recovery: A Comparative Analysis of Gubernatorial Leadership and State Agency Official Engagement, Collaboration and Capacity Building.	Smith	$30,000	FEMA
The Role of the State in Disaster Recovery: A Comparative Analysis of Gubernatorial Leadership and State Agency Official Engagement, Collaboration and Capacity Building.	Smith	$60,000.	Department of Homeland Security

2B: Leveraged Support	
Description	Estimated Annual Value
Note: All of the external funding listed above has been leveraged to support the certificate program.	
Three offices provided by NCEM in the Hurricane Matthew Disaster Field Office for 1 year.	$50,000
Supplies, lodging, and food to support the 5-day Princeville Design Workshop.	$50,000

Table 3: Performance Metrics:

SMITH PERFORMANCE METRICS

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17- 6/30/18)
HS-related internships (number)	2	14	
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)		1	
Graduate students provided tuition/fee support (number)	2	2	2
Graduate students provided stipends (number)		13	23
Undergraduates who received HS-related degrees (number)			
Graduate students who received HS-related degrees (number)		3	5
Certificates awarded (number)	1	3	5
Graduates who obtained HS-related employment (number)	1	3	5
Lectures/presentations/seminars at Center partners (number)	3	3	4
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)	1	1	2
Journal articles published (number)		2	2
Conference presentations made (number)	6	12	29
Other presentations, **interviews**, etc. (number)		11	14
Trademarks/copyrights filed (number)			
Requests for assistance/advice from DHS agencies (number)		1	5
Requests for assistance/advice from other agencies or governments (number)		4	2
Total milestones for reporting period (number)	10	11	11
Accomplished fully (number)	9	11	11
Accomplished partially (number)	1		
Not accomplished (number)			

10. Year 3 Education Activity and Milestone Achievement:

Education Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/17 – 6/30/18			
Education Activities	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
Teach certificate program courses	May 2018	100%	
Provide students with the knowledge and experience to actively contribute to the study and/or practice of natural hazards and disasters	June 2018	100%	
Recruit students into certificate program	June 2018	100%	
Attract and engage additional UNC faculty to coastal resilience to include developing new coursework (in addition to core courses already created and taught) that is closely aligned with the certificate and CRC's mission	June 2018	100%	Course developed by Mai Nguyen – Applied Housing Workshop to Hurricane Matthew Recovery
Education Milestones			
Deliver 3 core courses per year that support the certificate program	May 2018	100%	
Track student performance (including internships obtained and number of graduates).	June 2018	100%	
Four new students admitted to certificate program	June 2018	100%	
Develop one new elective course taught by UNC faculty (beyond the three core courses already developed)	June 2018	100%	Course developed by Mai Nguyen – Applied Housing Workshop to Hurricane Matthew Recovery

11. Year 3 Transition Activity and Milestone Achievement:

Transition Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/2017 – 6/30/2018			
Transition Activity	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
Promote internship opportunities for students/recruit end users to host students	January 2018	100%	See HMDRRI; Private sector has hired a number of graduates.
Promote certificate program graduates to potential employers	June 2018	100%	All certificate program graduates employed following graduation.
Transition Milestone			
Document internships obtained	June 2018	100%	
Document post-graduation job placement	June 2018	100%	

WHALIN, JSU
DHS COASTAL RESILIENCE CENTER
EDUCATION PROJECT
FINAL / YEAR 3 REPORT

Project Title: PhD in Engineering (Coastal and Computational Engineering) at an HBCU

Principal Investigator Name/Institution: Robert W. Whalin, Ph.D., P.E., D.CE, Professor of Civil Engineering and Education Director, Coastal Resilience Center of Excellence, Jackson State University (JSU)

Other Partners/Institutions: US Army Engineer Research and Development Center (ERDC), Vicksburg, MS and Texas A&M University at Galveston

Project Start and End Dates: Jan. 1, 2016- June 30, 2020

Short Project Description: The primary objective of this project is to establish the first PhD Engineering Degree at an HBCU (Jackson State University) with a concentration in Coastal and Computational Engineering focused on coastal natural disasters. This PhD Engineering concentration, (coupled with undergraduate and MS level Coastal Engineering programs completed during the Coastal Hazards Center) provides a continuum of advanced education engineering programs focused on coastal natural disasters. End user relationships with ERDC, Mississippi Department of Transportation (MDOT), Corps of Engineers Districts, Mississippi Emergency Management Agency (MEMA) and local emergency management agencies across the southeastern US are fostered and strengthened.

PROJECT NARRATIVE:

1. Introduction and project overview:

This project directly addresses the education need for graduate engineering programs focused on coastal natural disasters to provide engineers that can help mitigate the ever-increasing cost of damages, especially those from tropical storms and hurricanes, that DHS is confronted with through FEMA missions. Almost no graduate coastal engineering programs are focused on coastal natural disasters and none are located at an HBCU where a large percentage of African American engineers matriculate. Jackson State University has an African American student body exceeding 80% which will directly support the DHS Strategic Plan Goal to Enhance the DHS Workforce, especially the Objective to increase Workforce Diversity and Priority Goal 3 to Enhance Resilience to Disasters. Leverage of federal assets is assured by the Education Partnership Agreement (authorized by Public Law) between the Engineer Research and Development Center and Jackson State University. The Agreement facilitates ERDC providing Adjunct Faculty, student internships and potential use of ERDC experimental and computational facilities for graduate research. An outstanding record of DHS End User involvement and transition of graduates to end users has been established during the seven and one-half years of the Coastal Hazards Center of Excellence at Jackson State University and will continue to be strengthened throughout the five-year Coastal Resilience Center of Excellence program. Research staff and graduate students have direct participation in a CRC research project, summer research experiences (SUMREX) with CRC research partners and in highly relevant hurricane barrier projects nationwide (funded by others) including the Ike Dike concept for protecting Galveston Island and the greater Houston metropolitan area from devastating, albeit low probability, hurricane surges. Coastal Engineering programs nationwide have been on a decline for the past two decades and United States leadership in the coastal engineering profession has declined relative to other nations. This project will help ameliorate the trend while increasing the supply of minority coastal and computational graduate level engineers focused on the field of coastal natural disasters.

2. History:

The history of this project actually began on July 1, 2008 when DHS funded the Coastal Hazards Center of Excellence (Education) at Jackson State University with me (Dr. Robert W. Whalin) as PI and Director. One JSU CHC project had the objective of developing undergraduate and graduate coastal engineering courses and programs focused on coastal natural disasters. The CHC COE was quite successful including establishment of MS Engineering degree concentrations in Coastal and Computational Engineering focused on coastal natural disasters.

The CHC success provided a firm foundation, (including relations with end users in the greater Homeland Security Enterprise, HSE who employ graduates), for the current Coastal Resilience Center education project entitled, "PhD in Engineering (Coastal and Computational Engineering) at an HBCU" (Jackson State University). The MS Engineering, Coastal Engineering concentration graduates form a steady, albeit small, stream of potential PhD graduate students for the CRC PhD program.

During Year 2, Jackson State University experienced severe unanticipated fiscal challenges and leadership changes (President, Provost, and Vice Presidents all changed). Specifics are in the Year 2 Annual Report. The fiscal turbulence led to a decision to delay submittal of the new PhD Engineering (Coastal Engineering concentration) documentation until Year 3. We are gratified to report that this strategy succeeded and the PhD Engineering (Coastal Engineering concentration) was approved in April 2018. The project and milestones are back on the original schedule. The Education and Transition Activities and Milestones are summarized in the following sections.

3. Results:

The first three years of this five-year project have been highly productive. Year three proved to be a watershed year as the severe fiscal challenges impacting milestones in year two were overcome and all milestones through Year 3 have been met. No impact is envisioned for the remaining Year 4 and Year 5 milestones. Table 1 documents courses that were enrolled in by Coastal Engineering concentration students.

A summary of coastal engineering related degrees awarded during the first 3 years follows. Five MS Engineering (Coastal Engineering concentration) degrees were awarded during the first three years of this Project. One PhD Engineering (Civil Engineering concentration) degree was awarded to a student who also completed all requirements for the recently approved PhD concentration in Coastal Engineering. These courses were electives in the students Civil Engineering concentration. This PhD degree was awarded in April 2018. Seven BS degrees were awarded to students who enrolled in the graduate Coastal Engineering concentration of the MS Engineering degree.

Ethnicity of Graduates	BS	MS	PhD
African American	3	3	0
Hispanic American	0	0	0
Asian American	2	1	1
Caucasian	2	1	0
Total Graduates	7	5	1

The most significant milestone during Year 3 was institutionalization of the PhD Engineering degree (Coastal Engineering concentration) which was approved in April 2018 by the Vice President of Academic Affairs and Provost. The concentration will appear in the JSU graduate catalog for Fall 2018. This is the final step in formal institutionalization of the Coastal Engineering concentration. The Computational Engineering concentration was approved and institutionalized in 2016 along with the PhD Engineering degree and its other concentrations (Civil, Environmental, Computer, and Electrical Engineering).

The following three pages contain the approved modifications (in red) to the JSU Graduate Catalog that describes the approved Coastal Engineering concentration of the Doctor of Philosophy (Ph.D.) in Engineering degree program.

joins theoretical analysis and physical experimentation as tools for discovering new knowledge.

Program Objectives

1. Develop computational systems for the solution of physical problems in engineering and science.

2. Develop algorithms and software required for the mathematical models of physical processes. 3. Visualize, analyze, and interpret computed results and other physical data.

Core Courses

Course	Title	Semester Hours
CPE 503	Computational Methods	3
CPE 520	Advanced Engineering Analysis I	3
CPE 521	Advanced Engineering Analysis II	3
CPE 618	High Performance Computing	3
Elective Courses		
CPE 500	Software Engineering	3
CPE 505	Analysis of Algorithms	3
CPE 508	Operating Systems	3
CPE 512	Computer Architecture	3
CPE 515	Advanced Logic Design	3
CPE 530	VLSI Design	3
CPE 531	VLSI Testing and Design for Testability	3
CPE 532	Digital Integrated Circuit Design	3
CPE 533	Fault-Tolerant Computing Systems	3
CPE 541	Computer Networks	3
CPE 547	Modeling and Analysis of Computer and Communication Systems	3
CPE 552	Computer Vision	3
CPE 555	Control Systems	3
CPE 557	Robotics	3
CPE 560	Embedded Design with Microprocessors	3
CPE 601	Code Optimizations	3
CPE 610	Parallel Computing and Programming	3
CPE 611	Computer Arithmetic	3
CPE 630	Design Automation of VLSI Systems	3
CPE 640	Computer Security	3
CPE 641	Advanced Computer Networks	3
CPE 642	Computer Network Security	3
CPE 655	Advanced Control Systems	3
CPE 693	Advanced Topics in Engineering	1 to 4
CPE 695	Scientific Writing Seminar	1
CPE 696	Seminar	1
CPE 697	Internship	1-3
CPE 698	Independent Study	1-4
CPE 699	Dissertation Research	1-6

Doctor of Philosophy (Ph.D.) in Engineering

Program Description

The Ph.D. in Engineering Program consists of 8 emphasis areas including Computer Engineering, Telecommunications Engineering, Electrical Engineering, Computational Engineering, Civil Engineering, Coastal Engineering, Environmental Engineering, and Geological Engineering.

Mission

To provide students with the necessary advanced knowledge, research skills, creativity, ethics, critical thinking, and problem solving to be able respond to engineering challenges and needs of our ever-changing world for professional competence and lifelong and inquiry-based learning.

Objectives

The primary educational objective of the Ph.D. in Engineering Program is to produce engineers with terminal degrees to meet the needs for highly educated engineers with advanced technical and research skills in the workforces. The specific objectives of the eight emphasis areas are as following:

Civil Engineering: to prepare students for continued professional and scholarly development consistent with their technical interests in civil engineering by conducting a major independent and original research study with critical thinking.

Coastal Engineering: to prepare students with advanced knowledge and skills in coastal engineering, (including coastal natural disasters) and produce graduates with competencies in advanced original research, education and professional practice in coastal engineering.

Environmental Engineering: to equip students with advanced knowledge and skills in the environmental engineering field and produce graduates with competencies in advanced original research, education, and professional practice in the area of environmental engineering.

Geological Engineering: to train students with advanced knowledge and scholarly development in geological engineering and produce graduates with competency in advanced original research in the area of geological engineering.

Computer Engineering: to equip students with advanced knowledge in computer engineering and produce graduates with competencies in advanced original research, education, and professional practice in computer engineering.

Telecommunications Engineering: to equip students with advanced knowledge in telecommunications engineering and produce graduates with competencies in advanced original research, education, and professional practice in telecommunications engineering.

Electrical Engineering: to equip students with advanced knowledge in electrical engineering and produce graduates with competencies in advanced original research, education, and professional practice in electrical engineering.

Computational Engineering: to equip students with advanced knowledge in computational engineering and produce graduates with competencies in advanced original research, education, and professional practice in computational engineering.

Admission Requirements The applicants must meet all admission requirements set by the Division of Graduate Studies. In addition, the applicants must meet the following admission requirements.

1. A Bachelor of Science (B.S.) degree in civil engineering, environmental engineering, computer engineering, or electrical engineering or closely related engineering disciplines from accredited colleges and universities, or a Master of Science (M.S.) in related engineering field.
2. Applicants who do not have a B.S. or M.S. in an engineering field will be required to satisfy the articulation courses.
3. Minimum undergraduate grade point average (GPA) of 3.0 on a 4.0 scale and minimum graduate GPA of 3.50 on a 4.0 scale are required. In special cases, exceptional applicants with B.S. degrees in engineering will be considered. These applicants must have a minimum GPA of 3.5
4. Applicants with Minimum undergraduate grade point average (GPA) of 2.90 on a 4.0 scale and minimum graduate GPA of 3.250 on a 4.0 scale may be considered for conditional admission. These applicants must achieve a minimum graduate GPA of 3.50 during the first year of the Ph.D. Program to be eligible for consideration for regular admission.
5. International students must meet the English requirements as outlined by the Division of Graduate Studies.
6. Applicant must submit three letters of recommendation from professionals who are knowledgeable with applicant's credentials.
7. Applicant must submit a one-page statement on career goals and objectives, as well as research experience and interests.

Degree Requirements

The applicants must meet all degree requirements set by the Division of Graduate Studies. In addition, the applicants must meet the following degree requirements.

To obtain the Ph.D. in Engineering Degree, the students are required to complete a minimum of 72 credit hours beyond B.S. or 36 credit hours beyond M.S. degree. The program includes core courses, elective courses, and 24 hours of dissertation research. The adviser or the advising committee may recommend additional courses based on the students background and proposed research plan. Students have to maintain a graduate GPA of 3.0 or above to avoid academic probation.

A comprehensive qualifying exam is given to the student after six months of the study beyond the M.S. degree, but no later than after 2 years of study. Academic advisor and engineering faculty in a student's area of research determine the coursework needed for a student to prepare for the comprehensive qualifying examination. The comprehensive qualifying examination includes a written part and oral exam. During the comprehensive qualifying examination, students must demonstrate a sufficient depth and breadth of knowledge in their major to pursue independent and original research. However, the student must consult with their advisor and/or the exam coordinator in the major area of study for the schedule and specific procedures. A signature form, verifying that a student has passed the comprehensive qualifying exam, must be signed by the student's advisor and returned to the departmental office. After passing the comprehensive qualifying exam, the students will be admitted to Ph.D. Candidacy. If a student fails to pass the comprehensive qualifying exam, he/she will be allowed to take it again between one and six months after the first attempt. If the student fails twice on this exam, he/she will be dropped from the PhD program.

When at least 80% of coursework is completed and the comprehensive qualifying exam is successfully passed, the students are able to take a preliminary exam administered by the advising committee and academic advisor. Students should take the preliminary exam within 3 years of residence beyond the MS degree and at least two semesters before their final dissertation defense. This exam is based upon an oral exam and a written proposal and a detailed plan to carry out the Ph.D. dissertation. Students must consult with their advisors for specific details of the requirements for the preliminary exam.

The defense of dissertation is the final exam of the Ph.D. program. An oral defense and a written Ph.D. dissertation demonstrating original and independent research and major contributions to an engineering field have to be approved by the advising committee before graduation. Recognizing the importance of high quality graduates, each graduate is expected to publish at least 2 papers based on the results of his/her research in high quality refereed engineering journals. A summary of minimum degree requirements is shown below. 224

Summary of Minimum Degree Requirements for Ph.D. in Engineering

Credit Hours
A minimum of 72 credit hours beyond B.S. or 36 credit hours beyond M.S. degree. Must complete 24 hours of dissertation research, the required core courses, and elective courses. The adviser or the advising committee may recommend additional courses based on the students background and the proposed research area.

Comprehensive Qualifying Exam
Successful completion of written and oral Comprehensive Qualifying Exam, given after six months of the study beyond the M.S. degree, but no later than after 2 years of study.

Preliminary Exam
Successful completion of the preliminary exam within 3 years of residence beyond the MS degree and at least two semesters before their final dissertation defense.

Final Dissertation and Defense
An oral defense and a written Ph.D. dissertation demonstrating original independent research and major contributions. Each graduate is expected to publish at least 2 papers based on the results of his/her research in high quality refereed engineering journals.

Program: PhD in Engineering
Emphasis Area: Coastal Engineering
Department: Civil and Environmental Engineering

Core Courses

1. Choose four from the following list (CIV 520 is mandatory) after consultation and approval of the student's advisor.

Course	Title	Semester Hours
CIV 520	Advanced Engineering Analysis I	3
CIV 538	Coastal Structures	3
CIV 539	Advanced Coastal Engineering Design	3
CIV 558	Sedimentation and River Engineering	3
CIV 631	Linear Theory of Ocean Waves	3
CIV 632	Tides and Long Waves	3
CIV 636	Spectral Wave Analysis	3
CIV 637	Advanced Design for Breakwater Rehabilitation	3

Elective Courses

Course	Title	Semester Hours
CIV 521	Advanced Engineering Analysis II	3
CIV 530	Advanced Pavement Analysis and Design	3
CIV 531	Traffic Engineering	3
CIV 532	Pavement Materials and Design	3
CIV 533	Evaluation, Maintenance, & Rehabilitation of Public Works Infrastructure	3
CIV 556	Groundwater Engineering	3
CIV 557	Computational Fluid Dynamics	3
CIV 558	Sedimentation and River Engineering	3
CIV 559	Environmental Hydraulics	3
CIV 562	Hazardous Waste Engineering	3
CIV 564	Surface Water	3
CIV 633	Airport Planning and Design	3
CIV 640	Finite Element Method	3
CIV 650	Small Watershed Hydrology	3
CIV 652	Hydraulic Engineering Design	3
CIV 659	Advanced Topics in Water Resources Engineering	1-4
CIV 670	Rock Mechanics	3
CIV 680	Unsaturated Soil Mechanics	3
CIV 695	Scientific Writing Seminar	3
CIV 696	Seminar	3
CIV 697	Internship	1-3
CIV 698	Independent Study	1-4
CIV 899	Dissertation Research	1-6

4. **Students**:

Demographics of students enrolled in the project courses are most accurately portrayed by analyzing students advised myself. I advise all graduate students enrolled in the Coastal Engineering concentration (MS or PhD) and serve on the Graduate Committee (MS or PhD) of several other students who enroll in core Coastal Engineering courses that I teach. The following table summarizes some of the demographics for sixteen graduate students that I either Advise or serve on their graduate committee.

Coastal Engineering Concentration Graduate Students (16)

	Full-Time	Part-Time	Intermittent	Total	MS	PhD
African American	3	4	-	7	5	2
Asian/Indian	5	-	-	5	1	4
Hispanic	-	-	-	-	-	-
Caucasian	2	1	1	4	2	2
Total	10	5	1	16	8	8

A substantial number of our graduate students are non-traditional students. A number work at full-time jobs in the greater metropolitan area and several have families. Our engineering graduate programs seek to accommodate the non-traditional student by teaching almost all graduate courses in the evening for 3 hours one day a week, Monday thru Thursday; usually starting at 5:30pm.

The following table provides the ethnicity of graduates in the Coastal Engineering concentration during Years 1, 2, and 3.

MS Engineering Graduates (6)

	Number of Graduates	Work in HSE	In PhD Program	Other
African American	3	3	1 (Part time)	-
Asian/Indian	2	-	2	-
Hispanic	-	-	-	-
Caucasian	1	-	1 (Intermittent)	1
Total	6	3	4	1

PhD Engineering Graduates (2)

	Number of Graduates	Work in HSE	Work in Academia	Work Outside HSE
African American	-	-	-	-
Asian/Indian	1	-	1	-
Hispanic	-	-	-	-
Caucasian	-	-	-	-
Total	1	0	1	0

5. **Institutionalization**:

This project was formally institutionalized during Year 3 as previously described. It is a formal PhD Engineering degree concentration in the graduate catalog and has equal status with all other PhD degree programs and concentrations at JSU. Graduate students can apply for academic support on an equal footing with any other major. A steady, albeit small continuous supply of potential graduate students exists from ERDC and Vicksburg District Corp of Engineers employees. The PI plans to remain at JSU for the foreseeable future and will continue to prepare research proposals, mentor students and nurture the programs. It is reasonable to assume departing or retiring faculty (including the PI) will be replaced with comparable talented faculty. The degree concentration has a comfortable home in the Civil and Environmental Engineering Department and is envisioned to remain there. The Education Partnership Agreement between ERDC and JSU has been in existence for over two decades and is fully expected to remain in effect. There is a robust set of leveraged research and education programs by the PI and such a set of programs should continue.

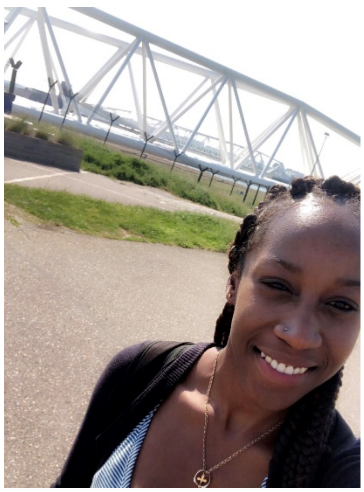
6. **Interactions with research projects:**

Research project interactions have been continuous and sustained with CRC research projects as well as externally funded research projects as summarized in Table 2A. During the summer of 2016 (June 1- Aug. 10), Mr. Xuesheng Qian, a PhD Engineering student, spent the summer as a JSU CRC SUMREX student at the University of Texas working with Dr. Clint Dawson and his team performing ADCIRC hurricane surge modeling research of Gulf of Mexico hurricanes. Early in 2018, we had Mr. Qian scheduled to have a 2018 SUMREX research experience at Oregon State University. Unfortunately, those plans did not materialize when Mr. Qian became Dr. Qian on April 28, 2018 completing his PhD research and dissertation defense earlier than envisioned. Dr. Qian is starting a career in an academic research position.

Ms. Sabrina Welch was a JSU SUMREX student during the summer of 2017 working with Dr. Stephen Medeiros and his teaching assistant at the University of Central Florida (May 21 to June 10) and with Dr. Scott Hagen and his research team at LSU (June 11 to June 30) in the ADCIRC modeling SUMREX program they started in 2016. Ms. Welch was joined by another graduate student from University of Puerto Rico, Mayaguez in this excellent UCF/LSU SUMREX program. Ms. Welch attended the ADCIRC Boot Camp and Users Group meeting held in Boston, MA (May 1 to May 5, 2017) and had the opportunity to meet Dr. Leuttich, CRC PI and Dr. Chris Massey, ERDC and other key researchers and graduate students using the ADCIRC modeling system.

Dr. Gavin Smith, CRC Director gave a seminar at Tougaloo College on April 7, 2017 at which a number of JSU CRC professors, staff and graduate students attended. All coastal engineering staff, graduate students and professors were invited.

One of most unusual research experiences for our education project students was the opportunity for them to compete for a summer research experience led by the Texas A&M University at Galveston. Dr. Sam Brody is the PI for the TAMUG five year NSF PIRE (Partnership for International Research and Education) Flood Risk Reduction project. A group of PIRE partner students (TAMUG, TAMU, Rice and JSU) compete for approximately 15 slots to plan and undergo research experiences in The Netherlands with students from the international partner Delft Technical University. We had three JSU students participate in Summer 2016, one in Summer 2017 and one in Summer 2018. The first two years' research projects are published in Publication 6. h below. I am the JSU PI for the PIRE subcontract from TAMUG. Our JSU students have done an outstanding job. They spend 14-16 days in The Netherlands collecting data, interviewing practicing engineers, professors and viewing coastal projects in The Netherlands. My students are enrolled in a 3-hour Independent Study course during the summer and complete their research, prepare a report and prepare a poster presentation. Mr. Bruce Ebersole, our CRC Senior Research staff member, is one of the mentors that make the trip to The Netherlands and oversee the students research.



Several CRC and ERDC researchers have given seminars attended by our JSU graduate students and professors. Those included Dr. Casey Dietrich, North Carolina State University; Dr. Gavin Smith, University of North Carolina; Dr. Jeff Melby, ERDC and Noble and Associates; and Dr. Chris Massey, ERDC.

In summary, students in this Education Project have benefitted from research project interactions at University of Texas, University of Central Florida, Louisiana State University, University of North Florida, and University of North Carolina, Texas A&M University at Galveston, Texas A&M, Rice University and Delft Technical University.

7. **Publications**:

The first seven publications below are authored or co-authored by one or more of the CRC staff at JSU and the last publication is edited by TAMUG faculty and staff and Technical University

Delft staff featuring research papers by the first two PIRE student cohorts. Four of the papers are authored by CRC JSU graduate Coastal Engineering concentration students.

- Whalin, Robert, W., "HBCU Engineering Faculty and Graduates: Implications for Race, Retention and Graduation Linkages", NAAAS & Affiliates 2016 National Conference, Baton, Rouge, LA, February 2016.
- Whalin, Robert, W.**;** Pagan-Trinidad, Ismael; Villanueva, Evelyn; and Pittman, David, W., "A Quarter Century of Resounding Success for a University/Federal Laboratory Partnership", ASEE 123rd Annual Conference and Exposition, New Orleans, LA, June 26, 2016.
- Whalin RW, Brody SD, and Merrell WJ. The Galveston Bay Region as an International Test Bed for Flood Risk Reduction, 8th Texas Hurricane Conference, University of Houston, Houston, TX, August 5, 2016.
- Ebersole B, Richardson TW, and Whalin RW. Modeling Coastal Storms: Past, Present and Future, 8th Texas Hurricane Conference, University of Houston, Houston, TX, August 5, 2016.
- Whalin RW. HBCU Engineering Faculty and Graduates: Implications for Race, Retention and Graduation Linkages, NAAAS & Affiliates 2016 National Conference Proceedings, Baton Rouge, LA, published Oct. 2016.
- Whalin RW, Pang Q, Latham J, Lowe LN. Assessment of a Summer Bridge Program: Seven Years and Counting, 2017 ASEE National Conference Proceedings, Columbus, OH, June 24-28, 2017.
- Ebersole, Bruce; Richardson, Thomas; and Whalin, Robert, W., "Surge Suppression Achieved by Different Coastal Spine (Ike Dike) Alignments", 9th Texas Hurricane Conference, University of Houston, August 4, 2017, Houston, TX.
- "NSF-PIRE, Coastal Flood Risk Reduction Program, Authentic Learning and Transformative Education", Volume 1-2015-2017; Edited by Baukje "Bee" Kothius, Yoonjeong Lee and Samuel Brody, March 2018.

8. **Lessons Learned:** If starting this project again under the same conditions, I would do nothing different. It has evolved exactly as planned and the severe unexpected university fiscal challenge was solved with, what turned out to be, a winning strategy. Regardless of whether this was good fortune or astute foresight, the end result could not have been better. All activities and milestones are now on the original schedule for Years 4 and 5. In summary, I would make no change in the project.

9. Tables:

Table 1: Documenting CRC Education Project Courses and Enrollments

Courses Developed and Taught by Jackson State University under Project PhD in Engineering (Coastal Engineering and Computational Engineering concentration) at an HBCU						
Course		Developed (D), Revised (R), and/or Taught (T), by Project Year				
Number	Title	1	2	3	4	5
CIV631	Linear Theory of Ocean Waves	T	T	-		
Offering: Elective (E), Concentration (C), Minor (M)		C	C	-		
Enrollment		6	5	-		
CIV637	Advanced Design for Breakwater Rehabilitation	T	-	T		
Offering: Elective (E), Concentration (C), Minor (M)		C	-	C		
Enrollment		3	-	7		
CIV642	Prestressed Concrete Design	T	-	-		
Offering: Elective (E), Concentration (C), Minor (M)		E	-	-		
Enrollment		4	-	-		
CIV698	Independent Study (4 separate courses)	T/R (4 courses)	T/R (4 courses)	T/R (3 courses)		
Offering: Elective (E), Concentration (C), Minor (M)		C	C	C		
Enrollment		1 each	1 each	1 each		
CIV538 Spring 17	Coastal Structures	-	T	-		
Offering: Elective (E), Concentration (C), Minor (M)		-	C	-		
Enrollment		-	6	-		
CIV636 Fall 16	Spectral Wave Analysis	-	T	T		
Offering: Elective (E), Concentration (C), Minor (M)		-	C	C		
Enrollment		-	5	5		
CIV539 Fall 16	Advanced Coastal Engineering Design	-	T	-		
Offering: Elective (E), Concentration (C), Minor (M)		-	C	-		
Enrollment		-	6	-		
CIV520	Advanced Engineering Analysis	-	T	T		
Offering: Elective (E), Concentration (C), Minor (M)		-	C	C		

Enrollment		-	9	4		
CIV535	Pavement Design	-	T	-		
Offering: Elective (E), Concentration (C), Minor (M)		-	E	-		
Enrollment		-	8	-		
CIV542	Advanced Design of Concrete Structures	-	T	-		
Offering: Elective (E), Concentration (C), Minor (M)		-	E	-		
Enrollment		-	9	-		
CIV544	Advanced Design of Steel Structures	-	T	-		
Offering: Elective (E), Concentration (C), Minor (M)		-	E	-		
Enrollment		-	8	-		
CIV544	Advanced Design of Hydraulic Structures	-	T	-		
Offering: Elective (E), Concentration (C), Minor (M)		-	E	-		
Enrollment		-	9	-		
CIV632	Tides and Long Waves	-	-	1		
Offering: Elective (E), Concentration (C), Minor (M)		-	-	C		
Enrollment		-	-	10		
CIV550	Engineering Hydrology	-	-	T		
Offering: Elective (E), Concentration (C), Minor (M)		-	-	E		
Enrollment		-	-	10		
CIV661	Biological Processes in Wastewater Engineering	-	-	T		
Offering: Elective (E), Concentration (C), Minor (M)		-	-	E		
Enrollment		-	-	9		
CIV561	Chemistry for Environmental Engineering	-	-	T		
Offering: Elective (E), Concentration (C), Minor (M)		-	-	E		
Enrollment		-	-	6		
CIV567	Environmental Remediation	-	-	T		
Offering: Elective (E), Concentration (C), Minor (M)		-	-	E		
Enrollment		-	-	7		
CIV675	Earth Dams and Slopes	-	-	T		
Offering: Elective (E), Concentration (C), Minor (M)		-	-	E		
Enrollment		-	-	9		
Total (Years 1-3)		17	69	70		

Table 2: Documenting External Funding and Leveraged Support Jan. 1, 2016 – July 1, 2018

2A: External Funding (Years 1-3)			
Title	PI	Total Amount	Source
Coastal Flood Risk Reduction	Whalin	$219,000	Texas A&M University at Galveston (Prime for NSF PIRE Grant)
Storm Surge Modeling for Comprehensive Barrier Protection, Galveston Bay and Vicinity	Whalin	$101,775	Texas A&M University at Galveston
Maritime Transportation Research and Education Center (MarTREC)	Whalin (since Aug. 2018, Co-PI prior)	$370,000	Univesity of Arkansas (Prime for DoT University Transportation Center
Southeastern Transportation Research, Innovation, Development and Education Center (STRIDE)	Whalin (since Aug. 2018, Co-PI prior)	$225,000	University of Florida (Prime for DoT Regional University Transportation Center)
Evaluation of Ike Dike Hurricane Protection	Whalin	$26,050	Bay Area Coastal Protection Alliance

2B: Leveraged Support (Years 1-3)	
Description	Estimated Total` Value
High Performance Computer Time	$39,000

Table 3: Performance Metrics: WHALIN

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17- 6/30/18)
HS-related internships (number)	5	4	3
Undergraduates provided tuition/fee support (number)	1	0	0
Undergraduate students provided stipends (number)	0	0	0
Graduate students provided tuition/fee support (number)	4	7	10
Graduate students provided stipends (number)	2	6	6
Undergraduates who received HS-related degrees (number)	2	3	3
Graduate students who received HS-related degrees (number)	0	4	4
Certificates awarded (number)	0	0	0
Graduates who obtained HS-related employment (number)	1	2	3
Lectures/presentations/seminars at Center partners (number)	1	1	1
DHS MSI Summer Research Teams hosted (number)	0	0	0
Journal articles submitted (number) (includes peer reviewed conference proceeding)	2	0	0
Journal articles published (number) (includes peer reviewed conference proceeding)	2	4	0
Conference presentations made (number)	2	4	3
Other presentations, interviews, etc. (number)	5	3	5
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	0	4	2
Requests for assistance/advice from other agencies or governments (number)	0	3	2
Total milestones for reporting period (number)	3	4	3
Accomplished fully (number)	2	3	3
Accomplished partially (number)	1	0	0
Not accomplished (number)	0	1	0

10. **Year 3 Education Activity and Milestone Achievement:**

All activities and milestones were completed 100% as scheduled. Two MS Engineering (Coastal Engineering Concentration) degrees were awarded and both are working in the greater Homeland Security Enterprise; one in Corps of Engineers and one in industry. Qualifying exam has been discussed with one student and scheduled for Fall semester 2018 and two other students are considering an appropriate time.

Education Activities and Milestones

Reporting Period 7/1/17 – 6/30/18			
Education Activities	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
1. Recruit PhD students in Coastal Engineering concentration	Continuous	100%	
2. Teach courses in PhD Coastal Engineering concentration and oversee dissertation research	6/30/18	100%	
3. Seek research funds from outside sources	Continuous	100%	
4. Continuous to teach BS/MS/PhD Coastal Engineering courses	6/30/18	100%	
Education Milestones			
1. Continue to graduate students in BS/MS Coastal Engineering courses	5/30/18	100%	
2. Schedule first PhD qualifying exam for a student	6/30/18	100%	

11. **Year 3 Transition Activity and Milestone Achievement:**

Three BS Year 3 graduates were recruited for the MS Engineering (Coastal Engineering concentration) graduate program for Fall 2018, the start of Year 4. In addition there were two MS students continuing their MS degree requirements in Fall 2018. At the end of Year 3, there were four students enrolled in the PhD Engineering (Coastal Engineering concentration). Two students graduated with MS Engineering degrees (one in Dec. 2017 and one in April 2018) and both are working in the greater HSE (one in the Corps of Engineers and one in private industry)

Transition Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/2017 – 6/30/2018			
Transition Activity	**Proposed Completion Date**	**% Complete**	**Explanation of why activity/milestone was not reached**
1. Continued enrollment of students in BS/MS programs	6/30/18	100%	
2. Enrollment of students in approved PhD concentration	6/30/18	100%	
Transition Milestone			
1. Graduation of BS/MS students and employment in the greater HS enterprise or, continued graduate school enrollment	6/30/18	100%	

KEIM, LSU
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Disaster Science and Management Program at Louisiana State University (LSU)

Principal Investigator Name/Institution: Barry D. Keim, Professor in the Department of Geography and Anthropology, Louisiana State Climatologist, Principal Investigator of the Southern Climate Impacts Planning Program (SCIPP) at LSU.

Other Partners/Institutions: NOAA's Southern Climate Impacts Planning Program (SCIPP)

Project Start and End Dates: January 1, 2016–June 30, 2018

Short Project Description ("elevator speech"):

The Disaster Science and Management (DSM) Program at LSU is designed to train the next generation of Homeland Security Enterprise professionals. Students in the program gain knowledge and skills to address issues of natural coastal disasters and to build resilience to these disasters.

PROJECT NARRATIVE:

1. Introduction and project overview:

Louisiana has been heavily impacted by natural disasters in recent years, including the landfalling Hurricanes Katrina and Rita in 2005. These high-profile hurricanes are in addition to other recent hurricanes (i.e., Hurricanes Ike 2008, Gustav 2008, and Isaac 2012). In addition, Louisiana was one of several states that was severely impacted by the Deepwater Horizon Oil Spill, adding a significant non-natural disaster to the list. The need and justification for a Disaster Science and Management (DSM) Program at Louisiana State University that focuses on coastal hazards and resilience is therefore unequivocal. The DSM program at LSU is training the next generation of Homeland Security Enterprise (HSE) professionals that will be able to respond to emergencies, work with partners at all levels of government, and ensure a swift and efficient recovery.

2. Project History:

The DSM program at LSU was founded in 2002 as a freestanding minor within the College of Humanities and Social Sciences, with a major in DSM added in 2007. However, the program lacked an official affiliation with an academic department and underwent several leadership transitions during this time, which led to instability of the program. In Year 1 of this CRC funded project, the DSM program was formally integrated into the Department of Geography and Anthropology, with students able to major in Geography (B.A. or B.S) with a concentration in

DSM or minor in DSM. Existing introductory level courses in hazards and emergency management plus several upper division courses under the previous DSM program were offered to students during Year 1.

Having integrated the program within the Geography degree program in Year 1, the focus of Year 2 was to revise the introductory courses, develop a new upper-division course in Hazard Risk Reduction, and grow enrollment in the program. The recruitment efforts were successful, with DSM course enrollment increasing by 31% in Year 2 as compared to Year 1. Three students who had been DSM minors under the previous program changed their majors to Geography with a concentration in DSM during year two, becoming the first cohort of students to enroll in the major.

Year 3 continued the success of Year 2. Overall course enrollment grew by 75% in Year 3 over Year 2 numbers, with over 500 students enrolled in DSM courses during the 2017–2018 academic year. An additional nine students became majors in Geography with a concentration in DSM, and seven students joined the DSM minor program. Finally, six students graduated with majors in Geography and the DSM concentration, with an additional six receiving a minor in DSM. Most of these students joined the DSM program due to recruiting efforts in Years 2 and 3 when they discovered they were one or two classes away from receiving the concentration or minor. Conversations with these students revealed that the additional skills gained in the concentration or minor greatly improved their job prospects and put them on a career path that gives them the opportunity to help their community. At the end of Year 3, we have 14 students majoring in Geography with a concentration in DSM and an additional 6 students minoring in DSM.

Throughout the project, end users were engaged by hosting DSM students as interns and by hiring DSM program graduates. The major obstacle during the three years of the program was translating our success at LSU to a proposed “feeder” program at Baton Rouge Community College. Despite some buy-in from the BRCC administration, the effort was unsuccessful due to low enrollment in the courses BRCC offered and staff turnover.

3. Results:

The major result of the three-year project was the development of a DSM program that is fully integrated within the Department of Geography & Anthropology at LSU. Students majoring in Geography with a concentration in DSM now make up approximately 25% of undergraduate Geography majors. Course development was a major aspect of the project. The core courses within the concentration and minor were either developed or completely revised during the course of the project.

4. Students:

The DSM program at LSU is focused on undergraduate education. During the course of the project, six students graduated from the DSM program developed under this grant with a major in Geography and a concentration in DSM, and six students earned a minor in DSM.

Approximately half of the graduates from this year are employed or seeking employment in the HSE, with the rest seeking employment in careers related to their major.

5. Institutionalization:

The DSM project at LSU is already a major component of the Department of Geography & Anthropology. The project will be supported in the future by resources provided by the Department of Geography & Anthropology and College of Humanities and Social Sciences at LSU. Dr. Barry Keim will continue to coordinate DSM activities.

6. Interactions with research projects:

The interaction between the DSM Program at LSU and the CRC research programs was excellent. Two students participated in the CRC SUMREX program. Dr. Don Resio at the University of North Florida hosted Rudy Bartels, Ph.D. candidate and DSM instructor during Year 1. They collaborated on research projects involving rainfall across the United States. Stephen Kreller, M.S. student at LSU was hosted by Dr. Brian Blanton at RENCI at UNC-Chapel Hill to work on a project focused on ADCIRC storm surge modeling during Year 2.

Other interactions include:

- Dr. Barry Keim presented to 9 delegates from Brazilian environmental agencies to discuss "Environmental Licensing in the United States." He presented on environmental recovery following extreme events in Louisiana.
- A lecture by Dr. Don Resio at LSU on March 17, 2017 as part of the ReTalk series.
- Dr. Barry Keim, Principal Investigator on this project, was invited by Gavin Smith to give a lecture for a course via Skype at UNC-Chapel Hill. The course was part of the Graduate Certificate program in Natural Hazards Resilience sponsored by the CRC.
- Dr. Barry Keim gave presentation at the Louisiana Governor's Office of Homeland Security and Emergency Preparedness (GOHSEP) to researchers from South American countries as part of the USAID program which was hosted by Brant Mitchell from the Stephenson Disaster Management Institute (SDMI) and is a part of the CRC research project spearheaded by Dr. Robert Twilley.

7. Publications:

Xue, G.Z., D.J. Gochis, W. Yu, B.D. Keim, R.V. Rohli, Z. Zang, K. Sampson, A. Dugger, D. Sathiaraj, and Q. Ge. 2018. Modeling Hydroclimatic Change in Southwest Louisiana Rivers. *Water* 10(5), Article No. 596. https://doi.org/10.3390/w10050596.

Keim, B.D., W.D. Kappel, G.A. Muhlstein, D.M Hultstrand, T.W Parzybok, A.B. Lewis, E.M. Tomlinson, and A.W. Black. 2018. Assessment of the Extreme Rainfall Event at Nashville, Tennessee and the Surrounding Region on May 1-3, 2010. *Journal of American Water Resources Association.* https://doi.org/10.1111/1752-1688.12657.

Gilliland, J.M., and B.D. Keim. 2018. Position of the South Atlantic Anticyclone and its impact on Surface Conditions across Brazil. *Journal of Applied Meteorology and Climatology* 57(3):535-553. DOI: 10.1175/JAMC-D-17-0178.1

Gilliland, J. M., and B.D. Keim. 2018. Surface Wind Speed: Trend and Climatology of Brazil from 1980–2014. *International Journal of Climatology* 38(2):1060-1073.

Shao, W., S. Xian, B. Keim, K. Goidel, N. Lin. 2017. Understanding Perceptions of Changing Hurricane Strength Along the U.S. Gulf Coast. *International Journal of Climatology* 37(4):1716-1727. DOI:10.1002/joc.4805.

Allard, J.M., J.V. Clarke, and B.D. Keim. 2016. Spatial and Temporal Patterns of In Situ Sea Surface Temperatures within the Gulf of Mexico from 1901–2010. *American Journal of Climate Change* 5:314-343. DOI:10.4236/ajcc.2016.53025.

Shao, W., J.C. Garand, B.D. Keim, and L.C. Hamilton. 2016. Science, Scientists, and Local Weather: Understanding Mass Perceptions of Global Warming. *Social Science Quarterly* 97(5):1023-1057. DOI:10.1111/ssqu.12317.

Hamilton, L.C, J. Hartter, B.D. Keim, A.E. Boag, M.W. Palace, F.R. Stevens, M.J. Ducey. 2016. Wildfire, Climate and Perceptions in Northeast Oregon. *Regional Environmental* Change 16:1819-1832. DOI:10.1007/s10113-015-0914-y.

Shankman, D., and B.D. Keim. 2016. Flood Risk Forecast for China's Poyang Lake Region. *Physical Geography* 37(1):88-91.

8. Lessons Learned:

As a whole, we feel that the project has been a success. The DSM program is fully integrated into an academic department at LSU where it can be sustained into the future. Recruitment efforts have been successful, leading to growing enrollments in courses and in terms of students in the major and minor. The biggest change we would make includes getting stronger support for the program at BRCC at higher levels of administration, which perhaps would have increased our chances of success. We believe this might have allowed us to succeed despite high turnover in the department offering the courses. This would have also allowed us to do more to recruit students to the DSM courses that were offered at BRCC. However, I note that our main contact at BRCC resigned over 6 months ago and her replacement has already resigned. This is a clear sign of the instability we were coping with at BRCC and it is likely that this effort was set up to fail from the very beginning.

Table 1: Documenting CRC Education Project Courses and Enrollments

Courses Developed and Taught by Louisiana State University under Project Disaster Science and Management Program at LSU				
Course		Developed (D), Revised (R), and/or Taught (T), by Project Year		
Number	Title	1	2	3
DSM/ GEOG 2000	Hazards, Disasters, and the Environment	T	R,T	T
	Offering: Elective (E), Concentration (C), Minor (M)	E,C,M	E,C,M	E,C,M
	Enrollment	150	164	300
DSM / GEOG 2010	Fundamentals of Emergency Management	T	R,T	R,T
	Offering: Elective (E), Concentration (C), Minor (M)	E,C,M	E,C,M	E,C,M
	Enrollment	54	135	212
GEOG 4200	Hazards Risk Reduction		D	D,T
	Offering: Elective (E), Concentration (C), Minor (M)		C,M	C,M
	Enrollment			11
DSM 3910	Hazards Seminar	T		
	Offering: Elective (E), Concentration (C), Minor (M)	C,M		
	Enrollment	10		
DSM 4000	Practicum in Disaster Science and Management	T		
	Offering: Elective (E), Concentration (C), Minor (M)	C,M		
	Enrollment	5		
DSM 4600	Crisis Management	T		
	Offering: Elective (E), Concentration (C), Minor (M)	C,M		
	Enrollment	8		

Table 2: Documenting External Funding and Leveraged Support

2A: External Funding			
Title	PI	Total Amount	Source
Southern Climate Impacts Planning Program (SCIPP)	Keim	$358,000	NOAA
2B: Leveraged Support			
Description			Estimated Annual Value
NONE			

Table 3: Performance Metrics

KEIM PROJECT METRICS	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17- 6/30/18
HS-related internships (number)	5	1	6
Undergraduates provided tuition/fee support (number)	0	0	0
Undergraduate students provided stipends (number)	0	0	0
Graduate students provided tuition/fee support (number)	2	2	2
Graduate students provided stipends (number)	2	2	2
Undergraduates who received HS-related degrees (number)	4	5	5
Graduate students who received HS-related degrees (number)	0	0	0
Certificates awarded (number)	0	0	6
Graduates who obtained HS-related employment (number	2	3	4
Lectures/presentations/seminars at Center partners (number)	1	0	0
DHS MSI Summer Research Teams hosted (number)	0	0	0
Journal articles submitted (number)	1	3	5
Journal articles published (number)	5	1	3
Conference presentations made (number)	2	17	11
Other presentations, interviews, etc. (number)	4	132	104
Trademarks/copyrights filed (number)	0	0	0
Requests for assistance/advice from DHS agencies (number)	2	1	2
Requests for assistance/advice from other agencies or governments (number)	5	8	10
Total milestones for reporting period (number)	6	6	13
Accomplished fully (number)	6	6	10
Accomplished partially (number)	0	0	2
Not accomplished (number)	0	0	1

9. Year 3 Education Activity and Milestone Achievement:

Education Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/17 – 6/30/18			
Education Activities	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
Continue to deliver DSM courses within the newly implemented DSM Concentration in Geography BS/BA.	8/1/2017	100%	
Implement approved Certification Program.	8/1/2017	100%	
Implement one (1) or more course curricula for Baton Rouge Community College (BRCC).	9/1/2017	100%	
Education Milestones			
Offer at least three (3) DSM courses during the Fall 2017 and Spring 2018 semesters.	5/31/2018	100%	
Promote and enroll four (4) students into the DSM Certificate Program	6/30/2018	100%	
Deliver one (1) or more course curricula for Baton Rouge Community College (BRCC) during the Fall 2017 and Spring 2018 semester.	5/31/2018	50%	Course enrollment targets not reached at BRCC so courses not offered; Curriculum is developed and could be implemented at any time if enrollment targets met.

10. Year 3 Transition Activity and Milestone Achievement:

Transition Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/2017 – 6/30/2018			
Transition Activity	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
Further promote DSM social media page (Facebook) to further capture DSM Student Post-Graduation activities.	8/31/2017	100%	Rather than use Facebook, an alumni tracking page was implemented through Google.
Continue with the American Red Cross Baton Rouge Chapter to offer service learning project for DSM 2010 course. Through HSE end users, identify additional community service projects for DSM students and DSMA members to participate in.	8/31/2017	100%	
Contact each HSE end user listed on the working document to capture end user input on internship program via one-on-one phone calls and email.	9/1/2017	100%	
Transition Milestone			
Continue DSM Student Post-Graduation tracking method and document post-graduation activities in Homeland Security enterprises or continued grad school of 60- 75% of Fall 2017 and Spring 2018 students	5/31/2018	100%	See new alumni tracking page as listed above.
Through the partnership with the ARC, 75-80% students completing Spring 2016 DSM 2010 Fundamentals of Emergency Management will complete the service learning portion of that class.	5/31/2018	90%	Reaching a full 75-80% service learning was impossible due to growing enrollment in GEOG 2010. However, many students did still volunteer for the ARC.
DSMA student organization will participate in at least two (2) community service project: one with ARC and one with another HSE with at least five (5) students participating in each activity.	5/31/2018	0%	DSMA student organization was re-formed but membership was insufficient to meet criteria.
Partner with three (3) additional end users in order to secure internships for DSM students	5/31/2018	100%	

KNIGHT, UMD
DHS COASTAL RESILIENCE CENTER
RESEARCH PROJECT
YEAR 3 PERFORMANCE REPORT
AND
FINAL PROJECT REPORT

Project Title: Development and Testing of a Project Management Curriculum for Emergency Managers

Principal Investigator Name/Institution: Sandra K. Knight, PhD, PE, D.WRE, D.NE, Senior Research Engineer, Department of Civil and Environmental Engineering, University of Maryland, College Park.

Other Partners/Institutions:

John Hart Cable, Director, Project Management Program, A. James Clark School of Engineering, University of Maryland. Lead advisor for Project Management curricula and certification.

Gregory Baecher, PhD, PE, Glenn L. Martin Institute Professor of Engineering, Department of Civil and Environmental Engineering, University of Maryland

Project Start and End Dates: January 1, 2016 – June 30, 2018

Short Project Description ("elevator speech"):

The goal of this educational work plan is to develop and test an educational and training curriculum that prepares professionals to manage and deliver disaster-related project(s), by merging the unique challenges of emergency management with the capabilities and technologies introduced by applying project management processes. By incorporating modern project management organizational processes, technologies, and skills, emergency managers will be able to manage and execute disaster-related projects and meet resilience goals more effectively and efficiently. By building disaster resilient concepts and emergency protocols and goals into project management processes, project managers will be equipped to contribute to a more sustainable and disaster-resilience future.

PROJECT NARRATIVE

1. Introduction and project overview:

Natural Disasters between 2003 and 2012 resulted in estimated global average annual economic losses of $156.7 billion and average annual deaths of 106,654[2]. In 2017, climate-related

[2] Guha-Sapir D, Hyois Ph., Below R. *Annual Disaster Statistical Review 2013: The Numbers and Trends.* Brussels: Center for Research on the Epidemiology of Disaster (CRED): 2014

disasters alone in the United States caused $306 billion in damages, the costliest year on record, according to the National Oceanic and Atmospheric Administration (NOAA). Three major hurricanes – Harvey, Irma and Maria – accounted for a staggering $265 billion of those losses. They ranked 2nd-, 5th- and 3rd-most costly, respectively, in the 38 years NOAA has recorded billion-dollar disasters (Hurricane Katrina in 2005 was the costliest).

Emergency managers from federal, state and local agencies and/or organizations must manage the billions of dollars expended to prepare and recover from these losses. For instance, the federal disaster appropriations following Hurricane Sandy were approximately $58 billion[3] and were dispersed via many programs and agencies with specific regulatory or policy requirements for execution. Disaster relief funds such as these are spent to get communities back on their feet by replacing or rebuilding critical infrastructure, key facilities, businesses and homes. Further, the organized response to a disaster shares all the characteristics and has all the organizational needs of a built project. It is also well understood that building resilience into our built, social and environmental systems prior to an event has recurring benefits to disaster losses. Therefore, resources are often allocated for mitigation following a disaster as well as on "sunny days."

Managing the influx of funding from many disparate sources and for many purposes and projects related to response, recovery, and mitigation, can be daunting. Additionally, in a disaster or post-disaster environment, to minimize cascading and long-term impacts of a slow recovery, there is often a tension between building back quickly and building back better. Emergency managers are often assigned to lead many of the emergency activities and oversee the execution of large programs in the wake of disaster that are funded through federal and state programs. Also, agencies and organizations (federal, state and local governments, utilities, non-profits, private industry, etc.) with a strong reliance on contract support and expertise, may be responsible for the response and recovery for sector-specific projects or program execution (marine transportation, healthcare, supply chain, utilities, etc.). Therefore, it is imperative, in this often-urgent environment, that project and emergency managers have the right training and educational skills to effectively deliver projects on-time and on-budget while being considerate of the needs of the community and planning for a resilient future.

This education grant was used to explore the gaps and develop and test an educational and training curriculum that prepares professionals to manage and deliver disaster-related project(s), by merging the unique challenges of emergency management with the capabilities and technologies introduced by applying project management processes. By incorporating modern project management organizational processes, technologies, and skills, emergency managers will be able to manage and execute disaster-related projects and meet resilience goals more effectively and efficiently. By building disaster resilient concepts and emergency protocols and goals into project management processes, project managers will be equipped to contribute to a more sustainable and disaster-resilience future.

2. The proposed research comprises three distinct phases:
   1) Understanding the requirements and needs of practitioners and developing a disaster-focused curriculum to be offered within the UMD Project Management program or Civil Engineering graduate program,

[3] https://www.congress.gov/113/plaws/publ2/PLAW-113publ2.pdf

2) Developing training and short course plans of instruction that align with existing certification programs, and
3) Executing initial course offerings and/or training programs for delivering the developed approaches and technologies to practitioners.

3. Project History:

Year 1 – January 2016 -June 2016

Building on the experiences of the principle investigator and her established connection to both emergency managers and project managers, there was a dialogue throughout the project between her and the potential end-users. To codify the needs and establish requirements, a literature review and interviews and discussions with more than 15 experienced emergency and project managers within and external to DHS were conducted the first year. The conclusions were that there was value in bridging the gaps between these two sets of practitioners and training would be needed to improve disaster performance.

Another initial objective of the grant was to assure that any training developed though the grant met requirements of existing professional certification programs, such as the Certified Emergency Manager, offered through the International Association of Emergency Managers and the Project Management Professional, offered by the Project Management Institute. In discussion with both organizations, it was clear that obtaining official certification could happen only after permanently establishing the training. Based on discussions, however, the concepts of both types of training appeared to fit within the requirements of those programs, respectively, and could add value to the professional programs.

In June 2016, the PI attended the Emergency Manager Higher Education Symposium at the Emergency Management Institute in Emmitsburg, MD. Information and contacts made through that activity helped support the concepts that would be moved forward in the development of both a college level course and the development of Plans of Instruction suitable for training at EMI.

Year 2, July 2016-June 2017

A major activity in late 2016 was the development of a graduate level course in the Civil and Environmental Engineering Department at the University of Maryland. Working with the Director of the Project Management Center in CEE, the course was approved as a graduate level engineering course to offer in the Spring 2017. The title would be *Principles of Disaster Management*.

In spring of 2017, the Principles of Disaster Management was offered and 11 graduate students enrolled. The course covered five key learning areas:

- Disaster-related policy and programs
- Emergency management protocols
- Phases of Disaster

- The Nexus of Emergency and Project Management
- Community Resilience

Through experiential learning, the students became immersed in the complexity and importance of disaster management. Using the lectures, socratic method of shared learning, and the rich experiences of guest lectures, the students gained knowledge and skills about disaster. They used these in a team project, a tabletop exercise and in a final individual research paper. For each assignment students were required to use both written and oral communication skills.

In June of 2017, the PI participated in the annual Hazard Mitigation Stakeholder Workshop, where she engaged approximately 50 students in a discussion and informal questionnaire about their own interest in project management training and what college courses might appropriate for a resilience engineering curriculum. Participation and feedback from this event informed ideas for project management training, identified critical tracks for higher education curriculum and helped to identify a sponsor within FEMA to further expand on these concepts.

Also in year 2, three new Plans of Instruction were developed in the format and with the requirements established by EMI to introduce new courses. These draft plans of instruction were to be the framework for establishing training that would provide participants with the project management knowledge and skills required to effectively facilitate and manage a disaster response. The three draft POIs were: Project Management for Emergency Managers in Response, Project Management for Emergency Managers in Preparedness and Project Management for Emergency Mangers in Recovery. Existing courses were already in place at EMI for mitigation that had elements of project management; E0214 Hazard Mitigation Assistance: Project Implementation and Closeout and E0212 Hazard Mitigation Assistance: Developing Quality Subapplication Elements.

Year 3 July 2017 – June 2018

The last year of the grant unfolded into two major accomplishments; the establishment of a resilience engineering set of courses and the delivery of a project management workshop to approximately 70 hazard mitigation disaster employees.

Concurrent with the execution of this grant, the University of Maryland hired three new faculty for the explicit purpose of advancing research and education in disaster resilience. The emphasis on resilience at UMD, made the grant even more important, as the results to date helped UMD jump-start a set of graduate level offerings in resilience engineering. A two-year program was developed in the spring of 2018 that was informed by the requirements and findings to date on curriculum gaps, as well as the information gathered through the June 2017 Stakeholder Workshop. The initial offerings can be found at this web site. Furthermore, the initial Principles of Disaster Management Course will be a core class offered every other year as a certification in resilient engineering is established in the engineering school at UMD.

Through the relationship established from the previous year's Stakeholder Workshop and following the major disasters that occurred in the fall of 2017, the PI collaborated with the Deputy Assistant Administrator of FEMA-FIMA's Risk Reduction Directorate and the Training Administrator for the Insurance and Mitigation Readiness Division, to build a half-day workshop for hazard mitigation mid-level disaster managers. The workshop, *A Project Management Framework for Hazard Mitigation Disaster Functions*, was designed to introduce a framework for project management for HM Disaster Cadre mid-level managers. The training identified current challenges and opportunities among individual jobs and processes and used a project management framework to identify priority areas to improve future delivery and performance.

The workshop was well-received by the 70 attendees and the FEMA sponsors. A follow-on briefing in July 2018, by the PI to the FEMA sponsor explored ideas to continue building project management into the activities of disaster employees. Several ideas emerged in the discussion including 1) offering a regular training at EMI capitalizing on the Plans of Instruction already developed, 2) developing a specialized training for specific programs such as grants, and 3) building a strategic guidance to incorporate new legislative requirements for implementing project management into federal agencies.

4. Results:

The results are described above and reiterated here.

A resilience engineering curriculum was initiated and is now being established with the original offering of Principles of Disaster Management becoming a regular biennial offering.

FEMA is interested in building project management into their practices and training. The exact approach has not been determined, but the seeds have been planted and some initial concepts explored.

5. Students:

The graduate level course in engineering had five women and 6 men at the masters and PhD level from diverse geographic origins: Chile, China, Iran, Puerto Rico, and the US.

The grant helped to support 1 graduate student part-time including tuition.

The training workshop at EMI included approximately 70 disaster employees with varying years of experience. The attendees were gender, age and racially diverse.

6. Institutionalization:

- What will be the sources of ongoing support?
  I do not have further grant funds to continue pursuit of the project management training for emergency managers. I will be supported by UMD to teach the Principles of Disaster Management course.

- Where in your institution will your project be maintained?
  The objective of the grant was to develop and test a training course and a college level course. Both were accomplished and therefore, nothing to maintain. However, the Civil and Environmental Engineering Department will continue to advance the resilience engineering curriculum and has institutionalized the graduate course developed under the grant as part of its regular curriculum.

- Who will be involved in sustaining your project? The project is over, but the PI is willing to continue discussions with sponsors such as FEMA. The existing faculty in CEE and the affiliates for the Center for Disaster Resilience will continue pursuit of disaster management.

7. Interactions with research projects:

   During the course of the project, the PI established informative and collaborative exchanges with LSU and UNC. The PI visited the LSU campus for discussions about their disaster science program and a LSU faculty visited the UMD Center for Disaster Resilience to share about establishment of their coastal sustainability institute. Additionally, the PI served on a review committee for another CRC project at UNC on Resilience education.

8. Publications:

   The PI has written a draft paper and is looking for the appropriate magazine or journal for submission. It was not submitted prior to the end of the project.

   Non-published, but available upon request, are the Needs Survey and the draft Plans of Instruction.

9. Lessons Learned: Assume you're starting your project again under the same conditions that existed at its beginning in Year 1. What would you do the same and why?

   My hypothesis on the need to bridge Project Management and Emergency Management would be the same. It is clear it is needed.

   What changes would you make and why?

   I would drop the professional certification objective. It appears that has its own set of requirements that will organically include new courses as appropriate.

10. Tables:

Table 1: Documenting CRC Education Project Courses and Enrollments

Courses Developed and Taught at U of MD under Project				
Course		Developed (D), Revised (R), and/or Taught (T), by Project Year		
Number	Title	1	2	3
CE688	Principles of Disaster Management		D,T	R
	Offering: Elective (E), Concentration (C), Minor (M)	-	E	N/A
	Enrollment	-	11	N/A
N/A	A Project management framework for hazard mitigation disaster functions			D,T
	Offering: Elective (E), Concentration (C), Minor (M)	-		N/A
	Enrollment	-		70

Table 2: Documenting External Funding and Leveraged Support

2A: External Funding			
Title	PI	Total Amount	Source

2B: Leveraged Support	
Description	Estimated Annual Value
Free office space at UMD	$8,000
Portion of salary covered under CEE funds	$12,000

Table 3: Performance Metrics:

KNIGHT METRICS TABLE

Metric	**Year 1** (1/1/16 – 6/30/16)	**Year 2** (7/1/16 – 6/30/17)	**Year 3** (7/1/17 6/30/18)
HS-related internships (number)			
Undergraduates provided tuition/fee support (number)			
Undergraduate students provided stipends (number)			
Graduate students provided tuition/fee support (number)		1	
Graduate students provided stipends (number)			
Undergraduates who received HS-related degrees (number)			
Graduate students who received HS-related degrees (number)			
Certificates awarded (number)			
Graduates who obtained HS-related employment (number)			
Lectures/presentations/seminars at Center partners (number)			
DHS MSI Summer Research Teams hosted (number)			
Journal articles submitted (number)			
Journal articles published (number)			
Conference presentations made (number)			
Other presentations, interviews, etc. (number)	20	2	2
Trademarks/copyrights filed (number)			
Requests for assistance/advice from DHS agencies (number)			2
Requests for assistance/advice from other agencies or governments (number)			
Total milestones for reporting period (number)	2	2	4
Accomplished fully (number)	1	2	2
Accomplished partially (number)	1		1
Not accomplished (number)			1

11. Year 3 Education Activity and Milestone Achievement:

Education Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/17 – 6/30/18			
Education Milestones	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
Top Priority Course Curriculum Offerings Descriptions: completion of 3 introductory course prospectus and targeted scheduling for initial delivery in year 2 and/or year 3 (depending upon university capacity): Course Prospectus and University Approval	02/28/2018	100	Actual completion date was 05/20/2018. A new resilience engineering curriculum was developed and prospectus completed and approved by department
Offer up to 2 initial training courses either on-line or in collaboration with partners such as FEMA, EMI or CDP	05/30/2018	100	One training workshop for FEMA was developed and executed May 15
Begin Certification Implementation Strategy with IAEM and PMI	07/31/2017	0	This activity was deemed not to be appropriate for a trial course or offering.
Education Activities: Note Activities were headers for milestones in my plan and did not have specific dates.			

12. Year 3 Transition Activity and Milestone Achievement:

Transition Activities and Milestones: Final Status as of 2018

Reporting Period 7/1/2017 – 6/30/2018			
Transition Milestones	Proposed Completion Date	% Complete	Explanation of why activity/milestone was not reached
Meetings and correspondence with PMI and IAEM, NEMA and others to develop process and implementation strategy (throughout project)	03/31/2018	95	Correspondence with appropriate end users and collaborators was maintained throughout the project. The actual connections were with some different agencies and organizations than listed in workplan.
Provide Plans of Instructions to interested institutions including FEMA, EMI and CDP	05/30/2018	95	The POIs were shared with FEMA. It is better for them to drive the implementation with EMI and others as appropriate.
Share course materials (POI and UMD Course syllabus) with IAEM, PMI, EMI, CDP, UMD and/or others for consideration and sharing with their members	03/30/2018	95	All of the course prospectus developed for UMD's resilience engineering courses have been widely disseminated to organizations including FEMA, USACE, and other universities as well as posted to internet. This was done after approval of those courses in June 2018. The POIs were given to FEMA are available if others want them.
Transition Activities: Note Activities were headers for milestones in my plan and did not have specific dates.			

Appendices

2017-2018 Workforce Development Final Student Annual Performance Report

Prepared by Darien Alexander Williams
Prepared for The Department of Homeland Security Coastal Resilience Center of Excellence

Darien Alexander Williams, Department of City & Regional Planning, University of North Carolina at Chapel Hill
Master of City & Regional Planning Degree Program, May 2018 Graduate
Mentor/Faculty Advisor: Dr. Gavin P. Smith, Research Professor

Relevant Course Work:

Fall 2016 Coursework

Fall 2016 semester, my first at the program at UNC, featured three especially relevant courses. The first, Urban Neighborhood Revitalization (PLAN763, DCRP), provided a cursory introduction to historic and contemporary community engagement strategies. While this class did not feature hazard-specific contexts, it furnished a mental toolkit for later work I would be doing through the fellowship regarding community engagement techniques that are commonly explored following a disaster event. Primary takeaways from this course include perspective on community groups, an understanding of neighborhood-scale planning history, and my first experiences thinking of marginalized populations in city-planning contexts.

The second relevant course taken during Fall of 2016 was Planning for Natural Hazard Resilience, led by Professor Gavin Smith (PLAN755, DCRP). This class was my first foray into academic understanding of not only disaster events but recovery processes and mitigation techniques. Smith drew upon his years of experience in both academic and professional settings, across a multitude of geographies in the American South. This class most neatly aligned with my initial interests, as it covered not only hazard events, but events and recovery processes taking place in my interest geography. Smith went so far as to use numerous examples from the state of North Carolina, where I would later be doing work. A macabre benefit to the facilitation of this class was Hurricane Matthew, which took place mid-semester and brought with it numerous challenges discussed in class playing out in real-time. This course primed me for navigating the tangled, acronym-laden verbiage of hazard mitigation and disaster recovery work.

Lastly, Introduction to Law for Planners (PLAN724, DCRP) proved to be an important foundational course for understanding not only planning but the intersection of the field and disaster events. Led by David Brower, a professor specializing in hazards and environmental challenges, the class drew upon hazard contexts to explain legal challenges. Class guests, including the professor’s daughter, spoke from an international perspective, detailing planning and institutional challenges following major earthquakes in Christchurch, New Zealand. The greatest benefit from this class was the connection it made between hazards and standard, mainstream planning processes and terminology. Rather than treating hazard mitigation and recovery as an area of specialization, it was presented as an assumed foundational context.

Spring 2017 Coursework

Spring of 2017 featured courses with foundations based less in theory and more in practice. Natural Hazards Resilience Speaker Series (PLAN754, DCRP), led by Gavin Smith, brought numerous professionals either linked to hazard planning by title or by fate – from mayors forced to lead their community through disaster recovery, data science experts, to internationally-oriented researchers. The semester also featured a Housing Workshop course, led by Mai Thi Nguyen and Andrew Whittemore, working in tandem with Gavin Smith, which propelled me into much of the work I’m engaged in this summer (PLAN823, DCRP). My team focused on Princeville, the oldest town found by freed African American former slaves. The research I engaged in alongside my team aided opportunities that would later present themselves, described further in this report.

Fall 2017 Coursework
This semester, I finished the core of the Natural Hazards Resilience Certificate with the completion of the Survey of Natural Hazards and Disasters (PLAN756, DCRP). Related and useful courses include a Special Topics (Environmental Science & Engineering) – R Programming class, which introduced the nexus of analytical statistics and environmental projects (ENVR890).

Spring 2018 Coursework
Much of this semester was focused on my Master's Project, described later in this report. The most useful and relevant course taken during Spring 2018 was at UNC School of Government's Public Administration program, Applied Environmental Finance (PUBA787) and Community-Based Participatory Research (ENVR890), which should be a recommended course to all participants in this fellowship.

Certificate:

Upon graduation (May 2018), I earned the **Natural Hazards Resilience Certificate**, which required three core courses and several elective credits.

Research Project(s): Provide title, department and name of principal investigator for each research project you were involved in. Include start and end dates of your participation in each project. Do not include research conducted during internships in this section of your report (see separate Internship section below).

- Research Project Abstract(s) Provide an academic abstract of each research project you were involved in. Abstracts should not exceed 1/2 page per project.
- Summary of Research Accomplishments: Provide a concise description of the major findings/accomplishments of the research project(s) you worked on, along with your role and any specific contributions you made to each project.

Principal Investigator: Dr. Gavin Smith, Research Professor, University of North Carolina at Chapel Hill. Director, Department of Homeland Security Coastal Resilience Center of Excellence

Title: Resilient Design Education Study.
Abstract:
The focus of this study involves the review of existing college and university educational programs that teach resilient design approaches in the face of natural hazards, disasters, and climate change adaptation. Resilient design is defined as architecture, planning, engineering and building sciences that advances "the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events" (National Research Council).

The review will emphasize planning, architecture, building sciences, and engineering programs that address the built, natural, and social environment, including how these elements are intertwined and help produce design solutions that are mutually reinforcing. An important sub-part of this effort involves the identification of multidisciplinary programs that bridge planning, architecture, building sciences, and engineering.

The impacts of climate change and extreme weather impose increasing risks to communities across the nation and world. These risks include sea level rise as well as increasing frequency of severe drought, storms, and floods. A key aspect of addressing these risks is planning and designing in ways that incorporate adaptability and uncertainty over time and rely on the utilization of the latest models that address the non-stationarity problem. That is, what is the latest thinking on how the design, planning, and development community should account for deep uncertainty and adapt to what amounts to a new normal?

Approach

The scope of work noted above will be addressed in two phases. In Phase 1, we will conduct a review of the existing academic and professional literature surrounding resilient design curricula and training. In Phase 2, we will analyze graduate, undergraduate, and professional programs addressing resilient design that builds on the work done in Phase 1.

This project will serve as a gauge for the next generation of design professionals who will engage in the work of climate change adaptation, resilient recovery, and hazard mitigation. This project outcome is important to homeland security because natural hazards and disasters affect the livelihoods of residents across all 50 states and territories of the United States – better understanding the gaps that exist within the programs that educate hazard professionals will enable educators to fill them, ideally leading to better disaster recovery and overall mitigated risk. Through assessing the educational landscape in the United States with regard to the fields of architecture, city and regional planning, engineering, building sciences, and landscape architecture, department chairs and program heads will be able to create or modify programs that maximize the potential for interdisciplinary education rooted in resilience.

The professional and intellectual markets are increasingly demanding the skillset and background that these programs produce. We can observe this by recognizing the increased number of resilience-oriented degree programs, certificates, and specializations emerging from universities across the United States with each passing year. This demand isn’t simply market-generated, but is becoming more so a cultural and institutional necessity. More specifically, resilience-oriented skillsets seem novel until a region is hit by a major disaster, often relating to flooding. Because the country is seeing greater number of flood-related disaster instances occurring, these skills are increasingly becoming a requirement.

The project remains in its nascent stage – concepts have been solidified, an interview guide has been produced, and interviews with professionals across the listed disciplines have taken place.

At the time of this report's drafting, 13 interviews have been conducted, with two more scheduled before the end of June 2017.

Knowledge gleaned from the interviews include an understanding of the institutional barriers to effective resilience-oriented education, ideas for interdisciplinary collaboration, and the opportunities that exist across the United States. These have the impact of helping me understand what opportunities exist in my field in other geographies. The study has larger impacts for pedagogy in these fields and even institutional organization at universities across the country.

Aside from amount of perspective I'm gaining from participation in this project, I have been able to hone my interview skills. Coming from the field of sociology, interviews are often an important way we collect data that cannot easily be measured. Having the opportunity to sharpen these skills, especially with interviewing high-achieving professionals, has aided in my understanding of techniques for the collection of qualitative information.

<u>Conferences Attended</u>

- PIE Seminar – Post-Disaster Temporary Housing: Urban Planning Considerations (2017) (Participant)
- Natural Hazards Workshop (July 2017, Broomfield, CO) (Attendant)
- Department of Homeland Security Coastal Resilience Center of Excellence Annual Meeting HMDRRI Poster Presentation (February 2018) (**Poster Presenter**)
- South Carolina Emergency Management Disaster Recovery Workshop (January, 2018) (**Presenter**)
- NOAA Sea Grant Weather and Climate Enterprise 10-Year Visioning Workshop, Participant (Raleigh, NC) Mar 2018 (Participant)
- Upcoming: Natural Hazards Workshop (July 2018, Broomfield, CO) (**Panel/Poster Presenter**)

<u>Publications</u>

Williams, D. (2017). [Review of the book Precarious Claims, by S. Gleeson]. Carolina Planning Journal, Vol 42, 118-119.

Durfee, C., Rohmer, A., & Williams, D. (2016, October 14). The Future of Floods: Lessons from Charlotte-Mecklenburg County. Carolina ANGLES. Retrieved from https://carolinaangles.com/2016/10/14/the-future-of-floods-lessons-from-charlottemecklenburg-county/

Forthcoming: Resilient Design Education Report (see: Research section)

Internship Placement and Experiences.

Internship 1:
My first summer internship took place between April and August 2017 at the Hurricane Matthew Disaster Recovery and Resilience Initiative (HMDRRI). This organization came into formation under Gavin Smith, with the support of both UNC – Chapel Hill and the State of North Carolina. HMDRRI selected six modest-capacity/high-need North Carolinian communities to do work with: Princeville, Windsor, Lumberton, Seven Springs, Fair Bluff, and Kinston.
My role within the initiative emerged over time. The aforementioned Housing Workshop course placed me in a group working primarily with Princeville, which enabled me to smoothly transition to doing Princeville work within HMDRRI – starting with thinking through organizational structure and relocation strategies. The research background the course provided a foundation for further research with HMDRRI. The work with this organization helped furnish the content for the drafting of disaster recovery plans.

Internship 2:
Between January 2017 and August 2018, I've worked as a Program and Research Assistant for the Southeast Disaster Recovery Partnership, an organization oriented to mobilizing and building on networks of public and private professionals across the southeast for improved regional hazard resilience. Between December 2017 and April 2018, I served in a promoted position as Project Manager while the regular manager was on leave, and learned a great deal about the responsibilities and challenges of managing a nonacademic project. In this role, I've been able to contribute through organizing the Partnership's annual meeting, coordinating calls, processing grant information, writing progress reports, serving as liaison between state governments and NOAA, among other duties.

Overall WFD Experience:

If anything, my experience with this fellowship, in tandem with acquiring the Natural Hazards Resilience Certificate, have taught me that I have the capacity to multitask to an extreme degree. I've also learned that this isn't my ideal workstyle. I've also learned quite a bit about project management, how to keep up with groups of people and not lose momentum – a skill I can see using in every endeavor following my time at UNC as a WFD student.

My experiences as a WFD student have brought me to the importance of meaningful community engagement, and even community-leadership, two concepts I witnessed brought up a lot but not entirely embodied in projects I found myself contributing to. I've had a lot of experiences dealing with the recovery phase of disaster – and I've since learned that it may be more fulfilling for me to consider applying my talents to different phases, or at least different contexts. I'm about to move into a project dealing mainly with mitigation strategies, and I am curious to see the differences.

Generally, the requirements and orientation of the grant furnished a useful, structured path of work and study during my Master's program. This structure, largely supported through helpful mentorship and guidance from my advisor (Dr. Gavin Smith), was useful for understanding the depth of education possible even outside the classrooms. Most instructive were the research opportunities I pursued to fulfill the WFD requirements, under Dr. Smith, which brought academic and professional work experience.

The opportunities presented through this fellowship pushed me to be involved in extracurricular endeavors such as Design Week 2017 – which forced me to contextualize my discipline (planning) within a large group that pulled together numerous design disciplines, towards understanding and addressing a real-world challenge (flooding in Eastern North Carolina). This experience was rewarding – enabling me to try out being part of a work group and both having my knowledge challenged as well as valued. Additional extracurricular involvement has been in organizations like the Carolina Resiliency Hazards Planners student group – which attracted about a dozen students to discuss issues in our subfields and how we can make the most of our time in graduate school learning about hazard resilience. This group received needed support from the DHS Coastal Resilience Center of Excellence, which provided symposium support and space, as well as opportunities for students to connect with seasoned professionals.

Holistically, the grant pulled together numerous formal and informal aspects of education (classes, mentorship, a certificate program, research opportunities, and internship direction) into a very thorough personal and professional development experience.

Lastly but possibly most important – the fellowship enabled me, a student of several marginalized backgrounds (Black, queer, Muslim, from a family who's experienced poverty and homelessness) to pursue a graduate educate with full funded support. This support allowed me to focus on my studies and nurture my interests outside of the regular semesterly frenzied scramble for graduate funding. Freedom from this stress undoubtedly contributed greatly to my successful completion of my graduate program, certificate program, as well as personal and professional goals during my time at UNC.

<u>Post-Graduation Employment:</u>

I have accepted a position as Research Assistant for a NSF-funded study into the resilience of energy, communication, and gas infrastructure across the U.S. Northeast, led by co-PI Dr. Amy Glasmeier. This research will be conducted for (at least) three years at the Massachusetts Institute of Technology, where I will be completing a PhD in Urban Studies & Planning. My role as research assistant will be to conduct focus groups, interview stakeholders, and exercise skills in qualitative data generation and analysis.

Further Graduate Studies

Massachusetts Institute of Technology – Department of Urban Studies & Planning – PhD in Urban Studies & Planning Program

- Starting Fall 2018
- Degree expected: PhD
- 2021-2022
- As stated above, I will be employed as a research assistant for a project relating to infrastructural resilience in the northeastern United States. Personally, I plan to do some pre-dissertation work relating to elevation and hazard vulnerability in black communities.

Darien Alexander Williams

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EDUCATION

Massachusetts Institute of Technology (Cambridge, MA)

- Doctor of Philosophy, Urban Studies & Planning **(Incoming)** September 2018
  - NSF-funded study on electric-gas-communication infrastructure failure
  - *Advisor*: Dr. Amy Glasmeier

University of North Carolina at Chapel Hill (Chapel Hill, NC)

- Master of City & Regional Planning, August 2016 - Present
  - Economic Development Specialization
  - Certificate in Natural Hazards Resilience
  - *Awards*: Dept. of Homeland Security Science & Engineering Workforce Development Grant
  - *Master's Project:* For the Long Haul: Public-Private Partnerships for Long-Term Disaster Recovery

University of Florida (Gainesville, FL)

- Bachelor of Arts in Sociology, May 2014
  - Minors: International Development & Humanitarian Assistance, East Asian Languages & Literatures - Japanese

  University of Pretoria, study abroad (Pretoria, South Africa) Summer 2013
  Universidad Autónoma de Yucatán, study abroad (Mérida, México) Summer 2010
  - *Awards*: John V. Lombardi Scholar, Doctor Martin Luther King Jr. Educational Achievement Scholar, Florida Academic Scholar, Presidential Gold Scholar

EXPERIENCE

Coastal Resilience Center of Excellence, Research Fellow (Chapel Hill, NC)
Aug 2016 – Present

- Collaborated on Department of Homeland Security and White House Initiative project focusing on hazard resilience in design education, under Dr. Gavin Smith and Dr. Mai Thi Nguyen

Hurricane Matthew Disaster Recovery & Resilience Initiative, Planning Assistant (Durham, NC)
April 2017 – Present

- Planned and executed disaster recovery visioning processes in six rural Eastern North Carolina towns
- Organized five-day long community recovery design workshop for Princeville, NC
- Created new recovery committee structure for Fair Bluff, NC town council involvement in recovery process

Southeast Disaster Recovery Partnership, Research & Program Assistant (Chapel Hill, NC)
March 2017 – Present

- Contributed to two white papers on economic recovery for a NOAA-funded coalition of public and private entities across the American Southeast
- Coordinated annual meeting logistics

- Served as interim project manager

In the Shadows of Ferguson, Research Assistant, Performer (St. Louis, MO/Chapel Hill, NC)
Feb 2017 – Present

- Conducted field, interview, and archival research in historic housing and municipal policy in St. Louis County, MO alongside Dr. Mai Thi Nguyen
- Workshopped 50 min-length interactive stage production detailing housing policy's intersection with systemic police brutality

Orange County Outreach Court, Program Evaluator (Chapel Hill, NC)
Sep 2016 – Dec 2016

- Assessed internal operations of county homeless outreach court program
- Conducted interviews, literature review, as well as analyses
- Produced report of key findings to program staff and graduate course

Japan Exchange & Teaching Program, Assistant Language Teacher (Tokyo, Japan)
Aug 2014 – Aug 2016

- Co-taught 16 weekly English classes for Nerima Technical High School students
- Extended English to extracurricular activities to further student out-of-class learning
- Participated in grassroots internationalization for city-wide 2020 Olympic preparation

Department of Sociology & Criminology, Undergraduate Research Assistant (Gainesville, FL)
Aug 2011 - Aug 2014

- Digitized quantitative survey data on subjects involving wisdom, aging, and death
- Guided new research assistants and analyzed qualitative data for theme patterns

Department of Housing & Residence Education, Undergraduate Assignments Assistant
Aug 2011 - May 2014

- Aided incoming students and families in the Main Housing office
- Assessed on-campus issues and worked with housing staff to oversee their resolution

LEADERSHIP

Plan for All, Co-facilitator (Chapel Hill, NC)
January 2017 – April 2018

- Facilitated regular programs focused on diversity, equity, representation, and inclusion as part of departmental admissions, operations, and syllabi
- Created & advocated new funding opportunities for students of marginalized identities

Marsha P. Johnson Threw The First Glass At Stonewall JAPAN, Founder (Tokyo, Japan)
Jul 2016 – Present

- Founded an organization serving the needs of queer and trans people of color across urban and rural Japan
- Organized meetups and group dialogues centering diasporic LGBTQ identities in Japan.

University Economics Society, President (Gainesville, FL)
Aug 2011 - April 2014

- Coordinated and executed weekly events for the student organization representing the Economics Department at the University of Florida

VOLUNTEERING

UNC – CH Queer Grads Advisory Board, Board member (Chapel Hill, NC)
Jan 2017 – Present

- Regularly met with students and administration to plan for the needs of university trans and queer graduate student population

Southern Fried Queer Pride, Fundraiser (Durham, NC)
Summer & Fall 2017

- Raised funds for arts advocacy organization dedicated to showcasing the achievements of Southern queer people of color.

AKTA Community Center, Health Delivery Project Volunteer (Tokyo, Japan)
July 2015 – July 2016

- Distributed HIV prevention supplies, community newsletters and information to over 160 businesses in the Shinjuku Ni-chōme area on a weekly basis

UF Honey Bee Research & Extension Laboratory, Volunteer (Gainesville, FL)
Jun 2014 – Jul 2014

- Maintained and improved hive health for various apidae research efforts

English Language Institute, Volunteer Partner (Gainesville, FL)
Aug 2013 - May 2014

- Assisted as conversation partner and volunteer, aiding visiting faculty with fluency goals.

ProWorld Peru, Volunteer (Cusco, Peru)
May 2012

- Participated in public health projects installing clean-burning stoves, and ventilation reconstruction, in conjunction with TOMS Shoes

ADDITIONAL INVOLVEMENT

NOAA Sea Grant Weather and Climate Enterprise 10-Year Visioning Workshop, Participant (Raleigh, NC)
Mar 2018

- Reviewed the current capacity of Sea Grant to assist coastal communities and businesses with using weather and climate information to improve resilience
- Drafted a set of goals and objectives that align existing and needed Sea Grant weather and climate resilience capacity with needs and gaps in the weather and climate resilience enterprise.

Town of Chapel Hill Street Audit, Researcher (Raleigh, NC)
Spring 2018

- Participated in ground-level road study for greenway expansion project.

Durham Peer Cities Team, Researcher (Workshop Course - Chapel Hill, NC)
Fall 2017

- Compiled report of women & minority-owned business supports provided by Durham, NC's peer cities
- Presented findings to Downtown Durham Inc., in report to be used in city council decisions

Princeville Recovery Design Workshop, Organizer/Design Team Member (Princeville, NC)
August 2017

- Participated in five-day design charrette envisioning Princeville's development through recovery from Hurricane Matthew
- Drafted orienting guidebook and GIS data for use and reference by all design teams

NC State Design Week, Participant (Raleigh, NC)
January 2017

- Brainstormed and created interdisciplinary design solution to buyout open space reuse for the municipality of Kinston, NC.

Environmental Justice Policy Lab, Participant (Chapel Hill, NC)
Aug 2016 – January 2017

- Collaborated with students to bring technical assistance to locally-organized groups with environmental justice concerns

Tokyo Metro Board of Education Youth Exchange Program, Participant (Tokyo, Japan)
Jul 2015 – July 2016

- Facilitated five-part series of cross-cultural events at an agricultural elementary school

Weiveld Organic Dairy Work Exchange, Worker (Pretoria, South Africa)
Jun 2013 - Jul 2013

- Joined local Pretoria North organic dairy daily operation, distribution, and marketing

InternationalStudent.com, Writer (Neptune Beach, FL)
Jan 2011 – May 2011

- Gathered and published resources for foreign nationals to navigate American higher education

- Carolina Hazards Resilience Planners Member
- Appointed Kizuna Ambassador under Japan's Ministry of Internal Affairs and Communications
- 36th Keizai Koho Center Fellowship Program Symposium Participant
- Maritime Risk Symposium Volunteer – Dept. of Homeland Security Coastal Resilience Center
- Rethinking Flood Analytics Volunteer – Dept. of Homeland Security Coastal Resilience Center
- Tokyo Metropolitan Board of Education JET Program Professional Development Presenter
- WUFT Radio Reading Service Broadcaster

ACADEMIC & ONLINE PUBLICATIONS

Williams, D. (2017). [Review of the book Precarious Claims, by S. Gleeson]. *Carolina Planning Journal, Vol 42*, 118-119.

Durfee, C., Rohmer, A., & Williams, D. (2016, October 14). The Future of Floods: Lessons from Charlotte-Mecklenburg County. *Carolina ANGLES*. Retrieved from https://carolinaangles.com/2016/10/14/the-future-of-floods-lessons-from-charlotte-mecklenburg-county/

PRESENTATIONS

- Department of Homeland Security Coastal Resilience Center of Excellence Annual Meeting HMDRRI Poster Presentation (February 2018)
- South Carolina Emergency Management Disaster Recovery Workshop (January, 2018)
- Racial Equity Training Follow-Up Community Conversation (September 2017)

TRAINING

- Racial Equity Training (2016, 2017)
- PIE Seminar – Post-Disaster Temporary Housing: Urban Planning Considerations (2017)

SKILLS

- Experience with qualitative and quantitative methods in research settings

- IMPLAN economic impact analysis, GIS, SPSS, R experience
- Teaching, curriculum development, and lesson-planning experience
- Knowledge and experience with coordination and executing multicultural events
- 90 WPM average keyboarding speed
- Conversational Japanese
- Microsoft Office Suite proficiency
- Public speaking & group coordination proficiency

Colleen Durfee
Department of City and Regional Planning
The University of North Carolina at Chapel Hill
Degree earned: Masters in City and Regional Planning, May 2018
Faculty Advisor: Dr. Gavin Smith

My time at UNC Chapel Hill has been spent absorbing as much information as possible, learning valuable skills, and being exposed to many diverse perspectives about city and regional planning and how to prepare for and recover from natural hazards and disasters. My coursework, advisors, professors, peers, and supervisors have taught me so much. Without this experience, I would not be able to work on the issues I am passionate about; social equity in the face of serious shocks and strains on communities and improving our disaster recovery process and response from the federal to the local level. The following report details my experience as a masters student in City and Regional Planning at UNC Chapel Hill as well as internships outside of school work, research projects, conferences attended, publications, and post-graduate employment prospects.

Coursework

Most of my course work at UNC Chapel Hill took place within the Department if City and Regional Planning with a few exceptions. In the Department of City and Regional Planning, I specialized in Economic Development and completed the Natural Hazards Certificate sponsored by the Coastal Resilience Center of Excellence. The following is a list of the relevant coursework taken:

Fall 2016

City and Regional Planning 714 – Urban Spatial Structure
City and Regional Planning 720 – Planning Methods
City and Regional Planning 740 – Land Use and Environmental Policy
City and Regional Planning 755 – Natural Hazards and Climate Change

Spring 2017

City and Regional Planning 721 – Advanced Planning Methods
City and Regional Planning 725 – Dispute Resolution
City and Regional Planning 754 – Natural Hazards Resilience Speaker Series
City and Regional Planning 770 – Economic Development Policy
City and Regional Planning 771 – Economic Development Techniques
City and Regional Planning 823 – Housing Workshop (Hurricane Matthew Recovery)

Fall 2017

Geography 702 – Contemporary Geographic Thought?
School of Law 243A – Employment Law
City and Regional Planning 756 – Natural Hazards and Disasters
City and Regional Planning 773 – Urban and Regional Development Seminar
City and Regional Planning 823 – Economic Development Workshop (Minority Business Development in Durham)
School of Public Health 720 – Leading for Racial Equity

Spring 2018

City and Regional Planning 590 – Special Topics Seminar (Career and Professional Development)
City and Regional Planning 704 – Theory of Planning I
City and Regional Planning 757 – Planning Historic Preservation
City and Regional Planning 760 – Real Estate and Affordable Housing Finance
City and Regional Planning 992 – Master's (non-thesis)

Certificates

As a master's student at UNC Chapel Hill, I received a Natural Hazards Certificate by completing 10 credit hours of coursework that covered the topic of hazard and disaster resilience. In the coursework listed above, the courses that counted towards this certificate include: City and Regional Planning 756 – Natural Hazards and Disasters, City and Regional Planning 755 on Natural Hazards and Climate Change, City and Regional Planning 823 which was the Housing and Community Development Workshop working on developing a fact base for recovery plans for hard-hit towns in North Carolina after Hurricane Matthew, and City and Regional Planning 754, the Natural Hazards Resilience Speaker Series. To complete the certificate, I had to take six credit hours of additional coursework in order to graduate. This provided for a fairly rigorous academic experience as most semesters I took five or more classes.

Research Projects

In addition to a busy course load, I was involved in several research projects related to natural hazards and resilience. Most prominently, I was a research assistant for my advisor, Dr. Gavin Smith. As his research assistant, I was involved in a project that researched the extent to which we teach resilient design in the United States. I was involved in this project from the development of the methodology to the delivery of the final report. This was a tremendously rewarding experience because I was able to see this particular research project develop from beginning to end. The final report is titled (TBD) It took place within the Department of City and Regional Planning and the principal investigator was Dr. Gavin Smith. I began participating in this project fall semester of 2016 and concluded my participating in May 2018, at the end of my last semester at UNC. The abstract is below:

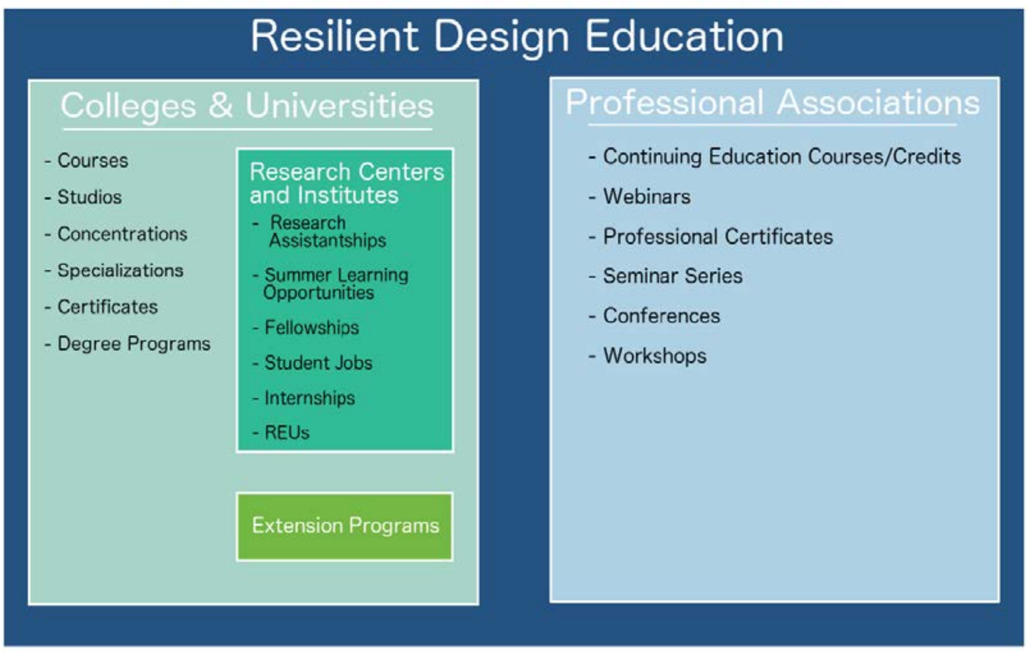
"Resilience has become an increasingly important organizing principle for the design community when thinking about how and where to build in relation to natural hazards and disasters. Resilience has also become a common theme among hazards and disaster scholars and educators and a growing body of research, policy, and educational initiatives reflect this trend. The increased reliance on resilience as an organizing principle in practice is evident in the growth of federal policies and programs that promote resilience. The rising interest in resilience within design-related disciplines is evident in the increasing number of courses and degree programs offered at US colleges and universities with this focus. While resilient design as a field of study has gained ground, there has yet to be a systematic study of what is taught and how it is taught. This study, funded by the US Department of Homeland Security's Office of University Programs, attempts to examine how resilient design curricula are being delivered at US colleges and universities in five design-related disciplines: architecture, building sciences, engineering, landscape architecture and planning. Our research seeks to understand the current state of training and education on resilient design, thereby providing an understanding of the types of educational training that practitioners and scholars gain. We employ mixed-methods,

including an internet search, key informant interviews, case studies, and feedback from an advisory panel to gain a multi-disciplinary perspective."

Key findings of this research include similarities and dissimilarities in how design related disciplines define resilient design, what obstacles faculty face in teaching resilient design principles in an academic setting, where resilient design education is being delivered within and outside of the classroom, and several case studies of particularly innovative or successful programs teaching resilient design across the country. We gathered data through a quasi-experimental research design including an internet search of the programs in existence teaching resilient design in the U.S. and key informant interviews of experts (practitioners and professors) in design related fields. Interviewees across our five disciplines (architecture, landscape architecture, planning, engineering, and building sciences) described resilient design as multi-scalar, systems-based, and interdisciplinary.

From our internet research, we found resilient design education focused on the multi-scalar and systems-based aspect of resilience while incorporating an interdisciplinary component is mostly happening outside of the classroom, in research centers and institutes and through studio and workshop classes meant to mimic the working world experience (see Figure 1). We then probed why this might be the case.

Figure 1: How Resilient Design Education is Delivered



In our interviews, we saw patterns and themes emerge related to the barriers faced by educators trying to teach resilient design. Resilient design education is often spearheaded by an individual or small group but is not institutionalized or embedded in curriculum to ensure that all students receive some training in resilient design. The institutional barriers related to how classes are funded in Universities also contribute to the difficulty in teaching interdisciplinary perspectives of resilient design. To support our findings and give examples of more institutionalized resilient design programs, we provided case studies of Texas A & M University, Clemson University, Cal Poly San Louis Obispo, North Carolina State

University, Louisiana State University, and a joint collaboration post-Hurricane Matthew between UNC Chapel Hill and North Carolina State University.

Conferences

The conferences and workshops I attended and will attend this summer related to my master's education are listed below

1. North Carolina American Planning Association Conference in Asheville, NC from September 13-16, 2016
2. National Housing Conference in Washington DC from December 14, 2016
3. Natural Hazards Workshop in Broomfield, CO July 9-12, 2017
4. Coastal Resilience Center of Excellence Annual Meeting in Chapel Hill, NC on February 28, 2018
    a. Presented a poster on my work this past summer with the Hurricane Matthew Disaster Recovery and Resilience Initiative (HMDRRI) and my master's project on home mortgage loan approvals in neighborhoods with buyouts.
5. Natural Hazards Workshop in Broomfield, CO July 8-11, 2018
    a. Will present my master's project poster as well as the HMDRRI poster.
    b. I will also be on a panel for the research I did with Dr. Gavin Smith on Resilient Design Education.

Publications

While a master's student at UNC I published several articles online for the Carolina Planning Journal's blog including co-writing "The Future of Floods: Lessons from Charlotte-Mecklenburg County", "Women in the Workplace: 4 Takeaways", and "Threading together Carolina's Textile Manufacturing Comeback". I also published a book review in the Carolina Planning Journal on a book written by Jeremiah Moss called Vanishing New York: How a Great City Lost Its Soul". As a research assistant I will also be a listed author on the Resilient Design Education Report.

Internship Placement and Experiences

First Internship
Hiring Company: Hurricane Matthew Disaster Recovery and Resilience Initiative
Location: Joint Field Office in the Research Triangle Park, NC
Dates: May 1 – August 3, 2017

In my first internship, I supported the Hurricane Matthew Disaster Recovery and Resilience Initiative (HMDRRI) team by investigating how best to rebuild the economic foundations of six highly vulnerable and impacted communities post-Hurricane Matthew. Through an internet search and collaborating with economic development agencies across the state in monthly conference calls, I developed a list of funding opportunities as a resource to assist communities in financing recovery. An additional job duty of mine was kickoff the effort to inform these communities on how to floodproof and flood retrofit their historic downtowns. I met with historic preservation experts and had conversations with representatives from the National Park Service working on the issue of historic properties in harm's way. I had to do much of my own research to become familiar with historic preservation as well as different methods to floodproof buildings. I compiled all of my sources and wrote a report detailing my findings. I also helped develop and follow through with community engagement strategies of these communities which will inform the relocation and rebuilding process. I helped facilitate community engagement in Fair Bluff, NC by assisting in a participatory mapping exercise. I also made several of the maps used to perform this activity.

In addition to mapping and community engagement, I served as a point person and liaison between HMDRRI and the other work on economic recovery for these towns happening across the state. I sat in on meetings with economic development agencies and kept lines of communication open with the Development Finance Initiative who was contracted to do a private market feasibility study for these towns. I also provided much of the GIS data for DFI to perform their parcel analysis and continually checked in with their project manager to make sure they had everything they needed and answer any questions as they completed their project for these towns.

Second Internship
Hiring Company: Hurricane Matthew Disaster Recovery and Resilience Initiative
Location: Joint Field Office in the Research Triangle Park, NC
Dates: August 20, 2017 – May 1, 2018

In my second internship, I continued working for HMDRRI. Most of the recovery planning process was just getting started as the summer was ending so I elected to stay on and continue this work through the school year.

In continuation of my report on how to flood retrofit several communities' historic downtowns, I developed three town-specific information packets. These packets were commissioned because we had recruited several experts in engineering, building sciences, and historic preservation from the Association of State Floodplain Managers (ASFPM) to assess the costs and feasibility of floodproofing specific buildings in these towns. In order to assess the feasibility of floodproofing and restoring these business districts, they needed all of the possible relevant information pertaining to these downtown buildings. I improved my GIS skills significantly in writing these information packets. I made dozens of maps for each town, Windsor, Fair Bluff, and Seven Springs, using ArcGIS. I detailed the building type, value, flood extent, damage level, and elevation of each building in each town. I also listed building ownership, land use, and zoning designations for each parcel to help inform the experts and the town on how to go about restoring their downtowns. Restoring a business district is crucial to retaining and attracting residents, which is foundational to a town's recovery, especially in a small town rural setting. My work on these reports was very rewarding because they proved extremely useful to the ASFPM experts and provided much needed context for potential recovery paths these downtowns could take.

As a part of the recovery planning process, I was also tasked with doing an analysis of the economic state of Fair Bluff, NC to go into the final recovery plan document. Using census data, I created several graphs, charts, and tables detailing the past, present, and potential future state of Fair Bluff's economic base. I assessed education level, income, home value, industry presence, distance workers travel to get to work, poverty, and unemployment level. I then compared Fair Bluff's statistics to the county and then the state as a whole to give a reference point. Once a clear picture of Fair Bluff's economic state was established, I developed a matrix of economic recovery goals, objectives, and action items to achieve those goals and objectives given my knowledge of their local capacity and assets from field research conducted in person and remote research online. For the recovery plan documents, I also developed a matrix of potential funding streams, the stipulations and requirements attached to them, where the money was coming from, and the likelihood of receiving that funding given the needs of the town, purpose of the funding, and competitiveness of the funding. This information informed all of the town recovery plans.

I was also a part of the Princeville Design Charrette which aimed to engage Princeville residents with design and planning professionals and students to develop a recovery plan and site plan for a new 52-acre site on which the town could relocate. There were several teams in the charrette focused on different time horizons which allowed residents to feel their immediate needs were being heard and addressed while also providing them space to dream big about the future of their town. As the first town chartered by freed enslaved people in the U.S., this experience was one of the most rewarding and impactful of my internship. Not only did I get exposure to interdisciplinary collaboration across planning, architecture, and landscape architecture, but I felt like we were meaningfully engaging with this community and really adding value to their recovery process.

In addition to being involved in community engagement processes, developing comprehensive town reports, and conducting economic stability analysis, I also assisted with the production of a video on the Fair Bluff community participation process. Throughout the past year I was consistently involved in editing maps for the final recovery plans as well.

Through these two internships, I have learned how complicated the recovery planning process can be. I gained experience in community engagement, which includes how to be sensitive to those going through traumatic experiences and giving them the platform to be heard and have agency in their recovery. I also learned cross-sectoral collaborations and how to coordinate with local, state, and federal officials, each with different priorities and agendas. Because these are small and low-income towns, there is a strong sense of identity tied to the community and often this sense of identity differs between residents of different races. This presents a real challenge in the recovery process as we try to create a unified vision for a town moving forward with residents that have drastically different needs, histories, and experiences in the same town. My experience with disaster recovery planning will be applicable to any community in which I work. This experience reinforced the importance of building local capacity, giving communities autonomy and agency, while lifting up the voices of those usually drowned out in these kinds of processes. I also now have a better idea of what work environment I want to be in and how important working with peers I admire and respect is for my enjoyment of my work.

Overall Experience

As a WFD student, I gained incredible experience and developed invaluable skills that will set me up for a successful career in community development and disaster preparedness. As a master's student, I was exposed to rigorous and interesting coursework in a field I am excited to begin my career in. I learned how to produce high quality research design and analysis and benefited tremendously from strong mentorship from my professors and advisors.

I learned a lot about the importance of project management and scheduling deadlines in advance to make sure I and my team accomplished what we set out to do. I learned about the challenges of the disaster recovery process and what it is like to be in a consultant role working with federal agencies. This will serve me well when considering future employment opportunities. During my internships, I grappled with difficult questions and challenges facing these rural communities. Even though these questions about relocation, racial tension, and identity went without answers, being forced to continue to work in the disaster recovery space with incomplete information and with much uncertainty prepared me well for a career in a planning related field.

I gained soft skills such as communication, facilitation, and mediation techniques as well as hard skills such as statistical analysis, GIS mapping, design, and economic impact analysis. My biggest take-away going into the working world is to think about the job acquisition process from the standpoint of where I ultimately want to end up in my career and how can I use this potential job as a stepping stone, gaining more experience, skills, and making contacts that will put me in a position to accomplish my goals. Additionally, using my peers, co-workers, and superiors for their unique expertise without hesitation is another takeaway I gained from this experience. Everyone I will be working with is so knowledgeable and can contribute so much to a project. I look forward to building a network of trusted and passionate planners, emergency managers, hazard mitigation specialists, and many others in this field to work with in improving our communities, cities, regions, and country.

Post-Graduate Employment

This fall I will be working for the City of University City, Missouri as the Planning and Zoning Administrator. Land use and zoning are particularly important in ensuring community facilities, assets, and infrastructure are not prone to degradation from environmental hazards. University City is at risk for extreme heat, winter storms, tornados, and flooding, all of which compromise the security of the City and its residents. As a Planning and Zoning Administrator for University City, I will be engaging with community stakeholders and City departments to address the vulnerabilities in the City using zoning and land use. Zoning and land use are key to building community resilience, whether that be by reducing the exposure of community assets to natural hazards like flooding and extreme temperatures, allowing for more diversified housing options, or promoting economic growth through attracting new industries and businesses. Examples of how I will reduce the City's vulnerability to natural hazards include advocating for increasing the amount of open space as well as using scheduled infrastructure maintenance as an opportunity to install green infrastructure such as storm water catchments and bioswales. I will also be able to influence the location of development, community assets, and critical services to ensure residents are not cut off in the event of a natural hazard. For example, I would place health facilities and grocery stores in areas so they remain accessible to residents in the event of flooding or a snow storm.

The Planning Department is also a part of a cross-departmental Green Team which focuses on environmental issues in University City. As the Planning and Zoning Administrator, I will be involved in the Green Team addressing environmental concerns and risks for the City. Energy efficiency, green infrastructure, increased open space and tree cover, and decreasing impervious surfaces will all be on the agenda for the Green Team. Initiatives promoting a greener University City will reduce the residents and businesses risk to environmental threats and ultimately ensure the long-term viability and livability of the area.

Resilience to environmental hazards also relies on a community being socially and economically resilient. University City is an area that has been subject to disinvestment and as a result experiences higher crime and poverty rates, both of which compromise the City's ability to respond to and rebound from environmental hazards. The area's current condition is in large part due to decades of discriminatory policies and systems. As the Planning and Zoning Administrator, I will help reverse decline and spur equitable and inclusive investment for the area by simplifying the zoning code. This aspect of my work will strengthen the City from all angles, resulting in a holistic approach to community resilience that will ultimately ensure the area and its residents less socially and physically vulnerable to natural. Hazards. In addition to zoning and land use work, I will be a part of a larger community planning effort specifically focused on how to plan for an equitable and sustainable University City. The new plan will be a comprehensive and coordinated effort between community stakeholders and City departments to make sure all residents of University City, current and future, will share in benefits of the changes the area is going through. Equity is key to building a resilient community and my work on this front will directly impact the City's resilience in the face natural hazards. Because of the education afforded to me through the Workforce Development Fellowship, I will be able to help make University City more socially, environmentally, and economically resilient.

DHS Year 3 Annual Report

ASGS Transition/Outreach Activities

Jason Fleming Seahorse Coastal Consulting, LLC

August 2018

Figure 1: 10 January 2016 Co-taught a storm surge workshop at the 2016 AMS Conference in New Orleans, Louisiana with Rick Luettich and Arthur Taylor (from the National Hurricane Center). Attendees included meteorologists and private sector engineers interested in advising their clients on storm surge using ADCIRC. **Funding leverage:** $1500 travel and attendance support from NSF, $5000 (est) in-kind logistical/organizational support and venue paid for by the American Meteorological Society, and co-teaching from the National Hurricane Center.

Figure 2: 11-13 April 2016 Provided ADCIRC Training for the South Florida Water Management District (SFWMD) personnel in West Palm Beach at their request. They purchased this training session to deliver on their mandate to build a model-based decision support system for water management in their jurisdiction. **Funding leverage:** $5000 (financed entirely by SFWMD).

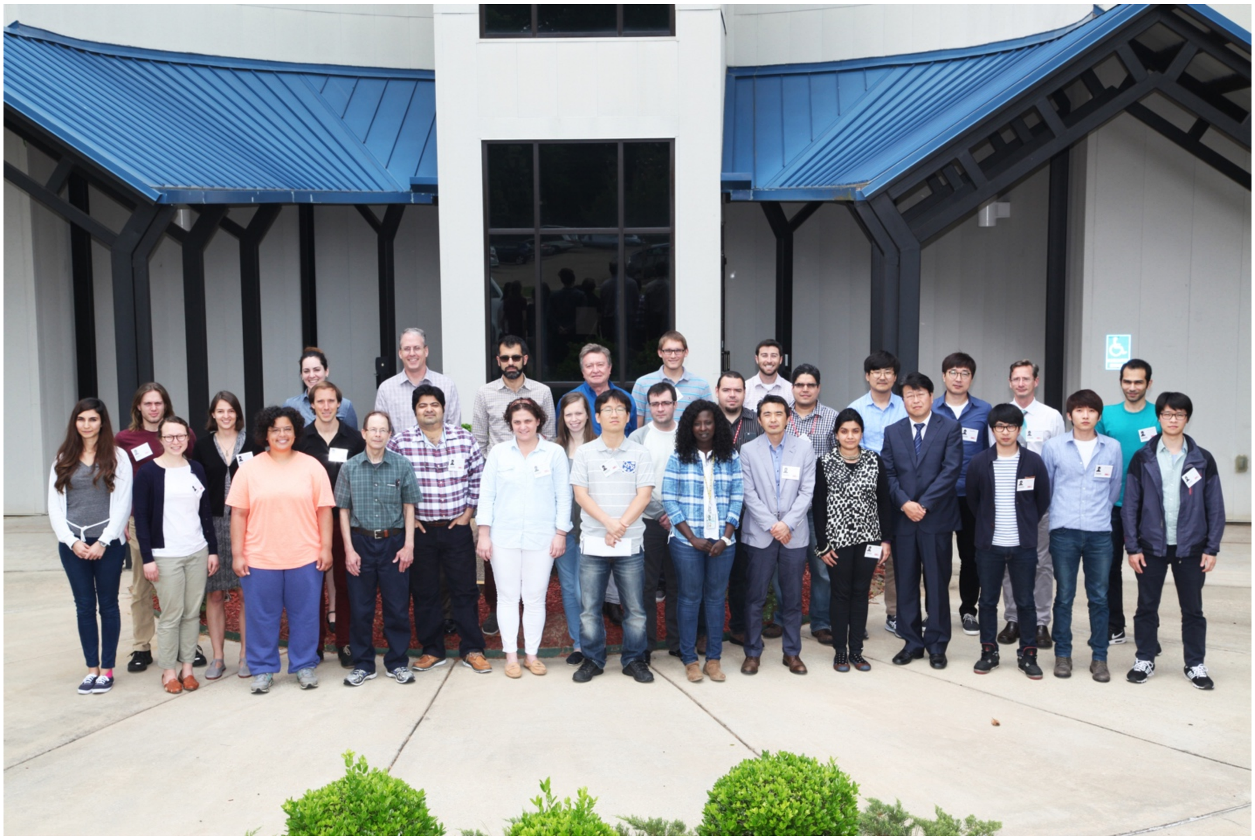


Figure 3: 2-6 May 2016 ADCIRC Users Group Meeting and ADCIRC Boot Camp at the Engineer Research and Development Center (ERDC) of the US Army Corps of Engineers in Vicksburg, MS. The Boot Camp represents a point of entry into the world of ADCIRC for many students and professionals and creates connections between DHS CRC PIs and projects. **Funding leverage:** $15824 direct revenue from participants; $10000 (est) in-kind support from host Agency (US Army Corps of Engineers Coastal and Hydraulics Laboratory) for the venue, audio/visual services, security, and organizational/logistical services. Plus $5000 (est) in-kind support for travel, lodging, and co-teaching provided by Alan Zundel of Aquaveo, makers of SMS.

Figure 4: **27 May 2016** ASGS/CERA Workshop for Emergency Managers in Cameron Parish (Lake Charles) Louisiana. This visit demonstrates synergies with other DHS CRC PIs including Robert Twilley and Carola Kaiser. **Funding leverage:** $2500 travel support from NSF STORM project; $2500 (estimated) in-kind support from Louisiana Sea Grant to support Robert Twilley's participation as well as Carola Kaiser and Danny Holmes (Danny is the developer of the CERA mobile app called "WAVE").

Figure 5: 21 June 2016 ADCIRC briefing performed for the Texas Department of Emergency Management (TDEM), National Weather Service (NWS) Regional Operations Center (ROC), and NWS West Gulf River Forecast Center (WGRFC) at the Texas State Operations Center (SOC) in Austin, Texas. TDEM expressed particular interest in the high-resolution model guidance available from ADCIRC. This meeting was a key element of our strategy to tie our DHS CRC project in with fellow CRC PI Clint Dawson. **Funding leverage:** preparation support from NSF STORM project: $1500; travel support from Clint Dawson: $1000.

Figure 6: 10 January 2017 Met with Rich Bandy (second from right) at the NWS Morehead City, North Carolina Weather Forecast Office (WFO) to circle back and discuss how ADCIRC results were used during hurricane Matthew 2016 as well as the more common winter nor'easter events that cause storm surge and inundation in eastern North Carolina. Rich Bandy is the main point of contact for storm surge at the National Weather Service. Travel support from Seahorse Coastal Consulting internal funds.

Figure 7: 23-26 April 2017 Presented ADCIRC for Decision Support at the North Carolina Association of Flood Plain Managers (NCAFPM) conference in Atlantic Beach. This event is heavily attended by North Carolina Emergency Management (NCEM) personnel at the decision maker level. Key contacts at this event include Tom Langan, Dan Brubaker, and Kurt Golembesky (all from NCFMP) and Greg Rucker (AECOM). Time support from NSF ($3000); travel and registration support from Sea- horse Coastal Consulting internal funds.

Figure 8: 1-5 May 2017 ADCIRC Week in Norwood, MA (near Boston), co-hosted by FM Global. Registered DHS participants included Kerry Bogdan and Paul Morey from FEMA as well as Alex Balsley from the US Coast Guard. **Funding leverage:** $27058 direct revenue from participants; $25000 (est) in direct corporate sponsorship from FM Global; plus $10000 in-kind support (est) in travel, lodging, and co-teaching services from Alan Zundel, Michelle Terry, Ashley Kauppila, Taylor Asher, and Nathan Dill. Travel support from Seahorse Coastal Consulting internal funds.

Army HPC User Group Review

Figure 9: 15-18 May 2017: Presentation at the US Army High Performance Computing (HPC) Review at Aberdeen Proving Ground in Aberdeen, MD. Met with Army HPC professionals to describe the value of real time decision support modelling produced with ADCIRC and used by the US Army Corps of Engineers and US Coast Guard, among others. During the same trip, also visited the NOAA Coast Survey and Development Laboratory (CSDL). Funding leverage from the New Orleans District of the US Army Corps of Engineers ($3000) and travel support from Seahorse Coastal Consulting internal funds.

Ignacio Harrouch
Chief, Operations

Figure 10: 11-15 June 2017: Meeting with Ignacio Harrouch, Director of Operations at Louisiana Coastal Protection and Restoration Authority (CPRA) as well as Malene Henville and Heath Jones from the New Orleans District of US Army Corps of Engineers. Co-presented with DHS CRC PIs Scott Hagen and Matt Bilskie. **Funding leverage** for travel and attendance support from Louisiana Sea Grant ($1500) and US Army Corps of Engineers ($1500). This trip led directly and successfully to follow-on cooperative contracts ($45000 for Jason Fleming at Scimaritan, L3C and $75000 for LSU to include fellow CRC PIs Carola Kaiser, Matt Bilskie, Scott Hagen and Robert Twilley) for real time ADCIRC model guidance for Louisiana CPRA. Travel support for Jason Fleming to this meeting provided by Seahorse Coastal Consulting internal funds.

Figure 11: 21 June 2017: Invited to provide feedback to National Weather Service Stakeholder Engagement forum in Greenville to discuss NWS Water Resources Products and Services. The meeting was heavily attended by Emergency Managers and city planners. Met with Tom Langan once again and also made new end user contacts including Lora Eddy of The Nature Conservancy. The event was organized by Rich Bandy, the coordinator for storm surge activities for the entire National Weather Service. Again discussed ADCIRC model guidance with Tom Langan and received a positive response. Travel support from Seahorse Coastal Consulting internal funds.

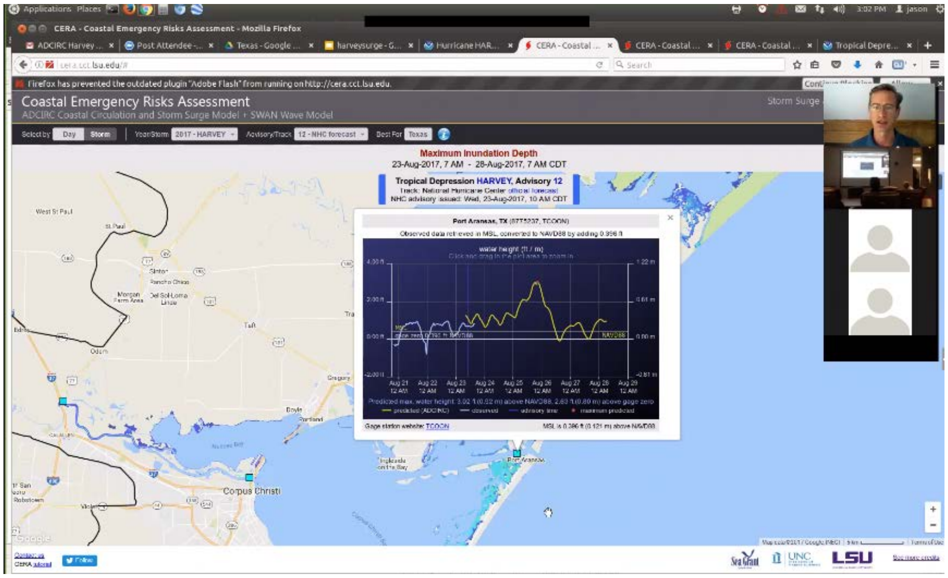


Figure 12: 7 November 2017: Zoom call with NWS Warning Coordination Meteorologists in Houston and Corpus Christi including John Metz, MIC Tom Johnstone, and Dan Reilly to review ADCIRC wind and storm surge performance during Harvey. They described their success in validating the guidance after the storm with measured data and their interests in future capabilities. This review was jointly presented with other DHS CRC PIs including Carola Kaiser (CERA) and Clint Dawson (Multi Resolution modelling).

Figure 13: 13-14 November 2017: Presented ADCIRC for Coastal Zone Decision Support to the North Carolina Beach Inlet and Waterway Association (NCBIWA) in Wrightsville Beach, NC. The event was attended by North Carolina Flood Plain Managers, Federal officials from BOEM, NOAA, and USACE; private sector contractors, and city and regional planners. Funding leverage for preparation time from NSF STORM project ($3000) and travel and registration support from Seahorse Coastal Consulting internal funds.

Figure 14: 8 January 2018: Site visit to Corpus Christi National Weather Forecast Office as follow-up to ADCIRC Harvey webinar held the previous November. We discussed topics and gathered feedback regarding ADCIRC, CERA, ASGS, the storm surge decision making process, and how ADCIRC model guidance fits into the overall operating picture for major weather events.

Figure 15: 8 January 2018 Site visit to Harte Research Institute (HRI) at Texas A&M Corpus Christi to meet with modelling and GIS researchers to discuss real time ADCIRC model guidance. Mukesh Subedee, Geospatial Scientist at HRI, subsequently registered as a professional attendee ($1000) at the 2018 ADCIRC Boot Camp. Travel support from Seahorse Coastal Consulting internal funds.

Figure 16: 9 January 2018 Site visit to Coast Guard Sector Houston-Galveston in Houston, Texas to meet with Capt. Patrick Cuty and Master Chief Eric Pugh to discuss the value of ADCIRC model guidance to the Coast Guard in general and Sector Houston-Galveston in particular. I developed this meeting from a cold call using contact information provided by Gordon Wells of the UT Center for Space Research. The discussion was very fruitful because we were able to determine that the value of ADCIRC guidance to the US Coast Guard is exclusively focused on consequences for search-and- rescue as well as oil and chemical spills. Most importantly, Capt. Cuty (far right) strongly encouraged us to apply for a Port Security Grant ($100M total annual budget across all Sectors) to develop a geo- database of vulnerable assets and even offered his personal assistance and guidance in the application process. Travel support from Seahorse Coastal Consulting internal funds.

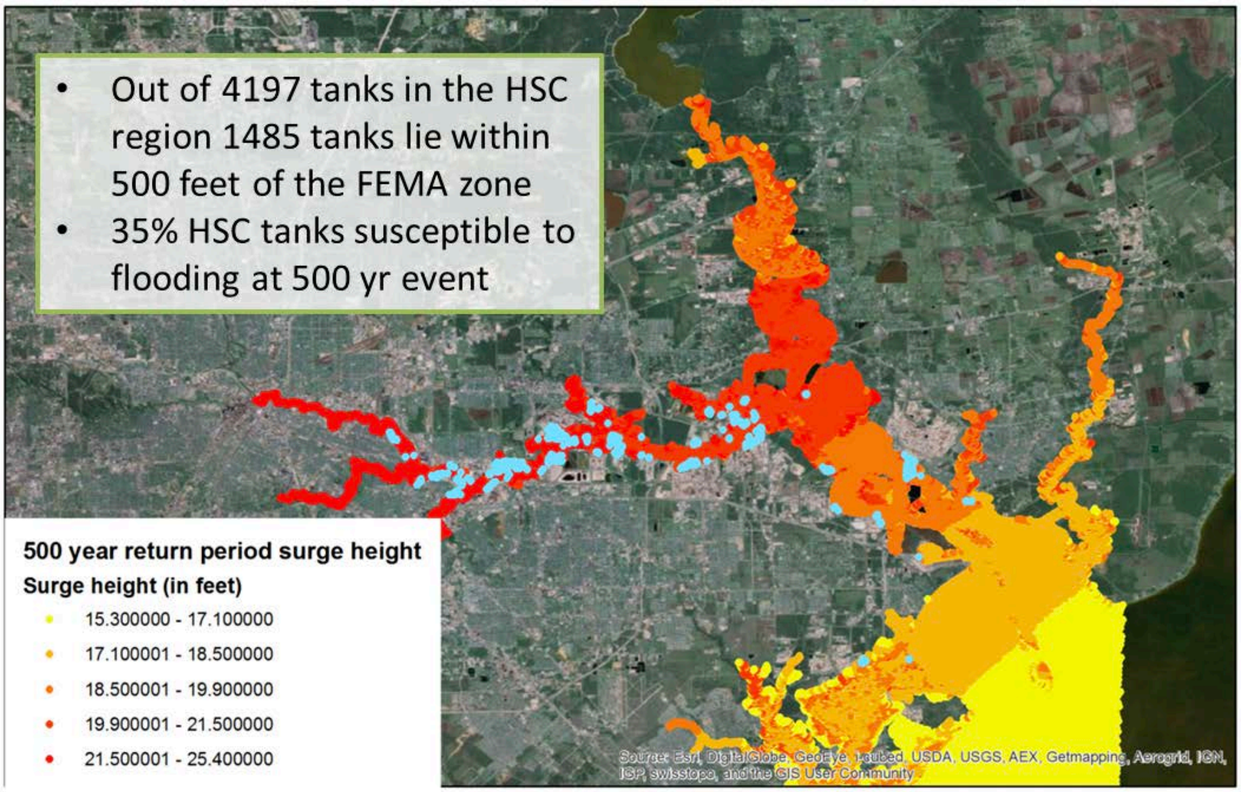


Figure 17: 9 January 2018: Meeting with Jamie Padgett and her research group at Rice University to discuss the geodatabase and consequence models her research group has developed for above ground storage tanks and other vulnerable coastal civil infrastructure in the Houston Ship Channel. These facilities are of interest to the US Coast Guard at Sector Houston-Galveston as well as other Sectors. Travel support from Seahorse Coastal Consulting internal funds.

HuRRI

Hurricane Resilience Research Institute

Figure 18: 9 January 2018: Meeting with Hanadi Rifai and her research group at University of Houston to discuss joint projects related to advanced oil and chemical spill modelling to support the Coast Guard. Travel support from Seahorse Coastal Consulting internal funds.

AMS

American Meteorological Society

98th Annual Meeting | AUSTIN | 2018

Figure 19: 10 January 2018: Presentation at joint coastal session at the American Meteorological Society (AMS) Conference in Austin. **Funding leverage:** $3000 via NSF STORM project.

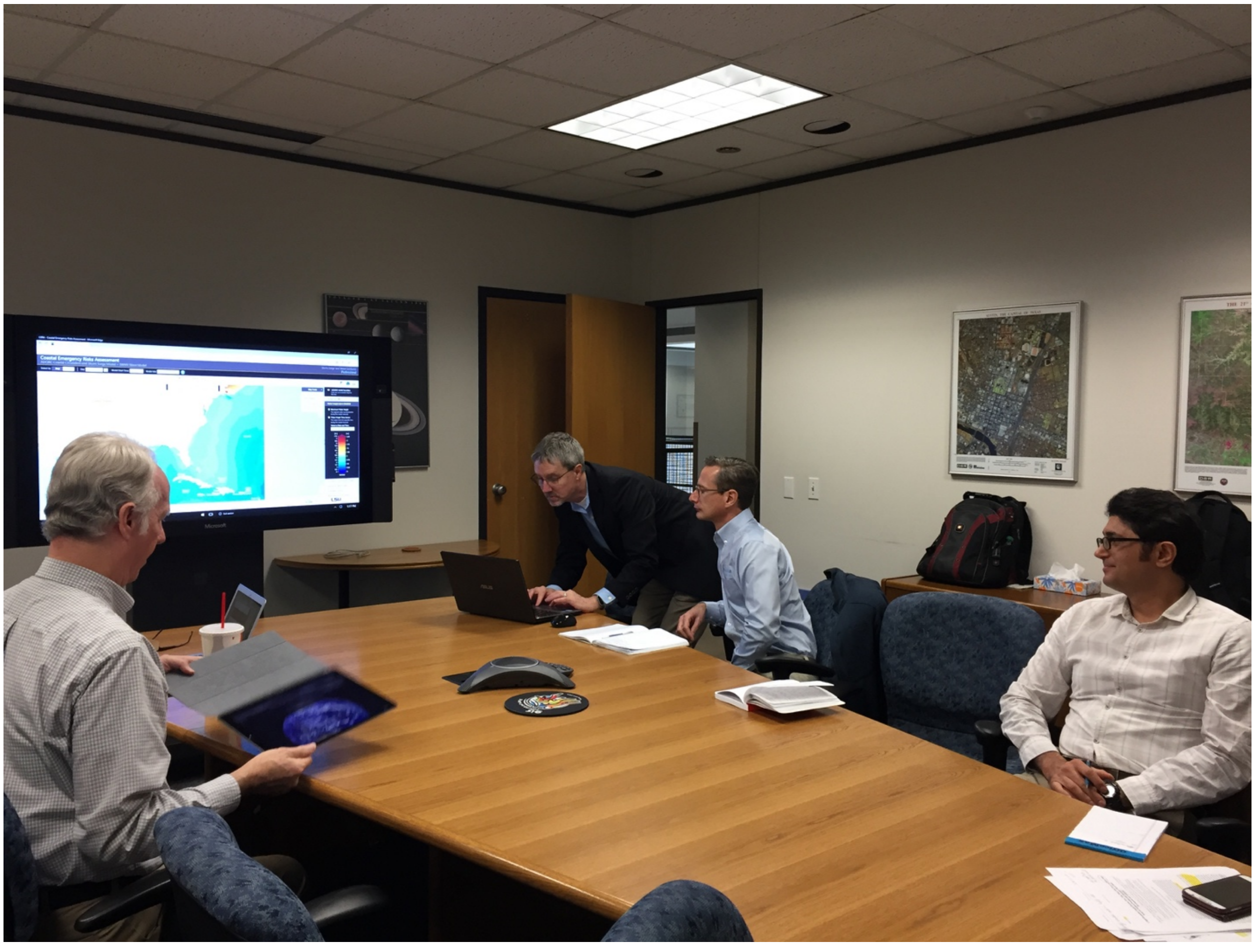


Figure 20: 10 January 2018: Briefing for the Texas General Land Office (GLO) in cooperation with DHS CRC PIs Clint Dawson and Carola Kaiser. The GLO is tasked with disbursing $5B of Harvey recovery money via Community Development Block Grants (CDBG). Travel support provided by Seahorse Coastal Consulting internal funds.

Figure 21: 7 February 2018: Travelled to the UNC Coastal Studies Institute near Manteo, NC meet Robert Netsch, Systems Engineer, US Coast Guard Search-And-Rescue (SAROPS). Our daily real time ADCIRC results are the only source of data available for USCG SAROPS in Albemarle-Pamlico Sound and have been used operationally by the USCG since late 2015. This meeting was critical to establish mutual expectations, determine additional public and private sector opportunities (e.g., through USCG contractor RPS Group), and secure a commitment from Robert to appear on the ADCIRC for Decision Makers panel at the ADCIRC Boot Camp in College Park in May to discuss USCG priorities in the ADCIRC context. Travel support provided by Seahorse Coastal Consulting internal funds.

Figure 22: 8-13 April 2018: 2018 ADCIRC Week, held at the NOAA Center for Weather and Climate Prediction Center in College Park, MD. Registered participants from DHS agencies include Rafael Canizares (FEMA), Tucker Mahoney (FEMA), Eleanore Hajian (DHS HQ), Jeff Gangai (Dewberry, a main FEMA contractor), and Robert Netsch (US Coast Guard). **Funding leverage:** $32460 direct revenue from participants; $15000 in-kind support (est) from host agency (NOAA) for the venue as well as organizational, logistical, parking, and security support; plus $30000 (est) in-kind support for travel, lodging, and co-teaching services from Alan Zundel, Brian Blanton, Clint Dawson, Jennifer Proft, Kendra Dresback, Robert Weaver, Peyman Taeb, Carola Kaiser, Chris Massey, Michelle Terry, Ashley Kauppila, Taylor Asher, and Nathan Dill. The NSF Science Gateways Community Institute sponsored usability testing for the CERA site for CRC PI Carola Kaiser and provided travel support for Stephanie Knab to help conduct the testing. In addition, 10 distinguished Panelists (including 5 fellow DHS CRC PIs) traveled and provided content for Decision Makers Day at their own expense including Robert Weaver (FIT), Rick Luettich (UNC-CH), Isaac Ginis (URI), Celso Ferreira (GMU), Andre van der Westhuysen (NOAA EMC), Sergey Vinogradov (NOAA CSDL), Matt Bilskie (LSU), Brant Mitchell (LSU SDMI), Derek Giardino (NWS WGRFC), and Clint Dawson (UT). The range of panelists served to integrate several CRC PIs and to connect model guidance producers with Decision Makers. Finally, the 2018 ADCIRC Week events enjoyed strong participation by NOAA personnel; this participation provided an opportunity for ADCIRC advocacy and funding leverage from this agency. For example, Ed Myers of NOAA NOS called an impromptu meeting of ADCIRC specialists to discuss their COMT solicitation for inland flooding, giving CRC PIs Blanton, Dawson, and Luettich a key opportunity to make their case for their NOAA COMT proposal. DHS CRC PI Blanton has subsequently received notification that his NOAA COMT proposal has been funded.

Figure 23: 16-18 April 2018: Storm Processes and Impacts Workshop in St. Petersburg, FL. From the conference agenda: "This workshop aims to bring together academics, government, and coastal and emergency managers from all geographic areas to synthesize our present capabilities for understanding, representing, and simulating storm processes and storm response that extends from offshore to the coastline and determine/prioritize where advancements are needed. An objective is to hear about challenges and needs from emergency managers and practitioners to identify the most pressing research requirements." I presented our work on real time ADCIRC model guidance production at this end-user oriented workshop, including its application and value in both impact prediction and post storm damage assessment. The event was sponsored by USACE, USGS, NOAA, and the American Shore and Beach Preservation Association (ASBPA).

Figure 24: 30 April 2018: Travelled to FEMA in DC to meet with Cristina Lindemer, Rafael Canizares, and Gene Longenecker (via telecon) to discuss the use of ADCIRC guidance during the 2017 hurricane season and ways to make direct connections between technical ADCIRC experts and FEMA stakeholders in future events. Travel support via internal funds at Seahorse Coastal Consulting.

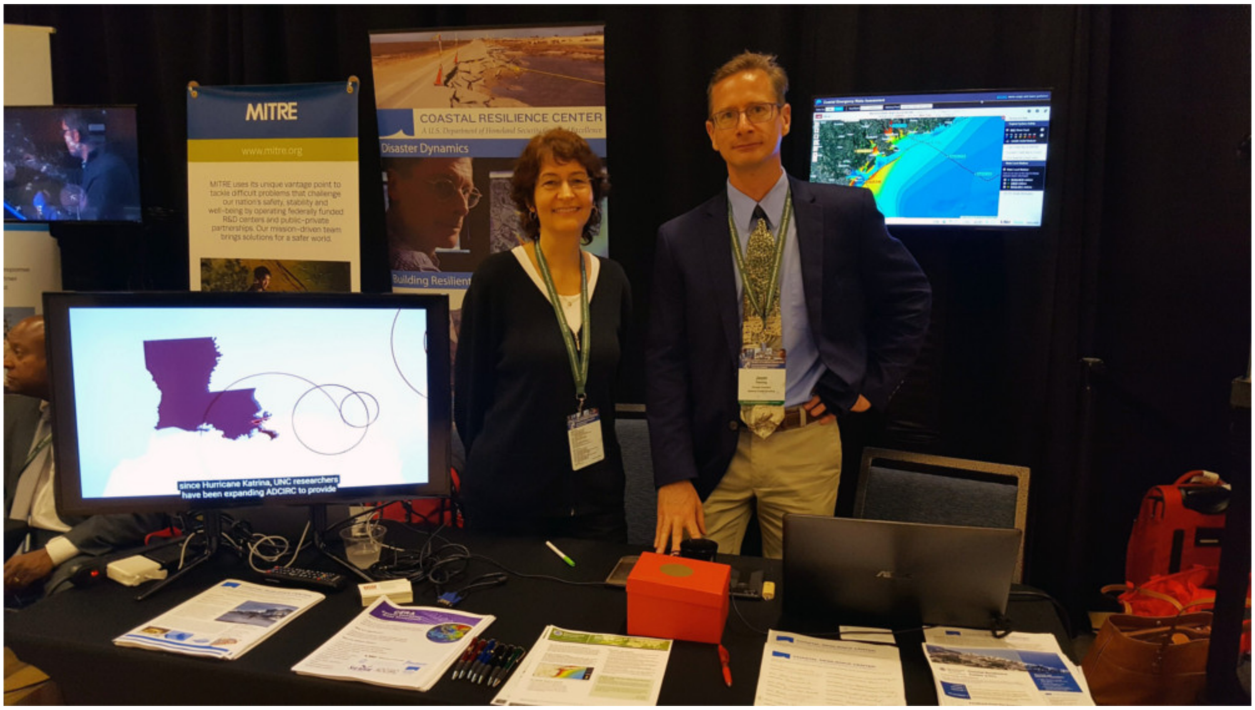


Figure 25: 29-31 May 2018: Presented ADCIRC, ASGS, and CERA to high level decision makers at DHS and other Federal Agencies at the DHS OUP Showcase in Arlington, VA. Travel support provided by Seahorse Coastal Consulting internal funds.

Figure 26: 11 June 2018: Met with forensic engineers John Miller and Chris Scallion from Donan, LLC at the National Flood Conference in Washington, D.C. to discuss private sector applications for ADCIRC model guidance in the insurance industry. Travel support from Seahorse Coastal Consulting internal funds.

Figure 27: 12 June 2018: Delivered invited plenary Keynote presentation on real time ADCIRC modelling for decision support with a focus on Chesapeake Bay at the Chesapeake Community Research and Modeling Symposium in Annapolis, MD. Travel support from Seahorse Coastal Consulting Internal Funds.

Figure 28: 29 June 2018: Visited Dave Michalson and Scott Brown at the Seattle District of the US Army Corps of Engineers to discuss their decision support needs and gaps and our ADCIRC model guidance capabilities. I developed this meeting from a cold call of District personnel some months prior, and leveraged NSF funds ($3000) for time support and Seahorse Coastal Consulting internal funds for travel and registration for the Estuarine and Coastal Modelling (ECM15) conference in Seattle to make this professional visit.

DHS Coastal Resilience Center

Annual Project Performance Report

Covers reporting period July 1, 2017 – June 30, 2018

Appendix

PI: Isaac Ginis, URI
Co-PI: Wenrui Huang, FSU
Project Title: Modeling the combined coastal and inland hazards from high-impact hypothetical hurricanes

In this Appendix we provide some details of the project main accomplishments during this time period.

1. Computational Developments in the Hurricane Boundary Layer Model

Over the last year, significant technical advancements have been made in the development of the hurricane boundary layer (HBL) models. The improvements to the models software infrastructure have enabled a transition from 4 km to 1 km resolution experiments to be performed within realistic real time wallclock time constraints. These advancements are necessary to transition the HBL models from the research mode to a robust real time forecasting system. All software development was performed on the RENCI systems at the University of North Carolina.

The HBL system consists of two components; the first is a parametric model that produces the necessary inputs to drive the forecast model. Due to the commonalities of the data-flow between the models, this has enabled them to share a common software infrastructure. This significantly simplifies support and development of the software for both models. The shared library software supports an I/O scheme, rather than the previous unformatted scheme, data is now written in the Network Common Data Format (NetCDF) which is used in most large-scale scientific applications. This NetCDF format also enables the use of standard powerful post-processing tools to analyze and visualize the data. The model software infrastructure has been standardized so they have common build, execute, and post-processing scripts. The infrastructure is completely modular and includes user documentation.

In addition to the use of a common software infrastructure, a significant number of changes have been made to the parametric model. Each analysis phase (wind-field, topography, and surface roughness) in the parametric model now supports its own grid domain that is then interpolated on to a common grid used in the forecast model. The development enables data from different sources to be used in the model. The model now supports the ETOPO1 (1 arc-minute) and ETOP012 (2 arc-minute) global land topography (Amante and Eakins, 2009). The difference between the two topography resolutions can be visualized in Figure 1.1 and the resulting difference between resolution in model wind structure is shown in Figure 1.2. The model storm input files have been generalized to simplify the storm specifications and allows a significant ease of specification for the different hurricane events. Depending on the data available for the parametric model, different methods are applied to generate the wind profile. The Holland method is used in the absence of four quadrant wind information and was updated to include additional assumptions about the Coriolis effect inside the storm eyewall (Holland, 1980).

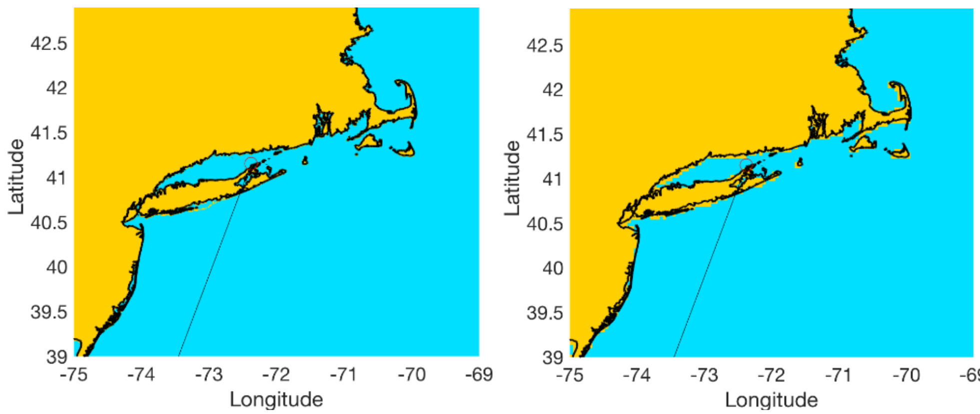


Figure 1.1. Land mask file overlaid with the actual cost line. Left: 1km Southern New England; Right 4km Southern New England. Track of a hypothetical Hurricane Rhody is shown as well.

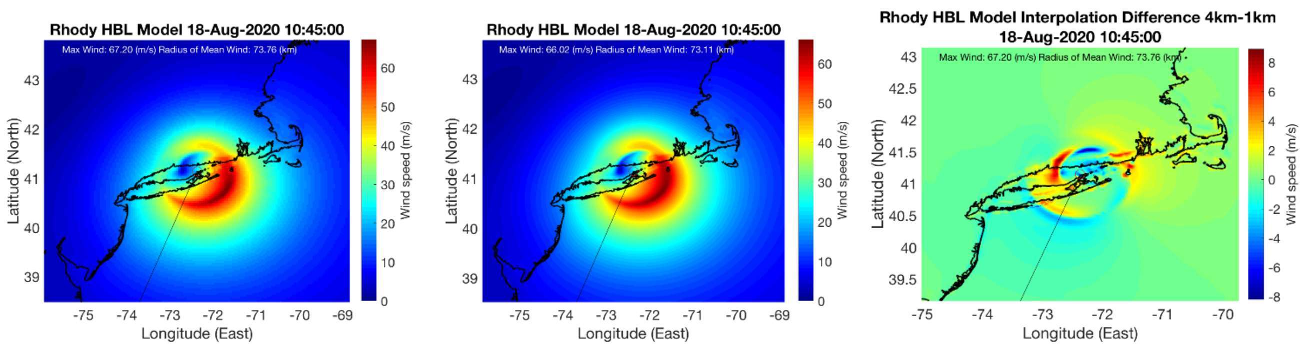


Figure 1.2. HBL model surface wind simulations of Hurricane Rhody during land fall over Connecticut. Left: 4km resolution; middle 1km resolution; right: the difference.

There were also major changes made to the forecast model as well. The initial work focused on improving the single-core performance of the forecast model. The model is memory bound and reducing the memory traffic has a significant impact on performance. With several key optimizations, more than a factor of two in single-core performance was achieved. The next significant improvement was to implement a Message Passing Interface (MPI) implementation into the model. Here the global domain is divided into sub-domains and each MPI-Rank computes its assigned sub-domain. The strong-scaling results, where the domain size remains constant and the numbers of MPI-Ranks are increased, showed excellent performance with the ability to scale up to 1024 MPI-Ranks. In the I/O, each MPI-Rank reads and writes its portion of the sub-domain which guarantees memory scaling in the model. In the post-processing phase a utility script combines the individual sub-domains into the global domain which is then used for post-processing analysis. These computational features are all necessary requirements to enable the forecast model to perform tropical cyclone experiments at high-resolutions (500m) and meet realistic real time wallclock time constraints necessary for an operational studies.

While large advancements have been made towards creating a robust real time forecasting system, work still needs to be done in expanding the hurricanes over different regions of North America, improving current model features, and incorporating more accurate assumptions such as spatial variations in surface-roughness. Progress has been made generalizing the model so it can be applied in all regions of the United States. Currently test have been run with Hurricane Irma (2017) which made land fall on the continental United States over the tip of Southern Florida. Surface wind from these tests can be seen in Figure 1.3. The future plan is to obtain track information for additional storms in other regions and then develop a diagnostic code infrastructure. The development of a diagnostics infrastructure is critical to this work to make comparisons of storms and validating experiments.

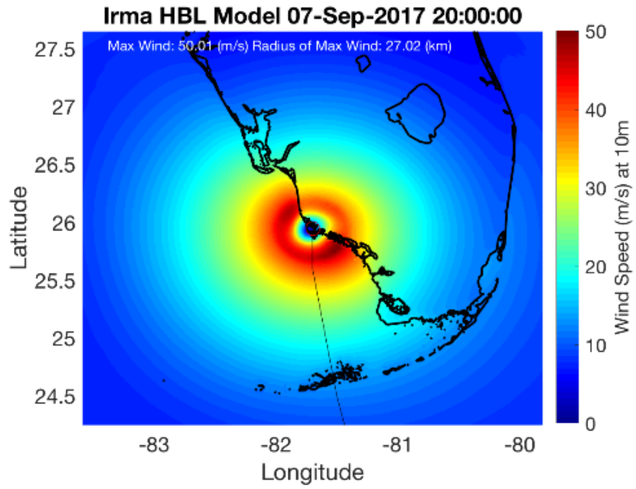


Figure 1.3. HBL surface wind simulations of Hurricane Irma (2017) during landfall over Southern Florida.

Work is currently underway to improve the feature in the parametric model that generates wind at the top of the boundary layer in the case of historical storms. This consists of creating an algorithm for scaling the parametric winds at ten meters to the top of the boundary layer. Simulations are being performed using ideal and historical storms to perform this study.

Currently the general assumption is made that land surface-roughness has a constant value to compute the drag coefficient over land. Figure 1.4 shows the impact of a constant surface roughness value on wind as the storm makes land fall. To the left in Figure 1.4 shows the structure with land present, and the middle where the land was removed. The difference of these two figures, on the right, shows the presence of the land has a significant impact on the storm winds, in particular the acceleration of winds on the western side of the storm on and off-shore due to the winds from the east being deflected by the presence of land. The next development is to use observational land cover variations to improve the constant value assumption and investigate impact of a spatial-variation in the surface-roughness on the wind structure at landfall. A high-resolution surface-roughness dataset over North America is being created to integrate into the model at 1km resolution.

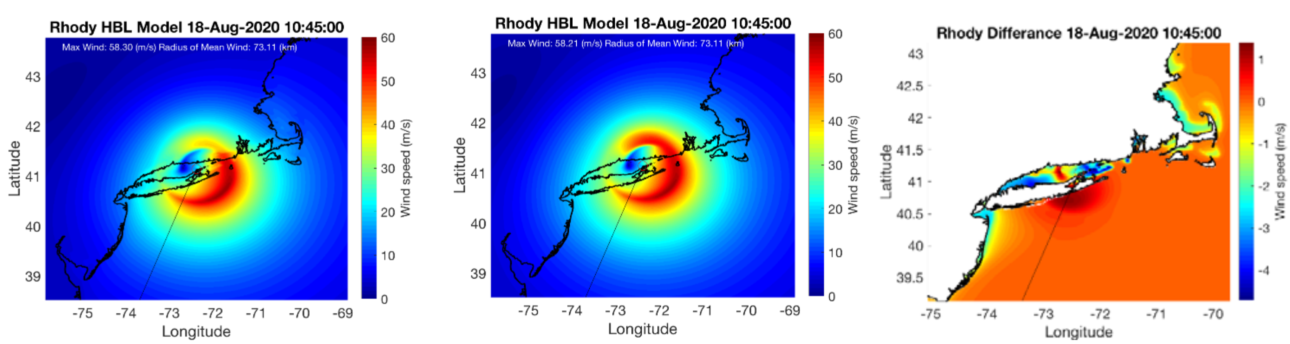


Figure 1.4. HBL model surface wind simulations of Hurricane Rhody during landfall in New England. Left: Land present; middle: idealized no land present; Right: the difference over water.

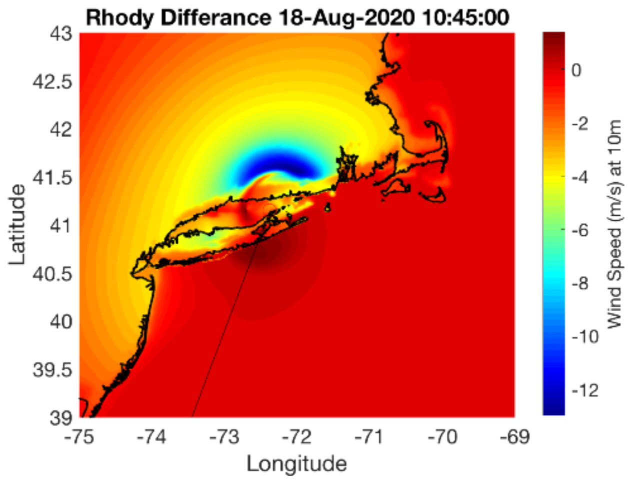


Figure 1.5. Same as right image in Fig. 1.4, but with the difference over land included.

2. ADCIRC Storm Surge Simulations

During the reported time period, we performed additional simulations of storm surge during hurricane Carol (1954) and the synthetic hurricane Rhody. The winds for these simulations were derived from the revised version of the hurricane boundary layer (HBL) model. These results were incorporated into a paper focused on examination of the impacts of an extreme hurricane on the Narragansett Bay region. This work will be submitted to the journal Natural Hazards.

2.1 Hurricane Carol

The simulation of storm surge in response to hurricane Carol winds derived from the revised HBL was not significantly different from the prior simulation. The modeled peak surge heights at Providence and Newport agree well with the available observations at those locations. However, the duration of the modeled storm surge is much shorter than was observed (Figure 2.1).

We tested the hypothesis that short surge duration is caused by overly strong frictional damping of the "forerunner" surge (e.g. Kennedy et al., 2011), which occurs due to geostrophic setup in response to strong storm driven shelf currents. The frictional formulation used in the ADCIRC storm surge simulations was the Manning form in which the quadratic bottom drag coefficient is given by:

$$C_f = \frac{gn^2}{\sqrt[3]{(H+\eta)}} \qquad (1)$$

where g is the gravitational acceleration, n is Manning's roughness, H is the undisturbed water depth, and η is the water surface elevation. A constant Manning's roughness of 0.03 was specified and, to avoid extremely low drag coefficient values in deep water that (1) produces, a minimum C_f value of 3×10^{-3} was specified. A simulation was performed with the minimum C_f set to 1×10^{-3}, which reduces the bottom drag coefficient on the continental shelf (and at deeper depths as well), but no significant difference in the modeled storm surge duration was found. This indicates that the poor model simulation of the duration of the hurricane Carol surge was not due to overly strong friction damping the forerunner surge.

After ruling out the bottom friction formulation as the cause of the poor modeled storm surge duration, it seems likely that the wind forcing is the culprit. Most likely the modeled hurricane winds are too localized in space and do not extend far enough from the storm center. Further experiments with a larger-sized hurricane Carol are planned in the future to test this hypothesis.

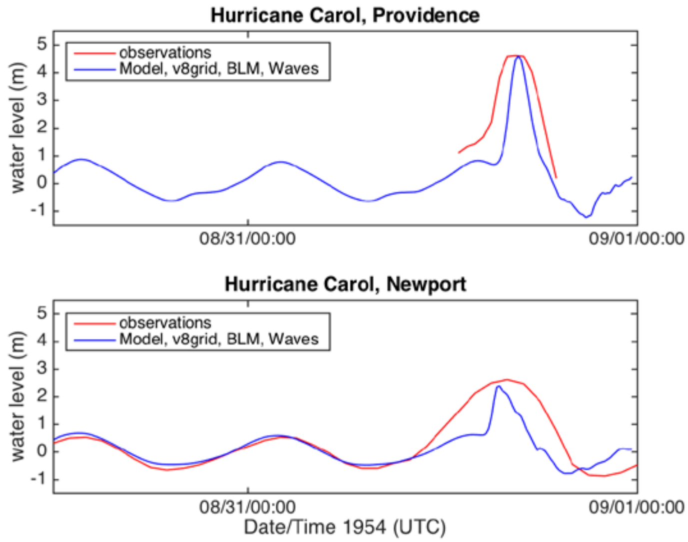


Figure 2.1. Time series comparison of model and observed water levels during Hurricane Carol at Providence (top) and Newport (bottom).

2.2 Hurricane Rhody

During the past year, we performed a number of storm surge simulations with forcing from the revised HBL model for the synthetic storm, hurricane Rhody. The aim of these model runs was to determine the robustness of Providence's Fox Point Hurricane Barrier (FPHB) by simulating storm surge under increasing hurricane intensity. Hurricane Rhody makes landfall to the west of Narragansett Bay and its timing is such that the wind-driven storm surge occurs during a spring high tide at Providence. Both of these characteristics cause maximal storm surge response in Narragansett Bay.

The base hurricane Rhody case is a strong category-3 storm, with maximum wind speed at landfall of approximately 57 m/s (111 knots). This is slightly stronger than the estimated strength of the 1938 hurricane and hurricane Carol, the strongest storms striking southern New England over the past century. Because of the presence of the so-called Cold Pool, a near-bottom layer of cold water on the continental shelf south of New England during summer, hurricanes approaching New England from the south tend to weaken as they cross the shelf due to cooling of the ocean surface arising from vertical mixing of the Cold Pool. This suggests that, with the Cold Pool present, hurricanes stronger than the base Rhody case (category 3) are unlikely. However, if the Cold Pool were to weaken or disappear in the future as global temperatures rise, this protection would be reduced.

In addition to the category-3 Rhody, two stronger versions of Rhody were created, a category-4 version (maximum wind speed at landfall of 66 m/s) and a category-5 version (maximum wind speed at landfall of 74 m/s), in order to test the ability of the FPHB to protect downtown Providence. The maximum storm surge elevation at Providence increases nearly linearly with maximum wind speed (Figure 2.2). These results indicate that the Hurricane Barrier will protect downtown Providence from flooding for storms of category-4 and below, but that category-5 hurricanes could cause overtopping of the Barrier with resultant flooding. As these results are based on simulations using present sea level, actual hurricanes in the future in combination with rising sea level will likely be more damaging than we have shown. Nonetheless, these simulations suggest that the FPHB should be sufficient to protect Providence during the coming decades against all but the most extreme hurricanes.

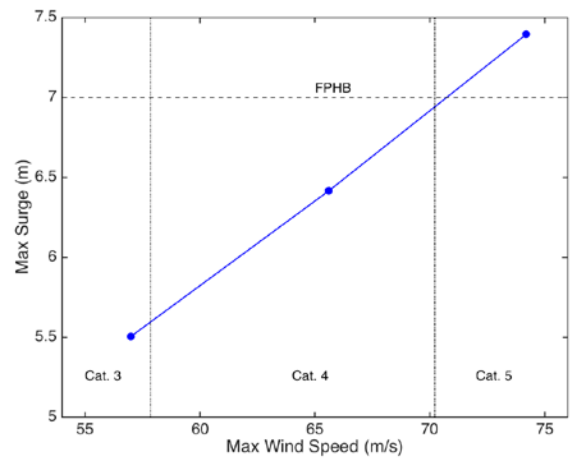


Figure 2.2. Maximum storm surge elevation at Providence (relative to MSL) versus maximum wind speed at hurricane landfall from simulations with varying strength Rhody forcing. The approximate elevation of the Fox Point Hurricane Barrier (FPHB) is shown by the horizontal dashed line. The vertical dotted lines denote the boundaries between Saffir-Simpson hurricane wind scale categories 3-5.

2.3 Running ADCIRC on Microsoft Cloud Computing Platform, Azure

With our ADCIRC mesh featuring high spatial resolution in southern New England and the improved HBL model to simulate hurricane winds, we envision building a real-time hurricane storm surge forecast system. A key factor in ensuring timely delivery of storm surge forecasts is the robustness of the computing platforms on which the models run. At present, we are dependent on the University of North Carolina's computer cluster for this purpose. A more robust approach, in which the computing is not tied to a system in a fixed location, would be to utilize cloud-based computing resources. With a grant from Microsoft, we investigated the use of Microsoft's Azure cloud computing services for running ADCIRC in an automated manner.

The use of Azure for ADCIRC simulations proved to be not simple in practice. Efficient ADCIRC model runs utilize multiple computer processors, which communicate using a Message Passing Interface (MPI). Although we were able to create a pool of virtual machines in Azure, each with the appropriate software (NetCDF, HDF5, ADCIRC), running an MPI job on the pool turned out to be very difficult. It is hard to say whether this was due to our lack of experience with the platform or whether the platform was to blame (note that we received assistance on use of Azure from Microsoft experts). Ultimately we decided against further use of Azure for our storm surge modeling.

3. The impact of tropical cyclones on shelf-estuary exchange: A Narragansett Bay data-model case study.

3.1 Introduction

In last year's annual report, we presented results from the Regional Ocean Modeling System (ROMS) model which focused on the effects of 2D vs. 3D on storm surge predictions. For all four of the storms tested – Carol (1954), Bob (1991), Floyd (1999), and hypothetical superstorm Rhody – the 3D ROMS configurations calculated greater surge than the 2D configurations. We concluded that the 2D model under-predicts surge height due to unrealistically high bottom drag.

Over the past year of work on this DHS project we have explored longer term impacts of how tropical cyclones impact estuarine systems. This chapter will present progress towards understanding the effects of hurricanes on the residual transport in Narragansett Bay. We focused on tracking water masses of ecological and economic significance – particularly offshore nutrient sources and industrial chemical spills.

Our approach to predicting realistic storm-induced transports does not place any additional demands on the operational storm surge models. We use a 2D ADCIRC storm surge model to force the boundaries of a regional 3D ROMS model and show that this ROMS model produces realistic velocities when compared to observations. Data-model comparisons confirm that the current operational models storm surge models do not produce realistic transports and that a 3D baroclinic model is necessary.

This work has focused primarily on water mass exchange at the mouth of the Narragansett Bay estuary in response to Hurricane Floyd (1999) and to hypothetical storm parameters. One reason for focusing on Hurricane Floyd is that an acoustic Doppler current profiler (ADCP) was in the water during this impact and captured a first-of-its-kind view of the ocean response to a tropical cyclone in this region. Current meter records showed a strong surface to bottom outflow pulse just after the storm hit followed by enhanced deep advection into the bay over the following 2-7 days. Most striking was a sharp cooling of bottom water during this inflow, indicating a sustained, high volume shelf water intrusion. Offshore nutrient sources represent the most poorly constrained component of the Bay's total nutrient budget. Understanding full biological and chemical budgets for estuaries, including inputs not simply from the watershed but from the ocean, is essential for proper management of these natural resources.

The effects of tropical cyclones on coastal ecosystems have been reported in numerous estuaries. In Chesapeake Bay, Hurricane Isabel (2003) enhanced plankton and fish abundance immediately following the storm but, on a longer timescale, is thought to be responsible for early onset hypoxia the following spring (Roman et al., 2005). Li et al. (2006) simulated the event using a hydrodynamic model and calculated a large intrusion of shelf water occupying about one-fifth of the bay's total volume. In developing models capable of predicting full impact of tropical cyclones on our nations coastal systems, it is essential to cover the range of temporal scales, from short flooding through to storm-induced degradation of the ecosystem.

The Regional Ocean Modeling System (ROMS) is used to develop a three-dimensional hydrodynamic model of the region which shows good agreement with both the tidal and residual components of the currents at the ADCP. We show that the post-storm intrusion is a baroclinic (density-driven) process which is not represented in the barotropic model. To isolate the storm's contribution to the intrusion, we ran the model both with and without the storm. Over the 2.5 days following the storm, a simulated deep intrusion of 5.9×10^8 m^3 is calculated through the deep East Passage. This intrusion is nearly three times larger than the no-storm intrusion of 2.0×10^8 m^3 and over 35 times the volume of all river inputs for the same period. Numerical experiments using a passive tracer show that the storm transports shelf water to the upper regions of the bay up to 5 times more effectively than the no-storm case. Considering the elevated levels of nutrients in the shelf water and the vertical mixing associated with the storm, we suggest that these event-driven intrusions could be an important component of the bay's total nutrient budget.

3.2 Observations

Hurricane Floyd hit the northeast coast in September 1999. Floyd peaked as a strong Category 4 but had weakened substantially by the time it reached Narragansett Bay. Peak winds at T.F. Green Airport in Warwick, RI were 13.4 m/s on September 17, 1999 3:11 UTC and peak storm surge at the Providence, RI NOAA tide gauge was 1.09 meters above the predicted astronomical tide. The NOAA Center for Operational Oceanographic Products and Services was operating two stations in Narragansett Bay in 1999: Newport (station 8452660, 41°30.2' N, 71°19.6'W) and Providence (station 8454000, 41°48.4' N, 71°24.0'W). Both recorded water level and water temperature for the entire year, plus salinity data beginning on August 19 (Newport) and August 24 (Providence). The wind record at these stations begins in October, after the passing of Floyd.

An upward-looking acoustic Doppler current profiler (ADCP) was moored near the mouth of the bay during Floyd, making it an ideal case study for this analysis. The ADCP measured water velocities throughout the water column and is the only known record of currents in Narragansett Bay during a tropical cyclone. Velocity data were collected by a single ADCP located towards the western side of the East Passage (41°30.33'N, 71°21.08'W). At 40 m depth, this is approximately the deepest part of the channel. This ADCP station has been previously described by Kincaid et al., 2008; Pfeiffer-Herbert et al., 2015; Rosenberger, 2001). The upward-looking, 300 kHz, 4-beam self-recording RD Instruments ADCP collected water velocity data at 2.0 m vertical bins. Bins within 5 m of the surface were ignored due to poor data quality. Data were obtained every six minutes by averaging a 10 s, 10-burst ensemble. Additionally, a thermistor attached to the ADCP housing measured near-bottom water temperature at the same 6-min interval. A thermistor on the ADCP recorded a 4°C drop in bottom water temperature over the 2.5 days following the storm. Enhanced wind-driven vertical mixing due to the storm would be expected to increase the bottom temperature, not decrease it. ADCP velocity measurements confirm that this cold water signal was caused by a non-tidal deep intrusion of shelf water. We use numerical models to simulate this intrusion event and track shelf water throughout Narragansett Bay.

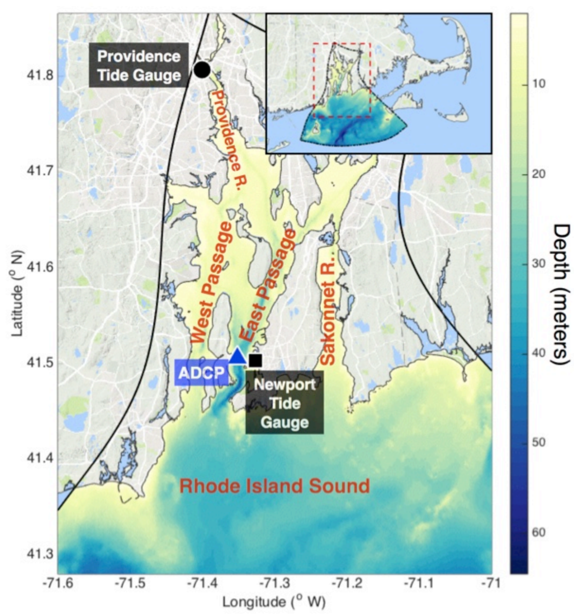


Figure 3.1. Map view of model domain and observational stations. Upper right inset panel shows the location of Rhode Island's Narragansett Bay, east of Long Island Sound and west of Buzzard's Bay and Cape Cod. The ROMS model domain is indicated by the region with bathymetry data; the model boundaries are outlined in black. The dashed red line shows the location of the main figure. In the main

figure, observational stations are indicated: Providence tide gauge (black circle), Newport tide gauge (back square), and East Passage ADCP (blue triangle).

3.3 Modeling

We recreate the post-Floyd intrusion of shelf water into the bay using the Regional Ocean Modeling System (ROMS) 3-D ocean model in order to investigate the role of storms on shelf-estuary exchange. Three main experiments are compared: (1) ROMS_realistic, the most accurate simulation of the ocean response to the storm, (2) ROMS_nostrat which has homogeneous density in order to remove the contribution of baroclinic effects, and (3) ROMS_nostorm, which is stratified like ROMS_realistic but the storm forcing has been replaced with normal background conditions.

First, the models are compared to the available sea surface height (SSH) and velocity data. These results confirm that the ROMS_realistic model is in good agreement with observations, though it over-estimates the net deep inflow at the ADCP location. The ROMS_nostrat model appears to agree with the data for SSH and instantaneous velocity but the model does not calculate any net inflow through the deep East Passage. We conclude that a baroclinic model is necessary when modeling shelf-estuary exchange, even with storm-enhanced vertical mixing. Next, deep inflows are compared for the two baroclinic models: ROMS_realistic and ROMS_nostorm. The ROMS_realistic transport resembles the trend at the ADCP with a post-storm period of at least 2.5 days of stronger-than-average inflow. During this time, nearly three times more deep water enters the bay in the ROMS_realistic model than in the ROMS_nostart case. Finally, a hypothetical dye is initialized in the deep shelf water of Rhode Island Sound in order to track high-nutrient water. As expected, the ROMS_nostrat model transports very little dye into the bay. The ROMS_realistic and ROMS_nostorm cases produce similar dye concentrations near the mouth of the bay but the storm case results in much more dye transported to the upper bay. These flux results are used to produce a rough estimate of offshore nitrogen inputs due to the storm. We estimate that offshore nitrogen input is of the same order as rivers and sewage sources.

The following section describes the 3 main models configurations used in the study: ROMS_realistic, ROMS_nostrat, and ROMS_nostorm. The reference case, ROMS_realistic, is described in detail and then the other two models are described by how their configurations differ from ROMS_realistic.

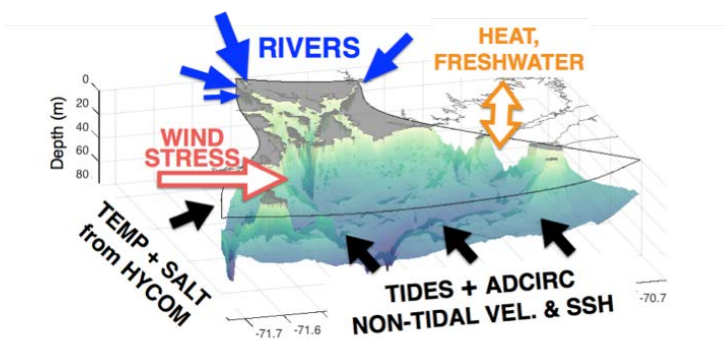


Figure 3.2. Schematic showing the entire ROMS domain and highlighting the multiple model inputs at the surface, the lateral open boundaries, and at river point sources.

ROMS_realistic: The ROMS model (Rutgers version 3.6) is a finite-difference, free-surface, primitive equations ocean model that makes use of the Arakawa staggered "C-grid" system (Arakawa and Lamb, 1977; Haidvogel et al., 2008; Shchepetkin and McWilliams, 2005). We used a 325x425 curvilinear grid with grid spacing varying from a minimum of 47.2 m in the Providence River to a maximum of 358.2

m in Rhode Island Sound. In the vertical, we used 14 terrain-following sigma layers with enhanced vertical resolution in the surface boundary layer.

Bathymetry from NOAA's U.S. Coastal Relief Model (National Geophysical Data Center, 1999) was interpolated to grid cells using bilinear interpolation. Bathymetry was then smoothed for numerical stability using the LP Bathymetry program (Sikiric et al., 2009) set to a minimum Beckmann and Haidvogel number (Beckmann and Haidvogel, 1993) of 0.2 as recommended by Shchepetkin & McWilliams (2003). This bathymetry smoothing method offered sufficient numerical stability without removing key features such as the dredged shipping channels.

In our model configuration, each cell is defined as either "land" or "water" – there is no wetting and drying of cells. This approach offered increased numerical stability and decreased computational cost. Wetting and drying is important for storm surge studies looking at coastal flooding but Floyd did not cause coastal flooding in Narragansett Bay and circulation is the focus of the present study. The grid has 80,852 water cells and 57,273 land cells. A minimum depth of 2 m was applied to all water cells to avoid drying in the intertidal regions.

To force the surface boundary, momentum flux (wind stress), salt flux, and short- and long-wave heat fluxes were applied. Additionally, atmospheric pressure was included in the momentum equations. Input data were obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA-Interim reanalysis at 1/8° spatial resolution with a 3 hour Δt (Dee et al., 2011). The coarser resolution of the atmospheric model didn't resolve the land-sea boundaries of Narragansett Bay and resulted in unrealistic surface fluxes in some areas. For this reason, spatially-uniform salt and heat fluxes were applied across the ROMS domain based on fluxes at the ERA-Interim grid node located at 41°N, 71°W in Rhode Island Sound. Wind stress and atmospheric pressure were allowed to vary spatially across the domain. Wind stress was not taken from ERA-Interim – instead we used the ERA-Interim 10 m windspeed vectors and calculated wind stress using the formulation presented by Large & Pond (1981) in order to match the wind stress used by the ADCIRC storm surge model.

At the lateral open boundaries, we forced tides using the TPXO8-atlas 1/30° global tide model (Egbert and Erofeeva, 2002) which makes use of satellite data from TOPEX/Poseidon and Jason. Elevations and transports for the M2, S2, N2, K2, K1, O1, P1, Q1, and M4 tidal constituents were included. Since the ROMS domain is too small to generate a realistic storm surge, we forced the lateral boundaries with non-tidal elevations and velocities from a basin-scale 2-D depth-integrated finite element model (Luettich et al., 1992). The ADCIRC model was an ideal choice for this since it is an operational storm surge model which means that our one-way nesting approach could be implemented for future storms in real-time. We removed the tidal signal from the ADCIRC output by running the model twice – once with tides-only and once with tides plus ERA-Interim winds – and then differencing the two solutions. Next, we interpolated the ADCIRC non-tidal output to the ROMS lateral boundaries. Barotropic velocities were applied using the Flather boundary condition (Flather, 1976) and free-surface perturbations were applied using the Chapman boundary condition (Chapman, 1985). Temperature and salinity at the lateral boundaries was obtained from the GOFS 3.0 HYCOM + NCODA Global 1/12° Analysis (available at hycom.org) and applied using a radiation boundary condition with nudging.

Freshwater point sources were included in the model to simulate river discharge from the major rivers emptying into Narragansett Bay: the Blackstone, Moshassuck, Woonasquatucket, Pawtuxet, Taunton, Ten Mile, and Hunt Rivers. River discharge data were obtained from the United States Geological Survey (USGS). For the simulated time period (1999), discharge data is available only for the Taunton, Woonasquatucket, and upper Blackstone Rivers. Using discharge data from more recent years, we trained a linear a regression model by stepwise regression to estimate discharge at the un-gauged rivers given discharge at the gauged rivers. River transport was assumed to be constant with depth in the model. Salinity was set constant at 0 and temperature was set to equal air temperature at the Newport NOAA station.

The temperature and salinity gradients in the model were initialized using a 6-month spin-up run. The spin-up was forced with tides, rivers, and reanalysis surface forcing for 1999 in order to establish realistic conditions.

ROMS_nostrat: Homogeneous-density models are the default tool for storm surge modeling. Most operational models are 2-D vertically-uniform and the few 3-D storm surge models are still barotropic (homogeneous density). While these models do a good job predicting the sea surface height, they are rarely validated by their ability to reproduce currents. By running a barotropic model side-by-side with the more-realistic baroclinic model, we are able describe how the models differ in their representation of the Lagrangian transport of the different water masses.

The ROMS_nostrat model presented in this study is forced by exactly the same wind stress, tides, and non-tidal boundary conditions as the ROMS_realistic model except that the density is constant everywhere in the model. Rivers are included in order to keep the total volume flux the same but these rivers are the same temperature and salinity as the rest of the model and thus provide no buoyancy flux.

ROMS_nostorm: Since this study is motivated by the question of how the storm affected the Narragansett Bay system, it is valuable to have a control case in order to make any quantitative comments about the effects of the storm. The ROMS_nostorm case is identical to ROMS_realistic up until September 16, 1999 – about one day before the storm's arrival. For surface forcing, the 3-day period of September 16-19 is replaced with the surface forcing of September 13-16. At the lateral boundaries, the ADCIRC non-tidal storm surge model is removed and only astronomical tides are included. The river forcing is altered using a similar technique to the surface forcing except over a longer period: September 10-30 was replaced with the river forcing of August 21 - September 10. A longer time range was used for the rivers than for surface forcing because the rivers showed a longer-lasting storm signal than the atmosphere. The storm passed by quickly but the effects across the watershed lasted longer than the atmospheric effects.

3.4 Results and Discussion

3.4.1 Sea surface height and instantaneous velocities

First, we compare the modeled sea surface height (SSH) to data at the two available tide gauge stations. A popular method for quantifying data-model agreement (Warner et al., 2005) is the metric presented by Willmott (1981), referred to here as the "Willmott Skill." The equation is shown in Equation 3.1 where, for any prognostic quantity, M represents the model's predicted value and O represents the observed value. The index ranges from 0 to 1, with 1 indicating perfect agreement between the observational data and the model.

$$\text{Skill} \equiv 1 - \frac{\sum_{i=1}^{N} (M_i - O_i)^2}{\sum_{i=1}^{N} \left(|M_i - \bar{O}| + |O_i - \bar{O}|\right)^2} \tag{3.1}$$

Comparing observed SSH with results from the numerical models, the ROMS_realistic model agreed well with observations in both locations for the timing and height of maximum water level, though the model does not capture the "double-peak" preceding maximum water level (Figure 3.3). Skill scores and maximum water heights for the three model configurations are seen in Table 3.1. The ROMS_realistic and ROMS_nostrat produced similar results, confirming that baroclinic processes had little effect on the SSH calculation. We think ROMS_realistic performed slightly better than ROMS_nostrat because unstratified models tend to have too much bottom drag which results in dampening the surge (Bode and Hardy, 1997).

Run	*SSH Skill Providence*	*Max SSH Providence (MSL)*	*SSH Skill Newport*	*Max SSH Newport (MSL)*	*Eastward Vel. Skill ADCP*	*Northward Vel. Skill ADCP*
Observed	-	1.05 m	-	0.82 m	-	-
ROMS_realistic	0.972	1.06 m	0.968	0.78 m	0.848	0.935
ROMS_nostrat	0.960	1.00 m	0.962	0.76 m	0.708	0.909
ROMS_nostorm	0.744	0.65 m	0.764	0.51 m	0.658	0.831

Table 3.1. SSH and velocity model-data agreement. The skill score refers to the "Willmott Skill" formulation presented in Equation 3.1. Skills and max water levels are calculated for a four-day period centered around September 18, 1999 (Figure 3.3).

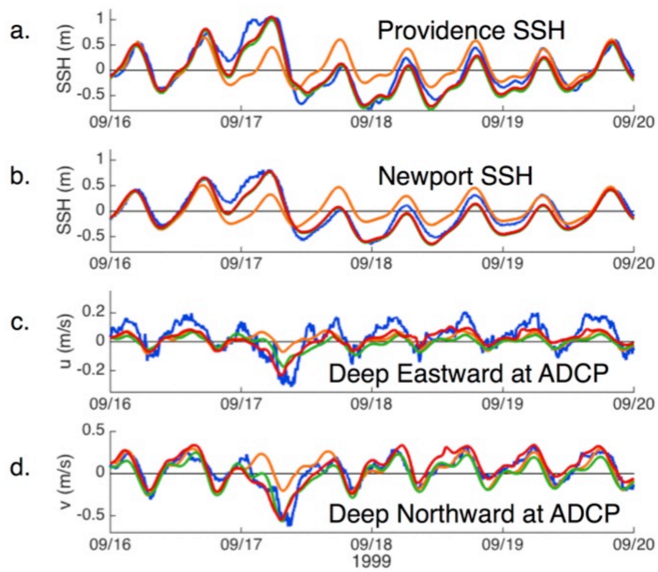


Figure 3.3. Instantaneous SSH and velocities. Observations (blue) and the three numerical models – ROMS_realistic (red), ROMS_nostrat (green), and ROMS_nostorm (orange) – are shown. Sea surface height at NOAA tide gauges in meters above mean sea level for Providence (**a**) at the head of Narragansett Bay and Newport (**b**) near the mouth of the bay. Deep eastward (**c**) and northward (**d**) velocities at the ADCP are depth-averaged over the bottom 25 m of the water column.

Next, we compare the models to the ADCP velocity data (Figure 3.3 and Table 3.1). For the velocity comparisons, we vertically integrated the flow through the bottom 25 m of the water column. We only considered the bottom 25 m of the water column for the two reasons. First, ADCP data quality is poor near the surface so a reliable full-water-column analysis is not possible. Second, the flow in this region is characterized as two-layer (see also Figure 3.4b for structure of modeled mean flow) and the present study is concerned with intrusions of dense shelf water through the deep layer.

The main takeaways from these results are that (1) our ROMS_realistic model is doing a good job reproducing the elevations and flows at our available data stations and (2) the ROMS_nostrat model has lower skill scores than ROMS_realistic but it is not immediately apparent from the Willmott Skill or the timeseries plots that this model is missing any fundamental hydrodynamic processes. The next sections will show that significant differences betwee these two models emerge when looking at residual flow instead of instantaneous flow. The ROMS_nostorm SSH and velocity results were included as a reference but this model will not be important to consider until Section 3.4.3.

3.4.2 Lateral structure of mean flow

The cross-channel structure of the time-mean velocity field is seen in Figure 3.4. The ROMS_realistic model demonstrates classic estuarine two-layer flow with southward outflow in the surface layer and northward inflow in the bottom layer while the barotropic ROMS_nostrat model produces a nearly depth-independent mean flow. We calculated the mean flux through each passage by integrating the mean velocity across each passage's cross-sectional area. Mean flux through the East and West Passages had magnitudes ranging between about 300 m^3/s and 550 m^3/s for both models, with the total net flux out of the bay balancing the total river input.

To quantify the two-layer nature of the flow, we calculated the mean deep flux through the East Passage by integrating mean velocities below 10 m depth. Here, the difference between the barotropic and baroclinic models is more pronounced – the baroclinic model has a nearly 1,400 m^3/s inflow while the barotropic model has a much weaker 250 m^3/s outflow in this deep layer. For a perspective on the magnitude of this exchange, the maximum instantaneous total river flux into the system during this period was 175 m^3/s so the mean deep flux through the East Passage is about an order of magnitude larger than the highest instantaneous river inputs.

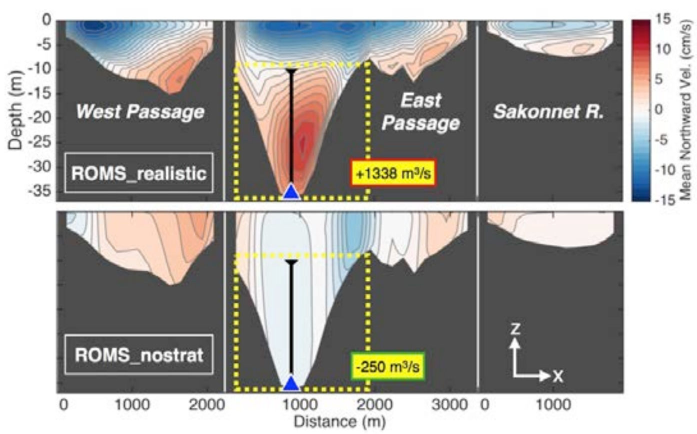


Figure 3.4. From left to right, zonal cross-sections through the West Passage, East Passage, and Sakonnet River showing time-averaged northward velocity. Red is mean northward flow (into the bay) and blue is mean southward flow (out of the bay). Results from ROMS_realistic (top row) and ROMS_nostrat (bottom row) are shown. Location of the ADCP and the 25 m integration column are indicated by the blue triangle with the black line above. Black text with yellow background shows mean flux through the deep East Passage region indicated by dashed yellow rectangle.

3.4.3 Time-integrated velocities

Integrated deep velocity is a proxy for net transport. We use this method for the data-model comparisons because we can't calculate volume transport from a single stationary ADCP. After validating that the modeled transport proxy agrees at this one location, we can then move on to calculate model volume transport.

Since we are interested in the residual transport, we integrated the instantaneous velocities through time for a clearer picture of the net flow (Equation 2).

$$f(t) = \int_{t_0}^{t} \int_{z_{bot}}^{z_{bot}+20} v(z,t)dzdt \tag{2}$$

This calculation is similar to a cumulative volume transport but it is calculated through a 1-D column instead of a 2-D surface so that we can perform the calculation on the ADCP data. While the ultimate goal is to calculate the volume transport, this calculation is a intermediary step used to validate the model against the ADCP data before proceeding. Results are seen in Figure 3.5.

The storm causes a rapid outflow as the surge tide ebbs, followed by about 2.5 days of enhanced inflow. The timing of this enhanced inflow matches that of the post-storm cooling event at the same location. The overall trend in the bottom layer at the ADCP is net inflow – as was shown in Figure 3.4 – but the results in Figure 3.5 shows considerable variability in this inflow. The ROMS_realistic model captures the timing and main features of the observations but overestimates the post-storm intrusion which leads to an overestimation of the net transport at this location.

The ROMS_nostorm case shows a relatively steady inflow over the same period, confirming that the variability in the observations was caused by Floyd. It is interesting to note that the total transport during this time period was approximately equal for the ROMS_realistic and ROMS_nostorm cases. The post-storm inflow serves to balance the initial outflow event. The post-storm inflow in the ROMS_realistic case was near 4 times greater than that of the ROMS_nostorm case over the same time period.

The ROMS_nostrat model completely misses the residual inflow and only captures the tidal transports plus a weak net outflow in response to the storm. This result was expected after seeing the mean flow in Figure 3.4 though it may have come as a surprise after seeing the seemingly-similar ROMS_realistic-ROMS_nostrat velocity records in Figure 3.3. Although the non-tidal velocities are an order of magnitude weaker than the instantaneous velocities, they determine the net transport of water masses in the system.

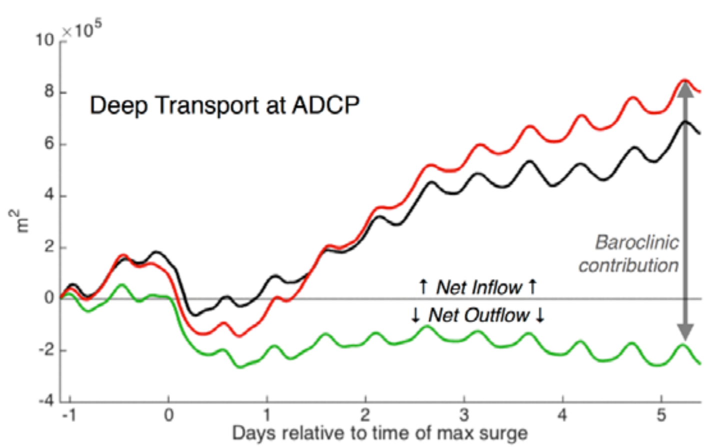


Figure 3.5. Deep northward cumulative 1-D transport at ADCP through the bottom 25 m of the water column at ADCP site as calculated by Equation 2. Notice that the units are m^2: this calculation is different from volume transport since it is transport through a 25 m tall 1-D column above the ADCP.

Positive values indicate net inflow and negative indicates net outflow. Time is in days relative to September 17, 1999 5:00, the timing of maximum observed surge in Newport. ROMS_realistic (red) over-predicts transport relative to observations (black). ROMS_nostrat (green) does not capture the observed deep inflow.

Though we cannot calculate volume transport from the ADCP record, we can calculate transport in the models. Here we consider the volume transport through the East Passage below 10 m depth for the 2.5 days following the storm. ROMS_realistic calculated a 5.9 x 10^8 m^3 intrusion which is nearly three times larger than the ROMS_nostorm intrusion of 2.0 x 10^8 m^3 and over 35 times the volume of all river inputs for the same period.

3.4.4 Bottom temperature

The ADCP bottom-temperature record (Figure 3.6) shows a 4°C temperature drop over the 2.5 days following the storm's arrival. A simple 1-D view of the water column would predict an initial warming following the storm due to enhanced vertical mixing, followed by a return to pre-storm temperatures as the water column re-stratifies. The observations show a slight initial warming but then the temperature drops below the pre-storm temperature.

Comparing with the model results, we see that the ROMS_realistic model over-predicts the initial warming associated with the storm's arrival and enhanced wind-driven vertical mixing but then shows a similar pattern for the cooling event, both in magnitude and timing. Similar to the transport results, the bottom temperature in the ROMS_nostorm model shows steadier change than the ROMS_realistic case but ultimately the two results converge within about one week after the storm.

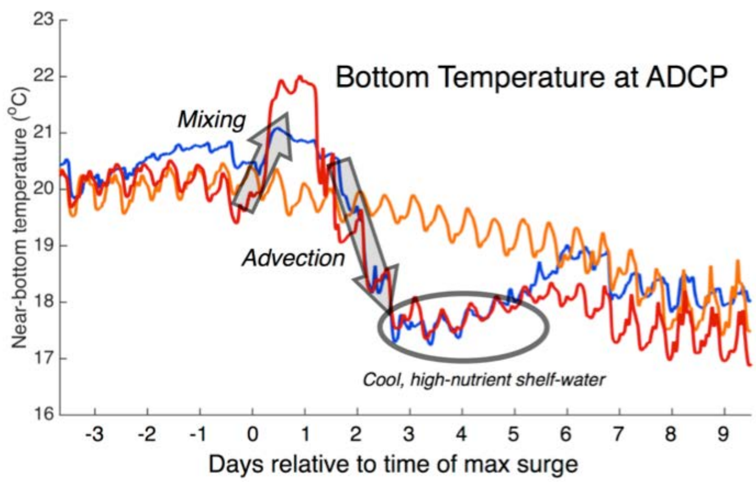


Figure 3.6. Bottom temperature at ADCP: observations (blue), ROMS_realistic (red), and ROMS_nostorm (orange). Vertical mixing alone would be expected to increase the bottom temperature yet a 4°C drop was observed over 2.5 days. This temperature drop was caused by the advection of cool shelf-water.

3.4.6 Theoretical passive tracer

All the results so far have included data-model comparisons but an advantage of using a numerical model is that we can track water parcels in ways which would be difficult or impossible to do in the real world. Motivated by the bottom temperature drop and the enhanced deep transport, we wanted to design a numerical experiment to track water originating in the bottom waters of Rhode Island Sound. A passive tracer – referred to here as a "dye" – was added to the model about 30 hours before Floyd's arrival on model-day September 16, 1999. The dye was initialized with a concentration of 1000 kg/m^3 in all model grid cells with density anomaly greater than 22.8 kg/m^3 in order to track the transport of water parcels originating on the shelf below the pycnocline.

Dye concentrations at seven points in the bay are seen in Figure 3.7. Based on the bottom temperature results at the ADCP, might predict that the dye concentrations at the ADCP would be similar between the storm and no-storm cases since these two models ended at nearly the same temperature within 7 days after the storm. This hypothesis appears to mostly hold up in the dye concentration comparisons, with the lower East Passage being the closest match-up between the two cases. Results begin to diverge further up the bay though. By the middle of the East Passage, the storm case shows nearly double the dye concentration of the no-storm case. On Ohio Ledge, the difference is over 500%.

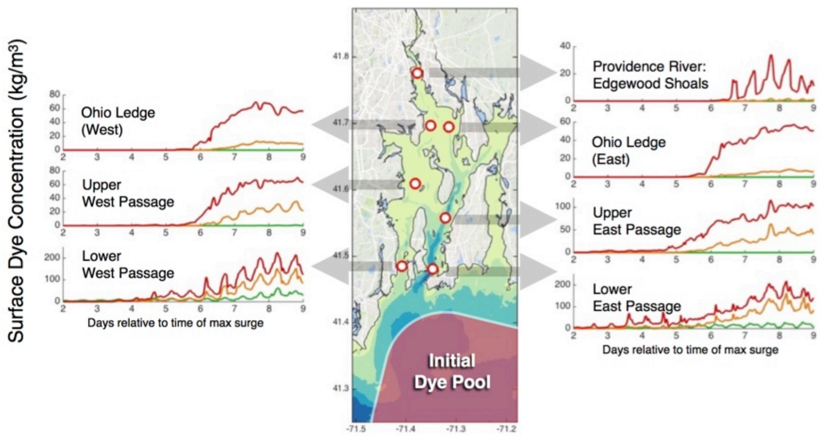


Figure 3.7. Surface dye concentrations. The red circles on the map correspond to seven locations in the bay where we have shown surface dye concentration timeseries. The y-axis is dye concentration in kg/m3 (dye was initialized in the deep shelf at 1000 kg/m3). Since the dye is meant to represent dissolved nutrients, the surface concentration indicates when these nutrients would be bio-available. We show 3 experiments: ROMS_realistic (red), ROMS_nostorm (orange), and ROMS_nostrat (green). Concentrations decrease with distance from the mouth but the storm's contribution, relative to the no-storm case, becomes more pronounced further up the bay.

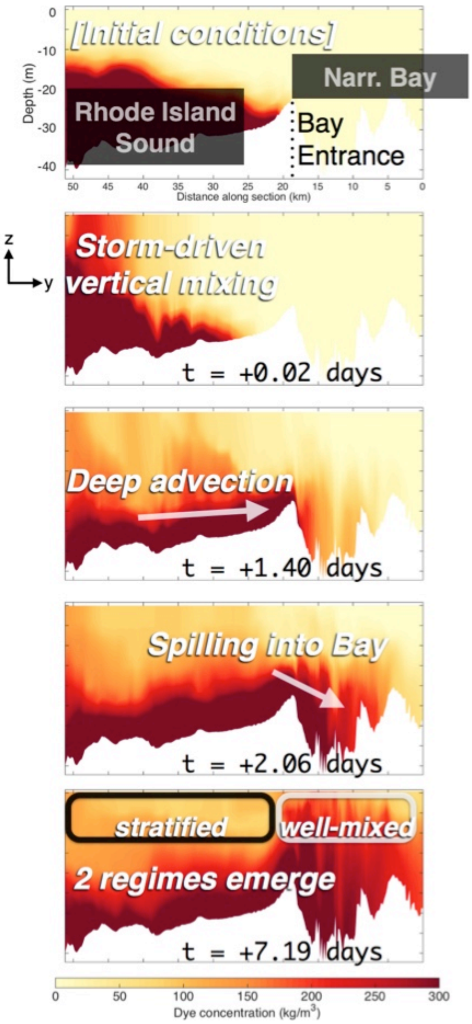


Figure 3.8. South-North cross-sections showing transport of deep Rhode Island Sound water into Narragansett Bay's East Passage. The dye is a passive tracer used to represent potential nutrient sources. Time is relative to the Floyd's arrival. Residual flow transports the dye into Narragansett Bay's East Passage where it experiences greater vertical mixing than on the shelf. At the entrance to the Bay, we predict that this nutrient source is mixed into the euphotic zone where it becomes bio-available.

3.4.7 Estimating nutrient flux contributions

Finally, we will make a rough estimate of the potential offshore nitrogen input associated with Floyd and compare to inputs from point sources over the same period. We focus on a 2.5 day period post-storm and, when faced with uncertainties, will make estimates that over-estimate point source inputs and under-estimate offshore inputs.

Nitrogen inputs to the bay from sewage and river inputs total about 182 x 10^6 mol/year (Oviatt et al., 2017) – this averages to about 1.2 x 10^6 mol every 2.5 days. For this estimate we will double that value and assume 2.5 x 10^6 mol of nitrogen from point sources over the 2.5 day post-storm period. Next, assuming the shelf water inflow has at least a 10 µM concentration of nitrogen (S. Granger, personal communication), then a 1000 m^3/s volume flux through the deep East Passage would deliver 2.2 x 10^6 mol of nitrogen from the shelf over 3 days. 1000 m^3/s is a conservative estimate based on the mean flux, but results from ROMS_realistic showed a 2900 m^3/s deep flux during the enhanced post-storm inflow event. This enhanced inflow would input 6.3 x 10^6 mol of nitrogen, which is more than double the input from point sources over the same period. Since the exact nutrient concentration of this inflow is still poorly-constrained, we calculated this inflow would need a nitrogen concentration of 4.0 µM to equal the contribution from point sources.

3.4.8 Modeling the transport of anthropogenic contaminants

The results so far have focused on intrusions of shelf water in Narragansett Bay since this is a process that is an ecologically-significant process that is enhanced by the storm and because ADCP data near the mouth of the Bay provides the opportunity to validate the model results. A problem of great significance for the regions citizen's and policy makers though is the transport of contaminants from point sources in Providence's shipping ports. Modeling the physics of this region is particularly important in response to a hurricane when this industrial infrastructure is most vulnerable.

No data is available for post-hurricane transports in the upper bay but the model-model comparisons have proved to be valuable in this case. Figure 3.9 compares the ROMS_nostrat and ROMS_realistic runs where a passive dye (representing a neutrally-buoyant chemical pollutant) has been released into the Providence River following Hurricane Floyd. The differences between the two results are striking: the fully 3D baroclinic model predicts greater southward transport of the dye. Figure 3.9 shows the surface concentration of the dye but similar patterns were found in the near-bottom concentration, which is significant for the state's shellfish industry.

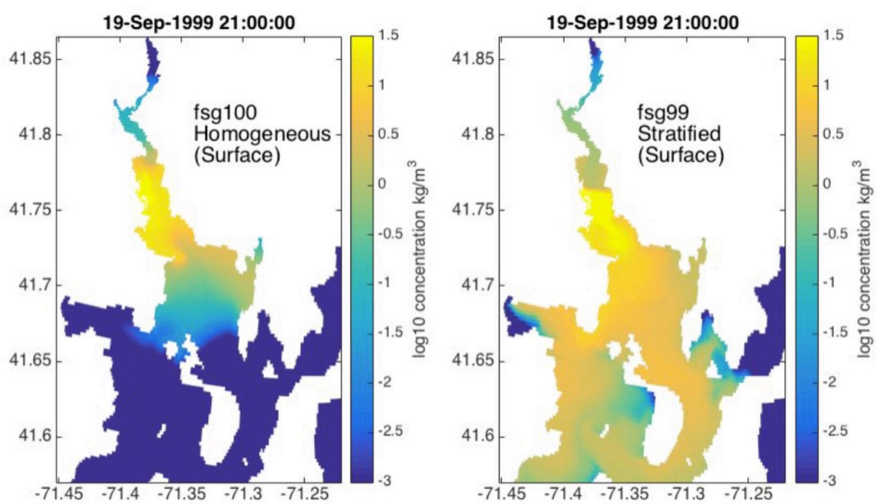


Figure 3.9. Surface dye concentrations for dye released in the Providence River following Hurricane Floyd. The barotropic ROMS_nostrat model (left) and baroclinic ROMS_realistic model (right) reveal the role of baroclinic pressure gradients in enhancing the down-bay transport of the dye. Dye was released near the Port of Providence in order to simulate a hypothetical spill of industrial contaminants.

3.5 Conclusions

3.5.1 Importance of baroclinic effects in post-storm response

We have confirmed that a barotropic model is unable to produce realistic post-storm non-tidal transport into Narragansett Bay. Therefore, in developing modeling tools that accurately represent the longer term impacts of a tropical cyclone it is not sufficient to rely on vertically integrated storm-surge models, which are incapable of representing baroclinic effects. Our side-by-side baroclinic vs.

barotropic models (ROMS_realistic vs. ROMS_nostrat) showed the barotropic model severely underestimated net transport compared to the ADCP data and the baroclinic model. One might assume that because the storm enhances wind-driven mixing, that this would diminish the roll of baroclinic processes in the ocean response but this hypothesis ignores the significant longitudinal density gradients in the system. Wind-driven mixing only breaks down the vertical stratification, but actually enhances horizontal density differences.

Previous studies of coastal circulation in response to storms, such as (Tutak and Sheng, 2011), showed only that the baroclinic pressure gradient term was of lower order magnitude in the momentum equation. Our results agree with this conclusion that the baroclinic term is of smaller magnitude, yet we showed that baroclinic effects are the dominant contributor to the non-tidal storm response. These results indicate tropical storms have the ability to influence estuarine ecosystem productivity and overall health on seasonal time scales. Models must be able to represent non-tidal biogeochemical transport transport, not just sea surface height and tidal velocities.

3.5.2 A computationally-efficient approach to regional modeling of storm events
We have shown that a 3-D baroclinic regional model, one-way nested at the boundaries with a basin-scale 2-D storm surge model, could skillfully reproduce the ADCP record of Hurricane Floyd in Narragansett Bay's East Passage. Operational storm surge models must use simplified physics due to computational restrictions but the present method opens up the possibility of running specialized high-resolution 3-D models in specific regions of interest and coupling these models to output from existing operational storm surge models. This approach places no new demands on the storm surge models but opens up the potential for more realistic modeling of the effects of storms on coastal circulation and bio-chemical processes.

3.5.3 Shelf-estuary exchange processes
Simple flux estimates show that even the relatively weak Hurricane Floyd had the ability to drive ocean-derived nutrient inputs that were larger than all rivers and sewage plants combined. In modeling variability at the mouth of Narragansett Bay, side-by-side comparisons between ROMS_realistic and ROMS_nostorm showed that the deep inflow into the bay via the East Passage can be strongly influenced by even a weak storm like Floyd. Net transport through the deep layer during the 2.5 days post-storm was nearly three times larger than in the no-storm case. The elevated nutrient content of this water mass shows that storms could be an important source of offshore nutrients in this system. Dye experiments also showed that the storm affected the northward progression of this water mass, advecting shelf water further up into the bay than the no-storm case.

4. Sediment Transport Processes in Narragansett Bay

4.1 Objective

We seek to quantify the erosion, transport and re-deposition of sediment in Narragansett Bay for the purpose of understanding the redistribution of potentially harmful pollutants from locations that are known to contain those contaminants to other, relatively contaminant-free locations. These processes are thought to play a pivotal role in the overall health of the Narragansett Bay ecosystem.

4.2 Model Setup

The Regional Ocean Modelling System (ROMS) was run using boundary conditions from a global general circulation model (HYCOM_NCODA; http://hycom.org/), with the ADCIRC tidal model (http://adcirc.org/) providing the tidal boundary conditions. River discharge is obtained from the U.S.

Geological Survey (USGS; http://waterdata.usgs.gov/nwis) and the atmospheric forcing is from ECMWF (https://www.ecmwf.int/). The domain topography is shown in Figure 1.

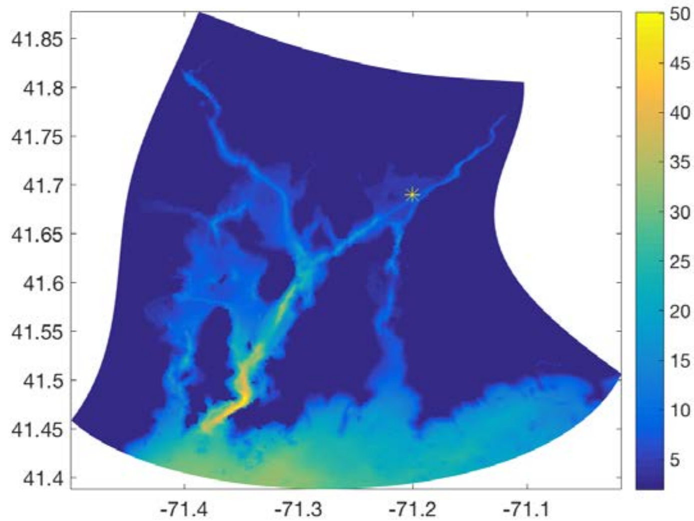


Figure 4.1. Domain topography.

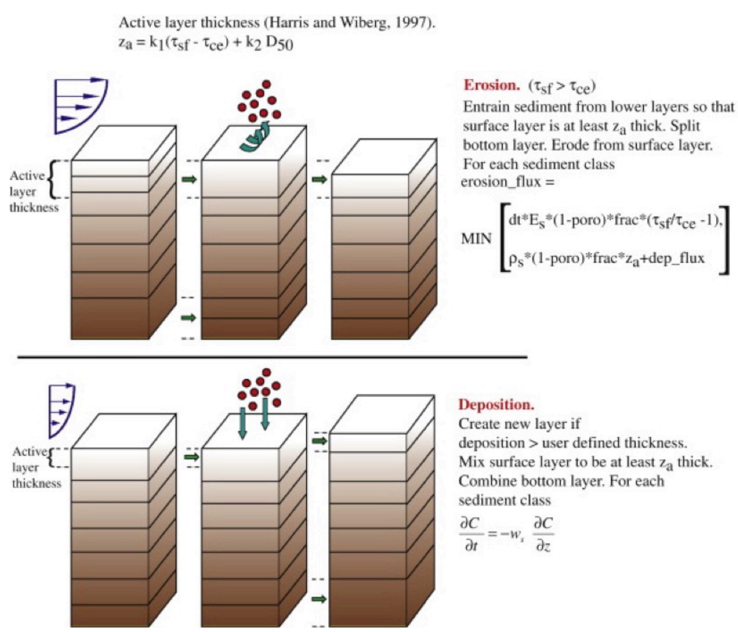


Figure 4.2. The dynamic process of erosion and deposition in the bed layer (adopted from Warner et al., 2008).

The resuspension and deposition of sediment is based on the critical erosion of every class of sediment (Warner et al., 2008) as shown in Figure 4.2. According to previous research (https://cida.usgs.gov/sediment/), there are two most common types of sediment in Narragansett Bay

(NB). One is fine sand with a 0.125 mm diameter; the other is so-called clayey silt with a 0.0156 mm diameter (Table 4.1). A sediment layer bed, with 10-meter thickness, is initialized with ROMS and composed of 50% sand and 50% silt, where sand and silt were well mixed. Silt is homogenously distributed in the domain (Figure 4.3).

Table 4.1. Initial Condition of Sediment

	Diameter (mm)	Density(kg/m3)	Setting Velocity (mm/s)	Critical Erosion (Pa)
Fine Sand	0.125	2650	8.7	0.140
Clayey Silt	0.0156	2650	0.15	0.038

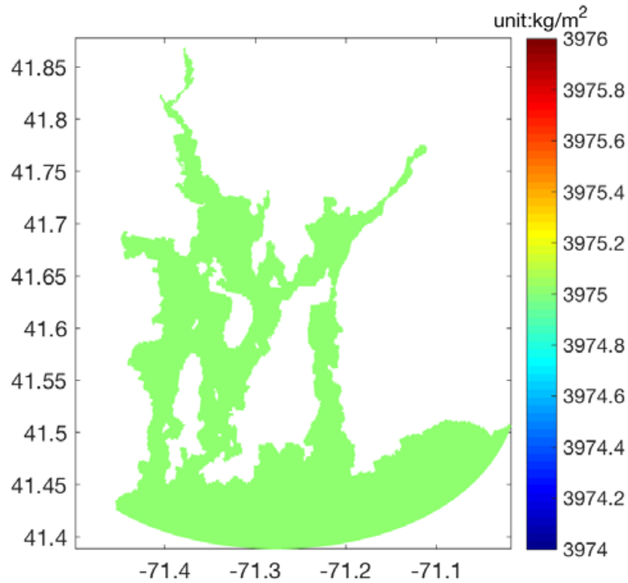


Figure 4.3. Initial silt mass in the bed layer.

4.3 Results

To investigate the influence of both winds and tides on sediment transport we set two separate experiments (Table 4.2). Both experiment simulations were run from September 8, 1999 to October 2,1999 in order to capture the Hurricane Floyd wind event. After 26 days of simulation with wind forcing alone, the change of silt mass in the bed-layer is significant in the East Passage of NB (Figure 4.4.a). Wind forcing also played an important role in changing the distribution of silt in Rhode Island Sound as well as in the adjacent region between the Sakonnet River and Rhode Island Sound. However, even during this hurricane event, the winds were not strong enough to suspend silt in the Upper Bay. In contrast, tides are responsible for suspending silt in the Upper Bay, especially in Providence River (Figure 4.4.b). The tides also suspend a significant amount of silt in both the lower West Passage and the East Passage. The suspended silt in the lower East Passage can be brought in from Rhode Island Sound.

Table 4.2. List of Experiment with ROMS

	Tides	Wind	RiverDischarge	SurfaceHeating
RivWind	No	Yes	Daily Data from USGS	3-hourly Data from ECMWF
RivTide	Yes	No	Daily Data from USGS	No

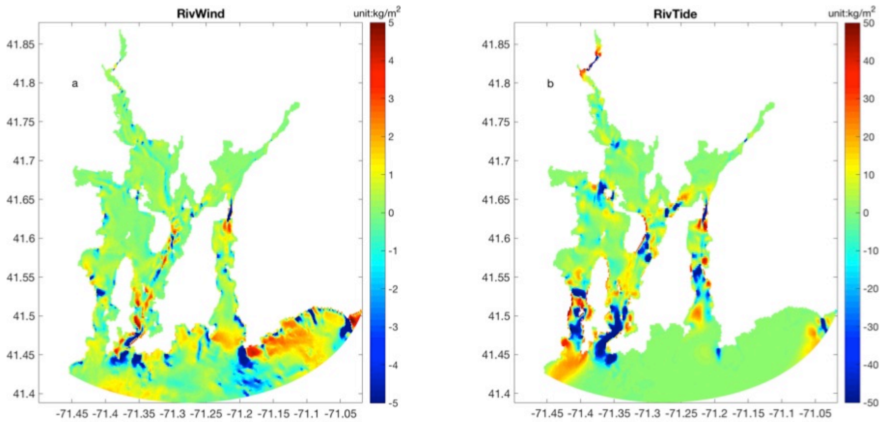


Figure 4.4. The change of silt mass in the bed layer for Case RivWind (a) and RivTide (b).

The Taunton River is a special region because its silt contains a significant amount of harmful chemicals. To investigate how silt will be suspended there and re-deposited elsewhere, a new initial silt mass has been configured (Figure 4.5), where silt only exits in the Taunton River, and the forcing is set as only tidal. There was significant erosion and re-deposition of silt in the Taunton River at the end of October 2,1999, approximately one month of tidal cycles (Figure 4.6). Erosion was always accompanied by nearby re-deposition.

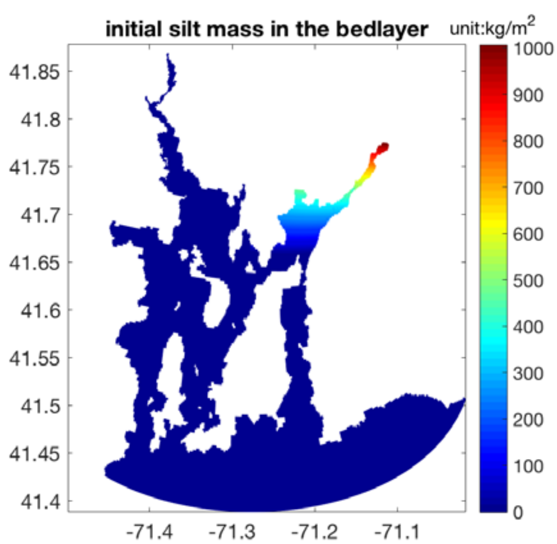


Figure 4.5. Initial silt mass in the bed layer, where silt only exists in the Taunton River.

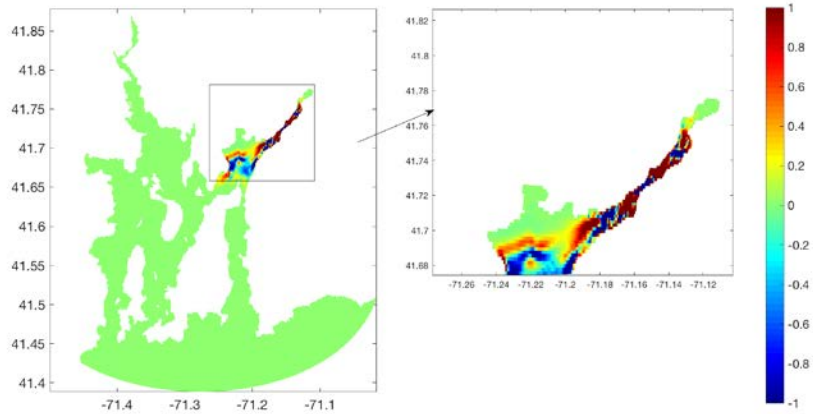


Figure 4.6. The change of silt mass in the bed layer for Case RivTide. Left is the whole Narragansett Bay. Right is the detailed Taunton River.

4.4 Summary

Tides are the dominant forcing for sediment transport processes in NB, causing potentially serious erosion and re-deposition of harmful sediments (Figures 4.3 and 4.5). Wind cannot be neglected for transporting sediment in Rhode Island Sound. The lower bay is the region where erosion and re-deposition of sediment are most significant. In the upper bay, the Taunton River is a special region because of its complex components of potentially contaminated sediment. The erosion and re-deposition of silt here is rather complex, not simply decaying along channel from its source. We will continue to focus on the Taunton River as well as other source regions of potentially hazardous, contaminated sediment to better understand the dynamical processes of sediment transport as well as the implications of that for the health of Narragansett Bay.

5. Modeling the Sea State Dependent Drag Coefficient under Hurricanes in Coastal Regions

During this report period, we have 1) concluded the effects of model grid resolutions on wave modeling in the offshore region; 2) investigated the sea-state dependent drag coefficient (Cd_{SSD}) in shallow water due to idealized shoaling hurricane waves. In the latter investigation, the WAVEWATCH III (WW3) model is used to simulate wave spectrum and to calculate Cd_{SSD} based on the method developed in Reichl et al. 2014. The WW3 is chosen primarily because the two published Cd_{SSD} modeling methods have already been implemented in the latest version of the model. The Simulating WAves Nearshore (SWAN) model will be used in the next step.

5.1 Effects of model grid resolutions on wave modeling in the offshore region

We have investigated the sensitivity of tropical cyclone (TC) wave simulations in the open ocean to different spatial resolutions (1/3º, 1/6º, 1/12º and 1/24º) using two wave models, WW3 and SWAN. Six idealized TCs of different radii of maximum winds (25km and 50km), and of different translation speeds (3m/s, 6m/s and 9m/s) are used to force these two wave models. Results from both models show that the coarsest resolution (1/3º,) introduces significant errors in both the significant wave height

(SWH) and the mean wavelength. Moreover, results reveal that sensitivity to spatial resolution strongly depends on storm characteristics. Waves simulated under the small (25km) and fast moving (9m/s) TC show the largest sensitivity to the coarse spatial resolutions; local SWH values can be underestimated by as much as 2.5~m with the 1/3º resolution, compared to those with the 1/24º resolution. Also, waves further away from the storm are overestimated in both models. Figures 5.1 and 5.2 show that the model sensitivity to the grid resolution in the front of the storm is very different from that behind the storm. These results suggest that spatial smoothing of the wind field, which would reduce wind input both near the front peak and near the rear peak, is not the main reason for the errors in the wave simulations with coarse resolution grids.

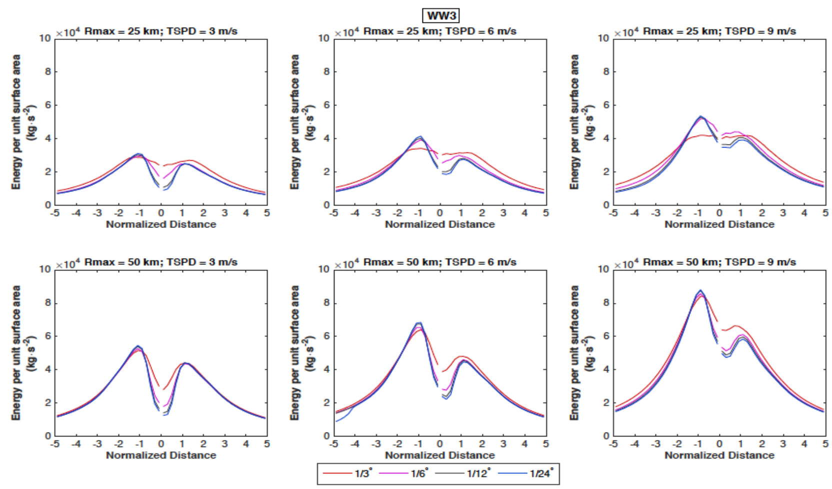


Figure 5.1 Average wave energy within a half-annulus area (front and rear) at different radii from the storm center under the 6 idealized storms from WW3. Negative and positive distances are in front of and behind the storm, respectively. Red, magenta, black and blue lines denote results from the coarsest to the highest resolution respectively.

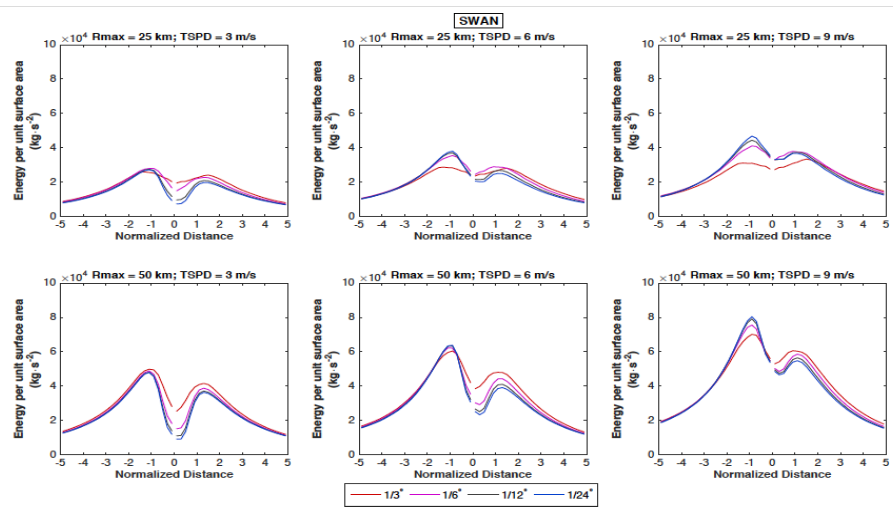


Figure 5.2 Same as Figure 5.1 but for SWAN model.

We also have tested the sensitivity to different translation direction of idealized storms and results are shown in Figure 5.3. In general, for a fixed translation direction, as the storm moves faster, the 1/3º resolution tends to underestimate the maximum SWH. The largest errors of the maximum SWH reaches 1m in WW3 and 2 m (or more than 10%) in SWAN with the 1/3º resolution. For a fixed resolution, the maximum SWH displays variability introduced by TC translation direction. In both models, this variability is reduced and the SWH results converge as the spatial resolution becomes finer. However, this convergence is slower in SWAN than that in WW3.

Figure 5.3 also informs that in both models, the variability caused by TC translation direction is comparable to the errors due to model resolution. Under the storm with a small Rmax (large wind gradient) and/or a large translation speed (fast moving), the variation of SWH due to TC direction becomes significant. This is again more evident in SWAN.

In summary, model errors in maximum SWH can be significant with coarser resolutions under a small and fast moving storm (Rmax=25km, U_T=9m/s), using SWAN in particular. The sensitivity of maximum SWH to spatial resolution is model dependent and there are no systematic trends that are common in both models. This model dependence may be partly caused by the differences in their source terms.

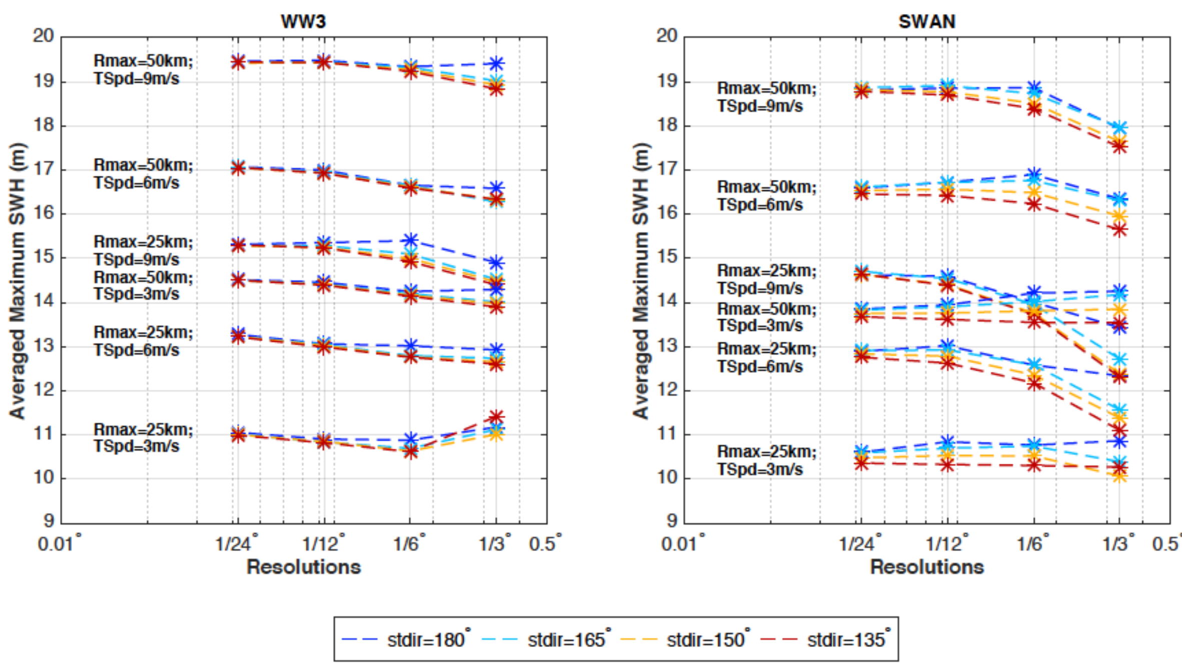


Figure 5.3 Maximum SWH in time-averaged quasi-steady state wave fields simulated with 6 different idealized storms, with 4 different spatial resolutions, and with 4 different storm propagation directions. a) WW3 results; b) SWAN results. Dashed lines of different colors represent different directions, with track (I) in blue, track (II) in cyan, track (III) in yellow and track (IV) in red. Asterisk marker denotes the actual data point.

5.2 Variability of Sea State Dependent Drag Coefficient in Shallow Water

We have investigated the sea state dependent drag coefficient in shallow water under hurricane wind conditions, by extending the approach of Reichl et al. (2014) that was developed for deep water. The first step of computing the sea state dependent drag coefficient (Cd_{SSD}) is to estimate the wave-induced stress, which reduces the near surface turbulent stress and hence increases the apparent aerodynamic roughness (Hara and Sullivan 2015). The wave-induced stress at the water surface is equal to the momentum taken by surface gravity waves, and hence can be computed from a wave spectrum and the wave growth rate by the following equation,

$$\boldsymbol{\tau}_w(z) = \rho_w \int_{k_{min}}^{k=\delta/z} \int_{-\pi}^{\pi} \beta_g(k,\theta)\sigma\Psi(k,\theta)d\theta\boldsymbol{k}dk$$

The total wind stress is then a summation of the turbulent stress and the wave-induced stress. With an energy-conserved wave boundary layer model, the feedback of the wave-induced stress on the wind profile is established.

Once the directional wave spectrum is provided together with a 10-m wind speed, the sea state dependent wind stress can be determined iteratively with this approach. The sea state dependent drag coefficient (C_d) is then computed from the sea state dependent wind stress. However, the wave spectrum computed by a wave model cannot be utilized as is. This is because the spectral tail (high frequency part of the spectrum) is not accurately resolved by any current spectral wave models, but it significantly contributes to the wave induced stress. Therefore, a complete input wave spectrum is first constructed by combining the resolved part of the wave spectrum (spectrum near the peak) and a modeled spectral tail (a constant saturation spectrum) in the short wave range. To avoid drastic change in the spectrum, a transition region is implemented to smoothly connect the resolved spectrum and the prescribed level of spectral tail. Hence, two critical wavenumbers have to be specified in this procedure. The first one determines the end of the resolved part of the wave spectrum and the second one determines the beginning of the spectral tail.

There are three tuning parameters in our sea state dependent stress model: the nondimensional parameter for inner layer height, the growth rate parameter, and the saturation spectrum level. The first two are tuned to produce the drag coefficient that is consistent with observations in low to medium wind speeds. This leaves the saturation spectrum level as the only adjustable parameter. Currently, this saturation spectrum level is set as a function of wind speed and is tuned so that the median of the sea state dependent drag coefficient is consistent with the bulk drag coefficient used in the GFDL hurricane model.

5.2.1 Sensitivity of simulated wind stress/drag coefficient to input wave spectrum of fetch-dependent waves

The WW3 model used in Reichl et al. (2014) is based on source terms (wind input and dissipation) developed by Tolman and Chalikov 1996 (ST2). For our drag coefficient modeling, the ST4 source terms are used as in the operational WW3 by the National Center of Environmental Prediction (NCEP). Since source terms affect the simulated wave spectrum, we have examined the sensitivity of Cd_{SSD} calculation (under uniform wind experiments) to:

1) different directional wavenumber spectra simulated by ST2 and ST4.
2) different methods to connect the resolved spectrum with the spectral tail.

1) Sensitivity of Cd_{SSD} to different directional wavenumber spectra

The difference between WW3-ST2 and WW3-ST4 omnidirectional saturation spectrum B(k) is shown in Figure 5.4. ST4 source terms produce a less pronounced spectral peak compared to ST2, and the saturation spectral tail level is higher than ST2.

Figure 5.5 shows that the directional spreading function in ST4 is wider than that in ST2 for waves in higher frequencies (shorter waves). A wider directional spreading is more consistent with the latest available observation (Lenain and Melville 2017), in which a bimodal directional wave spectrum is reported. However, this is not expected to have a significant impact on the computation of the sea state dependent stress.

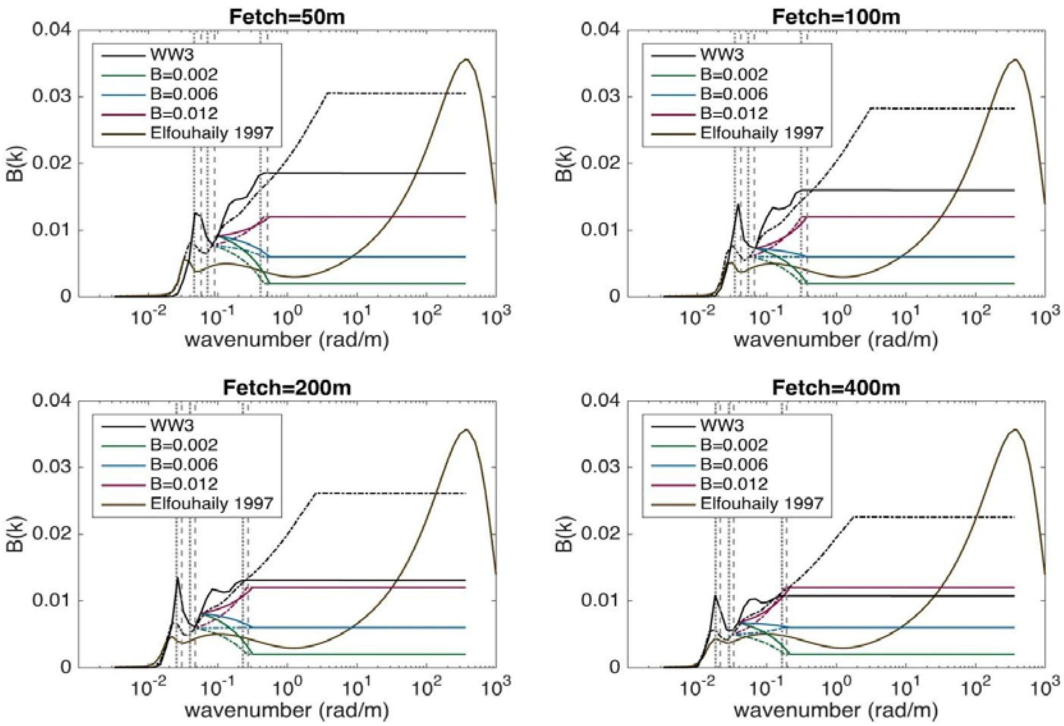


Figure 5.4 Saturation wave spectra at 4 fetches simulated by ST2 (solid black) and ST4 (dashed black) in WW3 under 40m/s uniform wind. Reconstructed saturation spectra with 3 different saturation levels are used in the sea state dependent stress module. Brown line indicates an empirical fetch-dependent spectrum by Elfouhaily (1997) for reference.

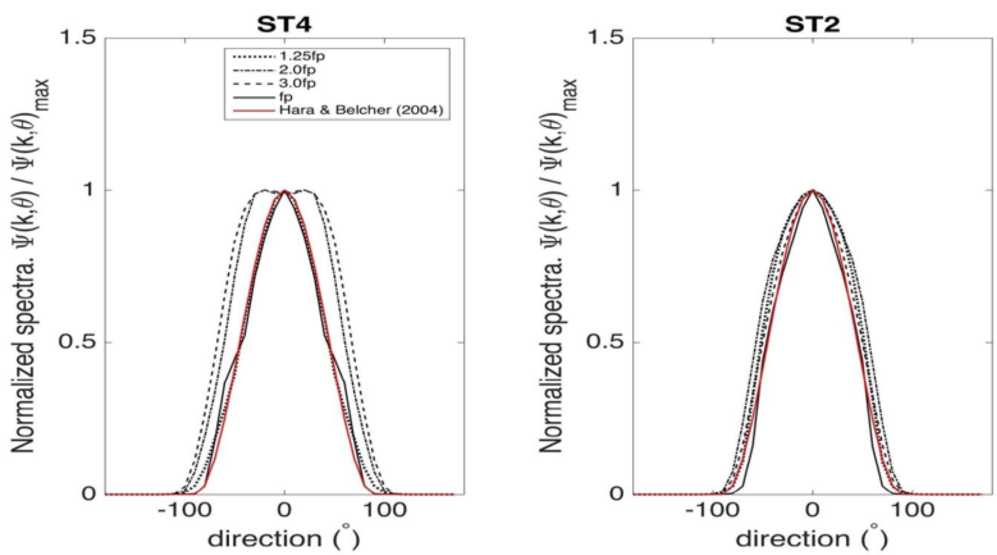


Figure 5.5 Example of directional spreading at four different frequencies in ST4 and in ST2 for a wave spectrum generated along a 400-km fetch under 30m/s uniform wind. Red solid line is the directional spreading function proposed in Hara and Belcher (2004). 0 degree is aligned with the wind direction.

Figure 5.6 presents an example of the difference in simulated drag coefficients under fetch-dependent waves between ST2 and ST4. The major difference is in the waves generated at short fetches. Drag coefficient for short-fetch waves (50-m fetch) in ST4 is smaller compared to its counterpart in ST2, especially with a low saturation spectral level of 0.002 (blue).

To summarize, we have clarified the differences between the ST2 and ST4 spectra (shape of the omnidirectional spectrum and the directional spreading of the spectrum), and their influences on the simulated wind stress.

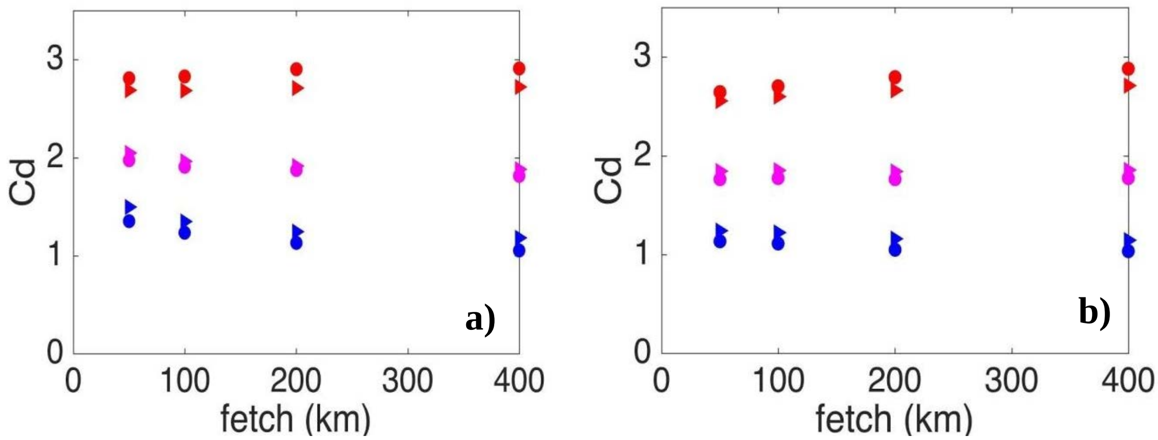


Figure 6.6 Drag Coefficient (x1000) simulated with three saturation tail levels in ST2 (left panel) and in ST4 (right panel). URI method (circle) and the Miami method (triangle) are both used here (Reichl et al. 2014). Colors represent the levels of the saturation tail: 0.002 (blue), 0.006 (magenta), 0.012 (red).

2) Sensitivity of Cd_{SSD} to different methods of connecting the resolved spectrum with the spectral tail

In Reichl et al. (2014), the peak frequency (f_{pi}) is used as a reference frequency to specify the end of the resolved spectrum (transition frequency) and the beginning of the saturation spectrum (attachment frequency). With ST4, we have tested the same approach as well as four different approaches, summarized in Table 5.1.

Table 5.1 A List of the different approaches to reconstruct wave spectrum for Cd_{SSD} calculation

Method (short name)	Transition frequency	Attachment frequency
FPI	1.25x peak input freq.	3.0x peak input freq.
FMEAN1.0	1.0x mean freq.	2.5x mean freq.
FMEAN1.5	1.5x mean freq.	2.5x mean freq.
FMEAN_locmin	At the 1st local minimum of saturation spectrum	2.5x mean freq.
FMEAN_intercept	At the intercept between the spectrum and a specified	At the intercept between the spectrum and a specified

	level.	level.

Figure 5.7 - 5.9 are examples of drag coefficient simulated with a shoaling wave field under a constant wind speed with a prescribed saturation spectral level. Each color represents a method listed in Table 5.1. In Figure 5.7 and 5.8, the secondary peak in WW3 wave spectra at depth less than 20m results from the triad interaction (black solid lines). This secondly peak is retained only if the original WW3 spectra are used up to 1.5fmean (as indicated by magenta lines). In this case, the Cd_{SSD} is slightly increased around 10m water depth. Figure 5.8 and Figure 5.9 further show the sensitivity of Cd_{SSD} to the triad interaction. In general, the triad interaction does not affect the drag coefficient significantly under uniform wind, with fetch-dependent wave fields.

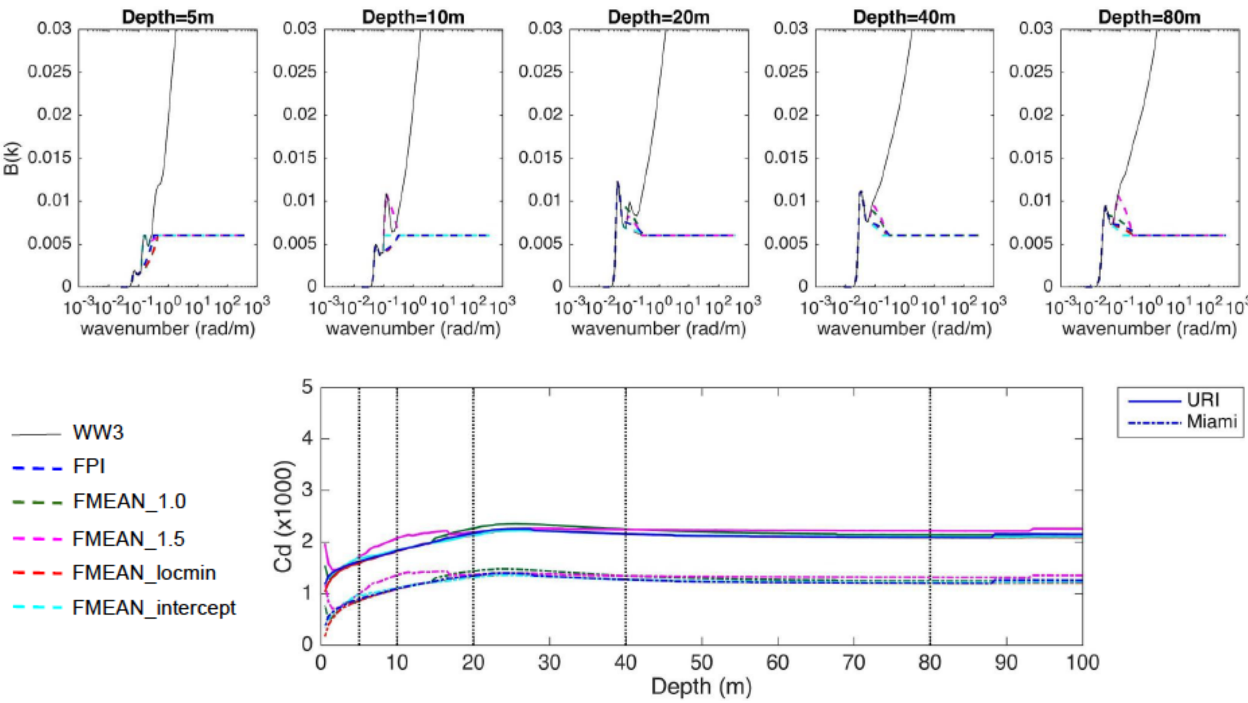


Figure 5.7 Cd simulated with a shoaling wave field under 50 m/s uniform wind (lower panel) and the associated saturation wave spectra at 5 selected depths (upper panel). In the wave spectra panels, solid black line shows the original WW3 simulated wave spectrum, dashed lines show the modified wave spectra with different transition wavenumbers and attachment wavenumbers. In the lower panel, solid lines are results from URI method, dashed lines are results from Miami methods. Note that results from the Miami methods are shifted by 1 for clarity. The drag coefficient is computed with a saturation tail level of 0.006 here.

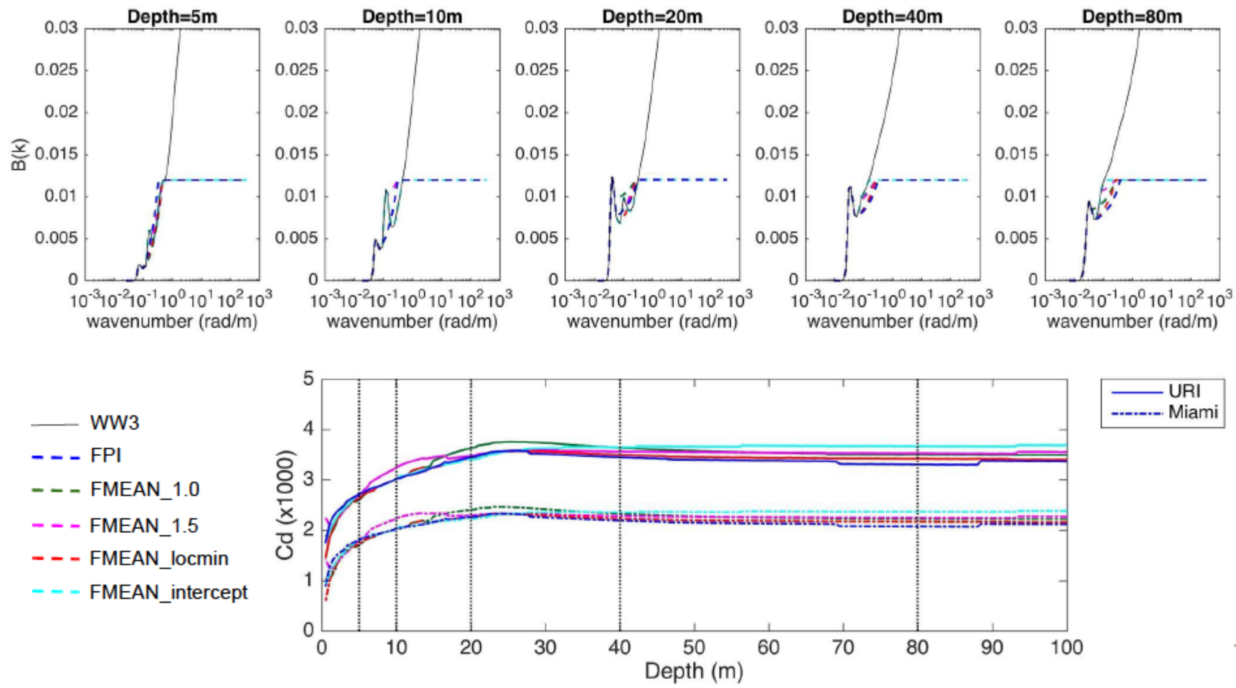


Figure 5.8 Same as Figure 5.7 but with a saturation tail level of 0.012.

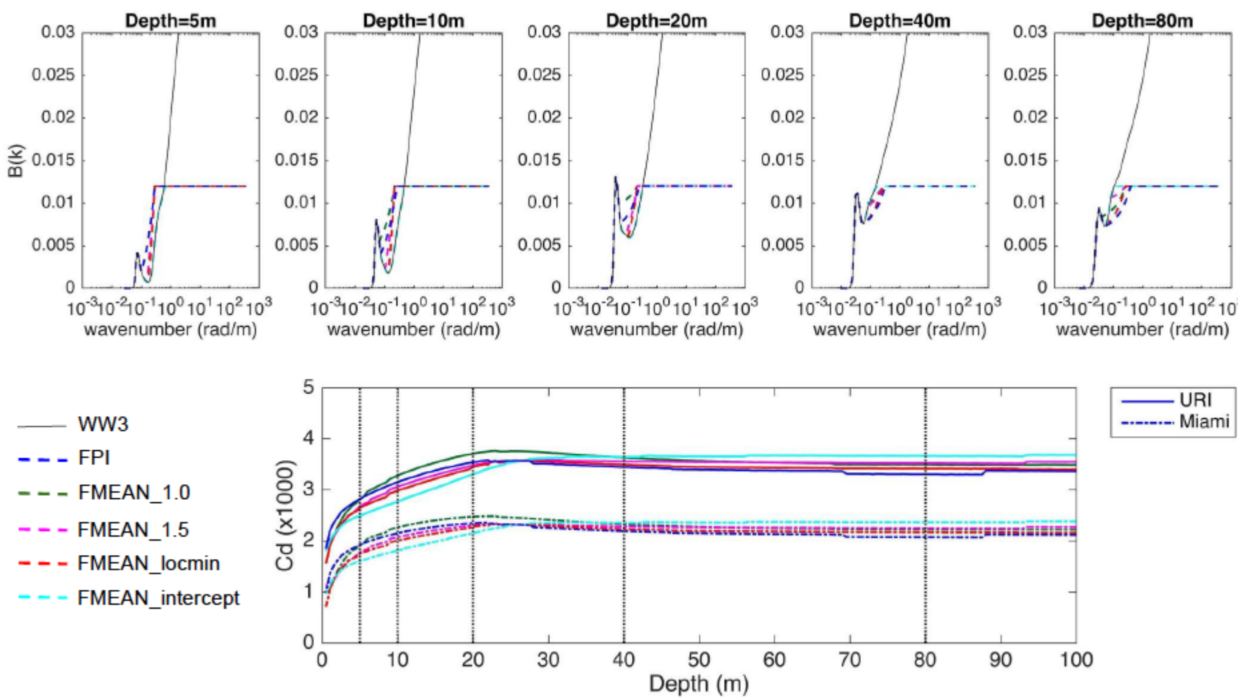


Figure 5.9 Same as Figure 5.8 but the wave spectra are simulated without the triad interaction effect.

The Cd_{SSD} reduces as the water depth decreases due to decrease of energy in the wave spectrum by depth-induced breaking. In general, the different ways to attach the spectral tail do not alter the results significantly, provided the saturation tail level is independent of water depth. In other words, the exact locations (in wavenumber space) of the end of the resolved spectrum and of the beginning of the saturation range are not as critical as the saturation level itself in affecting the magnitude of the drag coefficient.

Based on these findings, from now on the transition wavenumber is set to be $1.25f_{mean}$ and the tail attachment wavenumber to be $2.5f_{mean}$. This setting is expected to provide similar results to that in Reichl et al. 2014.

Although not shown here, we also have tested different parameterization of source terms (e.g. bottom friction) and have found that their impacts on the Cd results are not significant.

5.2.2 Variability of Sea-State dependent Drag Coefficient under Idealized Hurricane Waves in Shallow Water

Hurricane wave fields are generated with an idealized hurricane of 65m/s maximum wind speed, 70km radius of maximum wind and translating at 5m/s and 10m/s. The waves are first simulated in a deep water domain till they reach quasi-steady state. Then, the waves are propagated onto a gentle seafloor slope, where water depth decreases from 200m to 0m within a 400km cross-shore distance. Three shallow water source terms (bottom friction, depth-induced breaking and triad interaction) are activated to dissipate wave action as the hurricane wave field shoals. Figure 6.11 clearly shows i) a significant reduction in significant wave height during shoaling as water depth decreases; ii) decrease of the dominant wave phase speed (indicated by the length of vectors).

Figure 5.10 is an example of 10-m hurricane wind field generated by Holland model. Comparing with Figure 5.11, we see that the dominant wave vector misaligns with the wind vector in most areas except in the right rear quadrant. Hurricane wave fields are usually a mixture of swell and wind waves (Wright et al. 2001, Walsh et al. 2002) and can be categorized into three types - following swell, cross swell and opposing swell (Black et al. 2007, Holthuijsen et al. 2012, Liu et al. 2017). These three types of sea state condition are reported to be found in three azimuthal sectors under a hurricane - right-front, left-front and rear, respectively (Black et al. 2007), and can be quantified by wave directional spreading (Holthuijsen et al. 2012), or by the absolute misalignment angle θ_{uw} (Liu et al. 2017) between wind and dominant waves. With the latter approach, the following swell is defined as θ_{uw} less than 45º. The cross swell is further separated into two subgroups: cross swell positive ($\theta_{uw} \in$ (45º, 90º]) and cross swell negative ($\theta_{uw} \in$ (90º,135º]). The opposing swell is defined as θ_{uw} larger than 135º. To investigate how our modeled drag coefficient is modified by different wave conditions, we follow the Liu et al. 2017 approach and sort the drag coefficient by wave conditions.

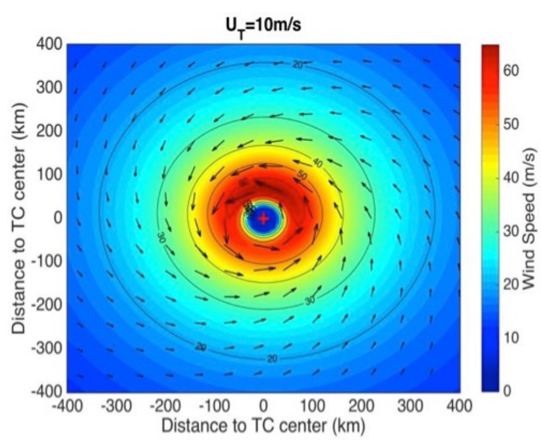


Figure 5.10 Example of the idealized hurricane wind field (U_T=10m/s). The storm moves from right to left.

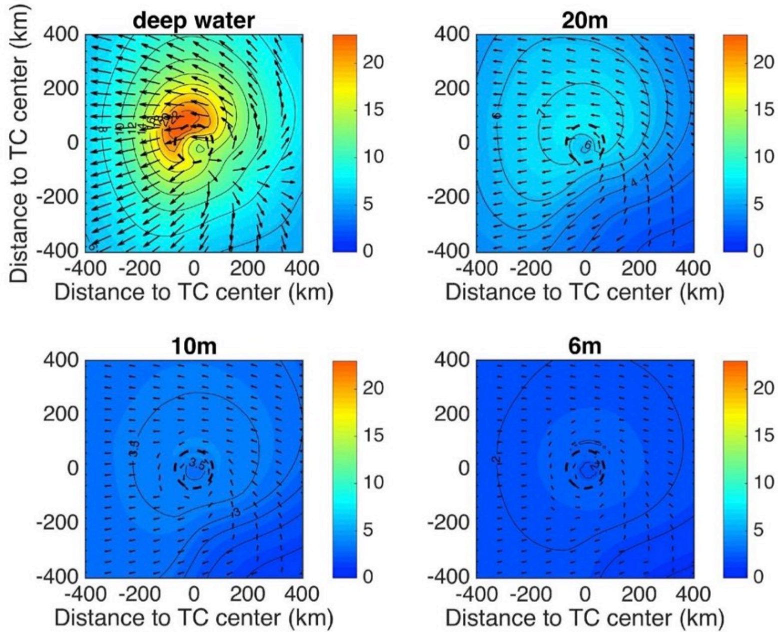


Figure 5.11 Variation of hurricane wave field with decreasing water depth. The color shading represents significant wave height. Vectors point to the propagation direction of the dominant waves and the length of the vectors is proportional to the phase speed of the dominant waves.

a. Sea state dependent drag coefficient under hurricanes in deep water:

Figure 5.12 shows the scatter plot of drag coefficient as a function of wind speed and color coded by the wave age of the dominant waves. The dashed line marks the median of the sea-state dependent Cd at each wind speed bin (2 m/s bin width). The box depicts the distribution of Cd in every 5 m/s wind speed bin. In each box the red line marks the median, and the height of the box represents interquartile range, where the middle 50% of the data fall within. The upper and lower whiskers enclose the middle 95% of the Cd values. As the storm translation speed increases, the variability (sea-state dependence) of Cd increases especially at high winds (>45 m/s).

b. Variability of drag coefficient under hurricanes in shallow water:

As water depth decreases, the sea state dependence of drag coefficient is enhanced. (See Figure 5.13) Also, the median value of Cd is gradually reduced at all wind speed with decreasing depth, compared to that in the deep water.

In the 10m/s translation speed case, the drag coefficient displays the largest variability in lower wind speed (10-20m/s) at around 10m depth. The statistical analysis shows that this variability mainly comes from the top 25% of the data. Further separation of the drag coefficient according to the misalignment angle between wind and dominant waves (θ_{uw}) shows that this large Cd variability in low winds occurs in the opposing swell condition. Also, we notice that the large variability in high wind appears in the following swell condition.

Figure 5.15 and 5.16 show the spatial variability of Cd (in terms of its ratio to the median Cd in deep water at the same wind speed) as depth decreases in the two translation speed cases. They reveal that the enhancement of Cd under the opposing swell condition occurs in the left front quadrant of a TC in lower winds (10-20m/s), and is as large as 20%-50% of the deep water Cd depending on the TC translation speed. Weak enhancement (5%-10%) can also be observed on the right hand side of the storm outside gale-force wind (17.5–24.2m/s). In other areas of a TC, the Cd is reduced. The largest reduction is in the vicinity of radius of maximum wind is about 20-25% of the deep water Cd.

In summary, our idealized hurricane experiment shows that:
1) The median of sea-state dependent Cd is reduced in shallow water (<30m).
2) The sea-state dependence of Cd under hurricane winds in shallow water is stronger than that in deep water.
3) In shallow water, opposing swell can introduce large variability on Cd at lower (10-20m/s) wind speed.

c. Comparison with the current Cd observation in shallow water under hurricanes
There are very few observations of the drag coefficient under hurricane conditions in shallow water environment. Zachry et al. (2013) used turbulence intensity method to derive drag coefficient (2-min averaged) over a 3-km-wide ship channel during the eye passage of Hurricane Ike (2008). They showed that Cd increases at lower wind speed due to a short fetch over the opening of a ship channel. Their observation also showed a saturation of Cd near hurricane force winds (~30m/s). Zhao et al. (2015) showed that the maximum Cd occurs at lower wind speeds (5-15m/s) than that in deep water. Also, Cd increased by about 50% relative to the open ocean below 24 m/s winds. However, their Cd derived from the wind profile method was very likely an overestimation as suggested by Bi et al. (2015). In Bi et al. (2015), Cd computed from the eddy covariance method in 7 typhoons followed the COARE 3.5 Cd closely at lower wind speeds but displayed a reduction at high wind speeds. Their finding is qualitatively consistent with the results of our idealized experiment.

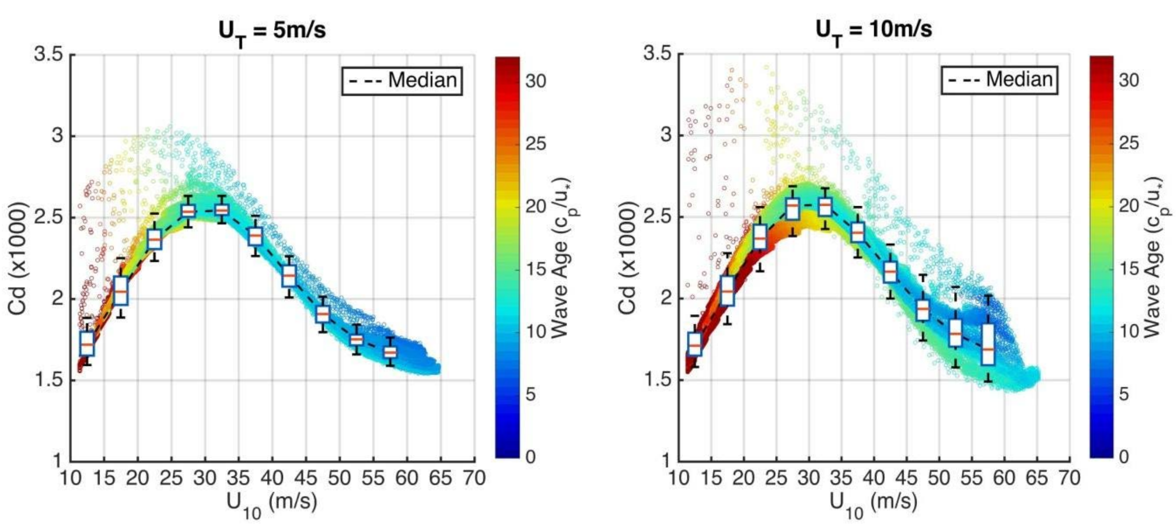


Figure 5.12 Sea state dependent drag coefficient under TC with 5 and 10 m/s translation speed.

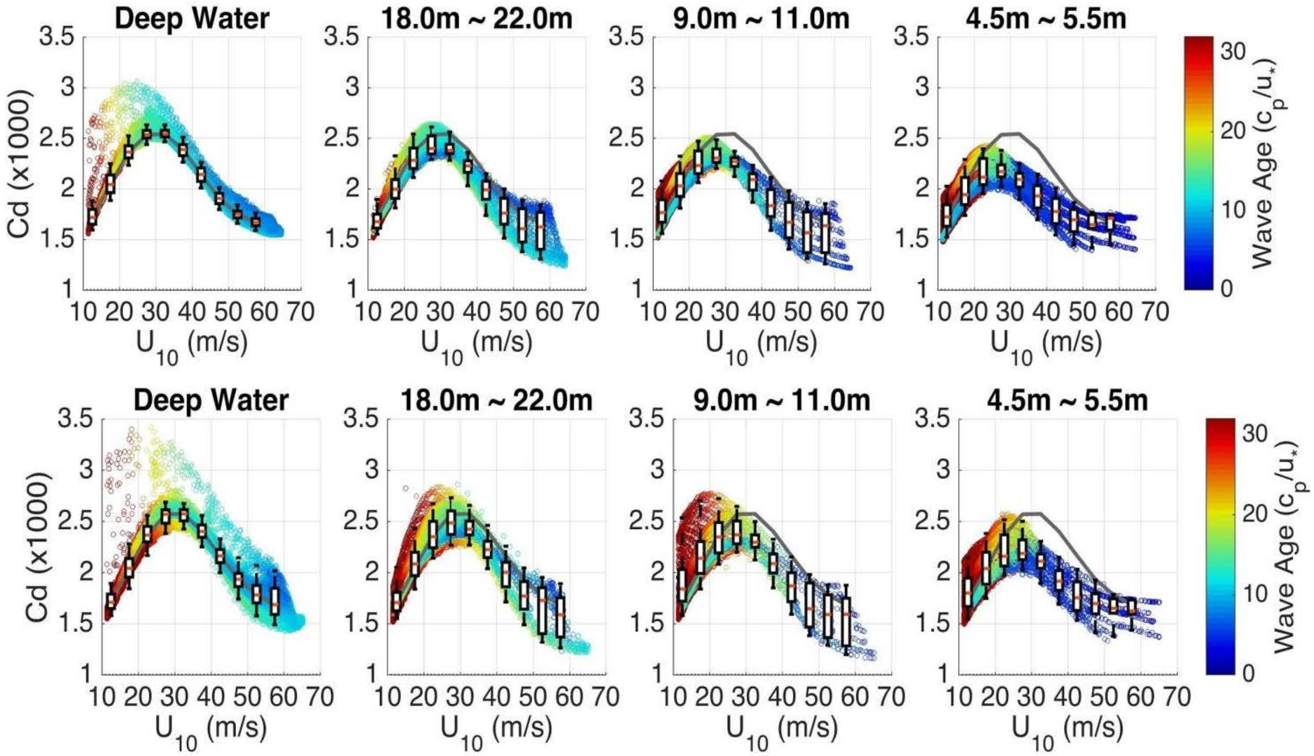


Figure 5.13 Variation of sea state dependent drag coefficient with water depth. (Top row: U_T = 5m/s; bottom row: U_T=10m/s)

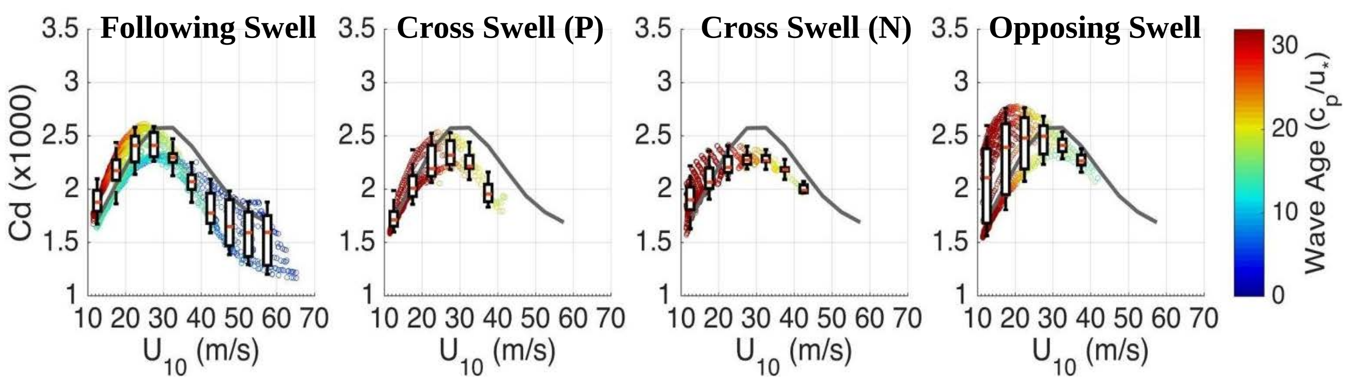


Figure 5.14 Variation of Sea state dependent drag coefficient at 10m depth in 4 wave categories: following swell, cross swell positive, cross swell negative and opposing swell (from left to right). (U_T=10m/s)

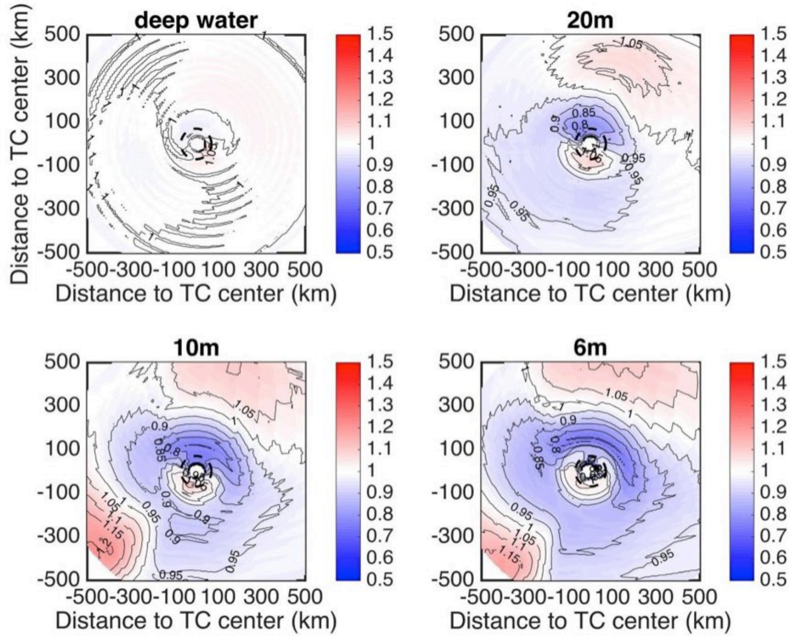


Figure 5.15 Spatial variation of sea state dependent drag coefficient shown as the ratio to the median Cd. (U_T = 5m/s). In deep water, horizontal distance and time are interchangeable because the wind and wave fields are stationary relative to the moving storm. At finite depths results are obtained as a function of vertical distance and time (not horizontal distance) only. However, the results are presented after time is converted back to horizontal distance as in deep water.

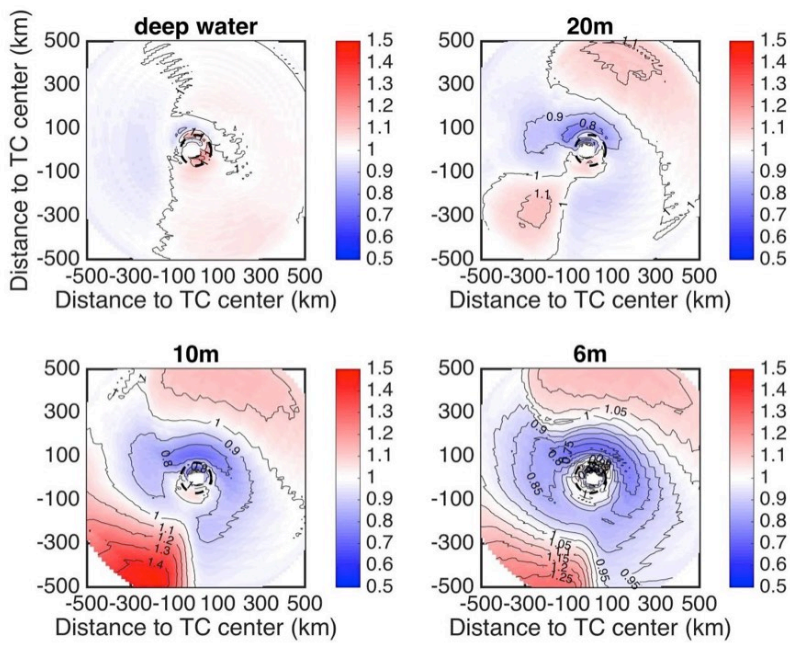


Figure 5.16 Same as Figure 5.15 but with U_T = 10m/s.

6. Rainfall runoff modeling in Blackstone River Basin by Applying PRMS model

6.1 Description of PRMS Hydrological Model

The Precipitation-Runoff Modeling System (PRMS), is a deterministic, distributed-parameter, physical process-based modeling system developed by USGS to evaluate the response of various combinations of climate and land use on streamflow and general watershed hydrology (Markstrom et al., 2015). PRMS's modular design allows users to selectively couple the modules in the module library or even to establish a self-design model. It has been widely applied in the research of rainfall-runoff modeling and was proved to be a reliable hydrological model. PRMS includes the modules of climate, plant canopy, impervious-zone interception, surface runoff, subsurface flow, groundwater, streamflow routing, evaporation, and snowpack. The model simulates the hydrologic processes of a watershed using a series of reservoirs that represent a volume of finite or infinite capacity. Water is collected and stored in each reservoir for simulation of flow, evapotranspiration, and sublimation. Surface runoff, interflow, and groundwater discharge simulate the flow to the drainage network segments, e.g. stream-channel and detention-reservoir. Surface runoff from rainfall is computed using a contributing-area concept. It is the most outstanding element of streamflow. The most influential elements of surface runoff and infiltration module in PRMS are subbasin area, surface storage depression, impervious area, and type of variable-source area. Subbasin area, impervious area, and type of variable-source area determine the water's transformation from precipitation to surface runoff. Depression parameters affect water storage during and immediately after precipitation events. A reservoir routing method is used to compute subsurface flow which is a rapid movement of water from unsaturated zone to stream channel. The groundwater is conceptualized as a linear reservoir and is assumed to be the source of all baseflow. Streamflow could be computed directly as the sum of surface runoff, subsurface flow, and groundwater discharge that reaches the stream network. However, a Muskingum flow-routing method computing streamflow to and from individual stream segments is also available in the module. PRMS uses the Muskingum method to calculate the stream flow route. Phase is determined by parameter kinematic wave coefficient (K_coef) that represents the travel time of flood wave in each segment.

The PRMS model has been applied to some rainfall runoff and snowmelt modeling. Niswonger et al., (2014) applied the PRMS model to an integrated decision support system. Markstrom and Hay (2009) used the model to investigate watershed responses to climate change. Hay et al., (2006) applied PRMS to a snowmelt-dominant watershed. Hay et al., (2000) and Christiansen et al., 2001) evaluated climate change impacts on rainfall runoff by PRMS model simulations. Dressler et al., (2006) conducted an evaluation of snow water equivalent for mountain basin in the PRMS model. Markstrom et al., (2008) integrated PRMS model into a ground and surface water flow model GSFLOW. In these studies, PRMS was applied to perform long-term hydrological process in order to provide supports to the local water resource managements. Yates et al., (2001) applied PRMS in flood forecasting in mountain region to explore how the accuracy of precipitation distribution in space and time affect the model's simulation. Tian et al. (2015) and Wu et al. (2015) applied the PRMS model through the application of GSFLOW to study the interactions of surface and ground waters in large river basins.

6.2 Application of PRMS model to Blackstone River Basin

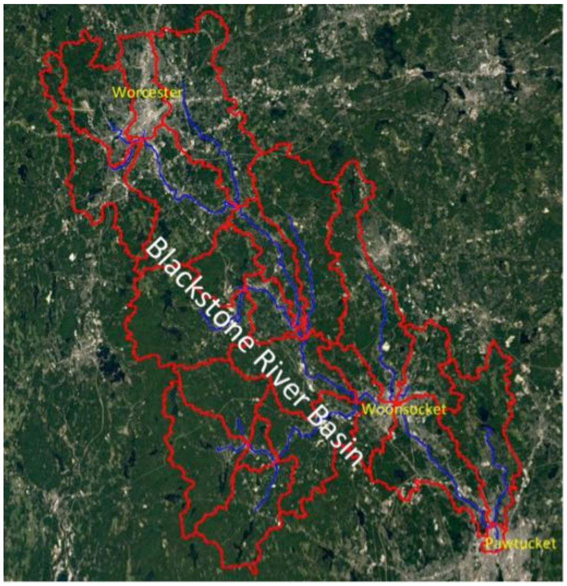


Figure 6.1. Blackstone River Basin, Rhode Island and Massachusetts, USA

In order to simulate the daily flow of Blackstone River Basin, PRMS model has been applied to establish the rainfall-runoff model in the Basin. National Hydrography Dataset and National Elevation Dataset provide Blackstone River Basin's DEM and river distribution data. PRMS's hydrological response units (HRU) and segments were calculated from the data above by EPA's BASINS system. The basin totally has 24 HRUs and segments for PRMS model's simulation (Figure 6.1). Basin's geographic information (sub-basin's area, slope, aspect, latitude and elevation), reaches' topological structure (stream length, side slope and longitudinal slope) were calculated by EPA's BASINS model.

Time period from February 1st to Dec 31st 2009 was used for model's calibration while the time period from February 1st to Dec 31st 2010 was used for model's verification. Time periods of January in 2009 and 2010 were used for model's initialization. The data series of daily flow which was observed at Roosevelt ST at Pawtucket, RI (Latitude 41°53'19", Longitude 71°22'55") by USGS were used for model calibration and verification (Figure 6.2).

Climate input data was obtained by NOAA's meteorology station, including daily maximum and minimum temperature, precipitation, evaporation, and solar radiation. Figure 6.3 shows the observed precipitation data at Woonsocket.

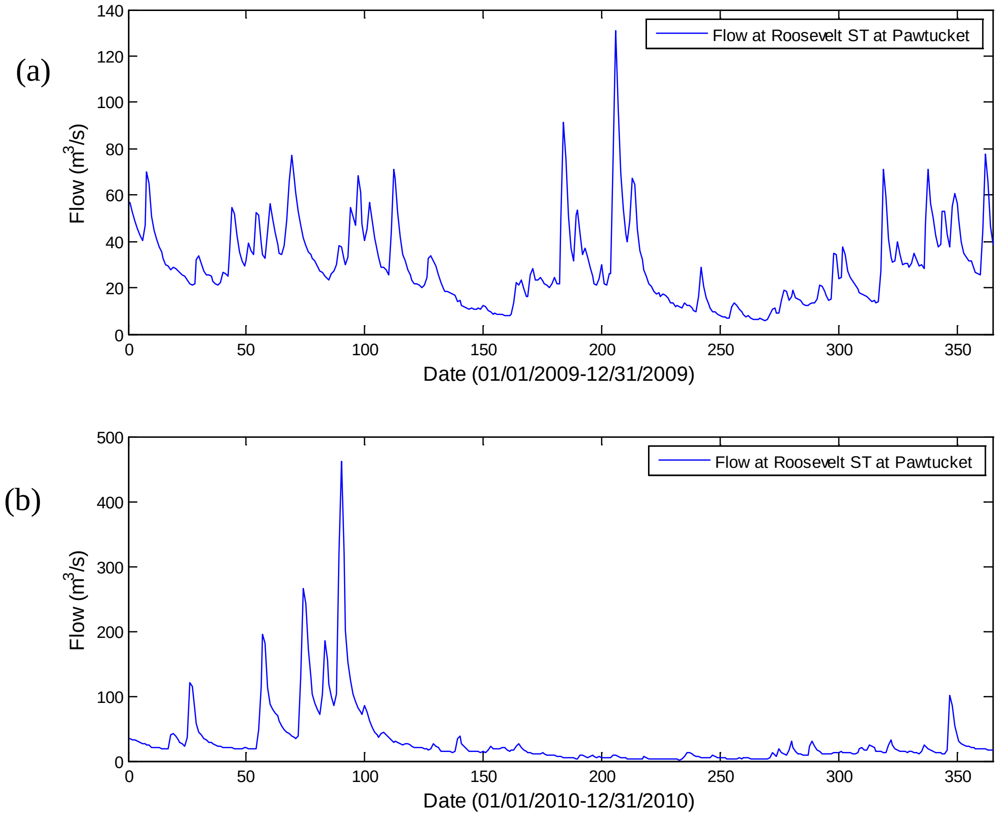


Figure 6.2. Blackstone River's observed flow at Roosevelt ST at Pawtucket, RI: (a) Year 2009; (b) Year 2010.

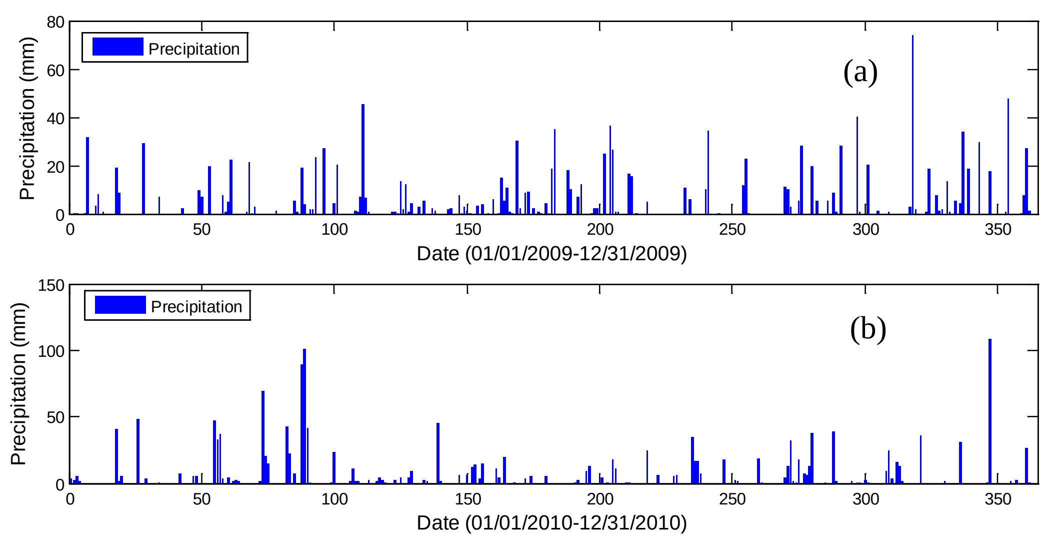


Figure 6.3. Observed precipitation at Woonsocket: (a) Year 2009; (b) Year 2010.

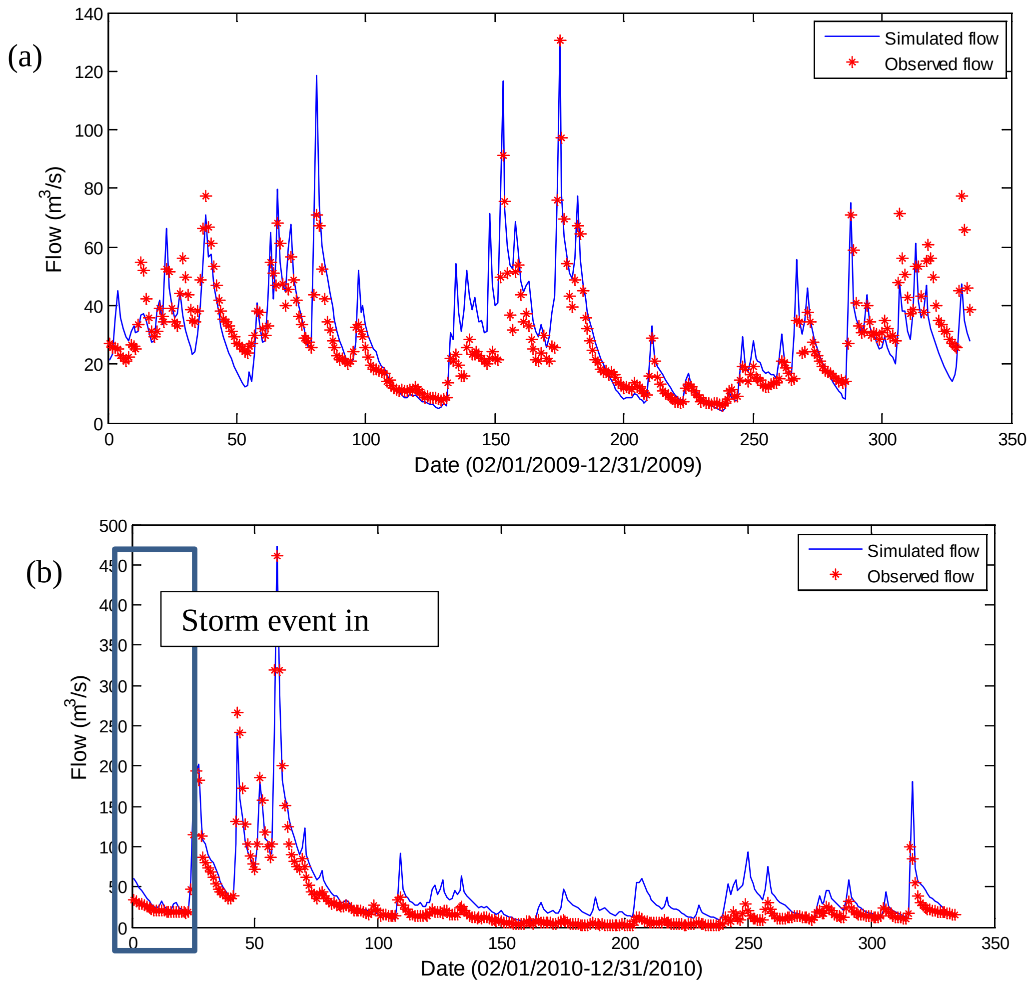


Figure 6.4. Comparison between observed flows at USGS gauges with PRMS simulations: a) year 2009; (b) Year 2010.

The simulation results indicate that PRMS model provides a reliable predictions of the daily rainfall runoff at the outlet of Blackstone River Basin. The correlation coefficient between simulated and observed flow of time period in 2009 is 0.8546 while the root mean square error (RMSE) is 10.1 m^3/s. These two values for the time period in 2010 are respectively 0.9466 and 20.6 m^3/s.

For the case study of extreme rainstorm event in March 2010, the hydrograph observation of maximum flow on March 31st is 461.3 m^3/s. The corresponding value simulated by PRMS model is 472.6 m^3/s. The error is only 2.4% (Figure 6.4). Therefore, for potential storm or hurricane events in the future, the PRMS model will be capable of providing reliable predictions of rainfall-induced runoff as the input for the ADCIRC flood hydrodynamic model for modeling flood area in the coastal rivers and flood plain. Previous modeling studies in Woonasquatucket River of RI indicates that ADCIRC model provides similar simulations of flood areas as HEC-RAS in the lower portion of the river, where storm runoff and storm surge interacts.

7. Real Time Chronological Hazard Impact Modeling

7.1 Introduction

The potential of ocean models such as the ADvanced CIRCulation model (ADCIRC) for assessing hazard impacts on individual critical facilities (e.g., inundation of a hospital) has long been recognized (e.g., Brecht, 2007). This includes creating time incremented assessments that illustrate the progression of hazard impacts during a storm (Brecht, 2007, Aerts et al., 2018). While methods for creating aggregate hazard models depicting large regions are well known (e.g., HAZUS), methods for creating highly granular impact models of individual points that take advantage of the time incremented aspect of ADCIRC models are not thoroughly elaborated (Brecht, 2007, Aerts et al., 2018). This may become increasingly important as researchers propose increasing integration of highly specific qualitative data to models (Aerts et al., 2018).

One means to realize this capability and enable forecasting of impacts to be run concurrently with or immediately following an ADCIRC model run is use of an all numerical process in which elevation and vulnerability data inheres with individual geographic points (representing individual facilities or objects) in a tabular format. Combining elevation and facility-based data into tables makes it possible to link geographic databases and ocean models using a variety of programming languages and eliminates the need for translation of data between formats (e.g., unstructured grid to raster or polygon in GIS). The implementation of this method makes it possible to use ADCIRC as a rapid hazard impact forecasting tool, and further supports the development of near-real-time visualization of modeled impacts.

7.2 Architecture of the All Numerical Method

Parallel of the HBL wind model and hydrodynamic simulations, the URI Department of Marine Affairs (MAF) has been developing hazard impact modeling and visualization methods based on the previously described all numerical connection to underlying models. Although this paper focuses primarily on connection to ocean models such as ADCIRC, the fundamental architecture can be applied to wind models or other simulations. Using these methods, geographic points representing specific pieces of infrastructure are indexed directly to multiple nodes of the simulation (Stempel, 2016).

Traditional GIS workflows typically involve transforming outputs of the ADCIRC or other model into raster maps or polygons that can be compared to geographic points using ArcMap or other applications. Depending on how this is accomplished, such procedures may involve multiple manual steps for each timestep tested, or compilation of maximum values. By contrast, the all numerical method pre-indexes each geographic point to nodes of the ADCIRC model (methods for interpolation are discussed in a subsequent paragraph). This indexing allows the values from the ADCIRC model to be associated with the geographic point, and for operations (calculating inundation depth at the point for instance), to be carried out continuously for each point for every time step without manual intervention.

The initial implementation of the all numerical method tested structures in the area around Galilee, Rhode Island, USA, and implemented damage functions developed by the U.S. Army Corps. Of Engineers as part of the North Atlantic Coast Comprehensive Study (Coulbourne et al., 2015). Once indexed to the unstructured grid, the structures and visualizations of those structures could be automatically updated based on adjustments to the model run, or tested against other storms (e.g., Hurricane Carol) that was run on the same grid (Figure 7.1). In addition to cataloging attributes of structures, extensive data was gathered for testing of debris objects and infrastructure such as electrical transmission poles.

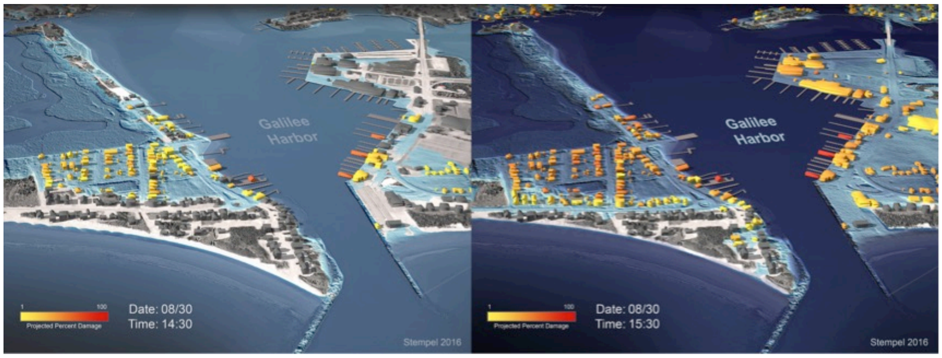


Figure 7.1 Progressive hazard impact model depicting the landfall of Hurricane Carol (1954) at the port of Galilee, Rhode Island, USA, at present sea level and build out. Hazard impacts for each structure are calculated using the all numerical method. Outputs are configured to be directly used by the 3d visualization platform such that damage levels may be displayed for any timestep.

The fundamental architecture used to depict Galilee, Rhode Island USA, formed the conceptual basis for developing the all numerical method into a rapidly updatable method for hazard impact modeling in which tabular databases of information of geographic information are pre-indexed to the nodes of ocean models. Outputs from the hazard impact models are formatted to drive visualization and rendering platforms (e.g. Unity) such that outputs may control pre-established 3d model content. Simpler outputs may include dashboards, or, in the case of the IEMC, time incremented tabular impact reports.

7.3 Data Interpolation

The fundamental innovation of the all numeric method is relating the geographic point and its attributes to the sea surface as described by the unstructured grid and interpolating values where necessary. The advantage of not using interpolation is speed of analysis over multiple timesteps. To determine the necessity of interpolation between points, a sensitivity test was performed in an area of concern in analyses, the Port of Providence. This analysis entailed 12,176 nodes. The first, second and third nearest neighboring points ranged between 22.8m apart and 73.9 meters. The variation reflects the optimization of the unstructured grid to fit the topography (e.g., greater node separation where less detail is required).

Most adjacent nodes vary by less than .003 meters (+/- 1/10th of an inch). The maximum variation between adjacent nodes in the sample set is .015 meters (.5 inch). Given the small variation between relevant nodes, it was decided that interpolation was un-necessary. Similar tests in other sites yielded similar results. The maximum variation between nearest nodes across the State of Rhode Island for these timesteps is 2.47 meters, reflecting adjacent nodes in Block Island Sound. Interpolation, where necessary, may be accomplished by indexing the geographic points to multiple adjacent nodes and using geometric interpolation, or processes such as inverse distance weighting. It's unlikely, however, that in situations where nodes are closely spaced such interpolation will be required. The indexing and associated interpolation or extraction methods include geographic points with three adjacent wet nodes (nodes which are reported to be inundated by the ADCIRC model): interpolate sea surface elevation, water direction and velocity based on the geometric relationship of the point to the planar surface described by the three points. Geographic point beyond the last wet node: use nearest adjacent node without interpolation (Figure 7.2).

This interpolation method presumes that sea surface is described by the z of each node as a Delaunay triangulation. This is the optimal triangulation for the unstructured grid and thus identical to the ocean model grid with the exception of reflecting z elevation of the water surface (Chen and Xu, 2004) (Figure 16). The interpolated value is understood to be measured where it intersects with the plane described by the three points. Interpolation between node points is thus optimized for each geographic point based on the available data (Chen and Xu, 2004). The evaluation of points beyond the model grid accounts for situations where small-scale topographic conditions would cause inundation to extend beyond the last wet point of the ADCIRC model. All points are constrained by a basin analysis, such that points outside of the basin are not included. Vertical data, such as LiDAR derived ground elevation, inheres with the geographic point. Registration is accomplished by referencing a common datum.

Figure 7.2 Example of a point with three adjacent nodes (green) and point beyond the nearest wet node (blue). The red lines represent wet portions of the unstructured ADCIRC grid. Points tested are both inside and outside of the grid, and constrained by a basin analysis.

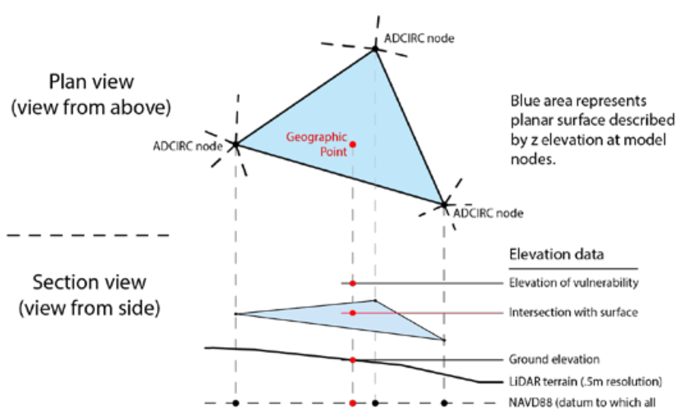


Figure 7.3. Interpolation between three points. A geographic point representing a facility is shown in red. The plan view is juxtaposed with a section view showing examples of elevation data related to the point.

The use of this method avoids compromises in speed and resolution associated with the translation of node-based data into raster maps. It allows outcomes for multiple timesteps to be easily determined and updated, and also preserves the elevation of the sea surface. Determining whether points are inundated based on transforming the wet portions of an ADCIRC model into a polygon defining inundation extent, by contrast, effectively transforms the middle areas of the simulation into a bathtub model (geographic points wet or not wet) even if the edges of the polygon capture elevation variation (e.g., if the polygon is determined through the comparison of two raster maps). In locations where there is significant change of geography, such as the narrowing of a river, the elevation of sea surface can vary by measurable amounts even in small geographic areas. (Figure 7.4).

Additional data, such as finish floor elevation of a structure, freeboard (clearance to vulnerable portions of a structure) details of its construction, or the presence and elevation of protective barriers such as flood walls inheres with the geographic point so that all calculations relevant to its involvement may be accomplished in a single process. Hazard impact assessments made with this method may thus combine a high degree of intricacy with speed, and potential improvements in resolution associated with interpolation.

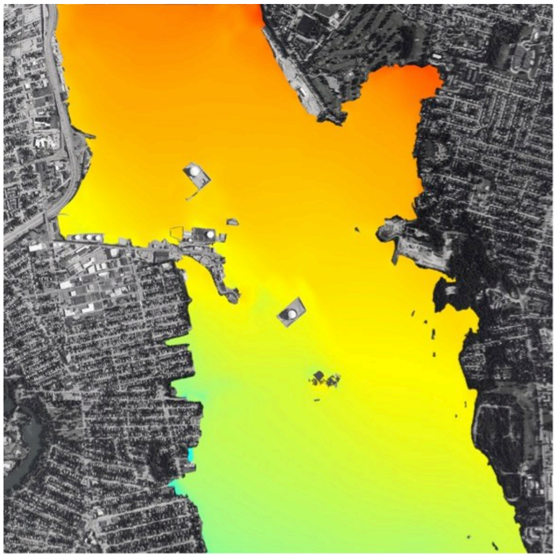


Figure 7.4. Variation in sea surface during a modeled inundation event. Total variation +/- 1 meter; total area shown $14km^2$. Lowest relative elevation shown in blue, highest relative elevation shown in red.

7.4 Quality of Spatial Data

The improvements to resolution and intricacy referenced above are highly dependent on the quality of underlying data. A fractional improvement to methodology is meaningless if there are gross errors in underlying points. The resolution of data often depends upon the purpose for which it was created (Liu and Palen, 2010, Couclelis, 2003). Developing highly specific predictions based on generalized data that has not been vetted for that purpose is thus problematic, and create misleading results that imply a level of precision that is not supported (Liu and Palen, 2010, Sheppard and Cizek, 2009). Ground truthing of geographic points, a process of determining whether point data is sufficiently detailed or accurate, is thus essential if highly specific predictions are to be made.

Points associated with databases made for other purposes, such as e-911 databases, while sufficiently accurate at geographic scales may have limited utility at granular impact modeling scales. A single point representing a wastewater treatment facility, for instance, may be located arbitrarily or at the centroid of the land parcel that the facility occupies. The elevation of this point may be at a significantly different elevation than vulnerable portions of the facility. Moreover, facilities may include multiple vulnerabilities with distinctly different hazard exposures (e.g., inundation vs. wind). For this reason, individual points in here to individual structures within a facility, or minimally, are located based on vulnerability.

A sensitivity test comparing elevations of existing point data (obtained from Rhode Island GIS, e911, and Department of Homeland Security Office of Cyber and Information Security) was performed to compare the existing points used in analyses (e.g., points marking structures or the centroid of the property) with the elevation of the vulnerability (e.g. a clarifier that will be damaged if water exceeds an elevation). This analysis revealed the difference between the lowest existing point and lowest point of vulnerability had a mean of 2.33 meters. In the analysis, least elevated points for each site were compared with least elevated vulnerabilities (Table 7.1), and most elevated points were compared with the most elevated vulnerabilities. Thus, this assumes that when existing points are used in an analysis that the “worst case” is utilized. Had highest been compared to lowest, the variations would have been more extreme. Waste water treatment facilities, which employ gravity as part of processes, often feature elevation changes on site, and are therefore acute examples, however they are not unique.

Table 7.1, summary of sensitivity test of 14 Waste-water treatment facilities in Rhode Island. "Existing - lowest" refers to the lowest existing point tested minus the lowest elevated vulnerability on site.

	Range	**Existing - lowest**	**Highest - existing**
Max	14.18	5.42	0.82
Mean	4.54	2.33	-0.92
Median	3.34	1.55	-0.73

Bridges, similarly create complex analytical problems, as they are subject to multiple forces (e.g., scour, shear) (Robertson et al., 2007, Padgett et al., 2008), and often involve structures at multiple elevations. Representing a bridge as a single point is therefore problematic. In addition to the question of structural damage, there is a larger question of the role the bridge plays in emergencies in providing access. For this reason, special attention was paid to the elevation of highway access points in analyzing data for the IEMC (Figure 7.5). These access points play a significant role in transportation to and from a major Hospital.

Ground truthing is also necessary where micro-topographical conditions are invisible to the ocean model. Such is the case with armored concrete reinforced protective dikes that surround liquified natural gas storage tanks in the Port of Providence (Figure 7.6). These types of conditions have necessitated the development of special attributes within databases developed for the IEMC and other projects. The presence of these dikes, including the threshold at which they are overtopped, is included in the point data representing the tank. Although wind damage to petroleum storage tanks was not specifically modeled for IEMC, these facilities serve as a primary example of points that can have multiple damage modes (e.g., buoyancy, wind damage) (Chang and Lin, 2006), and thus may require data for multiple analyses.

Beyond obvious issues of accuracy associated with using granular data, attention to observed conditions likely plays a significant role in the perceived credibility of visualization outputs (Lange, 2001, Schroth et al., 2011a, Hayek et al., 2010). To the extent that abstract simulations like ocean models are treated as equivalent to reality without sufficiently accounting for these conditions there is a danger that inconsistencies between the model outputs and observed reality undermine the credibility of the models when they do not agree with observed reality (Wynne, 1992).

Figure 7.5. Comparison of points located at highway access ramps compared to span centers (green). Before being corrected, span elevation was recorded as the channel bottom (bathymetry). A more logical way to determine whether a span would be compromised would be to ascertain elevation based on the underside of the span (direct impact/shear failure) or at pier locations (scour).

Figure 1.6. Example of micro-topographical condition. The gasometer is protected by an armored concrete dike that is not ‘visible’ to the ocean model. Determining inundation extents without accounting for this dike will lead to misleading results.

7.5 Participant Input

The role of experts in developing hazard impact models is widely recognized, and is, for instance, specifically cited in the recommended methods for developing impact models beyond level 1 models as part of HAZUS (Vickery et al., 2006, Schneider and Schauer, 2006). As previously argued however, there are logical questions regarding the application of generalized statistically derived damage curves to highly specific structures. Even in situations where appropriate ground truthing has taken place regarding the geometry of a vulnerability, the application of a generalized curve may not be appropriate. The description of highly specific outcomes based on vague data, for instance, can make highly uncertain outcomes appear certain (Kostelnick et al., 2013). This issue was particularly concerning as it pertained to the IEMC because of the need for highly specific outcomes (e.g., disruption of a generator or communication tower) to be reported as prompts used during the exercise.

To address this, a process to engage emergency managers was initiated at the outset of the process in collaboration with RIEMA. This process enlisted local emergency managers in the development of model inputs that would be used in generating the hazard impact models. These inputs primarily included the development of a “thresholds database” that included specific facilities of concern and quantifiable thresholds at which described outcomes could be expected.

The concept of using thresholds or triggers to define inter-related impacts of storm events is drawn from approaches to planning that seek to organize responses to uncertain future conditions and interdependencies (Ranger et al., 2013, Brown et al., 2011). In these planning processes, thresholds are identified for different levels of future hazards to assess future vulnerability (Brown et al., 2011, Ranger et al., 2013). As it pertains to the methods used by URI, quantifiable triggers related to measurable effects of wind, rain, and inundation were collected to be used as model inputs to be tested against storm scenarios and incorporated into databases tested against the relevant models. Where multiple factors contributed to a specific impact (e.g., the combination of wind and ground saturation from rainfall), connection between models was made manually. In future iterations, it is conceivable that such hand offs could be made automatically between parallel models referencing a common point database.

The adaptation of these methods made it possible to extend impact modeling to facilities for which there were not existing damage functions (e.g., communications towers compromised by wind or inundation, or cascading effects of communications outages). If further provided a credible basis for including areas of concern not conventionally captured by point based analysis (e.g., needed evacuation of a trailer park based on ground saturation and wind, creating a tree fall hazard).

It also provided an opportunity for local emergency managers, and emergency managers overseeing the process to participate in the development of the hazard impact modeling, such that outcomes tested in the models reflected ongoing stakeholder input. This involvement of participants has the potential to increase transparency and make the technical aspects of the process less of a “black box” (Schroth et al., 2011b). This participation may serve to enhance the perceived legitimacy of the outputs and build faith in the process (White et al., 2010). The further development of these methods thus not only expands the range of impacts that can be credibly modeled at a granular scale; it may be critical to the perceived credibility of the underlying processes (White et al., 2010).

7.6 Next Steps

The all numerical approach to hazard impact modeling has been developed as part of a larger effort to connect high resolution ocean models to detailed 3d visualizations. This is accomplished by indexing 3d model assets of structures and objects such as buildings bridges, telephone poles, and debris objects to the previously described geographic points. In the context of the IEMC, the use of these visualizations was confined to depicting inundation (Figure 7.7) for two reasons: 1) While the potential of 3d visualizations to make difficult to imagine impacts seem more tangible is widely acknowledged (Moser and Dilling, 2011, Sheppard, 2015), the effects of such visualizations on perceptions of risk, however, is less clear (Kostelnick et al., 2013, Bostrom et al., 2008). There are concerns that highly detailed depictions of impacts may make uncertain outcomes appear more certain than they are by virtue of contextualizing less detailed information in highly specific contexts (Kostelnick et al., 2013). Further research is needed to better understand the effects of these visualizations on risk perception. There is more generally, a lack of understanding of how 3d graphics and visualizations may influence perception of risk (Kostelnick et al., 2013). The development of the thresholds database, and the implementation of iterative processes involving end users is based in part on practices intended to contextualize and support the use of visualizations (Schroth, 2010). These practices will be further developed and refined based on the outcome of these surveys. 2) At the time of the IEMC databases had only been developed for a limited number of sites and facilities. Representations that mix structures for which there is highly detailed information available with structures for which there is no data may create misleading impressions due to the absence of reported effects. To the extent that specific vulnerability information is gathered from multiple emergency managers, there is also a concern regarding the consistency of the reported data for modeling purposes. This requires further development of consistent methodologies to elicit vulnerability data. The implementation of the databases as part of the IEMC has led to an ongoing collaboration between RIEMA and URI to develop more comprehensive databases for critical facilities in the state.

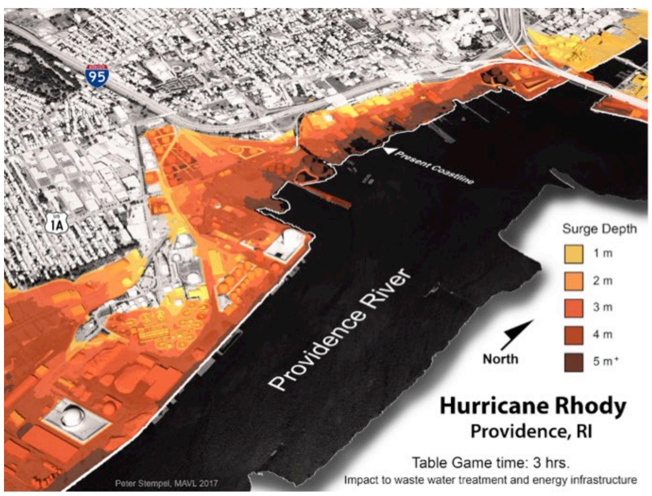


Figure 7.7. Inundation of waste water treatment and petroleum infrastructure near the height of the first surge of the simulated storm (Hurricane Rhody). Structures depicted in the visualizations are individual 3d models that are linked to hazard impact model output tables.

7.7 Conclusion

The implementation of these methods as part of the IEMC suggested that there was merit in the use time incremented impact analysis to better understand the progression of storm impacts. For instance, impacts of the 1938 Long Island Express hurricane which is often referenced by citizens and emergency managers in Rhode Island unfolded with particular swiftness for much of the state (Allen, 1976, Blake et al., 2007). The simulated storm used for the IEMC, by contrast, combined rapid storm surges and lingering rain and wind effects over multiple days. The volume of rainfall (46”) generated by the storm was more similar to Hurricane Harvey which made landfall two months after the exercise than it was to the Long Island Express (Pérez-Peña et al., 2017, Allen, 1976). The catastrophic effects of rainfall of Hurricane Harvey are a stark reminder that Hurricanes may do damage through means that are not anticipated by the public or emergency managers (Pérez-Peña et al., 2017), and that may be very different from previously experienced storms. This may be especially important at a time when, through the use of high resolution modeling, we can anticipate the possibility of highly unlikely but catastrophic events (Lin and Emanuel, 2016).

The use of time incremented hazard impact modeling also raises questions regarding the compression of events in training exercises. Damage modeling provided by the Department of Homeland Security Office of Information and Cyber Security (DHS OICS) that was also used in the exercise, indicated substantial wind impacts (80-100% of the state without power) 24 hours before the first storm surge made landfall. This placed substantial impacts prior to the bulk of the exercise, which was centered on the first of two storm surges. Furthermore, maximum rainfall occurred in the days following the first surge, prior to a second lesser surge making landfall. This points to a what may be a larger issue to be aware of during training: the compression and potential misordering of anticipated effects. To the extent that storm impacts can vary widely, chronological impact assessment may be a valuable tool to better anticipate and train for the impacts of hurricanes. These experiences, although limited in scope, suggest that further development of these methods is warranted to improve the capacity to predict and depict impacts of modeled storms.

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Overcoming Barriers to Motivate Community Action to Enhance Resilience

Final Project Report

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Overcoming Barriers to Motivate Community Action to Enhance Resilience[1]

Final Project Report

I. Introduction

This report describes activities carried out by our Research Team on behalf of the Department of Homeland Security Coastal Resilience Center of Excellence hosted at the University of North Carolina. The goal of this project is to improve our understanding how to improve community preparedness for coastal storm hazards by identifying barriers to adoption of protective actions, to identify interventions designed to overcome those barriers and to test interventions, as feasible.

How This Research Contributes to DHS Information Needs

This research will meet DHS priories by improving our understand of how to strengthen national preparedness and improving the resilience of coastal communities in the face of coastal storm hazards. As such, this research addresses Presidential Policy Directive 8, which calls for increasing our level of National Preparedness by preventing, mitigating, responding to, and recovering from the hazards that pose the greatest risk. Hurricanes are clearly among the the greatest risks we face, accounting for ten out of the top 15 most expensive natural hazards in US history, including the top 3 (NOAA, 2015)

Coastal communities face significant and increasing risks from coastal storm hazards. Despite the serious threat, communities are often slow to adapt to storm hazards by implementing measures to mitigate damages, including measures that appear to be of considerable benefit to the community. This has resulted in what has been termed the "adaptation deficit" (e.g., Burton, 2009), whereby actions to adapt to climate change threats are debated but never actually adopted or implemented.

It is widely recognized that national preparedness for hazards is not simply the responsibility of the government, but rather preparedness is a responsibility that is shared by everyone—including citizens, the private sector, and communities (e.g., Department of Homeland Security, 2014; National Academy of Sciences, 2012). Yet recent studies have shown that individual preparedness has remained largely unchanged for at least a decade (e.g., FEMA, 2014). Our research methods conform to the core guiding principles of the DHS Whole Community approach (Department of Homeland Security, 2014):

(1) Understanding and meeting the actual needs of the whole community;
(2) Engaging and empowering all parts of the community; and
(3) Strengthening what works well in communities on a daily basis.

There is now a significant literature that identifies impediments to adaption to coastal storm hazards, and that describes policy interventions (e.g., Ehrlich and Becker, 1972; Dionne and

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Eeckhoudt, 1985; Kunreuther, 1999; Kelly and Kleffner, 2003; Kunreuther, 2008) We do not repeat barriers and policy from that literature. Rather our research process uses we use various public forums, individual interviews, and review of news media reports to obtain some additional insights into steps that might be taken to improve community preparedness.

Organization of the Report

This report is organized as follows. Part I of the report provides an overview of the research activities of the project. The first chapter of Part 1 describes the pertinent literature on behavior change that was influential in the design of our research. The next chapter provides a set of brief overviews of the main research activities of the project. Part II of the report is comprised of several chapters that provide more detailed descriptions of the purposes, methods and findings of the major research activities.

It is important to note that several of these research activities were carried out with external funds that were leveraged with DHS/CRC funding, and these activities were developed in close collaboration with end users at the national, regional and local levels. It is important to note that these particular research activities were designed specifically to meet the needs of end users. This necessitates a degree of variability in the coverage, writing styles, and degree of technical detail of these research activities.

Part 1 Overview of Framework and Research Activities

II. Behavior Change Conceptual Framework

This chapter summaries the behavior change framework that we use in this project to improve our understanding of how to motivate individuals, organizations and communities to more actively engage in managing coastal storm risks. As indicated above, the need to engage the whole community in preparedness for coastal storm hazards is increasingly evident (e.g., DHS 2016; FEMA 2014; NRC, 2012). But doing so involves the challenge of bringing about a major change in behavior of the various affected communities, broadly defined, that is of necessity a long-term process (e.g., FEMA 2014).

A well-known finding of the social science literature is that simply providing information is not sufficient to bring about behavior change (Stern, 2000; Scott, 2002; Webb and Sheeran, 2006). Instead, carefully planned and well-designed interventions are needed (Velicer et al, 1998; Moser and Ekstrom, 2010; Lindell and Perry, 2012). This project adopts lessons from these frameworks for behavior change, including the Transtheoretical Model (TTM; Velicer et al., 1998), the Staged Approach to Adaptation (Moser and Ekstrom, 2014) and the Protective Action Decision Model (Lindell and Perry, 2012).

Below we summarize the three models of behavior change referred to above. A major finding of this literature is that behavior change is a not a single event, but rather is a process that requires decision makers to advance through a series of stages. This has important implications for programs to expedite behavior change, because different actions are effective for different individuals at the various stages of the behavior change. Thus, there is no "one-size-fits-all" policy action to bring about behavior change. Rather, a targeted approach is called for, whereby different interventions are designed to help expedite progress at overcoming barriers that are specific to each of the various stages of behavior change.

The Transtheoretical model (TTM; Velicer et al., 1998) is based on 5 stages of behavior change:

1. Precontemplation: The individual has no intention to change behavior. The individual may not even be aware of new behaviors or why change may be desirable.
2. Contemplation: The individual is generally considering changing behavior, but is not yet prepared to adopt new behaviors.
3. Preparation: The individual is actively considering specific options to change behavior in the immediate future.
4. Action: The individual changes behavior, but the new behaviors are not yet firmly established.
5. Maintenance: The individual has adopted a different lifestyle, where the new behaviors are firmly established as the normal mode of operation.

Other models are based on very similar process models of behavior change. For example, the Staged Approach to Adaptation (Moser and Ekstrom, 2014) has 9 stages that are comprised of three general Phases: Understanding, Planning, and Managing. Each of these phases is divided into three sub-phases. The Understanding phase is comprised of (1) Detecting the problem, (2) Gathering and using information, (3) Defining (or redefining) the problem with the new information. This Understanding phase is analogous to the TTM stages of Precontemplation and Contemplation. The Planning phase is comprised of (1) Developing options, (2) Assessing options, and (3) Selecting options. This is analogous to the Preparation phase of TTM. The

"Managing" phase is comprised of (1) Implementing options, (2) Monitoring and (3) Evaluating, which is analogous to Action and Maintenance stages of TTM. The Staged approach is explicitly a cyclical approach where there is no end point, but rather behavior change is a continuing process of changing a new set of behaviors after completing the previous set. Within the context of coastal storm hazards, communities complete protective actions for one set of threats, and cycle back to adapt to other threats.

The third model of behavior change is the Protective Action Decision Model (PADM) which conceptualizes decisions as a multi-stage process (e.g., Lindell and Perry, 2012), like TTM. But PADM focusses specifically on decisions to adopt protective actions for environmental hazards, such as floods or earthquakes. PADM considers how individuals' decisions to adopt protective actions (e.g., evacuation, or building retrofits) depend upon the processing of information they receive (e.g., hurricane warnings) to form perceptions of the threat they face, desirability of protective actions they might take, and actions other parties (e.g., protective actions taken by their neighbors, or evacuation orders from a state or federal agency). Given these perceptions, an individual may choose whether to take protective action, not take protective action, or seek more information before making a decision.

The PADM model also focusses on external conditions can either facilitate or obstruct adoption of protective actions. For example, well-publicized and attractive storm shelters can facilitate decisions to evacuate, while a lack of shelters can obstruct evacuation decisions. Similarly, protective actions can be facilitated by economic incentives such as cost sharing or insurance discounts, or by well-publicized programs that provide low interest loans or other financing for building retrofits. In contrast, an absence of such programs can obstruct decisions to adopt protective retrofits.

An important finding of the PADM model is the more stages in the decision process that are not adequately addressed, the more likely it is that individuals will choose to either not take protective action, or will delay the decision until they have a stronger motivation to take action.

As indicated above, these models of the stages of behavior change provide valuable insights because they recognize that different decision makers are at different stages in the process of behavior change. This project adopts the lessons from all of the approaches to behavior change in order to identify the stage in which Stakeholders currently reside; the barriers that impede them from progressing to subsequent stages; and various interventions that might be used to help them overcome those barriers.

FIMA's Preparedness in America (PiA) review document addresses this concept using "preparedness profiles" that refer to similar stages. The PiA documents describes the profiles:

1. Not on Their Radar, analogous to TTM's Precontemplation Stage
2. On Their Mind, analogous to TTM's Contemplation Stage
3. Working on it, analogous to TTM's Preparation Stage
4. Part of Life: analogous to TTM's Action and Maintenance Stages

Another advantage of the staged approaches to behavior change is they allow development of more timely metrics of program success by measuring progress along a spectrum towards behavior change. This is especially relevant for many of the behaviors that increase storm resilience, which includes many actions that happen only over long time periods, such as relocation of development outside of hazard areas or expensive construction activities such as elevating structures. In such cases, it is problematic to measure "success" only in terms of adoption of new behaviors, because it may take many years, even decades, to observe actual behavior change. In such cases we can run the risk of prematurely giving up on programs simply because long-term behavior change has not yet been observed. On the flip side, we might be too patient, and we persevere in expensive programs that truly are not successful. By the time it is clear that behavior change has not occurred in the long run, we would have spent enormous amounts of scarce funds and lost precious time with little or no progress to show for it.

In comparison, staged models of behavior change provide short run metrics of program effectiveness based on the extent to which progress is being through the various stages of behavior change, even if actual behavior change only occurs many years later. The means of more rapidly measuring program effectiveness (or lack thereof) allows us to employ adaptive management techniques, and revise or replace programs to improve community preparedness.

III. Summary List of Barriers and Interventions

This section briefly describes project findings regarding specific barriers improving community preparedness for coastal storm hazards, and potentially effective interventions to overcome those barriers. There is now a considerable literature on impediments to preparedness, and as indicated above, this report presents our findings, but does not attempt to provide a comprehensive review of the literature on impediments to improved community preparedness.

(1) Barrier to Behavior Change: The Rush to Rebuild

One important barrier we identified as part of our research is termed the "rush to rebuild" following storm damages. The immediate aftermath of a major storm event has been referred to as a "window of opportunity" to bring about action to increase resilience (Birkmann et al., 2010; Birkland, 2006). Major storms can serve as focal events that command the attention of decision makers, helping to adjust priorities and make major changes in the way society operates. As a consequence, it is often argued that major events can potentially serve as a tipping point, and provide a potentially advantageous time to take actions to improve resilience that may not be feasible in times of normalcy.

In the immediate aftermath of a major event, the financial, political and social costs of transition to adoption of protective actions may be minimized. Moreover, it is a time when both decision makers and the general public are most open to changing their way of thinking about events (Birkmann et al. 2010, Birkland 2006, Kingdon 1984). As noted by Chicago Mayor Rahm Emanuel, "You never let a serious crisis go to waste. And what I mean by that is it's an opportunity to do things you think you could not do before." Similarly, in reference to Super Storm Sandy, NOAA Administrator Jane Lubchenco remarked, "What can we do to take advantage of this horrible disaster? ... How can we have the next Sandy be something for which we are more prepared?"

While the immediate aftermath of the major storm may be an opportunity for change, the desire to return to normalcy is an important a barrier that impedes change at this time. As a consequence, we find that this "window of opportunity" for change provided by disasters can be of short duration, and it is often not well-used (Birkmann and Teichman 2010). People who are displaced from their homes or living with storm-related damages are anxious to have their life return to normal as quickly as possible. Similarly, businesses that are closed due to the storm need to resume operations as quickly as possible to minimize losses. Moreover, it is reassuring and politically advantageous to promise residents a return to normalcy as soon as possible. This creates enormous social and political pressures to rebuild as quickly as possible. This impedes our ability to rebuild damaged communities with an eye towards being less vulnerable to future storm events.

In terms of the models of behavior change, many displaced property owners are in the "precontemplation" stage of behavior change, because they are focused primarily on returning to their pre-storm circumstances as quickly as possible, and not thinking about increasing future resilience. This social dynamic of the rush to rebuild means that the "window of opportunity" of very short duration, if it exists at all. And displaced property owners must advance from precontemplation all the way to action within this very short time interval in order to capitalize on the window of opportunity.

This means the immediate aftermath of a storm is no time to start planning to become more resilient. Rather, this "rush to rebuild" social dynamic makes it imperative to have plans in place and ready implement, well before the need for rebuilding arises. And just as importantly, it is essential to have introduced ways to improve storm resilience to decision makers and to the public well in advance, to ensure society is receptive to change when the opportunity arises. As a consequence, strategies to encourage tipping points during the "window of opportunity" cannot simply wait for factors to align during an event; rather, we must start work immediately to prepare for and bring about change (Smith 2013).

Within the framework of the stages of behavior change, storm vulnerability audits can contribute to multiple goals when coupled with policies to incentivize the adoption of the recommendations. Property-specific recommendations from storm vulnerability audits are precisely the information that property owners need to move decision makers from "contemplation"–considering the possibility of taking action in a fairly general sense—to preparation, or having a plan for a specific set of actions. Thus, storm vulnerability audits can help overcome this barrier, which is termed "Not Knowing How to Get Prepared" identified in FEMA documents (FEMA, 2014).

Intervention: Storm Vulnerability Audits

Storm vulnerability audits coupled with policies such as expediting building permits for those who adopt the recommendations of audits, can also be effective in getting decision makers from "precontemplation" to "contemplation" to "preparation". Displaced property owners or property owners looking to make renovations might not wish to plan for future storms. But property owners could be more amenable to complying with recommendations of a prior storm vulnerability audit if it provides the most expeditious avenue to make repairs needed to get life back to normal, or to carry out desired renovations.

Furthermore, adopting the recommendations of a storm vulnerability audit might be coupled with eligibility for cost-sharing, low interest loans, reduced flood insurance premiums, etc., then a system of storm vulnerability audits might also contribute to the transition from "preparation" to "action" by providing much needed financial assistance. Note that "Believing that preparation is too expensive" is the top barrier identified in the FEMA's *Preparation in America* document (FEMA, 2014). A properly structured system of storm vulnerability audits, coupled with policies to incentivize property owners to adopt the recommendations, show promise as a tool for expediting the adoption of protective actions that are targeted to be most effective for the specific property.

An additional inducement might be to expedite building permits to repair damages in those cases where the property owner adopts specific recommendations from the storm vulnerability audits, and perhaps delaying permits for property owners who do not adopt important recommendations. This turns the "rush to rebuild" as an inducement to improve preparedness, rather than a barrier.

In 2006, the State of Florida instituted such a program, entitled the "My Safe Florida Home" (MSFH) program (e.g., Carson et al, 2013; http://www.wallstreetinstructors.com/ce/continuing_education/pc_ethics/pc_ethics6web_files/Page299.htm). The program provided for free wind inspections, and matching grants up to $5,000 for property owners who took actions recommended by the inspections. As of March 1, 2009, the My Safe Florida Home program received 42,887 grant applications and awarded 40,385 grants totaling $148 million for hurricane mitigation, and it was anticipated that 32,000 homes will have been retrofitted by the legislature's target date of June 30, 2009. (http://www.wallstreetinstructors.com/ce/continuing_education/pc_ethics/pc_ethics6web_files/Page299.htm)

Thus, the program appeared to be successful in overcoming barriers to improving preparedness for coastal storm hazards. Unfortunately, the program only lasted two years, and was cancelled in 2009 when the Florida legislature discontinued funding for matching grants in 2009. The budgetary concern was the primary reason for termination of Florida's program, as state taxpayers were in the position of providing the matching funds for individuals with coastal properties. An alternative is to have matching funds come from the insurance industry, who will save on claims if property owners adopt protective actions. Thus, the insurance industry could actually reduce outlays by providing matching funds to the extent that the program is effective motivating property owners to adopt protective actions that reduce mitigate storm risks, and subsequent damage claims (e.g., Kunreuther and Michel-Kerjan, 2009).

(2) Barrier: Threat is too "Theoretical"

In many cases community members viewed the threat of storm hazards as too "theoretical", and not sufficiently urgent. Many community members stated that they have more pressing things to think about, and they would worry about potential storm risks when the threat is more imminent. Community members also tend to have short memories, and have already moved on to other issues once the storm has passed and recovery is complete—often at great expense of both public and private funds. This represents individuals in the "precontemplation" and "contemplation" stages of behavior change, where individual have varying degrees of awareness of the issue and the reason for change, but have no immediate plans for changing behavior. This research activity was led by Drs. Austin Becker and Peter Stempel.

Of course, the challenge is that many decisions to mitigate storm impacts cannot be put off until a storm is imminent. Decisions such as making a structure more storm resistant, or relocating development only occurs over longer time periods. These decisions need to be made well in advance of a storm.

Intervention: Storm Impact Visualizations

We prepared 3-D visualizations of storm impacts as a way to make abstract risks like future coastal storm hazards seem tangible and relevant to community members by showing damages in local contexts (Stempel, 2016; Stempel and Becker, 2018). We also used these visualizations to engage the public and communicating risks, in combination with other exhibits and interactions in workshop processes. Figure 1 shows some example visualizations that were created and used in various stakeholder workshops. Further discussion of how we used visualizations in various workshops is contained in a later section of this report.

This research seeks to understand the ways in which realistic representations of storm surge and sea level rise impact perceptions of risk in order to provide guidance for practitioners, such as landscape architects, emergency managers, local planners, and policy makers. Visualizations of storm surge and sea level rise play an increasingly important role in decision making processes as communities confront climate change. Realistic portrayals of future conditions, such as inundation zones, help people localize and personalize what are otherwise very abstract concepts. The goal of this intervention is to help individuals transition from the "precontemplation" and "contemplation" stages, to the preparation stage.

Below are some of the key findings of this research activity:

(1) As advancements in visualization technology make it possible to use increasingly realistic visualizations it is important to further understand the implications these practices. When compared to traditional abstract maps, realistic visualizations can better communicate complex and nuanced information in a mode which humans have evolved to understand: imagery of the landscape. Since realistic visualizations create affective (emotional) responses on the part of the viewer, they may be more effective tools for communicating risk.

(2) Research has shown that cognitive understanding of risk alone may create misperceptions of risk when not aligned with an emotional response, thus it is possible that employing more realistic visualizations is essential to effective risk communication.

(3) The use of realistic visualizations also presents serious challenges. Realism can create the impression of certainty where there is none, and can invoke assumptions that strain scientific credibility. Increasingly common "mash ups" that combine realistic depictions of structures with abstract information of storm inundation can create further misconceptions due to a mixing information at different scales.

(4) Creating realistic visualizations of storm surge and sea level rise therefore requires both high ethical and technical standards.

We also carried out a preliminary test of some of the visualizations within the context of a coastal hazards pilot survey with visualizations administered to a treatment group (with visualizations), and a control group who answered the identical survey but with no visualizations. This survey was developed and administered by students participating in a Capstone class in the Department of Environmental and Natural Resource Economics at the University of Rhode Island. We found that respondents in the treatment of this pilot survey were significantly more likely to indicate the intention to take protective actions that increase storm preparedness, as compared to the control group.

(3) Barrier: Lack of Leadership in Port Preparedness

This research activity finds that a void in leadership in the Port of Providence serves as a significant barrier to resilience planning. The project identifies commonalities and differences in port stakeholder perceptions regarding port leadership in adaptation to flooding hazards, and proposes a definition of leadership within the context of port resilience. This research activity was led by Dr Austin Becker, and external support was received for this work from the Rhode Island Department of Transportation.

Stakeholders indicated that a collaborative effort was required to implement resilience strategies, and stated that planning should begin now. But the survey indicated that this is no clear consensus among respondents on who is responsible for providing leadership. As a consequence, port planning is not proceeding at an adequate pace. This indicates that Port of Providence stakeholders are spread primarily across the "contemplation" and "preparation" stages, but a lack of leadership is a barrier to progressing to the action stage.

Private sector respondents indicated that public leadership is required, while representative of the public sector indicated the business community should take the lead. Private and public stakeholders also disagreed on who should pay for specific resilience actions. Over 50% of the private sector respondents felt that they had little or even no financial responsibility for resilience investments and the majority felt that state and federal governments were the most responsible. Public sector respondents, on the other hand, tended to favor more of a shared approach. This might take the form of public/private partnerships, for example, or other strategies that involve private sector funding for resilience.

As part of this research activity, the research team participated in workshop of stakeholders in port planning, and participants in the workshop were recruited to complete an online survey. The goal of the survey was to compare perceptions of different stakeholders regarding leadership responsibility. The results of this survey were used as a starting point in conducting personal interviews with representatives of the organizations identified as having leadership responsibility.

This study finds stakeholder perceptions of leadership responsibility contribute to an institutional void, in which it is unclear who is responsible and who should pay for resilience investment. This research emphasizes the need for pre-planning dialogue to develop consensus and build momentum for resilience investment strategies. The specific findings are outlined below.

Follow up interviews were carried out with the organizations most frequently mentioned as having leadership responsibility in the online survey. Interview results showed that six of the seven interviewees stated that their organization is (or should be) a leader in resilience implementation. But they also indicated barriers that limit their ability to implement resilience planning. Three main barriers that limit the ability to provide leadership are (1) lack of expertise, (2) lack of jurisdiction or mandate, and (3) lack of resources. Also, many of those who perceived of themselves in a leadership role, indicated they should be a partner or supporter, not as the "main" leader. The interviews also found that there is a need for dialogue among all stakeholders to help motivate organizations into a leadership role.

Interventions in this case might include: (1) A planning process that focuses on developing stakeholder consensus on who is responsible for leadership on exactly which elements of the process, (2) developing appropriate mandates for the State and Federal agencies involved, (3) ensuring that those entities have appropriate expertise through selecting individuals with appropriate credentials and/or proving training programs and (4) providing funding mechanisms.

(4) Barrier: Challenges in Engaging Stakeholders in State-Level Coastal Resilience Actions

This research activity provides a synthesis of findings describing "barriers" to taking actions that enhance coastal resilience and interventions (or "enabling conditions") (political, economic, and/or social) associated with making progress on coastal resilience. This research activity was led by Dr. Donald Robadue and Dawn Kotowicz.

This report activity describes lessons learned for programs working to engage stakeholders in coastal resilience actions, drawing from the perspectives of the end users themselves, and the policy process in which they engage. A key aim of the overall investigation is to understand the factors which foster the adoption and uptake of more protective coastal development policies as well as the obstacles, or barriers revealed through the deliberations leading to new policies as well as decisions on specific shore protection measures

The research activity has very similar goals to the research activities described above, but employs a very different methodology to provide a completely different perspective on the issue. In particular, the activity uses a search of news media, public and private reports to elicit the public conversation from over the past 25 years. This research activity documented a broad, state-wide outline of events, actions, and responses for this period, focusing on the past 25 years since Hurricane Bob in 1991 in order to provide a detailed frame of reference on the Rhode Island context for understanding the changing perspectives related to coastal resilience. The information presented here has been requested by end users to provide documentation of the institutional memory that has been accumulating over time in these organizations with respect to their understanding and use of putting science to action and into policy.

The analysis describes the findings gathered from the following methods of analysis: (1) an aggregate timeline of hazard events, studies, and plans and policies; (2) a database of RI Coastal Resource Management Council (CRMC) permits with illustrations, both geographically and over time by number and type of ascent to document coastal hazards policy implementation by the CRMC; (3) a social network map documenting RI engagement regarding resilience policy among state organizations and with stakeholders; a nd (4) vignettes describing selected cases of locations or policies significant to resilience policy in RI to provide context for connections between each of the products described above and to assist in identifying the “semantic language” in print and in speech used to describe barriers to action to enhance resilience.

Putting the ten most commonly expressed obstacles in narrative form is revealing. In the public’s mind there is often a mismatch between an understanding of hazard impact causes and the available repertoire of effective solutions. Consulting engineers, regulators and experts possess a clear understanding but few residents in a coastal area apply for permits, and those who do rely on engineers and designers to fill in the many details. A low comprehension of risk does validate regulators concerns about the need for public and developer education. However this factor should not be confused with the overwhelming interest of both long time and new residents in extending the use of their property in hazardous areas as long as possible. This drives the strong pressure and interest in protecting property, business, investment. Even sophisticated and savvy coastal property owners are stymied by the high, often uncertain costs of more effective solutions, for example elevating an existing structure or moving it away from an eroding shore. On the one hand, safety fears spur demands for quick action, sometimes including illegal, and usually ineffective shore protection measures that regulators then have to act to remove. Attitudes on property rights can make this an entrenched behavior, causing conflict among owners, experts & regulators. On the other hand, many coastal property owners and local leaders may assume that their past safety will continue into the future, either based on little information or misinformation or a disbelief in scientific forecasts and modeling.

The following obstacles and opportunities for interventions were identified:

- There is a mismatch between causes of impact and effective solutions. Promising interventions include ongoing planning at the state and federal level, as well as zoning and regulatory processes. Unfortunately, actual responses tend to focus on structural solutions, such as shoreline protection through sea walls and sheet pile, which are short term "solutions" to the immediate problem of coastal damage, but that also raise their own problems.
- There is a poor comprehension of the risks that are faced. This requires improved risk communications methods, such as the visualizations described above, as well as holding of public meetings. But ultimately, the preferred solution is relocation of development away from coastal hazard zones.
- An obstacle to improved preparedness to coastal hazards is the desire to continue existing uses of coastal property as long as possible. Possible interventions include proposal hazard regulations policies and provision of financing for protective actions.
- Related to the previous barrier, is the interest in protecting existing properties from damages using structural solutions. An effective intervention might be temporary protection of property, but with a longer term goal of relocating properties using collaborations of private and public stakeholders.

(5) Barrier: Disconnect between Effect Solutions and Short-Term Fixes

A barrier to building long term preparedness to coastal storm hazard is the disconnect between what most managers view as effective solutions and short-term fixes. For example, most knowledgeable coastal managers favor long-term solutions such as the following: managed retreat from coastal hazard zones, providing space for wetlands and other habitats to migrate with sea level rise, etc. In comparison, many members of the public and the private sector prefer shoreline armoring solutions, like sea walls, rip rap, groins, etc.

Intervention

The Cape Cod Commission is developing decision support tools for communities to help them better understand the consequences of different mitigation strategies of this sort. They have requested out help in compiling data and a methodology for creating a public education tool that allows stakeholder to better understand the consequences of the different shoreline adaptation strategies.

To date, we have created a spreadsheet approach that estimates impacts on private and public shoreline from different adaptation strategies. The stragies range from "do nothing"—allow shoreline erosion to continue at the current rate—building sea walls, living shoreline, beach nourishment, allowing zones for salt marsh migration,

The approach is intended as an educational tool based on a low-cost approach with simplifying assumptions in order to provide "representative" outcomes from different shoreline adaptation strategies, rather than trying to develop a detailed site-specific analysis. Ultimately, the calculations embodied in the spreadsheet will be incorporated into a GIS based decision support tool, where users can select a location around Cape Cod, and compare outcomes of different restoration strategies.

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Part 2. Detailed Presentations of Research Activities

IV. Visualizing Disaster Consequences and Perceptions of Risk

Visualizations of percent damage in the community of Matunuck RI, based on the Coastal and Environmental Risk Index (CERI).(1)

Project motivation and how it addresses barriers to resilience building

As discussed above, one major barrier that impedes local communities from undertaking protective actions is the fact that many community members view potential storm hazards as "too theoretical", and they feel they can delay protective actions until they face a real and imminent threat. This Research Activity developed data-driven visualizations of storm impacts to help communities better understand potential impacts of different coastal storm scenarios. The research was led by Dr. Austin Becker and Dr. Peter Stempel.

Visualizations have been shown to play an important role in making seemingly abstract risks like future sea level rise seem tangible in relevant local contexts (Sheppard, 2015). They have become an important part of engaging the public and communicating risks and are often used in combination with other exhibits and interactions in workshop processes (e.g., Becker 2016). They are thus commonly viewed to overcome barriers to understanding risks by demonstrating that "it can happen here" (Sheppard, Shaw, Flanders, & Burch, 2008). Although applications of visualizations are well studied, there is a gap in basic research regarding the effects of visualizations on risk perception (Kostelnick, McDermott, Rowley, & Bunnyfield, 2013).

There is also increasing recognition that understanding quantitative impacts (e.g., total economic disruption) is not providing sufficiently actionable information for decision making (Aerts et al., 2018). Developing qualitative data (e.g., regarding the effects of disruption of interconnected systems), is an important next step in developing actionable and more useful information for decision makers (Aerts et al., 2018). This work therefore includes:

- Developing rigorous and repeatable methods for gathering qualitative data regarding vulnerabilities (e.g., communications towers).
- Developing rigorous methods for administering hazard impact models that intersect high resolution storm models (e.g., wind, rain surge) with granular data regarding vulnerabilities.
- Developing means to visualize outputs.
- Testing how granular impact models alter perceptions of stakeholders (e.g., emergency managers) to determine whether they effectively overcome barriers (e.g., being able to relate an abstract value such as windspeed to a highly specific local impact).

Description of hypotheses or research questions

Concerns have been raised regarding the effects of visualizations. For instance, compelling visualizations of sea level may cause people to focus on their exposure to that risk and discount others that are more difficult to model and visualize (e.g., wind, precipitation) (Moser & Dilling, 2011). Visualizations have also been criticized for potentially overstating the resolution and certainty of predictions (Kostelnick et al., 2013). Given these concerns, the project tested the effects of visualizations to determine whether these phenomena are taking place, and, whether visualizations are in and of themselves having positive effects on overcoming barriers to resilience (e.g., disbelief, discounting of risks related to personal stakes), or if they are exacerbating those very barriers they seek to overcome.

Description of methods

A large scale quantitative survey was conducted (n = 735) that purposively sampled a cross section of experts and the public. This survey was also designed to maximize the cross-sectional characteristics of the cohort to maximize variation in physical distribution of respondents (e.g., persons more and less familiar with the places visualized) and familiarity with visualizations. Respondents evaluated a total of five visualizations in random order and answered a range of questions related to risk perception and perceptions of authority and credibility.

Results

Among key findings regarding the perceptions of visualizations are results that specifically relate to overcoming barriers. For instance, evaluations of effects on risk perception suggest that individuals are more likely to discount highly personal risks (e.g., effects to their individual property) as opposed to risks that impact communities more generally (e.g., depictions of adjacent communities or publicly recognizable locations). Results also suggest that disbelief and discounting increases as scenarios diverge from what audiences already expect.

This research, however, also points to ways to overcome these effects. Results demonstrate, for instance that expectations also shape perceptions of the authority of visualizations. There are strong indications that both experts and the public have been conditioned to expect that historic storms are the most robust basis for projections of future inundation. This is potentially problematic in situations where probabilities of higher impact storm events are increasing, and projections must be increased. While this introduces potential barriers (scenarios more divergent from expectations) it also introduces a clear means to increase the perceived authority and likely effectiveness of visualizations: introducing multiple lines indicating not only the location of past storms but of future storms. Providing this context will signal credibility by acknowledging existing expectations and may thus increase acceptance of the projections together. Moreover, even if the extreme risk of the most severe projected storm is discounted, the intermediate inundation lines portrayed are likely to be more impactful than current expectations that are likely built on the most recent storm event.

Other results suggest that concerns over misleading characteristics of 3d visualizations may be over stated. It has long been recognized that 3d visualizations may be more effective at orienting diverse audiences in the landscape and helping them apprehend complex information quickly. The use of these visualizations in risk communication has been limited by concerns that by being detailed and evocative they overstate the certainty of a risk and be misleading. These potentially misleading effects, however, are offset by an apparent “style penalty”, a perception that a 3d visualization is less authoritative than a map or less evocative representation. These and other effects suggests that there are diminishing returns on levels of drama, and that modest, semi-realistic visualizations that adopt some standards of cartographic representation (e.g., legends) may be able to combine the positive orienting effects of 3d visualizations without diminishing authority to the point that they are ineffective.

This research strongly suggests that overcoming barriers to improved risk communication hinges on understanding audience expectations and avoiding fear appeals. Fear appeals are approaches that emphasize extreme scenarios or that seek to shock audiences. The qualitative literature has long suggested that this is the case (O'Neill & Nicholson-Cole, 2009), this research reinforces these findings with quantitative results. As indicated in the previous paragraph, the ineffectiveness of fear appeals potentially introduces problems where probabilities of storms are increasing. This research, however, suggests that judicious use of 3d visualizations, adoption of broadly recognized cartographic standards for those 3d visualizations, and acknowledgement of audience expectations as to referencing historic events in parallel with projected events will make visualizations highly effective tools. These tools will maximize engagement and acceptance, and thus aid in overcoming barriers.

Project Impacts

In addition to advancing the creation and application of visualizations, the outputs from this work have supported resilience and risk communication efforts in 14 specific communities, and across the State of Rhode Island, this has included the training of emergency managers and first responders in collaboration with the Rhode Island Emergency Management Agency and the Coastal Resources Management Council. Visualizations were created for the Beach Special Area Management Plan (Beach SAMP) to be used in local public engagement processes in Matunuck, Misquamicut (Westerly) Warwick, Charlestown, Barrington, Bristol, and Warren Rhode Island. These visualizations have become essential parts of the engagement processes conducted by the SAMP. Integration of visualizations into the SAMP process suggests that there are some issues surrounding the depiction of specific damages to individual structures. To the extent that there are no regulatory structures or means to address the specific impacts or vulnerabilities revealed there is discomfort with their publication or distribution. These experiences lend credence to the approach of placing emphasis on qualitative impacts identified by stakeholders: identifying specific concerns that are relevant and actionable. Additional collaborators include: University of Rhode Island, Coastal Resilience Center (CRC) and the State of Rhode Island, Coastal Resources Management Council (CRMC).

Hazard impact models and visualizations were deployed to support a Federal Emergency Management Agency Integrated Emergency Management Course (FEMA IEMC) in collaboration with the Rhode Island Emergency Management Agency, RIEMA. These included visualizations of Westerly, Providence, Middletown, and Pawtucket Rhode Island, and statewide assessment of damages. Additional support was provided by the Department of Homeland Security Office of Cyber and Information Security (DHS OCIS). Deployment included developing time incremented hazard impact models including qualitative impacts, and matching time incremented visualizations of inundation. The process of integrating the time incremented model into an existing simulation exercise made it immediately clear that many of the resources used in these kinds of training exercises (e.g. impacts derived from historic storms) were not well synchronized with the unfolding of the simulated storm. The use of the time incremented simulation made it possible to understand not only what happened, but when impacts occurred relative to other events. Given the significance of access to remote barrier islands for purposes for evacuation and the effects of wind on transportation, the timing of these effects has significant impact on response.

Publication s or products

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Stempel, P. (2016). Data Driven Visualization. Paper presented at the ECM14, Estuarine and Coastal Modeling Conference, South Kingstown, RI, June 14-17.

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Stempel, P, Becker, A. (2018). Visualizations out of context. Implications of using simulation based 3d hazard visualizations (submitted).

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Witkop, R., Stempel, P., Becker, A., (2017). “Coupling local scale, high resolution, qualitative data to interface with numerical storm models.” Poster Presentation. American Geophysical Union Annual Conference, New Orleans, LA. December 12.

Models and Visualizations:

Beach Special Area Management Plan (RI Beach SAMP):

- Matunuck (South Kingstown) Rhode Island
- Misquamicut (Westerly) Rhode Island
- Charlestown Rhode Island
- Warwick, Rhode Island
- Barrington, Rhode Island (in progress)
- Warren, Rhode Island (in progress)
- Bristol, Rhode Island (in progress)

Federal Emergency Management Agency Integrated Emergency Management Course (FEMA IEMC), June 2017:

- Pawtucket Rhode Island (maps)
- Providence Rhode Island (community wide 3d)
- Middletown Rhode Island (community wide 3d)

- Westerly Rhode Island (community wide 3d)

Ports:

- Port of Providence, Providence Rhode Island
- Port of Davisville, Rhode Island (in development)
- Port of Galilee, Rhode Island

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Figure 1. Example Storm Impact Visualizations Used in Various Project-Related Workshops.

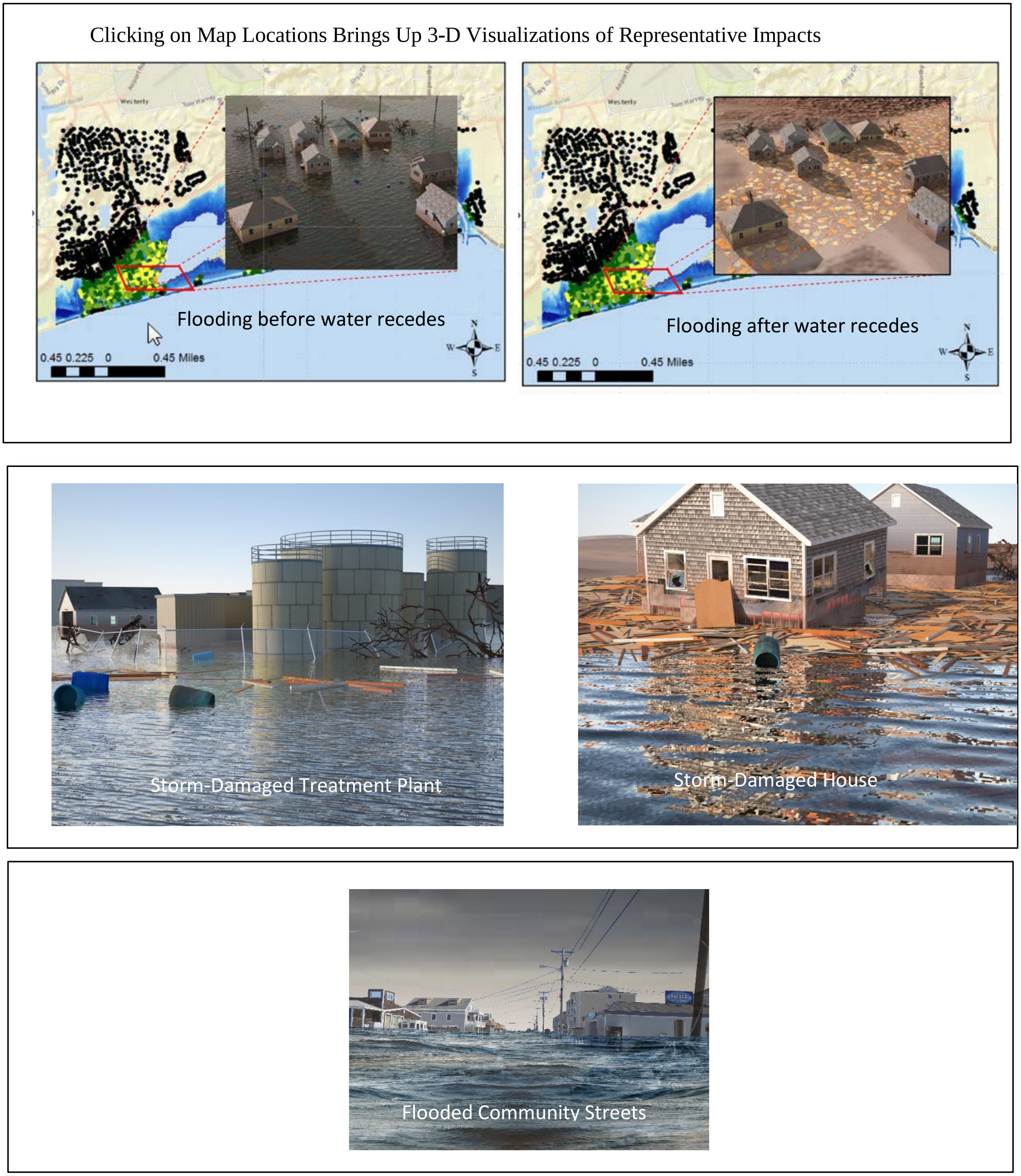
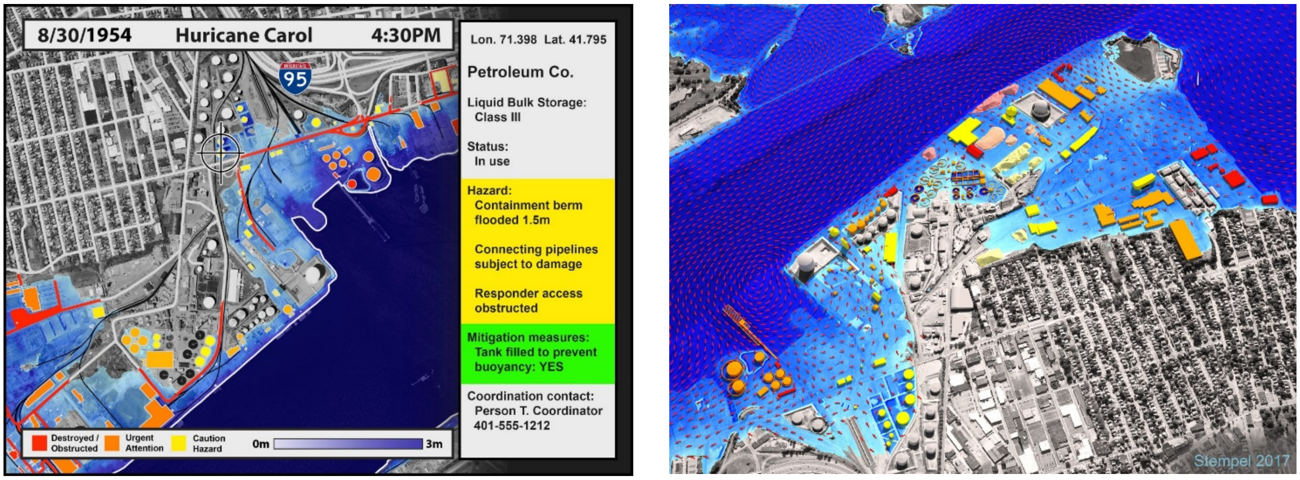
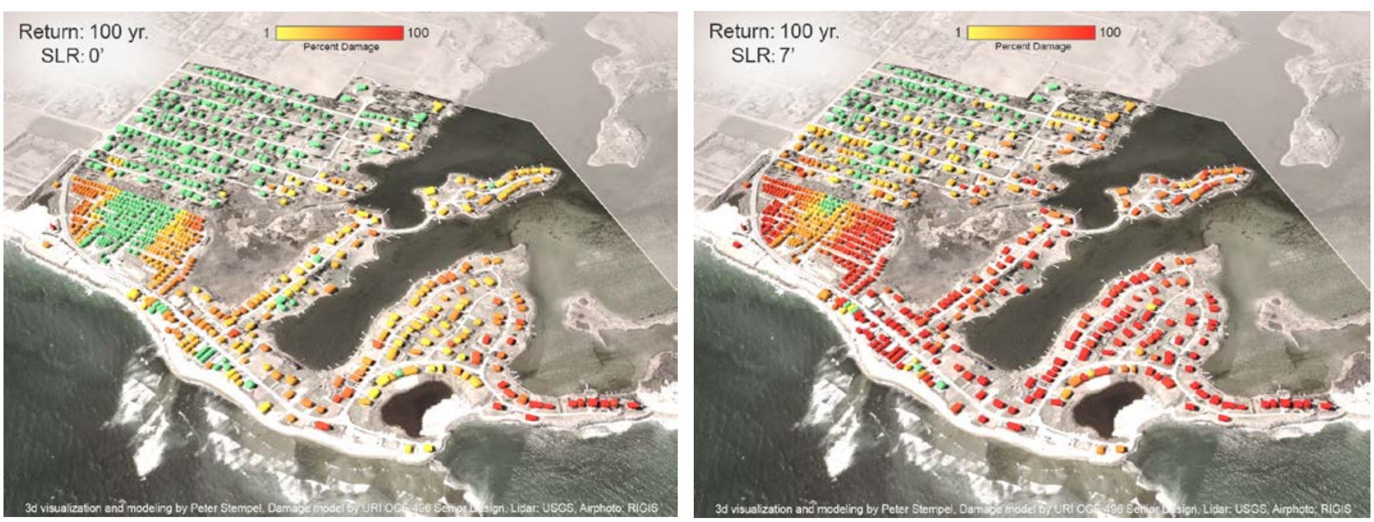


Figure 1 (Cont.) Example Storm Impact Visualizations Used in Various Project-Related Workshops.



Flooding Maps of the Port of Providence Used in Storm Visualizations



3D Visualizations of Flood Damage Maps at 0' and 7' Sea Level Rise Scenarios

V. The Leadership Void for Climate Adaptation Planning: Case Study of the Port of Providence (Rhode Island, USA)

Project Motivation and How it Addresses Barriers to Resilience

As discussed above, lack of effective leadership has been identified as a barrier to improved preparedness for coastal storm hazards in Rhode Island ports. This Research Activity, led by Dr. Austin Becker, built from prior work funded through the Rhode Island Dept. of Transportation that created a resilience planning exercise for port stakeholders. Climate adaptation requires leadership from a diverse group of stakeholders to shift investment priorities and generate political will for long-term planning. This is especially true for seaport stakeholders. Ports serve as access points to goods and services from around the world, promoting a higher and more robust quality of life. However, with the increased likelihood of intense storms, rising sea levels, and resource scarcity facing coastal communities, stakeholders will need to adapt coastal infrastructure to ensure long-term viability. Solving such problems requires leadership and participation from government across jurisdictional boundaries and/or the private sector. Using the case of Port of Providence (Rhode Island, USA), this study finds stakeholder perceptions of leadership responsibility contribute to an institutional void, in which it is unclear who is responsible and who should pay for resilience investment. This research emphasizes the need for pre-planning dialogue to develop consensus and build momentum for resilience investment strategies.

Description of Hypotheses or Research Questions

This paper contributes to the growing body of literature in climate change policy in two ways. First, we propose a definition of leadership within the context of coastal adaptation and resilience. Second, we provide empirical data supporting the notion that, at least in the case of the Port of Providence (Rhode Island, USA), a void in leadership serves as a significant barrier to resilience planning.

Description of methods

This study consisted of two components: First, we conducted an online survey to compare stakeholders' perceptions of leadership responsibility. We sent to the 31 stakeholders who participated in the workshop described above, with 25 respondents completing it. Thirteen respondents self-identified as representing the public sector (e.g., local, state, federal government) and 12 identified as representing the private sector. In the results section, we use these two broad groups to make some comparisons in attitudes for leadership responsibility. Second, we conducted interviews with representatives of the organizations identified by the 25 respondents as having leadership responsibility for the planning and implementation of three long-term transformational adaptation strategies developed in the earlier workshop.

Results

This section first discusses survey results and then interview results, then implications and gaps revealed by these findings.

Survey finding 1: Stakeholders see a collaborative effort as responsible to implement resilience strategies and believe planning should begin now

The results of the survey suggest the group's perception of the most appropriate leadership structures for resilience planning, as well as the specific actors who should take the lead (Figure 1).

Overall, respondents most supported a *public-private informal collaboration* structure, with the average respondent ranking it as *more responsible* to *entirely responsible*. *State lead* leadership scored as the second-choice leadership structure. On the other hand, port stakeholders did not see *private business independently* or *private businesses in collaboration* as responsible. Thus, most stakeholders see the government as playing a significant role in adaptation planning, with preference for either a completely top-down (state-lead) approach or a collaboration between state and private entities.

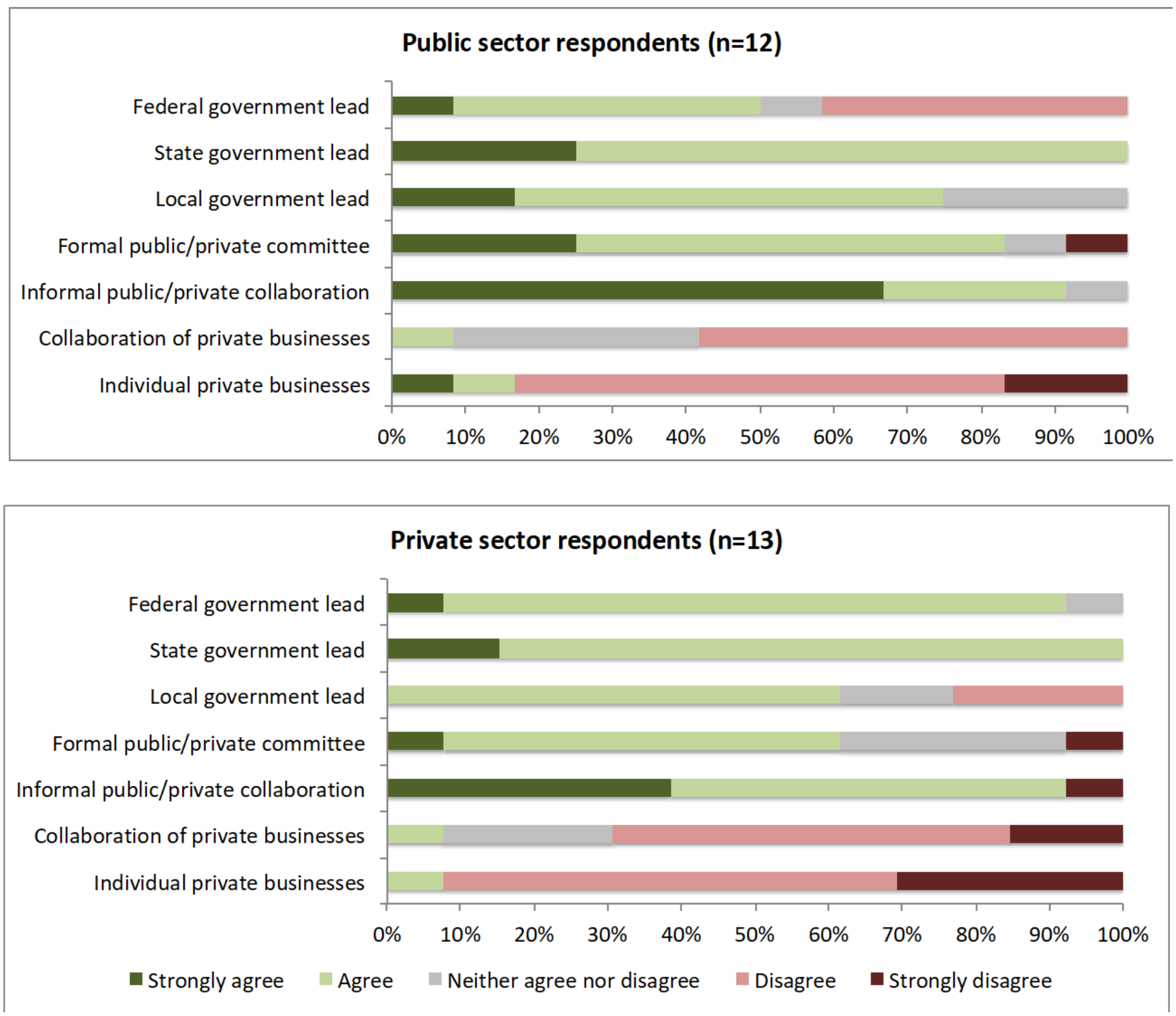


Figure 1 - Respondents' opinions of what structural organization should take the lead on planning and implementing resilience strategies.

However, respondents from different sectors (public vs. private) showed different preferences about which specific organization should be responsible for leading in different resilience approaches. For example, private sector respondents felt that the *Accommodate* approach required a more public (government) leadership approach. On the other hand, public sector respondents felt that the business side should take a stronger leadership role for *Accommodate* approaches. This example illustrates the finger-pointing nature of the resilience challenge, with government pointing to the business community to take the lead and vice-versa.

With respect to timing, 22 of the 24 respondents answering the question felt that planning for resilience should begin either immediately or within the next two years. Thus, while there was currently no organization in place to spearhead resilience planning for the port, the stakeholders felt that this should be a priority.

Survey Finding 2 – No clear specific leader

In the open-ended survey questions asking stakeholders who, specifically, is responsible for leading the implementation adaptation approaches, stakeholders named 25 entities, with various organizations rising to the top depending on the resilience approach specified (Figure 2). Though the survey questions was worded to elicit *specific* organizations or agencies, many respondents provided broader responses (e.g., RI Government or Courts). The private sector respondents listed the Rhode Island Department of Environmental Management as being responsible for *accommodate;* city government and CommerceRI as responsible for *relocate*; and the U.S. Army Corps of Engineers and the State of Rhode Island responsible for *protect*. Given the numerous organizations listed, we can deduce that survey respondents perceived many organizations as partially responsible for adaptation leadership. The results do not show a consensus around which organization is responsible.

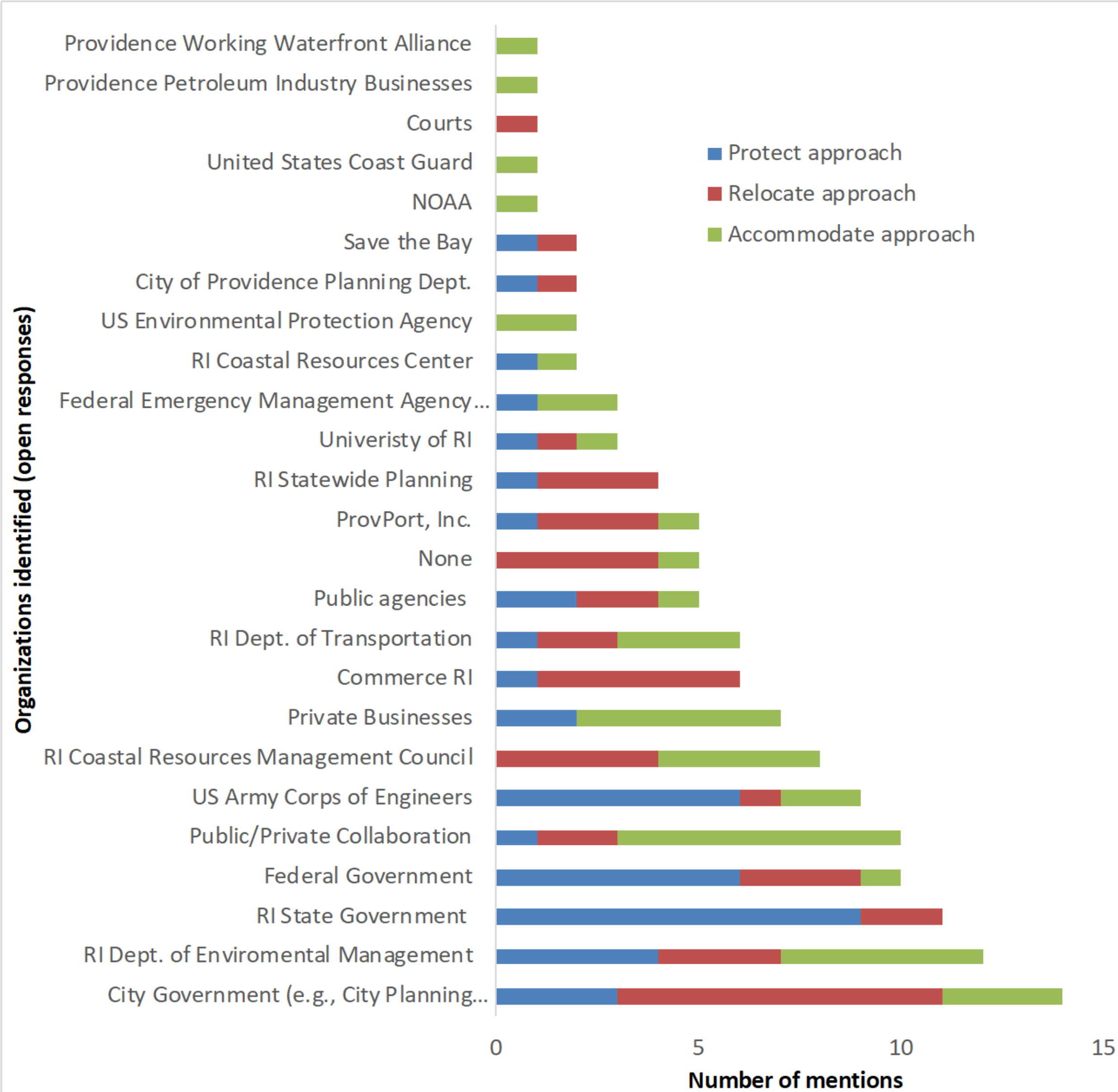


Figure 2 - Survey respondents from the public sector (n=12) and private sector (n=13) identified 25 organizations that they felt should take a leadership role for planning and investing in the three broad resilience approaches. A total of 131 responses to the open-ended question were received from the 25 survey respondents.

However, by aggregating the individual named organizations into broader categories, it becomes clear that this group of respondents feels that the state and federal government agencies need to play a lead role in developing resilience for the port (Figure 3), with 94 of the 131 total mentions naming government organizations and only 14 naming private firms.

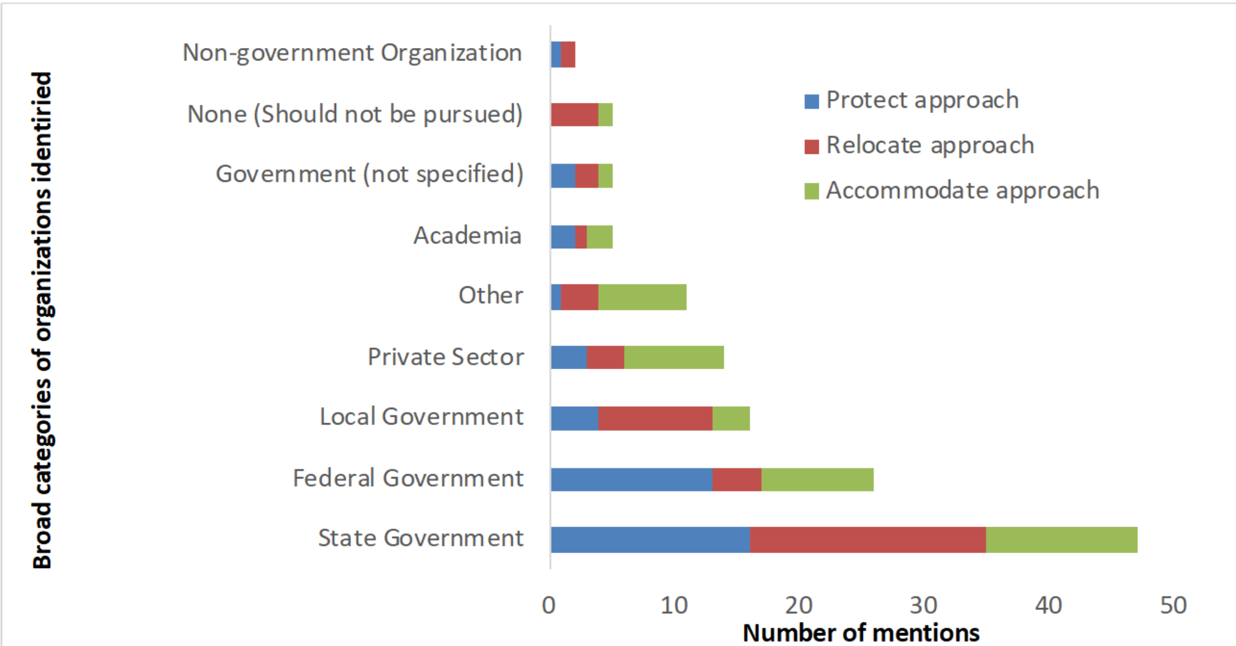


Figure 3 - Broad categories of organizations mentioned by respondents (n=25 respondents and 131 total mentions)

Survey Finding 3 – Private and public stakeholders disagreed on who should pay for resilience

When asked which types of entities should be responsible for funding long-scale resilience projects (e.g., protect, accommodate, relocate), survey respondents from the private sector were more likely to put the burden on governments (Figure 4). Over 50% of the private sector respondents felt that they had little or even no financial responsibility for resilience investments and the majority felt that state and federal governments were the most responsible. This finding points to the complexity of resilience investments, in which individual businesses may benefit, but the costs fall on shoulders of the taxpayer. Public sector respondents, on the other hand, tended to favor more of a shared approach. This might take the form of public/private partnerships, for example, or other strategies that involve private sector funding for resilience.

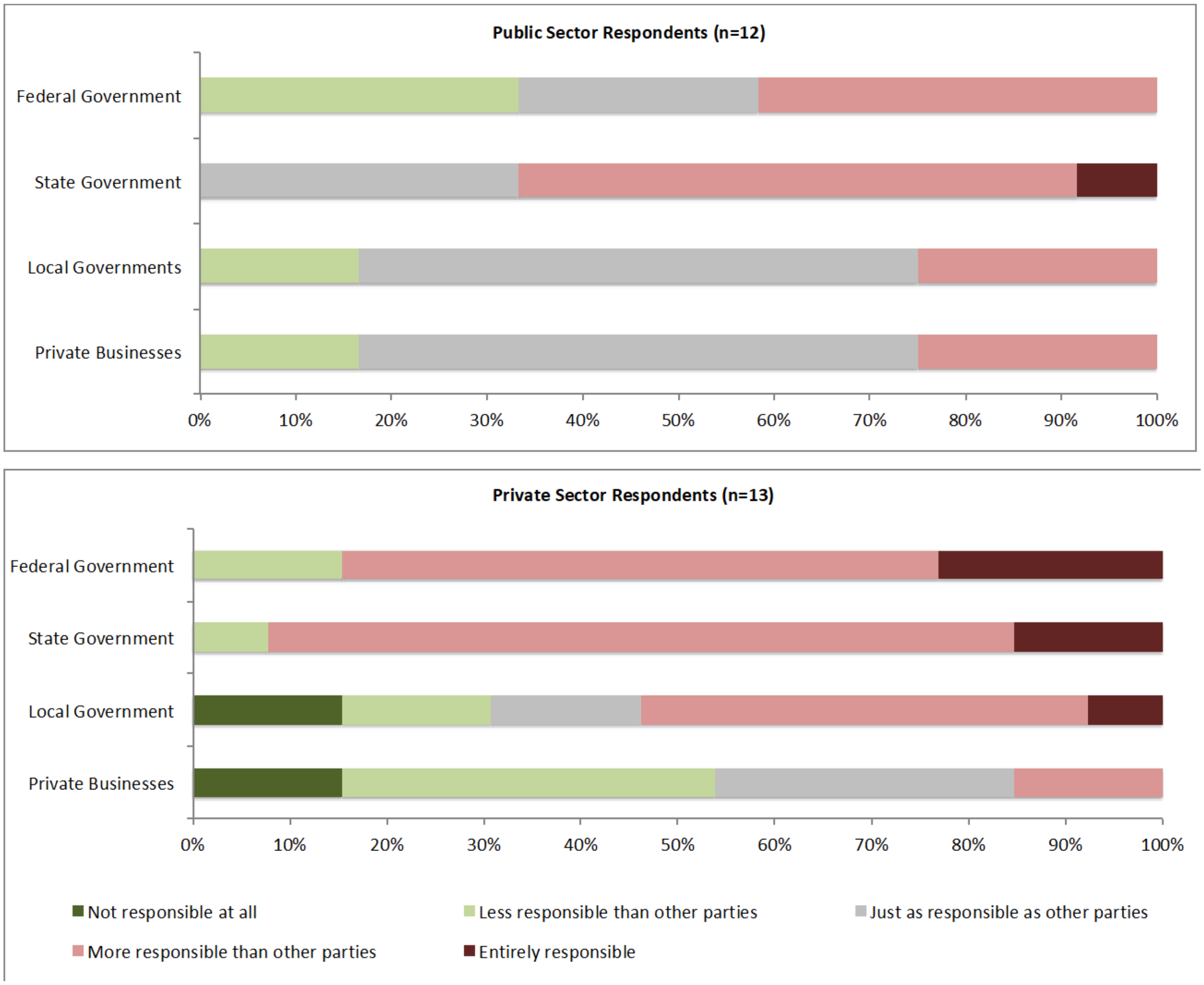


Figure 4 - Respondents identified who they felt should be responsible for funding resilience. Public sector felt responsibility should be shared, while private sector felt it was the government's responsibility.

Interview Finding 1 – Identified leaders agreed that they have some leadership responsibilities, but only in part and never for all five functions of the policy process phases

In Part II of this study, we conducted interviews with seven of the nine organizations most frequently mentioned as having leadership responsibility in the online survey. Interview results showed that six of the seven interviewees stated that their organization is (or should be) a leader in resilience implementation. With respect to their role in building resilience for the Port of Providence, the representatives characterized their leadership in two ways: First they perceived themselves as leaders, but cited limits in their ability to implement resilience planning at the Port of Providence. Second, they perceive themselves in a leadership role, but as a participant, partner or supporter, not as the “main” leader. As stated by one respondent “We do have a direct role. I see us as a direct participant.”

No representative felt his/her organization could fulfill all five of the functions of leadership throughout the various phases of the adaptation policy process. For example, two organizations felt they were responsible for fulfilling *the dissemination, adaptation,* and *connective* function during the planning phase; however, they felt they had no role in the implementation phase and that the responsibility would be passed to someone else.

Similarly, another stated that for *protect* strategies, in particular, they held responsibility for the implementation of that project but not necessarily responsible for the planning phases of that project. Another organization representative stated that it focused on the dissemination of information and helping port businesses understand their risk, indicating that this organization saw themselves as fulfilling the *dissemination* function during the *understanding phase* of the policy process. One interview indicated that his/her organization held responsibility for all five leadership functions, but only in the planning phase.

The results show that there is no one organization that holds a leadership role for resilience from conception to management, to construction, implementation and monitoring. Thus, numerous agencies and actors would need to share responsibility, requiring some overarching collaboration and management.

Interview finding 2 - Actors face three key barriers that affect their leadership ability

Interviewees identified four specific barriers to leadership: 1) lack of expertise, 2) lack of jurisdiction/mandate, and 3) lack of resources. These barriers left interviewees with the sense that they, even if they wanted to devote resources to resilience planning, they felt hindered and/or not wholly responsible.

Lack of Expertise

Interviewees cited a lack of skills or expertise to fulfill one or more of the leadership functions. For example, one organization found that they could not complete the *connective* function because their organization had no history of bringing together collaboration, stating, *"A limitation is our [lack of] understanding of all of the players."* The organization could not fulfill the *connective function* because they did not know who should be involved in the process. Limited planning horizons also factored into perceptions that they lacked expertise. Only one organization stated they could plan for 50-100 years ahead, a period in which many of the major impacts of climate change are likely to occur.

Lack of jurisdiction/mandate

Some interviewees felt limited by their jurisdiction, while others felt limited by the scope of their mandate. For example, one organization stated, *"Yes we take a lead role [but only] within [our City lines]."* This representative said that within their city they had the ability to take the lead; however, they would need to be part of a larger collaborative effort if a given resilience approach impacted multiple municipalities.

Others felt that planning at the port scale was too small of a unit to work: "*We have taken [a leadership role]… for the entire coastline, including in Providence Harbor."* Another organization stated, "*Yes, [we have] taken a high-level leadership role in Providence Harbor as well as in other locations.*" In the latter quote, the representative was discussing the fact that the organization focused on disseminating climate risk information at the local level throughout the state. This organization was currently working with the city and towns of the state in long-term resilience planning. He/she stated that if port business stakeholders reached out to them, they would be able to input information into the planning process. This organization followed up by saying at the current moment resources were also a limiting factor to their participation at the Port of Providence.

Two interviewees, one state (Rhode Island) and one federal, stated that though their involvement was within their jurisdiction, a lack of authorization from legislative organizations inhibited their leadership at the Port of Providence. An interviewee stated, *"If we are going to impose change … it would take specific authority to require that."* Other interviewees stated that though not totally in their jurisdiction but if mandated by law, their organization would take a lead role in resilience implementation at the port, particularly if grant funding was provided to conduct the work. Another interviewee stated, *"Funding, authority, and appropriation barriers — we can't just go out and do anything we want."*

Lack of resources

Every interviewee stated that a lack of staff and financial resources limited their ability to lead in adaptation planning and implantation at the Port of Providence, as evidenced in the following quotes:

> *"Funding is always an issue; if we don't have the resources to complete the job correctly, then that is a barrier."*
>
> *"Funding, authority, and appropriation barriers — we can't just go out and do anything we want."*
>
> *"Resources are always an issue, [we] are always spread everywhere thin — personnel and financial."*

All interviewees expressed the need for more money and more personnel if resilience measures were to be planned for and implemented. One organization expressed the importance of federal resilience grants to incentivize the participation of businesses, government, and non-governmental organizations (including universities).

Interview Finding 3 - Interviewees see opportunities to collaborate as motivation and a chance to clarify roles

Interviewees underscored the need for dialogue to help motivate their organization into a leadership role for resilience planning. As one stated, *"Resiliency is not something that is going to be addressed by one organization."* Interviewees cited the benefits of opportunities to cooperate and of groups that drive discussion. One interviewee mentioned the Port of Providence workshop conducted prior to this research as a valuable motivating force, stating, *"It is helpful to have things like the workshop to help remind [us of potential risks] and give ideas."* Another raised the value of workshops, *"to see what other people do."* This was the same interviewee previously mentioned that they did not know "*all the players."*

Project Impacts

In a complex decision-making system such as the Port of Providence, organizations will need to fulfill each of the five functions of leadership for each of the three phases of resilience planning. Interviews and surveys showed that those identified by the stakeholder community as being "leaders," agreed that their organizations had some level of responsibility. Further, the actors interviewed pointed to significant barriers, such as lack of expertise, jurisdiction, and financial resources, that stand in the way of prioritizing and implementing resilience planning. However, at the time of this project, the system, as a whole, was far too fragmented to determine a clear vision for which actors could (or should) serve as the catalyst for resilience planning. Though individual actors recognized their responsibility pieces of the process, none self-identified as a champion for resilience planning.

Results suggest that this is due in part to a lack of cohesion around the type of organizing body that would be most appropriate. Most participants favored the creation of stakeholder group, made up of both public and private sector representatives, to plan for and implement resilience. At the time of this project, no such group existed and, naturally, the formation of such a group requires one or more organizations to take a leadership role. This presents somewhat of a conundrum, given the various attitudes of the stakeholders themselves. The private sector, as seen in survey results, puts the leadership burden on the public sector. The public sector puts the burden, at least in part, on the private sector. In any case, most agreed that the state needs to play a large role in leading the process and thus resilience is not likely to occur in a bottom-up fashion from the business community of the Port of Providence.

External cooperators or end users

This project relied on input from the decision makers who participated in the surveys and interviews.

Name	*Affiliation*
Austin Becker (PI)	University of Rhode Island (URI)
Rick Burroughs (PI)	URI
Evan Matthews (Chair)	Quonset Development Corporation, Port of Davisville
Mike Sock	Rhode Island Department of Transportation
Meredith Brady	Rhode Island Department of Transportation and Rhode Island Climate Change Committee
Melissa Long	Rhode Island Department of Transportation and Climate Change Committee
Julia Rosati	U.S. Army Corps of Engineers
Kevin Blount	U.S. Coast Guard
Chris Witt	Rhode Island Statewide Planning
Dan Goulet	Coastal Resources Management Council
Pam Rubinoff	URI Coastal Resources Center and Rhode Island Sea Grant
John Riendeau	CommerceRI
David Everett	Providence Dept. of Planning
Jeff Flumignan/ Bill McDonald	United States Maritime Administration
Eric Kretsch (Graduate Student)	University of Rhode Island

Final Products

This project resulted in a publication currently under review:

Becker, A., Kretsch, E. (In Review) The leadership void for climate adaptation planning: Case study of the Port of Providence (Rhode Island, USA). Environmental Planning and Management.

And the following presentation:

Becker, A., (2018), “Leadership Void for Adaptation Planning,” International Workshop on Climate Change and Adaptation Planning for Ports, Transport Infrastructures, and the Arctic (CCAPPTIA). University of Manitoba, Winnipeg, MB, Canada, May 3-4.

Kretsch, E.*, Becker, A. (2016). “Leadership and Responsibility for Long-Term Hurricane Resilience: Port of Providence, RI.” Transportation Research Board Conference for Committee on Maritime Transportation System (CMTS), National Academy of Sciences, Washington, DC, June 21-22.

Kretsch, E.*, Becker, A. (2016). “Leadership and Responsibility for Long-term Hurricane Resilience: Stakeholder Perceptions in the Port of Providence, RI.” Social Coast Conference. Charleston, SC, Feb. 11.

VI. Overcoming Barriers to Motivate Community Action to Enhance Resilience - DHS Obstacles to Resilience/Adaptation

Introduction

This Research Activity was led by Dr. Donald Robadue and Dawn Kotowics to identify "barriers" to taking actions that enhance coastal resilience, as well as interventions and other "enabling conditions" (political, economic, and/or social) associated with strides in coastal resilience. This section describes lessons learned for extension programs working to engage stakeholders in coastal resilience actions, drawing from the perspectives of the end users themselves, and the policy process in which they engage.

The problem, policy and politics surrounding natural hazard impacts and mitigation are intertwined over time. The state of Rhode Island provides a unique opportunity to examine the conditions that have prevented or facilitated actions to enhance coastal resilience due to its small size, active coastal program, and ongoing engagement with the University of Rhode Island. Rhode Island is also identified by Burby (2006) as only one of ten states with "both state and local government building code and comprehensive plan requirements", thus having among the stronger governance settings for achieving more resilient communities and economy. URI researchers and extension staff have been involved with citizens, businesses, municipal, state, and federal actors for the past half-century, directly encountering and documenting resistance and obstacles to reducing vulnerability to hazards. For example, Project Impact in the late 1990s led to CRC involvement in preparing municipal hazard mitigation plans for Pawtucket and Narragansett, as well as a state-wide overview with the Rhode Island Emergency Management Agency (1996). The goal of this research is to understand the obstacles, incentives, and changing perspectives on adaptations to enhance coastal resilience, focusing on the interactions with public policy debates.

Below, we lay out the broad outline of events, actions, and responses for this period, focusing on the past 25 years since Hurricane Bob in 1991 in order to provide a detailed frame of reference on the Rhode Island context for understanding the changing perspectives related to coastal resilience. The information presented here has been requested by end users to provide documentation of the institutional memory that has been accumulating over time in these organizations with respect to their understanding and use of putting science to action and into policy.

This analysis specifically describes the findings gathered from the following methods of analysis: (1) an aggregate timeline of hazard events, studies, and plans and policies; (2) a database of RI Coastal Resource Management Council (CRMC) permits with illustrations, both geographically and over time by number and type of ascent to document coastal hazards policy implementation by the CRMC; (3) a social network map documenting RI engagement regarding resilience policy among state organizations and with stakeholders; a nd (4) vignettes describing selected cases of locations or policies significant to resilience policy in RI to provide context for connections between each of the products described above and to assist in identifying the "semantic language" in print and in speech used to describe barriers to action to enhance resilience.

Products

The following products have been produced to aid in the overall analysis:

Aggregate timeline of hazard events, studies, and plans and policies:

An Excel work book includes a chronological listing the set of documents and resources collected for the timeline provide the basis for understanding many of the federal, state, and municipal planning and decision-making responses along with hazard events. Many of the studies collected for the hazard events and hazards studies timelines have informed the construction of aggregate timeline inclusive of hazard plans and policies. The initial test of Timeline JS revealed that customized programming would have been required to accommodate the full layers of content so that outlet for the information was set aside.

Public information and policy accompanies the unfolding of storm events and other processes such as shore erosion and accretion and runoff from storms. The bibliography of over 1,000 entries includes pure hazard studies, mixed documents with some technical analysis and planning or policy recommendations, and adapted legislation and regulation. Entries range from National Weather Service's coverage of a flood in March 1936 resulting from melting of larger than normal snowmelt combined with rainfall that affected all of New England to an article in ricentral.com (a collection of media coverage for six Southern Rhode Island newspapers) of a planning board discussion about Transportation Improvement Program (TIP) application priorities. The review of policy covers federal, state and municipal planning and decision-making responses aligned with storm events and studies.

The timeline informs the analysis of 'semantic language' used to describe the barriers and to identify the enabling conditions presented in the vignettes further described below.

Hazard Events:

A review of hazard events affecting RI has been conducted as part of the time line. Although other collections of portions of this exist in gray literature, this review is a collection of documents describing hazard events that affected RI, with a focus on storms since 1991 have been collected and organized. Larger historical storms are often used as benchmarks for future damage or climate change visualizations, and storms since 1991 (Hurricane Bob) serve as focal events around which media coverage of emergency and longer term response has been generated.

This collection includes the following information sources: disaster declarations for RI from FEMA; a summary of storms from the Coastal Resources Management Council; a collection of storms to affect the Northeast US reported by the National Weather Service; and a story map of historic storms that have affected RI.

Hazard studies:

Hazard mitigation and climate change adaptation studies have been collected and organized.

These studies include analysis of physical, geological, economic and social aspects of hazard mitigation and climate change initiatives and projects focused in RI.

Hazard plans and policies:

A review of plans and policies that concern hazard mitigation, planning and rebuilding efforts from around RI.

Data sources include: town comprehensive plans; multi-hazard plans; state level emergency management policy and plans from RIEMA and RI CRMC.

Media coverage of hazard events, studies, plans and policies:

The compilation includes recent engagement between researchers and extension staff at the University of Rhode Island with the coastal hazards policy. Embedded in this work is a wide range of attempts to overcome opposition or obstacles by conveying information about the nature of hazards, policy and practice options, and to some degree aid to stakeholders in implementing better policies. From which lessons learned can be drawn. This collection includes documentation of patterns of stakeholder engagement with businesses, government and the public. These organizations have had sustained involvement with policy and economic implications of coastal hazards, including RIBA (RI Builders Association), RIMTA (RI Marine Trades Association), RI Realtors Association, and RI Flood Mitigation Association.

To complete the vignettes discussed in detail below, URI Library digital newspaper resources were discovered that enabled full text search of the Warwick Beacon, The Independent and the group of newspapers published under the banner of Southern Rhode Island Newspapers (http://www.ricentral.com/). This yielded about 200 items published since 2003 relevant to the Matunuck case. A headline search of the Providence Journal since 1981 and full text search using a recently available service Nexis Uni since 1994 for the Matunuck Beach vignette, 185 additional full text articles were identified for the case. Unique entries from these searches will be added to finalize the timeline.

CRMC Permit Maps and Database:

A technical report containing a cleaned and organized version of the Coastal Resources Management CRMC's permit database as well as spatial and temporal analysis of the data was provided to the CRMC in February, 2018 along with a detailed presentation to CRMC leadership and staff..

The data summary and analysis includes:

- CRMC decisions of all types by category of assent
- CRMC decisions by project activity type
- CRMC decisions by municipality.
- Trends in project decisions related to new coastal site development compared to rehabilitation and maintenance of existing coastal sites.

Several types of location based information based on the CRMC permit data base were made possible with a new capability in Excel to interact with ARCGIS. Assents and decisions of all types from the data base that included a municipality and street name (40,630) were geo-located. Maps and visualizations include:

- Overall patterns of coastal development decisions including an animation.
- Areas of greatest concentration of shoreline protection and management projects.
- Shoreline protection projects in port and working waterfront areas.
- Location of CRMC approved projects by new coastal site development compared to rehabilitation and maintenance of existing coastal sites.
- Detailed visualizations of hazard threats and shore line change to areas of focus

One category of areas of concern for coastal resilience are commercial waterfronts. Figure 1 shows the location of the five categories of shore protection assents within selected port and harbor areas mapped and analyzed in 2010. (Becker, A., Wilson, A., Bannon, R., McCann, J., Robadue, D.,2010). Providence Harbor, Newport Harbor and Wickford Cove have been the focus of vulnerability studies and adaptation planning.

A final version of the technical report will be provided to the CRMC taking into account a selection of additional information to complement the findings and recommendations of the Shoreline Change SAMP.

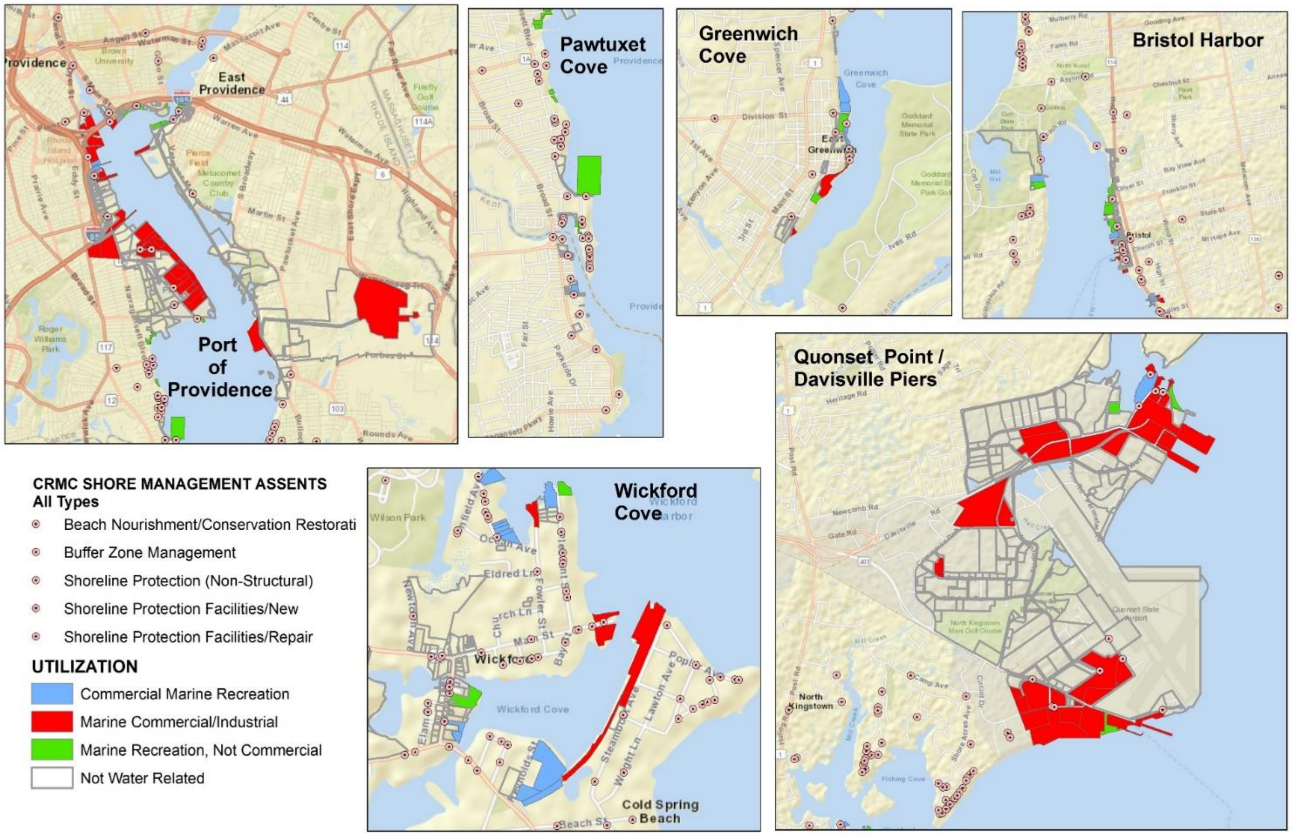


Figure 1 Location of shore management CRMC assents in ports and harbors, 2016

Shore management assents by themselves may not reflect the full amount of deliberation and decision-making activity. Figure 2 shows trends assents related to new and “rehabilitated” project sites such as docks, piers, commercial, and residential projects. Many of the policies aimed at improving the resilience of development in hazardous coastal areas, for example in the 2018 Shoreline Change Special Area Management Plan, are aimed at applicants for new permits. However, the amount of new construction in coastal locations has dropped dramatically as buildable coastal lots have diminished. By contrast, the number of permit requests for coastal development that rehabilitates and intensifies existing uses and structures has grown dramatically. On an annual basis relatively few CRMC decisions would trigger a full utilization of the sophisticated decision tools incorporated into the SAMP guidelines. More likely, the tools will be most useful to individuals seeking to purchase an existing home, business or structure within a high hazard area and invest in rehabilitation, expansion and potentially applying some storm and sea level rise – proofing as part of the remodeling.

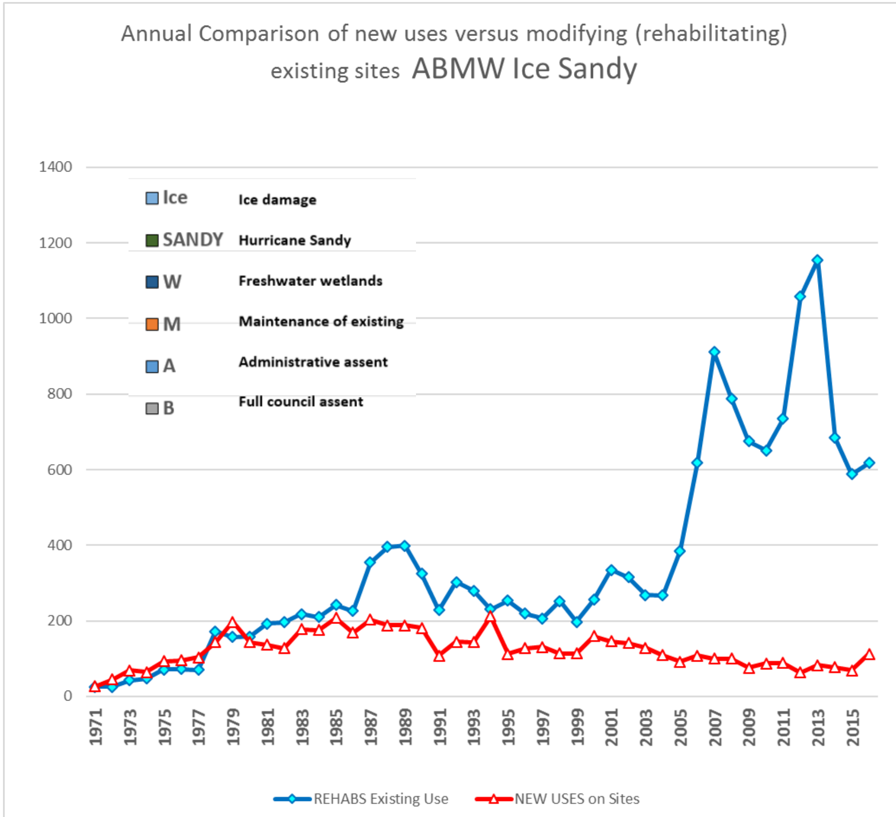


Figure 2 Annual Comparison of CRMC assents that allow new uses on a coastal site compared to projects that maintain or rehabilitate existing development on a site

Shore protection and coastal hazard focal areas

A key aim of the overall investigation is to understand the factors which foster the adoption and uptake of more protective coastal development policies as well as the obstacles, or barriers revealed through the deliberations leading to new policies as well as decisions on specific shore protection measures. Figure 3 shows the clusters of shore protection decisions made by the CRMC, a total of 3342 assents between 1971 and 2016. Although the South Shore has experienced a great deal of new development in past decades, shore protection issues are equally important throughout the state, occurring in a wide range of coastal physical settings.

The effects of the CRMC's continuous revision and updating of its shoreline change policies can be seen in Figure 4, a graph of cumulative percent of types of shore protection projects. In the 1970s more than half of the projects approved by the CRMC were for new hard shoreline protection facilities. With the adoption of the revised "Red Book" program document and subsequent policy revisions beginning in the early 1980s beach nourishment and non-structural shoreline protection became far more important. Repair of existing shore protection structures continued to be allowed and accounts for about 40% of the total. It remains to be discovered what impact the Shoreline Change SAMP will have on this evolving picture.

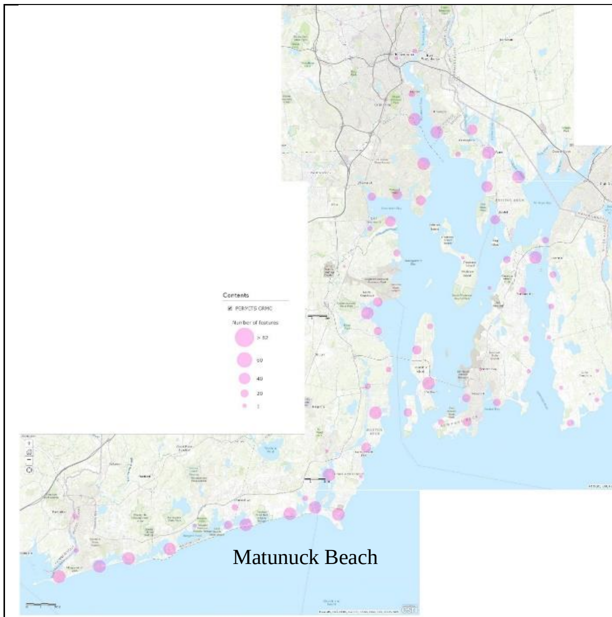


Figure 3 Clusters of CRMC shore protection decisions 1971-2016

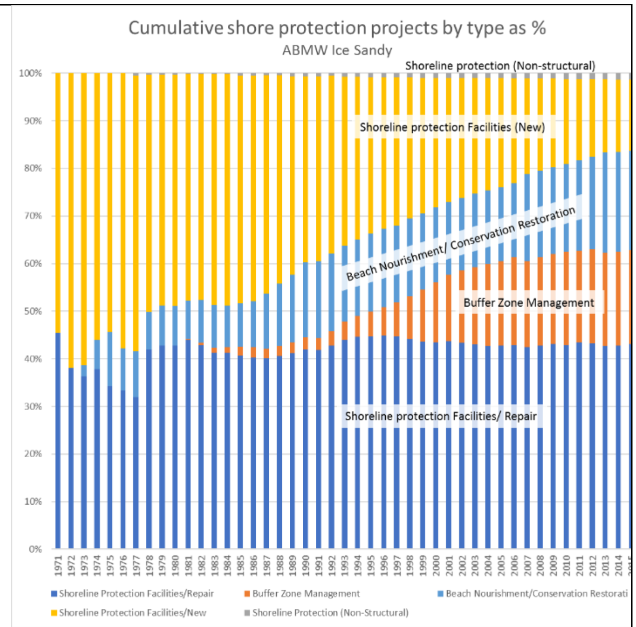


Figure 4 Cumulative shore protection projects by permit type as a percent of total, 1971-2016 (excludes pre-determinations, findings of no impact)

Vignettes to identify obstacles and opportunities for hazard adaptation and resilience.:

Two cases of the emergence of resilience policies in RI were examined in detail.

The March 2010 Rains and its impact on the Warwick Wastewater Treatment Facility

The aftermath of the March Rains of 2010, the worst inland flooding in a century, led to new hazard mitigation policy can emerge relatively quickly under the right set of circumstances. The watershed of the Pawtuxet River, which cuts through the town of West Warwick, and the cities of Warwick and Cranston, experienced 20 inches of rain over a period of 38 days in the spring of 2010. The Warwick Sewer Authority's wastewater treatment facility was completely inundated and suffered $14 million in damages. Until this massive event, the treatment facility had not been included in the City's hazard mitigation plan and was highly vulnerable to overtopping of the levee which guided the Pawtuxet River past the low-lying facility.

Figure 5 Flooded Warwick Wastewater Treatment Facility, March 2010.

Local leadership by the Warwick Sewer Authority and its executive director, Janine Burke, mobilized to restore functioning to the facility and spur a comprehensive review of its vulnerability. Coincidently, the city was updating its Multi-Hazard Mitigation Plan, and made sure it included a number of new policies and requirements to address the needs of the facility as well as residences in low-lying flood plain areas along the river which were flooded out for the first time. The policy process might have stopped there if not for the fact that Janine Burke had attended a meeting of the recently created Rhode Island Climate Change Coordinating Council, which led to a wider audience for the success story in the Pawtuxet River area and the incorporation of municipal waste water facilities in future multi-hazard plans in the state. William Patenaude of the Rhode Island Department of Environmental Management took the unusual step of sponsoring a report documenting in detail how the public works and wastewater treatment facility crews along the river interacted to insure recovery from the event and reforms to operations and facilities.

This vignette, prepared through the work of summer intern Courtney Hill of Tougaloo College, demonstrated the viability of several research techniques including content analysis of local documents and newspapers, where the case first came to the attention of the research team, and social network analysis using affiliation or two-mode data drawn from this documentation. The sociogram prepared for the vignette helps illustrate that while there is a high density of interactions among state level experts and leaders on hazard mitigation and climate change adaptation, the managers and staff of the vulnerable wastewater treatment facilities along the Pawtuxet were largely isolated and peripheral until Janine Burke (shown as Burke_J in the diagram) had made contact with state level groups which had many communication pathways to agency leaders such as Patenaude as well as being included in state level hazard planning exercises and simulations.

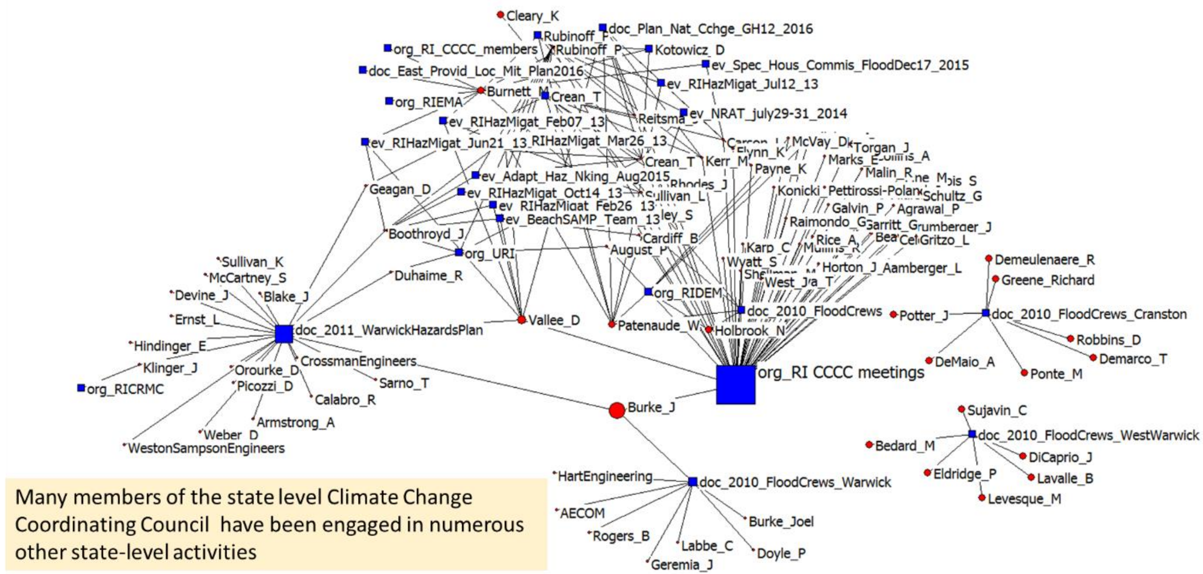


Figure 6 Social network analysis illustrating weak but important ties between Janine Burke, executive director, and the statewide network of climate change and hazards actors

The convergence of extreme crisis, local and state leadership, an ongoing revamping of the municipal hazard mitigation plan, successful aggregation of funds from several sources to implement needed hazard prevention measures, and recently opened new lines of communication led to an unexpectedly strong example of how a focusing event can lead to substantial progress.

The Matunuck Beach Century: Community Continuity in the face of Coastal Change

Matunuck has been the locus of coastal management challenges and controversies since the 1970s when the state created the Coastal Resources Management Council, but more importantly has been a unique community and summer colony since the mid-1800s. (Town of South Kingstown.2015. The Matunuck Village Plan. Prepared by Horsley Witten Group)

> While social and recreational aspects of Matunuck are usually the focus for the seaside village, the natural features that shape the landscape and provide habitat are also integral to the experience of Matunuck. ... Most recently, however, larger forces have become the center of attention as ocean currents and storms are working to reshape Matunuck in more dramatic ways than ever before, particularly the coastline. (P. 6)

In the past decade, Matunuck has frequently taken center stage in Rhode Island's struggles with coastal erosion, sea level rise, storm surge and coastal flooding, even garnering a headline in the NY Times: "In Rhode Island, Protecting a Shoreline and a Lifeline." (Jess Bidgood May 12, 2012, Page A16).

According to the recently completed Shoreline Change Special Area Management Plan adopted by the Rhode Island Coastal Resources Management Council:

> the Matunuck Headland area is one of the most at risk in the state to the combined effects of storm surge, sea level rise and coastal erosion. Evaluation of historic shoreline change revealed a very high rate of erosion along a stretch of Matunuck from Cards Pond to the east

end of South Kingstown Town Beach. Individual transects in this area exceed a loss of 1.4 meters/year. (Chapter 4, p. 52)

The focus of this vignette is on identifying broad categories of opportunities and obstacles that surround adaptation responses and actions since the 1970s related to shoreline change, storm impacts and sea level rise. The analysis of shoreline development decision making since 1971 by the RI Coastal Resources Management Council highlights Matunuck Beach as a coastal development hotspot.

ArcGIS Online

[*ArcGIS online clustering* routine]

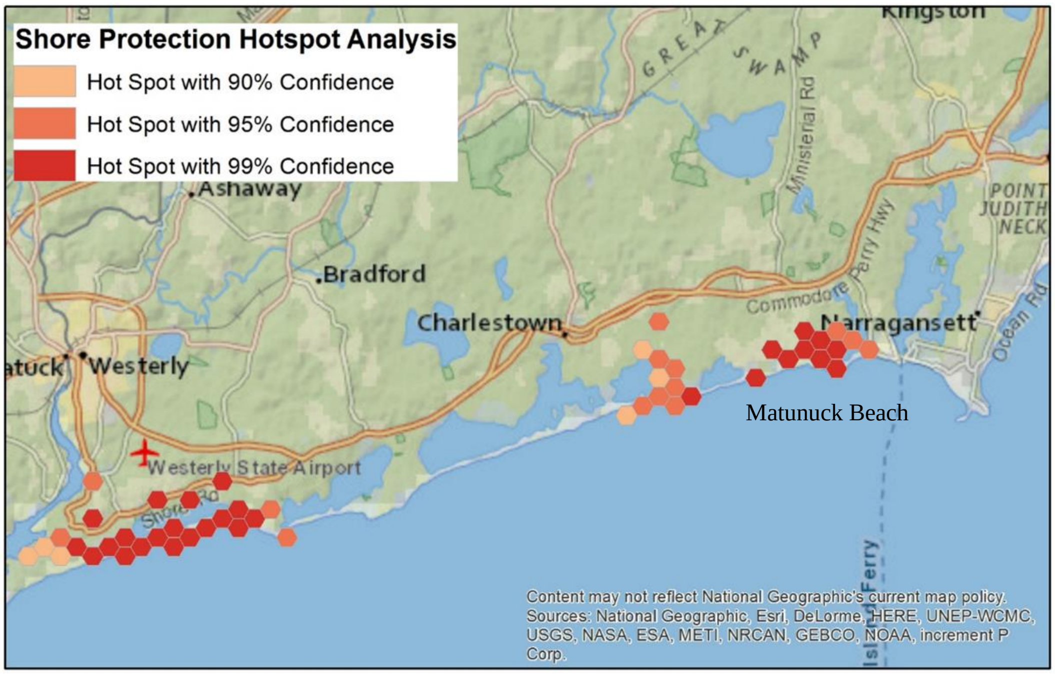


Figure 7 Shoreline protection hotspots in the Rhode Island south coast

Structures and CRMC assents within overwash zone of Hurricane of 1938

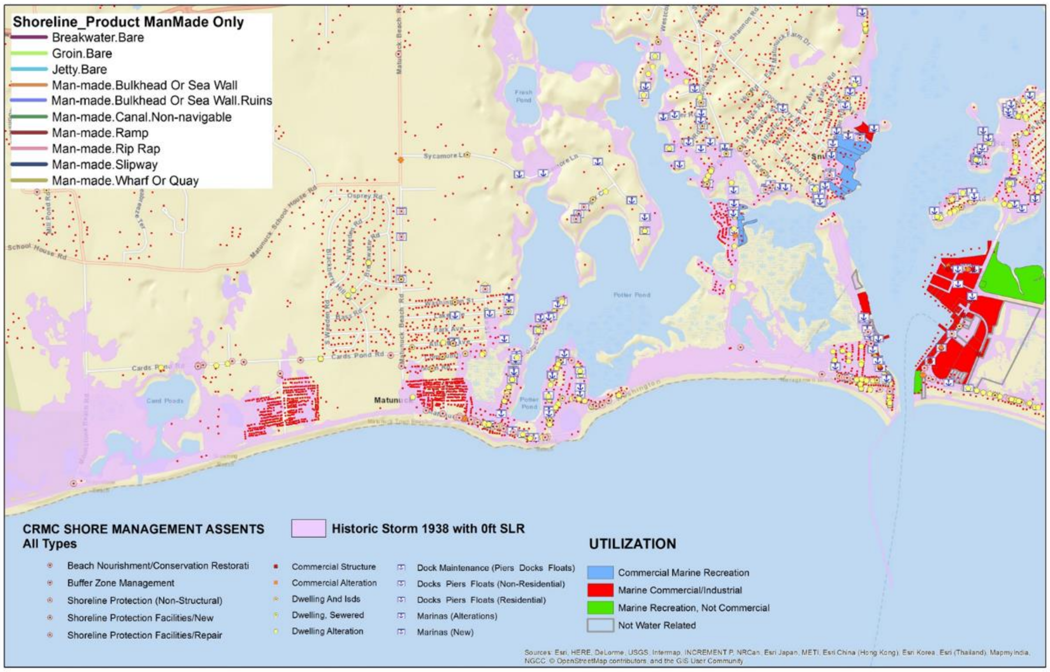


Figure 8 Structures and CRMC assents within the overwash zone of the Hurricane of 1938 in the Matunuck Beach and East Matunuck area

Coastal development since 1971 is largely within the zone of impact of the storm surge from the Hurricane of 1938 (in pink). Through 2016, the CRMC has issued 1953 permits for 58 types of activities involving 797 unique individuals. Shore protection actions were sought by 120 individuals and businesses who carried out 211 projects.

As in the case of the Pawtuxet River flooding vignette, much of the known story line involves relatively few actors. In this case we added the information on the permit holders to other sources of information and found that most of the news and publicity about controversies in Matunuck involves only 9 businesses and individuals.

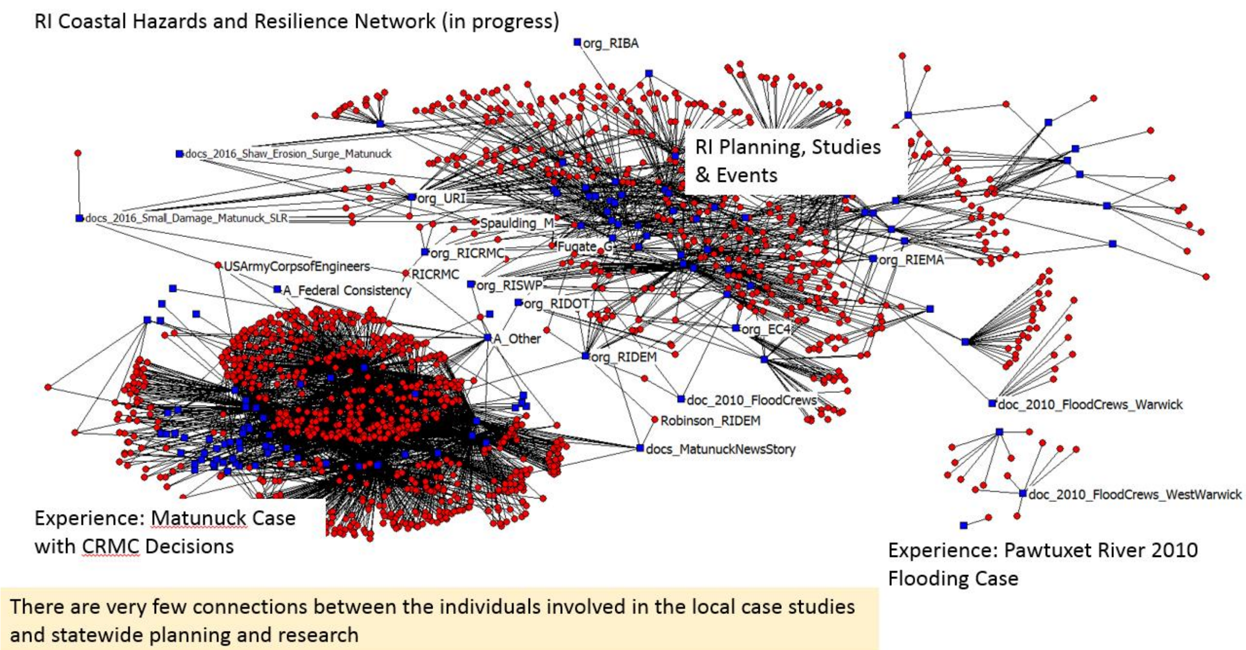


Figure 9 Social network analysis showing weak ties between the state level climate change and hazards actors and Matunuck Beach permit recipients and local actors.

We then compiled several dozen reports, plans and published studies, along with several hundred newspaper articles from 1983 to 2017 obtained using the simple search string "Matunuck AND erosion OR flooding". A combination of automatic and manual coding was done for sections of the documents and news articles relating specifically to shoreline change and management and Matunuck. This yielded 71 codes for quotes related to obstacles to adaptation, an equal number of codes covering adaptation responses, and 29 distinct codes for opportunities to adapt. The obstacles, opportunities and adaptation response types could be broadly grouped in six categories:

$: cost or financing to carry out actions

A: actions, specifically adaptation responses such as beach nourishment, demolition of threatened structures, relocation of structures.

KA: knowledge and attitudes, for example scientific uncertainty, low urgency in taking action, improving flood insurance maps using GIS, preference for maintaining community character over disruptive adaptation.

S: situational factors such as the amount of prior development in hazard areas that is already exposed to wind, waves, erosion or flooding or the presence of armored or hardened shoreline, any of which would constrain the use of more resilient practices.

P: policy—rules, regulations and proposals to change how and where development is allowed to occur

Pr: process--- planning efforts, public meetings, degree of trust among stakeholders and officials, fearfulness over safety that leads to quick or hasty actions.

A selection of the most frequently encountered mentions of concepts is shown below.

OBSTACLES	#	OPPORTUNITIES	#	RESPONSE	#
Obst KA,P: Mismatch between impact causes and effective solutions	72	Opport Pr: Ongoing state/ federal planning, zoning, regulation process	63	Response A,$: Shoreline protection (sea wall, sheet pile)	120
Obst KA: Low comprehension of risk	62	Opport Pr: Public meeting or hearing	56	Response A,$: Relocation	71
Obst $: Interest in extending the use of property in hazardous areas as long as possible	37	Opport Pr, $: Coordination & capacity for funding	48	Response P: Proposed Hazard Policy, Regulation	50
Obst $: Interest in protecting property, business, investment	36	Opport Pr: Collaboration between private and government stakeholders	38	Response A: Temporary sand bags, fencing, wooden walls, burritos	49
Obst $: High cost of more effective solutions	35	Opport P: Congruence between nature of problem and most effective solutions	37	Response A: Beach nourishment	45
Obst Pr: Safety fears > quick action	35	Opport Pr, KA: Educate private and public sector stakeholders	32	Response A: Beach nourishment w. dredging.	43

There are connections among the obstacles, opportunities and responses, but our aim here is to show broader ideas and patterns, for example in the following graphic the full set of obstacles, opportunities and responses are arrayed around the six broad categories of Process, Knowledge, Money, Action and Policy. The specific quotes captured by this type of coding for the Matunuck cover the full range of drama, frustration and doubt raised each time a major storm event causes damage and concern in the community.

By comparison, most public documents such as plans and studies focus mainly on Knowledge, Action and Process variables. The Shoreline Change SAMP is very clear and constrained in its approach:

> “The guidance offered by this Shoreline Change SAMP is primarily for applicants seeking coastal permits from CRMC. CRMC is proposing a requirement that coastal permit applicants complete a five-step risk assessment process for proposed developments within CRMC’s jurisdiction as part of the permit application.
>
> Other audiences for this SAMP, in addition to CRMC members, staff, and coastal permit applicants, are decision makers, planners, boards and commissions in Rhode Island’s 21 coastal communities who are principally responsible for coping with the impacts of storms, coastal erosion, and sea level rise outside of CRMC’s jurisdiction. The Shoreline

Change SAMP is also intended to aid other state and federal agencies responsible for coastal resources, assets and property in Rhode Island in future planning and decision making." (Page 2)

The document is rich and thorough in its scientific treatment of Matunuck and other high priority segments of the shore, as well as detailed in its recommendations on adaptation actions. It acknowledges a number of areas of constraint currently faced by state and local decision makers, mainly legal reforms that would expand the tools available to both permit applicants.

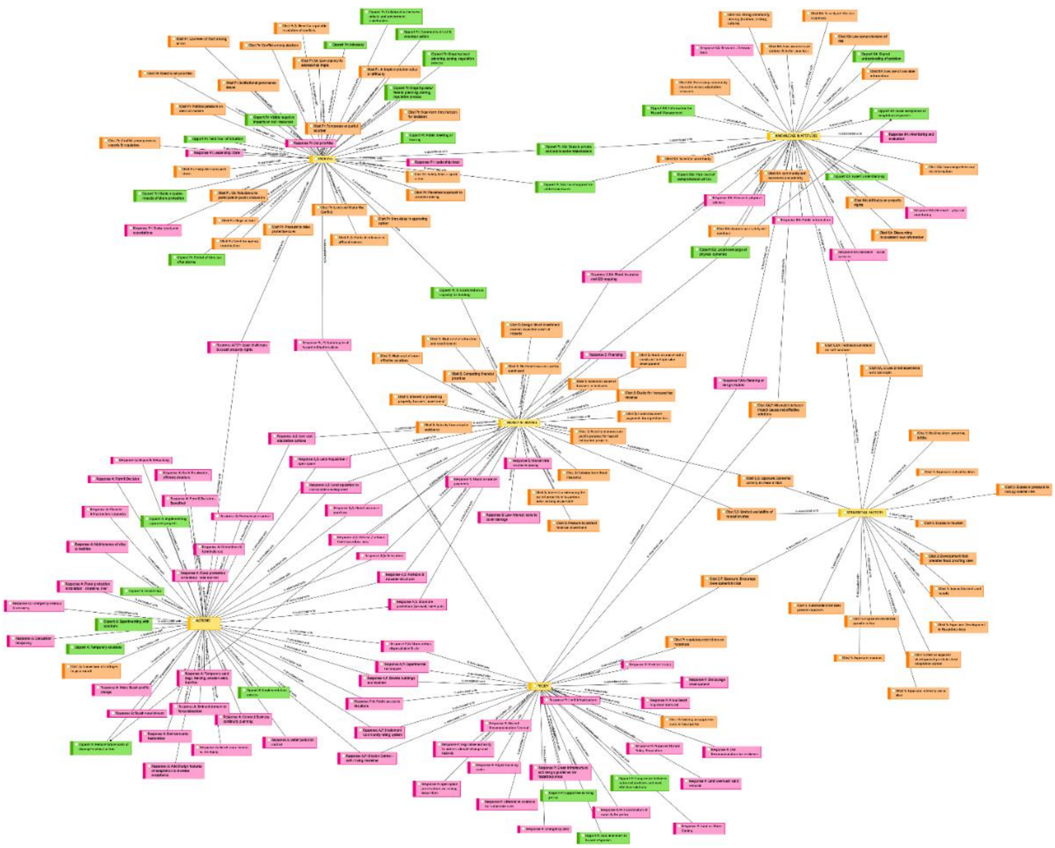


Figure 10 The network of obstacles, opportunities and adaptation responses from the Matunuck case

Outreach on Research Findings

Summaries of the analysis and findings were presented at two conferences in 2018.

"Resisting resilience: Experience and dynamics that limit or foster the adoption of policies and actions that can reduce the vulnerability of coastal communities" was presented to the Social Coast Forum on February 6, a biennial conference of social scientists and professionals working on coastal issues, held in Charleston, South Carolina. Funding for travel and registration was provided by the Coastal Institute of the University of Rhode Island. Co-authors of the presentation included Donald Robadue, Jr., Dawn Kotowicz, and Courtney Corvese of the Coastal Resources Center, Courtney Hill of Tougaloo College, and Ryan Moore of the Rhode Island Coastal Resources Management Council.

A similarly titled but updated version of the presentation was given to the Rhode Island Flood Mitigation Association annual conference held at Fidelity Investments, Smithfield, RI on April 5.

A more detailed technical presentation and round table discussion “Summary of CRMC permit data including georeferenced assents related to the research project “Overcoming Barriers to Motivate Community Action to Enhance Resilience – Identifying Obstacles and Incentives for Resilience/Adaptation in the Rhode Island experience” was given to the CRMC leadership on Wednesday February 14th.

Lessons Learned

Identifying enabling conditions for hazard policy development:

- We identified seventy distinct obstacles and thirty opportunities involved in determining and adopting adaptation responses through an analysis of key documents, public statements and press coverage of the ongoing situation in Matunuck Beach, arguably the most affected and sometimes controversial vulnerable coastal area. We sought to identify the ‘semantic language’ that stakeholders, regulators and citizens use to express their frustrations as well as their ability to see opportunities to create policy changes as well as defend against it. The plain language that is used by the various groups of stakeholders to discuss obstacles to resilience, and how they have been overcome is not readily captured in any of the analytical schemes used by resilience researchers including ourselves. We found ourselves creating catch phrases to capture the essence of authors, reports and quoted individuals. No one, in practice speaks using the sophisticated, carefully defined terminology or expressions found in key documents such as the Shoreline Change SAMP, the South Kingstown Multi-Hazard Mitigation Plan or the Matunuck Village Plan.
- Timelines of state and local experience as well as data on local situations in terms of past decision making, regulation, storm events, erosion and shore retreat studies and forecasts of future storm impacts provide essential background for the decision making story lines found in each place. Cases such as Matunuck Village and its beach are of statewide significance and more broadly known that most of the routine permits and development decisions along the coast. However every reach of the coast has a unique configuration and decision history that will influence for better or worse the ability of municipal and state agencies to foster more resilient coastal settlements and businesses.
- There is a strong bias in Rhode Island’s studies and plans based on the assumption that deficits in scientific and site based information and a dearth of specific response actions are key bottlenecks keeping Rhode Island from attaining a much greater measure of resilience than it currently has in the face of a “Hurricane Rhody” scale storm event). However, even our relatively simple approach to analyzing what individuals think and have expressed in the decades reveals a more complex and challenging reality.
- Putting the ten most commonly expressed obstacles in narrative form is revealing. In the public’s mind there is often a mismatch between an understanding of hazard impact causes and the available repertoire of effective solutions. Consulting engineers, regulators and experts possess a clear understanding but few residents in a coastal area apply for permits, and those who do rely on engineers and designers to fill in the many details. A

low comprehension of risk does validate regulators concerns about the need for public and developer education. However this factor should not be confused with the overwhelming interest of both long time and new residents in extending the use of their property in hazardous areas as long as possible. This drives the strong pressure and interest in protecting property, business, investment. Even sophisticated and savvy coastal property owners are stymied by the high, often uncertain costs of more effective solutions, for example elevating an existing structure or moving it away from an eroding shore. On the one hand, safety fears spur demands for quick action, sometimes including illegal, and usually ineffective shore protection measures that regulators then have to act to remove. Attitudes on property rights can make this an entrenched behavior, causing conflict among owners, experts & regulators. On the other hand, many coastal property owners and local leaders may assume that their past safety will continue into the future, either based on little information or misinformation or a disbelief in scientific forecasts and modeling.

- Considering the two cases, the March 2010 floods represent a case where significant strides in resilience policy did result where there was strong leadership with connections to decision makers and knowledgeable about access to financing, and a significant economic impact to the state as a whole. These factors were enabling conditions for this case, which could provide a framework for investigating future cases.
- Although we document one clear example where a flood hazard generated a crisis that led rather quickly to mitigating actions and policy change in the case of the March 2010 floods, most of the shoreline change and coastal hazard issue have their roots in decisions and phenomena that reach back many years, often decades. While the absence of lived experience with a major storm within recent memory might dampen interest in stronger, faster action, the localized, chronic impacts throughout the coast, as they become better understood, needs to provoke steady, sensible responses over not just the years but the decades to come.

Next Steps

Intended activities and products by end of the project:

1. Final draft of technical report combining timeline, shoreline decision-making analysis and the identification of obstacles and opportunities from Rhode Island experience taking into account the findings and recommendations in the recently adopted Shoreline Change Special Area Management Plan.
2. Peer-reviewed journal paper.

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Obstacles to adaptation

$: cost, financing
A: actions
KA: knowledge and attitudes
S: situational factors
P: policy
Pr: process

Obst $: Competing financial priorities
Obst $: Design life of investment exceeds expected onset of impacts
Obst $: Desire for increased tax revenue
Obst $: Economic value of business in hzd area
Obst $: flood insurance not a constraint to high value development
Obst $: Flood insurance payments for repetitive loss
Obst $: Funding for local staffing & capacity
Obst $: High cost of more effective solutions
Obst $: High cost of relocation and resettlement
Obst $: Interest in extending the use of property in hazardous areas as long as possible
Obst $: Interest in protecting property, business, investment
Obst $: Need to demonstrate public purpose for hazard mitigation projects
Obst $: No flood insurance policy purchased
Obst $: Pressure to protect financial investment
Obst $: Subsidy from disaster assistance
Obst $: Subsidy from flood insurance
Obst A: Conversion of cottages to year round
Obst KA, S: Low direct experience with hzd impts
Obst KA,P: Mismatch between impact causes and effective solutions
Obst KA: Assume past safety will continue
Obst KA: Attitudes on property rights
Obst KA: community self-awareness and identity
Obst KA: Discounting inconsistent new information
Obst KA: Low awareness of options & better practices
Obst KA: Low comprehension of risk
Obst KA: Low comprehension/ misinformation
Obst KA: Low use of available information
Obst KA: Preserving community character versus adaptation measures
Obst KA: Scarcity of effective responses
Obst KA: Scientific uncertainty
Obst KA: strong community identity (tradition, history, culture)
Obst P: Existing unsupportive state or local policy
Obst P: regulatory restrictions on responses
Obst Pr, A: Implementation delay or difficulty
Obst Pr, KA: Reluctance to participate in public discussion
Obst Pr,$: Need for equitable resolution of conflicts
Obst Pr,$: Political influence of affluent owners

Obst Pr,$: Site analysis for permit application process
Obst Pr,KA: Low urgency to address hzd impts
Obst Pr: Conflict among abutters
Obst Pr: Conflict among owners, experts & regulators
Obst Pr: Hasty decisions post-storm
Obst Pr: Illegal actions
Obst Pr: Institutional governance issues
Obst Pr: Land and Water Use Conflict
Obst Pr: Low level of trust among actors
Obst Pr: Near-term time horizon for decisions
Obst Pr: Need for agency coordination
Obst Pr: Need to set priorities
Obst Pr: Piecemeal approach to problem solving
Obst Pr: Political pressure on decision makers
Obst Pr: Pressure to relax protective rules
Obst Pr: Safety fears > quick action
Obst Pr: Temporary or partial solution
Obst Pr: time delay in approving option
Obst S,$: Exposure: Economic Activity Increase in Hzd
Obst S,$: Limited availability of relocation sites
Obst S,KA: Technical constraint on soft solutions
Obst S,P: Exposure: Encourage Development in Hzd
Obst S: Development that predates flood proofing rules
Obst S: Existing shore armoring, jetties
Obst S: Exposure: critical facilities
Obst S: Exposure: Development in Hazardous Area
Obst S: Exposure: intensify use in Hzd
Obst S: Exposure: marinas
Obst S: Exposure: pressure to occupy coastal sites
Obst S: Exposure: residential growth in Hzd
Obst S: Exposure: tourism
Obst S: low or blocked sand supply
Obst S: Past or adjacent development precludes best adaptation option
Obst S: Substandard lot sizes prevent reponses

Opportunities for adaptation
$: cost, financing
A: actions
KA: knowledge and attitudes
S: situational factors
P: policy
Pr: process

Opport A,Pr,$,KA,P: Mutual aid among municipalities
Opport A: Experimenting with solutions
Opport A: Implementation success

Opport A: Implementing approved projects
Opport A: Leadership
Opport A: Reduce future costs of damage via local action
Opport A: Temporary solutions
Opport KA: Expert understanding
Opport KA: High level of comprehension of risk
Opport KA: Information for Hazard Management
Opport KA: Local acceptance of adaptation responses
Opport KA: Local knowledge of physical dynamics
Opport KA: Shared understanding of problem
Opport P: Add amenities to hazard responses
Opport P: Congruence between nature of problem and most effective solutions
Opport P: Supportive existing policy
Opport Pr, $: Coordination & capacity for funding
Opport Pr, KA: Educate private and public sector stakeholders
Opport Pr, KA: Local support for addressing issues
Opport Pr: Advocacy
Opport Pr: Collaboration between private and government stakeholders
Opport Pr: Community direct & volunteer action
Opport Pr: Field Tour of Situation
Opport Pr: Ongoing local planning, zoning, regulation process
Opport Pr: Ongoing state/ federal planning, zoning, regulation process
Opport Pr: Period of time just after storms
Opport Pr: Public meeting or hearing
Opport Pr: Visible negative impacts of shore protection
Opport Pr: Visible negative impacts on nat'l resources

Adaptation responses /strategies
$: cost, financing
A: actions
KA: knowledge and attitudes
S: situational factors
P: policy
Pr: process

Response $,A: Flood insurance purchase
Response $,KA: Flood insurance and GIS mapping
Response $: Financing
Response $: Flood insurance payments
Response $: Low-interest loans to cover damage
Response $: Market rate insurance pricing
Response A,$: Land Acquisition / open space
Response A,$: Land aquisition to consolidate development
Response A,$: Low cost adaptation options
Response A,$: Portable & movable structures
Response A,$: Relocation

Response A,$: Retreat / setback from hazardous area
Response A,$: Shoreline protection (sea wall, sheet pile)
Response A,P,Pr: Legal challenges & assert property rights
Response A,P: Elevate buildings and facilities
Response A,P: Erosion Control - soft / living shoreline
Response A,P: Experimental Techniques
Response A,P: Implement Community rating system
Response A: Add Design features of adaptation to increase acceptance
Response A: Beach nourishment
Response A: Beach nourishment w. dredging.
Response A: Build Breakwater, offshore structure
Response A: Conduct Business continuity planning
Response A: Demolition & terminate use
Response A: Emergency cleanup & recovery
Response A: Emergency response
Response A: Eminent domain to force relocation
Response A: Environmental Restoration
Response A: Evacuation temporary
Response A: Flood protection installation - shoreline, river
Response A: Flood protection installation- tidal barriers
Response A: Maintenance of sites & facilities
Response A: Make Beach profile change
Response A: Permit Decision
Response A: Permit Decision - Expedited
Response A: Planned infrastructure upgrades
Response A: Repair & Rebuilding
Response A: Temporary sand bags, fencing, wooden walls, burritos
Response A: water pollution control
Response KA: Monitoring and evaluation
Response KA: Public information
Response KA: Research - Decision tools
Response KA: Research - physical monitoring
Response KA: Research - social sciences
Response KA: Research -physical sciences
Response P,A: Public access to the shore
Response P,A: Storm debris disposal plan & site
Response P,KA: Planning or design studies
Response P,Pr: Coordination & capacity for policy
Response P: Adjust Building codes
Response P: Allow Beach migration (natural)
Response P: Alternative locations for vulnerable uses
Response P: Discourage Development
Response P: Emergency plan
Response P: Green infrastructure' and design guidelines for hazardous areas
Response P: Hazard Recommendation General
Response P: Land or Water Zoning

Response P: Legislative authority to address climate change and hazards
Response P: Limit infrastructure
Response P: Limit overwash sand removal
Response P: open space preservation via zoning, acquisition
Response P: Prohibit Use(s)
Response P: Proposed Hazard Policy, Regulation
Response P: Use Recommendation for resilience
Response Pr, P: Updating local hazard mitigation plans
Response Pr,P: Update comprehensive plans
Response Pr: leadership: local
Response Pr: Leadership: State
Response Pr: Revise goals and expectations
Response Pr: Set priorities
Response P: Allow wetlands migration

VII. A Decision Support Tool to Assess Adaptation Strategies for Sea Level Rise and Flooding on Cape Cod

This Research Activity developed data and methods as input to a GIS-based Decision Support Tool created by the Cape Cod Commission. The tool and quantification of ecosystem values will be used in public engagement processes to make coastal planning tradeoffs explicit and to assist policymakers in selecting appropriate local and regional strategies to mitigate the impacts of climate change and SLR. This Research Activity was led by Dr. James Opaluch, and supplementary funding for this work was obtained from the Cape Cod Commission.

Project personnel collaborated with the Cape Cod Commission to develop socio-economic analyses to gauge how values of ecosystem services on Cape Cod will be impacted by climate change, erosion, sea level rise (SLR), and an evaluation of how implementing adaptation strategies may impact these estimated values. Project personnel also worked closely with the Commission to integrate these ecosystem service values into the Decision Support Tool prior to and during its development.

The work involved carrying out a literature review of ecosystem service values and working closely with the Commission to integrate this information into a GIS-based decision support tool. The tool is intended to:

- allow stakeholders to visualize the impacts of climate change, erosion, SLR, and adaptation scenarios;
- demonstrate the market and nonmarket values associated with these impacts;
- assess how people value adaptation strategies by weighing tradeoffs associated with different adaptation scenarios.

The goal of this task is to estimate the value of ecosystem services affected by climate change, erosion and SLR impacts on Cape Cod using previously conducted research. This is a benefit transfer study that estimates the impacts of implementation of climate change, erosion and SLR adaptation studies on the values of the ecosystem services, based on the adaptation strategies that were identified. Commission staff provided some relevant data, including GIS-based information; but any additional data required for the study was collected as part of this Research Activity. The Research Activity also involved the following tasks:

- A detailed explanation of data sources and the data collection process
- An explanation of methodologies
- Analysis of data, including basic descriptive statistics and tables/figures as needed
- Suggestions for further study

This benefit transfer study was carried out in a very limited time frame, and on a limited budget that precluded the possibility of carrying out new, primary studies. Hence, we use readily available studies only. Following earlier discussions with the Commission, it was agreed that there is a preference for identifying a smaller number of studies that are better fit for valuing ecosystem services on Cape Cod, as opposed to identifying a larger number of studies carried out in a large variety of contexts throughout the nation. Hence, the focus of this benefit transfer analysis is on studies within the Northeast region, and at marine and estuarine coastal values sites similar to coastal Cape Cod. We restricted consideration to studies done on Cape Cod, southeast Massachusetts, Rhode Island, Connecticut, New York, New Jersey, Delaware, Maryland, Virginia and North Carolina. Where feasible, studies carried out closer to Cape Cod were selected over studies carried out further away (e.g., Rhode Island rather than North Carolina).

We constructed a spreadsheet to document the various calculations described below. In some cases, several different methods are illustrated, which may be used in combination for different situations, depending on the availability of data. We anticipate working closely with the Commission to integrate these methods into the GIS-based decision support tool.

Our categories of impacts included in this analysis are:

- Value of lost recreational beach user-days
- Value of reduction in quality of beach recreation from reduced beach width
- Value of lost in recreational fishing days
- Value of lost saltmarsh and eelgrass habitat

Each of these is described in order.

I. Value of Loss in Recreational Beach User-Days

We provide estimates for recreational beach use and shoreline fishing. Beach losses are estimated combining (1) meters of beach impacted, (2) recreational user days per meter of beach and (3) value per recreational user-day.

(1) Meters of Beach Impacted

We consider the following types of beach impacts: loss of recreational beach, loss of public access to recreational beach, and narrowing of recreational beach. We also outline three alternative methods for quantifying beach impacts, described below. All methods described below assume no inland migration of shoreline types, as doing so requires site specific information. Rather, the calculations are based on simple loss of each category of shoreline. These calculations could be modified within the GIS-decision support tool by considering the spatial context of the landforms and land use. For example, sand beach or saltmarsh with developed land or uplands on the inland margin could be assumed to be lost. Sand or saltmarsh with low lying undeveloped land on the inland margin could be assumed to migrate.

The first method asks the user to specify length of lost recreational beach, the length of lost beach access, the length of beach that is narrowed and the associated reduction in beach width. This is the simplest approach from the modeling perspective, but requires direct user input of each category of impact.

The second approach is based on linking an adaptation strategy (e.g., constructing a revetment) to the beach impacts. First, the segment of the beach that is armored is lost to beach use. This is sometimes referred to as Encroachment or Placement loss (e.g., Coyle and Dethier, 2010). Our analysis assumes the footprint of the armoring structure is lost to recreational use, and that any beach on the seaward side is lost as the shoreface moves landward. This latter component is sometimes referred to as passive erosion (Ruggerio, 2010). For example, a 50 meter revetment constructed on a beach leads to the loss of 50 meters of beach recreation.

Armoring of shoreline can also increase the rate of loss of adjacent beach due to wave reflection, scouring and erosion along the edges of the structure. This is sometimes referred to as active erosion (Coyle and Dethier, 2010). We were only able to identify a few studies that allow us to quantify this category of impact. Fletcher et al (1997) found beaches adjacent to armoring structures were narrower by an average of 4.3 meters. Coyle et al (2010) conclude: "[r]eflection at the lateral ends of seawalls caused local erosion and arcuate indentations that extended from 50 to 150 m alongshore".

The current spreadsheet provides calculations based on these results, so that the beach within 75 meters of a structure is narrowed by 4.3 meters. The calculations also allow for different shoreline types, so this category of increased erosion can occur to beaches within different categories (e.g., town beach vs National Seashore), as well as to saltmarsh.

However, it is important to note that conclusions regarding erosion adjacent to shoreline armoring are controversial. While shoreline armoring is often cited as a cause of impacts to adjacent shoreline through beach narrowing and a decrease in the natural sediment supply, other research finds no difference in armored versus natural shorelines. For example, Griggs (2010) concludes "[c]omparison of data from 8 years of surveys reveals no distinguishable differences between the winter or the summer profiles for the seawall and the adjacent control beaches". Similarly, using data from 15 years of beach profile data in Virgina, Jones and Basco (1996) find that "… statistically, there is no difference in the erosion rates of walled and non walled beaches". Hearon et al., (1996) conclude "[t]en years of monitoring has revealed that the structures at these seven sites are having no adverse impacts on the surrounding beach or adjacent properties". Hence, inclusion of this category of beach impact appears to be subject to considerable controversy.

Shoreline armoring can cause additional impacts to recreational beach use in some circumstances due to loss of public access to a stretch of shoreline. This effect is entirely location specific, and requires evaluation and user input on a case-by-case basis.

The third set of calculations included in the spreadsheet are associated with sea level rise (SLR), and are not related to specific adaptation strategies in the spreadsheet. For these calculations, an annual rate of shoreline loss is specified by the user, and shorelines around Cape Cod are assumed to recede by that specified amount each year. Within the context of the GIS-based decision support tool, we anticipate these calculations will be integrated with site-specific rates of shoreline migration measured by the transects of shoreline change, and perhaps incorporating the regression results from the Massachusetts Shoreline Change Mapping Project (Thieler et al, 2013).

(2) Recreational Use per Meter of Shoreline

We consider beach recreational use, dividing shoreline into three categories: National Seashore, town beach and "other" beach shoreline. We employ data for each of these shoreline types to estimate average annual beach use per meter of beach.

For National Seashore, we use monthly attendance data collected by the National Park Service (https://irma.nps.gov/Stats/SSRSReports/Park%20Specific%20Reports/Recreation%20Visitors%20By%20Month%20(1979%20-%20Last%20Calendar%20Year). We tested and found no significant time trend for attendance, and therefore used average annual attendance at the Cape Cod National Seashore for the past 10 years. This is divided by the length of the Atlantic shore of the National Seashore to calculate attendance per meter of beach. So, for example, loss of 100 meters of beach on the Atlantic coast of the National Seashore is assumed to result in the loss of shoreline recreation by 100 * (attendance per meter) user-days. Similarly, narrowing of the beach on 100 meters of shoreline is assumed to impact the quality of the recreational beach experience for 100*(attendance per meter) user-days.

For town beaches, we obtained daily beach data for the towns of Barnstable, Chatham, Dennis, Falmouth, Harwich, Mashpee, Yarmouth. Note that we focus only on saltwater beaches in this analysis, not beaches on freshwater ponds. Unfortunately, only the town of Barnstable carries out beach counts for numbers of visitors. Other towns have sales data for permits, but these not very useful for estimating visitation, since permits are for varying length of time, including daily, week-long and seasonal permits. Since we have no way develop credible estimates of daily visitation from week long or seasonal permits, we use only Barnstable visitor count data to estimate user-days per meter of beach.

Very limited data are available for visitation to “other” beach access sites on Cape Cod. We combine two sources of data to estimate the number of visitors per meter at these minor beach access points around the Cape. First, we use visitor counts conducted by the town of Barnstable at beaches with lower attendance rates: Loop and Millway beaches. Each of these beaches has very limited parking, and much lower visitation rates compared to the larger town beaches in Barnstable.

We augment this with the very limited data collected from the US EPA, Atlantic Ecology Division (Lyon et al, 2018). They carry out full-day visitation counts for a total of 16 days at various coastal access sites, including access sites for beaches and boat ramps. This study focuses only on the beach access sites. which includes Ropes Beach (2 days), Loop Beach (3 days) and Cross Street Beach (1 day). Since we have daily town visitor day counts for Loop Beach, we use the EPA data only for Rope beach and Cross Street beach.

Using the data described above, we calculate average beach visitation during July and August, and divide by the length of the beach to estimate average summer attendance per meter of beach. We estimated the length of beach sites using Google maps and its distance function to get a rough idea of the length of beach shoreline associated with the various access sites. We use the year-round attendance data by month from the National Seashore to extrapolate July and August user-days to year-round user days in town beaches. In the National Seashore data, 50.08% of user days occur in July and August. Therefore, we roughly double July/August user-days per meter in order to estimate annual user-days per meter for town beaches.

Table 1 contains the calculations for visits per square meter to the National Seashore, town beaches and “other” shore access sites. Note that the numbers for town beaches and other access sites is preliminary, and based only on a small number of sites. These numbers will be updated, and are likely to be very different for the final analysis.

Table 1. Attendance per Meter of Beach: Updated Feb 19

Shoreline Category	Annual User-Days	Beach Length	User-Days per Meter
National Seashore	5.5 Million	64 km	70.28
Town Beaches	300.3 Thousand	2.5 km	238.8
Other Seashore	15.0 Thousand	1.6 km	18.4

(3) Value per User-Day

As indicated above, during preliminary discussions the Cape Cod Commission indicated a preference for using fewer value estimates for study contexts that are more similar to Cape Cod, rather than using a larger number of studies from a broader variety of contexts across the nation that are less representative of Cape Cod beaches. Therefore, we identified studies done in the northeast region and in similar contexts.

We also recognize at least two different types of beaches on Cape Cod—the relative pristine ocean beaches and beaches located on Nantucket Sound, and the less pristine beaches on smaller embayments and in Massachusetts Bay. We also aggregated our value estimates from the literature into two categories that we judged to be most similar to the minor access points and the more popular major town beaches and the National Seashore. Table 2 shows the value estimates for the various studies, and the average values for each category are contained in Table 2. Each study is briefly described below, along with the rational for selection of the category which seems more appropriate.

Table 2. User Day Values for Beach Use

Study	User-Day Value	Value Expressed in 2017$
Values for Higher Quality Sites		
Parsons et al, 2013	$34.78[1]	$36.59
Lyon et al, 2017[2]	47.58	$48.59
Average for National Seashore & Town Beaches (2017$)		$42.59
Values for Lower Quality Sites		
Kline and Swallow, 1998	$3.62	$5.82
Economic Analysis, Inc., 1999	$8.59	$13.82
Hwang, 2017	$17.42	$18.02
Lyon et al, 2017	$21.99	$22.46
Average for "Other" Beach Access Sites		$15.03

[1] Average of two estimates from the study

[2] Value for "pristine" sites

Parsons et al (2013) estimate the value of beach use in Delaware. The Delaware beaches include those in the southernmost part of Delaware bay and on the Atlantic coast. These beaches are in many ways roughly similar in character to beaches along Nantucket sound and the Atlantic coast of Cape Cod, although water temperatures are much lower along the Atlantic coast of Cape Cod. We include the estimates from this study to estimate value per day for town beaches and the National Seashore.

Lyon et al (2017, 2018) carried out two studies of the value of beach use on Cape Cod using benefit transfer. While the study focused on Cape Cod, using the same town beach attendance data as we use, their value estimates are based on a meta analysis of a beach use at variety of sites. One value is intended to be for relatively "pristine" sites, which we use for National Seashore and the major town beaches. Their estimate for less pristine sites, which have suffered from periodic beach closures, we use to estimate the value per day for "other" beaches.

Kline and Swallow (1998) estimate the value of beach use on a local, free-access site on Goosebury Island in Westport, Massachusetts. The article describes the Goosebury Island recreation site as an "alternative destination to large, more popular beaches" such as nearby Horseneck State Beach. This appears to be a good match to minor beach access points on Cape Cod.

Hwang (2018) employed the Travel Cost approach to estimate the user day values recreation in three salt ponds in Rhode Island, which have a similar character to the smaller embayments on Cape Cod, and similar water quality issues with excess nutrients.

Economic Analysis Inc. used a multi-site travel cost model to estimate the value of beach recreation in the Peconic Estuary on the East End of Long Island. These various Peconic bays vary in character, from the shallow and relative poor quality water in Great Peconic Bay and Little Peconic Bay, to the cleaner waters of Gardners' bay. On the whole, beaches in the Peconic bays are of similar character to the Cape Cod embayments and Massachusetts bay.

Value of Lost Beach Days

As discussed above, the numbers above are used to calculate the value of impacts to recreational beach use. Values per user-day are corrected for inflation by expressing them in 2017 dollars using the Consumer Price Index. We then multiply the value per user-day times annual user-days per meter to estimate the annual lost recreational value per meter of beach lost. These are expressed in capitalized value over time by discounting losses over time, then adding over the relevant time horizon. The spreadsheet calculations are designed to allow the user to input the appropriate discount rate and the planning time horizon. For illustrative purposes, we adopt a 7% discount rate and a 25-year planning horizon.

As an example, the value per user-day for recreational beach use on the Cape Cod National Seashore is $42.59, and the average annual attendance rate per meter of beach is 70.28 user-days per meter. This results in an annual lost value of roughly $3,000 per meter (42.59*70.28=$2,981). Adding up annual losses over 25 years discounted at a 7% rate results in a capitalized loss of $34,739 per meter of beach lost. Therefore, 100 meters of beach lost results in the loss of roughly $3.5 million over a 25-year planning horizon.

II. Value of Changes in Beach Width

Wider beaches tend to have a higher recreational value than narrow beaches, all else equal (at least up to a point), and there is a modest literature that estimates the recreational value of changes in beach width. Some of the literature evaluates *proportional* changes in beach width, such as the value of doubling beach width, or reducing width to one quarter of the existing level (Parsons, et al, 2013). This raises the problem that in order to assess changes in beach width in absolute terms (e.g., 1 meter of beach narrowing), knowledge of the current width of the beach is required. To our knowledge, this data is not generally available on beach width around Cape Cod.

Therefore, we use only studies that value changes in width in terms of a fixed distance, rather than in percentage terms. Studies based on proportional narrowing of beaches could be added to the analysis if data on Cape Cod beach width is available.

Table 3 contains the available estimates of values per user-day of changes in beach width. Values are corrected for inflation by expressing estimates in 2017 dollars, and translated into value per meter of lost width by multiplying value per user-day times user-days per meter of beach.

Table 3. Estimated Value of Change in Beach Width per User Day

Study	Study Location	Value per User-Day per Foot of Width	Average Value	Average Value (2017$)
Whitehead et al (2008)	North Carolina	\$0.17, \$0.23	\$0.20	\$0.23
Whitehead et al. (2010)	North Carolina	\$0.29-\$0.86	\$0.58	\$0.65
Huang et al. (2011)	New Hampshire	\$0.275	\$0.325	\$0.30
Average				\$0.40

As shown in Table 3, the value of increasing beach width is roughly \$0.40 per foot, or \$1.32 per meter. As an example, the average annual attendance for Cape Cod National Seashore is 70.28 user-days per meter of beach. So the annual lost value from a 0.1 meter reduction in beach width on 100 meters of National Seashore beach is approximately \$928 (=\$1.32 per meter * 0.1 meters reduced width * 70.28 user days/meter*100 meters shoreline impacted).

The spreadsheet also allows one to calculate losses from beach narrowing that occur over an extended period of time. The capitalized value of beach narrowing from sea level rise, for example, is calculated with an annual rate of beach narrowing, and summing the discounted value over time. The formulate for this calculation is:

$$\sum_{t=1}^{T}\left\{\text{Cumulative Beach Narrowing as of Year t} * \left[\frac{1}{(1+r)}\right]^{t}\right\}$$

Again, assuming a discount rate of r = 7%, a planning horizon T=25 years and beach narrowing that accumulates at 0.1 meters each year, this capitalized value factor is 11.23. Thus, narrowing of 0.1 meters per year that affects 100 meters in length of Cape Cod National Seashore beaches is roughly \$104 thousand (=\$1.32*0.1 meter*70.28 annual user-days/meter*11.23*100 meters). A narrowing of 0.1 meters per year affecting the entire 64 km Atlantic coast of the National Seashore results in lost discounted value of beach recreation of roughly \$67 million over a 25-year planning horizon.

III. Value of Lost Recreational Fishing User Days

We identified two studies of saltwater recreational fishing applicable to Cape Cod. As shown in Table 4, Economic Analysis (1999) estimated the value of recreational fishing in the Peconic Estuaries at \$40.25 per user-day, and Agnello and Yen (1995) estimated the value of fishing on Long Island at \$45.38[1] per user-day. Expressing these values in 2017 dollars, and taking the average results in \$70.86 per fishing day.

[1] Agnuello and Yen report values of \$41.47, \$44.02, and \$50.65, or an average of \$45.48.

Table 4. Estimated Recreational Fishing User Day Value

Study	Study Location	User-Day Value	User-Day Value (2017$)
Economic Analysis Inc.	Peconic Estuary, Long Island, NY	$40.25	$64.74
Agnello and Han	Long Island, NY	$45.38	$76.98
Average			$70.86

Unfortunately, we have not been able to identify data on number of recreational fishing days that occur on Cape Cod. Therefore, we calculate fishing days per meter for Cape Cod using the following three steps. First, we obtained the total number of shore-based recreational fishing days in Massachusetts from the analysis of the website of the National Marine Fisheries Service (https://www.st.nmfs.noaa.gov/recreational-fisheries/data-and-documentation/queries/index). NMFS estimates a total of 850 thousand shore-based recreational fishing days for Massachusetts in 2016, the latest year for which final data are available. Since the data analysis is only available at the State level, we estimate shoreline fishing days on Cape Cod assuming constant number of trips per meter of shoreline throughout Massachusetts. The Massachusetts tidal shoreline is 1,519 miles or 2,445 km (U.S. Census, 2011).

Similar to lost beach user-days, we calculate recreational user-days per meter of shoreline, and multiply by length of lost shoreline to calculate lost recreational fishing days. We do not calculate recreational fishing losses associated with reduction in beach width. Dividing number of fishing days by meters of tidal shoreline results in an estimate of 0.35 annual fishing days per meter of coastline. Multiplying by the value per user-day gives an annual recreational fishing value of $24.65 per meter of shoreline, or a capitalized value of $287.27 per meter of shoreline.

IV. Habitat: Saltmarsh, and Eelgrass

Saltmarsh and eelgrass are highly productive habitats that provide nursery grounds for many species. (e.g., Able et al, 1988; Heck et al, 1989). Two general approaches are applicable to estimating values of saltmarsh and eelgrass habitat: the productivity approach and stated preference approach. The productivity approach views these habitats as “inputs” in the production of ecosystem services that are valued by people. For example, saltmarsh and eelgrass serve as nursery grounds for fish and shellfish that are valued by recreational and commercial users. The productivity approach first estimates the level of “production” of ecosystem services (e.g., catch of commercial and recreational fish) then multiplying by the associated ecosystem service values. But these habitat types may also have values other than the specific biological production, such as aesthetic value and non-use value. For example, saltmarsh vegetation and low topography provide wide-open and visually appealing views, and may contribute to alethic beauty and the “sense of place” on Cape Cod.

The stated preference approach is a survey-based approach that asks respondents what they are willing to pay to support programs to protect or enhance saltmarsh and eelgrass. In principle, estimates based on the stated preference approach may include all categories of values, including use values, aesthetic values and non-use values.

We transfer estimates from the Peconic Estuary Program study by Economic Analysis, Inc. (EAI, 1999) to estimate habitat values for saltmarsh and eelgrass on Cape Cod. EAI use both a stated preference approach and a productivity approach to estimate values. We adopt the stated preference approach because it likely captures a more complete suite of values, including aesthetic and nonuse values.

EAI estimates the value of saltmarsh at $56.7 thousand per acre, and the value of eelgrass at $70 thousand per year. Correcting for inflation, and calculating value per meter results in $14 per square meter for saltmarsh and $17.30 per square meter for eelgrass.

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DHS S&T Coastal Resilience Center of Excellence

The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency

Federal Contract Number: 2015-ST-061-ND001-01

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1. Introduction

The importance of hydrologic inputs to total water levels has become increasingly clear in recent years. Hurricane Isaac (2012) was a moderate strength and size hurricane that struck the Louisiana coast. Although this storm only produced surges of 4 – 6 feet along the coast, rainfall amounts reached 20 inches over substantial portions of inland Louisiana and Mississippi (National Weather Service, August 28, 2012), with many inland locations exceeding the flood levels produced even by Hurricane Katrina in 2005. Notable hurricane-related events in 2017 reinforced the importance of rainfall to coastal flooding. Hurricane Harvey made its first landfall in Texas at San Jose Island as a Category 4 hurricane and a second landfall at Holiday Beach as a Category 3 hurricane before moving overland toward Houston and then moving back offshore as a tropical storm near the Texas-Louisiana border. Although this storm made two landfalls, the major damages from this event came from rainfall-induced flooding plus some backwater effects from elevated water levels along the coast due to persistent onshore winds (Figure 1). Damages in Hurricane Harvey tied Hurricane Katrina as the costliest tropical cyclones in history. Later in 2017, Hurricane Irma produced the highest levels of flooding ever recorded in downtown Jacksonville (Figure 2) due to the combination of high surges at the coast and high river discharge in the Saint Johns River.

The other end of the range of flooding types produced by coupled hydrologic-surge forcing occurs in very low areas that are undergoing sea-level rise due to a combination of land subsidence and global sea level changes. This repetitive class of flood ranges from what some refer to as “nuisance flooding” to enhanced flooding in major events. Figure 3 (Mitchell et al., 2013) shows the spatial distribution of repetitive economic losses from flooding in the Norfolk – Hampton Roads area. As can be seen here, the flooding is not limited to a strip of land along the coastline, but rather is distributed along rivers, streams, and tributaries that contribute rainfall effects on top of elevated water levels at the coast. Figure 4 shows the effect of a 1.5-foot (relative) sea level rise in this area with a moderate 3-foot surge, which significantly exacerbates the flooding hazard in this area and Figure 5 shows the frequency of road flooding in this area from Mitchell et al. (2013). The spatial pattern seen in the road flooding provides a strong case for the importance of rainfall in the overall flooding within this region.

Computer simulations of the effects of surge propagation up major rivers have now clearly demonstrated that such propagation depends strongly on river discharge and can significantly affect surge statistics in some areas. (Kerr et al., 2013; Resio et al., 2013). However, since much of the awareness of this problem has arisen quite recently, the present state of the art in coastal flood modeling for coastal flood mapping still neglects the contributions of hydrologic inputs (rainfall and streamflow) in simulating flooding in these areas. Thus, the overarching goal of this work is to develop a workable plan for bridging the gap between statistical approaches available today, which neglect rainfall and streamflow, and a new approach that allows their effects to be incorporated into improved estimates of flooding, while remaining within practical limits for required computational resources. This latter constraint comes from the potential impact caused by introduction of additional degrees of freedom into the multivariate statistics used in flood mapping today. Two variants of the Joint Probability Method (JPM) are commonly used today for this purpose: The JPM-Optimal Sampling-Surface Response Function (JPM-OS-SRF) and the JPM- Optimal Sampling-Bayesian Quadrature (JPM-OS-BQ), hereafter referred to as the SRF and BQ methods, respectively. As will be discussed in the section on probability theory, the SRF appears to offer a better basis for the coupled surge-rainfall-streamflow statistical approach. Given the amount of rainfall that can be concentrated in a TC and the compound effects of initial water levels and river discharge, it seems critical to understand to quantify this relationship. The coupled model system being developed will be termed the Joint Probability Method, Optimized Sample, Coupled Response Function, or JPM-OS-CRF.

This report describes work conducted and preliminary results from 2½ years of funding under contract 2015-ST-061-ND001-01. The specific objective of this effort was to develop an overview and guidance for the application of a coupled hydrologic-surge modeling system, using the Norfolk – Hampton Roads area as its area of application. At the outset, it was recognized that this was a very substantial undertaking would be needed to provide a broad perspective on what would be needed to proceed to a larger demonstration project.

To provide some perspective and direction for this effort, the following assumptions were considered to be implicit within the desired system:

1. The methodology should be capable of being executed within existing capacity for executing Regional Flood Studies, but should be applicable to forecast applications with minimal modifications;
2. Both statistical approximations and modeling approximations must be robust and provide unbiased results which include the effects of uncertainty; and
3. Statistical and modeling approaches should be as generalizable as required to meet the diverse set of needs along US coastlines;

The above set of assumptions led to the following working hypothesis for methodologies tested in this study:

1. The methodology should be adaptable to application in any well-posed surge/wave model, which suggests that the hydrologic model and the surge/wave model must be linked efficiently and in a manner that allows the two systems to be exercised independently, utilizing subdomains wherever possible to reduce overall simulation time.

To date, work on this project has investigated a number of diverse components of an overall system that might be required to couple hydrologic and surge models effectively and accurately into a FEMA RiskMap study for coastal areas. However, it is clear that the applicability of this methodology in the context of including uncertainty into forecasts, as well as quantification of longer term hazards, could be extremely important (Resio et al., 2013; Resio and Irish, 2015; Resio et al., 2017a; Resio et al, 2017b)

; Resio et al., Resio et al., 2017). These topics will be presented within the overall structure of the outline given below.

1. Statistical considerations
    a. Overall statistical approach
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5. Discussion and Conclusions

2. Statistical Considerations

2.1 Overall Statistical Approach

It has become increasingly clear in FEMA RiskMap studies that the number of different processed affecting inundation levels creates a very significant burden in terms of the computer resources required to estimate high-resolution statistical estimates of flooding hazards in coastal areas. Problems along the east coast that are presently facing RiskMap production teams include many factors which remain difficult to quantify within allotted resources. As an example of this, the treatment of tides along the east coast have formed the basis for successful challenges in key areas such as New York City. The reason that this is brought up early in this section is to point out the existence of a very important dichotomy in statistical approaches that have been applied and continue to be applied in these studies.

Maximum water levels in the Norfolk-Hampton Roads area, like most coastal areas along the east coast, are very affected by tides. Historically, two methods have been used to approach statistical representations: 1) methods based on the recognition that any discrete increments of probability should be carefully validated to show that it accurately represents the entire range of inundation probabilities and 2) methods based on the concept that the discretization is fine as long as it produces a correct mean value for a given combination of storm parameters. For example, if a set of eight storms at the Battery in New York is executed with 4 random (or sequentially ordered) tidal phases, the second approach assumes that the selected storms should not induce a bias into the estimated storm surge for that storm, sometimes taken to mean executing a small number of computer runs with phases selected by Monte Carlo methods (i.e. random phases), which can introduce a very substantial epistemic variation to the results. An alternative method examined the use of a defined range of phases intended to fall roughly equal distances on either side of the median value for combined water levels. The traditional way to approach this is to allow each tide value simulated to have an equal probability assigned to it. Ranking the results of total water levels from tide phases combined with eight simulated storms in two different manners, one showing the range of tidal influence and a second just using a standard ranking produces the interesting chart shown in Figure 6 for the Battery in New York. Here we see that the high surge values dominate the upper end of the distribution, making the tidal extrapolation dominant in the low-frequency Annual Exceedance Probabilities. This can be shown to be physical unrealistic and would lead to overestimation of the total water levels at this site.

This lesson from previous work is valuable for pointing out the importance of understanding the differences of continuous samples and discrete samples in RiskMap applications. This point is relevant for a number of reasons that will be reviewed here; and in most cases, the scale of potential errors introduced by poor statistical approximations is comparable to errors introduced by the use of inaccurate models. This is an important point in developing sets of events modeled in today's approach to surge-related hazard analyses. Before Hurricane Katrina the Joint Probability Method utilized poorly resolved surge models which ran very fast on computers. In this case, run-time constraints were minimal and all storms were modeled with sufficient resolution in probability space needed to provide good resolution for the entire range of expected events. After 2005 it was recognized that the inaccuracies of the poorly resolved models produced significant errors. This made it necessary to reduce the number of runs to perform the calculations and a new approach to the JPM, the JPM-Optimal Sampling (JPM-OS) approach became the standard method for estimating coastal hazards. In this new approach, only a subset of the entire JPM storm set is simulated in order to remain within tolerable computer-resource limits.

Two primary methods have been used in the JPM-OS approach. The Bayesian Quadrature (BQ) method and the Surge Response Function (SRF) method. The BQ variant is based on the general concept of Bayesian Quadrature in which it is assumed that weighted samples drawn from within a multivariate probability space can be selected to approximate the full integral threshold of convergence is obtained. This threshold of convergence will be universal throughout the model domain if the population is homogeneous. The BQ variant has been used extensively in recent large-scale FEMA and U.S. Army Corps of Engineers studies (e.g. Toro et al. 2010 and Niedoroda et al. 2010). It is probably more accurate to refer to these two approaches as JPM-Optimized Sampling Methods, rather than the JPM-Optimal Sample Methods. Like most optimization problems in nature, these methods are "optimal" only in the sense of the constraints they place on the system being optimized. Since additional storms will asymptotically increase the accuracy of the statistical results, the selected set in either the SRF approach or BQ approach does not represent the minimum achievable residual, but only a subset of storms that meets some accuracy thresholds within an acceptable number of simulations.

The BQ approach utilizes a set of optimized weights, obtained from the probability distributions of the Tropical Cyclone (TC) parameters, to relate the BQ subset of storms to the complete set of storms. The SRF approach, however, is not inherently tied to probability distributions within the JPM. At its core, SRFs are interpolants. They have, so far, been developed specifically for parameterized tropical cyclones, meaning they could equivalently be used with the extratropical storms. However, SRF method differs from these in that these interpolants provide a continuous form derived from the physical scaling of the response surfaces. The development of continuous functional forms for both the storm parameter space and the surge response allows for the AEP integral to be interpolated to a given level of accuracy. Since there is no underlying physical structure utilized in the BQ method, there is no physical basis for interpolation or extrapolation of surges and each event can only be treated as having a fixed value, plus (random) epistemic variability.

An additional difference between the SRF and the BQ is that the BQ uses a technique termed kriging to interpolated between different points in probability space. A critical assumption in this approximation is that the sample space must be spatially stationary, i.e. both the mean and the variance of the sampled values are invariant. When the BQ is applied to a large region without first removing large-scale trends, it can produce large-scale trends in the residual fields as seen in Figures 7 and 8 (taken from Resio et al. (2017b). In Figure 7, it can be seen that a ½-meter gradient exists between regions of surges which compared to the "gold standard" storm set (produced by the simulation of all storms) for an AEP of 0.01 (the 100-year surge); and as seen in Figure 8, the gradients over large areas for he AEP of 0.002 (the 500-year surge) produce differences of about 1 m. In applications focused on coastal resilience, such deviations would be very significant.

Much of the work on this project was undertaken within the context of the quantification of sources of overall errors in RiskMap applications and the relative efforts that different overall methodologies might require to meet pressing needs for coastal resilience in the future. Given the constraints placed on present-day coastal studies, this would seem to be an important consideration that will be addressed in this report.

2.2 Effects Related to Rainfall

As a background for understanding the state of the art in the analysis of rainfall patterns in tropical cyclones, we will present a synopsis of some recent studies. Since our own statistical analyses of rainfall patterns have to be cast within the framework, we will limit our background material to material that relate to some of the There have been many analyses of rainfall patterns generated by tropical cyclones; however, most of these have examined these patterns in the context of the synoptic environment surrounding these storms. For example Matyas (2010) used a multiple linear regression approach to investigate relationships between the extent of rain fields in each of 31 hurricanes at the time of landfall; however, her results were mainly used to develop which atmospheric forcing could be used to predict inland rainfall as the storm approached the coast. One of the more comprehensive references on rainfall patterns along the mid-Atlantic region can be found in Hudgins et al. (2005). This NOAA report provides a climatological context on TC rainfall from 1950 through 2004; however, it focuses more on the inland region along the Appalachian Mountains that along the coast. Konrad et al. (2001) investigated the relationship between hurricane attributes such as size, speed of storm movement and storm strength; however, considerable variability in the precipitation totals associated with each tropical cyclone was noted in Konrad and Perry (2009). This variability was at least partially tied to interactions between mid-latitude features and the moisture plume advected around the tropical cyclone. Some general aspects from additional studies are noted below.

1. Weaker storms tend to produce more widespread rains due to reduced organization.
2. Heaviest rainfall is generally highest near a 150-mile swath centered on the track (Gonski, 2006).
3. Rainfall totals are significantly affected by orography (Gonski, 2006).
4. Daytime heating affects TC rainfall rates, due to increased convection (Atallah et al., 2007).
5. Heavy precipitation can be intensified by TC interactions with coastal fronts (Klein et al. (Klein et al., 2006).
6. Extratropical transition can dramatically increase left of track precipitation (Atallah et al., 2007)

Rainfall rates typically vary on a much faster time scale than surge levels driven by TCs. Figure 9 for Norfolk shows an example of hourly rainfall rates at a selection of sites in the overall study area. This introduces two important considerations: 1) the “flashiness” of the drainage system (i.e. how quickly the water levels respond to this rainfall) and 2) the spatial-temporal scales of rainfall that are appropriate for quantifying the time scale for the study area. As can be seen in this figure, the hourly rainfall rate in these areas tends to be quite erratic, as expected from elements of the TC infrastructure. Based on the typical flashiness of this area, a 6-hour time averaging is used here for all subsequent analyses.

As noted in the statistical overview section, two statistical approaches are available to select the rainfall events in conjunction with the standard parameters used to quantify the event probabilities for computer simulations. Since the rainfall rates tend to be spatially distributed in patterns that are not similar to hurricane surges, the application of the BQ would be quite tedious and the lack of spatial homogeneity would present significant problems to its implementation for this purpose. For this reason, the SRF has been used in the work presented in this report.

The SRF method used physics-based, dimensional scaling to develop its functions (Irish and Resio, 2010). The development of new estimation methods for the rainfall patterns and magnitudes builds upon existing well tested rainfall models used in forecasts. The model, which appears to provide the best fit to rainfall rates and spatial patterns, is the Parametric Hurricane Rainfall Model (PHRaM), currently coded within available ADCIRC models for testing. Figures 10 and 11 show a comparison of rainfall rates and patterns from Lonfat et al. (2007). Both figures show that the cross-track distribution of rainfall can be very significantly influenced by local topography; however, areas affected by major combined hydrologic-surge flooding are focused on relatively flat coastal plains within the US Gulf and East coast regions, so the influence of topography is neglected in this report. From Figure 10 we see that the PHRaM model produces results that are quite similar to the R-CLIPER model (Tuleya et al., 2007). Figure 11 shows a similar comparison, using rain rate (flux) instead of the total rainfall amounts.

Our results suggest that the PHRaM model captures the general form of the rainfall distribution, but requires local tuning, particularly as a function of storm track in areas such as southeastern Virginia. In particular, the relationship between storm intensity and rainfall intensity was found to be very much a function of storm track angle across the area, with tracks having long overland tracks producing substantial decay in storm intensity compared to its intensity at landfall. Our studies suggest that the identification of specific rainfall patterns and their time-space relationship to surges in the study area can be very important to the accuracy of the coupled=model results. Similar to the approach used by Hudgins et al. (2005), we will categorize different track types as a basis for understanding and quantifying temporal and spatial distributions of rainfall during TCs in our study area. Since the tracks in this area often reflect an interaction between tropic steering currents aloft and larger-scale extratropical synoptic patterns, it is useful to separate these patterns into a mean (deterministic) mode and some possible multivariate modes of variability around this mean. Once all of the organized variability is quantified, the remaining variability will be treated as a Gaussian distribution with estimated variances given in terms of the remaining variance not explained by the organized patterns. In applications to specific areas, the PHRaM model will be taken as a first approximation to the deterministic mode of variation, once calibrated/validated for this area.

2.3 Effects related to stream/river discharge

The effects of river discharge have been shown to be well represented in the ADCIRC model for situations in which the river discharge can be specified as a discharge rate at a selected input section (Dietrich, et al., 2010). In some locations, however, the input into the river can vary significantly during the storm interval itself. The Mississippi River in the vicinity of New Orleans is a good example of a case in which the discharge at the upper end of the river is much larger than discharge contributions from tributaries along the river in this area. In this case, the backwater curve is expected to be very close to that estimated from the Gradually Varied Flow (GVF) equations. In contrast to the lower Mississippi River Basin, the lower James River in Virginia and the Saint Johns River in Jacksonville represent two cases in which rainfall during a major rain event has been shown to be capable of significantly affecting water levels along the river.

The methodology for addressing the second type of coupled hydrologic-surge was a major aspect of the coupled addressed during our project and will be considered in section 3 of this report. The areas along the James River between Richmond and the Hampton Roads area (Figure 12) tend to be characterized by rolling hills and a well-developed stream network with moderate slope. It is likely that the flow in many of these streams will exceed the velocity of a wave in the stream's water depth (i.e. the flow is supercritical); whereas the ADCIRC model is specifically developed for subcritical flows. Because of this, the flow of water from the adjacent bank area must be supplied by a hydrologic model. In such situations, the hydrologic-surge model coupling is not negligible and should be addressed via a mass-conserving paradigm. Additional discussion of this point will be given in subsequent sections of this report.

Initially, it was hoped that radar data might provide a very valuable information se for quantifying TC rainfall patterns in this area; however, the duration and number of events within the 12 years of data for which radar data was available was insufficient for this type of multivariate problem. Instead, we used rainfall gage data from seven long-term stations in this area to provide a consistent data set for analysis from 1951 through 2014. Figure 13 shows the location of these stations in our study area listed in Table 1.

Table 1. List of Meteorological Sites Used in Study, Site Name an NOAA Station Number

Site Number	Name	Station Number(s)
1	Norfolk VA (Airport)	
2	Hatteras (Airport)	
3	Elizabeth City	
4	Greenville	
5	Greensboro (Airport)	
6	Raleigh (Airport)	
7	Richmond (Airport)	

Using the most recent HURDAT data set for TCs, 45 events were identified as passing within a distance of 3 degrees (approximately 300 km at this latitude) of Norfolk and passed within latitude and longitude boundaries set at 75 to 80 degrees West longitude and 35 to 39 degrees North latitude. To examine the possible relationship between storm intensity and rainfall, this set of storms was subdivided into storms with minimum central pressures less than 990 mb within the geographic selection area (termed major storms in this report) and those with minimum central pressures greater than or equal to 990 mb within the geographic selection area (termed minor storms in this report). This threshold is chosen to approximately represent the threshold between hurricanes and tropical storms; however, its practical impact is simply to stratify the storms into stronger and weaker categories and is used to information on the surge generation potential of these storms. Tables 2 and 3 give the names of the storms in each of these categories along with the dates analyzed for each.

Table 2. List of "major" TCs from 1950 through 2014 (TCs which attained a central pressure less than 990 mb in the geographic selection area centered on Norfolk).

Storm Number	Storm Name	Beginning date-time	Ending date-time
A1	Hazel	19541012	19541016
A2	Connie	19550808	19550816
A3	Alma	19620809	19620813
A4	Agnes	19720618	19720624
A5	David	19790903	19790908
A6	Gloria	19850924	19850929
A7	Charley	19860814	19860820
A8	Emily	19931828	19930902
A9	Fran	19960903	1996090
A10	Josephine	10961007	19961012
A11	Bonnie	19980824	19980831
A12	Dennis	19990902	19990910
A13	Floyd	19990913	19990918
A14	Isabel	20030915	20030921
A15	Alex	20040801	20080908
A16	Hanna	20080903	20080908
A17	Irene	20110824	20110830

Table 3. List of “minor” TCs from 1950 through 2014 (TCs which attained a minimum central pressure greater or equal to 990 mb in the geographic selection area centered on Norfolk).

Storm Number	Storm Name	Beginning date-time	Ending date-time
B1	Diane	19550814	19550820
B2	Dora	19640911	19640917
B3	Doria	19670913	19670919
B4	Alma	19700522	19700530
B5	Ginger	19710928	19711006
B6	Bret	19810628	198107703
B7	Dennis	19810816	19810823
B8	Unnamed	19820616	19820622
B9	Diana	19840911	19840917
B10	Danielle	19920922	19920928
B11	Allison	19950603	19950610
B12	Authur	19960617	19960623
B13	Bertha	19960710	19960716
B14	Danny	19970721	19970726
B15	Earl	19980901	19980906
B16	Gordon	20000916	20000922
B17	Allison	20010611	20010619
B18	Kyle	20021009	20021014
B19	Bonnie	20040810	20040816
B20	Gaston	20040827	20040922
B21	Ivan	20040914	20040920
B22	Jeanne	20040925	20041001
B23	Cindy	20050705	20050711
B24	Alberto	20060613	20060619
B25	Ernesto	20060829	20060904
B26	Barry	20070601	20070606
B27	Gabrielle	20070906	20070912
B28	Beryl	20120528	20120602

Table 4 gives the monthly distribution of major and minor storms, which appears consistent from what we might expect based on the available variation in sea surface temperature (SST) in the Atlantic coast along the east coast during these months. Although a relatively large difference in the monthly distribution of major storms appears to exist, a Chi-Square test of the probability of this difference not being due to only randomness is 0.113, which is greater than the typical values used to denote marginal and strong evidence that the parent distributions from which that are drawn are different. This apparent contradiction between the expected physics-based concept of storm intensity and its statistical confirmation is likely due to the relatively low sample numbers in the categories used in this table.

Table 4. Storm count by month.

	May	June	July	August	September	October
Major Storms	0	1	0	7	7	2
Minor Storms	1	8	3	5	10	1

If we combine the first three months and last three months into the same category, we obtain the 2 by 2 contingency table shown in Table 5. Fisher's exact test for this table shows that this distribution of occurrences has a probability only a 0.0154 probability of being due to randomness, or conversely, a 99.48% chance of indicating that early season storms are significantly weaker than late season storms. Obviously, this is consistent with the Sea Surface Temperature (SST) off the southeastern U.S. coast, which is the energy source for TCs, and helps justify our use of this categorization in our analysis of the synoptic behavior of these storms.

Table 5. Contingency Table showing occurrences of major and minor TCs by 3-month groupings.

	May-June-July	August-September-October
Major Storms	1	16
Minor Storms	12	16

Two aspects of storm tracks are used here to understand their relevance in our treatment of coupled surge and hydrologic effects, landfall location and the location of the storm at the time of closest approach to the Norfolk area. Following extensive examinations of storm tracks and rainfall patters produced, we elected to use a track categorization that incorporates the synoptic patterns accompanying the storm as well as its ability to be included within typical storm sets used in FEMA flood studies. This categorization pattern attempts to isolate four basic storm types:

1. Storms making landfall within a distance such that some significant surge generation is possibly generated at the time of landfall, designated here as landfalling TCs (LaTC) ;

2. Storms passing close or slightly over the mainland North Carolina-Virginia coast within a distance that bothsurge generation and large amounts of rain can be possible, designated here as along-coast TCs (AcTC).

3. Storms which made landfall at a sufficient distance from the Norfolk area that they can be considered as exiting storms in which the rainfall may still be very significant, but the surge generation is not linked directly to its landfalling characteristics, designated here as ExTC.

4. Storms which pass outside of the area defined in category 2, designated here as bypassing TCs (ByTC).

Storms that enter the box outlined in black and cross its western boundary are LaTC storms. Storms that enter the dark outline and do not cross its western boundary are AcTC storm. Storms that exit land and pass through the eastern boundary are ExTC storms. Storms that pass eastward of the box without entering it are ByTC storms. Table 6 gives a list of the category in which each storm falls. It should be noted that David was a bypassing storm in its “major storm” phase, which is why it is categorized in this table as such.

Table 6. Categorization of track characteristics of major storms in this report.

Storm Number	Category	Storm Name	Beginning date-time	Ending date-time
A1	LaTC	Hazel	19541012	19541016
A2	ByTC	Connie	19550808	19550816
A3	ByTC	Alma	19620809	19620813
A4	ExTC	Agnes	19720618	19720624
A5	LaTC	David	19790903	19790908
A6	ByTC	Gloria	19850924	19850929
A7	ByTC	Charley	19860814	19860820
A8	ExTC	Emily	19931828	19930902
A9	ByTC	Fran	19960903	1996090
A10	ByTC	Josephine	10961007	19961012
A11	ByTC	Bonnie	19980824	19980831
A12	ByTC	Dennis	19990902	19990910
A13	AcTC	Floyd	19990913	19990918
A14	LaTC	Isabel	20030915	20030921
A15	ByTC	Alex	20040801	20080908
A16	AcTC	Hanna	20080903	20080908
A17	ByTC	Irene	20110824	20110830

Before proceeding to analyses of spatial and temporal organization of major and minor storms, it is worthwhile to investigate the rainfall totals during the time periods selected as a function of storm category. Tables 7 and 8 provide the total rainfall of the period shown for all seven stations combined for the major and minor storms, respectively.

Table 7. Rainfall totals for major storms in this report.

Storm Number	Storm Name	Beginning date-time	Ending date-time	Rainfall Total (inches)
A1	Hazel	19541012	19541016	21.43
A2	Connie	19550808	19550816	19.06
A3	Alma	19620809	19620813	2.84
A4	Agnes	19720618	19720624	4.29
A5	David	19790903	19790908	38.28
A6	Gloria	19850924	19850929	7.57
A7	Charley	19860814	19860820	23.47
A8	Emily	19931828	19930902	10.91
A9	Fran	19960903	1996090	13.39
A10	Josephine	10961007	19961012	8.06
A11	Bonnie	19980824	19980831	10.45
A12	Dennis	19990902	19990910	2.23
A13	Floyd	19990913	19990918	18.22
A14	Isabel	20030915	20030921	15.28
A15	Alex	20040801	20080908	8.67
A16	Hanna	20080903	20080908	8.78
A17	Irene	20110824	20110830	14.33

As can be seen in these tables, the total rainfall over the entire is quite variable. These tables show that the amount of total rain appears to vary significantly as a function of the TC category in the major storms. As will be shown subsequently, this information is needed to synchronize the surge and hydrologic models.

Table 8. Rainfall totals for minor storms in this report.

Storm Number	Storm Name	Beginning date-time	Ending date-time	Rainfall Total (inches)
B1	Diane	19550814	19550820	21.43
B2	Dora	19640911	19640917	19.06
B3	Doria	19670913	19670919	2.84
B4	Alma	19700522	19700530	4.29
B5	Ginger	19710928	19711006	38.27
B6	Bret	19810628	198107703	7.57
B7	Dennis	19810816	19810823	23.47
B8	Unnamed	19820616	19820622	10.91
B9	Diana	19840911	19840917	13.39
B10	Danielle	19920922	19920928	8.06
B11	Allison	19950603	19950610	10.45
B12	Arthur	19960617	19960623	2.23
B13	Bertha	19960710	19960716	18.22
B14	Danny	19970721	19970726	15.28
B15	Earl	19980901	19980906	8.67
B16	Gordon	20000916	20000922	8.78
B17	Allison	20010611	20010619	14.33
B18	Kyle	20021009	20021014	16.01
B19	Bonnie	20040810	20040816	29.83
B20	Gaston	20040827	20040922	11.78
B21	Ivan	20040914	20040920	9.05
B22	Jeanne	20040925	20041001	7.03
B23	Cindy	20050705	20050711	5.53
B24	Alberto	20060613	20060619	9.71
B25	Ernesto	20060829	20060904	45.73
B26	Barry	20070601	20070606	10.02
B27	Gabrielle	20070906	20070912	0.83
B28	Beryl	20120528	20120602	8.86

An Empirical Orthogonal Function analysis of the covariation within these sites was conducted, but as expected, differences in tracks across this area and the inherent variability of rain bands and other meso-scale features produced a significant degree of uncorrelated variability among the rainfall at different sites. The standard deviation between PHRaM estimates and the rainfall exhibited site-dependent biases in the range of 8 – 17% at the stations, with highest biases occurring at the most inland sites, as one might expect from the neglect of topography in the PHRaM version used in this study. The rms (random) variations around the biases were in the range 1.4 – 2.1 inches for total rainfall amounts.

2.4 Effects related to initial hydrologic conditions in the study area

Some areas can be very slow to drain and residual effects of flooding can persist for prolonged intervals following a flood event in these areas. In the investigation conducted for this project, the effect of pre-existing water levels at the beginning of a storm event was examined for the case of an area recognized for its remarkable slow drainage following a surge event, at a very slow draining portion of the Upper Barataria Basin. Figure 14 shows a simple relation in this basin between initial water level and maximum subsequent event water level at a gage in this slowly draining basin. It is clear that the poor drainage in this basin produces a net increase in water levels within it when a second flooding event occurs. The cases studied here also demonstrate a second significant point noted in previous studies (Resio and Irish, 2015) that hurricanes tend to exhibit a temporal autocorrelation such that these storms often cluster within specific areas with a given intervals of time. It should be recognized that the effects on subsequent water levels will be very site specific; hence any conclusions drawn from this particular example should not be generalized. However, in flat coastal areas with poor water-conduit connectivity, the effects of initial water levels in many areas of the Gulf coast and East coast should be investigated before being neglected in coupled hydrologic-surge modeling efforts.

3 Modeling Considerations and Testing

3.1 Coupling methods and integration into a modeling approach for resilience

The information presented up to this point suggests that considerable work needs to be undertaken before an efficient coupling system can be implemented for application in a particular area for quantifying coastal resilience. Although the statistical analysis of flooding levels is often assumed to follow a well-established precedent, these analyses have continued to evolve markedly from site to site. In particular, it is clear that the effects of combined hydrologic-surge inundation require additional attention that include the following elements:

1. Detailed studies of discrete probabilistic methods such as BQ, kriging, and hybrid applications of these techniques should be compared to SRF methods to determine which provides the most accuracy for the same computational effort. It has been stated in some publications that the advantage of the BQ class of methods is that they include an estimate of uncertainty. However, this is true of both methods. The equally quantitative SRF metric uses the accuracy of its interpolation (incorporating physical structure into basic functions) to evaluate the accuracy of this approach. It also allows a physics-based extrapolation relationship for estimating extremes larger than those simulated.

2. The efficiency of the overall process depends on the total number of dimensions that have to be included in coupled computer simulations. If a detailed surge model execution is required for each combination of storm characteristics needed for an assessment of surge level probabilities, along with each different combination of rainfall rates, patterns and the initial basin water level, this could lead to orders of magnitude increases in the total simulations time required. However, as will investigations of coupling presented in section ?????. Sensitivity studies conducted as part of this study have suggested that surge levels affect the backwater in hydrologic models much more than the hydrologic models affect the water levels in relatively open water areas. These results potentially offer at least two significant benefits: 1) the ability to run surge models independently to define an initial definition of storm surge levels primarily based on the set of hurricane parameters used to form the set of storms in the JPM-OS for surges only and 2) the ability to use a fixed boundary between the two areas dominated by these different processes. A logical argument can be made that such a boundary should be placed at least as far inland as the extent of the highest annual tide level in order to allow the ADCIRC model to cover as much of the domain as possible, since the ADCIRC model requires much less empirical, site-specific tuning than hydrologic models due to the much more empirical bases for most hydrologic models. Subsequent discussion of this point will be given in section ???? later in this report.

3.2 Modeling Testing by Year

<u>Year 1</u>

In year 1 of this project, the availability of two existing models for the coastal riverine system of the Neches/Lake Sabine area of Texas were utilized to efficiently begin exploring benefits and difficulties related to coupling riverine and coastal wave models. Rather than developing new models, existing HEC-RAS and ADCIRC/SWAN models were used to examine the interplay of downstream surge. Of interest during year 1 was to understand,

1. Can HEC-RAS and ADCIRC be effectively combined?
2. How much spatial overlap is required for the correct capture of combined riverine and surge flows?
3. What are the benefits and deficiencies of this model coupling?

The model tests revealed a number of insights regarding the tandem use of these two models to compute combined riverine and surge dynamics.

First, HEC-RAS is not an ideal model for this type of coupling because it is primarily controlled and run through an MS Windows-based GUI. Specialized codes and scrips were created during this project which allowed for batch processing of multiple scenarios. However, the HEC-RAS platform is still not ideal because the HEC-RAS source code is not publicly available. This prevents HEC-RAS from being compiled on general Unix-based platforms that are optimal for large ADCIRC/SWAN runs thus requiring the two codes to run on different computer systems. This limits the efficiency for potential large-scale FEMA flood mapping studies.

Second, HEC-RAS does not account for several essential physical components of surge dynamics. The only impact of downstream surge is to create back water effect. Whereas real surge has momentum and often creates upstream flow, HEC-RAS cannot account for surge propagating upstream. Moreover, there is not a mechanism for accounting for wind stress which may be an important component of setup in wide rivers and bays at the mouth of a coastal river. Finally, Lake Sabine at the mouth of the Neches River has been shown to attenuate surge coming in from the Gulf of Mexico through two-dimensional flow features. The attenuation of surge is not represented in HEC-RAS models that include Lake Sabine.

Despite the limitations of HEC-RAS for coastal surge scenarios, a series of methodical tests revealed some understanding of the spatial extent of surge impact in riverine systems. A series of numerical experiments were performed that altered the overlap of spatial extent between HEC-RAS and ADCIRC/SWAN (Figure 15). In a sequence of different simulations, the output of the ADCIRC/SURGE model was provided to HEC-RAS at the various locations shown in blue in Figure 16. Because the Neches River is relatively large and well resolved in the ADCIRC model, the fidelity of simulations improved as more ADCIRC domain was used (BC applied further upstream). During these studies, it was observed that upstream distance of surge effects are sensitive to downstream flow rate, with increasing flow rate limiting the upstream propagation. For most scenarios, the extent of surge impact is limited to the lower 30 miles of a Neches River. However, the behavior on the Neches River may not be easily generalized to all coastal rivers. It is anticipated that differences in river slope, distance from the coast, and watershed size will influence this conclusion. It was also observed that rainfall during a hurricane may require a relatively long time to accumulate in large watersheds, thereby delaying the impact on stage for some coastal rivers. For instance, during Hurricane Ike, the effect of rainfall on stage in the Neches River was not observed until more than one day after the coastal surge had attenuated. Thus, for some coastal riverine systems like the Neches, the existing ADCIRC modeling paradigm may be adequate provided that additional simulations are performed to capture the sensitivity of flow rate on upstream surge impact within the statistical framework.

When rivers are large and can be resolved, it works well to include computation of their effects within ADCIRC. However, there are smaller watersheds and drainage features in many coastal regions of the United States that cannot be adequately resolved within ADCIRC and may benefit from resolving their dynamics with a different hydrology model than HEC-RAS. HEC-RAS is designed as a riverine model, but not one optimal for addressing surge near the coast. Thus, the tests with the Neches River are not adequate for exploring some important details of coastal hydrology that are missing in existing FEMA procedures. Large independent river systems do not have the same dynamics local nuisance flooding or heavy local precipitation. The flow hydrograph in rivers like the Neches develop over much larger distances and time scales than nuisance flooding concerns as experienced frequently in Norfolk and during the precipitation dominated flooding in Jacksonville during Irma and in Houston during Harvey. Thus, it is important to note that the ADCIRC/SWAN model used during FEMA flood studies does not include the effect of direct rainfall. For these reasons, year 2 of this project changed its focus to exploring the implications of local precipitation and runoff in the area around Norfolk, VA.

Year 2 and 3

To examine rainfall and small-scale watershed contributions, attention was turned to the low-lying areas around Norfolk, VA including the James River, the Elizabeth River, and several watersheds adjacent to southern Chesapeake Bay. In these regions, the landscape has a very low gradient and even small amounts of rainfall accumulate in nearshore areas and quickly influence surge in coastal streams and rivers. In this regard, the dynamics are slightly different than previously explored in the Neches River basin.

To account for these specific regional dynamics, the ADCIRC model was modified in two ways. First, accumulation of rainfall mass during a hurricane simulation was added according the method developed RAND during the 2012 Master Plan for CPRA (Johnson et al. 2013) which was based upon the risk and reliability model previously used by IPET (Ebersole et al. 2007). This approach is an approximation of a relationship developed by Lonfat, Marks, and Chen (2004) based on hurricane observations from the Tropical Rainfall Measuring Mission (TRMM). In this method, the baseline rainfall rate is assumed to be a linear function of pressure deficit (ΔP) inside the radius of maximum wind speed (R_{max}) and to exponentially decay with distance beyond R_{max}. The approximation is written:

$$I = 1.14 + 0.12\Delta P \; for \; r \leq R_{max}$$

$$I = (1.14 + 0.12\Delta P) \cdot \exp\left[-0.3 \cdot \left(\frac{r - R_{max}}{R_{max}}\right)\right] for \; r > R_{max}$$

where,

I = Rainfall intensity (mm/hr)

ΔP	=	Pressure deficit (difference between standard atmospheric and local pressures) (mbar)
r	=	Distance from center of storm to location (km)
R_{max}	=	Radius of maximum wind speed (km)

Based on TRMM observations, Lonfat, Marks, and Chen (2004) demonstrate that rainfall intensity varies from quadrant to quadrant around the storm center. To account for this, the IPET analysis included a multiplier of 1.5 for rainfall intensity at points to the right of the storm track (the azimuth) and 1.0 for rainfall intensity at points to the left of the storm track (Ebersole et al, 2007). The same approximation was employed in this study. There are other precipitation models available that consider rainfall dependence upon more storm parameters, such as forward speed, track angle, and surface drag. While the methodology employed here is not a complex approach, it allows for assessing the implications of rainfall on water surface elevation within a coastal region.

Second, the second modification applied run-off water mass from a coastal watershed into the ADCIRC domain via and custom internal boundary condition created for this investigation. The runoff for local hydrologic areas is computed manually and applied as a time varying boundary condition within the ADCIRC domain. An example of inflow locations are shown in Figure 17. Through a sequence of experiments, inflow locations were added and relocated to test their impact on computations of maximum surge.

With these two modifications, ADCIRC/SWAN simulations are able to account for three hydraulic contributions to coastal flooding; antecedant flow rate, local watershed routing, and direct precipitation (Figure 18). Each of these contributions may be improved in the future through more detailed estimates or through direct computation via an overland flood routing model. Simulation results were compared for dry, moderate, and wet rainfall conditions and for several antecedant flow conditions in the James River. Representative simulation results are provided in Figure 19 showing the increase in maximum surge computed by a standard ADCIRC/SWAN simulation and one that includes the three additional sources of water mass. Note that areas of 0.5ft to 2ft exist with the model domain as well as increases in the extent of inundation. The areas of increased flooding predicted by this method roughly align with the regions of repeditive loss and flooding zones shown in Figure 3 and 4. It is anticipated that precision for rainfall and hydrologic runoff can be enhanced by replacing these approximations with improved model output from other rainfall and runoff models. What has been accomplished here is to demonstrate that ADCIRC/SWAN is stable with these additional mass inputs and that the magnitude of impact on flood prediction generates results in reasonable agreement with known local dynamics.

The one aspect of this overall effort in the boundary coupling routine that remains to be tested is the influence of the surge levels on increased backwater flooding on the hydrologic side of the fixed boundary. On one hand, it is clear that the water levels in many of these areas are expected to be somewhat higher than the level at the boundary; however, the discharge in these areas is very low, so the slope should not be large. For this reason, the flood levels shown in

Figure 19 are probably reasonable first approximations to the water levels that will be produced when an improved hydrologic model is included in the modeling conducted for a moderate TC. Extreme TC could, of course, generate considerably larger differences.

4 Educational Component of Project

4.1 SUMREX Program

During the summer of Year 1 of this project LSU PhD Student Rudy Bartels spent 3 weeks at UNF working directly with Dr. Resio on the application of multivariate classification methods to climatological atmospheric data within the continental United States. This work went very well and the product became part of his PhD thesis.

4.2 UNF Educational Activities

Amanda Tringer has been supported as a PhD student for three years under this program. She has become a leader of the graduate student group at UNF and has led several key efforts within the UNF program.

1. Hurricane Matthew forensics study – Amanda led the effort to hindcast the storm surges along the northeast Florida coast and well into the Saint Johns River to establish base levels for observed damages in Duval, St Johns, and Flagler Counties. This effort was presented at the national conference of American Shore and Beach Preservation Association as an entire session and was very well received.

2. Journal of Geophysical Reseach (JGR) manuscript – Amanda has developed an method for combining high resolution (currently barotropic) vertical structure into the ADCIRC model. This work has been submitted to JGR and is under review. This work is also being transferred to the version of ADCIRC being used by Chris Massey and the USACE Engineering Research and Development Center.

3. Development of Stochastic Capabilities for vertical variations in ADCIRC - Amanda is continuing to build upon her vertical structure work via the inclusion of stochastic dependencies on prior vertical velocity distributions and changing surface/bottom stresses as the final portion of her dissertation.

4.3 Outreach and Coordination Efforts

Bruce Ebersole (Jackson State University) headed the outreach portion of this project in years 1 and 2. He assembled an oversight committee consisting of repesentative from different agencies and local representatives from the area being studied (Table 9). This group coordinated directly with Mr. Ebersole until July 2017 and several participated in a teleconference in early October in which the results of testing and ongoing statistical considerations were presented. There was also a strong coordination between researchers and groups in the Norfolk – Hampton Roads and the project team which included a presentation by the UNF PI at Old Dominion University and a webinar that many of the participants in the Norfolk – Hampton Roads area.

Table 9. List of Agency Representatives on Project Coordination Team

Agency	Individual
FEMA HQ	Jon Westcott, Tucker Mahoney
FEMA Region I	Kerry Bogdan
FEMA Region II	Alan Springett
FEMA Region III	Robert Pierson
FEMA Region IV	Christina Lindemer
FEMA Region VI	Larry Voice
US Coast Guard	LCDR Blair Sweigart
USACE	Ty Wamsley
NOAA	Andre van der Westheysen

5 Conclusions and Future Work

Overall, the basic objective of this project were met. The team developed a good basic understanding of many of the important aspects required to execute a modeling system for the Norfolk – Hampton Roads area and was able to establish a capability to link a hydrologic model to a surge model along a fixed boundary. However, due to the lack of good validation data in the study area, as needed for a final selection of a single coupling method (fixed boundary, moving boundary, tightly coupled, loosely coupled, etc.) and a recommended hydrologic model for applications, these two questions remain and will become the focus of future efforts along the Saint Johns River in Jacksonville, where a large amount of such data was collected during historic flooding associated with Hurricane Irma.

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Resio, D.T., Irish, J.L, Westerink, J.J., N.J. Powell, 2013. The effect of uncertainty on estimates of hurricane surge hazards, *Nat Hazards*, DOI 10.1007/s11069-012-0315-1.

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FIGURES:

Figure 1. Picture of flooding in the Houston area following the landfall of Hurricane Harvey.

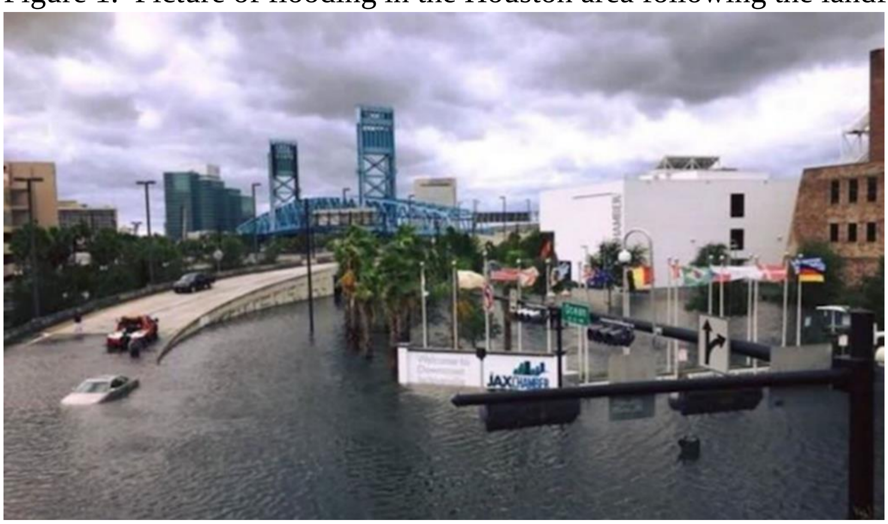

Figure 2. Downtown flooding in Jacksonville, Florida during Hurricane Irma.

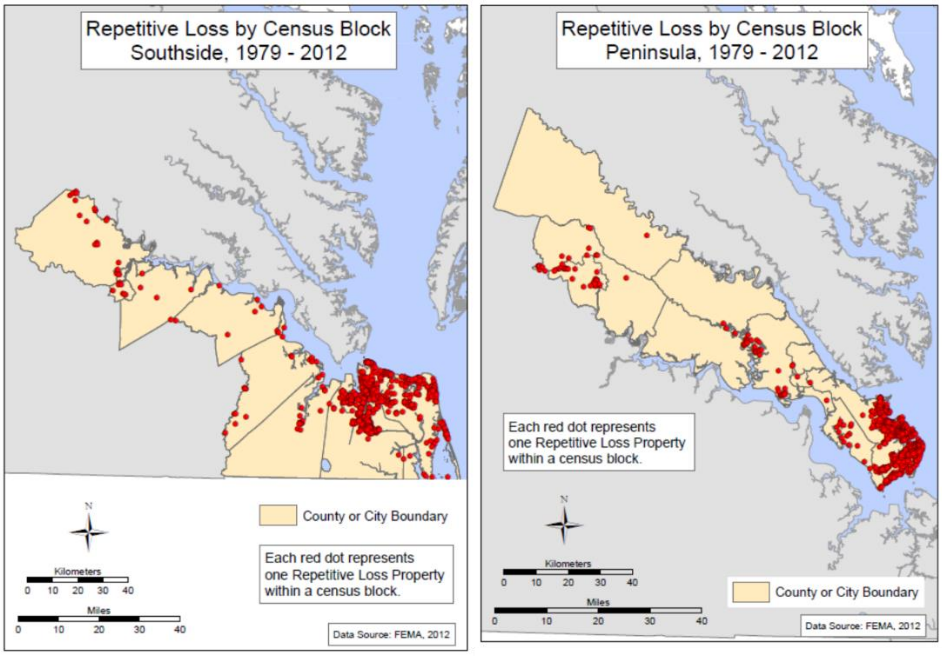

Figure 3. Depiction of repetitive damages in the Norfolk – Hampton Roads area (Mitchell et al. 2013).

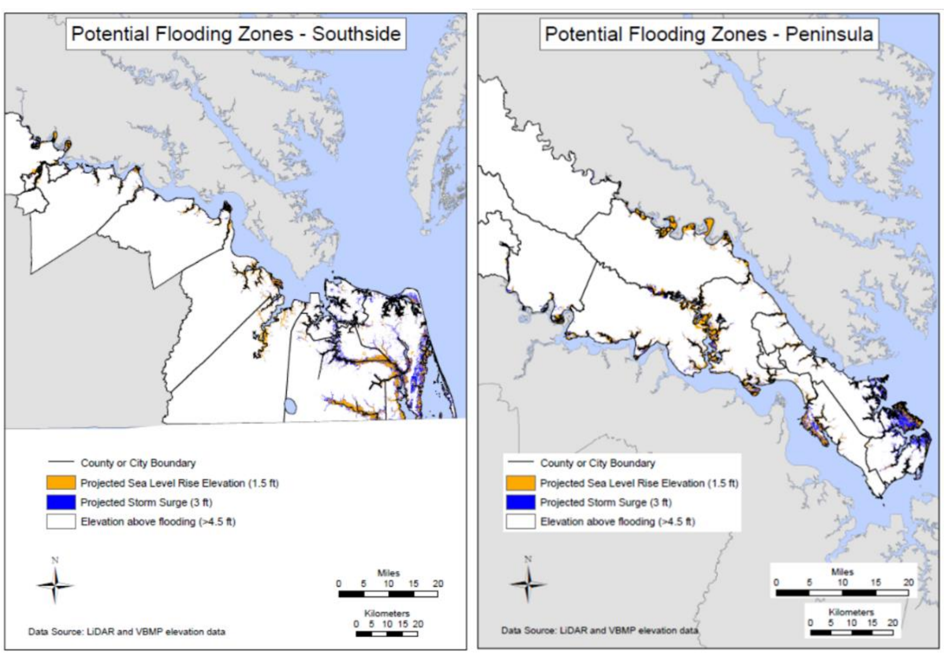

Figure 4. Projected flooding zones wit 1.5 ft of sea level rise (Mitchell et al. 2013).

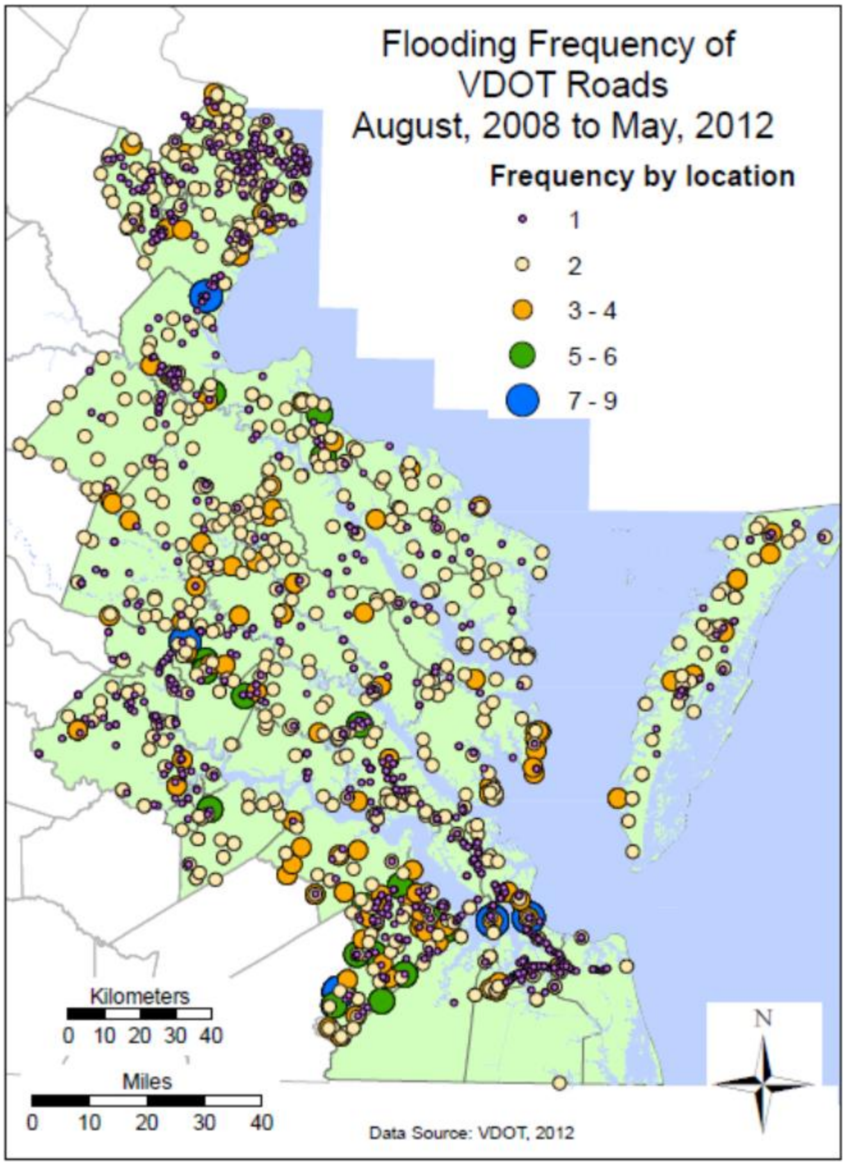

Figure 5 Flooding frequency of Virginia Department of Transportation Roads (Mitchell et al., 2013)

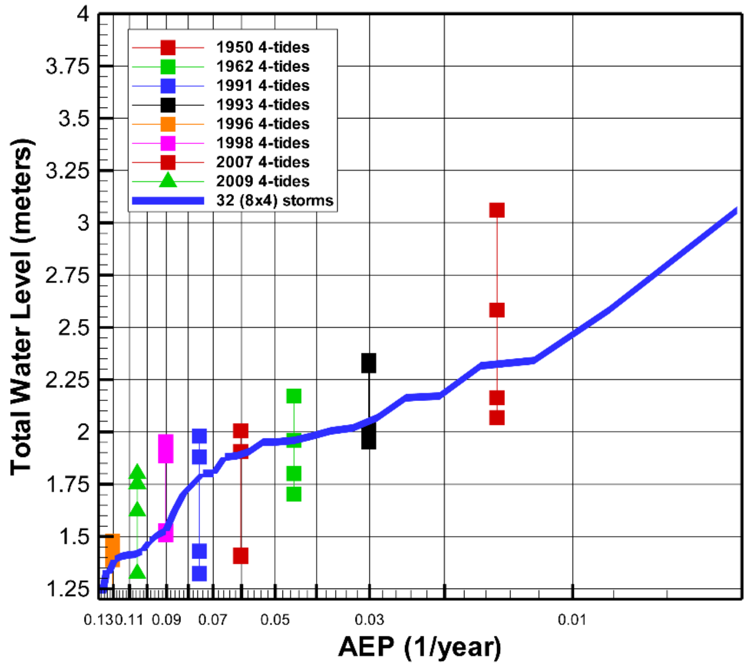

Figure 6. Plot of ranges of surge plus tide variations for eight extratropical storms run with 4 different tidal phases at the Battery in New York compared to the estimated AEP values obtained from the set of all 32 values. The highest values for each storm dominate the AEP estimation.

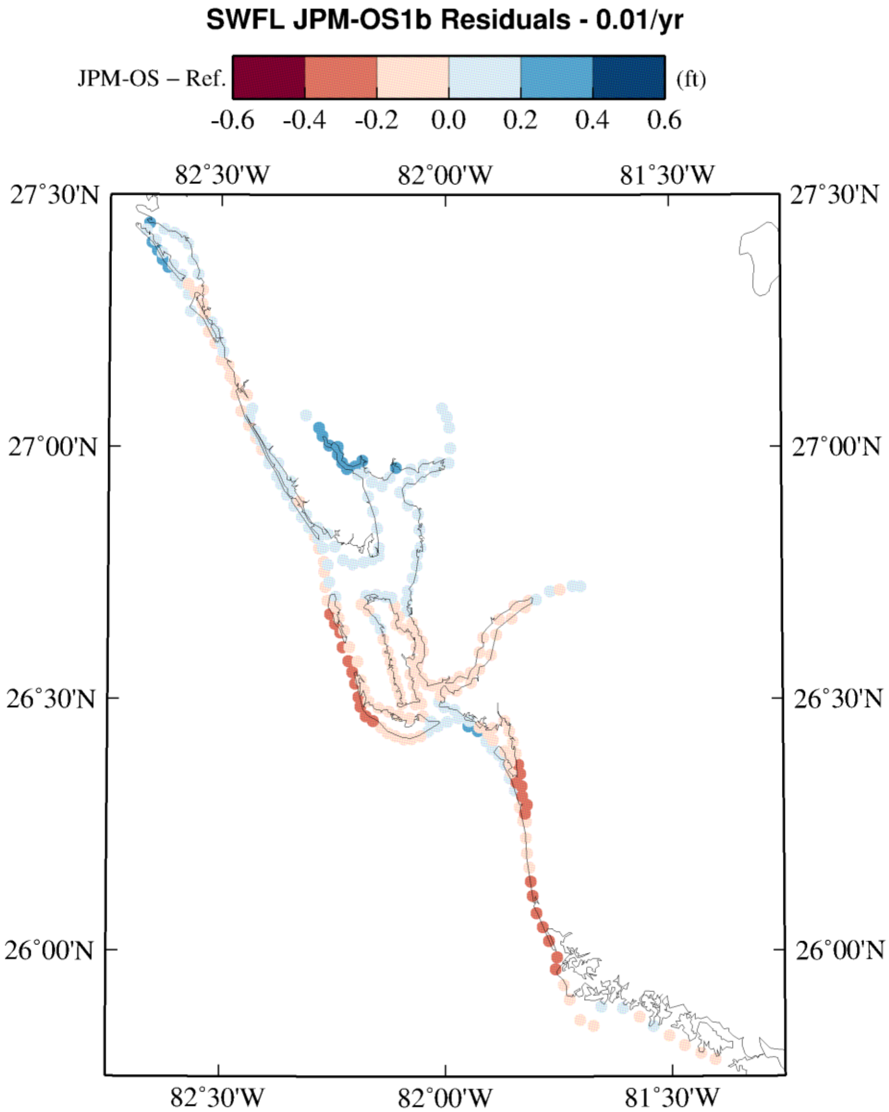

Figure 7. Deviations between estimated surge levels associated with AEP of 0.01 along the coast and in Tampa Bay produced by Bayesian Quadrature storm set and “Reference-Set storms.

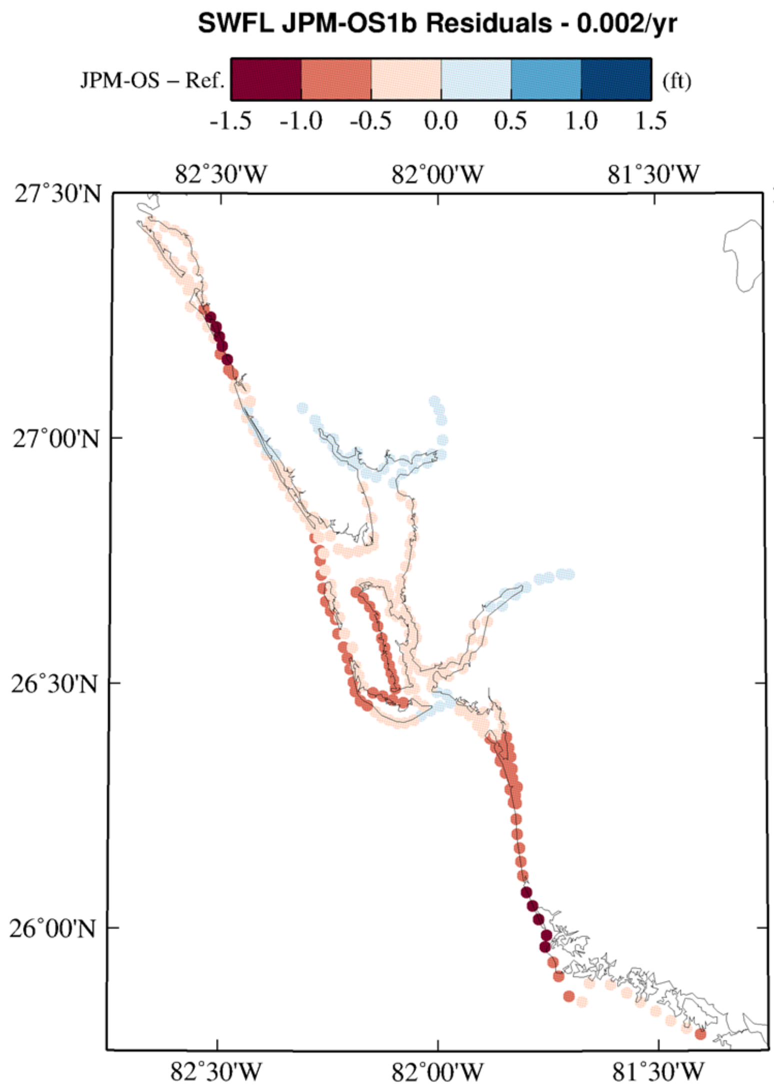

Figure 8. Deviations between estimated surge levels associated with AEP of 0.002 along the coast and in Tampa Bay produced by Bayesian Quadrature storm set and "gold-standard" storm set.

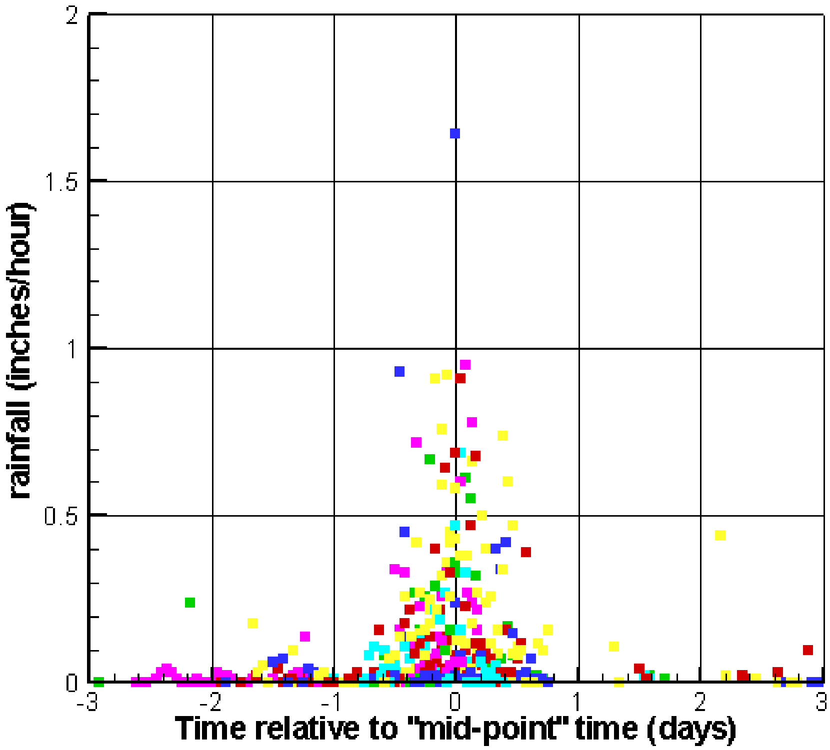

Figure 9. Hourly rainfall rates at Norfolk for all storms as a function of time relative to time of minimum distance from Norfolk to the storm center.

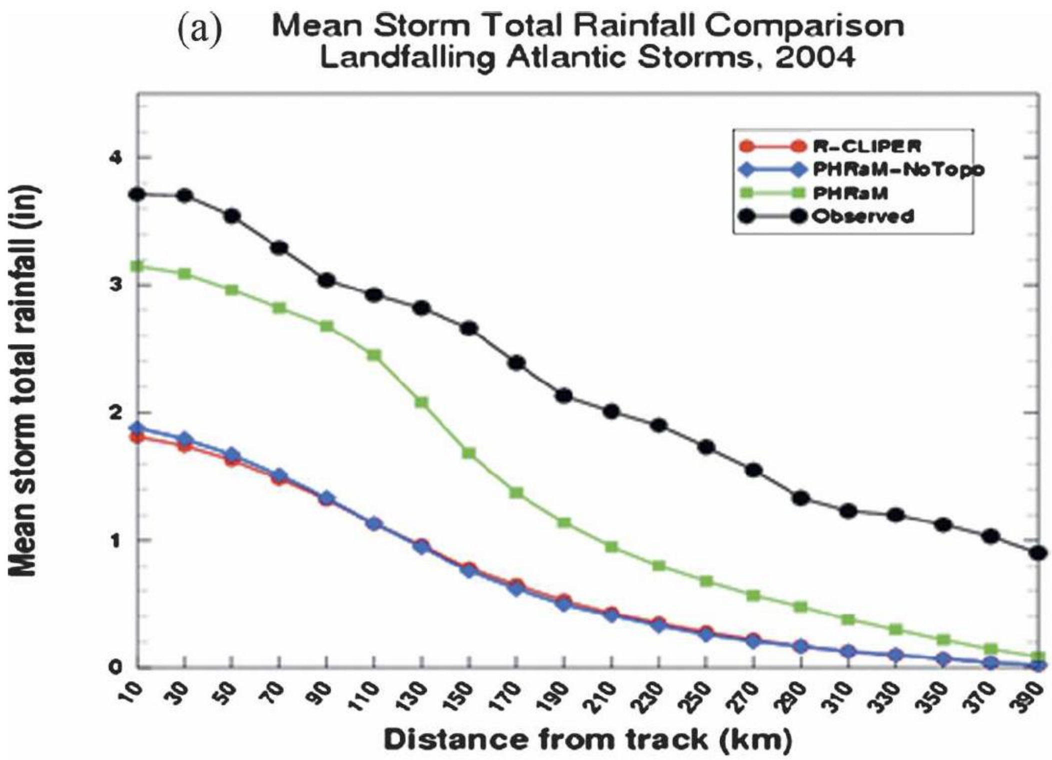

Figure 10. Estimated total storm rainfall as a function of distance from the track using different models compared to observed rates.

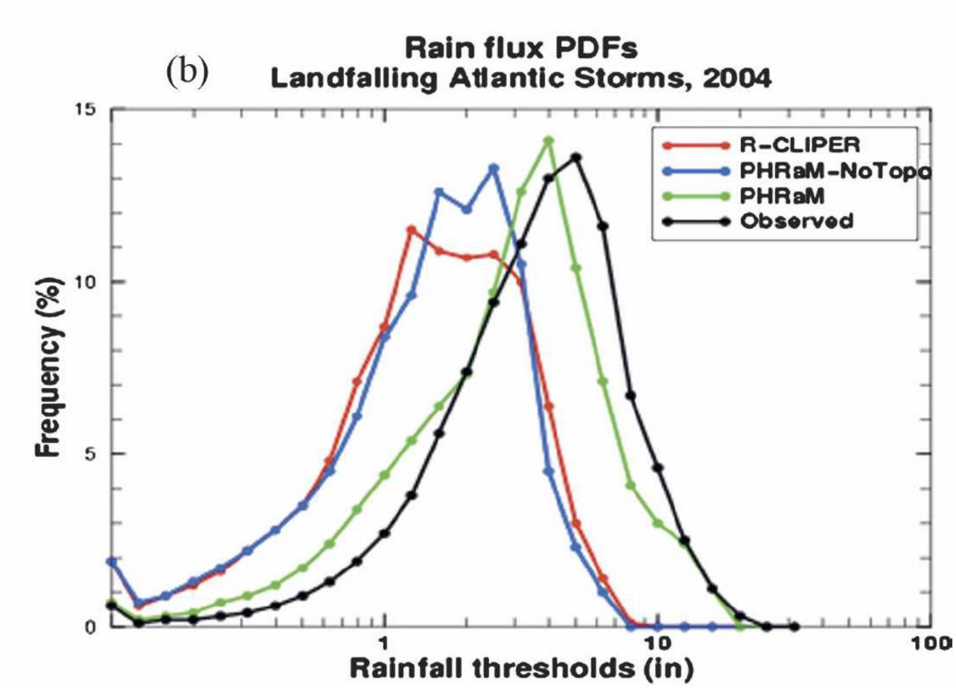

Figure 11. Estimated percentage of occurrences of rainfall amounts from different models compared to observed percentages.

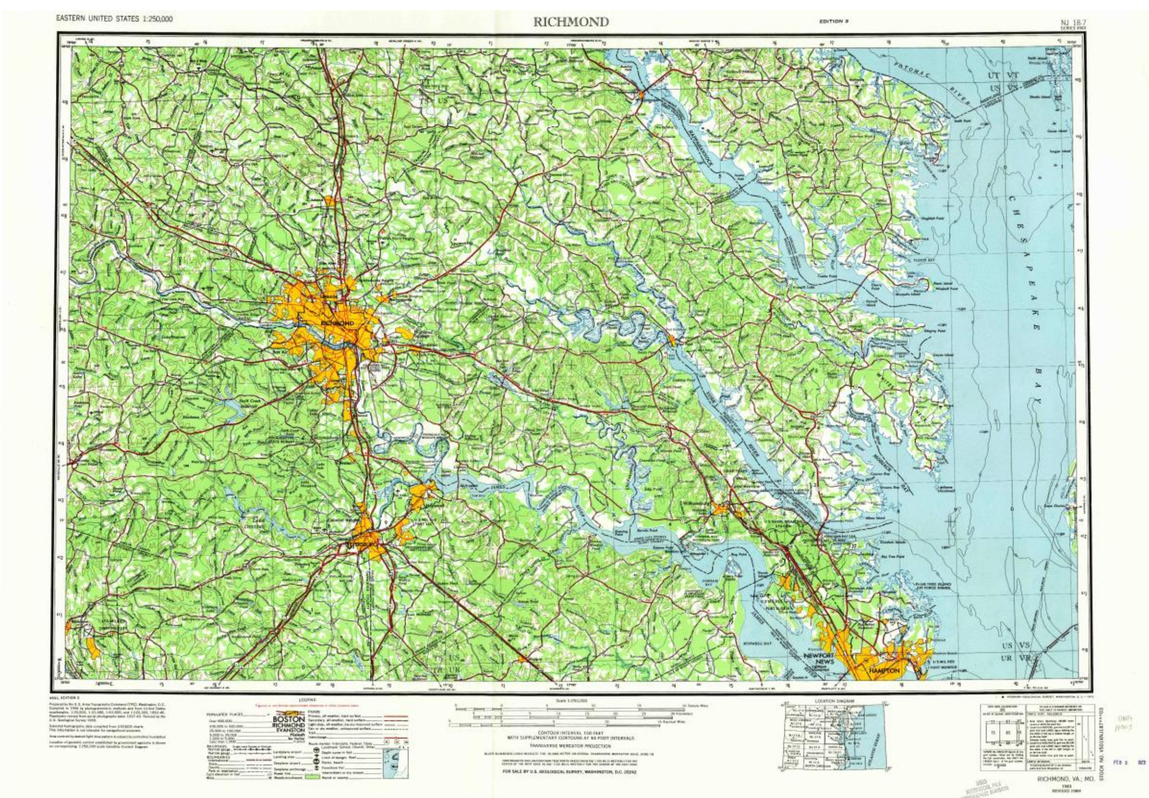

Figure 12. Topographic map of eastern Virginia showing the James River from Richmond (extent of tidal action in the river) to the Hampton Roads area.

Figure 13. Map of study area showing stations for rain

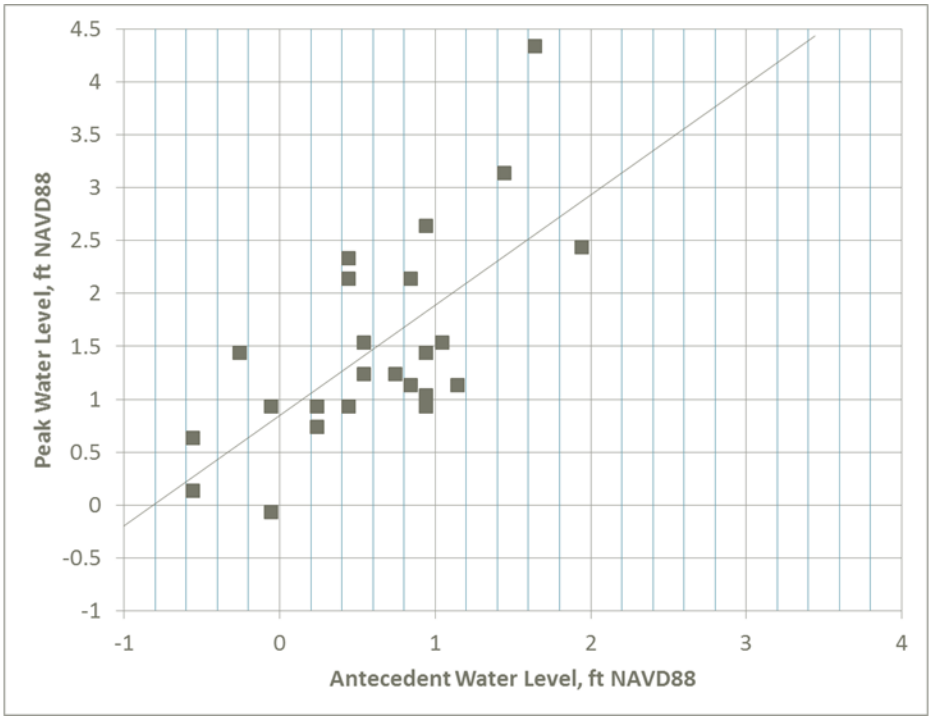

Figure 14. Effects of Antecedent Water Level on Peak Water Level at Bayou Des Allemands Gage.

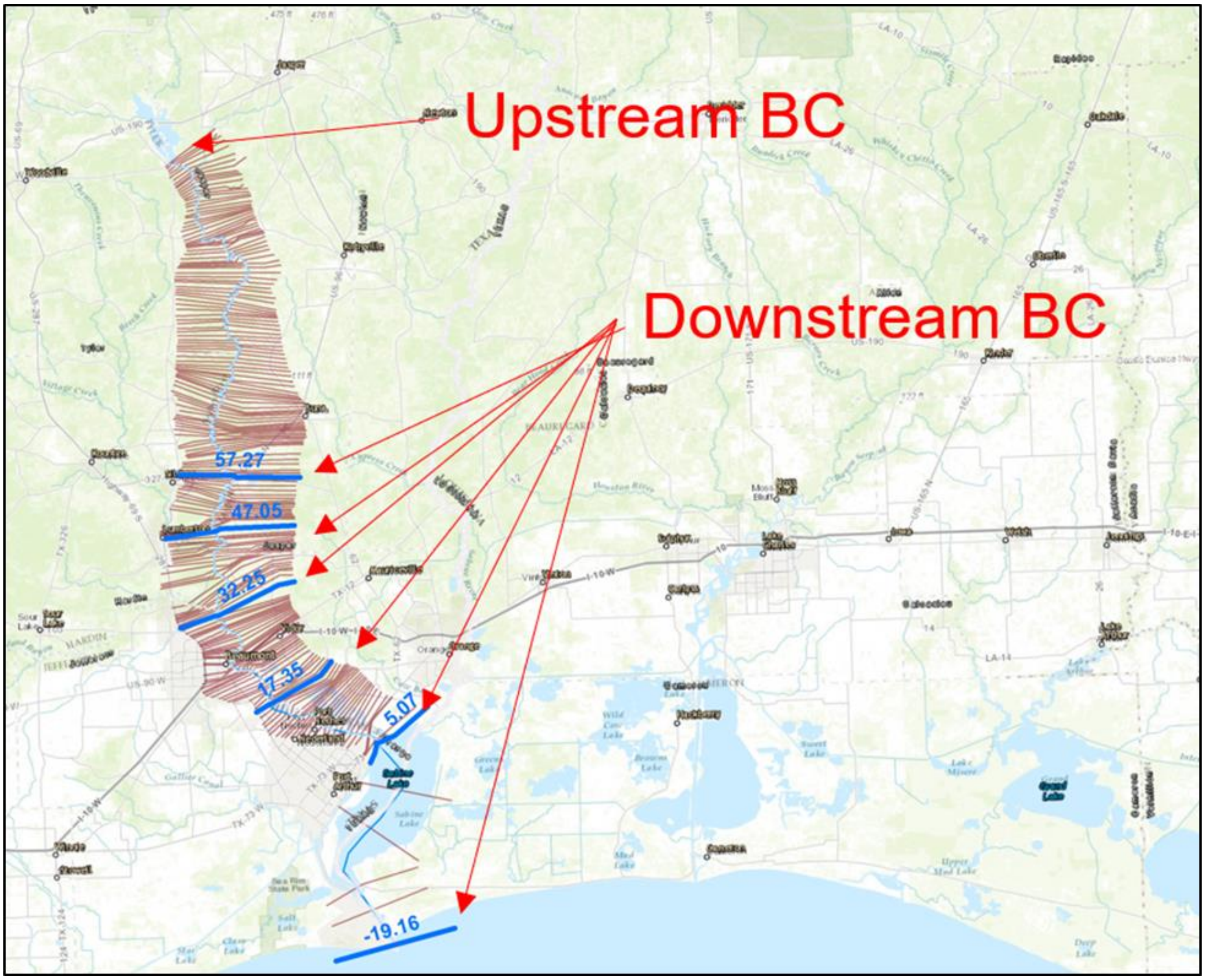

Figure 15. HEC-RAS cross-sections shown in red. Blue sections labeled by river mile used as alternative Boundary Condition Locations.

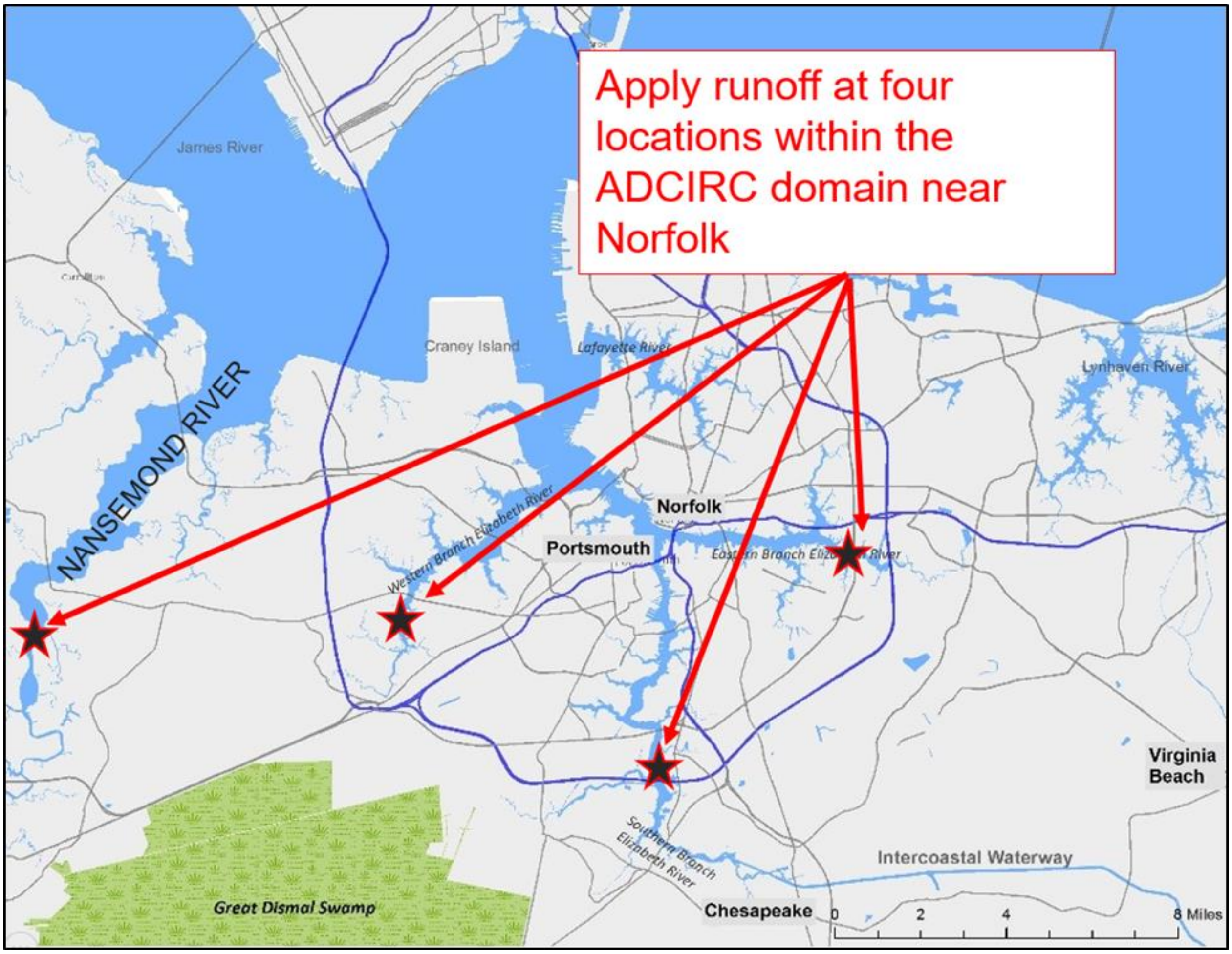

Figure 16. Locations of internal boundary conditions applied in Norfolk to account for watershed runoff.

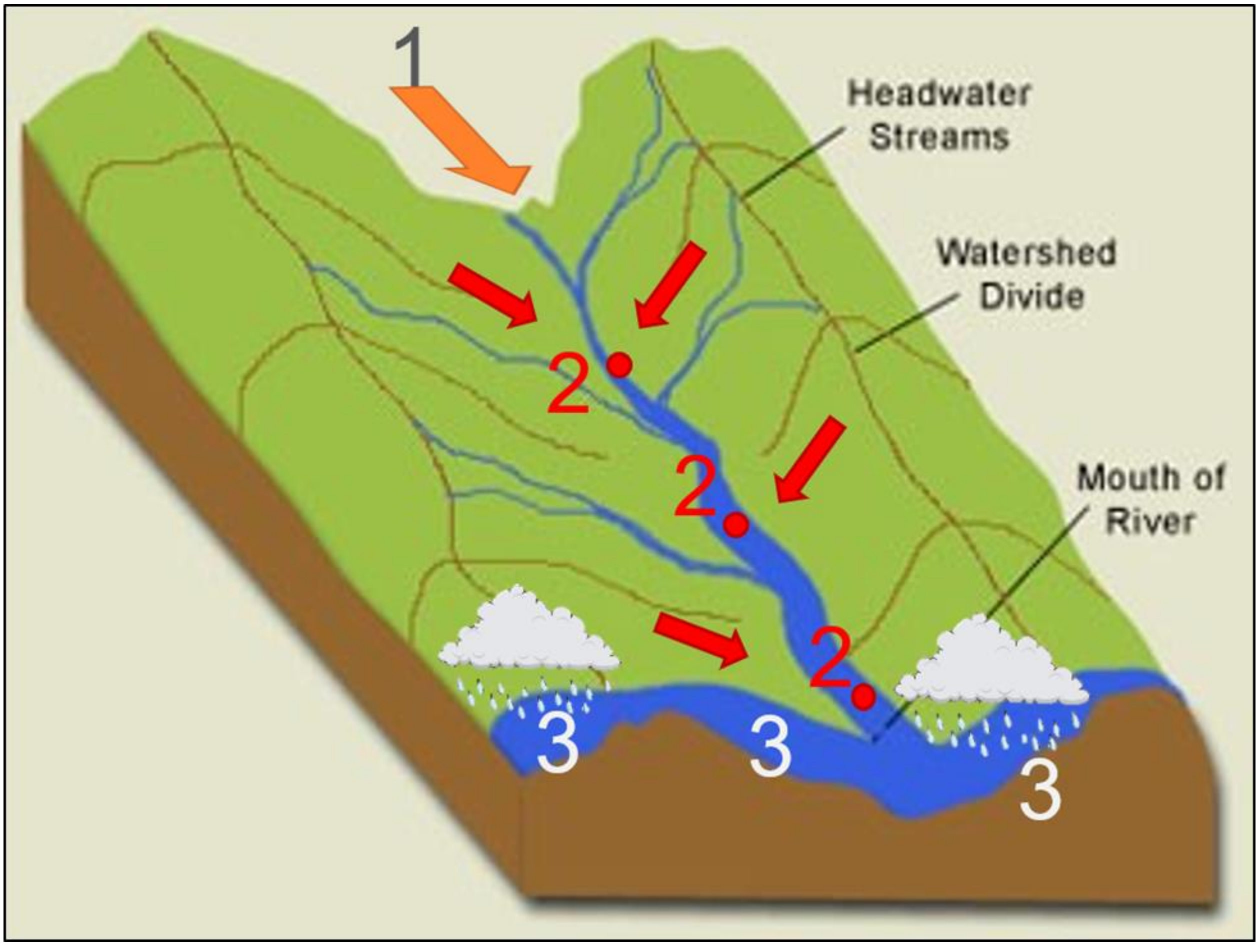

Figure 17. Upland hydraulic conditions added to coastal surge model. 1. antecedent riverine flow (can vary temporally through storm event), 2. local watershed routing, 3. direct precipitation.

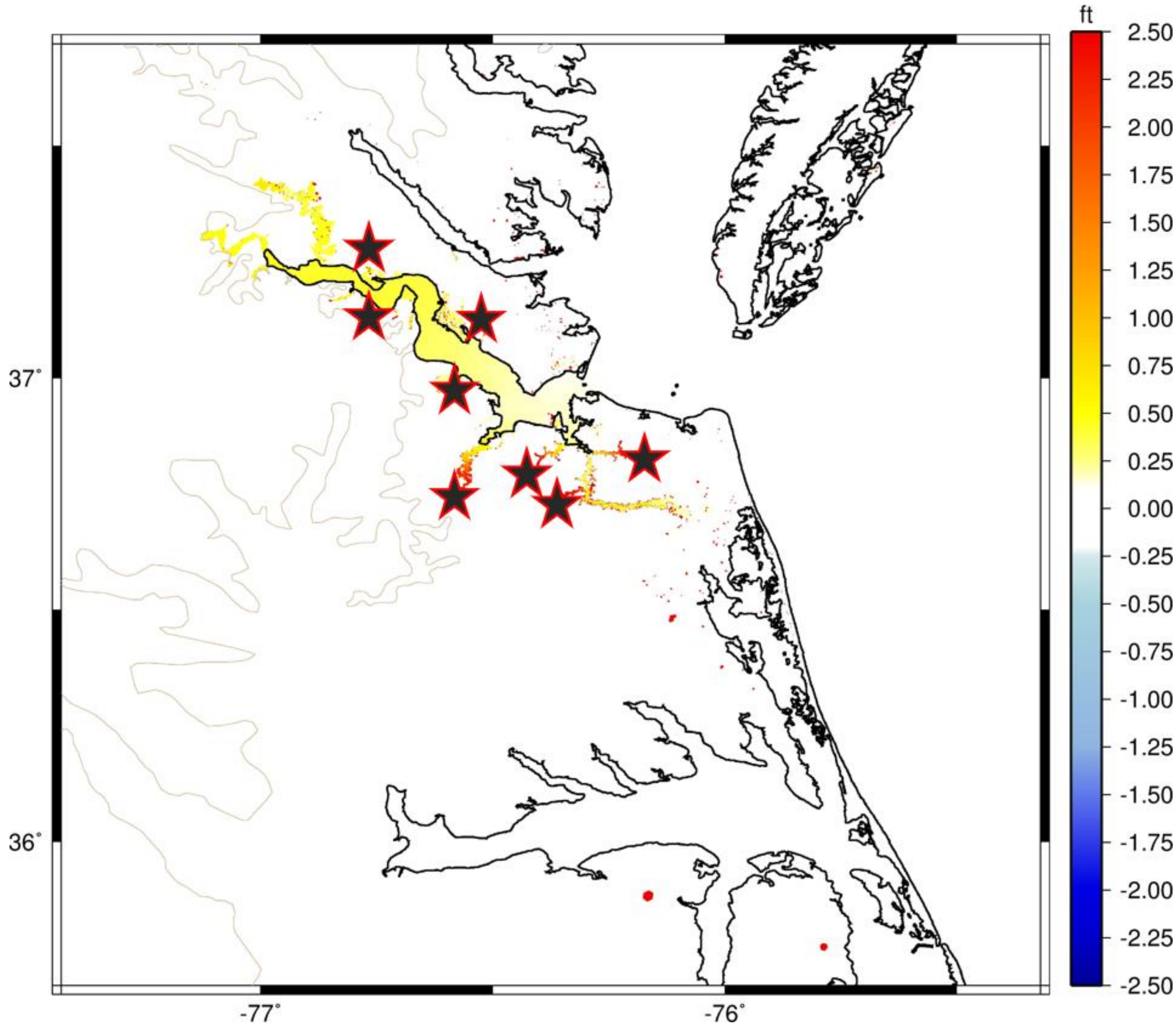

Figure 18. Stars denote location of mass transfers into the ADCIRC domain from the adjacent hydrologic domain.

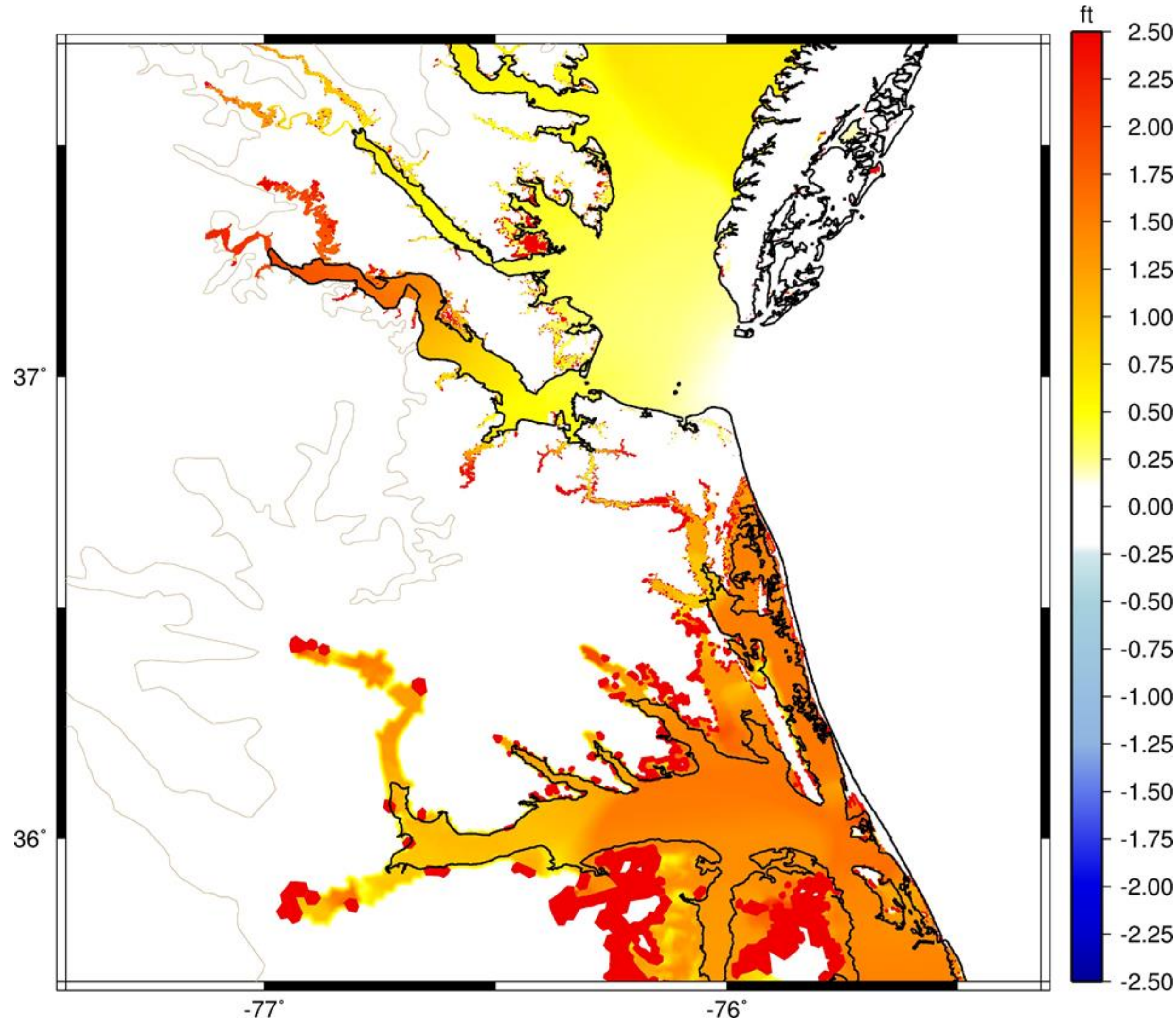

Figure 19. Typical differences generated by hydrologic component of coupled hydrologic-surge test simulation.

Appendix C
Coastal Resilience Center of Excellence
Publications and Other Material
Years 1-3
July 1, 2015 – June 30, 2018

Victoria Bennett, RPI
Mohammed Gabr, NCSU

Project Title: Establishment of a Remote Sensing Based Monitoring Program for Performance Health Assessment of the Sacramento Delta

Journal Papers

Amr Helal, Victoria Bennett, Mo Gabr, Roy Borden and Tarek Abdoun.“Monitoring and Modeling of Peat Decomposition in Sacramento Delta Levees,” Geotechnical Frontiers 2017, Orlando, Florida. DOI: 10.1061/9780784480458.054

Victoria Bennett, Cathleen Jones, David Bekaert, Jason Bond, Amr Helal, Joel Dudas, Mohammed Gabr, Tarek Abdoun.“Deformation Monitoring for the Assessment of Sacramento Delta Levee Performance,” Geo-Risk 2017 (Geotechnical risk from theory to practice), Denver, Colorado. DOI: 10.1061/9780784480717.003

Conference Papers

Victoria Bennett, Chung Nguyen, Tarek Abdoun, Amr Helal, Mohammed Gabr, Cathleen Jones, David Bekaert, Joel Dudas.“Use of remote-sensing deformation monitoring for the assessment of levee section performance limit state,” Proceedings of the 19th International Conference on Soil Mechanics and Geotechnical Engineering, Seoul 2017.

Rowshon Jadid, Brina Montoya, Victoria Bennett, and Mo Gabr. “Deformation-based versus Limit Equilibrium Analyses to Assess the Effect of Repeated Rise and Fall of Water Level on the Stability of Princeville Levee,” Dam Safety 2018, Seattle, Washington.

Rowshon Jadid. “Strain-Based Approach versus Limit Equilibrium Analyses: Assessing the Effect of Hydraulic Loading History on the Stability of Princeville Levee,” DHS COE Summit 2018, Arlington, Virginia.

Rowshon Jadid, Brina Montoya, Victoria Bennett, and Mo Gabr. “Effects of Load History on Seepage-Induced Deformation and Associated Performance in Terms of Probability of Exceeding Limit States - Case Study of Princeville Levee,” Geo-Congress 2019, Philadelphia, Pennsylvania. (under review)

Other Reports

Amr Helal. “Analysis of Earth Embankment Structures using Performance-based Probabilistic Approach including the Development of Artificial Neural Network Tool,” PhD dissertation, Civil Engineering Department, North Carolina State University, June 2017.

Philip Berke, TAMU
Jaimie Masterson, TAMU

Project Title: **Local Planning Networks and Neighborhood Vulnerability Indicators**

Journal Papers

Berke, P., Lee, J., Newman, G., Combs, T. Kolosna, C., Salvesen, D. 2015. Evaluation of Networks of Plans and Vulnerability to Hazards and Climate Change: A Resilience Scorecard, Journal of the American Planning Association 81(4): 287-302. DOI: 1080/01944363.2015.1093954

Berke P., Malecha M., Yu S., Lee J., Masterson J. (2018). Plan Integration Scorecard for Resilience: Evaluating Networks of Plans in Six US Coastal Cities, Journal of Environmental Planning and Management, DOI:10.1080/09640568.2018.1453354.

Malecha, M., Brand, A., & Berke, P. (2018). Spatially evaluating a network of plans and flood vulnerability using a Plan Integration for Resilience Scorecard: A case study in Feijenoord District, Rotterdam, the Netherlands. Land Use Policy, 78, 147-157. DOI: 10.1016/j.landusepol.201

Masterson, J., Berke, P., Malecha, M., Yu, S., Lee, J., & Thapa, J. (2017) Plan integration for resilience scorecard: How to spatially evaluate networks of plans to reduce hazard vulnerability. College Station, Texas: Institute for Sustainable Communities, College of Architecture, Texas A&M. http://mitigationguide.org/wpcontent/uploads/2013/01/Scorecard_3Oct2017.pdf

Other Reports

Berke. P. *Mitigation Planning for Resilient Cities. Coastal Resilience Center ReTalk Webinar*, March 8, 2018. Johnson C Smith University, Charlotte, NC

Brian Blanton, UNC-CH
Jason Fleming, Seahorse Consulting

Project Title: A multi-tiered ADCIRC-based storm surge and wave prediction system

Journal Papers

Thomas, A., J. Dietrich, T. Asher, M. Bell, B. Blanton, J. Copeland, A. Cox, C. Dawson, J. Fleming, and R. Luettich (2018). Influence of Storm Timing and Forward Speed on Tides and Storm Surge during Hurricane Matthew (2016). Submitted to *Ocean Modelling.*

Conference Papers

Storm Surge Probabilities for Hurricane Events, J. Smith, B. Blanton, R. Luettich, 2017. Poster presented at AMS 2017 in Seattle WA (Jan 2017), DHS CRC Annual Meeting in Chapel

Hill, NC (Feb 2017), and the annual Hurricane Awareness conference at East Carolina University (May 2017).

Smith, J., Blanton. B., and Luettich, R. 2018. Probabilistic Hurricane Track Generation for Storm Surge Prediction. Presented at the American Meteorological Society 2018, Austin, TX.

Other Reports

Smith, J. December 2017. Probabilistic Hurricane Track Generation for Storm Surge Prediction. Master's Thesis, UNC-Chapel Hill, Department of Marine Sciences.

Hang Chen, JCSU
Ahmed Faik, JCSU

Project Title: Preparing Tomorrow's Minority Task Force in Coastal Resilience through Interdisciplinary Education, Research, and Curriculum Development

Journal Papers

Ying Bai, Hang Chen, "Build a Real Time Optimal Evacuation Contraflow Model for Natural Disasters by Using a Fuzzy Inference System," Natural Hazards Review. (Submitted on June 13rd, 2016)

Conference Papers

Ying Bai, Hang Chen, "Build a Real Time Optimal Evacuation Contraflow Model for Natural Disasters by Using a Fuzzy Inference System," 2016 IEEE Symposium Series on Computational Intelligence (IEEE SSCI 2016). (Submitted on May 20th, 2016)

Ying Bai & Hang Chen, "Build an Optimal Evacuation Contraflow Model for Natural Disasters by Using Fuzzy Inference System", to be appeared on Proceedings of the 2018 IEEE International Conference on Fuzzy System, July 8-13, Rio de Janeiro, Brazil, 2018.

Other Reports

Cody Byrd, Jean-Marie Nshimiyimana, Ehije Idehenre, Hang Chen (Faculty Advisor), "Data Analysis of Haiti's Resiliency Post-2010 Earthquake". Presented at the 2017 Emerging Researchers National (ERN) Conference in Science, Technology, Engineering and Mathematics (STEM).

Shania Knight, Christian Fair, Ramoya Grandison, Ying Bai (Faculty Advisor) "Using Fuzzy Interference System to Build Real Time Optimal Evacuation Contraflow Model".

Thandiwe Balani, Quintavious Coleman, Ashenafi Tsaudu, "Using Fuzzy Interference System to Build Real Time Optimal Evacuation Contraflow Model."

NyJae Dickerson, Adonis Tillman, Desmond Taylor, Awatif Amin (Faculty Advisor), "Using Data Mining to analyze Natural Disasters at 10 countries". Presented at the 2017

Emerging Researchers National (ERN) Conference in Science, Technology, Engineering and Mathematics (STEM).

Aaron Smith, "Analyzing Mecklenburg County's Flooding Resilience."

Amyr Washington, Tendru Howell, "Vulnerability Assessment: New Orleans, Louisiana vs. Savannah, Georgia."

Imyer Majors, Frandy Prince, and Djerhkea Epps Dukes, "Hurricane Vulnerability Assessment: North Carolina Coastal Counties."

Daniel Cox, OSU
John van de Lindt, CSU

Project Title: Experimental and Numerical Study to Improve Damage and Loss Estimation Due to Overland Wave and Surge Hazards on Near-Coast Structures

Journal Papers

Do, Trung, van de Lindt, J., Cox, D.T. (2016) "Performance-Based Design Methodology for Inundated Elevated Coastal Structures Subjected to Wave Load Engineering Structures," *Engineering Structures*, 117, 250 – 262. DOI: 10.1016/j.engstruct.2016.02.046

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Do, T., van de Lindt, J., Cox, D. "Hurricane Surge-Wave Building Fragility Methodology for Use with HAZUS-MH," (submitted 2018)

Tomiczek, T., Wyman, A., Park, H., Cox, D.T. "Application and Modification of Goda's Formulae to Estimate Horizontal and Vertical Forces on Elevated Coastal Structures. Part 1: Nonbreaking Waves," Coastal Engineering (re-submitted 2018)

Conference Papers

Do, T., Tomiczek, T., van de Lindt, J. Cox, D. (2017) "Development of Physics-Based Building Fragility Surfaces for Near-Coast Community Modeling," *International Conference on Coastal and Ocean Engineering*, Osaka, Japan.

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Other Reports

William Short. *A laboratory study of horizontal and vertical regular wave forces on an elevated structure*. (2016). MS Thesis, Oregon State University.

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Rachel Davidson, U Del
Jamie Kruse, ECU
Linda Nozick, Cornell U.

Project Title: An Interdisciplinary Approach to Household Strengthening and Insurance Decisions

Journal Papers

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Robinson, C., Davidson, R. A., Trainor, J. E., Kruse, J. L., and Nozick, L. K. 2018. Homeowner acceptance of voluntary property acquisition offers. *International Journal of Disaster Risk Reduction* 31, 234-242. DOI: [10.1016/j.ijdrr.2018.05.002](https://doi.org/10.1016/j.ijdrr.2018.05.002)

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Other Reports

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Wang, D. (expected 12/18) A Computational Framework to Support Government Decision-making in Regional Natural Disaster Risk Management. PhD dissertation. University of Delaware.

Xu, K., Nozick, L., Kruse, J., Davidson, R., and Trainor, J. (2017) Affordability of Natural Catastrophe Insurance: game theoretic analysis and geospatially explicit case study, Chapter 15in *GEOValue: the socioeconomic Value of Geospatial Information*, ed. J. Kruse, J. Crompvoets, and F. Pearlman, Taylor & Francis Group, LLC Baton Rouge, FL.

Yahyazadeh, Z., Davidson, R., Trainor, J., Kruse, J., and Nozick, L. Homeowner decisions to retrofit to reduce hurricane-induced wind and flood damage. *Journal of Infrastructure Systems*, in review.

Casey Dietrich, NCSU
Clint Dawson, UT-Austin

Project Title: Improving the Efficiency of Wave and Surge Models via Adaptive Mesh Resolution

Journal Papers

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A Thomas*, JC Dietrich, JG Fleming, BO Blanton, T Asher, RA Luettich. "High-Resolution Modeling of Surge during Hurricane Matthew." *ADCIRC Users Group Meeting*, NOAA Center for Weather and Climate Prediction, College Park, Maryland, 13 April 2018.

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Isaac Ginis, URI
Wenrui Huang, FSU

Project Title: Improving the Efficiency of Wave and Surge Models via Adaptive Mesh Resolution

Journal Papers

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Stempel, P.*, Becker, A., (*In Prep*). Visualizations out of context. Implications of using simulation-based 3d hazard visualizations.

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Fei, T., W. Huang, I. Ginis, Y. Cai, 2016. Characteristics of River Flood and Storm Surge Interactions in a Tidal River in Rhode Island, USA. Proceeding of IUTAM Symposium on Storm Surge Modelling and Forecasting, Oct 17-19, 2016, Shanghai, China

Stempel, P.*, Becker, A., (Accepted). "Effects of localization on perceptions of storm surge risk depicted in model driven semi-realistic visualizations." International Conference on Sustainable Development, NY, NY. September 26-28, 2018.

Chen, X. *, I. Ginis and T. Hara (2018). "Sea-State Dependent Drag Coefficient in Shallow Waters Under Tropical Cyclones", 21st Conference on Air-Sea Interaction, June 18 https://ams.confex.com/ams/23BLT21ASI/meetingapp.cgi/Paper/345222

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Rosa, K.*, Kincaid, C. (2018). "Transporting Nutrients Northward from Rhode Island Sound Bottom Water to the Upper Narragansett Bay Euphotic Zone", RI C-AIM/RI NSF EPSCoR Symposium. Kingston, RI, April 9.

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Whitney, M. M., D. S. Ullman, and D. L. Codiga, 2016. Subtidal Exchange in Eastern Long Island Sound, *J. Phys. Oceanogr*. (in press).

Scott Hagen, LSU
Stephen Medeiros, UCF

Project Title: Development of an Optimized Hurricane Storm Surge - Wave Model for the Northern Gulf of Mexico for use with the ADCIRC Surge Guidance System

Journal Papers

Tahsin, S., **S.C. Medeiros**, A. Singh, M. Hooshyar (2017), "Optical Cloud Pixel Recovery via Machine Learning", *Remote Sensing*, 9(6), 527, DOI: **10.3390/rs9060527**

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Jennifer Horney, TAMU

Project Title: Implementing the Disaster Recovery Tracking Tool

Journal Papers

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Chirra, B., & Horney, J. (2016, April). Measuring disaster recovery: A case study of six communities in Texas, United States. Oral presentation at the Texas Public Health Association's 92nd Annual Education Conference, Galveston, TX

Kirsch, K., Sullivan, E., Horney, J., and Goidel, K. (2018, July). Are slow-onset disasters well represented in hazard mitigation plans? Poster presentation at the 43rd Annual Natural Hazards Research and Applications Workshop, Broomfield, CO.

Kirsch, K. (accepted for publication). Session summary. Equitable and resilient design: Past and present infrastructure challenges. Proceedings of the 43rd Annual Natural Hazards Research and Applications Workshop, Broomfield, CO.

Other Reports

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Barry Keim, LSU

Project Title: Disaster Science and Management Program at LSU

Journal Papers

Xue, G.Z., D.J. Gochis, W. Yu, B.D. Keim, R.V. Rohli, Z. Zang, K. Sampson, A. Dugger, D. Sathiaraj, and Q. Ge. 2018. Modeling Hydroclimatic Change in Southwest Louisiana Rivers. *Water* 10(5), Article No. 596. https://doi.org/10.3390/w10050596.

Keim, B.D., W.D. Kappel, G.A. Muhlstein, D.M Hultstrand, T.W Parzybok, A.B. Lewis, E.M. Tomlinson, and A.W. Black. 2018. Assessment of the Extreme Rainfall Event at Nashville, Tennessee and the Surrounding Region on May 1-3, 2010. *Journal of American Water Resources Association.* https://doi.org/10.1111/1752-1688.12657.

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Shankman, D., and B.D. Keim. 2016. Flood Risk Forecast for China's Poyang Lake Region. *Physical Geography* 37(1): 88-91.

Gilliand, J., and B.D. Keim. Submitted. Surface Wind Speed Trend Climatology of Brazil from 1980-2014. *Journal of Climate*.

Allard, J.M., J.V. Clarke, and B.D. Keim. In Press. Spatial and Temporal Patterns of In Situ Sea Surface Temperatures within the Gulf of Mexico (GoM), 1901–2010. *American Journal of Climate Change*.

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Meherun Laiju, TC

Project Title: Institutionalization, Expansion, and Enhancement of Interdisciplinary Minor: Disaster and Coastal Studies

Journal Papers

Mage, D. Reed, S. Hokins, A. Mangum, C. & Banerjee, S. (2018) Using Arc GIS to Map Disaster Effects on Mississippi, abstract published in *The journal of Mississippi Academy of Sciences (*ISSN 0076-9436) vol 63, 1 February edition

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Conference Papers

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Laiju, M. (2017) *A Global Issue: Natural, Manmade Disaster, and Exploitation of Children,* Pardee RAND Faculty Leaders Fellowship, manuscript under review.

Laiju, M. & Banerjee, S. (2017) *Innovative Interdisciplinary Undergraduate Curriculum in Homeland Security at a HBCU*, Presented at the 10th Anniversary Homeland Defense & Security Education Summit on March 23, 2017

Other Reports

Laiju, M. (2018) *Social Impact of Natural and Manmade Disasters***.** developed this course

Laiju, M. (20016) *A Global Issue: Natural Disaster and Child trafficking,* proposal to write a paper was funded by Andrew W. Melon Foundation, the completion and submission date is May 2017.

James Opaluch, URI

Project Title: Overcoming barriers to motivate community action to enhance resilience

Journal Papers

Becker, Austin, Pamela Matson, Martin Fischer, and Michael D. Mastrandrea, Forthcoming. "Towards Seaport Resilience for Climate Change Adaptation: Stakeholder Perceptions of Hurricane Impacts in Gulfport (MS) and Providence (RI)" Progress in Planning. Status: Accepted for Publication. Anticipated Publication Date November 2017. DOI: 10.1016/j.progress.2013.11.002

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Spaulding, M. L., Grilli, A., Damon, C., Crean, T., Fugate, G., Oakley, B., & Stempel, P. (2016). Stormtools: Coastal Environmental Risk Index (CERI). Journal of Marine Science and Engineering, 4(3). DOI: 10.3390/jmse4030054

Stempel, P. (2018). Are visualizations scientific? How viewer expectations for scientific graphics shape perceptions of storm surge visualizations. Technical Communication Quarterly (In press).

Stempel, P., Ginis, I., Ullman, D. S., Becker, A., & Witkop, R. (2018). Real-Time Chronological Hazard Impact Modeling (In preparation).

Stempel, P, Becker, A. (2018). Visualizations out of context. Implications of using simulation based 3d hazard visualizations (submitted).

Conference Papers

Becker, A., (2016). "Findings from a port vulnerability assessment." Dept. of Homeland Security Center of Excellence for Coastal Resilience and University of North Carolina Maritime Risk Symposium University of North Carolina, Chapel Hill, North Carolina, Nov. 14-15, 2016, scheduled. (I).

Becker, A, (2016). "Adapting ports to climate change: Providence (RI) Case Study," AIVP Ports and Cities Conference, Netherlands, Oct 10-12, scheduled. (I)

Becker, A., (2016). "Inspiring leadership for Adaptation," North American Symposium on Climate Adaptation, New York, New York. Aug. 16-18, scheduled. (I)

Becker, A., (2016). "Inspiring resilience thinking for seaport systems." Transportation Research Board Conference for Committee on Maritime Transportation System (CMTS), National Academy of Sciences, Washington, DC, June 21-22, scheduled.

Becker, A, (2016). "Adapting ports to climate change: Providence (RI) Case Study," Adaptation Futures 2016, Rotterdam, Netherlands May 11-13.

Becker, A., (2016). "Inspiring resilience thinking for seaport systems." Green Ports for Blue Waters Conference, University of Rhode Island April 4-5, (I)

Green, W., Becker, A., (2016). "Built environments and rising seas: Service learning recommendations for the future of the Port of Galilee." A presentation of student work resulting from a course on resilient planning, policy, and design. Keeping History Above Water Conference, Newport, Rhode Island, April 10-13.

Becker, A. (2016). "Hurricane Resilience and Impacts to Seaport Supply Chains." Invited Speaker for the 2016 Stu Clark Speaker Series at the University of Manitoba. March 4 (I,E)

McIntosh, R.*, Becker, A. (2016). "Towards a Comparative Index of Seaport Climate-Risk: Development of Indicators from Open Data." Poster presentation at American Geophysical Union 2016 Ocean Sciences Meeting, New Orleans, LA, Feb. 21-26.

Kretsch, E.*, Becker, A. (2016). "Leadership and Responsibility for Long-term Hurricane Resilience: Stakeholder Perceptions in the Port of Providence, RI." Social Coast Conference. Charleston, SC, Feb. 11.

Becker, A., Burroughs, R. (2016). "More holistic planning for long-term coastal resilience? Port of Providence Demonstration Project." Social Coast Conference. Charleston, SC, Feb. 10.

Zhang, H., Ng, A., Becker, A. (In Press), "Institutional Barriers in Adaptation to Climate Change at Ports, Regions, and Supply Chains." North American Symposium on Climate Adaptation, New York, New York. Aug. 16-18, 2016. (Refereed Conference Paper)

Stempel, P. (2016). Data Driven Visualization. Paper presented at the ECM14, Estuarine and Coastal Modeling Conference, South Kingstown, RI, June 14-17.

Stempel, P., Becker, A. (2018). Perceptions of risk and legitimacy: how scenario selection and presentation of ocean models undermines disaster risk reduction. Paper to be presented at the ECM15, Estuarine and Coastal Modeling Conference, Seattle, WA, June 25-27.

Witkop, R., Stempel, P., Becker, A. (2018). "Incorporating facility manager knowledge into storm impact models: A case study of critical facilities in Westerly, Rhode Island." Oral presentation. 2018 Rhode Island Flood Mitigation Association Annual Conference. Smithfield, RI. Apr. 5.

Witkop, R., Stempel, P., Becker, A., (2017). "Coupling local scale, high resolution, qualitative data to interface with numerical storm models." Poster Presentation. American Geophysical Union Annual Conference, New Orleans, LA. December 12.

Robadue, Donald D. and Dawn Kotowicz, 2018. “Understanding resistance to resilience in coastal hazards and climate adaptation: three approaches to visualizing structural and process obstacles, opportunities and adaptation responses” Submitted to the 52nd Hawaii International Conference on System Sciences, Disaster Information, Technology, and Resilience Mini-Track of the Digital Government Track, June 16.

Other Reports

Kuffner, A. (2016, November 20, 2016). Rising Seas, Rising Stakes. Providence Journal.

Touzinsky, K, Rosati, J., Fox-Lent, C., Becker, A., Luscher, A., 2016. “Advancing Coastal Systems Resilience Research: Improving Quantification Tools through Community Feedback” under review at *Shore and Beach*. Expected publication date 2017.

Zhang, H., Ng, A., Becker, A. 2016, “Institutional Barriers in Adaptation to Climate Change at Ports, Regions, and Supply Chains.” under review at *North American Symposium on Climate Adaptation.* Expected publication date 2017.

Ismael Pagan, UPRM

Project Title: Education for Improving Resiliency of Coastal Infrastructure

Journal Papers

Morales-Velez, A. C., and Hughes, K.S., “Comprehensive Hurricane María Mass Wasting Inventory and Improved Frequency Ratio Landslide Hazard Mapping”, Revista Dimension Year 32, Vol 1, 2018

Aponte Bermúdez, Luis D., “Huracán María,: Sinopsis y Análisis Preliminar del Impacto en la Infraestructura de Puerto Rico”, Revista Dimensión Year 32, Vol 1, 2018

Martínez-Cruzado, José A. Huerta-López, Carlos I. Martínez-Pagán, Jaffet, Santana Torres, Erick X,and Hernández-Ramírez, Francisco J., “Destrozos, Recuperación, y Planes en la Red Sísmica de Movimiento Fuerte a Raíz de los Huracanes Irma y María”, Revista Dimensión, Year 32, Vol 1, 2018

Acosta, Felipe J, Esquilín-Mangual, Omar, Wood, Stephanie G., Long, Wendy R. and Valdés, Didier, Lessons Learned from the Evaluation of Concrete Pole Failures Following Hurricane María, Revista Dimension Year 32, Vol 1, 2018

Conference Papers

Ismael Pagán-Trinidad and Ricardo R. López, editors, Digital proceedings of Conference “Lessons Learned and Best Practices: Resilience of Coastal Infrastructure” , organized by the project, 2017, can be found in the link http://engineering.uprm.edu/inci/?page_id=3522

The following two presentations were given by Dr. Ricardo López at the World Engineering Conference on Disaster Risk Reduction. More information at http://www.wfeo.org/events/world-engineering-conference-disaster-risk-reduction-wecdrr-2016/

Ismael Pagán-Trinidad, Ricardo López-Rodríguez, Agustín Rullán, Oscar Perales-Pérez, John Fernández-Van Cleve, "THE ROLE OF UNIVERSITIES ON DISASTER RISK REDUCTION IN THE COMMUNITY: UPRM CASE STUDY", World Engineering Conference on Disaster Risk Reduction, Peruvian Association of Professional Engineers, Lima Perú, December 5-6, 2016.

López-Rodríguez, Ricardo R., Pagán-Trinidad, Ismael, "Structural Vulnerability to Natural Hazards in Puerto Rico", World Engineering Conference on Disaster Risk Reduction, Peruvian Association of Professional Engineers, Lima Perú, December 5-6, 2016.

Robert W. Whalin, Ismael Pagán-Trinidad, Evelyn Villanueva and David Pittman, "A Quarter Century of Resounding Success for a University/Federal Laboratory Partnership", Proceedings, 123rd ASEE Annual Conference and Exposition, Vol 1, presented June 27 2016 in New Orleans, LA. ISBN: 978-1-5108-3480-4

Ismael Pagán-Trinidad, Ricardo López-Rodríguez, "Overview of the Impact of Hurricane María in Puerto Rico", Presented at UNC-Chapel Hill, Graduate Resilience Certificate, by invitation from Dr. Gavin Smith, Feb 28, 2018

Ismael Pagán-Trinidad, Ricardo López-Rodríguez, "Education for Improvement of Coastal Infrastructure in PR", CRC First Annual Meeting, UNC Chapel Hill, March 2-3, 2016.

Ismael Pagán-Trinidad, Ricardo López-Rodríguez, "Education for Improvement of Coastal Infrastructure in PR", CRC Second Annual Meeting, UNC Chapel Hill, Feb 1-3, 2017.

Ismael Pagán-Trinidad, Ricardo López-Rodríguez, "Education for Improvement of Coastal Infrastructure in PR", CRC Third Annual Meeting, UNC Chapel Hill, Feb 28 - March 1, 2018.

Ismael Pagán-Trinidad, Ricardo López-Rodríguez, "Education, Resilience and the Built Environment: Impacts and Some Lessons Learned on Infrastructure for Improvement of Coastal Infrastructure in PR", Symposium: Planning and Resilient Recovery in Puerto Rico, Graduate School of Planning - University of Puerto Rico – Río Piedras, May 18-19, 2018

Benjamín Colucci Ríos (Presenter), Alexander Molano Santiago, Ismael Pagán Trinidad and Didier. M Valdés Díaz. Impact of Extreme Climate in Coastal Transportation Civil Infrastructure in the Caribbean, World Engineering Forums November 26 to December 2, 2017, Rome, Italy

Benjamín Colucci Ríos (Presenter) and Alexander Molano Santiago, Impact of Hurricane Maria on Puerto Rico's Transportation Infrastructure: Lessons Learned, 97th Transportation Research Board Annual Meeting, AHB55 Committee, *Work Zone Traffic Control Committee Meeting,* January 9, 2018.

Benjamín Colucci Ríos (Presenter) and Alexander Molano Santiago, Impacto del Huracán María en la infraestructura de transportación de Puerto Rico (Impact of Hurricane María in

Puerto Rico's Transportation Infrastructure), 4to Conversatorio para un Puerto Rico Resiliente. February 20, 2018

Benjamín Colucci Ríos (Presenter), Alexander Molano Santiago and Joel F. Alvarado López, El impacto del Huracán María en la infraestructura de transporte de Puerto Rico: Lecciones aprendidas (The Impact of Hurricane Maria in Puerto Rico's Transportation Infrastructure: Lessons Learned), Mega Viernes Civil 2018: Resiliencia Aplicada, College of Engineers and Surveyors of Puerto Rico, San Juan, April 6, 2018

Benjamín Colucci Ríos (Presenter), Alexander Molano Santiago, Luis Sevillano García, Launelly M. Rosado Rosa and Joel F. Alvarado López, Transportation Engineering Innovation Spearheading the Economic Development of Puerto Rico after an Extreme Natural Disaster, XXX Congress of Engineering and Surveying, COINAR 2018, San Juan, April 17, 2018.

James Prochaska, URI

Project Title: Communicating risk to motivate individual action

Journal Papers

Mundorf, N., Redding, C.A., Prochaska, J.O., Paiva, A.L., & Rubinoff, P. (2017). Resilience and Thriving in spite of Disasters: A Stages of Change Approach. In A. Fekete & Fiedrich, F. *Urban Disaster, Resilience and Security.* Berlin: Springer.

Don Resio, UNF

Project Title: The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency

Journal Papers

Resio, D.T., T.G. Asher, J.L Irish, 2017. The Effects of Natural Structure on estimated tropical cyclone surge extremes. *Nat Hazards,* **88,** 1609-1637. DOI: 10.1007/s11069-017-2935-y

Other Reports

Irish, J.L., Weiss, R. and D.T. Resio, "Physical Characteristics of Coastal Hazards and Risks", Chapter 25, Springer Handbook of Ocean Engineering, Springer Dordrecht Heidelberg London New York, M. Dhanak and N. Xiros (Eds.), 549–562.

Resio, D.T., Tumeo, M.A., and J.L. Irish, "Statistical Characterization of Hazards and Risk in Coastal Areas," Chapter 26, Springer Handbook of Ocean Engineering, Springer Dordrecht Heidelberg London New York, M. Dhanak and N. Xiros (Eds.), 567–593.

Irish, J.L., Weiss, R. and D.T. Resio," Physical Characteristics of Coastal Hazards and Risks", Chapter 25, Springer Handbook of Ocean Engineering, Springer Dordrecht Heidelberg London New York, M. Dhanak and N. Xiros (Eds.), 549 – 562.

Resio, D.T., Tumeo, M.A., and J.L. Irish, "Statistical Characterization of Hazards and Risk in Coastal Areas," Chapter 26, Springer Handbook of Ocean Engineering, Springer Dordrecht Heidelberg London New York, M. Dhanak and N. Xiros (Eds.), 567 – 593.

Gavin Smith, UNC-CH

Project Title: Expanding Coastal Resilience Education at UNC - University of North Carolina

Gavin Smith, Lea Sabbag and Ashton Rohmer. A Comparative Analysis of the Roles Governors Play in Disaster Recovery (submitted for review-Spring 2016).

Smith, Gavin, Lea Sabbag, Ashton Rohmer. Role of States in Recovery Video Training Guide. March 2016. Chapel Hill, North Carolina: Department of Homeland Security, Coastal Resilience Center of Excellence.

Smith, Gavin. March 2016. Role of States in Disaster Recovery Video. Produced by Horizon Video Productions, Durham North Carolina. (30 minutes).

William Wallace, RPI

Project Title: Community Supply Resiliency (COMSURE) (A. Wallace, RPI)

Journal Papers

Loggins, R. A., & Wallace, W. A. (2015). Rapid Assessment of Hurricane Damage and Disruption to Interdependent Civil Infrastructures Systems. *J. Infrastruct. Syst.*, doi: http://dx.doi.org/10.1061/(ASCE)IS.1943-555X.0000249.

Ni Ni, R. Little, T. Sharkey, and W. Wallace. "Modeling the Recovery of Critical Commercial Services and their Interdependencies on Civil Infrastructures." *International Journal of Critical Infrastructure Systems.* (in review).

Little, R., R. Loggins, J. Mitchell, T. Sharkey, and W. Wallace. "CLARC: An Artificial Community for Modeling the Effects of Extreme Hazard Events on Interdependent Civil and Social Infrastructure Systems." *Journal of Infrastructure Systems*. (in review).

Loggins, R., R. Little, J. Mitchell, T. Sharkey, and W. Wallace. "CRISIS: A Tool for Modeling the Restoration of Interdependent Civil and Social Infrastructure Systems Following an Extreme Event," *Natural Hazards Review.* (in review).

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Loggins, R.A., W.A. Wallace, and B. Cavdaroglu. (2013). "MUNICIPAL: A Decision Technology for the Restoration of Critical Infrastructures," in Proceedings of the 2013 Industrial and Systems Engineering Research Conference, A. Krishnamurthy and W.K.V. Chan, eds.

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Loggins, R. A. (2015). Improving the Resilience of Social Infrastructure Systems to an Extreme Event. Ph.D. Thesis. Troy, NY: Rensselaer Polytechnic Institute.

Robert Whalin, JSU

Project Title: PhD in Engineering (Coastal/Computational) at an HBCU - Jackson State University

Conference Papers

Whalin RW. HBCU Engineering Faculty and Graduates: Implications for Race, Retention and Graduation Linkages, NAAAS & Affiliates 2016 National Conference Proceedings, Baton Rouge, LA, published Oct. 2016.

Whalin RW, Pang Q, Latham J, Lowe LN. Assessment of a Summer Bridge Program: Seven Years and Counting, 2017 ASEE National Conference Proceedings, Columbus, OH, June 24-28, 2017.

Whalin RW, Brody SD, and Merrell WJ. The Galveston Bay Region as an International Test Bed for Flood Risk Reduction, 8th Texas Hurricane Conference, University of Houston, Houston, TX, August 5, 2016.

Ebersole B, Richardson TW, and Whalin RW. Modeling Coastal Storms: Past, Present and Future, 8thTexas Hurricane Conference, University of Houston, Houston, TX, August 5, 2016

Whalin, Robert, W.**;** Pagan-Trinidad, Ismael; Villanueva, Evelyn; and Pittman, David, W., "A Quarter Century of Resounding Success for a University/Federal Laboratory Partnership", ASEE 123rd Annual Conference and Exposition, New Orleans, LA, June 26, 2016.

Ebersole, Bruce; Richardson, Thomas; and Whalin, Robert, W., "Surge Suppression Achieved by Different Coastal Spine (Ike Dike) Alignments", 9th Texas Hurricane Conference, University of Houston, August 4, 2017, Houston, TX.

Other Reports

"NSF-PIRE, Coastal Flood Risk Reduction Program, Authentic Learning and Transformative Education", Volume 1-2015-2017; Edited by Baukje "Bee" Kothius, Yoonjeong Lee and Samuel Brody, March 2018.

Whalin, Robert, W.; *Trinidad, Ismael Pagan*; Villanueva, Evelyn; and Pittman, David, "A Quarter Century of Resounding Success for a University/Federal Laboratory Partnership", ASEE 123rd Annual Conference and Exposition, New Orleans, LA, June 26, 2016

Whalin, Robert, W., "HBCU Engineering Faculty and Graduates: Implications for Race, Retention and Graduation Linkages", NAAAS & Affiliates 2016 National Conference, Baton, Rouge, LA, February 2016

CRC Year 2 Publications:

Philip Berke, TAMU
Jaimie Masterson, TAMU
Project Title: **Local Planning Networks and Neighborhood Vulnerability Indicators**

Berke, P, Lee, J., Newman, G., Combs, T. Kolosna, C., Salvesen, D. 2015. Evaluation of Networks of Plans and Vulnerability to Hazards and Climate Change: A Resilience Scorecard, *Journal of the American Planning Association* 81(4): 287-302. DOI: 1080/01944363.2015.1093954

Brian Blanton, UNC-CH
Jason Fleming, Seahorse Consulting
Project Title: A multi-tiered ADCIRC-based storm surge and wave prediction system

Storm Surge Probabilities for Hurricane Events, J. Smith, B. Blanton, R. Luettich, 2017. This is a poster presented at AMS 2017 in Seattle WA (Jan 2017), DHS CRC Annual Meeting in Chapel Hill, NC (Feb 2017), and the annual Hurricane Awareness conference at East Carolina University (May 2017).

Daniel Cox, OSU
John van de Lindt, CSU
Project Title: Experimental and Numerical Study to Improve Damage and Loss Estimation Due to Overland Wave and Surge Hazards on Near-Coast Structures

Tomiczek, T., Park, H., Cox, D.T., van de Lindt, J.W., Lomonaco, P. "Experimental Modeling of Horizontal and Vertical Wave Forces on an Elevated Coastal Structure," *Coastal Engineering*, (submitted 1/2017).

Do, Trung, van de Lindt, J., Cox, D.T. (2016) "Performance-Based Design Methodology for Inundated Elevated Coastal Structures Subjected to Wave Load Engineering Structures," *Engineering Structures*, 117, 250 – 262.

William Short. *A laboratory study of horizontal and vertical regular wave forces on an elevated structure*. (2016). MS Thesis, Oregon State University.

Benjamin Hunter. *Exceedance Probabilities of Hurricane Wave Forces on Elevated Structures*. (2016). MS Thesis, Oregon State University.

Isaac Ginis, URI
Wenrui Huang, FSU
Project Title: Improving the Efficiency of Wave and Surge Models via Adaptive Mesh Resolution

Blair, A., I. Ginis, T. Hara, and E. Ulhorn, 2017: Impact of Langmuir Turbulence on Upper Ocean Response to Hurricane Edouard: Model and Observations, submitted, April 2017.

Chen, X, I. Ginis, and T. Hara, 2017: Ocean surface wave modeling under tropical cyclones: sensitivity to spatial resolutions, *Ocean modelling,* to be submitted in August 2017.

Gao, K. and I. Ginis, 2016: On the equilibrium-state roll vortices and their effect in the hurricane boundary layer. *J. Atmos. Sci.*, 1205- 1222.

Gao, K., I. Ginis, J.D. Doyle, Y. Jin, 2017: Effect of boundary layer roll vortices on the development of the axisymmetric tropical cyclone *J. Atmos. Sci.*, in press.

Fei, T., W. Huang, I. Ginis, Y. Cai, 2016. Characteristics of River Flood and Storm Surge Interactions in a Tidal River in Rhode Island, USA. Proceeding of IUTAM Symposium on Storm Surge Modelling and Forecasting, Oct 17-19, 2016, Shanghai, China

Fei, T., W. Huang, I. Ginis, Y. Cai, 2017. Hydrological modeling of storm-induced runoff and snowmelt in Taunton River Basin. Submitted for review to the journal of Natural Hazards.

Fei, T., W. Huang, I. Ginis, D. Ullman, Y. Cai, 2017. Integrated rainfall runoff and river hydrodynamic modeling for flood analysis in Woonasquatucket river basin. In preparation for submission the journal of Frontiers of Civil and Structure Engineering.

Liu, Q., L. M. Rothstein, Y. Luo, D. S. Ullman, and D. L. Codiga, 2016. Dynamics of the periphery current in Rhode Island Sound, *Ocean Modelling*, 105, 13-24.

Liu, Q., L. Rothstein, and Y. Luo, 2016. Dynamics of the Block Island Sound estuarine plume. J. Phys. Ocean., Accepted for publication.

Reichl, B. G, D. Wang, T. Hara, I. Ginis, T. Kukulka, 2016: Langmuir turbulence parameterization in tropical cyclone conditions*. J. Phys. Oceanogr.,* 46, 863-886.

Reichl, B. G., I. Ginis, T. Hara, B, Thomas, T. Kukulka, and D. Wang, 2016: Impact of sea-state dependent Langmuir turbulence of the ocean response to a tropical cyclone, *Mon. Wea. Rev*, (in press).

Rosa, K., and C. Kincaid, 2017: Modeling and observations of mixing, circulation and exchange in Narragansett Bay and Rhode Island Sound during Hurricane Floyd, manuscript in preparation for submission to J. Geophys. Res.

Rosa, K., C. Kincaid and D. Ullman. Comparing 2D and 3D ROMS models of historical and hypothetical hurricanes storm surge in Narragansett Bay, manuscript in preparation for submission to J. Geophys. Res.

Sun, Y., C. Chen, R. C. Beardsley, D. Ullman, B. Butman, and H. Lin, 2016. Surface Circulation in Block Island Sound and Adjacent Coastal and Shelf Regions: A FVCOM-CODAR comparison, *Progress in Oceanography*, 143, 26-45.

Ullman, D. S. I. Ginis, B. Thomas, X. Chen, and W. Hwang, 2017. Storm Surge/Rainfall Impacts of a Major Hurricane in Southern New England (Rhode Island), in preparation for submission to Natural Hazards.

Whitney, M. M., D. S. Ullman, and D. L. Codiga, 2016. Subtidal Exchange in Eastern Long Island Sound, *J. Phys. Oceanogr*. 46, 2351-2371.

Scott Hagen, LSU
Stephen Medeiros, UCF

Project Title: Development of an Optimized Hurricane Storm Surge - Wave Model for the Northern Gulf of Mexico for use with the ADCIRC Surge Guidance System

Tahsin, S., **S.C. Medeiros**, A. Singh, M. Hooshyar (2017), "Optical Cloud Pixel Recovery via Machine Learning", *Remote Sensing*, Accepted.

Jennifer Horney, TAMU

Project Title: Implementing the Disaster Recovery Tracking Tool

Kirsch, K., & Horney, J. (2017). Steps toward recovery: A tool for disaster recovery planning, management, and tracking. *Carolina Planning Journal, 42,* 104-109.

Horney, J., Dwyer, C., Aminto, M., Berke, P., & Smith, G. (2017). Developing indicators to measure post-disaster community recovery in the United States. *Disasters, 41,* 124-149. doi: 10.1111/disa.12190

Barry Keim, LSU

Project Title: Disaster Science and Management Program at LSU

Gilliland, J. M., and B.D. Keim. Submitted. Spatiotemporal analysis of upper-level wind speed trends of Brazil during 1980-2014. *Journal of Climate*.

Gilliland, J. M., and B.D. Keim. Submitted. Surface Wind Speed: Trend and Climatology of Brazil from 1980–2014. *International Journal of Climatology*.

Black, A.W., and G. Villarini. Submitted. Effects of Methodological Decisions on Rainfall-Related Crash Risk Estimates. *Accident Analysis and Prevention*.

Xue, G.Z., K. Sampson, W. Yu, B.D. Keim, Z. Zang, A. Dugger, D. Sathiaraj, D. Gochis, Q. Ge. Submitted. Assessing Hydroclimatic Change in Southwest Louisiana Rivers using WRF-Hydro. *Journal of Hydrology: Regional Studies*.

Black, A.W., G. Villarini, and T.L. Mote. 2017. Effects of Rainfall on Vehicle Crashes in Six U.S. States. *Weather, Climate, and Society* **9**: 53–70.

Shao, W., S. Xian, B. Keim, K. Goidel, N. Lin. 2017. Understanding Perceptions of Changing Hurricane Strength Along the U.S. Gulf Coast. *International Journal of Climatology* **37(4)**:1716-1727. DOI:10.1002/joc.4805.

Allard, J.M., J.V. Clarke, and B.D. Keim. 2016. Spatial and Temporal Patterns of In Situ Sea Surface Temperatures within the Gulf of Mexico from 1901–2010. *American Journal of Climate Change* **5**:314-343. DOI:10.4236/ajcc.2016.53025.

Shao, W., J.C. Garand, B.D. Keim, and L.C. Hamilton. 2016. Science, Scientists, and Local Weather: Understanding Mass Perceptions of Global Warming. *Social Science Quarterly* **97(5)**:1023-1057. DOI:10.1111/ssqu.12317.

Hamilton, L.C, J. Hartter, B.D. Keim, A.E. Boag, M.W. Palace, F.R. Stevens, M.J. Ducey. 2016. Wildfire, Climate and Perceptions in Northeast Oregon. *Regional Environmental* Change **16**:1819-1832. DOI:10.1007/s10113-015-0914-y.

Meherun Laiju, TC

Project Title: Institutionalization, Expansion, and Enhancement of Interdisciplinary Minor: Disaster and Coastal Studies

Ball, I & Laiju, M. (2017) Sociodemographic Characteristics and Natural Disaster Preparedness among Mississippi Residence, abstract published in *The journal of Mississippi Academy of Sciences* (ISSN 0076-9436) April edition.

Young, K, & Hunter, F. (2017) Hurricanes, Mudslides, and Drought: Considering the Publics Perceptions of the Role Governments Should Play in Providing Aid Using the NORC General Social Survey (GSS), presented at MCTC research Symposium

Hopkins, A. & Banerjee, S. (2017) Using ArcGIS to Map Natural Disasters in Mississippi presented at MCTC research symposium.

Laiju, M and Banerjee, S (2017) Innovative Interdisciplinary Curriculum in Homeland Security at a HBCU presented this at the 10th Anniversary Homeland Defense & Security Education Summit at George Mason University in Fairfax, Virginia, on March 23, 2017

James Opaluch, URI

Project Title: Overcoming barriers to motivate community action to enhance resilience

Becker, Austin, Pamela Matson, Martin Fischer, and Michael D. Mastrandrea, Forthcoming. "Towards Seaport Resilience for Climate Change Adaptation: Stakeholder Perceptions of Hurricane Impacts in Gulfport (MS) and Providence (RI)" *Progress in Planning*. Status: Accepted for Publication. Anticipated Publication Date November 2017.

Zhang, H., Ng, A., Becker, A. (In Press), "Institutional Barriers in Adaptation to Climate Change at Ports, Regions, and Supply Chains." North American Symposium on Climate Adaptation, New York, New York. Aug. 16-18, 2016. (Refereed Conference Paper)

Touzinsky, K, Rosati, J., Fox-Lent, C., Becker, A., Luscher, A., 2016. "Advancing Coastal Systems Resilience Research: Improving Quantification Tools through Community Feedback" *Shore and Beach* Vol. 84 No. 4 · November 2016.

Ismael Pagan, UPRM

Project Title: Education for Improving Resiliency of Coastal Infrastructure

Digital proceedings of Conference **"Lessons Learned and Best Practices: Resilience of Coastal Infrastructure"** , organized by the project, can be found in the link http://engineering.uprm.edu/inci/?page_id=3522

Ismael Pagán-Trinidad, Ricardo López-Rodríguez, Agustín Rullán, Oscar Perales-Pérez, John Fernández-Van Cleve, "THE ROLE OF UNIVERSITIES ON DISASTER RISK REDUCTION IN THE COMMUNITY: UPRM CASE STUDY", World Engineering

Conference on Disaster Risk Reduction, Peruvian Association of Professional Engineers, Lima Perú, December 5-6, 2016.

López-Rodríguez, Ricardo R., Pagán-Trinidad, Ismael, "Structural Vulnerability to Natural Hazards in Puerto Rico", World Engineering Conference on Disaster Risk Reduction, Peruvian Association of Professional Engineers, Lima Perú, December 5-6, 2016.

James Prochaska, URI

Project Title: Communicating risk to motivate individual action

Mundorf, N., Redding, C.A., Prochaska, J.O., Paiva,A.L., & Rubinoff, P. (2017, in press). Resilience and Thriving in spite of Disasters: A Stages of Change Approach. In A. Fekete & Fiedrich, F. *Urban Disaster, Resilience and Security.* Berlin: Springer.

Don Resio, UNF

Project Title: The Incorporation of Rainfall into Hazard Estimates for Improved Coastal Resiliency

Resio, D.T., Asher, T.G., and J.I. Irish, 2017: The effects of natural structure on estimated tropical cyclone surge extremes, J. Nat. Haz., currently available online, Nat Hazards, DOI 10.1007/s11069-017-2935-y\.

Gavin Smith, UNC-CH

Project Title: Expanding Coastal Resilience Education at UNC - University of North Carolina

Smith, Gavin. "The Role of States in Disaster Recovery: An Analysis of Engagement, Collaboration, Leadership, and Capacity Building." 2017. In *Building Community Resilience to Disasters: The Handbook of Planning for Disaster Resilience*, Routledge Press. (published)

Smith, Gavin. "Pre- and Post-Disaster Conditions, their Implications, and the Role of Planning for Housing Recovery." 2017. In *Coming Home After Disaster: Multiple Dimensions of Housing Recovery*, Eds. Ann-Margaret Esnard and Alka Sapat. Boca Raton, Florida" CRC Press. (published)

Smith, Gavin, Amanda Martin and Dennis Wenger. "Disaster Recovery in an Era of Climate Change: The Unrealized Promise of Institutional Resilience." 2017. In *Handbook of Disaster Research*, Second Edition, Eds. Havidan Rodriguez, Joseph Trainor and William Donner. New York: Springer. (accepted/submitted)

Smith, Gavin. 2016. Remembrances of the Past, Concerns for the Future, and the Potential Resilience of a Small Coastal Town, Southern Cultures. Summer: 64-87. (published)

William Wallace, RPI

Project Title: Community Supply Resiliency (COMSURE) (A. Wallace, RPI)

Little, R.G., R.A. Loggins, J.E. Mitchell, T.C. Sharkey, and W.A. Wallace. "CRISIS: Modeling the Recovery of Interdependent Social Infrastructure Systems after an Extreme Event," *Natural Hazards Review*, submitted 4/23/2017 (in review).

Robert Whalin, JSU

Project Title: PhD in Engineering (Coastal/Computational) at an HBCU - Jackson State University

Whalin RW. HBCU Engineering Faculty and Graduates: Implications for Race, Retention and Graduation Linkages, NAAAS & Affiliates 2016 National Conference Proceedings, Baton Rouge, LA, published Oct. 2016.

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