North Carolina Sea Grant Preproposal Form

Number assigned by NCSG: ________

TITLE: Identifying the drivers of chronic coastal flooding: a community-centric approach

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SEA GRANT FOCUS AREA: Resilient Communities and Economies

FEDERAL FUNDING MAXIMUM - $120,000:

A) **SEA GRANT FUNDS REQUESTED:** $120,000
B) **PROPOSED COST SHARING*:** $60,000

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STATEMENT OF PURPOSE AND RELEVANCY:

This project will address ***the problem of recurrent, shallow flooding in low-lying coastal communities***. As local sea-level rise (SLR), land subsidence, and heavy rainfall events increase, so does the frequency of flooding in low-lying coastal areas. The tidal cycle now takes place on higher average sea levels, resulting in "sunny-day" flooding of roadways during high tides. Sea water also infiltrates stormwater drainage systems at low tidal levels, such that ordinary rainstorms lead to flooding. While these minor floods draw less attention than catastrophic storms, their ***high frequency imposes a chronic stress on coastal communities and economies by disrupting critical infrastructure services***.

Information on the incidence of recurrent, minor floods is scarce because they are hyper-local – often affecting a city block or intersection at a time – and relatively brief in duration. Further, prediction of chronic flooding is hindered by a poor understanding of subterranean contributions (i.e., stormwater networks, groundwater), non-tidal hydrodynamic contributions (i.e., wind setup in estuaries, rainfall runoff, riverine discharge), and their interactions with tides and SLR. Resilient investments for adaptation response hinge on a clear understanding of the drivers of chronic coastal flooding, how these drivers may change with land use and climate, and predictive modeling capabilities. Without this knowledge, adaptation decisions by local governments could be counter-productive over long timescales. For example, local governments may invest in an expensive bulkhead that is ultimately ineffective over long-planning horizons (30 years) because it does not prevent flooding driven by rising groundwater levels and decreased stormwater capacity. This problem is particularly critical for (but not unique to) communities in North Carolina (NC), many of which are densely developed and border large, shallow estuaries.

The proposed work integrates outreach and research activities over the two-year project period ***to improve our prediction and communication of chronic flood hazards to stakeholders***. First, we will couple an existing high-resolution hydrodynamic model used for prediction of estuarine flooding in the region (SWAN+ADCIRC) with a stormwater management model (SWMM5) to hindcast and identify the drivers of unexpected flood events in Carolina Beach, a community plagued by chronic flooding. In parallel, we will co-develop potential flood-mitigation actions with Carolina Beach's Flood Working Group to inform future work using the coupled model framework. Second, we will deploy a real-time flood sensor network (in development by PIs Anarde, Hino, and Gold) in Carolina Beach to fill data gaps on the incidence and causes of chronic flooding. These data will inform an early-warning system, designed with local officials and community members, for real-time communication of flood hazard.

By focusing on a single community, we can improve understanding of the drivers of chronic flooding while also creating tools that can be used directly by decision makers to enhance coastal resilience. We have consulted with local officials in Carolina Beach, and they have agreed to participate in the project. Further, the project activities (i.e., the modeling and measurement frameworks) were developed based on their expressed need. ***Therefore, the proposed work should receive public support because local officials and community representatives will help define the research questions and products, and because the project will directly contribute to improving short-term public safety and long-term sustainable management of the coastal zone in Carolina Beach.***

More broadly, this project serves as a proof-of-concept for this approach to community-engaged research for climate change adaptation. By spearheading this approach in Carolina Beach, we will be better prepared to engage and partner with other flood-prone communities across NC and the United States to deliver the information they need to invest scarce public resources.

RATIONALE: Describe the issue, problem or opportunity to be addressed. Document the magnitude of the situation and its relevance to state, regional and national issues. Why is this project/topic innovative and important?

The threat of rising sea levels to coastal communities is severe. It has been estimated that in the United States, up to 3.6 million people occupy land at risk to overland flooding driven by SLR (Hauer et al., 2016). Not included in this estimate is the risk of flooding from below: rising sea levels are also pushing tidal water into stormwater drainage systems. In Norfolk, VA, recent instrumentation efforts have shown that SLR has reduced the city's stormwater system capacity by 50% (independent of the tide), and thus is hampering the ability of the system to handle heavy rainfalls (The Virginian Pilot, 2020). The viability of stormwater systems is also affected by rising groundwater, which has led to corrosion and failure of underground infrastructure in Hawaii and Florida, a problem that is likely to occur elsewhere. These subterranean components of flooding are not typically included in large-scale SLR driven flood risk assessments (e.g., "bathtub" inundation modeling approaches), and therefore the frequency, spatial extent, and social and economic consequences of recurrent flooding (e.g., business and school disruptions from impassable roadways; Jacobs et al., 2018, Hino et al., 2019) are likely underestimated. At a community level, questions surrounding *how* or *if* infrastructure should be built and rebuilt in response to SLR – including roadways, distribution infrastructure (stormwater, sewage, telecommunications), and flood mitigation structures – necessitate a local understanding of the current viability of stormwater networks and hydrodynamic drivers of recurrent floods.

This project will take a community-centric approach to addressing the problem of recurrent, shallow flooding in coastal NC. Through the NC King Tides program, we know that high-tide flooding is a ubiquitous problem along the entire NC coast. However, there appear to be regional differences in flood drivers. Along the Outer Banks, ocean and bay shorelines are overtopped during high tides, cutting off portions (e.g., Ocracoke) or entire communities (e.g., Rodanthe) from critical transportation networks. In Beaufort and Carolina Beach, flood waters can emanate from the storm drain during both high-tide events and sometimes unexpectedly during moderate tidal stages. For both regions, it is unclear to what extent wind setup in estuaries and riverine discharge contribute to extreme water levels, nor the capacity of local stormwater distribution networks prior to flood events. Furthermore, while local residents often know of problem areas and streets to avoid, information on the drivers, frequency, and spatial extent of these floods has not yet been gathered systematically anywhere in NC.

GOAL: Describe how the proposed work would contribute to the appropriate Sea Grant focus area(s) and related goal(s). (See North Carolina Strategic Plan – 2018-2023).

Our goals are to ***improve prediction and communication of chronic flood hazards to stakeholders***. We will ***test hypotheses about the drivers of recurrent, shallow floods in coastal NC*** by hindcasting flood events and collecting in-situ data in a single community, Carolina Beach. In response to the expressed need from local officials, we will also use the in-situ data to ***develop an early-warning system*** and ***engage community members to co-develop*** flood-mitigation design scenarios for future testing using the new model framework.

This proposed work will contribute to all three goals of the NC Sea Grant focus area of *Resilient Communities and Economies*. We will address Goal 1 of the focus area by providing a community (Carolina Beach) with "decision support tools that reflect their needs and priorities". By increasing understanding of the drivers of coastal flooding – both immediately (by hindcasting and measuring chronic flood events) and in the future (by developing a framework for long-term data collection and modeling of stakeholder-defined adaptation scenarios) – this project will help Carolina Beach be "better prepared to plan and implement adaptation strategies to increase resilience" (Goal 2) and "effectively prepare for, respond to, and adapt to the current and anticipated risks" associated with SLR and climate change (Goal 3).

OBJECTIVES: Number and list the objectives of the project. State objectives in a way that enables measurable comparison to expected project results.

The objectives that will be achieved in this project include:

1. ***Develop a model for hindcasting chronic flood events (at least 2 unexpected, 2 expected) in Carolina Beach.*** We will couple an existing hydrodynamic model (SWAN+ADCIRC) with a stormwater model (SWMM5) to consider multiple drivers of flooding.
2. ***Deploy a real-time flood sensor network (at least 10 sensor stations) that captures flooding both by overtopping and through stormwater networks.*** The flood sensor network will provide real-time data on the presence and depth of water (using pressure sensors and cameras) in flood-prone areas and is currently in development by the PIs.
3. ***Establish an operational early-warning system for street flooding.*** The early-warning system will display real-time data from the flood sensor network in a user-friendly web interface and notify public officials at their determined action thresholds (e.g., at a "warning" level and a "road closure" level).
4. ***Define at least 3 potential flood mitigation strategies in collaboration with local stakeholders.*** The scenarios will be informed by modeling results and tested as future work using the validated model.

RESEARCH APPROACH: Describe the project design and explain how the work will accomplish the stated objectives.

This project consists of two research tasks: measurement and modeling of chronic flooding. Model development and experiments will span Years 1 and 2 (Leads: PI Anarde and Dietrich); sensor deployment will occur in Year 1 and we anticipate will be maintained beyond the 2-year scope of this project (Leads: PI Hino and Gold). This research will be conducted to test the hypothesis that coastal flooding in Carolina Beach is driven by a combination of tides, wind, rain, waves, river discharge, and stormwater network viability.

The modeling will be done in two stages. First, we will refine an existing high resolution hydrodynamic model, SWAN+ADCIRC – a model commonly used for simulation of coastal, estuarine, and riverine flooding – to obtain downstream boundary conditions (i.e., the total water level) at the stormwater network outfalls and to identify overtopping of back-bay shorelines. The SWAN+ADCIRC outputs will then force a hydrologic model, the Environmental Protection Agency's Storm Water Management Model (SWMM5), that is representative of the stormwater system at Carolina Beach. The coupled model will be used to hindcast at least four flood events: two unexpected (i.e., influenced by non-tidal contributions to the total water level) and two expected events (i.e., predominantly tidal contributions). Modeled flood extent and depths will be compared to observations from Carolina Beach's recently installed tide gauge and meteorological station, and records of street flooding and closure provided by local officials. Once available, model simulations will be validated using data from the flood sensor network installed as part of this project (Objective 2).

To provide the highest resolution for model coupling, an existing SWAN+ADCIRC grid developed by PI Dietrich will be refined to provide 10-20 m resolution in the Intracoastal

Waterway, back-barrier estuary, and Town of Carolina Beach. Atmospheric data to force SWAN+ADCIRC will come from the National Oceanic and Atmospheric Administration's North American Mesoscale Forecast System. River discharge from the Cape Fear River will be applied as an upstream boundary condition within SWAN+ADCIRC using USGS gauge data.

Carolina Beach does not have an existing stormwater model. Therefore, the bulk of model development in this project will surround the SWMM5 model. Given the large size of Carolina Beach, we will only model the stormwater system (catch basins, pipes, channels, outfalls, junctions) along the barrier segment that borders Canal Drive and the back-barrier estuary (~2 km in length). We will build on a detailed inventory of stormwater, bulkhead infrastructure, and watershed parameters conducted by the town in 2019 to build the model. Curve numbers will be used for rainfall runoff modeling and will be derived based on satellite imagery (Mullick et al., 2019). Rainfall, evaporation, temperature, and humidity will come from Carolina Beach's meteorological station.

The flood sensor network will be a replica of a system currently in development by PIs Anarde, Hino, and Gold, which is being tested in Beaufort, NC. Each sensor consists of a low-cost IoT pressure transducer (PT) mounted within a storm drain for measurement of inundation depth and stormwater network viability. The PT transmits data to a remote server in real-time over WiFi via a gateway mounted to the nearest telephone pole. This gateway also contains a Raspberry Pi camera for visual tracking of flood extent. At least 10 PTs will be deployed within storm drains, with additional sensors placed along bay shorelines in areas that are frequently overtopped. By instrumenting stormwater infrastructure, this novel approach enables us to capture flood events of all sources and to measure the extent to which drainage is impaired by rising sea levels. In contrast, traditional instrumentation that measures ocean or stream water levels may not detect floods that occur when drainage infrastructure is overwhelmed by rainfall – and thus, any predictive models built on such sensors will also miss those events.

This project also consists of two outreach tasks: development of an early flood warning system and co-production of flood mitigation scenarios for future modeling. In Year 1, we will design the user interface for the early-warning system with local officials (Planning Director, Town Manager, and Director of Public Works), whom we have consulted with and have agreed to participate in the project. With their guidance, we will determine how to prioritize the different data streams to be shown on the web interface (e.g., camera imagery, water depth in storm drains, tide and meteorological predictions), the action thresholds for triggering notifications to officials (e.g., at a "warning" level and a "road closure" level), and how early to notify them. Concurrently, we will connect with community representatives in the town's Flood Working Group to identify flood-mitigation scenarios that are deemed desirable. To date, the working group has been focused on flood management by increasing bulkhead elevations – a strategy that may be ineffective over long-time scales because it does not prevent flooding driven by decreased stormwater capacity and groundwater – so this engagement process will explore a larger range of strategies, such as wetland restoration or raising the elevation of distribution infrastructure (a potential adaptation strategy identified through preliminary engagement with local officials).

In Year 2 we will launch the website and early-warning system. The website design and components of the early-warning system will be refined throughout the duration of the project based on user needs and input (sourced from online comments, the Flood Working Group, and local officials). We also plan to align efforts with the NC King Tides Project so that public reporting of flooding is incorporated directly into the website. These crowd-sourced reports will help us refine and validate our modeling efforts by providing additional data on flood incidence.

EXPECTED RESULTS AND BENEFITS: Describe the expected outcomes of the project. What new solutions and/or opportunities will be available to industry and/or management agencies? What impact will successful completion of this project have on North Carolina, the region and/or the nation?

The results of the project will directly contribute to short-term public safety and long-term sustainable management of the coastal zone in Carolina Beach. The early-warning system will provide town staff with more accurate and earlier information about when road closure and emergency management measures are needed. The real-time web interface will increase flood risk awareness and engagement within the community. The coupled model framework will serve as a new decision-support tool for Carolina Beach to test the viability of a wide range of adaptation decisions. Through co-development of mitigation strategies, we will ensure that future modeling efforts inform stakeholder priorities and that their chosen adaptation strategies are effective against multiple drivers of flooding, even as the climate changes.

More broadly, the research will provide new insight on the frequency and drivers of coastal flooding, which is becoming increasingly disruptive across NC and the East Coast. By providing high-resolution data on flood frequency, this project will also support ongoing efforts by PI Anarde and Hino to analyze the impacts of chronic flooding on household risk perception, finances, and mental and physical health. This project also serves as a proof-of-concept for this approach to community-engaged research for climate change adaptation. By spearheading this approach in Carolina Beach, we will be better prepared to partner with other coastal communities to deliver the information they need to invest scarce public resources.

In the long-term, this project will support interdisciplinary research that tests hypotheses related to how chronic flood drivers evolve with climate change and the long-term ecological and economic consequences of traditional management strategies for bay-side flooding (e.g., bulkhead retrofits). By supporting this multi-campus effort, the project enables us to integrate our expertise in engineering, urban planning, and ecology to ultimately tackle questions critical to the future of the NC coast. It also provides the opportunity to train a graduate student in this interdisciplinary environment, which we are eager to continue doing in the future.

ANTICIPATED INFORMATION TRANSFER: Describe how results will be communicated to the relevant audience(s) to deliver the anticipated impacts of the proposed research.

Communication and information sharing are central to the goals of this project. By incorporating stakeholder input in the design of two key deliverables of this project, the early-warning system and the online data interface, we will improve scientific communication of the incidence, frequency, and multiple drivers of chronic flood hazards to local officials and the broader community. The results of model hindcasts will be presented to the town's Flood Working Group in Year 2. Thereafter, the project will conclude with a final listening session to refine flood-mitigation scenarios (for future modeling) that are deemed desirable to local stakeholders in light of project findings.

All of the research products – the data repository, stormwater model, publications, and any additional information gathered on infrastructure – will be provided to the town for their use. The PIs will work with the town officials to explore follow-on funding to maintain the sensor network and website beyond the timeline of this project, so we can continue to exchange information with the town as we collect more data and better diagnose the drivers of the flooding they face.