ADAPTIVE MANAGEMENT FOR SEA LEVEL RISE AT UGA'S SKIDAWAY ISLAND CAMPUS

by

SARAH HUTCHINSON

(Under the Direction of Jon Calabria)

ABSTRACT

Coastal campuses like UGA's Skidaway Island campus, home to the Skidaway Institute of Oceanography and UGA Marine Extension and Georgia Sea Grant, are faced with a conundrum: needing to stay in place to continue in-situ research and education while their infrastructure is vulnerable to the impacts of sea level rise, from higher tides and storm surges to upland migration of salt marshes. This thesis analyzes functions on the Skidaway campus in light of these issues, discussing the applicability of an adaptive management approach for managing in the face of uncertainty, and suggests management actions to create functional resilience in a three-phased approach. A campus-specific SLAMM model was generated to visualize marsh migration at one-foot sea level rise increments up to six feet if no actions were taken. A second SLAMM model is based off an edited elevation model to show marsh migration if suggested nature-based management actions were implemented.

INDEX WORDS: sea level rise, coastal resilience, adaptive management, landscape architecture, SLAMM

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by

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BS, Cornell University, 2014

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF LANDSCAPE ARCHITECTURE

ATHENS, GEORGIA

2020

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August 2020

DEDICATION

This work is dedicated to the Georgia coast, including the extraordinarily beautiful, unique ecosystems and kind, friendly human communities that it hosts. I am so grateful to have spent two years of life there, and hope that I can give back in some small way through this work. More specifically, I want to dedicate this thesis to the Skidaway Institute of Oceanography, and UGA Marine Extension and Sea Grant. Your service is vital to understanding this world, communicating that knowledge widely, and encouraging people to understand and respect the natural communities of the coast.

ACKNOWLEDGEMENTS

I extend sincere gratitude to everyone who has helped me throughout the challenging process of graduate school. I would first like to thank my committee for their help and guidance along the way. The UGA Campus Sustainability Grant helped support my work and enabled this research to go further, thanks to the modeling work by Dr. Roderick Lammers in the UGA College of Engineering. Other UGA associates have also been incredibly generous with their time—conversations with Dr. Mark Risse, Jill Gambill, and Anne Lindsay with MAREX; Chuck Hartman and Wayne Aaron with SKIO; Elliot Lam with GRNMS; and CED Professor Brian Orland have provided valuable guidance. CED Associate Professor Alison Smith and Mike Robinson with SKIO provided crucial GIS support. The support of my family and friends, near and far away, has been instrumental. I would especially like to acknowledge two of my friends and colleagues, Saadia Rais and Katharine Bugbee, for their undying moral support and Katharine's coastal expertise.

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CHAPTER 1

INTRODUCTION

Sea level rise poses a major threat to thousands of communities worldwide. Higher tides are observed each year due to the melting of polar ice caps combined with land subsidence and expansion of water due to a warming climate (Church and White 2011). While sea level has been rising steadily for over 10,000 years due to climate warming after the last ice age, the past 4,000 years have been fairly stable until the effects of anthropogenic global warming began increasing rates over the past century (Sweet and Park 2014, Kemp et al. 2011). During this time, global mean sea levels have risen approximately 1.7 millimeters per year, with higher rates of 3.2 millimeters per year in the past few decades (Church and White 2011).

Consequences reach beyond the obvious concerns of flooding and damage caused by storms (Field et al. 2012). The gradual process of sea level rise (SLR) threatens communities with more frequent and longer-lasting high tide flooding, saltwater intrusion into aquifers, coastal erosion, and landward migration of coastal wetlands. These effects have serious physical, financial, and social impacts. Many municipal and regional policymakers have developed adaptation or resilience plans that may include protection or restoration of native ecosystems, structural measures like seawalls and breakwaters, and nonstructural interventions (e.g. floodplain building policies, education programs, evacuation plans) (Bridges et al. 2013).

Though few municipalities on the coast of Georgia have planned to adapt to these consequences, they are vulnerable. The National Oceanic and Atmospheric Administration

(NOAA) provides a wide range of scenarios for the change in relative mean sea level since 2000, ranging from 1.54 to 10.73 feet by the end of the century (Figure 1).

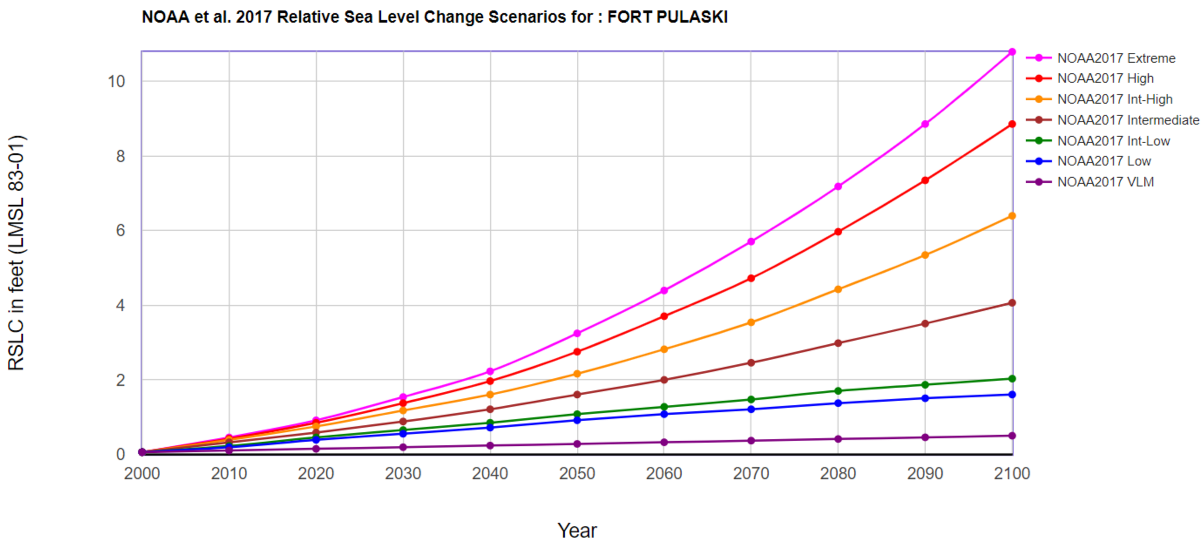

Figure 1: Change scenarios for relative lower mean sea level (low tide) at ten-year increments between 2000 and 2100, for the Fort Pulaski tide gage. Values are expressed in feet, and account for local vertical land migration (VLM) of 0.00440 feet per year (Sea-Level Change Curve Calculator (Version 2019.21), NOAA and USACE, 2019.).

Between 2000 and 2019, the relative mean lower low water level (MLLW) at the Ft. Pulaski tide gage has risen about 0.5 feet (NOAA Tides and Currents 2020). This change falls between NOAA's "intermediate low" and "intermediate" SLR scenario projections Most projections show that an acceleration will begin around 2030. In the United States, high tide flooding frequency is increasing at the highest overall rate on the Southeast Atlantic coast (Sweet et al. 2018).

On a smaller scale, oceanographic research and educational campuses face a unique conundrum as coastal community members. While researchers and educators require facilities on the coast due to their field of study, SLR challenges these facilities. Campuses throughout the Southeast are taking various actions to adapt—some are moving to higher ground, some are elevating buildings, and others are taking action with smaller, site-scale interventions (Wendland 2018, Virginia Institute of Marine Science 2020, Coastal Studies Institute 2016, Duke University 2020). Currently there are no published, holistic SLR adaptation plans developed specifically for coastal oceanographic institutions. This may be due to their smaller scale as compared with regional and municipal plans.

Site

The Skidaway Institute of Oceanography (SKIO) and the Georgia Sea Grant and Marine Extension (MAREX), units of the University of Georgia, are vulnerable due to their location on

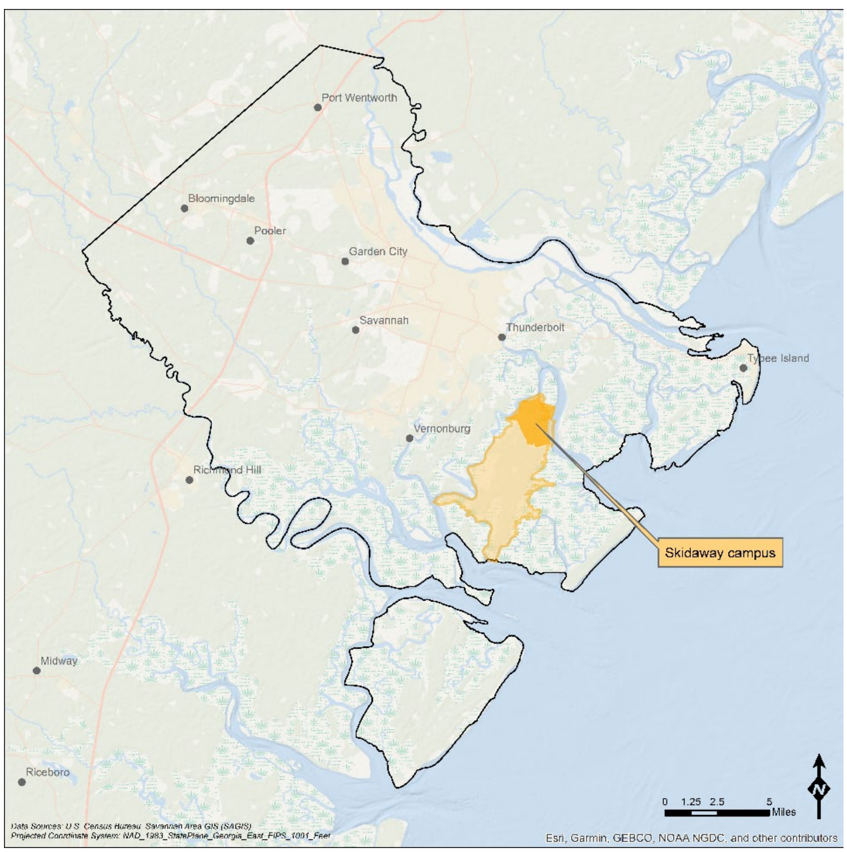

Figure 2: Context map showing location of Skidaway campus parcel (dark orange) within Skidaway Island (light orange).

Skidaway Island, a Pleistocene back-barrier island located just east of Savannah, Georgia (Figure 2).

SKIO is in charge of the whole 785 acres of university land, sharing parts of the parcel with MAREX, a small Georgia Southern University field station, and the administrative offices for NOAA's Gray's Reef National Marine Sanctuary (GRNMS). SKIO utilizes historic buildings from a renowned cattle farm as some campus facilities, although many of its buildings are new. Although everyone mentioned above is an invested stakeholder, SKIO maintains basic infrastructure on the entire parcel and MAREX maintains its own core campus area of about five acres.

The campus functions as a hub of coastal research and education, with public outreach functions as well. SKIO and MAREX both generate important theoretical and practical research. At SKIO, researchers and college students—both undergraduate and graduate—use the campus to learn and generate scientific advances in biological, chemical, geological, and physical oceanography. The MAREX research team focuses on generating knowledge with direct applications to fisheries and aquaculture for the purpose of coastal economic development. The Marine Education Center & Aquarium interprets and communicates the research occurring at SKIO and MAREX, conveying environmental awareness about Georgia's unique coastal ecosystems through hands-on programs for K-12 students and the public.

As units of a major research university, SKIO and MAREX can set a positive precedent for other campuses. In order to continue functioning despite future challenges, the campus must protect and adapt its valuable assets, from docks and research vessels to expensive scientific equipment and a public aquarium. Since SKIO and MAREX are the most prominent entities on the campus, the thesis will focus on the preservation of their functions.

Thanks to the support of UGA's Campus Sustainability Grant, the development of adaptation recommendations in this thesis can address an important goal specified in UGA's 2020 Strategic Plan: responding to one of the most pressing climate change-related issues in Georgia (UGA Strategic Planning Committee 2012). UGA can sustain its positive influence on the coast by integrating resilience planning into the landscape.

Purpose

This thesis will review SLR-related issues and solutions, then analyze the functions of the Skidaway campus to develop recommendations that can help stakeholders create a long-term, phased, strategic adaptation plan using the principles of Adaptive Management (AM). The focus is building resilience for campus functionality, acknowledging that working with a changing environment prone to disasters guarantees unexpected challenges around every turn.

Part of AM is the implementation of models and metrics to help stakeholders evaluate the performance of prior actions and make better decisions for the future (Zedler 2017). One of the most powerful models that planners have used in recent years is the Sea Level Affecting Marshes Model, or SLAMM (Park, Armentano, Cloonan 1986). A UGA Campus Sustainability Grant enabled collaboration with the College of Engineering to create two site-scale SLAMMs. One depicts how the marsh may migrate upland if nothing was done to accommodate SLR, while the other shows how it might migrate if recommended adaptative measures detailed in Chapter 5—including tidal creek restoration and living shoreline in place of the bulkhead—were implemented.

This thesis addresses the following general questions:

- How is sea level rise—past, present, and future—affecting the Skidaway campus' ability to fulfill its functions?
- What actions could stakeholders implement to build resilience of campus functions by defending, adapting, and retreating in response to SLR?

<u>Methods</u>

A mixed method approach addresses several research questions. Methods included semistructured interviews, exploratory analysis, modeling and forecasting.

The semi structured interviews with stakeholders established programmatic functions and future direction, drawing from the semi-structured interview technique used in the social sciences (Gordon 1975). The conversations helped define the scope of campus functions, gather information about SLR-related issues on campus, and vet ideas for potential solutions. Limitations included the number of individuals willing or able to engage, and individuals' availability.

Some of the most helpful conversations took place on campus and during walking tours. In addition to class field trips and assistantship work, the Campus Sustainability Grant enabled travel to the campus for this thesis project. A total of five site visits were made between August 2018 and February 2020, one of which involved a three-night stay in the student housing area. Site visits enabled the author to familiarize herself with the setting, experiencing campus functions from an inside perspective. The amount of on-site experience was somewhat limited by time, because unrelated, off-site fieldwork was required during these trips.

A literature review was conducted to learn more about the general effects of SLR on coastal human populations and ecosystems. After learning about the effects, techniques that municipalities use for mitigating damage and adapting to new conditions were researched.

Adaptation involves both physical and non-physical features. The gradient of shoreline stabilization techniques, from natural to heavily engineered, is discussed as physical adaptation. Policies and planning in coastal Georgia, and Chatham County in particular, are discussed as non-physical interventions, to contextualize the site. AM literature was also reviewed, to investigate the method and its applicability to the Skidaway campus. Stemming from the necessity for modelling in AM, quantitative coastal models were reviewed to make recommendations.

The site was analyzed using information from conversations with stakeholders and other experts, on-site experience, and further reading about the site's history. Schematic diagramming and a cognitive map modelling software enabled the analysis.

A SLAMM model was created to visualize marsh migration at one-foot sea level rise increments up to six feet if no actions were taken. Six feet was the chosen endpoint because it is a common planning horizon for the end of the century (Dr. Clark Alexander, thesis defense discussion, June 30, 2020). A second SLAMM model was created, based on a version of the elevation model that was edited by the author, to show marsh migration if suggested nature-based adaptation strategies were implemented. The modeling, conducted by the College of Engineering, helped inform recommendations for adaptation strategies.

A delimitation in this part of the research was restricting the extent of changes to the edited elevation model because time was a limiting factor. And, as with all GIS models, data quality and extent were limitations. In this case, the resolution of the elevation model was finer than that of the plant community data, which was finer than that of the wetland classification data. All of these data were combined when creating the SLAMM model, which is standard practice, but the inherent limitation should be noted.

Another limitation was the amount of time that modelers could allocate to the model. Miscommunications occurred within that limited time frame which affected the validity of results. Disruptions to the planned timeline were caused largely by the switch to remote work because of UGA's COVID-19 pandemic response.

Ideas for adaptation strategies were generated using information from all of the above information. Six feet of SLR served as a delimitation for phased planning ideas. Another delimitation was that the three phases of suggestions presented are not meant to form a prescribed plan. The values that would inform an AM plan must be defined by stakeholders. Lastly, the thesis exhibits some bias against saving historic structures due to a focus on functions rather than individual infrastructure elements. The lack of complete consideration surrounding the importance of historic infrastructure is a delimitation.

Overview

Chapter 2 of the thesis introduces the SLR-induced challenges faced by coastal communities and discusses some solutions. Challenges come in the form of various "slow-moving emergencies"—issues that slowly creep up and increase in magnitude—and "fast-moving emergencies"—disasters that strike quickly, like coastal storms (Phillips, Neal, and Webb 2016). Next, the chapter reviews the topic of coastal resilience, examining the ideas behind plans that municipalities have prepared. Because the Skidaway campus land is governed by Chatham County, the county's efforts toward adaptation are reviewed.

Chapter 3 details the site and its functions. This includes an environmental history; functions of SKIO, MAREX, and other campus entities; and descriptions of the infrastructure and how it supports campus function.

Chapter 4 is a discussion of management. It first introduces AM and explains the reasoning behind why it is proposed. Then, interconnections between infrastructure on campus are analyzed. This helps recommend guiding principles for management.

Chapter 5 presents potential models for stakeholders to use, discusses methods and results for a SLAMM that was prepared for the campus, and finally presents suggestions for three phases of management actions informed by the research presented thus far, using two-foot SLR increments as endpoints.

Chapter 6 concludes the thesis, presenting the most immediate needs for action on campus and suggesting future monitoring research.

CHAPTER 2

LITERATURE REVIEW

The literature review describes gradual and immediate effects of SLR on coastal settlements, and then reviews approaches to adapting to LITthese effects. Adaptive measures typically address natural, structural, and non-structural features, so the review covers all three (Bridges et al. 2013). Natural and structural features are discussed as shoreline stabilization options, and non-structural features are discussed in terms of Chatham County's adaptation plans, which also contextualizes the campus.

In emergency management literature, disasters are classified as slow- or fast-moving. A fast-moving disaster is easy to pinpoint—a sudden event that quickly strikes a population, like a hurricane or tornado. Events known as slow-moving disasters develop over long periods of time as a result of changing long-term patterns, environmental and/or anthropogenic. In these cases, it can be hard to tell when the event has crossed the imaginary threshold that warrants calling it a disaster (Phillips, Neal, and Webb 2016). SLR, though accelerating in pace, is a gradual process. It goes unnoticed on a daily basis, but gradual changes are accumulating which cannot be ignored. There are also fast-moving disasters, namely coastal storms, whose increased impacts are also associated with SLR.

Slow-Moving Disasters

Marsh Migration & Degradation

One of the most important ecosystems along the East Coast is the common salt marsh dominated by *Spartina alterniflora*. The marsh forms a buffer between inland areas and tidal waters, typically occurring behind barrier islands or at the mouths of tidal rivers (Tiner 1993). It provides vital habitat, filters out pollutants from runoff, and buffers wave energy to provide erosion control and protection during storms (Borchert et al. 2018). It also lends a unique and iconic type of natural beauty to the coast.

Within the salt marsh ecosystem, there are two primary vegetation zones: low marsh and high marsh. The low marsh is flooded daily due to the tides, as it sits at a lower elevation. Very few plant species other than *S. alterniflora* can survive in these high salinity levels, so there is low floristic diversity. The high marsh is flooded irregularly, so it can support a wider range of species like salt grass, salt meadow cordgrass, black needlerush, and glassworts. As the high marsh transitions to upland, the edge supports a wide variety of woody plants and shrubs such as wax myrtle, palmetto, Eastern red cedar, and groundsel tree. (Tiner 1993)

Marshes maintain their elevation relative to sea level through accumulation of mineral and organic matter (Schile et al. 2014). If lacking adequate sediment supply, the lowest areas of marsh are drowned as sea level rises, so the marsh gradually migrates upland, outcompeting the coastal forests that border it inland. There are certain barriers to the seemingly inevitable process of marsh migration, caused by the consequences of anthropogenic climate change as well as direct human actions.

Landholders, both public and private, with marsh-front property are loath to lose upland acreage to encroaching wetlands. Hardening tactics like bulkheads and revetments are used to maintain the current shoreline and protect property (EPA 1995). Salt marsh existing seaward of these hardened shores faces an insurmountable obstacle in keeping pace with the rising sea. This phenomenon is known as "coastal squeeze" (Borchert et al. 2018).

Due to the advent of Geospatial Information Systems (GIS), it is now possible to predict—with varying degrees of accuracy—the position, rate, and species composition that marshes exhibit as they move upland. One model, called Sea Level Affecting Marshes Model (SLAMM), will be discussed in greater depth in Chapter 4.

More generalized climate change-related processes also pose threats to the marsh. Rising temperatures and more frequent droughts can negatively affect salt marshes. For instance, a drought during the summer of 2002 suddenly killed almost 1,000 acres of Georgia salt marsh due to lack of freshwater supply and resulting over-salinization, heat stress, and altered soil pH. The altered pH caused uptake of toxic metals in the soil and reduced the ability of vegetation to take in freshwater from upstream (Seabrook 2013).

Nutrient enrichment has presented itself as a driver of salt marsh loss in recent years as well. When soils are oversaturated with agricultural nutrients, particularly nitrogen, these compounds are washed into rivers and down to the ocean. While nutrient enrichment at today's high rates increases above-ground leaf biomass in marshes, it decreases below-ground biomass of roots and increases microbial decomposition of organic matter. These alterations lead to reduced soil stability, causing creek bank collapse and conversion to unvegetated mud (Deegan et al. 2012). This has negative implications for marshes' resilience to hurricane damage (Mo, Kearney, and Turner 2020).

While the coast of Georgia is expected to see an overall increase in freshwater availability, areas further north are expected to lose up to 5% of their current water supply due to a warming, drying climate (EPA 2017). These areas include the Savannah River watershed, which supplies fresh water to marshes on Skidaway Island and surrounding areas. The supply of fresh water from these rivers is vital to marsh health.

Ghost Forests

Because marsh plant species tolerate higher salinity levels than those growing in the adjacent upland coastal forests, their upland migration comes at the expense of the forests. At rates that vary by species, vegetation slowly dies off when roots are inundated with saltwater (Taillie et al. 2019). Coastal forests gradually become stands of bleached trunks known as "ghost forests"—foreboding specters of the lush greenery that recently stood (Velasquez-Manoff 2019). Climate change and resulting SLR are generating more impactful and frequent storms, which can exacerbate the problem. Storm surges pushes large amounts of saltwater into the forests, which can kill trees as it slowly drains back into the groundwater through the soil. However, the interactions are complex, because soils that are already saturated by precipitation (another feature of storms) are less likely to absorb this over-wash (Taillie et al. 2019).

On the other hand, upland drought has major impacts on the survival of coastal forest as well. When freshwater inflow from rivers decreases, nearshore waters increase in salinity irregularly. The saltier waters move inland, killing trees in a similarly irregular pattern. (Velasquez-Manoff 2019)

Historically, most maritime forests and adjacent marshes of coastal Georgia experienced frequent understory fires in spring or fall (Frost and Johnson 2005). Today, people suppress fire, which leads to an accumulation of fuel. Especially combined with droughts, wildfires can severely damage maritime forests (Taillie et al. 2019). In recent years, some coastal forests have failed to recover after fire because the increased soil salinity prevents seed germination, decreases survival of tender young seedlings, and favors the establishment of salt-tolerant species. Instead, the land regenerates to salt marsh (Taillie et al. 2019, Velasquez-Manoff 2019).

Tree species differ in their salinity tolerances (Taillie et al. 2019). Hardwoods like live oak (*Quercus virginiana*) and many of the other Georgia native maritime forest species are most sensitive to salinity, making them the first to die off. Loblolly pine (*Pinus taeda*), a softer wood, is more salt tolerant than the hardwoods (Velasquez-Manoff 2019).

Nuisance Flooding

Minor coastal flooding—also known as "nuisance flooding," "high tide flooding," or "sunny day flooding"—refers to the temporary inundation of low-lying areas due to natural tidal fluctuations. It is increasing in frequency and severity due to SLR (Sweet and Park 2014). Twice a month, high tide increases during "spring tides," which occur during full and new moon phases. Strong onshore winds can also raise tidal heights, especially if they coincide with a spring tide. Annual "king tides" are the highest spring tides that occur each year (Evans et al. 2016).

While these minor flood events do not instantly devastate like major flooding caused by storm events, they present other hazards and cause long-term consequences. Frequent inundation with saltwater is detrimental to the health of upland vegetation. Flooding raises the groundwater table, so it can compromise belowground infrastructure (Sweet et al. 2018). Slowly weakening infrastructure and financial strain caused by nuisance flooding can deplete the resources needed to respond to fast-moving emergencies with more immediate consequences. It is quite possible that these "...diffuse, low-cost incidents will aggregate over time into extremely high-cost outcomes," especially as they become more frequent (Moftakhari et al. 2017).

In the United States, high tide flooding frequency is increasing at the highest overall rate on the Southeast Atlantic coast (Sweet et al. 2018). Relative to the Skidaway campus, the closest NOAA tide gage, the official collection point for tidal and weather data, is located approximately nine miles northeast at Fort Pulaski. All local data referenced henceforth comes from that station. The gage shows a typical daily tide range of 7.5 feet. In coastal Georgia, minor "nuisance" flooding begins at 1.7 feet above the normal 7.5-foot MHHW level, or 9.2 feet above MLLW level (National Weather Service 2020). It is more likely to occur during the fall, when the annual sea level cycle has reached its maximum (Sweet et al. 2018).

The Fort Pulaski tide gage record indicates a steady increase in nuisance flood events over the past several decades (Figure 3). For instance, 23 separate events were recorded in 2015 alone, which is the most of any year within the 80-year data record (Evans et al. 2016). The worst high tide flooding documented on the Skidaway campus occurred during a king tide on

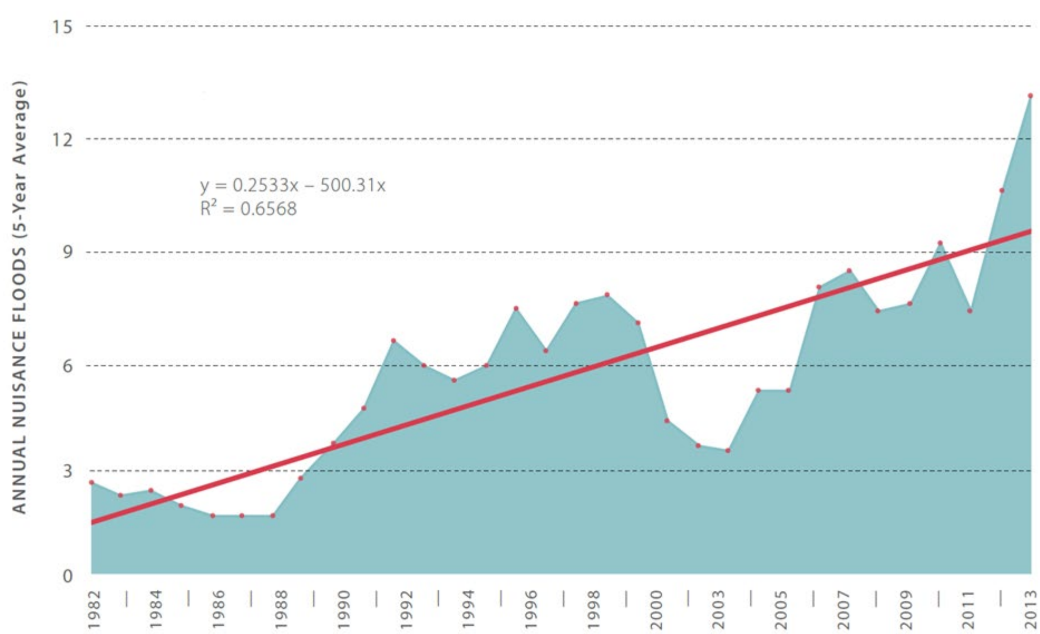

Figure 3: Five-year averages of annual local nuisance flood events show upward trend. Data from NOAA Fort Pulaski tide gage. Adapted from Evans, Gambill, et al. 2016.

October 27, 2015, impeding access to the Main Dock and other low-lying areas for extended periods of time (Dr. Clark Alexander, on-site meeting, December 13, 2019). Clearly, high-tide flooding can present more than just a "nuisance."

Erosion

Coastal erosion is defined in terms of "the movement of shore contours," caused by chronic SLR and/or consequent removal of geologic materials that compose the shoreline. Although barrier islands like Skidaway are natural buffers, erosion rates are increasing in response to SLR because new portions of the shoreline are exposed to wave and current action. (National Research Council 2007, 37)

Loss of land due to shoreline erosion becomes a problem when there is no space upland to accommodate the occurring changes (Rangel-Buitrago, de Jonge, and Neal 2018). As with marsh migration, landholders typically resist conceding their limited parcels of land as sea level rises, so they implement protective measures to prevent the shoreline from creeping upland. Bulkheads like the one on the Skidaway campus are among the most common purported solutions.

In the long term, bulkheads can end up exacerbating the problem (Polk and Eulie 2018). Heightened tides inevitably overtop walls, allowing waves to scour around them, pulling sediment back out to leave water and collapsing soil behind (Hesselgrave 2019). Also, bulkheads reflect almost all of the wave energy that strikes them, leading to sediment scour from the bottom of the structure, which deepens the area and degrades benthic habitat (National Research Council 2007, Palinkas, Sanford, and Koch 2018). On a larger scale, bulkhead armoring permanently withholds sediment from the littoral transport system that should be nourishing downstream shorelines (National Research Council 2007).

Saltwater Intrusion

Rising sea levels coupled with large human populations in coastal areas threaten the availability of fresh water in aquifers. Withdrawal of groundwater for human use depletes the aquifers, sometimes at rates greater than those of recharge. Most of the freshwater supply in the Savannah area is extracted from the Upper Floridan aquifer, which is located underneath at least one confining unit, or aquitard, that separates it from the surficial aquifer just below the earth's surface.

When freshwater extraction from the Upper Floridan aquifer began in the late 1800s to supply water for a growing population, a cone of depression developed on the aquifer's potentiometric surface—the water table has lowered in this area, and continues to lower as more water is extracted for the growing population. Because the aquitard is thin or absent in several areas within the cone of depression, seawater could leak downward through the seabed and into the aquifer (Foyle, Henry, and Alexander 2002). Saltwater contamination of freshwater wells has already been documented in Brunswick, Georgia, and Hilton Head, South Carolina (Krause and Clarke 2001). As sea level rises, saltwater zones in coastal aquifers will be pushed landward and upward, which could "accelerate rates of saltwater intrusion into aquifers already experiencing saltwater contamination" (Barlow 2003).

On Skidaway Island, an unconfined, surficial aquifer about 75 feet deep sits atop an aquitard separating it from a thin layer of the Upper Brunswick aquifer. The Upper Floridan aquifer is located under the next aquitard beneath it. Like the rest of the Savannah area, SKIO's campus wells draw from the Upper Floridan aquifer (John S. Clarke 1999).

Fast-Moving Disasters

Climate change is undeniably altering the "intensity, spatial extent, duration, and timing" of extreme weather events (Field et al. 2012). On the Southeastern coast, the most common disruptive events are hurricanes and tropical storms (Marcy et al. 2012). These coastal storms can be devastating to infrastructure on their own, and also accelerate the effects of the previously mentioned "slow-moving" emergencies. The most damaging aspect of any storm is the storm surge (NOAA 2020). Wind damage can also be a problem, depending on location.

Storm Surge & Storm Tide

Storm surge is a "non-tidal addition to the predicted tide level," caused by the winds and low pressure associated with an atmospheric front that is caused by a storm (Marcy et al. 2012). Because of the weight of water, infrastructure that is not specifically designed to withstand such forces may be damaged or destroyed upon impact. Storm surge is also responsible for flooding/saltwater inundation and acute erosion (NOAA 2020). It produces all the same effects of nuisance flooding mentioned in the previous section, but more strongly. Both storm surge and storm tide are difficult to predict because they are so sensitive to minor changes in wind, pressure, speed, and size of the storm—the shape and position of the land area can affect it as well (NOAA 2020).

The damaging consequences are exacerbated when a storm surge coincides with a high tide. The combination of storm surge and tide is referred to as a "storm tide," (NOAA 2017). The storm tide gives the best estimate of how much water is experienced on land.

Storms have always been the primary drivers of coastal sediment shift/erosion, even before human activity accelerated the pace of SLR. Strong currents and wave energy from storm tides scour the shoreline, removing sediment and depositing it elsewhere along the coast. (National Research Council 2007)

Wind Damage

As the climate changes, it is likely that windspeeds associated with tropical storms will increase (Field et al. 2012). Higher winds can cause severe damage to buildings, which is costly and time-consuming to repair.

The main cause of wind damage to buildings is breaching of the envelope. Loss of roofs, walls, soffits, or their component parts is expensive to repair, and opens buildings up to significant interior damage from rain or flooding. It is also common for window panels to blow out. The resulting flying debris can damage other structures nearby. If their construction is not sound, large doors or windows are vulnerable to destruction by wind suction. (FEMA 2000)

Coastal Resilience Planning

Coastal communities of all sizes have begun to address issues presented by SLR. The most organized approaches usually occur at large, municipal or regional scales and are known as resilience or adaptation plans. The term "resilience" has been used extensively in the fields of landscape architecture and urban planning in recent years, with various definitions. The working definition in this thesis will be "the ability of a system to prepare, resist, recover, and adapt to disturbances in order to achieve successful functioning through time," which was presented by the Army Corps of Engineers in 2015 (Rosati, Touzinsky, and Lillycrop 2015). This definition requires characterizing functions and performances on all systemic levels, which will be addressed for the Skidaway campus in Chapter 3 (Ayyub 2019).

Municipal governments have a greater variety of concerns to address than stakeholders of a site like the Skidaway campus—larger economies, more infrastructure, and human populations with vulnerable sectors. The Skidaway campus is nested within the planning boundaries of Chatham County, which deals with these issues, so the campus must conform to county regulations and hopefully even exceed them in foresight.

Successful coastal planning usually addresses natural and nature-based features (e.g. naturally occurring or created marshes, dunes), structural interventions (e.g. seawalls, breakwaters), and nonstructural interventions (e.g. floodplain building policies, education programs, evacuation plans) (Bridges et al. 2013). Natural and structural features, as well as hybrids between the two, function to stabilize shorelines to protect infrastructure and human well-being in populated areas. The next section of this chapter will review the implementation of nonstructural interventions in Chatham County, which affect the physical interventions—natural, nature-based, and structural—possible on campus. Physical interventions will be discussed explicitly as well.

Local Coastal Resilience Planning

Chatham County's boundaries contain the Skidway campus. Skidaway Island functions as an unincorporated community within Chatham County, meaning that the Island receives services, planning, and governance under the county's direct jurisdiction. Because of this direct linkage, resilience measures that the Skidaway campus takes must comply with and hopefully exceed county regulations.

Though the county has no discrete SLR adaptation or resilience plan yet, it employs a growing variety of strategies to increase its resilience to SLR, from the technical to the conceptual level. This section will provide an overview of the efforts currently underway.

In its 2016 Comprehensive Plan, Chatham County recognized the growing concern of the populace regarding SLR. The majority of respondents in a community-wide survey acknowledged SLR as a major concern and favored policy responses to addressing the SLR-induced problems. The action-oriented “Short Term Work Program” section of the report calls for the development of “…a long-range regional plan for [SLR] which evaluates multiple adaptation methods,” (Chatham County 2016)

As of 2020, Chatham County has not yet met that objective, but the City of Tybee Island, which is part of the county, published an acclaimed SLR adaptation plan in 2014. This collaborative effort involved UGA and MAREX researchers working with citizens and city officials to identify specific adaptation options for increasing the city’s resilience with a timeline between 2012 and 2060. The plan won NOAA Sea Grant’s highest national outreach award and was included as a SLR adaptation case study in the U.S. Climate Resilience Toolkit. The context-specific, stakeholder-centered, and foresighted approach were keys to its success. (Evans et al. 2016)

Chatham County has recently demonstrated increasing foresight in its efforts toward responsible floodplain management. The county adopted a new, extensive Floodplain Management Plan in 2018, which intends to identify, assess, and mitigate flood risk within the county to protect people and property from increasing flood hazards.

Enacting the new Floodplain Management Plan ensures that the county will be eligible for federal disaster assistance and reduced flood insurance premiums through a good rating in FEMA’s National Flood Insurance Program (NFIP) Community Rating System (CRS) (Chatham County 2018, FEMA 2016). Chatham County is currently in Class 5, among the best that a Georgia community, coastal or inland, has achieved (FEMA 2016).

The management plan includes a new floodplain zoning map for the entire county. On the map, the Skidaway campus is classified as Zone X-500, which means its flood risk is "moderate," or an approximately 0.2% annual chance of being flooded, situating it between the limits of the 100- and 500-year floodplains (Chatham County Dept. of Engineering 2018). Ironically, the campus has experienced significant flooding in 2015, 2016, and 2017 at least (Dr. Clark Alexander, on-site meeting, December 13, 2019). Under this designation, flood insurance is recommended but not required, and the campus is "not regulated for floodplain management purposes by Chatham County and FEMA for home construction" (Chatham County Dept. of Engineering 2018). Thus, building additions and new construction are unrestricted on the campus.

However, county commissioners voted to increase freeboard from one to three feet in 2019 (Chatham County 2019). Freeboard refers to the height between the base flood (1% annual chance, or "100-year flood") elevation and the bottom of a structure. Lower risk of structural damage is associated with higher freeboard, so flood insurance premiums typically decrease with increasing freeboard. While it is an important start, floodplain management for human and ecological well-being represents only a piece of creating resilience.

Working with the best possible data is essential to any planning effort. Until 2017, the NOAA tide gauge at Fort Pulaski was the only sea level sensor for the entire Georgia coast, which extends nearly 100 miles south of the gage. Localized flooding was unpredictable. In response, the City of Savannah, Chatham Emergency Management Agency (CEMA), and scientists and engineers from the Georgia Institute of Technology (Georgia Tech) are working together to install a series of small water level sensors throughout Chatham County, known as the Smart Sea Level Sensors project. This network of 50-100 sensors captures data from a variety of tidal waters—creeks, beaches, rivers, etc.—rather than relying on data from the FOPU gage only, in hopes of creating more localized flooding predictions and responses (Cobb et al. 2020). Appropriately, the Skidaway campus hosts one of the water level sensors and personnel from MAREX are trained in educating visitors about it (Jill Gambill, email message to author, March 23, 2020).

<u>Shoreline Stabilization</u>

A large part of coastal resilience or adaptation consists of protecting infrastructure and population. Though people have been modifying the coast for these purposes for hundreds of years, SLR has increased concern recently. Because land loss from erosion and inundation are the most urgent issues, most of the defense measures work to stabilize the shoreline. There is a variety of shoreline stabilization techniques that fall into a gradient from natural (naturally protective coastal ecosystems) to "hard armoring" (engineered man-made structures made of hard materials like rock, concrete, or steel). Figure 4 illustrates examples along this gradient. "Nature-based" solutions may refer to natural, soft, or hybrid stabilization measures (Bridges et al. 2015). Regional variation in SLR rates, topography, municipality size, building density, shoreline change rate, etc, preclude a one-size-fits-all approach to planning these structural defenses, so planners must develop objectives and consider context (Bridges et al. 2013, EPA 2009, Gedan et al. 2011, Palinkas, Sanford, and Koch 2018).

An increasing body of evidence shows that natural shoreline habitats like dunes, submerged aquatic vegetation, mangroves, coral reefs, salt marshes, and oyster reefs reduce the risk of coastal flooding by forming physical structures that can attenuate wave energy, block winds, and reduce erosion—depending on the ecosystems' context and health (Van Wesenbeeck

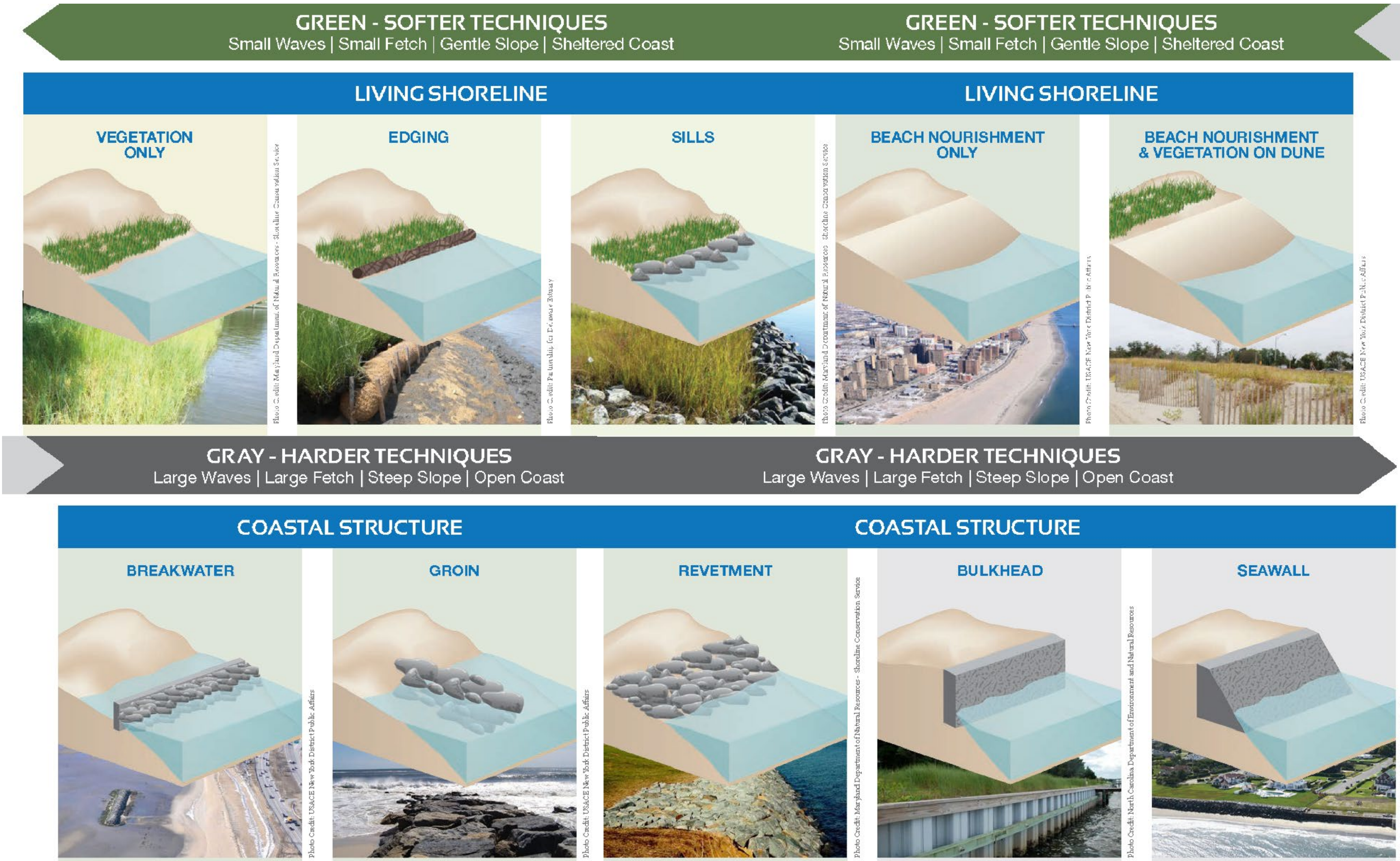

Figure 4: Examples of the gradient between soft and hard shoreline stabilization (SAGE 2015).

et al. 2013, Gedan et al. 2011, Sutton-Grier, Wowk, and Bamford 2015, Sutton-Grier et al. 2018, Shepard, Crain, and Beck 2011). These ecosystems have co-benefits like greenhouse gas mitigation, water quality enhancement, habitat provisioning for economically important species (e.g. shrimp, fish), and natural beauty (Needelman et al. 2012). Restoration of natural shorelines may include removal of structural modifications and enhancement of natural features, but does not include any added components (Gianou 2014).

Soft shoreline stabilization uses natural materials to enhance or restore natural processes and topography, increasing connectivity between aquatic and terrestrial environments. The approach can involve removal of structural modifications like seawalls and riprap, with the intent of restoring a lower gradient. Examples include beach nourishment with dredged material, strategic placement of large woody debris, vegetation enhancement, marsh toe reinforcement with coir logs, structures made of natural materials, and some forms of “living shoreline.” While soft stabilization provides more ecological benefits than hybrid or hard stabilization, short-term environmental damage still occurs. (Gianou 2014)

Living shorelines have become a hot topic in shoreline stabilization in recent years. On the East Coast, living shorelines typically consist of salt marsh and/or oyster reef creation or restoration, sometimes with benches, sills, or breakwaters (Bridges et al. 2015). Depending on how much engineering and man-made material goes into the project, it can range from “soft” to “hybrid.” If the project is successful, it can provide services similar to those of natural shorelines: wave energy dissipation, erosion reduction, sediment accretion, and habitat (Mitchell, Bilkovic, and Pinto 2019, Polk and Eulie 2018, Smee 2019, Bridges et al. 2018). Unlike hard or some hybrid stabilization techniques, the biotic components of oyster reef and marsh living shorelines have potential to keep pace with SLR (Rodriguez et al. 2014, Mitchell, Bilkovic, and

Pinto 2019). Howevert should be noted that many living shoreline installations fail because of poor siting and insufficient maintenance (Mitchell, Bilkovic, and Pinto 2019).

Sometimes it is most useful to enhance or rebuild coastal ecosystems systems to address human objectives via engineering, in which case the approach becomes "hybrid" or "nature-based" (Bridges et al. 2015, Sutton-Grier et al. 2018). A "hybrid approach" may also refer to a solution that combines specifically selected hard armoring with natural systems (Sutton-Grier, Wowk, and Bamford 2015). These solutions are gaining traction in recent literature because they combine the best of both approaches—grey infrastructure performs well in reducing flood risk, while green infrastructure complements it with co-benefits from ecosystem services (Alves et al. 2019). Hybrid coastal infrastructure has the potential to function like hard armoring while conferring social, economic, and ecological co-benefits, potentially making it more cost-effective in the long term (Sutton-Grier, Wowk, and Bamford 2015). Examples of hybrid solutions include stream-design culverts to restore natural tidal flow and reduce flood damage, and breakwaters made from artificial oyster reef habitat (Sutton-Grier et al. 2018, Bridges et al. 2018).

The traditional solution to stabilizing the shoreline is armoring with engineered structures—often referred to as "gray" or "hard" infrastructure. These structures use materials such as large rock, concrete, or steel to alter shoreline configuration (Gianou 2014). They include seawalls, bulkheads, levees and storm surge barrier gates, culverts, dikes, jetties, breakwaters, groins, and revetments (Sutton-Grier et al. 2018, Sutton-Grier, Wowk, and Bamford 2015, Bridges et al. 2013). Seawalls, bulkheads, levees, and storm surge barrier gates are intended to reduce flooding, while the other structures are created to reduce erosion and/or promote sediment accretion; all are capable of reducing storm wave damage (Bridges et al. 2013).

Each of these structures comes with its own set of drawbacks. Moreover, current infrastructure is aging and degrading in condition, necessitating expensive repair or replacement. Failure to perform when needed can be catastrophic (Sutton-Grier et al. 2018)—for instance, flooding in New Orleans, Louisiana, during Hurricane Katrina was exacerbated when levees failed. While the structures may be temporarily effective in flood protection, they are expensive to construct and maintain, and inflexible—as climate conditions continue to change, static structures become less practical (Hamin et al. 2018, Alves et al. 2018). Generally, coastal armoring confers few ecological benefits and severely limits natural processes (Sutton-Grier et al. 2018, Gianou 2014). It has resulted in significant declines in aquatic organism abundance due to habitat loss (Morris et al. 2018, Sutton-Grier et al. 2018).

CHAPTER 3

CAMPUS ANALYSIS

Site History

In order to plan for a site's future, it is necessary to examine its past. The land upon which the campus sits has changed hands many times before recent stakeholders gradually repurposed it into a functioning research campus. This is well-evidenced by archaeological surveying on about one-quarter of the entire parcel, leading to documentation of roughly 50 prehistoric and historic archaeological sites (Messer et al. 2018).

Pre-History

Skidaway Island was formed during the Late Pleistocene epoch around 125,000 years ago, after receding shorelines left behind barrier islands (Turck and Alexander 2011). Until recently, it was believed that the islands were formed only 35-40,000 years ago (UGA MAREX 2020). Over the next 100,000 years, temperatures decreased and sea levels fell as northern glaciers formed. The sea level dropped 300-500 feet, leaving the ocean 70-80 miles east of where it is today (UGA MAREX 2020, Kelly 2003). Around 18,000 years ago, temperatures began rising, melting the glaciers and causing sea levels to rise again. This re-flooded former shorelines and created a mix of older and newer features (Turck and Alexander 2011). By about 5,000 years ago, low-lying areas west of the island were flooded into marshland and the rate of sea level rise slowed to about four to six inches per century (Kelly 2003, UGA MAREX 2020). Neighboring outer barrier islands like nearby Wassaw, Little Tybee, and Tybee were formed about 2,500 years ago during the Holocene epoch (Turck and Alexander 2011). Until about 5-10,000 years ago, prehistoric mammals like horses, mastodons, mammoths, and giant ground sloths inhabited the island (Kelly 2003).

Because marshes around the island are rich in estuarine resources like oysters, fish, and contain relatively fertile soil for agriculture, people have occupied it since the 14th century at least (Keene 2004). The original inhabitants were ancestors of the Creek people. A former marsh-side village associated with a large oyster shell midden is located on SKIO's property along Groves Creek, which horizontally bisects the parcel on the eastern side (Keene 2002).

Archaeologists excavated the Groves Creek site on three separate occasions between 1985 and 2001. They found ceramics from both the Savannah phase (A.D. 1150-1300) and Irene phase (A.D. 1300-1450), though other evidence indicates that the most intensive occupation occurred around A.D. 1450. The site was occupied year-round, and inhabitants utilized at least five structures constructed from cane matting and daub. In addition to foraging for marsh fauna, agriculture was a primary means of subsistence on-site. Villagers cultivated maize, beans, squash, sunflower, and a variety of fruits. (Keene 2004)

Colonial & Antebellum

During the 1730s, English General James Oglethorpe, founder of the Colony of Georgia, constructed a small fortification at the northern end of the island, near the current campus. European settlers found it difficult to sustain themselves and abandoned the settlement by 1740. New colonists attempted to live on Skidaway in 1745, when land was granted to various wealthy families. In 1753, the colonial government granted John Milledge property on the northwestern side of the island where the core campus area is currently located. He named it "Modena," after the Italian seat of silk culture— "an industry imagined for early Georgia," (Messer et al. 2018).

Enslaved people on the plantation grew indigo and raised hogs and cattle. Milledge's son sold Modena in 1843 (Messer et al. 2018).

During the antebellum period, Skidaway Island was well-populated at around 2,000 inhabitants. The largest portion of the population was composed of enslaved people descended from Africans. A Catholic bishop named John Barry purchased a 717-acre tract of land called Hampton Place in 1859, which came to be known as Priests Landing long after it was transferred to Bishop Gross for use as a monastery and orphanage (Kelly 2003).

By the time the Civil War began, most of the white residents had already moved to Savannah to avoid being trapped in battle on the island. Only a few landowners and the people they held as slaves remained. Earthen batteries were built in several locations around the island, including one at Priests Landing and another at Modena Plantation (Kelly 2003). The ruins of at least one of these structures remains on site in an unmarked location (Messer et al. 2018).

An 1864 map shows a road leading to Modena in a similar location to present-day McWhorter Drive. The map indicates that most of the island was wooded except for a few cleared areas, including the current core campus area (Figure 5).

Figure 5: 1864 map of part of Skidaway Island, showing road to Modena Plantation, current location of main campus. (Major George Davis et al. 1864, as cited in Messer et al. 2018).

Post-Civil War

Few people stayed on the island after the Civil War. Most of those who remained were recently emancipated from slavery and had few resources to support themselves. They subsisted as sharecroppers, fishermen, or caretakers of property owned by people on the mainland. (Kelly 2003)

Eventually, wealthy landowners from the North began re-colonizing the island and Stephen Bond from Indiana acquired Modena Plantation. Ownership turnover was rapid—between 1843 and 1944, the plantation was owned by 12 different parties. Hampton Place changed hands six times between 1852-1877. (Kelly 2003)

In 1877, Benedictine Catholic monks began constructing a monastery and school for the sons of newly emancipated people on the Hampton Place (Priests Landing) tract on the Wilmington River. The monks wanted to help them find a place in society by way of education and conversion to Catholicism. However, the school failed by 1889 because most of the families on the island were Baptist, Methodist, or Protestant by faith, and also were not interested in sending their sons to a manual labor school, given the hundreds of years of slavery in their recent past. The Poor Clare order of English nuns attempted to create a school for girls on the adjacent property, but that project also quickly failed due to lack of funding and animosity from the Benedictine monks. When several of the monastery buildings burned down and a storm surge temporarily destroyed the freshwater supply in 1889, the schools finally closed their doors. (Kelly 2003)

The settlement remained vacant until 1906, when the Benedictines sold it to the Floyd family. At this time, the tract encompassed 717 acres, 300 of which had been cleared. In 1924, the family defaulted on their mortgage and the land became a holding of C&S Bank. While the land was vacant during the Prohibition Era, hunters, campers, and moonshiners utilized the woods (Kelly 2003). Moonshine was also made in the woods adjacent to the MAREX side of the main campus, as evidenced by the remains of a still.

In 1941, the Union Bag and Paper Corporation (Union Corp.) purchased the Hampton Place property. Union Corp. was a pulp and paper company that used the land for harvesting pines as timber. The company destroyed hundreds of acres of native live oak maritime forest to plant fast-growing pines. The ruins of about ten structures from the Benedictine school remained on the site, which were dismantled due to safety concerns. By 1953, the timber industry had become economically unfeasible, so no harvesting took place after that time. (Kelly 2003)

On the northern part of the Skidaway campus parcel, where the core campus currently lies, Modena Plantation was sold from Stephen Bond to Ralph Heywood Isham, from New Jersey, in 1927. He and his friends used the land for hunting parties. (Kelly 2003)

Roebling Era

The Modena Plantation area was a gift from the Roebling family in the 1960s that enabled the current Skidaway campus to exist. Robert Roebling was a member of the prominent and wealthy Northeastern Roebling family. His great-grandfather John A. Roebling was a German immigrant who emigrated to the United States in 1832. John became an engineer and designed many well-known bridges, founding a wire cable company to produce the materials. It was this business that formed the family's fortune. Robert and his wife Dorothy ("Dickie") built their home in Trenton, New Jersey, in 1925, but when crime befell many Northeastern cities during the 1930s and one of their children was almost kidnapped, they began considering moving south like other family members. (Megathlin 2020)

Ralph Heywood Isham was a neighbor and friend of the Roeblings in New Jersey, and they once visited him on his Modena Plantation land. They enjoyed their time there so much that they purchased the land, intending to restore the plantation to working order. With five children, the family moved there in 1936, living on their schooner, the Black Douglas, for several years. They moored the boat on the north pier where the fuel dock currently lies. Due to the threat of war, they built a power plant on the property in 1940 and moved into one of the first buildings they created, the gymnasium building, now known as the Roebling House. The U.S. Fish & Wildlife Service bought the Black Douglas from the Roeblings in 1941. (Messer et al. 2018)

In the 1930s, the Roeblings asked Georgia's Department of Agriculture and UGA what the best use of the land might be, and they recommended raising purebred cattle in an effort to increase Georgia's standards. The Roeblings took this advice, gearing Modena Plantation toward Aberdeen Angus cattle production. Large swaths of upland area were kept clear as pasture. Quickly the Roeblings built an excellent reputation for their cattle, but when the breed cattle market become flooded with Australian imports during the early 1950s, the farm became inviable. (Kelly 2003)

Much of SKIO's current infrastructure comes from this time period. Robert Roebling, an engineer like much of his family, devised complex infrastructure systems on the plantation. The systems included efficient cattle housing and material storage, a large circular show barn, two sturdy docks, and an automatic water system for fire extinguishing that includes the now-iconic water tower (Kelly 2003) (see Appendix, Figure 42). His innovative designs left a network of well-constructed buildings, many of which are still in use.

Skidaway Institute

After the end of the breed cattle era in the 1950s, the Roeblings intended to donate Modena to UGA as an agricultural experiment station, but the University already had plenty of farmland. They asked the Roeblings to consider donating to a different project in the coming years. (Kelly 2003)

The Georgia State Legislature created an Oceanographic Task Force under the new Georgia Science Technology Commission in 1964, which proposed an oceanographic research and education center on the coast of Georgia. The Roeblings donated their land to this cause shortly thereafter. After learning of the U.S. Environmental Science Services Agency's plans to establish an East Coast facility, the task force established the Ocean Science Center of the Atlantic Commission (OSCA) in 1967, in hopes of attracting the facility to Georgia. This plan failed, but OSCA established a similar idea with the inception of the "Institute at Skidaway" in 1968. It was formed by combining the donations of the Roeblings' 790-acre Modena Plantation and the Union Corp's 635-acre Priests Landing tract (Messer et al. 2018).

The OSCA facility first opened in the summer of 1968. Around this time, the new administration ceased maintaining some of the formerly pastured areas, although most of today's pine forest was not allowed to regenerate until the 1980s. Most of the old buildings were repurposed to fit OSCA's needs, and some of the Roeblings' employees stayed on. When Governor Jimmy Carter abolished OSCA in 1971, the Board of Regents created a new autonomous entity within the University System of Georgia (USG) called the "Skidaway Institute of Oceanography." In 2013, the Institute merged with UGA. (Messer et al. 2018)

The marine extension service became part of the campus early on. UGA's vice president for Public Services at the time procured funds to start the service in 1970. A year later, the marine education center was added to the campus. The original intention of this facility was for use as a field station for university groups (UGA MAREX 2020d).

Potential for National Register of Historic Places Listing

UGA's 2018 Historic Preservation Master Plan (HPMP) classified structures into five categories based on age and potential for listing in the National Register of Historic Places (NRHP). Surrounding landscapes are also included in the assessment. According to the HPMP, the campus "appears significant at the state level as a historic district…in the areas of Agriculture and Architecture for its history as a twentieth century plantation," potentially qualifying it for district-level listing in both the National and Georgia Registers of Historic Places with a period of significance between 1936 and 1967. A total of 17 structures could contribute to the Agriculture and Architecture district listing. When some of the newer SKIO buildings from the early 1970s reach fifty years in age, the campus might become eligible for listing in the NRHP in the area of Science as well. (Messer et al. 2018)

Campus Entities' Functions

Any future planning for the Skidaway campus must be conducted with understanding of the component entities' functions. Both the campus and its component entities operate via a hierarchy of systems. The function of each system varies, and these functions are layered: the institutions work separately and together to educate and produce new information, while they are supported by infrastructure systems that must operate properly to do so. Disruption of any of the infrastructure systems (which SLR makes inevitable) will interrupt the institutions' functions in a variety of ways—unless strategies for systemic resilience are put in place. It is often said that form follows function, so this thesis will discuss the functions of campus before the infrastructure that upholds them.

SKIO

The functions of SKIO are twofold: to generate new knowledge in the oceanographic sciences by way of research, and to educate university students in the process. SKIO acts as a hub for coastal research, particularly in the Southeast. Research is centered on the biological, chemical, geological, and physical aspects of oceanography.

Dr. Clark Alexander, who specializes in the geological aspects of oceanography, is the current director of SKIO and a primary stakeholder in planning its future. SKIO currently employs nine faculty, two post-doctoral scientists, eight research staff members for faculty lab support, and 23 support staff members. Eight emeritus faculty are associated, and SKIO hosts scientists from other institutions as well. The biological oceanography program is growing—SKIO is recruiting new faculty. There are eight graduate students pursuing both master's and doctoral degrees. (SKIO 2020a)

Summer is SKIO's busiest time of the year for education. From May through August, between 40 and 50 graduate students visit the campus to learn and aid in research, with one to three of the students residing on campus. Twenty to 30 undergraduate students also visit the campus during the summer for classes and Research Experience for Undergraduates (REU) programs. Many of the REU students come from nearby Savannah State University, with whom SKIO has been working for at least ten years. Plans for a marine science undergraduate program at UGA have been approved, which will bring more students to campus, in addition to reinforcing the need for good distance learning capabilities between the Athens and Skidaway campuses. (Dr. Clark Alexander, on-site meeting, December 13, 2019)

SKIO relies on funding from a variety of sources. While state funding covers basic operation costs, all of the research is funded by federal and state grants. SKIO successfully balances the competitive and time-consuming nature of grant applications, and performing the research. (Dr. Clark Alexander, on-site meeting, December 13, 2019)

Certain research outcomes are especially important for the public to know about. SKIO communicates with MAREX so that they can interpret and disseminate this new information to the public. SKIO scientists also participate in a Speakers' Bureau, a periodic on-campus evening lecture series, and sometimes offer workshops and educational cruises to K-12 teachers as well (SKIO 2020b, 2017). Although SKIO's outreach efforts are substantial, MAREX specializes in outreach on campus.

MAREX

The mission of MAREX, as stated on their website, is the following:

> "To support research, education and training, and outreach activities that promote the environmental and economic health in coastal Georgia by helping improve public resource policy, encouraging far-sighted economic and fisheries decisions, anticipating vulnerabilities to change and preparing citizens to be wise stewards of the coastal environment." (UGA MAREX 2020c)

There are several locations, branches, and specialties within the MAREX program. It is headquartered in Athens, Georgia, with the main facility on the Skidaway campus and a station further south on Georgia's coast in Brunswick. Currently, MAREX employs about 40 people and operates on funding from a variety of sources, including the State of Georgia, federal Sea Grant funds, grants and income, and private donations. (UGA MAREX 2019)

At Skidaway, MAREX's Shellfish Research Lab functions as an aquaculture research entity. Generally, MAREX scientists work on various projects to develop sustainable aquaculture opportunities for Georgians. In 2019, MAREX helped 590 personnel from Georgia fisheries and aquaculture modify their practices for efficiency and sustainability using new knowledge, which was generated largely on campus (UGA MAREX 2019).

MAREX partners with other UGA departments and higher education entities such as Georgia Southern University (particularly the local branch formerly known as Armstrong State University), Savannah State University, Georgia State University, and Georgia Tech. Non-university entities such as private corporations, the City of Savannah, NOAA, and the Georgia Department of Natural Resources (DNR) collaborate frequently too (UGA MAREX 2019). On campus, MAREX often partners with SKIO scientists. They have also worked with GRNMS in hosting native reef fish in the aquarium. Collaboration between GRNMS and MAREX will likely increase in upcoming years as GRNMS bolsters their outreach program (Elliot Lam, Zoom meeting, March 27, 2020). In 2019, a total of 52,554 individuals were involved with MAREX's programs in some way (UGA MAREX 2019).

The Marine Education Center & Aquarium works to interpret the work of SKIO and the Shellfish Research Lab and communicate coastal ecological knowledge to students of all ages and the public. Pre-K through 12th graders are engaged in hands-on, on-campus learning programs. Almost 6,200 young students in Georgia were educated by MAREX in some capacity in 2019 (UGA MAREX 2019). Most of these students come from the Savannah area for day trips, but some students visit from further away and stay overnight. Summer day camps for children ages six through fifteen are also an integral part of MAREX's program base. (Anne Lindsay, on-site meeting, February 28, 2020)

Most student programs are pre-planned, including indoor and field studies. Indoors, students engage with the aquarium, saltwater lab facilities, and on-campus experts. Outdoor classes are conducted both on campus and in the field at beaches, dunes, and salt marshes. Some of these programs utilize campus vessels to shuttle students. (UGA MAREX 2020a)

MAREX tries to involve adults too. The Marine Extension Service provides a diverse range of internships and fellowships for undergraduate and graduate students—as well as recent graduates—in marine policy, law, education, research, and program planning (UGA MAREX 2019). Fellows and interns often stay on campus in the dorms (Anne Lindsay, on-site meeting, February 28, 2020). Coordinating citizen science efforts involving all age groups is another substantial part of their programming (UGA MAREX 2019).

Furthering MAREX's efforts to reach as many people as possible, they also participate in or host several special events each year. The most important public event of the year for everyone on campus—including SKIO and GRNMS—is Skidaway Marine Science Day, held each October. At this open house event, the three organizations offer hands-on science learning activities and present current research to the public (UGA MAREX 2020f). While celebrating the campus' education function, Skidaway Marine Science Day puts campus infrastructure on display.

Other Entities

NOAA's Gray's Reef National Marine Sanctuary (GRNMS) headquarters is located on the Skidaway campus, in facilities rented from SKIO. The organization facilitates and performs research on federally protected live-bottom reef seaward of Sapelo Island. Outreach professionals work to educate the public about the reef. Due to the necessity of site visits, dive operations are essential for GRNMS to fulfill its research function. Often, NOAA collaborates with SKIO scientists to conduct this research, as well as researchers from other institutions. (GRNMS 2020)

While state-funded SKIO and MAREX work to research and educate about a wide variety of topics, GRNMS is federally funded, smaller, and more specialized. Another major difference in the functions of SKIO and MAREX versus GRNMS is that the former work to immerse students in the local environment for experiential learning, but GRNMS must focus on remote education because very few people can access the reef directly.

Georgia Southern University (Georgia Southern) has a small satellite campus within the Skidaway campus as well, which increasingly falls under the umbrella of SKIO's management. About 12 faculty and five students currently use the facility, though there is potential for more interaction between SKIO and Georgia Southern since local Armstrong State University merged with Georgia Southern in 2017. Like SKIO, Georgia Southern uses its facilities for research and education of university students. (Dr. Clark Alexander, on-site meeting, December 13, 2019)

Conclusion

Although the functions of the campus entities are diverse as detailed above, there are three main functions that are shared with most other academic campuses, especially those with Land Grant or Sea Grant programs. These purposes guide every action that Skidaway campus stakeholders take:

1. Research
2. Education
3. Public service & outreach

These overarching themes structure the campus ideologically and physically. It would be impossible to fulfill these functions without the physical support of campus infrastructure and connections between aspects of it.

Supporting Infrastructure

It is important to understand functions nested within the functions of the campus overall, which are performed by the infrastructure. The campus infrastructure, which is maintained and managed by SKIO, is a system made of component parts including ecosystems, academic and research facilities, boats, docks, housing, support and maintenance, and landscape. Currently, most of the parts must be performing well in order for the campus to carry out is overall missions—but changes must be made in the future because SLR will alter the infrastructure whether prepared for or not.

Ecosystems

Ecosystems may not fall under the traditional definition of infrastructure, but they physically support all functions because campus is nested within them. They may be easiest to view on the undeveloped portions of the parcel. The undeveloped land and marsh surrounding the core campus and Priests Landing areas constitutes about 90% of the SKIO parcel, and is used for research, education, and public recreation. These 710 acres of conserved forest and salt marsh ecosystems provide direct ecosystem services, including the reduction of flood risk and erosion, greenhouse gas mitigation, water quality enhancement, habitat provisioning, and natural beauty (Needelman et al. 2012).

Because of its location between the 588-acre Skidaway Island State Park and a 391-acre public marsh area on the northernmost tip of the island, the parcel of undeveloped land begins to form a corridor for wildlife (Figure 6). Between the three largely undeveloped parcels, most of the land is held by The Landings or private owners therein. UGA's conservation of habitat can set a precedent for these landowners. Many property holders affiliated with The Landings use the campus trails and those of the State Park (Anne Lindsay, on-site meeting, February 28, 2020), so

Figure 6: The Skidaway campus begins to form a habitat corridor when combined with Skidaway Island State Park and public marsh at the northern tip of the island. Scale (and subsequent map scales) shown as representative fraction (RF), ratio between number of units on the map to the number of units on the ground.

perhaps they can be influenced by MAREX to contribute to the creation of a corridor by ensuring that their property is managed in an ecologically sound manner.

Over ten miles of publicly accessible trails on the campus parcel provide recreation opportunities for locals and island visitors (Figure 7). The trails are popular for dog-walking, off-road biking, and hiking, and people enjoy fishing from the bluffs in clearings along Groves Creek. Inviting the public to use the trails draws interest in and interaction with the campus itself, particularly MAREX. In addition to forging positive informal relationships, the trails have instituted a more formalized partnership with a community organization. The South East Georgia (SEGA) chapter of the Southern Off-Road Bicycle Association (SORBA)—known as SEGA-

SORBA—maintains some of the trails for off-road biking. (Anne Lindsay, on-site meeting, February 28, 2020)

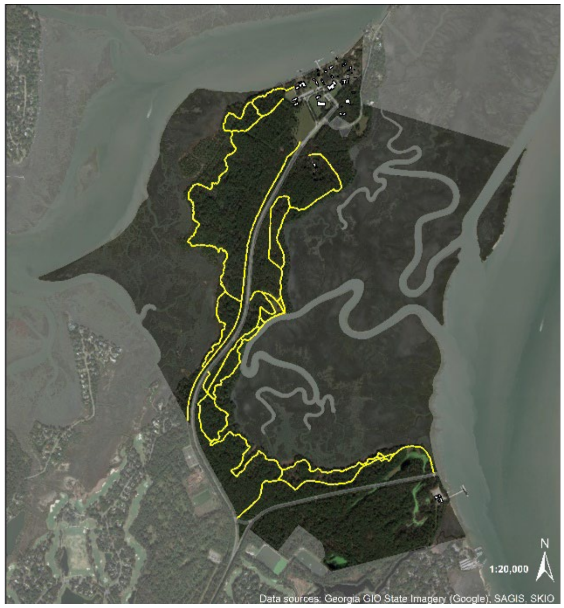

Figure 7: Map of the ten miles of publicly accessible trails on campus. Trail data created by Dr. Clark Alexander, SKIO, 2019.

The undeveloped land also contains about eight parcels deeded to the Georgia Department of Economic Development in the 1990s, located along McWhorter Drive. The department, headquartered in Atlanta, can allow businesses to develop the parcels at any time (Dr. Clark Alexander, on-site meeting, February 28, 2020). Another function that may occur on the undeveloped land is harvesting pines for timber, hearkening back to the days of Union Corp (Dr. Clark Alexander, on-site meeting, February 28, 2020). If developed or harvested, these areas would add a new function to campus—profitability—in lieu of the ecosystem services provisioned by the forest.

By area within the parcel, salt marsh is the most ubiquitous ecosystem. Therefore, any changes to salt marsh are highly impactful to the campus. According to a 2013 marsh classification study performed via remote sensing on the Georgia coast, the Skidaway campus parcel hosts most types of low and high marsh (Figure 8) (Hladik 2013). This includes plant communities dominated by tall, medium, and short salt marsh cordgrass (*Spartina alterniflora*); black needlegrass (*Juncus roemarianus*) and bulrush (*Schoenoplectus* sp.); marsh hay (*Spartina patens*); and big cordgrass (*Spartina cynosuroides*) and softstem bulrush (*Schoenoplectus tabernaemontani*). The largest portion of the marsh is dominated by medium *Spartina alterniflora*. (Hladik 2013)

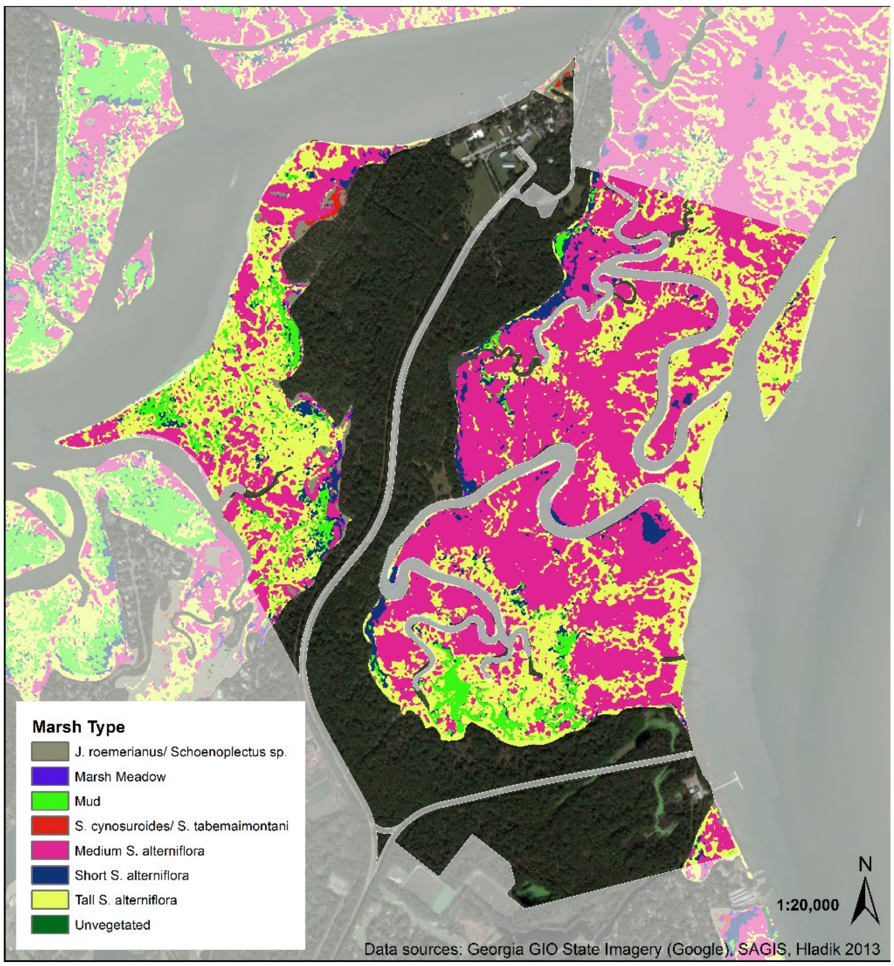

Figure 8: Marsh types and extent on the Skidaway campus (Hladik 2013).

The tidal inlet just northeast of the core campus area provides water to high marsh behind a berm, dominated by black needlegrass (*Juncus roemarianus*) and bulrush (*Schoenoplectus* sp.). Southwest of the core campus, high and medium marsh types dominate. This area has long been used to support MAREX's education mission (see Appendix, Figure 38). Students are taken into the marsh for hands-on learning, and there is a universally accessible public boardwalk with interpretive signage. The marsh also serves as scenery for those in the picnic area and along the Jay Wolf Nature Trail. The public trails frequently skirt the marsh for scenic opportunities.

As discussed in Chapter 2, there are substantial threats to salt marsh quality and migration. It is important to keep in mind that the marsh which currently supports campus functions and buffers it from storms, is sure to encroach on upland areas within the century. If addressed with foresight, however, this does not need to impact the functioning of the campus in a negative way.

Ecosystems: Maritime Forest

Upland areas, where most of the campus infrastructure lies, are supported by mixed successional pine forest and maritime forest. Maritime forest dominated the upland areas before the core campus area, Priests Landing, roadways, and Union Corp. holdings were cleared. Maritime forests in Georgia are dominated by a hardwood tree canopy, consisting primarily of live oak (*Quercus virginiana*), Southern magnolia (*Magnolia grandiflora*), and water oak (*Quercus nigra*). The understory is dense with saw palmetto (*Serenoa repens*), dwarf palmetto (*Sabal minor*), yaupon holly (*Ilex vomitoria*), red bay (*Persea borbonia*), and other shrubs. Spanish moss (*Tillandsia usneoides*) blankets most species (UGA MAREX 2020b). Large maritime forest tree species dot the core campus area as specimens, despite turfgrass as the only groundcover. In some areas of the parcel, maritime live oak forest ecosystems are still intact amidst successional pine forest (see Appendix, Figure 41).

Although maritime forests add character and provide shade to campus spaces, there are risks involved with occupying areas therein, which will increase with more intense, frequent storms. Trees blown down by high winds can pose hazards and interfere with power lines. Figure 9 shows trees near the GRNMS facility that fell on a fence due to wind from Hurricane Matthew in 2016. Had the trees been located less fortuitously, damage to the building would have occurred.

Figure 9: Wind damage near GRNMS headquarters after Hurricane Matthew (Skidaway Campus Notes Blog, 2015).

Both successional pine forest and maritime forest are susceptible to saltwater inundation and will likely become "ghost forest" in the coming years as the marsh gradually migrates upland. The maritime forest is at more immediate risk, however, because hardwoods are more sensitive to soil salinity and pine forest generally grows upland of maritime forest on the Skidaway campus parcel (Velasquez-Manoff 2019).

Ecosystems: Successional Pine Forest

In the Southeastern coastal plain, the successional pine forest plant community is dominated by loblolly pine (*Pinus taeda*) and slash pine (*Pinus elliottii*), which grow very quickly. Without fire or other disturbance, the pine forest will gradually return to the dominant maritime forest community (UGA MAREX 2020b).

During the Modena Plantation era, large swaths of maritime forest were cleared for pasture in and around the core campus area, and the Priests Landing tract and forest north of it were cleared for timber harvest in the early 1940s. Since the harvest ceased in 1953, a successional pine forest has been regenerating (Kelly 2003). Succession of some pasture areas began in the mid-1960s when the land changed ownership to OSCA. Around 1984, most of today's forest near the core campus area was allowed to regenerate.

Ecosystems: Freshwater Wetland

Directly adjacent to the Priests Landing area, bordering salt marsh, successional pine forest, and maritime forest, lies a freshwater wetland of about eight acres. It is especially significant as a breeding ground for the threatened wood stork (*Mycteria americana*) (Hussey, Gay, Bell & DeYoung 2004). During the Hampton Place and Union Corp. era, the wetland was attached to the marsh north of it and tidal creeks extended inland (Figure 10). When the Priests

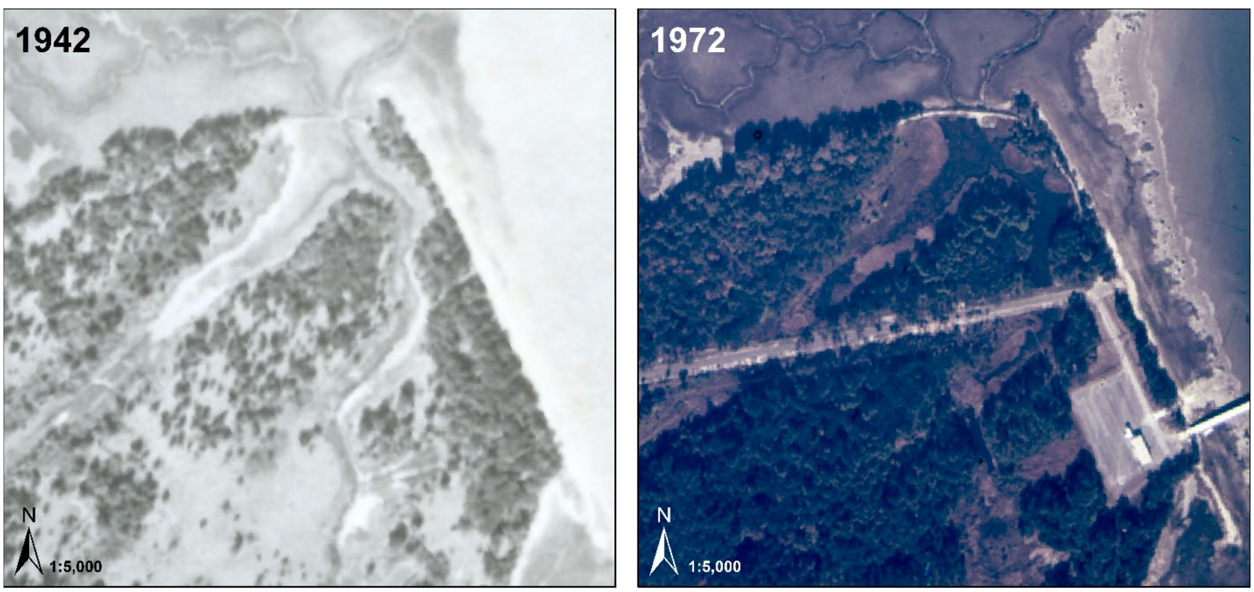

Figure 10: Historic aerial imagery shows that a berm was installed around the time of the Priests Landing dock construction in 1972 (SKIO historic imagery collection).

Landing dock was constructed in 1972, a narrow berm, approximately eight feet tall, severed the marsh and wetland (Figure 10). OSCA Road now bisects the wetland. A portion of the wetland backs up to the Priests Landing facilities, with only about 80 feet separating wetland from upland where large buildings stand. This is a flooding concern, as storm surge could overtop the narrow berm separating freshwater wetland from salt marsh. Rising sea level will overtop the berm as well, making it easy for marsh to migrate into the Priests Landing complex.

Utilities: Electricity

Key to the campus' continued operation is consistent, stable electrical power. SKIO is the steward of utilities on campus, including electricity. Electricity originates at a Georgia Power substation about two miles south of the main campus area, that shares a parcel with the wastewater treatment plant. From here, power is transported through overhead lines along McWhorter Drive. Upon reaching the core campus area, the lines are buried and tie into a loop. (Charles Hartman, Zoom meeting, April 15, 2020)

Compared to underground lines, overhead power lines are unstable and susceptible to damage. The interaction of the power lines with the forest along McWhorter Drive has caused service interruptions (Charles Hartman, Zoom meeting, April 15, 2020Charles Hartman, Zoom meeting, April 15, 2020). Power outages are common during and after storms, and potential fallen power lines are extremely hazardous (Dr. Clark Alexander, on-site meeting, December 13, 2019).

Power outages can halt operations on campus for many reasons. Specialized scientific equipment, computers, internet, interior lighting, climate control (heat/air conditioning), et cetera cease functioning. The campus has backup generators to compensate, but if more frequent and intense storms increase power outages—mainly due to the overhead lines—this could tax the generators' capabilities.

The primary generator is located at the maintenance shop facility, which serves the Roebling Laboratory and Administration Building. It is concerning that this vital equipment is located on the lowest area of campus, known to flood during storms or king tides. A backup generator is located higher in elevation, at the MCSRIC building. Another generator is located on the main dock, to power seawater pumps. There is a portable generator as well, which can be used for emergency operations, lift stations, and powering fuel pumps to refuel the other generators. (Charles Hartman, Zoom meeting, April 15, 2020Charles Hartman, Zoom meeting, April 15, 2020)

The immediate and proper functioning of these generators is vital to the continuity of campus function in the event of an emergency. Labs at SKIO have emergency circuits that include their most important equipment, which are served as soon as power is lost (Charles Hartman, Zoom meeting, April 15, 2020Charles Hartman, Zoom meeting, April 15, 2020). At the aquarium, generator power keeps organisms alive and healthy, circulating seawater, regulating temperature, and enabling other life support systems. At the cafeteria, generators can protect MAREX's investment in mass quantities of food, preventing spoilage in the refrigerator if power goes out. (Anne Lindsay, on-site meeting, February 28, 2020)

Utilities: Information Technology (IT)

Another vital use of electricity is the support of internet access on campus, which is one of the most important systems to campus functioning. In the future, power outages that affect internet connectivity will become less and less tolerable. Reliable power for computer processing, excellent internet connectivity, and high bandwidth are essential to fulfill evolving demands in oceanographic research. Moving forward, SKIO scientists' research will be performed increasingly via remote sensing. Buoys, submarines, and autonomous underwater equipment can provide real-time data delivery if properly supported with strong connectivity. (Dr. Clark Alexander, on-site meeting, December 13, 2019)

SKIO is taking a proactive IT approach that reduces dependence on physical infrastructure while accommodating data-intensive workflows—ideal to ensure that the campus can retain function despite rising sea level. MAREX operates on the same system. Recently they transitioned from a centralized, physical server-based system to a cloud-based system. Campus personnel now work from Microsoft OneDrive, which enables easy collaboration on campus and remotely with researchers worldwide. Computers are synced to the cloud, where all data is stored, eliminating the problem of data loss from issues with individual computers. This is especially important due to the increased risk of flood damage that SLR brings. (Wayne Aaron, Zoom meeting, February 14, 2020)

Data management is controlled remotely, but hardware (e.g. switches, routers) is still necessary to provide internet access on campus. Local internet access originates at SKIO's Roebling Lab, then spreads throughout campus via a network of switches and routers that can be viewed by the IT manager via an online portal. This modular approach allows for quicker recovery in the event of emergency damage because it is easy to identify which piece(s) of equipment need(s) repair or replacement. (Wayne Aaron, Zoom meeting, February 14,2020) Distance learning is another important part of campus IT, especially as SKIO expands its course offerings. Strong distance learning capabilities will also benefit SKIO if infrastructure becomes damaged or inaccessible due to a storm and/or flooding. Programs such as Desire2Learn, WebX Teams, and Zoom integrate campus hardware (e.g. video cameras, interactive screens) with software to enable faculty-student engagement. The two new distance learning classrooms in the OSIC were created for this purpose. (Wayne Aaron, Zoom meeting, February 14, 2020)

Utilities: Water Circulation

The Skidaway campus' potable and non-potable freshwater all comes from two on-site wells. The main campus well beside the OSIC (USGS 37P083) runs 485 feet down into the Upper Floridan aquifer ((USGS) 2020). There is another well at Priests Landing that services this area of campus (Hussey, Gay, Bell & DeYoung 2004). Saltwater intrusion could become a concern as sea level rises, storms intensify, and more people use the campus, drawing more water from the aquifer (Barlow 2003).

From the main well, water is pumped to the historic water tower via an eight-inch water main, from which it is distributed throughout campus (Charles Hartman, Zoom meeting, April 15, 2020Charles Hartman, Zoom meeting, April 15, 2020) (see Appendix, Figure 42). The water tower has been used continuously since it was installed by the Roeblings (Messer et al. 2018). Distributing water via gravity is efficient, especially on a site with low topographic change. From the water tower, fresh well water circulates on a 2,600-foot loop through campus, with about 20 individual service connections (Charles Hartman, Zoom meeting, April 15, 2020Charles Hartman, Zoom meeting, April 15, 2020).

In recent years, SKIO has added a new function to the tower. Since local ordinances limit the height of new structures on the island, SKIO leases space on the historic water tower to cellular and internet companies so that they can transmit service throughout local islands without constructing unsightly towers in the scenic area. This agreement generates revenue for SKIO, so SKIO risks losing a funding source if SLR jeopardizes the water tower. (Wayne Aaron, Zoom meeting, February 14, 2020)

Freshwater supply is typically enough to sustain a campus, but SKIO and MAREX require access to saltwater, too. Two pumps on the main dock draw water from the Skidaway

River, which is then distributed through underground pipes to the Marine Education Center & Aquarium, Shellfish Research Lab, and use a separate pipe system to reach SKIO's saltwater lab (Anne Lindsay, on-site meeting, February 28, 2020, Charles Hartman, Zoom meeting, April 15, 2020). MAREX's education and outreach missions depend largely on the system, as the aquarium and labs are primary vehicles for hands-on learning. It is also essential to operations at the Shellfish Research Lab—circulating water mimics natural conditions in oyster and algae research tanks. SKIO scientists need circulating seawater for biological research in the saltwater lab (Charles Hartman, Zoom meeting, April 15, 2020). Seawater that has served its purpose on campus circulates back out to the Skidaway River, while used freshwater takes a different route.

Utilities: Sanitary

Both greywater and blackwater from campus are pumped to a treatment facility at The Landings via four large lift stations and two small lift stations on campus (Charles Hartman, Zoom meeting, April 15, 2020). Underground lines from the main campus run parallel to McWhorter Drive, and lines from Priests Landing run along OSCA Road.

Utilities: Rainwater Management

Rainwater on campus is managed primarily through a series of roadside ditches and landscape channels and swales, including some underground pipes. There are also two large retention ponds near the SKIO housing area that were constructed in the late 1960s for catfish research. Water drains into the system through overland flow, weir inlets, drop inlets, and double wing catch basins. Infiltration is rarely an issue, as water percolates easily into the sandy soil. Most storm-related flooding is caused by storm surge rather than rainwater. On the main campus, there are nine locations where runoff water is channeled directly into the Skidaway River by the docks. While this is convenient for the time being, rising tides find their way up onto campus through these points of contact during king tides.

There are two cisterns behind the Marine Education Center & Aquarium that were once used for rainwater harvesting. They have degraded in condition, though stakeholders have expressed interest in refurbishing them (Anne Lindsay, on-site meeting, February 28, 2020). Refurbishment and integration into existing campus infrastructure would be a great way to uphold MAREX’s mission as ambassadors of sustainable practices.

Academic & Research

The SKIO campus map (Figure 11), presented on the next page, will be referenced throughout this section.

Academic & Research: Boats

Boats are a keystone of the campus infrastructure for both MAREX and SKIO. Both entities rely on vessels to conduct education and research. Vital to SKIO and MAREX’s education mission is the ability to educate students within the environment they are learning about. Moreover, research teams require access to open waters, estuaries, islands, and marshes for data collection.

SKIO’s 92-foot R/V *Savannah* is a substantial part of the campus infrastructure, carrying an array of scientific equipment to provide overnight educational and research opportunities anywhere from inshore waters to beyond the Gulf Stream (SKIO 2015). The vessel is expensive to charter, so it is only used when its capabilities are needed. For most inshore operations, SKIO’s R/V *Jack Blanton* and two Carolina Skiffs are sufficient. These trailerable boats require access to the boat lift on the main dock (see Appendix, Figure 40). They are used on inshore waters and frequently shared with other USG entities.

Figure 11: Current SKIO campus map (SKIO 2018).

MAREX also could not perform its valuable education and public outreach functions without its primary vessel on campus, the 43-foot R/V *Sea Dawg* trawler. When outreach programming includes a boating component, students embark the *Sea Dawg*. The *Sea Dawg*, skiffs, and SKIO's boat lift are often used by Shellfish Lab researchers as well.

GRNMS administration uses its two boats frequently because the reef is located off Sapelo Island, a two-hour boat ride south of Priests Landing where the boats are stored and launched. The R/V *Joe Ferguson* is typically accompanied by the smaller R/V *Sam Gray* for support. The DNR law enforcement fleet is stored at Priests Landing and launched from the Main Dock (Elliot Lam, Zoom meeting, March 27, 2020). The Georgia Aquarium also utilizes the dock to collect specimens for exhibits in Atlanta, and sometimes film production companies launch boats from there as well.

Academic & Research: Docks

Boats, of course, require the means to be embarked and debarked by passengers, stored, fueled, and maintained. The logistics of boat access are vital when time is of the essence—scientists need to bring samples back to the lab for immediate analysis, and student groups must frequently embark and debark with efficiency.

MAREX and SKIO vessels both use SKIO's fuel dock in the core campus area, which has been amended over time. When the Roeblings arrived in 1936, they moored the Black Douglas here on the "North Dock," (Messer et al. 2018). Antebellum Modena Plantation's dock was likely in the same location. There is a Smart Sea Level Sensor installed on the fuel dock, furthering its function as support for education and research (Smart Sea Level Sensors 2020).

Like the Fuel Dock, the Main Dock was in its current location during the Roebling era, formerly known as the "Freight Dock," (Messer et al. 2018). SKIO scientists and students stage equipment, store, and embark vessels from this dock. All campus vessels utilize the dock at some point because of the boat lift (see Appendix, Figure 40). The DNR launches its law enforcement fleet from here, and GRNMS sometimes launches from here as well (Elliot Lam, Zoom meeting, March 27, 2020). The Main Dock has recently experienced concerning high tide and storm-induced flooding during a 2015 king tide (Figure 12) and Hurricane Matthew (Dr. Clark Alexander, on-site meeting, December 13, 2019).

Figure 12: October 2015 king tide flooding covers the Main Dock, cutting off access to boats and equipment (Skidaway Campus Notes Blog 2015).

The MAREX Dock lies west of the other two docks. This dock is the newest of the three core campus docks, installed in the 1970s and expanded since. It is used for education and outreach programs, as well as Shellfish Lab research.

The 1972 Priests Landing dock is located on the eastern side of Skidaway Island on the Wilmington River near Wassaw Sound, providing closer access to deep ocean waters. With this benefit comes the drawback of rougher waters than the protected shoreline of the core campus, so SKIO is unable to moor the R/V *Savannah* here. Because of the proximity, GRNMS keeps both of its boats here. Georgia's DNR Law Enforcement and the Georgia Aquarium use the dock to moor and/or launch their boats as well. The Priests Landing dock and complex is a hub of collaboration, in addition to providing income through rental space. However, the concrete pilings supporting the dock are beginning to fall apart because of the rusting rebar within them. Efforts are underway to stabilize the pilings by encapsulating them (Dr. Clark Alexander, on-site meeting, December 13, 2019).

Academic and Research: Buildings

The campus buildings are mostly concrete masonry unit (CMU) and brick construction from the 1970s, shortly after OSCA was formed, in addition to 15 historic structures from the Roebling era (Messer et al. 2018). The 1970s era buildings—the first new buildings on the campus—stand in functional condition, though CMU construction is not ideal for proximity to saltwater, due to the corrosive effects of salt spray.

One of the most significant and iconic buildings on campus is the Ocean Sciences Instructional Center (OSIC), formerly known as the Cattle Barn (#22). In 1948, Robert Roebling designed the 9,800-square foot barn for showing cattle in a circular layout to promote greater efficiency (Messer et al. 2018). For many years after USG acquired the property, the barn was used for equipment storage (Hussey, Gay, Bell & DeYoung 2004). SKIO recently renovated the barn's interior into functional, educational laboratories, classrooms, and study spaces. It will also serve as an events center.

Before the completion of OSIC, events were hosted at the Roebling House (#4) (see Appendix, Figure 36). During the first years of the campus (1968-1970), it held OSCA's administrative offices (UGA MAREX 2020d). The Roeblings originally built the structure, their first on the property, as a gymnasium—but the urgency of World War II's impending arrival in the United States caused them to feel safer moving in directly from the Black Douglas in 1941. From the beginning, the gymnasium's construction was rushed, as the Roeblings were not the only Americans scrambling for building materials. Despite 2017 interior renovations via the Lowe's Heroes program, its less-than-optimal construction quality makes it even more vulnerable to high winds and storm surges (SKIO 2018). It also occupies one of the lowest, most flood-prone areas on campus, though it may be one of the most historically significant remaining buildings.

In 1970, the Dorothy Roebling Laboratory and Administrative Building (Roebling Lab, #1) became the first new campus building (UGA MAREX 2020d). This large brick building houses many of SKIO's offices and research labs, supporting both academics and research.

Most of the buildings on SKIO's campus function dually as academic and research facilities because academics are integrated into research. The Post-Doc Facility (#18) is located northwest of the Roebling Lab, and houses the offices of post-doctoral researchers on campus. The Saltwater Lab (#7) lies north of the Roebling Lab. Interior biological research functions rely on the campus-wide seawater circulation system (Charles Hartman, Zoom meeting, April 15, 2020). North of the Saltwater Lab is the brick Geochemistry Building (#2), situated on a ten-foot high building pad close to the coastline. The Collaborative Teaching Lab (#16), formerly a part of the BERM complex (#6), is adjacent to Marine Ops A (#11).

To the southwest of the Roebling Lab, the Marine and Coastal Science Research and Instructional Center (MCSRIC, #19) is a LEED Gold-certified building completed in 2009. It represents innovation toward achieving more sustainable—if not necessarily resilient—practices on campus. The building is located on a high point of SKIO's campus, directly adjacent to the McGowan Library (#17). Providing modern research and instructional space, MCSRIC is instrumental for SKIO's functional performance. Many of the research labs are headquartered here, as well as offices, instructional spaces, a conference room, and other workspace (Sullivan 2009). MCSRIC hosts campus personnel, visiting scientists, and students from throughout the USG, as well as some of SKIO's most valuable technology, including the Skidaway Institute Scientific Stable Isotope Laboratory (SISSIL) and the Laboratory for Imaging Microbial Ecology (LIME).

Situated in close relationship to MCSRIC is the John McGowan Library (#17). As information is digitized and the pace of scientific advancements quickens, books are becoming defunct as scientific research tools. SKIO plans to move most of the books to storage and convert the library into a study space (Dr. Clark Alexander, on-site meeting, December 13, 2019). The McGowan Library currently functions as an event space as well, with an auditorium and conference room.

Within the MAREX campus area, research is conducted at the Shellfish Research Laboratory (#28), which was built in 1972 then expanded in 1989. The algal greenhouse behind the main facility was constructed in 1990 (Hussey, Gay, Bell & DeYoung 2004). Home to Georgia's first oyster hatchery, the facility houses specialized aquaculture equipment, offices, laboratories, and instructional space (UGA MAREX 2020e). It accommodates large tanks to grow oysters and algae, which are fed by the seawater circulation system.

On McWhorter Drive about a quarter mile south of the core campus area, the GRNMS headquarters (#32) is located in a forest clearing. GRNMS has two buildings: a storage warehouse and an office, both constructed during the 1950s and renovated in 1997 (Hussey, Gay, Bell & DeYoung 2004). From these facilities, the GRNMS team processes field data, creates maps and outreach media, and coordinates dive/vessel operations (Elliot Lam, Zoom meeting, March 27, 2020). The area is shared with Georgia Southern's satellite campus building (#31). This 1955 barn was recommended for demolition in 2004, which implies that it is degrading rapidly and will probably not be able to withstand stronger storms in the future (Hussey, Gay, Bell & DeYoung 2004).

The Priests Landing complex is located about two miles south of the main campus. Several warehouse-like buildings house GRNMS, SKIO, and other UGA entitites' personnel and equipment. SKIO's facilities include three bare labs for general use and office space for visiting faculty in the summer (Dr. Clark Alexander, on-site meeting, December 13, 2019).

Academic and Research/Public Service and Outreach: Marine Education & Aquarium Building

The direct outreach and education functions performed by MAREX are stationed at the 19,000-square foot Marine Education & Aquarium building (#27), built in 1974 (Hussey, Gay, Bell & DeYoung 2004). Most of the time, this center serves as the public interface for the entire campus (Anne Lindsay, on-site meeting, February 28, 2020). It contains an aquarium, teaching labs, classrooms, an auditorium, and offices.

The aquarium is Georgia's first saltwater aquarium, featuring only local estuarine and marine species, some of which reside at Gray's Reef. Some of MAREX's educational programs are conducted indoors at the facility. The seawater circulation system is used to sustain the aquarium animals and provide circulating water for classroom lab activities.

MAREX uses the space inside its primary education & outreach facility to capacity and fulfills many of its functions outside. This important outdoor infrastructure will be discussed later in the chapter.

The building is aging and the concrete masonry units (CMUs) and metal from which it is constructed are corroding due to saltwater in the air—this has been an issue since 2004 or earlier

(Hussey, Gay, Bell & DeYoung 2004). Despite temporary fixes, the problem will worsen. Fortunately, the building has never experienced flooding, but this could occur with stronger storms and higher storm surge. Currently there are plans to extend the building about 30 feet toward Skidaway River to accommodate a new lobby and educational space (Anne Lindsay, on-site meeting, February 28, 2020). Though permissible by Chatham County law, this may be unadvisable given the building's condition and impending SLR.

Housing

Housing: MAREX Dormitory & Cafeteria

MAREX's dormitory (#30) houses most of the program's fellows, interns, and students who are visiting from out of town. The corroding, CMU-construction, two-story dorm from 1972 has 24 rooms. MAREX is planning to demolish this structure and build a new dorm adjacent to the cafeteria (#29), which would comfortably accommodate up to 100 students and ten staff. The dorms are used most heavily during the school year, for one to three nights per group, from September to May—unfortunately coinciding with hurricane season. MAREX cancels programs in advance when a hurricane is predicted, but this alters their schedule and income. (Anne Lindsay, on-site meeting, February 28, 2020)

Alongside the dorm there is a cafeteria similar in construction to the dorm that will also require replacement soon, but the dorm is a higher priority. The cafeteria operates only when students are on campus. It serves an education function, too—summer camp activities frequently occur in the open-air screened annex. (Lindsay 2020)

Housing: SKIO Historic Apartments

SKIO hosts interns, students, and visiting faculty throughout the year. The busiest time of year for housing is during the summer, when one to three graduate students live on campus and

20-30 undergraduates visit throughout the season (Dr. Clark Alexander, on-site meeting, December 13, 2019). Depending on availability, SKIO and GRNMS guests can stay in either historic Modena Plantation apartments (#20, 22, 23), or recently built facilities (#21, 24).

The historic apartments are spacious enough to be comfortable, and maintained in good working condition. They generally provide picturesque views of the marsh or forest, and ideal proximity to SKIO's main campus. However, SLR presents a growing concern because of their low elevation. They are dispersed throughout the historic section of campus and can only accommodate about seven guests total. The Rice House (#20) and Thomas & Martin duplex (#23) were built in the 1950s, and the Baggett Apartment (#22) is original to the cattle barn, completed in 1948. (Messer et al. 2018)

Housing: SKIO Modern Construction

The newer housing at SKIO is dormitory-like, mostly used for student groups, and provides a higher volume of accommodations. These two buildings are in the woods, separate from the rest of campus. The Quadruplex (#24) was built in 1999, and the Commons (#21) was built in 2006 (Messer et al. 2018). In total, they can accommodate about 16 people. Both facilities are in very good condition, and their relatively high location makes them less vulnerable to the effects of SLR.

Support: Maintenance/Mechanical Shops, Storage

Support: Shops

Another necessary support system that all campus entities rely on is the maintenance and fabrication/mechanical shops. SKIO is the steward of campus, taking care of all facilities. This includes routine maintenance, custodial duties, and repairs. Substantial resources must be devoted to these tasks. Also, researchers at the Shellfish Lab and various SKIO labs need to have specialized equipment fabricated or customized for their projects. Scientists design the equipment they need, and machinists build it using the equipment at the mechanical shop (Charles Hartman, Zoom meeting, April 15, 2020).

The mechanical shops (#8, 9, 10) are a hodgepodge of structures dating from the Modena Plantation era in the 1940s, to 2005. Each building was amended over time. The shop area is situated within the low-lying historic core of campus. The area also houses the campus' primary generator (Charles Hartman, Zoom meeting, April 15, 2020).

Support: Storage

With so much specialized equipment, not all of it can be in use at one time. Storage facilities are vital to retaining these resources. Storage is dispersed throughout many small historic buildings—perhaps it was more practical and economical to use them this way than to retrofit them for modern functions. SKIO's chemical solvents are stored in what was once Modena Plantation's brick fire house, built in the late 1930s or early 1940s (#15). Gas bottles are stored in a small wooden building from the 1950s, adjacent to the Post-Doc Facility (#14) (Hussey, Gay, Bell & DeYoung 2004). The small 1940 fuel oil storage building from Modena Plantation is currently in use as the Marine Emergency Spill Response Building, adjacent to the fuel dock (#13) (Messer et al. 2018). Given that the essential seawater circulation system draws water directly from the river bordering campus, the equipment stored here is especially important.

It will become progressively more challenging for SKIO to keep their vital storage and maintenance infrastructure intact. Because most of these buildings are located in historic buildings on the Modena Plantation side of campus, they are at low elevations. They have experienced high tide and storm flooding, which will only worsen as sea level rises.

GRNMS requires storage at Priests Landing because of their frequent research-oriented dive operations. They use a small metal building called "The Grouper" to store dive equipment, including compressed air tanks. Also, the warehouse and office attached to their main building is used as storage for old documents, educational materials, vessel maintenance tools and parts, and diving/ROV equipment. (Elliot Lam, Zoom meeting, March 27, 2020)

Landscape

Landscape: Campus Layout

The campus evolved from the network of roads and buildings put in place by the Roeblings. The layout of the roads may have been in place even earlier, during the antebellum era. This layout was, and remains, relatively informal due to its farming origins, devised to meet needs in the most efficient way possible (see Appendix, Figure 37). The road networks were formalized and paved once OSCA gained ownership of the land. If it remains unaltered, the layout will help lend historic significance to the campus, providing support for any potential NRHP listings. (Messer et al. 2018)

When UGA first acquired the campus, OSCA moved into the Roeblings' buildings out of convenience. The administrative offices originated in the Roebling House. Expansion of the campus with new facilities moved westward, with the Roebling Lab marking the first new construction. Some buildings were constructed as infill within the historic area as well. As the campus grew, some expansion occurred toward the south (the Quadruplex and Commons housing area) and upland toward the southwest (the Library and MCSRIC).

Because of this institutional progression and necessity for similar functions to be grouped together, the campus can be divided simply into the SKIO and MAREX zones. Within the SKIO zone, there is the historic core and the network of newer buildings, though most are functionally interconnected.

Landscape: Outdoor Education

A significant amount of MAREX's active and passive education features are found outside in the campus landscape. In front of the Marine Education & Aquarium building, the Skidaway Learning Garden displays some of coastal Georgia's native plants and creates a welcoming entryway with small water features that house aquatic animals.

Behind the Marine Education & Aquarium building, there is a picnic area overlooking the bluff, used by school groups and informally. A nearby pavilion provides a sun and rain shade for learning and picnicking. The picnic area funnels into the Jay Wolf Nature Trail.

This 1.5-mile, ADA-compliant loop trail with informational kiosks allows universal access through a maritime forest and onto a boardwalk in the marsh. Bridges provide access to much of the trail, but they are increasingly threatened by high tide flooding. Along the trail are several vacant 1930s cabins that were formerly used as part-time residences by Modena Plantation workers (see Appendix, Figure 41). Most of them are deteriorating in the forest. Between 2006 and 2008, one of them was rehabilitated to become the "interpretive cabin," providing informational signage inside about the site and coastal ecosystems. The cabin lies dangerously close to high tide flooding and future storm surges. Near this section of the trail, there is also an iconic live oak, probably the oldest on the campus. Because of its close proximity to the shore, it will soon be in danger of saltwater inundation. The trail is attached to the SEGA-SORBA trails, though the Jay Wolf loop itself terminates in a recreational field adjacent to the dorm and cafeteria. (Anne Lindsay, on-site meeting, February 28, 2020)

Landscape: Bulkhead

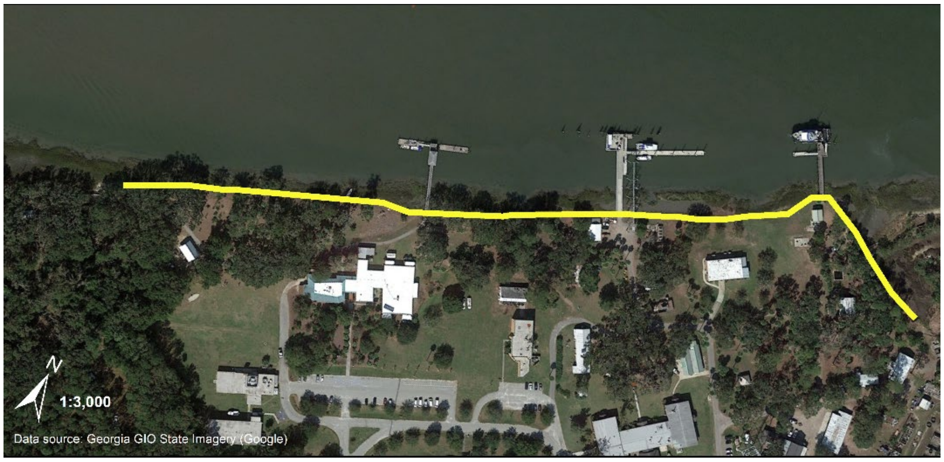

Figure 13: Skidaway campus bulkhead location as indicated by yellow line.

The approximately 1,800-linear foot bulkhead (Figure 13) running along the Skidaway River and high marsh shoreline of the core campus area provides flooding and erosion protection, but not without problems. During the early 1980s, it was installed in an area formerly dominated by salt marsh species (Wakefield 2016). Currently, between 25 and 75 feet of marsh remain fronting the bulkhead, exemplifying the "coastal squeeze" phenomenon (Borchert et al.

Figure 14: One of a few washout locations behind bulkhead (Jon Calabria, 02/27/2020).

2018) (see Appendix, Figure 40). While the bulkhead has prevented marsh from migrating onto the core campus so far, it is aging and requires constant, costly repairs like many other "hard" shoreline stabilization efforts (Charles Hartman, Zoom meeting, April 15, 2020, Sutton-Grier et al. 2018). Funding for these projects is challenging to procure (Charles Hartman, Zoom meeting, April 15, 2020). The bulkhead has begun to fail in a few locations where washout has occurred (Figure 14).

Landscape: Berm

Figure 15: Berm location bracketed in orange. Purple lines show adjacent privately-owned parcels.

The bulkhead connects to an unmaintained, 700-foot long earthen berm running parallel to the shoreline between SKIO's campus and the private property to the north (Figure 15). Low marsh fronts the berm and a tidal creek enters through a culvert with a flap gate into an area of irregularly flooded high marsh. The berm and flap gate largely sever the connection between the river and marsh behind it.

While the berm has been successful in preventing campus flooding on the low-lying historic part of campus in the past, water has entered through and over the culvert and inundated the area during recent storms and spring tides.

Without the berm there would be a gradient between river, low marsh, high marsh, and upland. Storm surge overtopping the berm into the high marsh behind it could kill many of the high marsh species because they are not adapted for extended exposure to high salinity and drainage is poor (White and Kaplan 2017, USFWS 1983).

Landscape: Landscaping

The landscaping of the core campus area is mainly turfgrass, shaded by mature live oaks and palmettos from the Modena Plantation era or before (Messer et al. 2018) (see Appendix, Figures 37, 39). The public entryway to the campus, a left turn off McWhorter Drive, is lined with an allee of young live oaks, planted circa 2000. Aside from the Learning Garden, there are sparse ornamental foundation plantings around many buildings, including common landscape plant species for USDA Zone 8b such as wax myrtle (*Myrica cerifera*), sago palm (*Cycas revoluta*), oleander (*Nerium oleander*), century plant (*Agave americana*), and azaleas (*Rhododendron* spp.). The beds are mulched with pine straw.

The Roeblings established a landscaped area near their residence which is well-preserved and tended (see Appendix, Figure 42). This historically significant landscaping includes brick walkways, terraces, walls, a swimming pool, and a covered patio with garden beds and turf bordering the hardscape. The area extends far toward the Skidaway River and high marsh at the northeastern tip of campus, making it especially vulnerable to SLR, despite its historic value.

At SKIO, landscaping tasks such as mowing the many acres of turf are completed by one in-house employee. In coming years, they may switch to hiring an outside contractor (Charles Hartman, Zoom meeting, April 15, 2020). MAREX uses an outside contractor for the landscaping around their five acres of outdoor space (Anne Lindsay, on-site meeting, February 28, 2020).

Landscape: Other Features

A few unique features within the campus landscape stand alone. One of these is the syrup boiler, a conspicuous open hexagonal pavilion with a brick fireplace and chimney (see Appendix, Figures 37, 39). It was likely used to process sugarcane syrup at Modena Plantation. Another feature is the brick livestock watering trough, the only one of three originally on campus from the Roebling era, which were located in the open pasture near the entry (Messer et al. 2018). There are also remains of a moonshine still along the current Jay Wolf Nature Trail (and probably in other places in the woods), and oyster shell middens from the original Creek inhabitants in the vicinity of the Priests Landing complex (Keene 2002, Messer et al. 2018).

The historically significant Hodgson House and Whitted Residence are also located in the low-lying Modena Plantation area. Both are prefabricated buildings from the Hodgson company, which were shipped to the island in component pieces, similar to Sears catalog homes (Messer et al. 2018). The two buildings occupy a prominent position, flanking the sides of the pathway from the Roebling Lab to the Main Dock. The buildings were used as housing until they were abandoned almost ten years ago, and have incurred significant termite damage since (Charles Hartman, Zoom meeting, April 15, 2020). They will soon be torn down (Dr. Clark Alexander, on-site meeting, February 28, 2020).

A newer, yet similarly defunct area lies at the back of the campus. The former bioremediation research complex or “BERM” consists of several unused research plots and storage sheds around a rectangular area enclosed by a low earthen berm. It was last used for research before 2005 and has recently been cleared to create new open space, which will be advantageous for marsh migration.

CHAPTER 4

MANAGEMENT

Adaptive Management

Skidaway campus decision-makers face unique planning challenges due to SLR. Not only must they address conventional campus planning challenges (e.g., growing student body, rapidly changing technology), but they must plan for resilience in the face of SLR, accounting for high levels of uncertainty surrounding future conditions. Stakeholders are required to consider risks without a solid time frame or level of certainty. Factors such as the amount of SLR over time, storm frequency and severity, and marsh migration are impending, but planners can only work off projections to address them. Moreover, storm-induced damage could thwart adaptation efforts at any point.

What is adaptive management?

While these challenges are difficult to face, adaptive management (AM) has the power to help stakeholders plan for them, as embracing uncertainty is inherent to the process. The focus of this systematic, iterative approach is to learn about how a system functions and adapt it to changing conditions and results of prior management actions through a collaborative process. AM is not passive trial and error—there are necessary, consistent actions required during all steps of the process (Williams 2009).

The first step is stakeholder engagement, in which decision-makers identify the scope and nature of the issue, then define management objectives. Because of the uncertainty surrounding the system to be managed (in this case, SLR-related factors), these objectives must be clear, measurable, and specific. Next, stakeholders must generate a set of potential management actions, keeping in mind the difficulty of predicting cause-effect relationships. They will then use models to predict the behavior of the system and/or management actions. Before implementing the actions, stakeholders also must develop a monitoring plan to provide relevant data (performance metrics) to inform future management actions. At pre-determined decision points, stakeholders reconvene to analyze the data, comparing predicted and observed changes in the system to evaluate the accuracy of the models and effectiveness of the actions. The iterative process repeats—stakeholders choose new action(s), use models to predict consequences, develop and implement a monitoring plan, and reconvene at the next decision point (Figure 16).

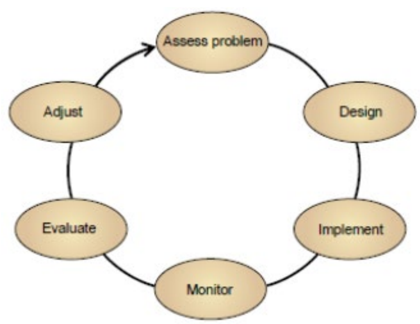

Figure 16: Adaptive Management Cycle (Williams 2009).

Constant, ongoing monitoring and assessment efforts comes at significant cost, but substantially improved future decision-making justifies the resources expended—and due to the nature of the Skidaway campus functions, there may be ways to work monitoring into pre-existing programs.

The Skidaway campus provides a promising context for AM. There are certain conditions that warrant the approach, most of which the campus meets. First, it must involve real-world choices among feasible management alternatives whose consequences vary. There must be opportunities to apply learning as well, through iterative decision-making (Williams 2009).

University campuses are always changing and applying new knowledge—some of which is generated in-house—to decision-making because of variations in funding and priorities. UGA's strategic plan states an intention to become a "living laboratory where sustainability is researched, taught, tested, and constantly refined," (UGA Strategic Planning Committee 2012). Employing AM at the Skidaway campus provides a perfect opportunity to do so.

AM can be especially powerful when researchers and decision-makers work together. Scientists like the stakeholders at SKIO can suggest modifications to projects, while other decision-makers can identify new questions (Zedler 2017). Working together they will develop sound new priorities for future management approaches. Recent literature has situated science in an even more central location within AM, because of the importance of proper evaluation criteria and monitoring programs (Zedler 2017). With their expertise in isolating specific variables, SKIO scientists may be able to distinguish the effects of management actions from the impacts of SLR (Wigand et al. 2017).

For AM to work, management institutions must be stable enough to measure outcomes and use the results at later times (Williams 2009). Though UGA and SKIO will undoubtedly undergo leadership changes, research avenues on campus (biological, chemical, physical, and geological oceanography) and the missions of research, education, and outreach will remain constant.

In successful adaptive management, understanding must be acquired quickly enough to apply to subsequent management decisions. Iterations of the process will be faster if knowledge is acquired more efficiently—the best way to do this is through the principles of scientific experimental design. If funding and interest prioritize other types of projects for researchers, it could be feasible for outreach and education programs at MAREX and/or students at SKIO to take on monitoring efforts. Implementing monitoring plans would support the research, education, and outreach functions of campus.

Another qualification for successful AM is a high “value of information” for decision-making. “Value of information” refers to how much the expected performance of a managed system would improve if uncertainty were reduced (Williams 2009). Although AM offers no way to reduce the uncertainty surrounding SLR, reducing uncertainty about the performance of management actions in the face of its impacts would be extremely valuable, justifying the cost of monitoring. It could significantly reduce risk of infrastructure damage during storm events and even help retain campus land.

However, there are potential barriers and drawbacks to the AM approach, in general, and for the Skidaway campus in particular. Some of them stem from the physical disconnect of the campus with the rest of UGA, its parent organization. Stakeholder opinions on objectives and decisions vary widely in any context, despite the best efforts at modeling potential consequences. In this case, stakeholders with direct experience working on the campus could have different objectives for its management than those who may work for UGA or USG in a more general capacity, from Athens or Atlanta. Reaching consensus could be challenging.

There is also a risk of focusing too heavily on monitoring while neglecting overall outcomes and the decisions that must be made using them (Williams 2009). A call for “more science” may be an intentional procrastination tactic to put off difficult decisions (Allen and Gunderson 2011), or an unintentional product of geographic distance between stakeholders. It may be difficult for stakeholders and planners to meet frequently and for long enough to effectively collaborate at decision points, though online meetings can help mitigate this. Failures in collaboration limit and impede AM experiments (Allen and Gunderson 2011).

Another challenge of working in a university context with an inconsistent, limited budget is that decision-makers might be risk-averse, unwilling to tackle the larger-scale challenges of SLR on the campus (Allen and Gunderson 2011). For instance, small management experiments like a short stretch of living shoreline might take place, while the hard truth of frequent campus flooding remains unaddressed.

Depending on the management action(s) chosen, timing could present a challenge. It may take years of monitoring to determine whether an action is effective. Commitment to monitoring and evaluating a project throughout its lifetime is imperative to success in AM, but the constant changes in university budgeting and grant funding could render this commitment impossible. Monitoring over the course of many years can be costly, individual stakeholders will change, and the effects of SLR may not afford that amount of time. (Williams 2009, Allen and Gunderson 2011)

Overall, the Skidaway campus is a strong candidate for AM because of its focus on science, variety of stakeholders, uncertainty surrounding SLR impacts, and potential ability to weave a monitoring program into pre-existing campus functions. If campus stakeholders were to write and implement an AM plan tailored to SLR impacts, it would set a positive precedent for the Chatham County government and other coastal land managers.

The remainder of this thesis will integrate principles of AM, but it is not meant to be an AM plan, because stakeholders have been involved only minimally, through a limited number of semi-structured interviews. Instead of objectives, this thesis will recommend four guiding principles that could help stakeholders define objectives in the future, informed by literature review and analysis of the campus. Ultimately, stakeholders' values will inform the objectives. The thesis will build off the author's defined guiding principles to recommend management actions and models tailored to address the issues on campus. Developing these principles requires a holistic understanding of the interconnections between the component parts on campus.

Understanding Interconnections

Opportunities and challenges regarding campus infrastructure were addressed in Chapter 3.3, but a larger-scale analysis of the relationships between infrastructure is needed.

An overall look at the SKIO parcel divides campus functions and supporting infrastructure into relatively clear functional groups: SKIO, MAREX, GRNMS, and Priests Landing (Figure 17).

Priests Landing is the main point of functional overlap between all entities. Utilities and support/maintenance infrastructure (roads, shops, fuel dock, and sometimes the main dock) unite SKIO and MAREX as well.

The main campus SKIO and MAREX zones can be further subdivided in several ways. At SKIO, historic buildings are located in the low-lying historic area and newer facilities are typically located on higher ground (Figure 18). There are some exceptions: additions to the maintenance shop complex, the BERM area, the teaching laboratory, and Marine Ops A. Figure 19 shows that SKIO's core area consists of its academic and research buildings. Housing is concentrated mainly in the southeastern corner of the main campus, although the historic Thomas & Martin duplex is further away. This is one of the most vulnerable buildings to SLR due to its low elevation and marsh proximity, which will soon force consolidation of housing to the southeastern corner. Maintenance, support, and storage infrastructure span the historic and newer sections of the campus, between lower and higher elevations. Marine Ops B and the gas

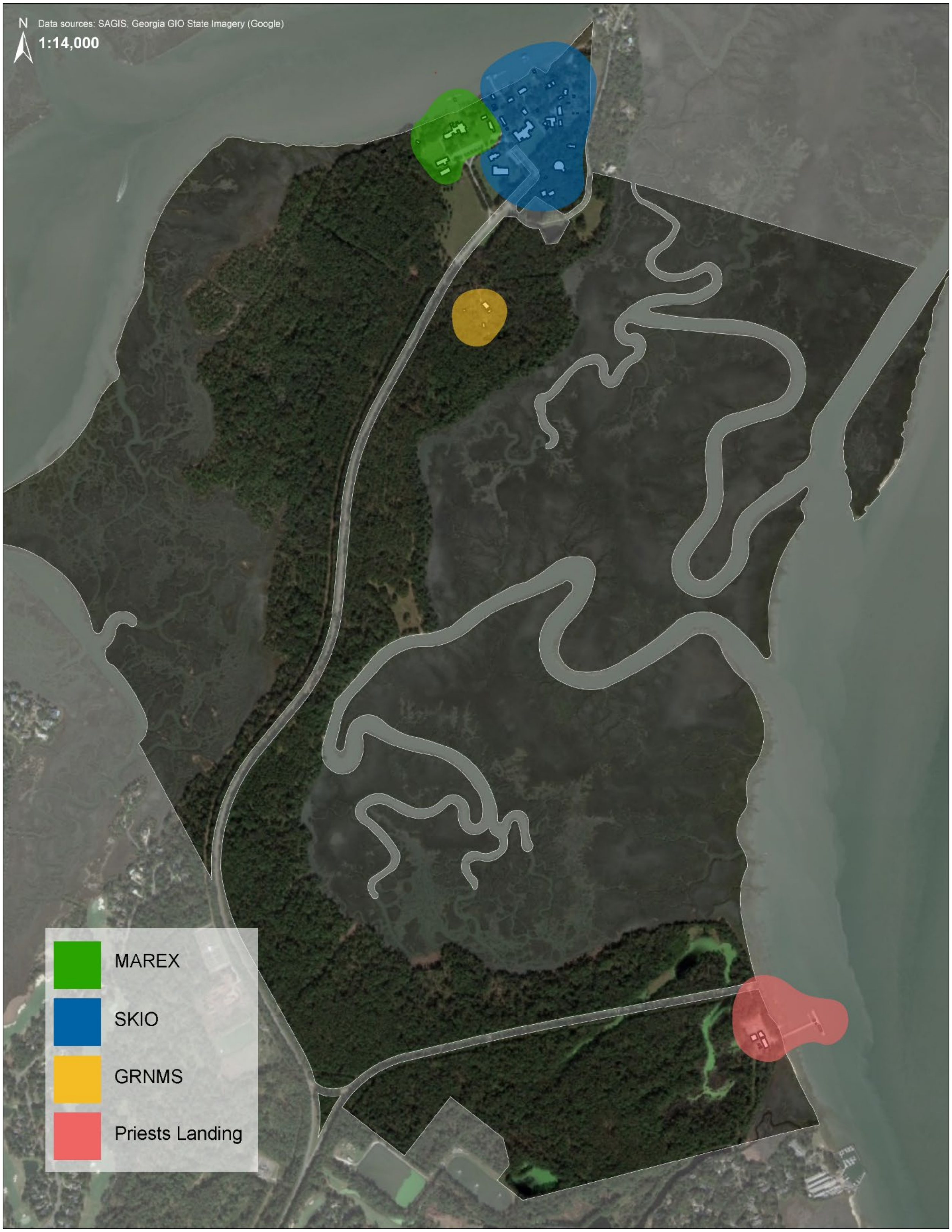

Figure 17: Large-scale campus function and infrastructure zones.

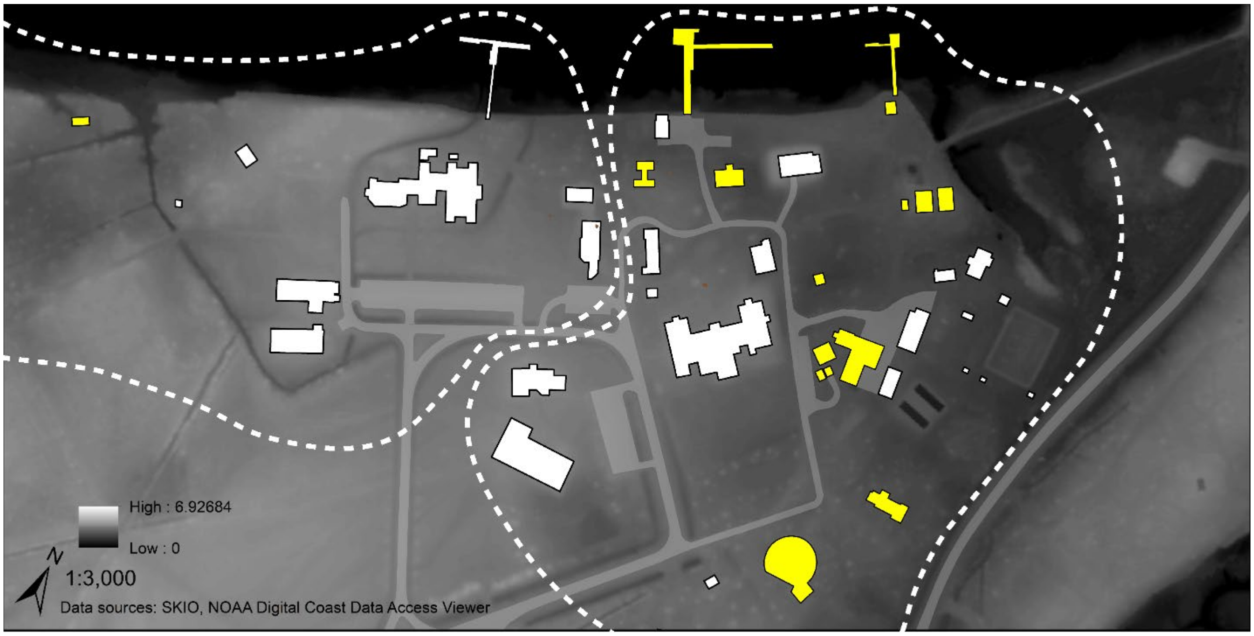

Figure 18: Main campus area divided into MAREX (left) and SKIO (right) zones on an elevation map. Lower elevations are darker, higher elevations are lighter (scale in meters). Historic Modena Plantation structures are depicted in yellow.

bottle storage facility are disconnected from the rest of the area, but Marine Ops B must be next to the Main Dock. Docks, even the MAREX dock, are all connected by the vessels and their reliance on the fuel dock.

The main dock, fuel dock, and supporting Marine Ops buildings relate directly to the functions of most buildings. In general, the campus was built progressively onto higher ground, so many of the buildings that currently relate directly to the docks are further away—the historic buildings occupy closer areas. This may pose inconveniences, but it is advantageous given the future impacts of SLR.

The GRNMS and Georgia Southern satellite campus area are separated spatially from the rest of the campus. While GRNMS functions mostly separately from SKIO and MAREX, there is significant overlap between SKIO and Georgia Southern, which can make this disconnect inconvenient.

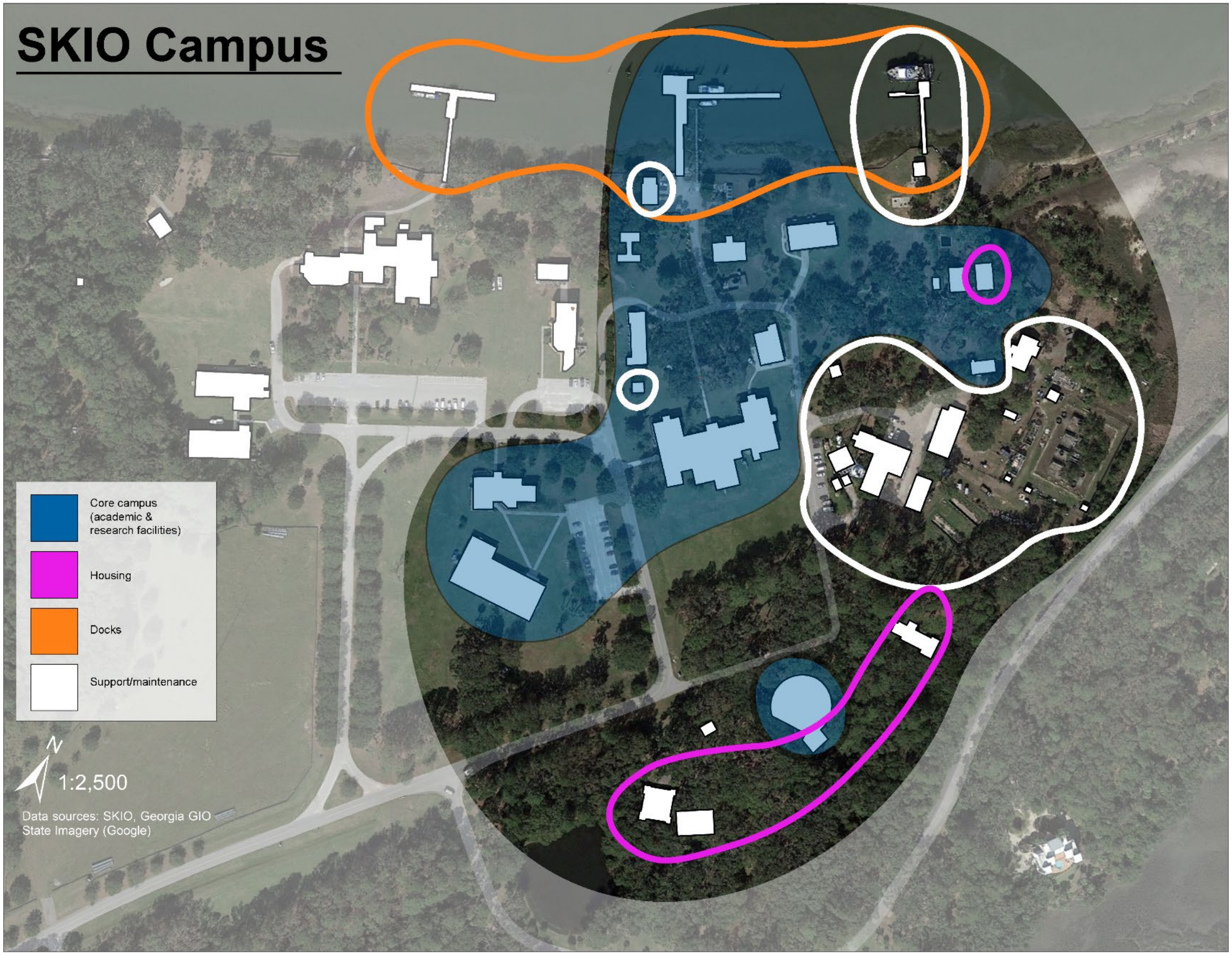

Figure 19: Schematic diagram of existing SKIO campus.

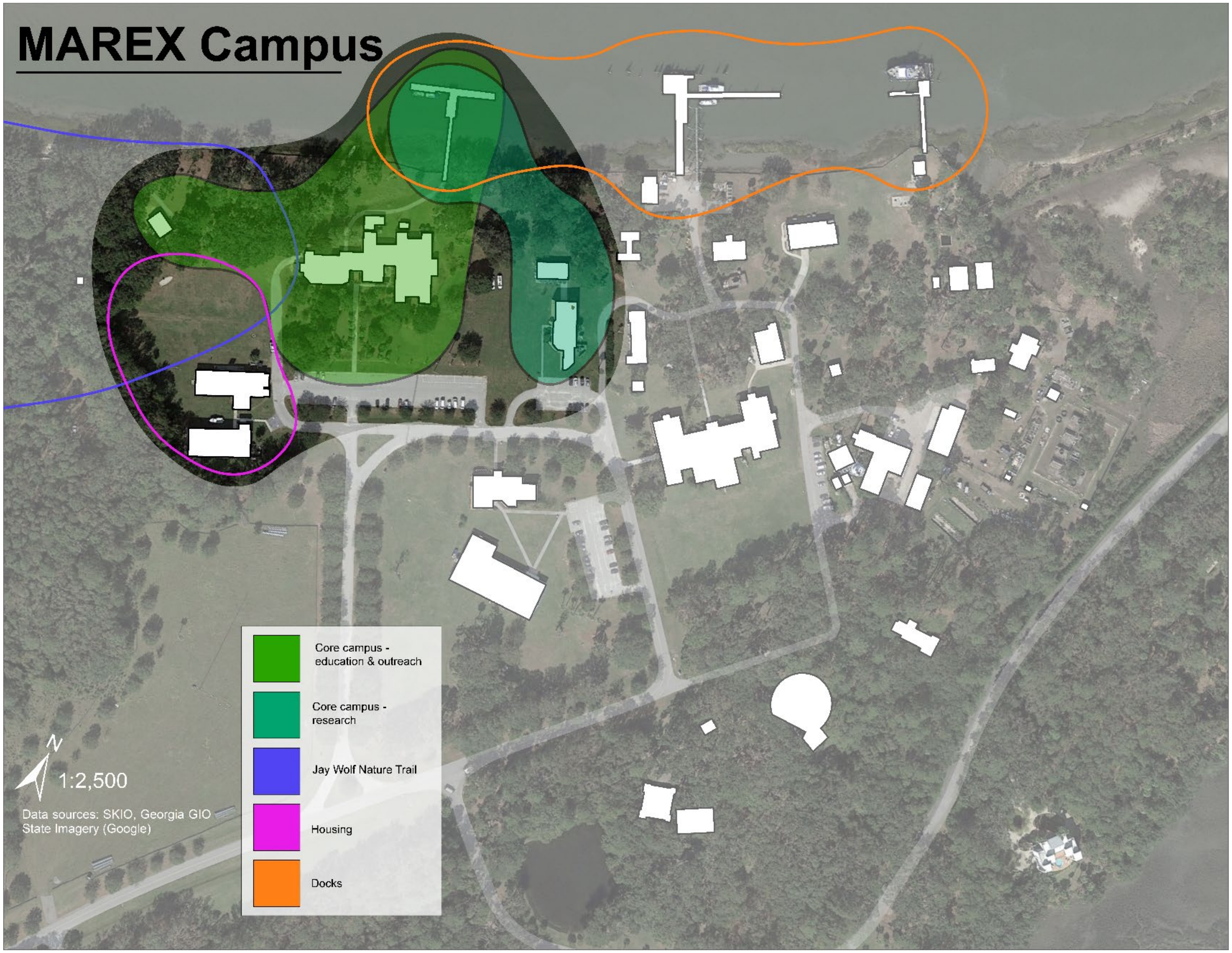

Figure 20: Schematic diagram of existing MAREX campus.

Figure 20 shows that the MAREX dock and fuel dock relate directly to the functions of most buildings as well. Unlike SKIO, MAREX's higher ground allows for convenient connection between buildings and docks, although the fuel dock is further away. The Marine Education & Aquarium building is located close to the dock, which is important for education, but the Shellfish Lab is inconveniently far away given its reliance on the dock. MAREX's education core is distinct from its research and housing areas, except for overlap at the dock and screened-in cafeteria annex. The Jay Wolf Nature Trail connects with the education core functionally although it is spatially distinct.

Guiding Principles

This thesis will recommend four guiding principles based on the literature review and analysis previously described. Author bias and lack of complete understanding of the campus, having never worked there for extended periods of time, may factor into the creation of the principles. It is imperative in AM that stakeholders convene to define their own objectives. The principles are meant to synthesize the information presented in earlier sections, in hopes of providing useful guidance to their process.

1. Focus on Functions

In order to continue research. education, and outreach on campus, stakeholders must focus on the functions that pieces of infrastructure fulfill, and then dynamically adapt the infrastructure system to fit these functions as sea level rises. The amount of usable space on campus will decrease when SLR claims land and buildings, but the uses of these areas can be re-mapped strategically to remaining spaces.

Many of the structures that SLR will impact are historically significant, but it may be impractical to save them all. The significance of these buildings tends relate more strongly to past functions of the land rather than current or future functions. A focus on functionality suggests that SKIO's limited resources may be better allocated to projects that support current missions than those of the past, though this decision is ultimately up to the entire group of diverse stakeholders, some of whom may be more inclined toward preservation of historic structures.

2. Favor Natural & Nature-Based Strategies

Another principle to guide future management actions is favoring natural, nature-based, and hybrid adaptations over "hard" shoreline stabilization. Not only do these "softer" strategies dissipate wave energy and reduce erosion, they can also provide co-benefits like the promotion of sediment accretion, habitat provisioning, water quality enhancement, and greenhouse gas mitigation (Mitchell, Bilkovic, and Pinto 2019, Polk and Eulie 2018, Bridges et al. 2015, Smee 2019). Alone, hard armoring decreases habitat, limits natural processes, and requires frequent costly upkeep (Sutton-Grier et al. 2018, Gianou 2014, Morris et al. 2018).

Using ecologically beneficial tactics to adapt to SLR would set a positive precedent for other educational institutions as well as coastal communities that are influenced by MAREX throughout Georgia. UGA's 2020 Strategic Plan states that "the University's campuses should be examples to others in reducing their environmental footprints," and that UGA "must demonstrate and promote leadership in sustainable living and learning," (UGA Strategic Planning Committee 2012).

3. Defend. Adapt. Retreat.

SLR adaptation or resilience plans often incorporate these three categories of actions (Sinay and Carter 2020, McCrehan et al. 2013). With guidance from MAREX, nearby Tybee Island is taking this approach, which was also outlined for coastal Georgia communities in a 2013 Georgia Tech studio project (McCrehan et al. 2013). Defense refers to holding onto land and protecting resources for as long as possible, usually using "gray" or "hard" infrastructure. Adaptation accommodates the effects of SLR and mitigates potential storm damage, often using natural or hybrid infrastructure (McCrehan et al. 2013). While many SLR plans bill themselves as "adaptation" plans, they do not always focus on the type of adaptation defined above; they may include defense or retreat strategies, too. Retreat, or "managed retreat," strategies involve phased, strategic migration away from the shoreline. A full retreat approach "assumes that the hydrological problems are far too advanced to solve with no viable alternatives present," (McCrehan et al. 2013).

At Skidaway, a full defense strategy is not advisable due to the reasons enumerated in Chapter 3. Adaptation and retreat will be the focus of the recommendations to follow.

4. Plan Incrementally

Many SLR adaptation or resilience plans operate in terms of time frames, assuming a certain increment of SLR will have occurred by a given point in time. This is economically practical, because financial allocations (e.g., grants, university funding) are typically attached to a time frame. However, the amount of SLR in any given time frame is unknown and depends on factors outside the control of planners. NOAA provides several scenarios illustrating extreme variation in the range of projections, especially on longer time scales.

Planning by SLR increments (a set number of centimeters, inches, feet, etc.) would be optimal because it can flexibly accommodate both gradual and catastrophic scenarios (McCrehan et al. 2013). Incremental planning is ideal for AM because it provides natural points for stakeholders to evaluate the effectiveness of prior actions and plan new interventions in an AM plan.

If the incremental planning method presents practical challenges for funding requests, time frames could be presented in conjunction with potential bracketed SLR increments. Another strategy is suggested in a NOAA technical report: planners can choose a plausible upper boundary or worst-case scenario to use as guidelines for overall risk assessment and long-term strategies, and also select a mid-range scenario to use for shorter-term planning (Sweet et al. 2017).

2000 is the beginning year of NOAA's SLR projections. Between 2000 and 2019, relative mean sea level (MSL) at the Fort Pulaski tide gage has risen about 0.5 feet. This change falls between NOAA's "intermediate low" and "intermediate" SLR scenario projections (NOAA Tides and Currents 2020). It is consistent with the recommendation that planners utilize a mid-range scenario for shorter-term planning, while allowing for using plausible upper boundary or worst-case scenario for long-term strategies. Six feet of SLR is an even increment that makes incremental planning straightforward and forms a "plausible upper boundary" for the end of the century if stakeholders decide to plan via time frame.

In this thesis, recommendations will be made using a three-phased approach in increments of two-foot, four-foot, and six-foot relative SLR since 2000. Six feet of SLR is an even increment that makes incremental planning straightforward and forms a "plausible upper boundary" for the end of the century. It is a generally accepted planning horizon for 2100 (Dr.

Clark Alexander, thesis defense discussion, June 30, 2020). The recommendations will be loose and adaptable, acknowledging that SLR will not necessarily progress as projected in models and that fast-moving emergencies could destroy existing or created infrastructure.

CHAPTER 5

MODELS, METHODS, AND RESULTS

A major tenet of AM is the use of models for guidance in future planning, to make predictions about how the system will respond to management actions. They can be qualitative, quantitative, conceptual, highly detailed, or anywhere in between (Williams 2009). In this special case involving high uncertainty levels about SLR and storm impacts in addition to management actions, models can also be used to predict these effects, which can inform future actions. Because of the wide variety of expertise within the Skidaway stakeholder group, using both qualitative and quantitative models is recommended.

Qualitative Models

Fuzzy-Logic Cognitive Mapping

One method that may be useful to help stakeholders understand interconnections and evaluate infrastructure importance within the campus system is a diagramming exercise called fuzzy-logic cognitive mapping (FCM). Developed in 1986 by engineer Bart Kosko, this technique can elucidate connections within a system by translating concept maps (qualitative static models) into dynamic, semi-quantitative models. Participants list system components then create a web of positive or negative relationships between them, assigning a degree of magnitude between zero and one to each connection. Mathematical formulas built into the model allow participants to examine what would happen to other components if certain components were to increase or decrease by a defined degree of magnitude, thereby enabling them to explore different scenarios. The free online software Mental Modeler automates this process. (MentalModeler 2020)

FCM is ideal for use with complex systems with few empirical data and high uncertainty—like those affected by SLR (MentalModeler 2020). It has been helpful for engaging stakeholders within coastal AM approaches (Gray et al. 2013, Henly-Shepard, Gray, and Cox 2015). Skidaway campus decision-makers are a diverse set of professionals—including university administrators, SKIO scientists, MAREX associates, campus planners—all of whom bring different perspectives, knowledge, and skill sets, which FCM can help integrate (Gray et al. 2013). Finding a way to accommodate everyone's strengths would be key to success in AM decision-making.

To test potential for applicability, a conceptual model for the campus was generated using Mental Modeler (Figure 21) (Gray 2020). The campus's main functions are represented in the green boxes, while system components are shown in gray. Blue directional arrows indicate positive relationships or increases, and orange represent negative relationships or decreases. The width of each arrow represents the degree of influence between the components.

Using the work of Gray et al and Henly-Shepard et al as precedents, relationship strengths were set as listed in Table 1. The model has 16 components and 71 connections.

Table 1: Values used for strength of connections between components (adapted from Gray et al 2013 and Henly-Shepard, Gray, and Cox 2015).

Type of connection	Strength of connection
High or strong positive	1
Medium positive	0.5
Low positive	0.25
No relationship	0
Low negative	-0.25
Medium negative	-0.5
High negative	-1

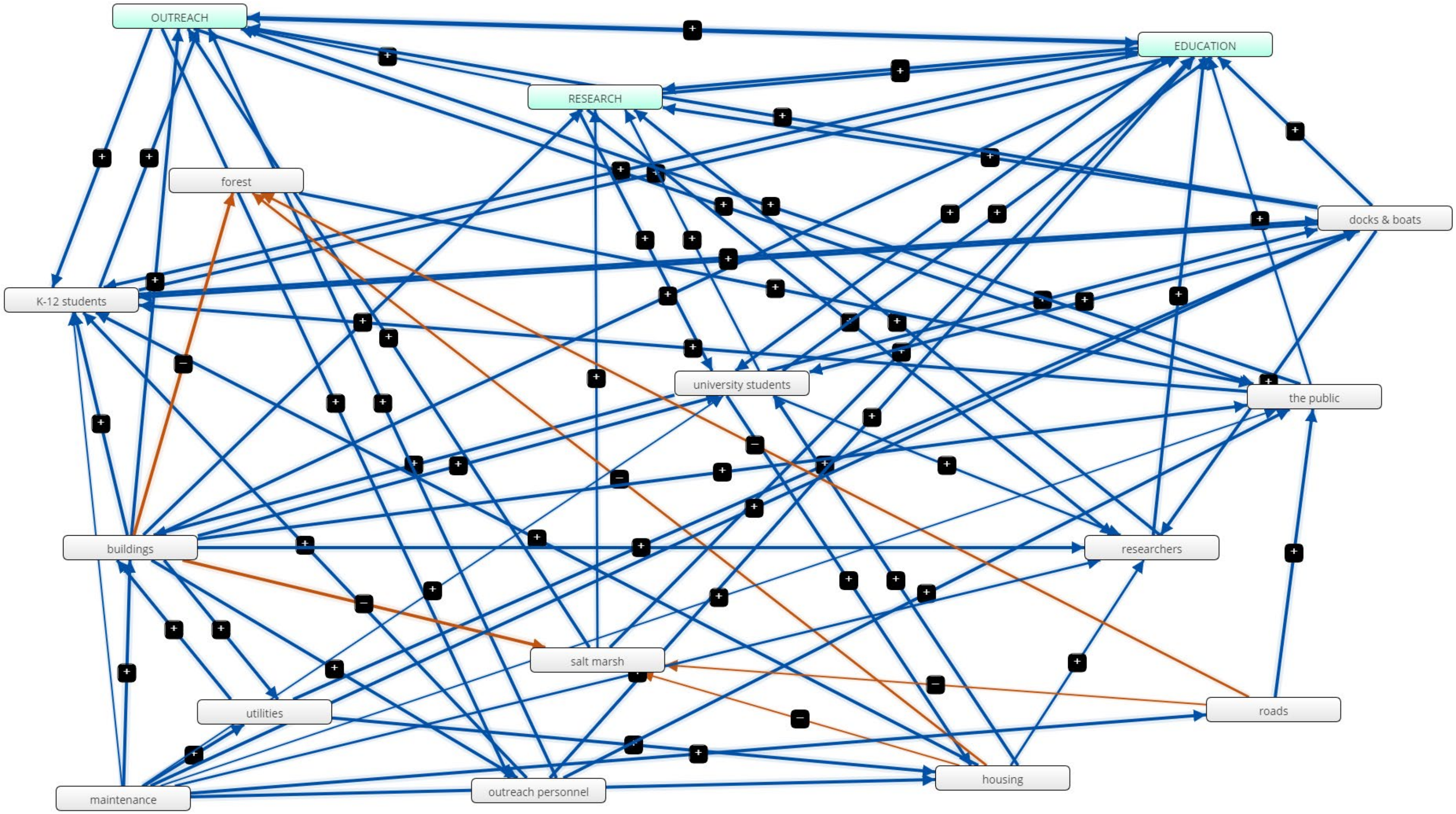

Figure 21: Campus system components model (MentalModeler 2020).

Various scenarios were modeled, in which selected component values were altered to reflect the potential effects of SLR and/or storms. However, results did not appear meaningful. For example, under a scenario representative of a fast-moving emergency, in which the housing, utilities, buildings, docks, boats, roads, and maintenance infrastructure components were decreased by 0.25, the model shows that only the research mission of the campus would be impacted while outreach and education remain unaffected. In reality, it is obvious that all three missions would be affected.

There are numerous reasons why the model may not be useful at this time. The Skidaway campus is a smaller system with smaller components than those analyzed in the coastal AM studies that were reviewed. And, while Mental Modeler can be used by individuals, models are typically generated iteratively in a group context (Henly-Shepard, Gray, and Cox 2015, Gray et al. 2013). This allows for deliberation to reduce and refine components and relationships. The model prepared for this thesis carries the inherent bias and perspectives of the researcher alone. While the model itself may not be useful, the process of creating it was helpful in analyzing the interconnections within the campus system. Mental Modeler still has potential as a useful tool for AM stakeholder meetings.

Augmented Reality

There is another interesting way to generate models that can be readily comprehended by non-scientist stakeholders. It can be challenging to plan proactively without a visual representation, which lends a sense of realism to the future. Most renderings are flat representations of a three-dimensional reality. With something as dynamic as the ocean's interaction with the coastline, static renderings can be limiting.

Research is currently underway at CED to apply the emerging field of augmented reality (AR) to coastal planning. One study tests participants' response to visualizations of well-known coastal Georgia areas in the future. Participants can view digital timelines augmented onto the scenery at historic markers throughout nearby McIntosh County, Georgia, through their smart-phone cameras. The timeline shows historic materials as well as imagined future scenarios on the site, "complete with visuals showing sea-level rise, adaptation plans for the future, and visually altered landscapes around the location of the markers" (Taylor et al. 2020).

Employing something similar for the Skidaway campus could be help stakeholders make decisions based on views of alternative management interventions in action. Ideally the AR would be localized so that stakeholders could walk around the campus to view site interventions, lending a sense of physical space to the visualization. And, if AR technology were available at the Marine Education & Aquarium building for the public or students to visualize the campus in future years, it would bolster MAREX's outreach mission and generate positive publicity for UGA by showcasing its latest innovations.

Quantitative Models

Qualitative models can be useful for interpersonal deliberation and holistic perspective, but quantitative models provide results that are measurable, which is required for AM. However, it is vital that stakeholders interpret quantitative model results as the approximations they are—it is impossible to reproduce the dynamic complexities of the real world with numbers. As stated in a NOAA document geared toward land managers, "models are a useful tool for helping with decisions, but they are a simplification of natural processes and although they can be used to explore scenarios, actual future real-world outcomes will be different," (Cofer-Shabica et al. 2011).

Hydrodynamic Models

Hydrodynamic models provide an example of quantitative modeling. Two-dimensional hydrodynamic models have been used widely to predict flooding extents, yielding results similar to conditions observed in reality. There are structured and unstructured grid models. The latter tends to work best for complex shorelines because of its flexibility, however structured grid models are simpler computationally, and easier to integrate into geographic information systems (GIS). Hydrodynamic models could be useful in helping stakeholders determine extent of flooding on campus, enabling informed decisions about future infrastructure locations and storm response. Two examples are presented below.

The structured grid model LISFLOOD-FP uses a raster Digital Elevation Model (DEM) with water inflow details, and applies hydraulic continuity principles to calculate floodwater depth in each cell of the raster grid. To determine flow rates, it uses continuity and momentum equations involving height of water surface above topographic elevation, and the Manning friction coefficient. TELEMAC-2D is an unstructured grid model that yields water depth and velocity components as results for each node of the grid. This model can account for a wide range of factors, including bed friction, the Coriolis effect, atmospheric pressure and wind, turbulence, salinity, and intertidal flats. (Seenath, Wilson, and Miller 2016)

Hydrodynamic models are most useful in conjunction with GIS. Using both approaches together allows managers to estimate flood extents and their effects. This is especially true in small geographical areas where greater details are required, like the Skidaway campus (Seenath, Wilson, and Miller 2016).

Geospatial Models

Many of today's most powerful models are geospatial, involving GIS. A selection of geospatial models that could be useful for future campus planning at adaptive management checkpoints is presented below. In addition to the general quantitative model limitations stated above, geospatial models have some inherent limitations. They are only as good as the data they are based on. Publicly available datasets are usually created at regional or municipal scales, so the data may distort or oversimplify site scales. Though collecting site-scale data can decrease uncertainty in modeling, it may be prohibitively expensive. Fortunately, the existing expertise on SKIO's campus as well as collaborations with UGA's Center for Geospatial Research and Engineering department may make site-scale data acquisition possible.

Some coastal GIS-based models are also limited by their simplistic approach to flood analysis. The "bathtub approach" uses a DEM to determine which land will be inundated during a flood by identifying land below a set elevation. Topography is the only factor used, and the approach ignores hydraulic connectivity. Other factors that influence floodwater flow—like bed friction, flow direction, and structural barriers—are not accounted for. According to a 2016 study, hydrodynamic models like LISFLOOD-FP and TELEMAC-2D may be able to predict flood extents more precisely than GIS models because they can account for these factors, while bathtub models are likely to overestimate flood extent. Hydrodynamic models can also include time series data. (Seenath, Wilson, and Miller 2016)

AMBUR

One geospatial modeling tool is the software package AMBUR (Analyzing Moving Boundaries Using R), which can analyze and visualize historic shoreline change using the R software environment coupled with GIS. AMBUR also contains a forecasting function, allowing the user to estimate future shoreline locations and visualize them in GIS. A major advantage to this modeling technique is its ability to leverage on-campus stakeholder expertise. Dr. Clark Alexander was one of its primary developers, and members of his lab have experience using it. (Jackson Jr., Alexander et al. 2012)

The model results could be used to estimate where the campus' shoreline might lie at a given point in time, which would aid in the siting of future infrastructure. Multiple iterations could assist with planning for a variety of SLR scenarios. While the software cannot incorporate variables like SLR-induced inundation or erosion into the shoreline projections, the model can be run using a starting point of a new, pre-determined sea level (Dr. Clark Alexander, on-site meeting, February 28, 2020).

MIKE FLOOD

The program "MIKE FLOOD" by DHI offers a promising platform for smaller scales like the Skidaway campus, with no modifications necessary. The software can aid in flood forecasting, management, mitigation, risk analysis, and strategies for addressing infrastructure failure at almost any scale and environment (Browder et al. 2019). DHI has a suite of modules designed for coastal use, that can address user-chosen factors such as storm surge, wave-induced inundation, water quality, and shoreline morphology (DHI 2020). The three-dimensional option (MIKE 3) provides more visual results that may be easier for non-scientist stakeholders to understand. The model can even predict flood locations behind structures. This could be instrumental in illustrating the results of different management actions, but while most of the other modeling platforms are open source, MIKE FLOOD is only accessible with a paid subscription (DHI).

Table 2 compares all of the models listed above, and SLAMM, which is discussed below.

Table 2: Potential quantitative models

MODEL	DEVELOPER	FUNCTION	APPLICATION POTENTIAL	PROS	CONS
LISFLOOD-FP	Bates and De Roo 2000	Hydrodynamic model – uses a raster DEM and water inflow details to simulate flood dynamics	Predicting flood extents and impacts	May be able to predict flood extents more precisely than GIS models; structured grid is computationally simpler than unstructured; outputs easily integrated into GIS; no cost.	Limited by DEM resolution; structured grid may be less suitable for complex shorelines
TELEMAC-2D	French National Hydraulics and Environment Laboratory	Hydrodynamic model – provides depth of water and velocity at each node of a computational mesh	Predicting flood extents and impacts	May be able to predict flood extents more precisely than GIS models; considers a wide variety of phenomena; may be more suitable for complex shorelines than structured grid; no cost.	Unstructured grid is computationally more complex than structured
AMBUR	Jackson Jr., Alexander, and Bush 2010	Analyzing historic shorelines and projecting future shorelines	Predicting future campus shorelines to improve planning	No cost; on-campus expertise; learning opportunity for students.	Cannot directly accommodate effects of SLR in projections
MIKE FLOOD	DHI	Analyzing and simulating flood risks to assess vulnerabilities and improve design of flood defenses and coastlines	Aiding flood forecasting, management, mitigation, risk analysis, and strategies for addressing infrastructure failure; creating real-time systems for controlling pumps, tide gates, etc.	Flexible: can be used for various simulations with various input parameters; designed for all scales (including site scale); also addresses water quality; high efficiency and accuracy.	Costly; high volume of accurate data required
SLAMM	Park, Armentano, Cloonan 1986	Simulating upland marsh migration	Developing alternative future scenarios based on management actions to inform decisions	Already performed; opportunity for collaboration with UGA's Engineering department; promotes ecologically sensitive adaptation decisions.	Limited by accuracy of DEM (especially vertically), and other input data

Geospatial Models: SLAMM

Thanks to a UGA Campus Sustainability Grant, the author worked with a modeler at UGA's College of Engineering, Dr. Roderick Lammers, to create two geospatial models specifically for the SKIO campus. Marsh migration models are used widely in coastal planning, and the Sea Level Affecting Marshes Model (SLAMM) is particularly well-known (Cofer-Shabica et al. 2011, Park, Armentano, Cloonan 1986). It yields projections about the location, rate, and species composition that marshes exhibit as they migrate upland due to SLR. The data are symbolized in GIS to show location and marsh type at various increments of SLR. Like any other geospatial model, SLAMM generates approximations, not accurate predictions, but its simulations of wetland change have proven more accurate than those of neutral models in at least one study (Wu et al. 2015). SLAMM has been used before in the modeling phase of AM as well (Wigand et al. 2017).

The purpose of the models generated for this thesis is to show approximately how the marsh would migrate upland if nothing were done to accommodate migration, versus how it would migrate upland if the recommended adaptative measures detailed in the next section—including tidal creek restoration and living shoreline in place of the bulkhead—were implemented. A similar strategy was employed by Propato et al. in a 2018 paper. For study sites in New York City, a SLAMM was generated for each of five adaptation strategies. Modeling two of the adaptation strategies required modification of an elevation layer. However, unlike this thesis, the results were focused on uncertainty analysis within the SLAMM results, and then linked to an ecosystem valuation assessment from stakeholders.

Methods

In this project, the one meter-squared, LiDAR-derived DEM used in this SLAMM came from NOAA's Charleston, South Carolina, Office for Coastal Management, and was generated in 2016-2017 after Hurricane Matthew (NOAA 2017). Plant community data came from a 2013 marsh classification study for the entire Georgia coast, represented as a raster that identifies eight dominant marsh types, including non-vegetated areas like mud and reflective surfaces (Hladik 2015). Dr. Lammers reclassified these data into classes used by the National Wetland Inventory (NWI) in their wetland classification system, which is standard protocol for SLAMM modeling (USFWS 2020). Classes present on the campus parcel were: Developed Dry Land, Undeveloped Dry Land, Transitional Salt Marsh, Regularly-Flooded Marsh, Tidal Flat, Inland Open Water, Estuarine Open Water, and Irregularly-Flooded Marsh (Lammers 2020). SLAMM also uses data about dike locations, tide ranges, historic SLR, projected eustatic SLR, and land cover; and corrects for differing tidal datums. Calibrating the model using this localized data is important to ensure the most accurate projections possible (Wu et al. 2015). The most recent versions of SLAMM (Version 6) can incorporate salinity, but salinity data were not available for the area (Clough et al. 2016). The starting point for the model was 2010, because this was the most current year for which necessary data existed.

To model the effects of adaptive measures, a new, edited DEM was created from the original (Figure 22, top). It shows the physical effects of the management interventions that would have occurred on the main Skidaway campus by the time relative sea level has risen six feet, if the approach presented in this thesis were followed. Modifications occur on the core campus area, as shown. Producing an accurate grading plan informed by extensive research was not within the scope of this thesis—the conceptual forms shown on the new DEM provide a platform for SLAMM to show marsh migration potential without the bulkhead and with tidal creek restoration. It serves as a foil to the unaltered DEM, which represents "do-nothing" approach to addressing SLR (Figure 22, bottom). Unfortunately, the modified DEM does not reflect all proposed changes. Most notably, the berm removal is not depicted, so SLAMM results cannot account for the significant difference this might make in migration and composition of the existing high/brackish marsh in the northeastern corner of the parcel.

To make the changes to the DEM, the author first graded new landforms by modifying contours (AutoCAD Civil 3D). Next, the modeler drew boundaries around the perceived extents of the proposed contours. The error occurred because the boundaries did not cover the full extents of modified contours. The contours within the boundaries were converted to DEM rasters, then overlaid onto and merged with the existing DEM.

In order to design the new DEM, it was necessary to approximate the landforms that would be created by re-grading the land behind the bulkhead to create a living shoreline. Living shoreline suitability analysis, engineering, and construction are broad, technical topics that require expertise outside the scope of this thesis. A wide variety of factors must be considered in evaluating the potential of a site for a living shoreline (Mitchell, Bilkovic, and Pinto 2019, Morris et al. 2019, Wisener 2018, etc). However, stakeholders have indicated that installing a living shoreline on campus would be desirable and possible (Dr. Mark Risse, conversation, January 30, 2020). Because researchers in the MAREX Shellfish Lab hold expertise in this topic, it is recommended that they lead the planning and implementation of any such project. Tidal creek restoration is a similarly complex subject, the specifics of which should be left to experts.

Grading along the shoreline was as minimal as possible, to minimize soil disturbance. Because of potential property line restrictions and the desire to preserve existing marsh, grading

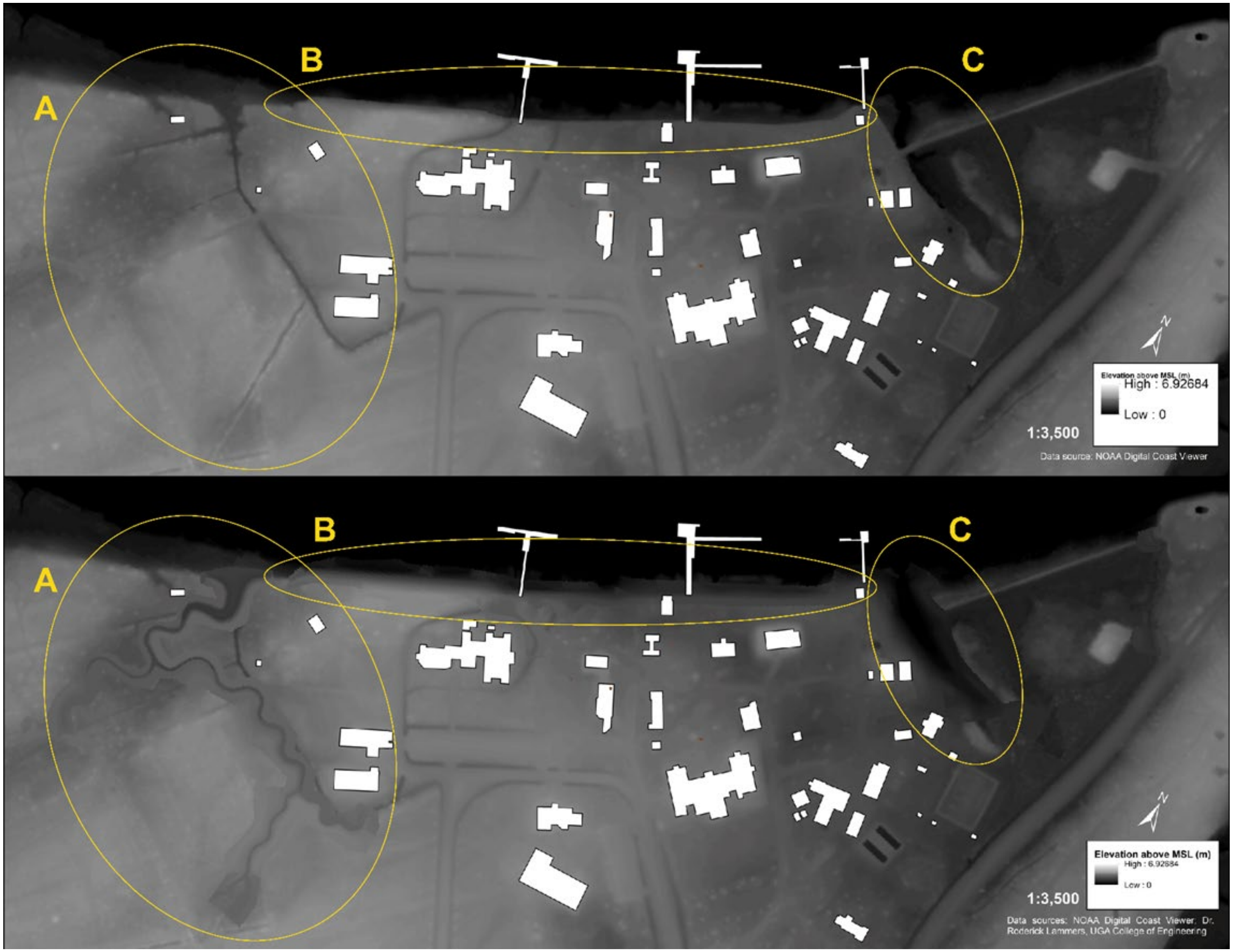

Figure 22: Original DEM (top) and DEM altered to reflect proposed land changes (bottom). A: tidal creek restoration. B: living shoreline in place of the bulkhead. C: tidal inlet/marsh restoration.

was primarily proposed inland of the bulkhead. This was balanced by a desire to preserve as much of the higher-elevation campus land as possible, especially near existing buildings. Grading was largely informed by existing living shoreline precedents in Georgia, including the Burton 4-H Center on Tybee Island, Sapelo Island, and Little St. Simon's Island.

Depending on the specific site and type of living shoreline, both steeper and shallower slopes can be appropriate (GA DNR 2013, Polk and Eulie 2018). According to a 2013 review of Georgia's living shorelines, a maximum slope of 50% (2:1 run over rise) is "essential in most locations to create the proper zone for oysters and vegetation" (GA DNR 2013). This review concluded that a higher slope like 100% (1:1 run over rise) is "more prone to failure" (GA DNR 2013). According to guidelines for living shorelines in the Chesapeake Bay, grading should create a slope that is "as flat as possible with a width between 15' and 30' in the intertidal area," (Priest III 2017).

At the Burton 4-H Center site, buildings are close to the shoreline so the slope is high. Also, this living shoreline was installed in a creek that already had steep sides and included mostly oyster shells with minimal *S. alterniflora* plantings, while the Skidaway River extent of the campus living shoreline would include many plantings and oysters at the toe of the marsh. The maximum slope at the Burton 4-H Center is an eight-foot elevation gain over 20 horizontal feet, or 40%. The 370-foot long Ashantilly Site on Sapelo Island was graded to a 2:1 (50%) slope. The 270-foot long Long Tabby Site was graded to a 1:1 (100%) slope on one end and 2:1 (50%) on the other end. The undesirably high 1:1 slope was justified by its proximity to an existing road. The Little St. Simon's living shoreline was graded at 2:1 (50%) and 3:1 (33%) slopes along most of the site, and 1.5:1 (67%) in areas where existing trees were to be protected (GA DNR 2013).

The grading on the Skidaway campus living shoreline fits within the above precedents. Steeper slopes in proposed tidal creek restorations mimic existing shoreline conditions southwest of the proposed tidal inlet. Shallower slopes may use plantings only, relying on the oyster sill fronting existing marsh for protection.

Along the Skidaway River shoreline where the bulkhead is removed, the new DEM shows all new slopes with a maximum of 30%. At least 65 feet buffer the upland buildings (those not already ceded because of their low elevation) from the top of the living shoreline.
On the shoreline side of the Marine Education & Aquarium building, drainage is altered to minimize rainwater washout through the living shoreline. Like at the Long Tabby Site on Sapelo Island, a small berm with a swale behind it redirects rainwater to prevent erosion of the living shoreline in this area (GA DNR 2013).

Toward the northeastern corner of the main campus, the slope is graded to be gentler, so that marsh can migrate upland more easily without buildings in the way. At the northeast corner of the parcel, the berm is removed to reconnect the low and high marshes that it previously separated. Rerouting of the small tidal creek inlet is also shown, which redirects the flow of water currently restricted by the tide gate, berm, and bulkhead, toward the marsh.

Sinuosity is restored to part of the closest channelized tidal creek network southwest of the MAREX campus. The tidal inlet is modified to divert water away from the MAREX dorm area, which was achieved by altering the path of the creek to turn southwest rather than southeast upon entering the inlet. Sinuosity is also added to the ditch behind the dorm area, so that it can function as a small tributary as well as drainage.

The new DEM depicts only the northernmost extent of the ideal creek restoration due to time constraints on the process of grading. The inlet extends to the natural endpoint of an existing land bridge along the Jay Wolf Nature Trail. Although the creek restoration would be more beneficial if it extended further inland, the new DEM can illustrate general effects of restoration on marsh migration, as well as a short-term solution for keeping tidal water away from the MAREX dorm area.

The main tidal creek was designed by tracing the midline of a tidal creek of a similar desired length from a site with similar morphology on the western shore of a back-barrier island

Figure 23: Location and morphology of tidal creek traced from an island within Ossabaw National Wildlife Refuge, then superimposed onto the Skidaway campus in the area of the proposed tidal creek restoration.

about 6.5 miles south of Skidaway, within the Ossabaw National Wildlife Refuge (Figure 23). This reference was overlaid onto the area and altered to better fit the on-site topography while retaining the form of the meanders as much as possible. Some of the meanders were reduced in amplitude to allow for deepening over time without forming islands and/or oxbows. Only the northernmost portion of the reference creek, extending to the land bridge, was used in the DEM. The midline was offset at various widths to form the contours of the creek banks.

The headwaters are significantly narrower than the tidal inlet, and creek banks are all relatively high in slope (with a maximum of 50%), to mimic the conditions of natural tidal creeks. The minimum longitudinal slope throughout the proposed creeks is 0.4%, which is necessary to convey water. Although tidal water will move into and out of the creek network, drainage must flow toward the river to account for rainwater runoff. Original elevations are maintained at all headwaters and the tidal inlet.

Because there were no precedents for created tidal creeks functioning as drainage ditches, the primary drainage creek behind the MAREX dorm area was designed using circles that increase in radius ("radius of curvature") as they approached the confluence with the main creek, which is typical for most creeks, and a technique used in the natural channel design stream restoration method (Doll et al. 2017). An adjacent drainage channel to the south connects with a lower-lying area within the upland forest near the MAREX entry from McWhorter Drive. This minor channel is smaller and less significant than the ditch behind the dorm, and located in a wooded area where grading would be highly disruptive, sinuosity is restored only slightly. The channel terminates in the lower-lying area, which was altered to enhance drainage.

Overall, the restored creek network was sited to follow the existing topography, dechannelizing tidal waters to promote conversion of forest to salt marsh and diverting tidal water away from the MAREX dorm area.

Results

The SLAMM results consisted of one existing conditions raster (Figure 24), and one raster for each one-foot increment of SLR until six feet—for both original (unmodified) and modified DEMs. The rasters show NWI class extents at each increment, to demonstrate the extent and location of marsh migration. Figure 25 shows the core campus area at six feet of SLR if nothing were done to adapt. Figures 26-28 depict NWI classes on the modified DEM at two, four, and six-foot increments of SLR. These results were chosen as figures because they correspond to the phased plan endpoints described in the next section of this chapter, and help to inform the recommendations. All figures display results in core campus area, where the DEM was modified.

Figures 26-28 show results from the DEM that was modified to reflect proposed changes: tidal inlet and creek restoration west of the MAREX core campus area, bulkhead removal, and tidal inlet re-routing/restoration east of the historic core campus. Figure 26 shows the changes in NWI classes that may occur at two feet of SLR, figure 27 shows changes at four feet, and figure 28 shows changes at six feet. Figure 28 may be most useful because the interventions shown on the modified DEM reflect all of the proposed changes that would have been implemented by six feet of SLR. For instance, Phase 1 of the recommended management actions would have only re-routed and restored the tidal inlet east of the historic core campus by the time sea level rose two feet, even though the DEM and SLAMM show the tidal inlet and creek restoration west of the MAREX area too, which will not have been completed until four feet of SLR.

The SLAMM results rasters covered about 56% of the parcel. These new rasters were imported into GIS, projected, and symbolized as “unique values” (one for each NWI class). For the results shown in Tables 3-4 (next page), they were then clipped to parcel boundaries and acreage was calculated for each NWI class. Percent change for each NWI class between the start point (2010) and six feet of SLR was calculated for both unmodified and modified rasters within the area of the parcel. In both rasters, most classes had the same percent change between 2010 and six feet of SLR. However, while transitional salt marsh increased from 15.23 acres to 198.61

Figure 24: Existing conditions SLAMM (Lammers 2020).

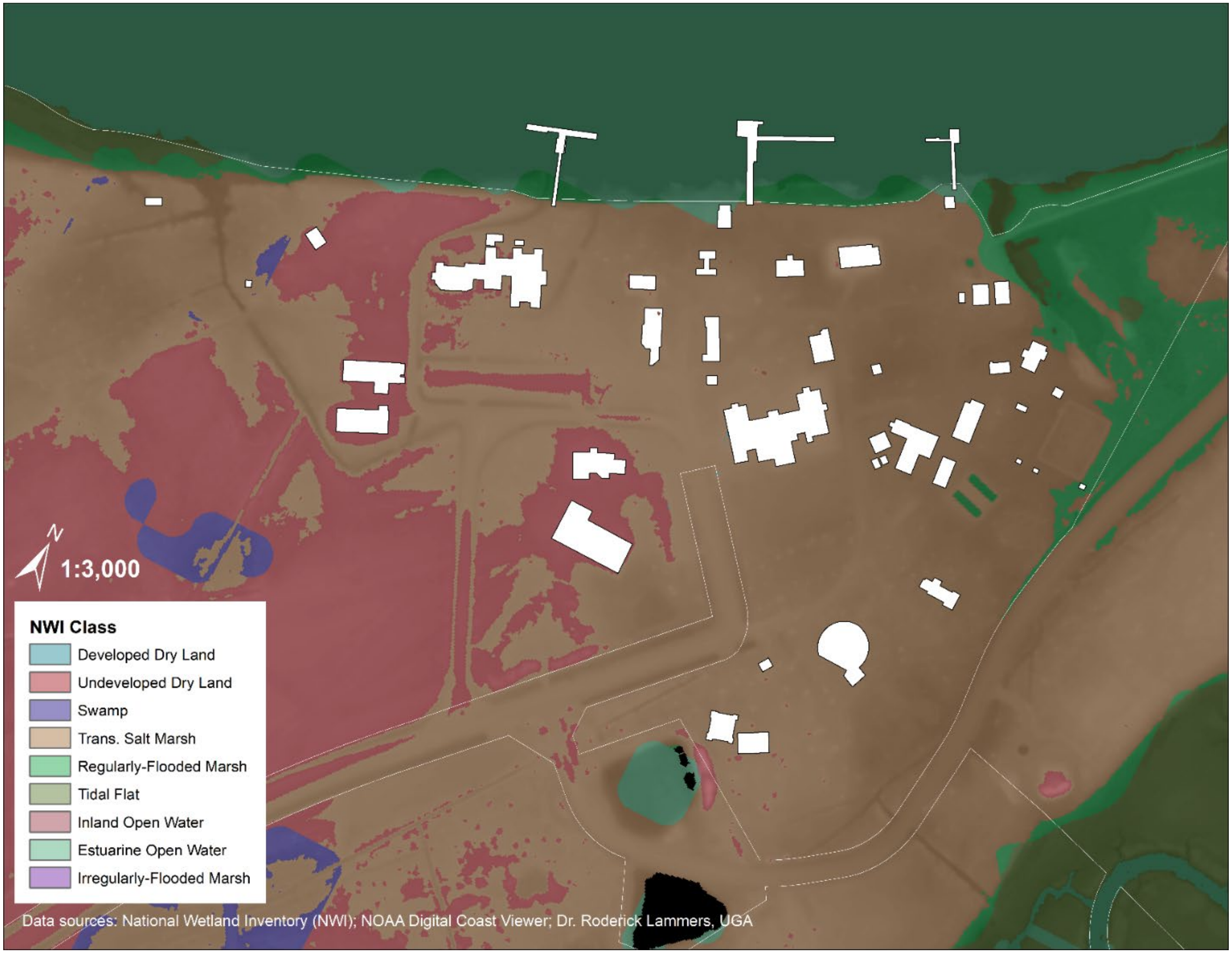

Figure 25: Unmodified DEM SLAMM. NWI classes at six feet of SLR (Lammers 2020).

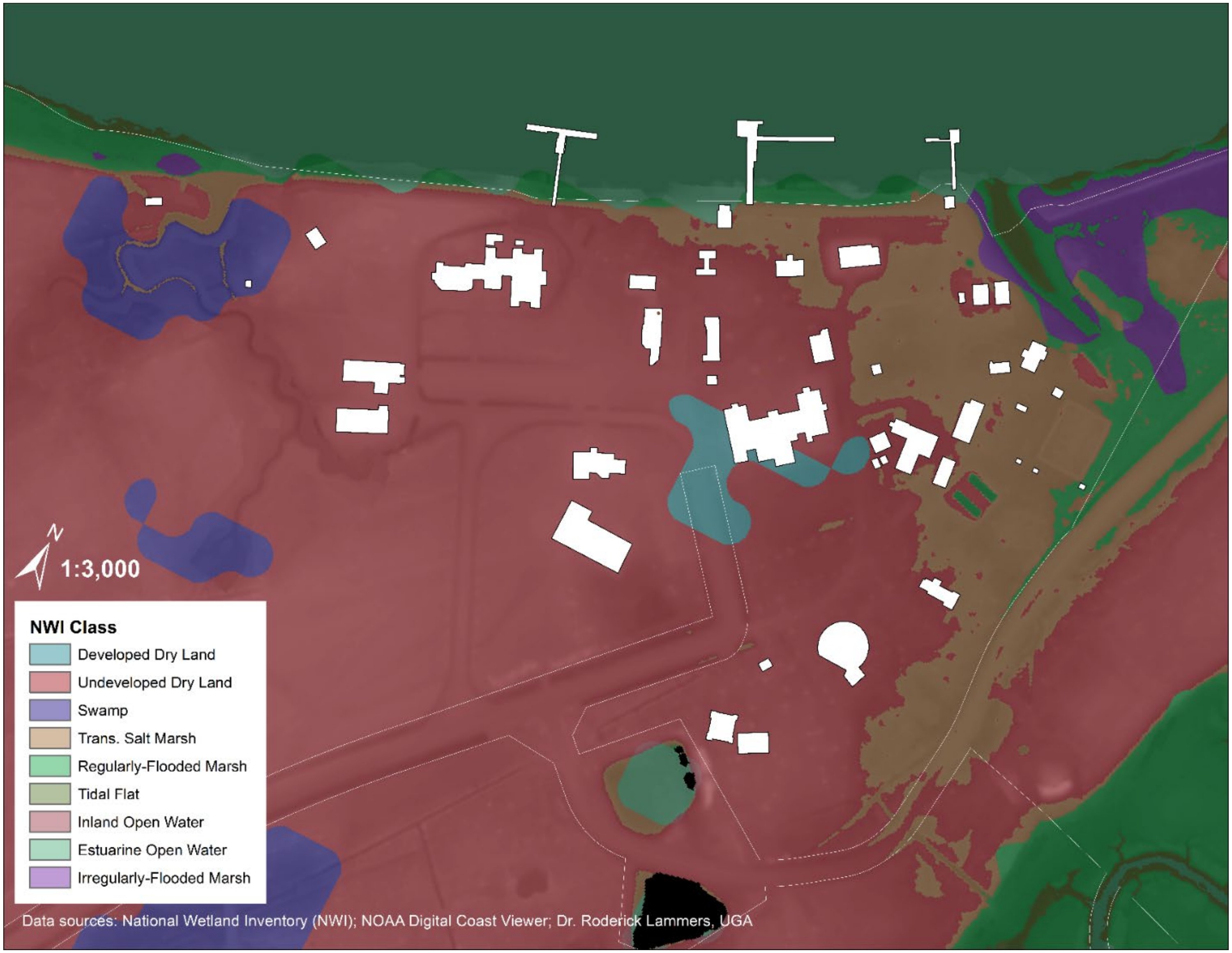

Figure 26: Modified DEM SLAMM. NWI classes at two feet of SLR (Lammers 2020).

Figure 27: Modified DEM SLAMM. NWI classes at four feet of SLR (Lammers 2020).

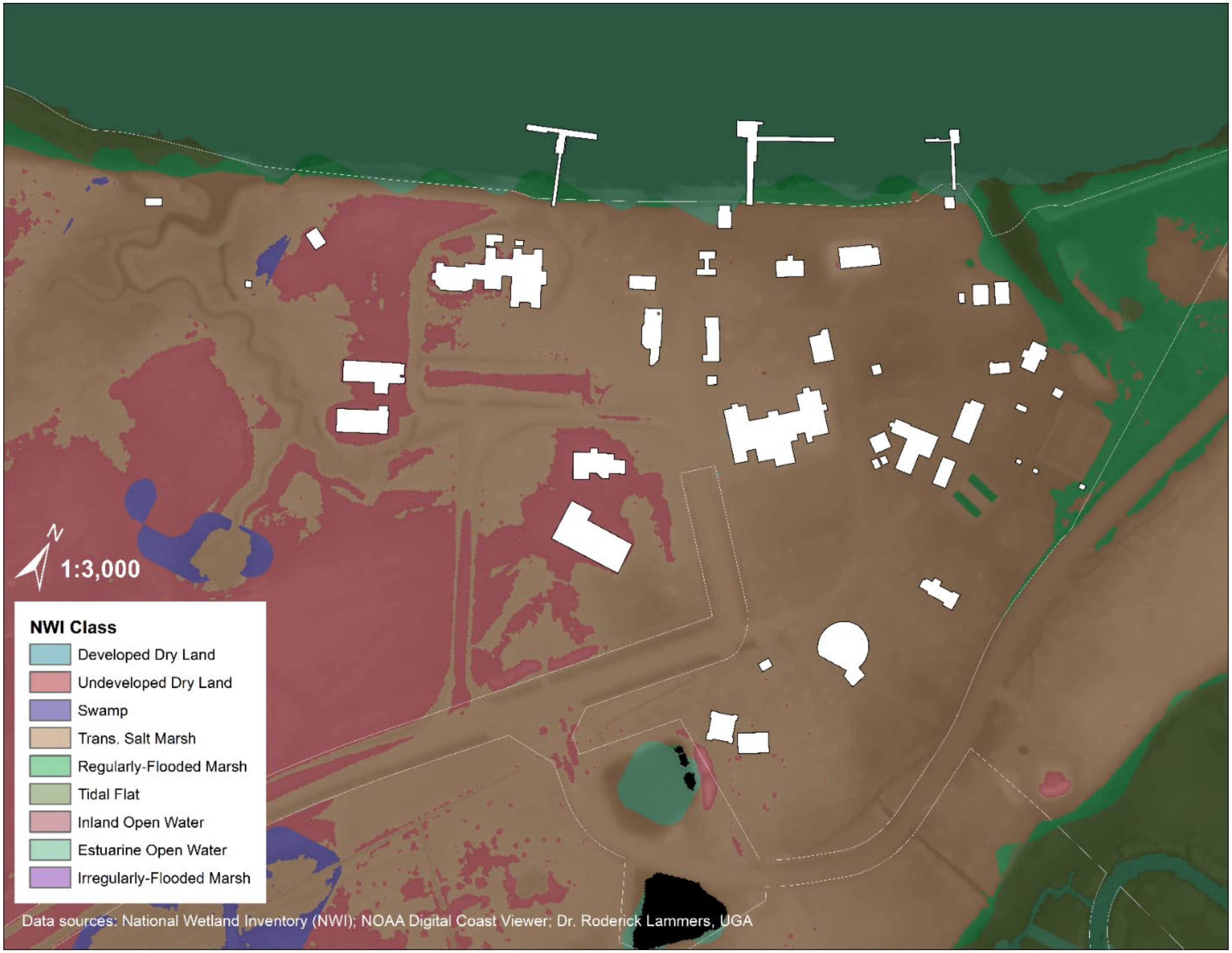

Figure 28: Modified DEM SLAMM. NWI classes at two feet of SLR (Lammers 2020). Relative scale

acres on the original-DEM SLAMM (1204% change), it increased to 199.45 acres on the modified-DEM SLAMM (1210% change) (highlighted in tables for emphasis). The greatest change occurred near the tidal creek restoration, indicating that restoring the creek would increase extent of salt marsh migration, thereby increasing protective benefits for the neighboring upland.

Table 3: Unmodified DEM. Changes in NWI class acreage between 2010 and six-foot SLR.

NWI Class	Existing acreage	Projected acreage	Change in acreage	Percent change
Developed Dry Land	1.05	0.05	-1.00	-95%
Undeveloped Dry Land	337.85	158.98	-178.87	-53%
Swamp	30.34	10.35	-19.99	-66%
Transitional Salt Marsh	15.23	198.61	183.38	1204%
Regularly-Flooded Marsh	649	28.66	-620.34	-96%
Tidal Flat	112.83	552.82	439.99	390%
Inland Open Water	0.05	0	-0.05	-100%
Estuarine Open Water	10.98	219.63	208.65	1900%
Irregularly-Flooded Marsh	11.77	0	-11.77	-100%

Table 4: Modified DEM. Changes in NWI class acreage between 2010 and six-foot SLR.

NWI Class	Existing acreage	Projected acreage	Change in acreage	Percent change
Developed Dry Land	1.05	0.05	-1.00	-95%
Undeveloped Dry Land	337.85	158.23	-179.62	-53%
Swamp	30.34	10.24	-20.10	-66%
Transitional Salt Marsh	15.23	199.45	184.22	1210%
Regularly-Flooded Marsh	649	28.62	-620.38	-96%
Tidal Flat	112.83	552.88	440.05	390%
Inland Open Water	0.05	0	-0.05	-100%
Estuarine Open Water	10.98	219.63	208.65	1900%
Irregularly-Flooded Marsh	11.77	0	-11.77	-100%

Building the Plan: Phased Action Recommendations

The overarching goal for the campus is to achieve functional resilience. SKIO and MAREX must be able continue performing their research, educational, and outreach functions while the campus is subject to acute and chronic SLR-induced stressors. While this thesis does set forth an AM plan, certain actions that could be implemented as part of one will be recommended below, in three chronological phases. The phased recommendations are intended to be flexible considering the unpredictable effects of SLR and yet unknown results of models and monitoring of implemented actions. The chronology of infrastructure function migration is loosely based on NOAA's bathtub-approach SLR model (Figure 29)—showing approximate new mean sea levels at two, four, and six feet of relative SLR—for lack of a more robust model, but the migration can be done in whatever order necessary. The changes represented by the NOAA SLR model are generally more drastic than those shown by the SLAMM results, so they were used as guidance, while SLAMM results still informed the recommendations in that they confirmed that more marsh migration would occur if sinuosity were restored to the tidal inlet.

In Phase 1, the thesis recommends actions that should be completed by the time relative mean sea level has risen two feet (since 2000). Phase 2 corresponds to an endpoint of four feet, and Phase 3 corresponds to six feet.

Some general recommendations can be stated that follow the guiding principles presented earlier on. First of all, function must guide all decisions. Functions of specific pieces of infrastructure must be re-mapped as necessary to support continued functioning of the campus as a whole.

As a nature-based strategy, campus planners should aim to accommodate marsh migration. Although marsh migration will decrease usable acreage overall, it can protect adjacent

Figure 29: Two, four, and six feet of relative SLR since 2000, represented on the Skidaway campus parcel (NOAA 2019).

upland areas from storms and erosion, create habitat, and set a positive precedent for other coastal land managers and community members. Dechannelizing tidal creeks wherever possible would likely aid in accommodating marsh migration. In wooded areas, this could expedite the transition from ghost forest to salt marsh. Although vegetation removal may be necessary to restore creek sinuosity, it should be limited on the parcel overall, to mitigate erosion.

There are numerous defense and adaptation strategies that could help the campus persist in its current location until six feet of SLR or more, but their success or failure depends upon the unknown effects of future storms. Therefore, retreat must be the ultimate goal on a long-term time horizon. Downsizing and consolidating campus functions to upland infrastructure and eventually an off-site upland area will enable research, education, and public outreach to persist despite decreased space. While new construction will be necessary to continue occupying the parcel on a shorter time scale, it should be well-considered and limited. Temporary or mobile structures could be considered. Cost-benefit analysis is especially important in this context.

In AM, stakeholders must evaluate how well their prior management decisions are working at defined intervals—in this case, two-foot SLR increments. Evaluation frameworks must be in place in order to do so. Everything about the success or failure level of a management action is defined by stakeholder objectives, therefore performance metrics must be carefully developed and selected by stakeholders themselves (Williams 2009, Zedler 2017).

PHASE 1

The focus of Phase 1 interventions is the northeastern part of the main campus, where SKIO and the historic Modena Plantation infrastructure are concentrated. It is significantly lower in elevation than any other area—retreat from here must begin first. Stakeholders have expressed concern over worsening flooding during high tides and storms. Floodwaters enter through the tidal inlet currently restricted by a culvert and bulkhead adjacent to the fuel dock.

Phase 1: Migration of Functions

According to the rough estimate provided by NOAA's SLR bathtub model, the historic fuel dock, Thomas & Martin duplex, emergency spill response building, collaborative teaching lab (part of the former BERM complex) and potentially the Roebling House, annex, and garden could be inundated by two feet of SLR. Figure 30 shows suggestions about building function migration that will be described in the following paragraphs.

The Roebling House is one of the most important historic buildings on campus because it helps tell the story of the land. While the decision is ultimately up to stakeholders and would be best made with help of historic preservationists, it may not be advisable to put great efforts toward flood-proofing, elevating, or moving the structure. Its relatively large size and hasty construction may limit its lifespan and ability to withstand storms or relocation efforts. A focus on functions suggests that a "record and let go" approach might be appropriate for this and most other historic structures on campus. This involves "allowing [SLR] to impact a historic property, with efforts focused on preserving its memory," through written records and/or photography (Mutnansky et al. 2015).

Historic preservationists are equipped to inform stakeholder decisions on the fate of historic buildings, and it would be beneficial to employ their expertise in any planning situation involving historic infrastructure. If a "record and let go" approach is used, preservationists can recommend numerous avenues to achieve this, including the National Park Service's Heritage Documentation Programs. Even if the landscape, district, or structures are not nominated for the Georgia or National Register of Historic Places, they can be documented through Heritage

Figure 30: Schematic Phase 1 interventions. NOAA's model shows that the structures in yellow will likely be affected by two-foot SLR. Structures nearby inundation (though not necessarily inundated) are assumed to be affected by storm/high tide flooding, or access restrictions.

Documentation Programs that include the Historic American Buildings Survey (HABS) and its companion programs, the Historic American Engineering Record (HAER) and Historic American Landscapes Survey (HALS). The nature of the site suggests that all three programs could be applicable. The annual HALS Challenge in 2020 is to document "vanishing or lost landscapes," that may be under threat of loss due to factors such as climate change. This year's challenge will soon be over, but the topic indicates that HALS would be an appropriate venue to document the Modena Plantation landscape. Documentation techniques include written descriptions, drawings, and photographs. There are also newer technologies such as terrestrial laser scanning to create virtual, three-dimensional models. (National Park Service 2020)

After proper documentation, the Roebling House's function as a conference center could be fulfilled by the new OSIC. The same approach could be applied to the Thomas & Martin duplex, whose function as housing could migrate to the new SKIO housing area. The historic marine emergency spill response storage building, adjacent to the fuel dock, will likely be affected by SLR, though its higher finished floor elevation and masonry construction may enable it to remain longer. Functions of this building could migrate to Marine Ops B if equipment in the latter were consolidated. Marine Ops B could also be expanded with temporary or moveable construction. The teaching area in the Collaborative Teaching Lab could find a new home in the new OSIC with plenty of student lab space. The fuel dock cannot persist in its current position, so a temporary fueling station could be installed at the MAREX dock (less prone to flooding than the Main Dock) and eventually moved to a new dock location, as described in Phase 2.

The Main Dock, which is vital to SKIO's research operations, is also in jeopardy. Before sea level rises two feet, vessels and equipment (including the boat lift and seawater pump) should be relocated to either the MAREX dock or Priests Landing before a new dock is built, despite temporarily inconvenience. At first, the vessels could be relocated only during hurricane season and spring tides. The Carolina Skiffs could be stored at Priests Landing, while the R/V *Savannah* may need to remain in the more sheltered Skidaway River.

The Georgia Southern facility is in poor condition and located far from collaborators on the SKIO campus. While the facility will not be directly affected by SLR at this point, it presents a liability because of its poor condition and location in the forest, susceptible to damage from blown-down trees during storms. As collaboration between SKIO and Georgia Southern increases, it could be beneficial to merge Georgia Southern's research and education missions with those of SKIO on its campus, and demolish the current facility.

Phase 1: Elevate New Buildings

On the MAREX side of campus, there are plans for a new dormitory to replace the failing 1970s building. Eventually the cafeteria must be replaced, too. The new dormitory's significantly larger capacity might make it suitable to accommodate SKIO guests when necessary. Though the elevation of the MAREX area is approximately ten feet and technically out of the floodplain, heightened storm tides could impact the new building (Dr. Mark Risse, conversation, January 30, 2020). To protect their investment for a longer period, campus stakeholders could consider elevating all new construction. The Coastal Studies Institute in Wanchese, North Carolina, can provide an example,

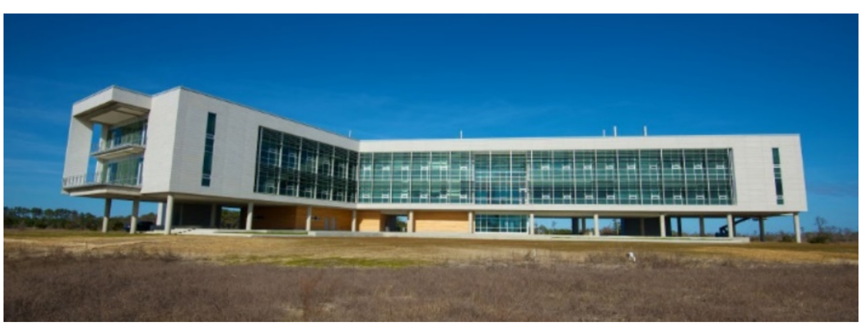

Figure 31: The Coastal Studies Institute in Wanchese, North Carolina provides an example of an elevated campus building (Coastal Studies Institute 2015).

although on a much larger scale, of an appealing elevated building on a coastal campus (Figure 31).

Landscaping around new construction could consist of attractive native, salt tolerant plantings that thrive in full-sun environments, similar to those at the Orrin Pilkey Research Lab on the Duke Marine Lab campus, Beaufort, North Carolina (Figure 32).

Figure 32: Orrin Pilkey Research Lab, Duke Marine Lab, Beaufort, North Carolina (Nicholas School of the Environment, Duke University).

Phase 1: Electrical Power

Because of the increasing importance of reliable power for internet, burying the power lines along McWhorter Drive is advisable. Tree damage is becoming more likely as storms become more intense. As a less costly alternative, more trees could be cleared along the power lines and sold as timber. Timber sales were proposed by a stakeholder, and are also part of the site's history. Stakeholders might also consider installing solar panels or wind turbines to support some of the most vital infrastructure, which would reduce overall reliance on the above-ground power lines and dependence on generators in the event of a storm.

The current location of the main generator near the maintenance shops is precarious and may need to be reassessed soon. Flooding has already approached the area. Important scientific equipment and life support systems for aquarium organisms depend on the generator, so the generator must be reliable. The secondary generator at MSRIC is on higher ground that has yet to be flooded, so the main generator could occupy this position instead.

Phase 1: Marsh Restoration

The main nature-based adaptation measure that Phase 1 proposes is a restoration project for the marsh that occupies the northeastern-most extent of the parcel. The project would occur after the fuel dock, Thomas & Martin duplex, Roebling House, Marine Ops A, and BERM were documented and removed. Encouraging marsh vitality and migration in this area would provide more storm protection for the remaining upland than leaving it merely relying on a bulkhead and turfgrass at a significantly higher elevation than existing marsh.

First, the 700-foot berm would be removed to reconnect the low and high marshes that it previously separated, allowing the impounded high marsh area to slowly revert back (Roman and Burdick 2012). Reconnecting the marshes would prevent sudden salinity-induced die-off of high marsh vegetation in the event that storm surge overtops the berm and saltwater ponds behind it (White and Kaplan 2017, USFWS 1983).This intervention would require purchasing the adjacent property, where a house currently stands on a hammock connected to the upland by a land bridge. In this position, the house is very vulnerable to storms, so it may not be inhabitable for much longer. With the berm removed, the hammock areas within the marsh would probably become ghost forest and then marsh.

Simultaneously, rerouting of the small tidal creek inlet is proposed. This would redirect the flow of water through the natural inlet, which is currently restricted by the culvert and bulkhead, toward the marsh. The project would divert the flow of water away from campus while restoring natural hydrology. Figure 33 shows the creek morphology in 1965 (left), shortly after the berm was installed, juxtaposed with the current conditions (right). South of the tidal creek in the 1965 aerial, a channel crosses the current BERM complex, which may have previously been part of the creek. This feature might return as part of the salt marsh once the land is no longer in use.

Figure 33: 1965 aerial imagery shows inlet before bulkhead and shortly after installation of berm (left) (SKIO historic imagery 1965). Current aerial imagery shows berm and bulkhead restricting flow into/out of tidal inlet (right).

Another requirement for the project would be the removal of the bulkhead that is currently holding back the creek. A living shoreline would take its place. This area, in addition to the fuel dock corner, would be graded to a shallow slope and planted with a marsh species composition similar to that of the adjacent marsh. Oysters could be installed at the marsh toe, bordering the creek to mimic natural conditions. The living shoreline could be tied into the existing bulkhead where the fuel dock corner rejoins the main bulkhead parallel to the Skidaway River. This was done at the Little St. Simon's Island living shoreline project by "curving the slope behind the bulkhead and trimming the bulkhead to match the slope," (DNR 2013).

PHASE 2

The second phase of SLR adaptation, after two feet and before four feet of SLR, would be the busiest. Phase 2 of recommended actions will necessarily be vaguer than Phase 1. In reality, more specific actions for Phase 2 would be developed as Phase 1 is underway or completed, because stakeholders would be evaluating the performance of the previous cycle's actions. Also, the probability of the campus experiencing impactful storm events increases over time, so it is impossible to know the conditions under which stakeholders will be working.

According to the NOAA SLR model, the main dock, Marine Ops B, saltwater lab, solvent storage, Rice House, maintenance shop area, water tower, Geochemistry, OSIC and Baggett Apartment, interpretive cabin, and potentially the Roebling Lab and Shellfish Lab annex would be inundated by four feet of SLR. The facilities at Priests Landing would also need to be addressed at this point.

Between two and four feet of SLR, efforts should be directed away from the low-lying historic area of the parcel—which will be in the marsh migration process—and toward the upland area on the parcel, most of which is currently occupied by MAREX. Stakeholders may also consider or begin developing a nearby, off-site, inland parcel of land for managed retreat. The campus may be consolidating onto the remaining upland area, requiring a closer partnership between SKIO and MAREX as they share this limited space. An innovative new dock complex could form a central node for the campus, as boats have always been key to its functions. The campus may begin to look more like Priests Landing—an assemblage of facilities relating to the dock—and less like a university campus and outreach center. Functions that can take place without direct access to the water may migrate to a new inland parcel. Proposed interventions on the core campus area are shown in Figure 34.

Figure 34: Schematic Phase 2 interventions. NOAA's model shows that the structures in yellow will likely be affected by four-foot SLR. Structures nearby inundation (though not necessarily inundated) are assumed to be affected by storm/high tide flooding, or access restrictions.

Phase 2: Priests Landing

The dock at Priests Landing is degrading in condition due to rebar and concrete piling corrosion, but rebuilding may not be worth the cost. The eight-foot-tall berm separating the freshwater wetland from the salt marsh is only about 20 feet wide, while the roots of the vegetation on top largely hold the berm together and are susceptible to die-off from saltwater inundation. According to NOAA's SLR bathtub model, the wetland will begin reconnecting to the marsh by the time sea level has risen two feet, despite the berm's eight-foot height, and regain full connectivity by four feet of SLR. Even with a more conservative approach, storm surge could easily overtop and/or wash out the berm. The low-lying area around the wetland will quickly become inundated and surround the elevated Priests Landing complex and access via OSCA Road. A ghost forest will likely form before the area becomes marsh.

Continuing to stabilize the dock until two feet of SLR may be the best option. At that point or before, managers could begin phasing out the facility, relocating GRNMS' boat storage to a new dock on the main campus and encouraging other tenants to seek off-site alternatives before sea level has risen four feet.

The Priests Landing facility is the least efficient for SKIO to manage because of its distance from the core campus area. If a disaster were to necessitate repairs, it would take more resources to address damage at two separate locations (Priests Landing and the core area) than just one. Because the labs and office space are mostly used seasonally, the research functions of these spaces could be consolidated to SKIO's core campus area, given that a new, expanded dock and associated facilities were implemented.

Phase 2: New Dock

Stakeholders could focus funding and efforts on building a large, multi-tiered, innovative new dock to serve the functions of the fuel dock, main dock (including the boat lift), MAREX dock, and Priests Landing. The dock could be designed to set the Skidaway campus apart and establish a positive model for other coastal campuses. Because it would need to be large enough to accommodate all entities' boats, the large underwater footprint could be used to support the surrounding ecosystem and potentially contribute to accretion along the campus shoreline.

The dock could serve as a hybrid approach to SLR adaptation, incorporating natural and structural elements into a structure similar to a living breakwater or artificial oyster reef—designed carefully and creatively in such a way that the oysters do not interfere with boat operations. When sited properly to maximize wave energy reduction, living breakwaters have been successful in protecting against storm surge and erosion while creating habitat for native organisms (Naturally Resilient Communities 2020). The project could draw inspiration from the Reef Ball Foundation's artificial reef technologies (Reef Ball Foundation 2017).

Properly siting the dock/living breakwater project is not within the scope of this thesis. Factors such as depth, width, height, size, position relative to the shoreline, and local influence of currents must be considered by professional engineers before siting a living breakwater (Naturally Resilient Communities 2020). For this thesis, the new dock is proposed on axis with the road segment just southeast of the Marine Education & Aquarium building, because it utilizes an existing pathway to transport people and equipment, minimizes ecological disturbance from construction, situates the dock at a relatively high elevation, sets up convenient, economical transitions from existing infrastructure, and creates strategic access for future SKIO and MAREX facilities (Figure 34).

Phase 2: Bulkhead Removal/Living Shoreline

Once the main dock and Marine Ops B were documented and removed, the bulkhead removal and living shoreline project beginning at the fuel dock corner could be extended to the main dock's former location. The equipment in the marine ops and spill response facilities near the main dock could migrate to a new location: the aquarium wing of the former Marine Education & Aquarium building. This would minimize expensive new construction in a precarious area, and repurpose a structure that is no longer suitable as office or classroom space due to its degraded condition. Keeping the bulkhead on the western side of campus would help protect the shoreline from erosion in the short term, retaining land to support remaining and potentially new buildings.

Phase 2: Construction

The maintenance and mechanical shops are indispensable to the functions of campus, but will likely be unusable by the time sea level has risen four feet—or even before, if flooding occurs. Because there would be less infrastructure overall and technological progress will have likely reduced equipment size, the physical space of the facility could be smaller. The shops could be consolidated and moved to occupy the current McGowan Library. Like its historic predecessors, the building could be amended as necessary.

MCSRIC and the new shop area would begin to form a new core campus for SKIO. Depending on the performance of prior interventions and the storm climate, SKIO could choose a more aggressive managed retreat strategy and migrate most of its labs and classrooms to a new inland parcel while retaining MCSRIC as their primary on-campus facility—or create a new research and education facility on the high ground of the current MAREX parking lot, to replace the valuable lost teaching and lab space from the Roebling Lab, OSIC, and other lab/classroom facilities. The location would provide easy access to the dock, marine ops, shop area, and Shellfish Lab.

Situating the main SKIO facility adjacent to the Shellfish Lab could foster the research collaborations between the two entities. The lab may need to cede the annex to its north, but could add a new wing onto the building toward the east or merge with the new SKIO or MAREX facility. However, it is important that the Shellfish Lab remains on campus because of the necessity for frequent boat access.

The Marine Education & Aquarium building is already becoming outdated. It could be replaced by a new facility located south of the dorm area. This would provide dock access via the existing road segment, and close proximity to the dorm area. Parking could be located between the new MAREX and SKIO facilities. Another, more economical and ecologically friendly alternative to building new SKIO and MAREX facilities would be to create one shared facility that incorporates flexible classroom and lab space.

Although access to the Skidaway River gives the current MAREX aquarium an easy supply of seawater, it would be not be advisable to rebuild the facility on site when the current one becomes outdated. Locating the aquarium on a new inland parcel closer to the Savannah metropolitan area would protect it from storms and bolster MAREX's outreach capabilities by increasing accessibility for schools and the general public. Outreach functions could generally migrate to the new facility.

With the loss of the Baggett Apartment and Rice House, SKIO's housing capacity would be diminished. If this is problematic, the quadruplex and the commons could be supplemented with an addition or new accompanying building.

Phase 2: Tidal Creek Restoration

Tidal creeks once traversed the western side of the campus before they were channelized into a network of irrigation and drainage ditches, and canals to aid in mosquito control during the Modena Plantation era. Some vegetation die-off is occurring surrounding these channels, which will eventually transition to ghost forest. Restoring natural sinuosity could be a nature-based solution to help expedite the imminent transition from ghost forest to more protective and ecologically valuable salt marsh. Another aim of the creek restoration is to divert tidal water away from the MAREX dorm area, which could be achieved by moving the inlet further toward the Skidaway River and adding sinuosity to the ditch behind the dorm area.

Only the northernmost extent of ideal creek restoration, extending from the tidal inlet near the interpretive cabin to the land bridge along the Jay Wolf Nature Trail, was depicted for SLAMM due to time constraints on the process of grading (Figure 35, shown in blue). Over three miles of channels on the parcel could be restored to sinuous creeks (Figure 35, shown in cyan), but this may be infeasible due to time and financial restraints.

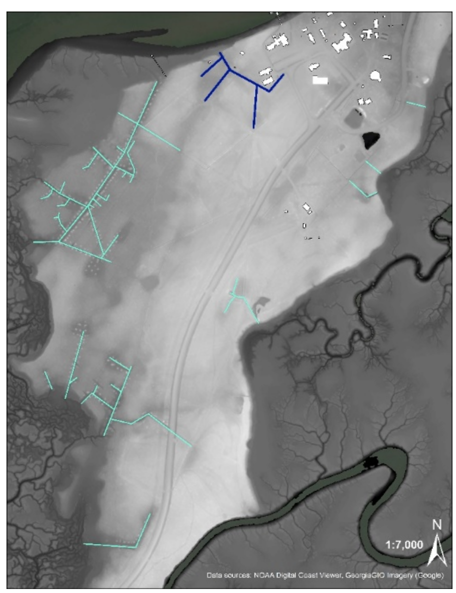

Figure 35: Over three miles of channelized tidal creeks on the parcel could be restored. Blue lines represent extent of first priority restoration.

Though the creek restoration would be more beneficial if extended further inland, the new DEM can illustrate the general effects of restoration on marsh migration, alongside a short-term solution for keeping tidal water away from the MAREX dorm area. To help offset project costs, stakeholders could sell timber from the forest that must be disturbed to grade in the creek sinuosity.

Phase 2: Historic Structures

While the "record and let go" approach may need to be applied for most historic structures on campus, it could be practical to save a select few via relocation. Other strategies exist for addressing historic buildings in the face of SLR, including floodproofing and elevation, but the Skidaway campus' low-elevation island location imposes risks that may outweigh the benefits of these other strategies that allow the structures to remain in place (Mutnansky et al. 2015).

First, the former residence now known as the interpretive cabin was recently rehabilitated into a valuable educational tool that retains much of its historic integrity. Due to the risk of storm surge and the proposed tidal creek restoration—with consequent rerouting of the Jay Wolf Nature Trail—it would be nearly impossible for the structure to remain in place. The cabin is small, which makes it amenable to relocation. It is worth preserving further into the future to memorialize the fact that Modena Plantation was built and tended by poorly paid—and, during the antebellum era—enslaved laborers, and illuminate the conditions under which they lived. Relocating the cabin to the nearest possible trailside location, still within the forest and overlooking the marsh, would minimize the disturbance to context, and preserve the cultural resource and its interpretive function.

Another on-campus historic structure could undergo significant change for practical reasons. The Modena Plantation water tower is both a celebrated, recognizable part of the campus and an essential working feature that would be impacted by four feet of SLR. It could remain in place with some hardening measures around its base, perhaps encasement by concrete up to at least six feet to accommodate future SLR. The accompanying equipment and pump could be elevated or relocated. This would enable the water tower to continue its water storage and distribution functions, and maintain the revenue stream from the cellular and internet companies who rent space on it.

PHASE 3

According to NOAA's model, the existing SKIO housing area, post-doc facility, gas bottle storage, shellfish lab, MCSRIC, Roebling lab, Marine Education & Aquarium building, MAREX pavilion, and potentially the GRNMS area may be inundated by six feet of SLR. In addition to monitoring and evaluating Phase 1 and Phase 2 projects, stakeholders could continue modeling efforts to better understand the nature and impacts of storms on campus, which may be severe by this point in time. With very little upland infrastructure left, and the continuation of marsh migration, it would be advisable to completely remove the bulkhead and grade the shoreline back to create living shoreline.

Phase 3: Continue Tidal Creek Restoration

Depending on the success of the tidal creek restoration in Phase 2, stakeholders could pursue more restoration for the channelized creeks to the southwest The protective functions of salt marsh would be most useful in the areas closer to campus infrastructure, so this area should be prioritized.

Phase 3: Continue Retreat

By six feet of SLR, all campus functions that do not require direct access to the water would have retreated to the inland parcel. Some infrastructure must remain to continue SKIO and MAREX's emphasis on educating within the study environment. Facilities on the remaining parcel would be modest, with flexible classroom and lab spaces. New buildings should not be constructed at this point.

CHAPTER 6

CONCLUSION

Numerous uncertainties surround SLR, including the rate, magnitude, and extent of its effects, both fast and slow-moving. Marshes are migrating upland, forests are dying as their roots become inundated by saltwater, high tide flooding presents serious problems in populated areas, remaining upland areas are lost to erosion, and saltwater intrusion threatens freshwater supply for coastal settlements. Higher storm surges and windspeeds from more severe storms can devastate these areas.

People are recognizing the need to address these issues, responding with adaptation or resilience plans that may incorporate structural and non-structural measures to help them defend, adapt, and retreat. The challenge for coastal campuses like SKIO's is to remain in close proximity to the coast for as long as possible, in order to keep researching this unique environment and educating future researchers and the public about it.

This project used conversations with campus experts, site visit observations, literature review, GIS modeling, and conceptual modeling as methods. The thesis inventoried and analyzed functions of the Skidaway campus system on both conceptual and physical levels, detailing the missions of SKIO, MAREX, and other campus entities, and the ways in which campus infrastructure supports them. Understanding the interconnections between the components of campus is key to preparing it for the uncertain future.

AM can be successful for helping decision-makers plan for complex systems in the face of uncertainty, so it is recommended that the diverse group of Skidaway campus stakeholders employs this approach. Focusing on functions, favoring nature-based solutions, taking a "defend-adapt-retreat" approach, and planning by SLR increments rather than time frames may serve as suggested guiding principles to help stakeholders develop objectives for creating sound management action alternatives. Ultimately, values and the guiding principles they generate must be defined by stakeholders themselves before they set objectives.

Funding is the factor that dictates the actions to be implemented, no matter which ones are proposed, or from which values they stem. Therefore, exploring financial and functional trade-offs is vital for stakeholders as they develop a SLR adaptation plan. This is especially important in the context of AM, where long-term monitoring and nature-based adaptation measures may be costly but pay off over time. Significant literature is available on topic of cost-benefit trade-offs in SLR planning, and it is recommended as an avenue for future research.

Using models and monitoring is a tenet of AM, as stakeholders aim to make better management decisions each cycle. This thesis employed SLAMM to model the future of marshes on campus if nothing were done to adapt to SLR versus if nature-based modifications were made to encourage marsh migration by restoring natural landforms. The increase in marsh area demonstrated by the latter model will hopefully encourage nature-based adaptations, as marshes form a protective barrier between open waters and upland, imparting co-benefits as well.

The SLAMM and literature review were used to generate suggestions for management structured as a three-phased plan to help campus build functional resilience at two, four, and six feet of SLR. The suggestions are meant to provide management ideas for stakeholders, but unless they implement well-designed monitoring plans to evaluate the effectiveness of the actions, investments may be wasted.

Many evaluation frameworks for management actions exist on multiple scales. Stakeholders must define the objectives of these actions so they can choose the right frameworks to determine whether actions are effective. For example, projects like the berm removal or tidal creek inlet can be measured in terms of restoration success of marsh/creek habitat over time, an excellent research opportunity for MAREX associates and/or biological oceanographic scientists at SKIO. They can also be measured in terms of their contribution to overall campus resilience via a set of "resilience metrics," (Ayyub 2019, Schultz, McKay, and Hales 2012, Rosati, Touzinsky, and Lillycrop 2015).

Regardless of the methods by which actions are measured and evaluated, the need to take strategic actions now cannot be stressed enough. SKIO's facilities are currently threatened most of all, because of their lower elevation toward the northeastern corner of the parcel. The alarming flooding in recent years, which will surely increase, is endangering both historic structures and high-tech equipment—and, more importantly, the functions they serve. Taking action to address issues on this side of campus is a vital first step to ensuring that SKIO can continue its role as a research and education institution.

Concurrently, stakeholders must begin planning for a longer-term horizon, looking toward what the campus could be like once sea levels have increased significantly and storms of unknown magnitude have inflicted unknown amounts of damage. Devising and implementing a resilience plan based in AM would put UGA ahead of the curve in preparing for an uncertain future, using natural and nature-based solutions to set a positive precedent for coastal campuses throughout Georgia and the nation.

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APPENDIX

CHARACTER IMAGES

The following series of images supplements the descriptions of the campus landscape and infrastructure in Chapter 3, to convey a sense of place.

Figure 36: Roebling House and Garden. Image courtesy of Dr. Jon Calabria, 02/27/2020.

Figure 37: View from Roebling Lab toward Main Dock. Note historic syrup boiler on left. 09/25/2019.

Figure 38: CED graduate students participating in field studies led by John “Crawfish” Crawford in campus marsh behind Marine Education & Aquarium building. 08/23/2018.

Figure 39: View toward Roebling Lab (1970 construction) with historic water tower behind it and historic syrup boiler on right. 02/27/2020.

Figure 40: Marsh fronting bulkhead, view toward Main Dock with boat lift, R/V *Savannah*, and smaller vessels. Image courtesy of Dr. Jon Calabria, 02/27/2020.

Figure 41: Former Modena Plantation worker residence situated within maritime live oak forest—live oak on left is said to be the oldest on campus. 08/23/2018.

Figure 42: Historic Modena Plantation water tower and accompanying equipment. 02/27/2020.