4.0 CONCLUSIONS

As we have seen in Darien and the Port of Savannah, sea level rise confronts industries and communities with very real challenges to livelihood, heritage, the environment, and physical and economic well-being. These challenges exist not only at the Port of Savannah and in the City of Darien, but also in numerous other coastal communities. The impacts are not purely local, however. Regional, national and even international economies tie working waterfronts to businesses and communities hundreds of miles away so that impacts from coastal sea level rise propagate outwards through economic interactions.

This report has analyzed many of the connections that exist between working waterfronts of different sizes and the broader economy. Though the Port of Savannah and City of Darien are very different from each other in size, industry makeup, and level of industrialization, it is unequivocal that the communities are linked with broader economies that sea level rise threatens to disrupt in multiple ways. The analysis provides several overall findings that may guide efforts by the business community, policy makers, planners, stakeholders, and citizens in sea level rise preparations.

4.1 SUMMARY OF FINDINGS

The *Blueprints* team analysis of the Port of Savannah's Garden City Terminal and the City of Darien have revealed many important economic impacts of sea level rise in both, very diverse locations. Key findings at the Port of Savannah include the following:

- Sea level rise is unlikely to permanently inundate significant amounts of the Garden City Terminal or nearby warehouses. The storm water drainage canal that bisects the Garden City Terminal and lowlands near the Mason Intermodal Container Transfer Facility may incur limited flooding due to one meter of sea level rise, but infrastructure improvements are likely to mitigate most effects. Similarly, fewer than 2% of Chatham County's warehouse acres are likely to be permanently inundated.

- Sea level rise and storm surge may threaten a limited number of homes of employees at the Garden City Terminal. The Georgia Ports Authority has detailed employee residence information that may illustrate potential future impacts of sea level rise on the port labor force.

- Sea level rise is like to require expensive retrofits of coastal roads, many of which transport port-related trucks. The exact cost of retrofit depends on water heights, engineering methods chosen, material costs, and many other variables. The study team estimates that adaptation for regionally important roads in Georgia's coastal counties may range from $349 million to $922 million. 84 private rail segments may also be inundated.

- Sea level rise may increase storm-induced flooding at the Garden City Terminal, resulting in port disruptions, which would reverberate through the local and state economies. A Category one hurricane may result in $1 billion of reduced output through the Garden City Terminal and a $537 million harm to the state GDP. For a Category 3 storm, output reduction is over $1.5 billion and GDP reduction is nearly $752 million. A Category 5 storm could close the Garden City Terminal for weeks, resulting in $13.5 billion in lost output and $6.6 billion harm to the state GDP.

- While hurricanes have been rare in recent years, the historical record suggests that hurricane strikes on Georgia's coast are likely in the medium term, and sea level rise is likely to worsen the resulting flooding. Sea level rise will make all storm categories affect more properties in Chatham County and worsen flooding. Sea level rise is also likely to worsen surge-related flooding at the Garden City Terminal, making even minor hurricanes flood much of the terminal by several feet. Finally, sea level rise increases the vulnerability of warehouses near the Garden City Terminal to storm surge, both in terms of the extent and depth of potential flooding.

- Finally, sea level rise may negatively impact the Garden City Terminal by increasing river salinity and concomitant infrastructure corrosion and decreasing vertical clearance for ships entering the port.

The studio's analysis also unveiled important sea level impacts at the City of Darien. As a town whose primary industries are fishing and tourism, the sea level rise impacts are of a different nature than the infrastructure- and logistics-based impacts at the Garden City Terminal.

- Sea level rise is likely to change the salinity levels in fish and ocean invertebrate habitats, further degrading the species there. Commercial fishers and shrimpers in Darien are likely to bear the brunt of any harmful effects to local fishing communities. Fishers will need flexibility to move along the coast and diversify their dependence on fisheries to help the industry survive. Efforts to protect the estuarine environments and wetlands will be important to sustain the fishing industry.

- Land use controls need to account for not only existing wetlands, but also adjacent parcels, which may face future inundation and wetland migration. In order to protect these vital habitats and nursery grounds ,communities should examine in greater depth the impacts of wetland migration.

- Tourism may suffer if SLR degrades wetlands and other natural attractions around Darien, and other historic sites — including Fort King George and the Butler Island Rice Plantation — will likely ultimately suffer permanent inundation. It will be important to the local economy to protect historic and natural tourist attractions through protection or relocation. Tourism may also present opportunities for public outreach on sea level rise through education about the effects as manifested in Darien.

- Many small businesses in Darien may be indirectly affected by sea level rise, including hotels, restaurants, and tour companies whose customers come for historic or ecotourism. Some businesses may be faced with long-term prospects of relocation, or a disruption of materials used for their business such as local fish.

- The residential real estate industry will be impacted by a greater chance of storm surge flooding, and an increase in rates for flood insurance. This may make owning a home overly expensive for some seasonal or permanent homeowners.

SEA LEVEL RISE EFFECTS EXIST AT MANY DIFFERENT SCALES

Sea level rise is not purely a local issue, though, to be sure, there are local effects. Sea level rise threatens localized inundation, increases storm-related flooding, environmental changes, and disruptions to small and large businesses alike. However, economic connections cause local effects to spill over into regional economies. Employees at disrupted businesses carry sea level rise impacts back to their homes in lost wages. Disrupted freight flows may disrupt warehouse operations in other counties that process port shipments, decreased catches may affect fish, shrimp, or jellyfish processing or tourism; and, permanent or storm-related flooding may harm regional road and rail infrastructure.

Disrupted coastal activities may also threaten economic activity and industry clusters elsewhere in the state that depend on coastal ports and industries. The Port of Savannah is one of the largest and fastest growing container ports in the country, which means that its flows impact Georgia and other states far beyond Georgia's boundary.

Finally, economic processes reveal how global effects of sea level rise and climate change are linked at the national, state, and local levels. Melting Arctic waterways may open new trade routes and change trading partners, just as changing ocean environments could in the long term change fish habitats or migratory patterns. Both effects are unpredictable. They may occur thousands of miles from the Port of Savannah or Darien yet still impact demand for each location's exports and services. Economic analysis is important because it uncovers connections at numerous different scales in sea level rise impacts that other analyses do not address. Economic impacts are among sea level rise's most important and least studied impacts.

CONTINUING RESEARCH SHOULD SEEK TO UNDERSTAND SEA LEVEL RISE'S ECONOMIC IMPACTS

This *Blueprints* research report has analyzed two very different locations on the Georgia coast from an economic perspective. It uncovered important relationships and impacts that can help communities to prepare for sea level rise. Future research should build off of the relationships documented in this

research report by addressing economic impacts in new locations, uncovering nuanced applications, or assessing economically viable responses to protect against sea level rise. The research has the potential to improve the ability to recommend appropriate mitigation efforts that are justified by economic impacts, meaning that it would be easier for leaders to justify corporate, individual, or tax dollar investment into mitigation efforts. As is apparent in Darien, armoring, retreat and accommodation may each be appropriate in different circumstances. The choice of an appropriate strategy depends on other demographic, social, cultural, and historical factors, but economic impacts are particularly important because of the connections at different scales and the fiscal constraints within which communities exist. Economic analysis allows decision maker to prioritize mitigation efforts to those areas with the largest and most widespread impacts.

PLANNING FOR SEA LEVEL RISE WHEN INFRASTRUCTURE IS BUILT OR REBUILT ALLOWS ENGINEERS TO BUILD IN PROTECTIONS AT LITTLE OR NO ADDITIONAL COST

This study addressed sea level rise effects over a 100 year timeline. Sea level rise and concomitant effects will be progressive, meaning that the timeline for sea level rise will surpass the useful life of many pieces of infrastructure, including wharves, roads, and bridges. Moreover, research has revealed that most ports operate on a five- to-ten year planning horizon even though much infrastructure's useful life is beyond 10 years. If infrastructure is not built to account for sea level at the end of its useful life, sea level rise may disrupt operations or require more expensive retrofit during the useful life. It is also important to note that sea level rise is not expected to stop 100 years in the future or at any particular date, even though this study used a 100 year timeframe to ground analysis. Thus, infrastructure managers will need to remain abreast of sea level rise models in case the amount or timelines change. The models do not currently make clear the height or level or protection that will allow infrastructure to be safe in perpetuity. Instead, there will be needs to address sea level rise in infrastructure construction and reconstruction as sea levels change.

Stakeholder outreach is needed to begin addressing sea level rise impacts. Economic analysis offers a possibility to change the conversation that exists in public outreach, revealing linkages between coastal and inland communities in a way that highlights invisible stakeholders in sea level rise adaptation and mitigation efforts. Sea level rise has many stakeholders, and not just on the coast. They may include coastal residents and business owners, county and municipal leaders, coastal investors, logistics companies, port users, port employees, freight companies, fishers, shrimpers, and exporters, and many others linked economically with areas likely to suffer sea level rise effects. Strengthening public outreach will enable them to take the actions that they can to prepare and protect their long-term interests while also kick starting the public discourse that must exist to support democratic decision making. Addressing sea level rise will require both public and private actions; stakeholder outreach is a starting point for each.

Sea level rise will challenge working waterfronts in new and unprecedented ways. This report has shown how sea level rise may affect the Port of Savannah and the City of Darien, and how those impacts may propagate at the local, regional, and state scale. Building future sea level rise analysis based on economic impacts can lead to economically justified, fiscally constrained, culturally sensitive, and environmentally necessary mitigation steps to help protect working waterfronts and inland communities.

5.0 APPENDIX

5.1 BATHTUB MODEL

The “bathtub model” is normally used to approximate sea level rise based on the assumption of uniform water level rise at all levels of the land being examined. The bathtub model is useful to project uniform sea level rise by assuming inundation on all land below a specified elevation. It can in some cases also model storm surge, but the results are less accurate than for sea level rise because the assumption of equal water levels does not hold for storm surge. In storm surge, water levels are affected by wind direction, air pressure, seafloor and land contours, and natural obstacles.

5.2 ROAD NETWORK CONSTRUCTION COST METHODOLOGY

The *Blueprints* team assumed that each segment of major road inundated under one meter of sea level rise would be raised as a bridge. Therefore, in order to quantify the adaptation costs for the road network, the study team estimated a range of costs for each of the inundated segments.

The study team used roadway shapefiles for the six coastal counties that were obtained from the U.S. Census Bureau. For four of the counties, the functional classifications were already coded into the shapefile. The study team then used Georgia DOT functional classification maps to code the functional classifications

of the roadways in the remaining two counties, and merged the six county road networks into on regional road network layer. Once coded and merged, the study team selected only the four most important functional classifications for mobility (interstates, freeways/ expressways, principal arterials, and minor arterials) and created separate layers for each of these functional classifications. The study team then intersected the inundation map created
in the previous studio with the layers for each of the functional classifications to identify the segments in each functional classification that would be inundated. Next, for each functional classification the study team calculated the lengths of each of the segments, and exported the results to an Excel file, where the team completed the remainder of the calculations.

At this point, the study team had four tables. All contained a list of roadway segments inundated along with the corresponding lengths of the segments that would be inundated. The tables were divided by functional classifications; one contained the interstate segments, another freeway/expressway segments, and so on. The study team then calculated the range of the typical minimum cross section widths for each of the functional classifications. It is important to note that the inundated segments were grouped by functional classification since the characteristics that go into the calculation of a typical minimum cross section width, such as average number of lanes, minimum lane width, and minimum shoulder width, vary for the different functional classifications. The team calculated these ranges for each of the functional classifications by multiplying the range of minimum lane widths by the average number of lanes and adding the range of minimum shoulder widths. The values for each of these variables, average number of lanes, range of minimum lane width, and range of minimum shoulder width, were obtained from the Federal Highway Administration.

Next, using the tables with the list of segments and corresponding lengths and the range of minimum cross section widths, the study team calculated the range of minimum bridge area for each of the segments. The study team simply multiplied the range of minimum width by the length to determine the range of minimum bridge area. Finally, the study team applied the appropriate range of per square foot bridge construction cost estimates published by the Florida Department of Transportation (FDOT). FDOT classified bridges as short span or medium/long span bridges which had different ranges of per square foot construction costs. The study team used if/then logic in Excel to apply short span per square foot bridge costs to short segments (< 45') and medium/long span per square foot costs to short span bridges. The study team multiplied the range of minimum bridge area (in square feet) by the appropriate range of per square foot bridge construction costs to obtain the range of construction costs for each of the segments. The study team then aggregated these values to obtain the impacts along the entire Georgia coast.

5.3 METHODOLOGY OF THE UGA DEEPWATER PORTS STUDY

The study team primarily used economic inputs provided by the University of Georgia's 2012 report, "Economic Impact of Georgia's Deepwater Ports," to quantify the economic impact of a one meter of sea level rise at the Garden City Terminal ("UGA Study"). The UGA study looked at the economic impact of the Port of Savannah and Port of Brunswick (Georgia's deepwater ports) on Georgia's economy in terms of output, income, GDP, employment and taxes. The UGA study separated economic impact into direct economic impact, indirect economic impact, and induced economic impact. Economic data from the Port of Savannah included information from both the Garden City Terminal and the Ocean City Terminal. Likewise, economic data at the Port of Brunswick included information from

both Colonel's Island Terminal and Mayor's Point Terminal. Because our report focuses solely on the Garden City Terminal, the *Blueprints* team had to make assumptions about the data, which are explained in detail below. Additionally, the UGA study separated the economic data for port users and port industry. The study defined the "port industry" as including "economic activity (spending) that involves the transportation of waterborne cargo and port services, including the ports themselves, the companies engaged in deepwater transportation, as well as companies that provide ship services, and companies that provide inland transportation of waterborne cargo" (Humphreys 2012). The Garden City Terminal is included as part of the port industry. Port users, on the other hand, are primarily "manufacturers, agricultural firms, wholesalers, distributors, and warehousing and storage firms that use the ports to transport materials and/ or products" (Humphreys 2012).

This section describes how the UGA study was conducted, what assumptions were made, and how specific terms were defined in the report. Stated more simply, port users utilize Georgia's deepwater ports to import and export goods and product. The port user definition excludes transportation expenditures associated with waterborne cargo, however, to avoid double counting economic activity with that of the port industry (Humphreys 2012).

Furthermore, the UGA study separated economic impact into direct economic impact, indirect economic impact, and induced economic impact. All economic activity (spending) generated by port industry, and a portion of spending generated by port users, whose decision to locate, expand, or remain in Georgia hinges on the presence of Georgia's deepwater ports were counted as direct economic impact (Humphreys 2012). Indirect economic impact measures the changes in inter-industry purchases as industries respond to demands triggered by port users and port industry (Humphreys 2012). In a similar study on the economic impact of ports, Pan (2011) defined indirect economic impacts as the "ripple effects from direct final demand changes on related industrial purchases, and induced impacts reflect the effects on regional industries caused by changes in household consumption in response to the effects of direct final demand changes." Induced economic impact measures the "ripples of activity that are created when households spend more due to the increases in their earnings that were generated by the direct and indirect spending" (Humphreys 2012).

Economic output was defined as the gross receipts or sales, minus inventory. Total economic output is the most inclusive and comprehensive measure of economic impact, though it does involve some double counting of economic activity by including the value of inputs produced at other industries. State GDP measures value added, which consists of employee compensation, proprietor income, other property income, and indirect business taxes (Humphreys 2012). Value added is equivalent to gross output less intermediate inputs (Humphreys 2012). The income figure includes all forms of employment income, including wages, salaries, and proprietors' income (Humphreys 2012). The income figure included in the UGA study and thus this report, however, does not include nonwage compensation (Humphreys 2012). Finally, the employment figure includes total wage and salary employees as well as self-employed employees (Humphreys 2012). The employment figure includes both full-time and part-time jobs and is measured in annual average jobs (Humphreys 2012).

The UGA study received its data from the Georgia Ports Authority and other governmental and administrative organizations. The study used two types of economic impact software: (1) MARAD Port Economic Impact ToolKit; and (2) IMPLAN Version 3.0. The Selig Center used the IMPLAN Version 3.0 software to estimate the indirect economic impacts of the ports-related portion of spending by users (Humphreys 2012). Furthermore, the Selig Center used a specialized version of the MARAD Port Economic Impact model to measure the direct, indirect

and induced economic impact of spending by the ports industry.

5.4 ECONOMIC IMPACT ANALYSIS: PORT RECOVERY PERIODS

PORT RECOVERY PERIOD AFTER A CATEGORY 1 HURRICANE

Superstorm Sandy struck New Jersey and New York on October 29, 2012. Sandy hit land with sustained winds of 70 mph and was considered a post-tropical cyclone (approximately a category 1 Hurricane) (Smythe 2013). The Port Authority of New York- New Jersey and the U.S. Coast Guard shut down the New York-New Jersey Port at 6:00 p.m. on October 28, 2012 before the storm made landfall. Hurricane Sandy's storm surge was as high as 14 feet in some parts of New Jersey and New York, and inundation levels ranged from 2 to 9 feet around port infrastructure (Blake et al. 2013). The record storm surge, unusually high in part because of a maximum astronomical tidal event, and sustained winds had a significant impact on commercial port operations. Flooding affected these operations in numerous ways, including damage to electrical equipment and electric motors that powered cranes for offloading cargo and truck chassis for transporting cargo beyond the Port (Smythe 2012). Electrical damage to container cranes was a major reason the Container Terminal at the Port was slower to recover than other terminals at the New York-New Jersey Port (Smythe 2012). The loss of electrical power also created security and safety concerns. Security fences were down and the absence of traffic lights raised security risks for employees and drivers at the Port (Smythe 2012). Loss of electricity from saltwater intrusion also disrupted generator use. The Port had electrical generators that were not well-designed to handle saltwater inundation. Diesel generators are better able to handle inundation, but these were not in heavy use at the container terminal during Superstorm Sandy.

Most of the port activity at the Port of New York-New Jersey was shut down for approximately a week, with operations resuming at limited capacity on November 4, 2012, though partial opening began on November 1, 2012 (Smythe 2013). However, the Port's container terminals did not fully reopen on November 4, 2012 because of facility damage and loss of power (Smythe 2013). We therefore estimated that upon re-opening the Port was operating at very limited capacity. We estimated it was operating at 10% of its normal capacity because of the electrical issues and damage to docks noted above. It appears from the literature that the Port of New York-New Jersey recovered quickly after the initial closure, however, so we estimated that after week two the container terminal within the Port was already operating at 75% of its pre-Sandy capacity. Reports from three weeks after the hurricane indicated that the Port was still experiencing some delays because of damage to truck chassis and local road networks, which reduced the number of containers able to be drayed off the terminal (OOCL 2012). Therefore, we estimated that the Container Terminal would be operating at 90% of pre-Sandy capacity after week three. Finally, it appeared that after four weeks the Port was operating at a normal level and therefore the team placed the Port's capacity after week four at 100% of its pre-Sandy capacity.

PORT RECOVERY PERIOD AFTER A CATEGORY 3 HURRICANE

In 2005, the World Bank commissioned a study to look at the economic impact of Hurricane Ivan on Grenada. Hurricane Ivan struck Grenada on September 7, 2004 as a category 3 Hurricane (World Bank 2005). The Port of St. George's in Grenada was initially overwhelmed by Ivan and remained closed for three days following the storm (World Bank 2005). The international community responded with overwhelming support to this disaster and sent much needed aid and supplies to the country and directly to the Ports Authority. The Ports Authority was able to start accepting supplies and assistance at the port a week following the storm thanks in large part to

help from the Trinidadian and St. Lucian Ports Authorities (World Bank 2005). A major impediment to reaching full capacity at the Port of St. George's was the lack of labor available to receive imports and open containers at the Port, which are both labor-intensive processes (World Bank 2005). After an initial recovery effort spurred by international support, the Port had trouble sustaining pre-Ivan operations the weeks following the storm because of damage to all six of its storage sheds on the Port property (World Bank 2005). Three of the storage sheds were rebuilt approximately three months after Hurricane Ivan (World Bank 2005). Storm surge did not cause significant damage because of sea walls that were in place to mitigate the impact of sea waves; wind caused most of the damage at the Port (World Bank 2005). Microburst downdrafts appeared to be the largest cause of damage (World Bank 2005).

The Port recovered to pre-Ivan levels approximately one month after Hurricane Ivan due in large part to the aid from international NGOs and governments (World Bank 2005). At the time the World Bank report was conducted, eight months following Hurricane Ivan's impact, Port of St. George's was handling construction materials (a primary good shipped through the port) "without significant delay" at levels beyond what it was receiving before the hurricane (World Bank 2005).

Hurricane Rita hit made landfall as a category 3 hurricane on the Louisiana and Texas border on September 24, 2005. The eye of Hurricane Rita passed 3.5 miles east of the Port of Port Arthur in Port Arthur, Texas. The economic losses from Rita vary over a wide area (Pan 2011). Officials at Port of Port Arthur reported that Hurricane Rita caused moderate damage to facilities and cargo at the port (Transportation Board 2008). After the storm, Port Arthur officials moved quickly to assess damages and reopen port facilities. The port's emergency management team was permitted to enter the city on September 28 to start cleaning up the Port. In August 2006, the Port of Port Arthur reported it was operating at pre-Hurricane Rita levels. Hurricane Rita's total economic damage was estimated at approximately $10 billion at the Port itself (Pan 2011). Little additional information on specific port recovery times has been published.

Based on information on port recovery times at the Port of St. George's and Port of Port Arthur, and based on the operations, planning and infrastructure in place in and around the Garden City Terminal, the authors estimated a recovery time schedule for the Garden City Terminal in the event of a category 3 hurricane event. As shown in Table 2.14, the team estimates the port will return to pre-category 3 hurricane levels approximately five weeks after the storm event. As is noted in each section, these closure and reduced capacity figures vary widely depending on the hurricane plans in place at the ports, how well these plans are followed, the proximity of the storm to the port, age of infrastructure, and recovery and relief resources available after a storm makes landfall.

One week after a category 3 hurricane, the Garden City Terminal would likely operate at 10% capacity and therefore the overall capacity of the Terminal would be reduced by 90%.Two weeks after a category 3 hurricane, the Garden City Terminal would likely be operating at 50% capacity. Because of the Terminal's importance to the national economy, relief and recovery efforts would be significant to get the Terminal open and operating at normal levels. Three weeks after a category 3 hurricane, we estimate that the Garden City Terminal would be operating at 75% of its pre-hurricane capacity. Finally, the team estimates that five weeks after a category 5 hurricane the Garden City Terminal would regain full operational capacity. This five-week time frame may be optimistic considering that a category 3 event would likely flood and damage critical road and rail infrastructure surrounding the Garden City Terminal. Damage to the container cranes from high wind speeds would extend this recovery time by at least a few weeks, but these additional considerations were too speculative based on available information.

PORT RECOVERY PERIOD AFTER A CATEGORY 5 HURRICANE

Hurricane Katrina destroyed one-third of the Port of New Orleans (Grenzeback & Lukmann 2008). The Port of New Orleans is the fifth largest port in the United States in terms of the volume of cargo handled, and includes the twenty-fourth busiest container terminal in terms of volume of TEUs handled in the United States (Grenzeback & Lukmann 2008). During Hurricane Katrina, three major container cranes were damaged (NIST 2006). The container cranes were secured by four hurricane tie-down connections designed to withstand hurricane winds (NIST 2006). Despite this hurricane planning effort, each crane was pushed more than fifty feet inland and severely damaged (NIST 2006). Replacement and repair of container cranes was problematic because the container cranes are not easily transported and have long lead times for assembly and delivery.

In addition to damage to container cranes, the Port of New Orleans severely flooded, canals extending to the Port were silted in, and navigational aids were significantly damaged. As of September 29, 2005, approximately four weeks after Hurricane Katrina struck, 850 of the 1,350 aids to navigation discrepancies identified by the Coast Guard had been repaired with permanent or temporary aids (Grenzeback & Lukmann 2008). Moreover, the port's 36-foot channel connecting it to the Mississippi River-Gulf Outlet was nearly completely silted in from sediment and debris flowing into the channel (Grenzeback & Lukmann 2008). Today, a storm surge barrier blocks access to the Mississippi River-Gulf Outlet and the channel has been closed to maritime shipping since Hurricane Katrina.

Traffic at the Port of New Orleans recovered faster than many expected. The Port of New Orleans welcomed its first vessel approximately two weeks after Hurricane Katrina devastated the Gulf Coast. The Port reached half capacity three and a half months after the storm but would not reach full capacity until much later (Sayre 2006). Six months after Hurricane Katrina, the Port of New Orleans had regained 100% of its pre-hurricane capacity and was averaging 20-22 vessels per week (U.S. Department of Commerce 2006). Though the Port of New Orleans regained its pre-Katrina operational capacity more quickly than most estimated, a report issued by the U.S. Department of Commerce noted that the amount of cargo moving through the Port's facilities fell by approximately 20% compared to pre-Katrina levels of cargo (U.S. Department of Commerce 2006). Moreover, it was estimated that the Port sustained $100 million in damage, and port users (industry that relied on the port) sustained between $280 million and $300 million in damage (Sayre 2006). In addition to massive damage from storm surge and flooding, one of the greatest challenges facing recovery at the Port of New Orleans was in finding labor to clean up and repair damage at the Port. Many of the Port employees' homes had been affected by the hurricane, and many employees relocated to ports on the East Coast for better employment opportunities (Sayre 2006).

When Hurricane Katrina hit the Gulfport in Mississippi's port in 2005, its record-setting 25-foot storm surge knocked down container cranes, blew apart storage sheds, destroyed navigational aids and pushed barges hundreds of feet inland (Wright 2013). Hurricane Katrina destroyed over 300,000 square feet of warehouse space and most of the rail lines into the Port of Gulfport (U.S. Department of Commerce 2006). A year after the storm, the Port of Gulfport was still only operating at 70% of its pre-Katrina capacity (U.S. Department of Commerce 2006). Before Hurricane Katrina the Port had been handling approximately eight vessels a week; a year after the storm the Port of Gulfport was handling four or five vessels a week (U.S. Department of Commerce 2006). Moreover, some research has indicated that even after five years and over $250 million in new investments, the Port of Gulfport was still only operating at 80% of its pre-Katrina capacity (Wright 2013).

The team used an average recovery time between the Port of New Orleans and Port of Gulfport after Hurricane Katrina to estimate a port recovery time line in the event of a category 5 storm. The estimation of port recovery times is found below in Table 2.15. In general, the team estimates the Garden City Terminal would not regain full operations, or 100% capacity, for eight months (32 weeks) after a category 5 Hurricane based on recovery time lines at the Port of Gulfport and the Port of New Orleans. The team also considered factors such as government response and aid, state response and aid, and the port equipment and surrounding infrastructure likely to be damaged in the event of a catastrophic hurricane event in determining the eight-month figure.

The team estimates that one week after a category 5 Hurricane a port would be 100% inoperable. After two weeks, the authors estimated that the port would be 10% operable. It took approximately two weeks for the Port of New Orleans to allow one ship to enter, which we estimated meant that the Port was operating around 10% capacity, or at a 90% reduced capacity compared to normal operating levels. This very limited operational capacity also includes administrative work, repair to navigation stations, and clean up at the Port. Three weeks after a major category 5 hurricane, we estimate that the Port of Savannah would return to 15% of its pre-hurricane capacity. Thus, the extent of capacity reduced would be 85%. After four weeks, the authors estimate the Port of Savannah will be at 20% of pre-hurricane capacity, which equates to an 80% reduction in capacity. Eight weeks after a category 5 Hurricane, the team estimates that the Port of Savannah will be operating at 35% of normal capacity. After twelve weeks, the Port is estimated to operating at 45% of pre-hurricane capacity. Furthermore, after 16 weeks, the Garden City Terminal would be operating at 55% of its pre-hurricane capacity, and after 20 weeks the Garden City Terminal would be at 65% of pre-hurricane capacity. At 24 weeks, we estimate that the Terminal would be 75% operational. This is a reduction in capacity of 25%. Finally, we estimate that the Terminal would be operating at 90% of its pre-hurricane capacity after seven months (28 weeks), and would fully recover to pre- hurricane operating capacity (100% capacity) after 32 weeks, or eight months.

5.5 HAZUS MODEL

The *Blueprints* team explored using Hazus to quantify the building damage incurred by different categories of hurricanes with and without sea level rise. Hazus is designed to account for social effects and physical damage incurred by hurricanes, flooding, and earthquakes. Hazus has been used to assess the economic impacts of sea level rise and storm surge independently. Storm surge analysis in Hazus is based on combining analysis in two modules: the hurricane module and the flood module. The user inputs the sea level rise at the beginning of the hurricane module, which ostensibly should allow the user to account for sea level rise by comparing model outputs for equivalent scenarios that different only by sea level. After running the hurricane module with two different sea levels, the user can feed output files into the flood module and run a coastal surge analysis.

The study team considered using Hazus to analyze the effects of sea level rise on storm surge. Hazus has several advantages, including its ability to provide input for flood insurance rate (Scawthorn et al. 2006) and the fact that the studio by Keating and Habeeb (2013) used Hazus to estimate storm surge damage at the county level. However, SLOSH (Sea, Land, and Overland Surges from Hurricanes) from also has several disadvantages, including the difficulty in changing built-in assumptions and the extremely long process time for each scenario. Moreover, Hazus has severe compatibility problems, both with other programs and among its hurricane and flood modules. Hazus MH version 2.1 is only compatible with ArcGIS 10.0 service pack 2. The College of Architecture IT department provided a computer system with the

appropriate version of windows and ArcGIS for Hazus compatibility, and it troubleshot other software bugs. However, the Hazus help desk was unable to overcome an incompatibility between the hurricane and software modules by study termination that prevented uploading a digital elevation map in the flood module to scenarios with hurricane module outputs.

5.6 SLOSH MODEL AND METHODOLOGY

The Georgia Conservancy *Blueprints* team estimated flooding using the SLOSH model in the Savannah basin by using built-in scenarios for hurricanes of category 1 through 5 that aggregate the maximum wave heights for a variety of different storm locations, speeds, and directions. The study team overlaid SLOSH flooding output with a parcel file provided by the Chatham County Board of Assessors in ArcGIS to determine the parcels that were fully or partially inundated by storm surge for different hurricane categories at current sea levels. By overlaying the two polygons in ArcGIS, the study team identified the flooded parcels for each scenario and built a table with acreages, building value, land value, and flood height for each. This initial analysis provided the aggregate characteristics for the parcels that were vulnerable to storm surge at current sea levels for five different hurricane categories.

SLOSH does not incorporate sea level rise. Therefore, the study team extrapolated the amount by which sea level rise would increase vulnerability to storm surge by drawing a connection between the maximum wave height produced by SLOSH and the exposure for each scenario. The study team made a new data series of tables for scenarios with sea level rise, and it scaled the values produced in the initial analysis based on the amount by which sea level rise increased maximum storm surge between one scenario and the next.

The method of extrapolating storm surge exposure based on sea level makes several assumptions. It assumes that there is a linear relationship between the maximum wave height and storm surge exposure. This linear relationship may not reflect wave propagation influenced by topography. The extrapolation method also assumes that sea level rise will not change the basic patterns of storm surge, which is an assumption that all SLOSH-based analysis makes. However, storm surge may submerge some barrier islands, which would increase inland vulnerability beyond what is modeled.

The interpolation method has several advantages over GIS-based methods. GIS-based methods are often constrained based on the extent of SLOSH output and are unable to easily assess sea level rise's impact outside of grids produced in SLOSH. Second, GIS- based methods also require the researcher to make assumptions on a case by case basis about how storm surge will propagate to surrounding areas, similar to those assumptions made in a bathtub model.

However, the interpolation method also has several limitations. While it estimates how much sea level rise may increase exposure to storm surge, researchers must rely on other knowledge or models to estimate where those increases are likely to occur. Moreover, the interpolation method requires SLOSH-produced output at higher and lower wave heights. This means that five SLOSH outputs can produce four interpolations. Therefore, the study team was not able to estimate the effects of sea level rise on category 5 storm surge because SLOSH cannot model flooding above category 5.

The study team used outputs of the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model produced by the National Oceanic and Atmospheric Administration (NOAA). SLOSH has several advantages over Hazus. First, it isolates the effects of storm surge compared with wind damage. SLOSH also processes quickly and is compatible with most versions of Windows and other programs. Moreover, SLOSH- based analysis allowed the study team more control over the analytical

assumptions. This is more appropriate because SLOSH does not model damage to vehicles, containers, container fields, electrical infrastructure, rubber tired gantry cranes, container cranes and other port infrastructure that constitute the bulk of the port facilities.

SLOSH estimates storm surge with different hurricane categories. SLOSH offers three analysis options. The first applies historical storms whose paths and wind speeds can be imported. Historical storms were not appropriate because they do not allow for comparisons among equivalent storms of different strengths. The second analytical option allows users to create a storm scenario by setting storm direction, category, tide level, and storm speed. SLOSH produces a flood grid that represents the maximum envelopes of water (MEOW), which is the highest wave height under that scenario. This analytical option is not ideal because storm surge heights would vary by user characteristics, so a hurricane output may not be representative of other hurricanes of that category with a different speed or direction. The third option aggregates the maximum wave heights (MEOWs) for all directions and speeds of a hurricane of a given category into the maximum extent of MEOWs called MOM. The MOM is the maximum wave height of all hurricane scenarios for that water basin and that hurricane category. MOM is most appropriate because it eliminates the need for arbitrarily selected user inputs and it represents the maximum storm surge damage that could be expected with a given hurricane category.

The study team produced five hurricane scenarios in SLOSH for hurricane categories 1 through 5 at high tide. The study team imported the "Savannah/Hilton Head v4" basin in SLOSH. To select the storm type, it clicked the "select-storm" menu and "select storm." Using high tide and MOMs produces the highest expected wave heights for a hurricane category. The study steam also selected the option in SLOSH that automatically subtracts ground level from storm surge heights. Therefore, values in the flood grid represent the expected height of water above ground level in that grid rather than water height above a tidal datum. The study team subtracted land value from storm surge heights by selecting "display," and "subtract land" in SLOSH before running each model. The study team exported each of the scenarios by selecting "file," "save data as SHP," and saving the flooding output as a shapefile for analysis in ArcGIS.

The *Blueprints* team examined ways in which past researchers have used SLOSH output to analyze sea level effects on storm surge. While SLOSH does not account for sea level rise within the model, most perform further spatial analysis on model outputs. For example, Frazier, Wood, Yarnal, and Bauer (2010) analyzed SLOSH storm surge predictions for all five hurricane categories in Sarasota County, FL to approximate the increased extent of surge-related flooding due to sea level rise. Frazier et al. (2010) first subtracted elevation values in a digital elevation model (DEM) from a rasterized flood grid produced in SLOSH. Those areas where the difference was positive were identified as submerged due to storm surge at current sea levels. To account for 120 centimeters for sea level rise, Frazier et al. (2010) subtracted 120 centimeters from all elevations in the DEM and compared the flood grid with the DEM as it had previously. More grid cells had positive values because of sea level rise, showing that more areas were flooded due to storm surge. Frazier et al. (2010) produced maps in ArcGIS with a raster file showing the additional areas in Sarasota County that were flooded under the sea level rise scenarios compared with the current sea level scenarios. The study team used SLOSH outputs to assess the increased severity of surge floods.

Another method to account for sea level rise effects on storm surge vulnerability is through mathematical extrapolations. Researchers may choose extrapolations for reasons including data availability, the lack of geographically specific methods in the past, or an emphasis on aggregate measures. Nicholls et al. (1999) used a nonlinear equation to estimate the increase in

storm surge vulnerability in Bangladesh due to sea level rise (Nicholls et al. 1999). The study team derived a similar mathematical model based on the assumption of a linear relationship between water height and storm surge vulnerability, which is explained in Appendix Section 5.5.

5.7 ArcGIS ANALYSIS

CHATHAM COUNTY

SLOSH produces a grid of flood heights for hurricane categories 1 through 5, but it does not itself assess the value of property that is vulnerable to storm surge. Therefore, the study team imported flood shapefiles into ArcGIS to analyze in conjunction with Chatham County Parcel data to determine the economic impact of storm surge at current sea level. ArcGIS is a geographic information system built by ESRI which allows advanced spatial analysis. The study team used a shapefile of Chatham County parcels provided by the Chatham Board of Assessors to analyze with SLOSH-produced flooding shapefiles. The parcel shapefile provided zoning category, property owner, building value, land value, total assessed value, parcel acreage, land use, and many other variables that the study team did not employ. The parcel shapefile provided a rich dataset for Chatham County.

The study team imported the parcel shapefile and the storm surge shapefiles for hurricanes of categories 1 through 5 into '.mxd' ArcGIS files, creating a file for each hurricane scenario.

Importing the flood grids had the following steps.

1. Define the flood grid projection to the North American Datum (NAD) 1927.
2. Add the parcel shapefile.
3. Project the flood grid into the same coordinate system as the parcels, which is Georgia East.

The study team used a series of spatial selections to isolate the parcels that overlapped with the sea storm surge shapefile for each category. These parcels represent those that would be flooded in part or in whole due to storm surge. The flooded parcels' attribute table provided the acreage, building value, land value, and total assessed value likely to be affected at current sea levels by hurricanes of different categories. The study team estimated the average and maximum flood levels by clipping the SLOSH-produced flooding shapefile by the flooded parcels shapefile for each hurricane category. The "statistics" function in the attribute table provided the mean and maximum flooding. The study team built tables to show the acreage, number of parcels, and monetary value of the parcels that overlapped with storm surge grids for each hurricane category at current sea level. This table summarized the county-level storm surge impact.

GARDEN CITY TERMINAL

Next, the *Blueprints* team assessed flooding at the Garden City Terminal by selecting the single parcel that is the Garden City Terminal and clipping the SLOSH-produced storm surge shapefile to those parcel boundaries. It is important to note that flooding amounts at terminal level are approximations because SLOSH flood grids are very large and lack fine geographic granularity. To account for the lack of data granularity, the study team checked flood heights at the river against the wharf heights provided by the Georgia Ports Authority to make sure that flooding produced in SLOSH represented flooding on terminal property rather than flooding in the adjacent river.

Moreover, the team evaluated flood height on port property as far away from the river as possible to ensure that the height reflected on-land flooding rather than river flooding. The team used the "identify" tool on a flood polygon that was on port property but did not overlap with the Savannah River to produce flood height.

The study team clipped the storm surge grid to the port parcel boundaries for each category, dissolved boundaries among surge grid, and compared the areas of the surge grid and the parcel property to approximate the port area that was flooded for each hurricane category at current sea level. Percentage flooding are more accurate at large scales than at smaller scales because of the large size of the flood grids produced in SLOSH. Therefore, port flooding percentages are rough approximations. However, the method allows the study team to estimate flooding severity when combined with other knowledge about port topography and wharf height.

The study team also produced a table showing the flood height and percent of terminal inundation for each hurricane category at current sea level.

WAREHOUSES

Finally, the study team analyzed warehouse exposure to storm surge at current levels because many goods to and from the Garden City Terminal are processed in local distribution centers. The study team analyzed warehouse exposure to flooding by selecting all parcels in the parcel shapefile with a land use description of "warehouse-detached," and it manually verified that the category included the port-related warehouses owned by Target and IKEA. Warehouses were spread throughout Chatham County with a large number in northwestern Chatham County near the port. The study team assessed the number of warehouses likely to be affected by storm surge by clipping the warehouse parcels to the SLOSH-produced flood polygons produced for each storm category. It then used the "statistics" tool in the attribute table to obtain the parcel acreages and values for each storm category.

Finally, the study team built an Excel table showing the warehouse exposure to storm surge from each hurricane category at current sea level similarly to how it had for Chatham County and for the Garden City Terminal. These tables did not includes the effects of sea level rise, but rather provided the basis for extrapolating increases in vulnerability to storm surge due to sea level rise.

Section 5.9 of the Appendix includes the vulnerability tables for Chatham County, the Garden City Terminal, and warehouses.

5.8 LINEAR EXTRAPOLATION

Independent research and the past Georgia Conservancy sponsored studio estimated a 100 year sea level increase of one meter, or approximately 3.28 feet (Georgia Conservancy 2012). The research has posited a one meter sea level increase over the next hundred years. Therefore, the research team added one meter to expected surge-related floods produced in SLOSH and analyzed them for key infrastructure.

The study team extrapolated exposure to storm surge with one meter of sea level rise by using the data points and average water levels for the five storm categories as base points and assuming linear exposure increases between one storm category and the next highest. It followed the same procedure for Chatham County, the Garden City Terminal, and warehouses.

First, the study team assessed the percentage of the difference between maximum flooding of one hurricane category and the maximum flooding in the next highest storm category. It assumed a linear relationship in exposure at the two levels of mean flooding. Based on this linearity assumption, the study team multiplied the percentage by the difference between each variable in the two storm surge categories, and added that scaled difference to the storm surge at existing sea level.

The *Blueprints* team replicated each of the tables that it had built for storm surge vulnerability at the level of the county, terminal, and warehouses, but with vulnerability estimates scaled by the ratio of sea level rise compared

with storm surge heights. Section 5.9 of the Appendix shows the complete vulnerability tables.

Linear extrapolation has several advantages compared with analysis in ArcGIS. First, it avoids the need to isolate land that is lower in elevation than SLOSH-based storm surges, which is a very complicated process due to the ways in which wave heights vary based on topographical characteristics. Moreover, the digital elevation map provides much more precise height granularity than SLOSH output, undermining any potential precision increases in the ArcGIS-based approach. Instead, Excel uses datapoints derived from SLOSH itself to extrapolate the relationship between sea level captured in wave heights and each of the variables assessed. As such, the data is internally consistent because it avoids the assumptions required to geographically isolate new areas that might flood without higher sea level.

The Excel-based approach has several weaknesses. First, it does not allow the study team to determine the exact locations that might flood due to high sea level and storm surge. Rather, outputs are aggregated for the geographic unit of analysis. It is possible to estimate areas of potential flooding by examining the digital elevation map for low-lying areas adjacent to flood grids from SLOSH.

Linear extrapolation depends on several assumptions that may not hold in all circumstances. The first is the linear relationship between each vulnerability variable and maximum wave height. In other words, linear extrapolation assumes that vulnerability by any measure will increase linearly as maximum storm surge heights increase. While this assumption is reasonable on large geographic areas, it may cover a more complex relationship based on land contours, particularly at fine geographic scales.

Linear extrapolation also it assumes that an increase water level due to sea level rise is comparable in characteristics to temporary water level increases due to hurricanes. While this assumption is built into most storm surge and sea level rise analyses, including those using ArcGIS by Frazier et al. (2010), the true relationship is probably more complex. Further research should explore new ways of accounting for sea level rise in storm surge models that account for different characteristics.

Finally, linear interpolation allows estimation of each of the variables with sea level rise for storm categories 1 through 4, but not for category 5. The reason is that interpolation requires point with greater flooding than the case being examined, which does not exist for category 5 storms. Therefore, category 5 variables with sea level rise are marked ‘N/A’ because they are incalculable. It can be assumed that category 5 storm surge with sea level rise would produce even more severe damage than without.

5.9 STORM SURGE VULNERABILITY TABLES

Chatham County	
Total Area (acres)	258,738
Total Assessed Land Value	$8,877,078,301
Total Assessed Building Value	$20,542,508,293

Table 5.31: Chatham County Characteristics
Source: Chatham County Board of Assessors 2013

	Current Sea Levels				
Affected Parcels	Category 1	Category 2	Category 3	Category 4	Category 5
Number of Parcels	24,988	48,387	87,318	103,605	107,418
Affected Area	156,903	184,437	235,578	256,647	257,818 (acres)
Percentage Area	61%	71%	91%	99%	100%
Total Assessed Building Value	$5,249,243,788	$9,035,332,800	$15,464,649,519	$17,662,242,056	$18,158,817,431
Mean Building Value	$210,796	$187,090	$177,306	$170,641	$169,207
Percentage Building Value	26%	44%	75%	86%	88%
Total Assessed Land Value	$3,554,160,302	$5,040,781,496	$7,377,421,159	$8,199,476,192	$8,343,644,581
Mean Assessed Land Value	$142,726	$104,377	$84,584	$79,218	$77,748
Percentage Land Value	40%	57%	83%	92%	94%
Max Flooding	10.3	16.5	21.8	25.8	29.6 (feet)
Average Flooding	7.7	11.5	13.6	16.2	19.9 (feet)

Table 5.32: Chatham County Vulnerability to Storm Surge - Current Sea Level

	One Meter of Sea Level Rise				
Affected Parcels	Category 1	Category 2	Category 3	Category 4	Category 5
SLR as % of Surge Height Increase	53%	62%	82%	86%	N/A
Number of Parcels	37,366	72,480	100,673	106,896	N/A
Affected Area (acres)	171,469	216,086	252,855	257,657	N/A
Percentage Area	66%	84%	98%	100%	N/A
Total Assessed Building Value	$7,252,207,007	$12,436,648,741	$16,627,246,861.15	$17,924,946,448	N/A
Mean Building Value	$198,255	$181,914	$173,780	$169,883	N/A
Percentage Building Value	35%	61%	81%	87%	
Total Assessed Land Value	$4,340,630,869	$6,276,939,253	$7,812,314,789	$8,275,745,920	N/A
Mean Assessed Land Value	$122,438	$93,906	$81,745	$78,440	N/A
Percentage Land Value	49%	71%	88%	93%	
Max flooding (feet, one meter SLR)	13.6	19.8	25.1	29.1	32.9
Average flooding (feet, one meter SLR)	11	14.7	16.9	19.5	23.2

Table 5.33: Chatham County Vulnerability to Storm Surge - 1.0 Meter SLR

	Current Sea Level				
	Category 1	Category 2	Category 3	Category 4	Category 5
Water Level above High Tide (feet)	6.8	12.5	17.4	22.7	26.6
Water Level above Ground (feet)	0	1.4	5.5	12	16.2
Percentage of Port Inundated	57%	86%	100%	100%	100%

Table 5.34: Flooding at Garden City Terminal Due to Storm Surge at Current Sea Level

	One Meter of Sea Level Rise				
	Category 1	Category 2	Category 3	Category 4	Category 5
SLR as % of Surge Height Increase	58%	67%	62%	84%	N/A
Water Level above High Tide (feet)	10.1	15.8	20.7	26	29.9
Water Level above Ground (feet)	3.3	4.7	8.8	15.3	19.5
Percentage of Port Inundated	73%	95%	100%	100%	100%

Table 5.35: Flooding at Garden City Terminal Due to Storm Surge with 3 Feet of SLR

Warehouses in Chatham County	
Total Warehouse Area (acres)	2,147
Total Warehouse Building Value	$896,204,735
Total Land Value	$167,121,902

Table 5.36: Warehouse Characteristics in Chatham County

	Current Sea Level				
	Category 1	Category 2	Category 3	Category 4	Category 5
Affected Area (acres)	172	762	1,884	2,106	2,112
Percentage Area	8%	36%	88%	98%	98%
Total Assessed Building Value	$111,977,107	$390,210,977	$786,543,254	$874,600,335	$875,489,635
Percentage Building Value	12%	44%	88%	98%	98%
Total Assessed Land Value	$7,713,200	$54,859,430	$145,308,949	$160,551,102	$161,440,802
Percentage Assessed Value	5%	33%	87%	96%	97%
Max Flooding (feet)	8.7	15.5	21.2	24.4	27.6
Average Flooding (feet)	7.1	6	6.7	10.5	14.3

Table 5.37: Warehouses in Chatham County Affected by Storm Surge at Current Sea Level

	One Meter of Sea Level Rise				
	Category 1	Category 2	Category 3	Category 4	Category 5
SLR as Water Rise to Next Category	48%	58%	103%	103%	N/A
Affected Area (acres)	456	1,408	2,111	2,112	N/A
Percentage Area	21%	66%	98%	98%	N/A
Total Assessed Building Value	$246,184,033	$618,275,826	$876,801,790	$875,511,867	N/A
Percentage Building Value	27%	69%	98%	98%	N/A
Total Assessed Land Value	$30,454,323	$106,907,565	$160,932,161	$161,463,045	N/A
Percentage Assessed Value	18%	64%	96%	97%	N/A
Max Flooding (feet)	12.0	18.8	24.5	27.7	30.9
Average Flooding (feet)	10.4	9.3	10.0	13.8	17.6

Table 5.38: Warehouses Affected by Storm Surge with 1.0 Meter of SLR

5.10 SLAMM OUTPUT TABLES

This table shows the results of the SAMBI SLAMM model by decade. Percentages are calculated land cover classification changes from 2000 base year.

	Percentage Change Since 2000									
	2010	2020	2030	2040	2050	2060	2070	2080	2090	2100
Upland Developed	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Upland Undeveloped	-1.68	-2.09	-4.45	-5.61	-6.30	-7.06	-7.58	-7.95	-8.33	-9.41
Swamp	1.12	0.37	4.03	3.81	2.62	1.28	1.20	1.68	2.12	-1.30
Cypress Swamp	0.11	0.02	0.34	0.30	0.19	0.16	0.18	0.24	0.89	-1.29
Inland Fresh Marsh	1.21	1.17	3.55	2.48	0.62	-3.15	-7.42	-11.35	-15.15	-18.08
Tidal Fresh Marsh	*	*	*	*	*	*	*	*	*	*
Scrub/Shrub Transitional Marsh	896.08	1397.49	2048.00	2948.60	3790.90	4747.85	5184.73	5203.30	5105.21	6251.94
Salt Marsh	-9.63	-14.63	-21.27	-29.67	-37.86	-47.76	-57.11	-61.33	-59.25	-50.00
Mangrove	*	*	*	*	*	*	*	*	*	*
Estuarine Beach	-18.09	-20.78	-24.85	-30.05	-35.14	-39.38	-45.35	-31.82	-36.96	22.97
Tidal Flat	-31.64	-20.97	-5.23	58.25	128.35	252.00	373.07	439.27	434.17	387.44
Ocean Beach	7.34	6.46	17.54	31.12	36.92	40.72	38.79	36.76	28.28	27.66
Ocean Flat	-14.34	-20.84	-29.01	-38.78	-49.04	-61.48	-73.97	-83.77	-86.47	-89.02
Rocky Intertidal	0.00	0.00	0.00	0.00	0.00	0.00	-100.00	-100.00	-100.00	-100.00
Inland Open Ocean	-0.73	-0.74	-3.97	-4.35	-4.68	-5.04	-5.36	-5.64	-5.94	-6.90
Riverine Tidal Open Water	-0.81	-0.80	-55.58	-68.16	-79.35	-81.83	-84.55	-87.17	-88.85	-90.05
Estuarine Open Water	25.82	36.75	53.77	69.29	85.73	103.90	121.45	138.94	154.88	170.61
Tidal Creek	1.17	1.20	1.94	2.05	2.16	2.16	2.23	1.66	1.66	1.84
Open Ocean	1.23	1.50	3.11	4.30	5.27	6.19	7.20	8.14	9.13	10.18
Brackish Water	13.75	20.37	28.70	37.21	41.02	41.74	40.97	35.63	26.08	17.14
Tall Spartina	*	*	*	*	*	*	*	*	*	*
Inland Shore	-71.76	-71.88	-71.87	-71.86	-72.07	-72.05	-73.31	-73.32	-73.32	-73.32
Tidal Swamp	-18.39	-27.57	-39.96	-55.20	-66.52	-78.11	-88.73	-93.96	-94.64	-95.17

Table 5.39: SLAMM Percentage of Land Cover Change from Base-Year 2000.
Source: South Atlantic Migratory Bird Initiative. "SLAMM Output for DSL-SAMBI Utilizing A1B Emission Scenario, Decadal Predictions 2000-2100 (ESRI GRID)." GIS Data Set. Designing Sustainable Landscapes. Accessed October 21, 2013. http://www.basic.ncsu.edu/dsl/slr.html.

This table shows the results of the SAMBI SLAMM model in 20 year increments, which are reported in square kilometers of each land cover type.

	Square Kilometers of Land Cover Type					
	2000	2020	2040	2060	2080	2100
Upland Developed	603.65	603.84	603.83	603.83	603.83	603.83
Upland Undeveloped	18245.89	17863.72	17223.06	16957.15	16795.34	16528.68
Swamp	6919.01	6944.29	7182.40	7007.86	7035.22	6829.31
Cypress Swamp	71.71	71.72	71.92	71.82	71.88	70.78
Inland Fresh Marsh	375.18	379.59	384.47	363.35	332.61	307.33
Tidal Fresh Marsh	0.00	0.04	0.04	0.06	0.07	0.06
Scrub/Shrub Transitional	896.08	1397.49	2048.00	2948.60	3790.90	4747.85
Marsh	24.82	371.64	756.59	1203.11	1316.15	1576.39
Salt Marsh	1322.25	1128.76	929.93	690.74	511.37	661.09
Mangrove	0.00	0.03	0.03	0.03	0.03	0.03
Estuarine Beach	11.54	9.14	8.07	6.99	7.87	14.19
Tidal Flat	52.80	41.73	83.56	185.86	284.74	257.37
Ocean Beach	22.22	23.66	29.14	31.27	30.39	28.37
Ocean Flat	16.14	12.78	9.88	6.22	2.62	1.77
Rocky Intertidal	0.00	0.00	0.00	0.00	0.00	0.00
Inland Open Ocean	236.25	234.51	225.97	224.35	222.93	219.94
Riverine Tidal Open Water	43.51	43.16	13.85	7.91	5.58	4.33
Estuarine Open Water	594.80	813.39	1006.92	1212.82	1421.21	1609.61
Tidal Creek	2.55	2.58	2.60	2.60	2.59	2.59
Open Ocean	1352.51	1372.76	1410.68	1436.18	1462.67	1490.14
Brackish Water	507.72	611.15	696.65	719.64	688.61	594.75
Tall Spartina	0.00	0.00	0.00	0.00	0.00	0.00
Inland Shore	12.24	3.44	3.44	3.42	3.26	3.26
Tidal Swamp	402.27	291.36	180.22	88.06	24.29	19.43

Table 5.40: SLAMM Square Kilometers of Land Cover Change from Base-Year 2000
Source: South Atlantic Migratory Bird Initiative. "SLAMM Output for DSL-SAMBI Utilizing A1B Emission Scenario, Decadal Predictions 2000-2100 (ESRI GRID)." GIS Data Set. Designing Sustainable Landscapes. Accessed October 21, 2013. http://www.basic.ncsu.edu/dsl/slr.html

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6.3 FOOTNOTES

1. Every 3-5 years, the University of Georgia's Selig Center for Economic Growth completes a report on the economic impact Georgia's deepwater ports have on the State's economy in terms of output, income, employment and taxes. Georgia's deepwater ports include the Port of Savannah (Garden City Terminal and Ocean City Terminal) and the Port of Brunswick (Colonel's Island Terminal and Mayor's Point Terminal).
2. The figure for the wetlands within Darien excludes the Altamaha Wildlife Management area, which is primarily wetland.
3. See Water Research Foundation. Estimating Salinity Effects Due to Climate Change on the Georgia and South Carolina Coasts. 2012.; and Fisheries and Climate Change: Potential Challenges and Opportunities for Commonwealth Fisheries. Annette Sands - Australian Bureau of Agriculture and Resource Economics and Science. 2011.
4. Farfantepenaeus aztecus
5. Litopenaeus setifereus
6. Interviews with fisherman indicate that some may begin as early as February with roe fishing, but this must be done beyond three miles out to avoid violation of state law.
7. At the Commissioner's discretion the offshore waters may also be opened during January and February if the shrimp count is 50 or fewer per pound, with heads on.
8. Information gathered through informal interviews with shrimpers in Darien.
9. These shortages have, in turn, been brought on by disease in Thailand's shrimping ponds.
10. Local Fisherman Interview by John Risher and Carrie Coburn. Darien, GA. September 28, 2013.
11. This symbol denotes parts per thousand of salt.
12. Litopenaeus vannamei
13. Both P. setiterus and P. aztecus
14. P. vannamei
15. Palamonetes pugio
16. Local Fisherman Interview by John Risher and Carrie Coburn. Darien, GA. September 28, 2013.
17. Local fishermen Interview by John Risher and Carrie Coburn. Darien, GA. September 28, 2013.
18. It is important to note the salt marsh (titled regularly flood marsh in the table) is converted through increased inundation on the scrub-shrub/transitional marsh land cover category. This transitional marsh, in turn, can result from inundation to swamp, inland fresh marsh, and tidal fresh marsh land cover types. Inundation of salt marsh, however, results in conversion to tidal flats.
19. Estimates in the study were created through a synthesis of a number of previous studies based on a variety of methods; however, many of the valuation techniques are directly or indirectly based on the 'willingness-to-pay' of individuals for various ecological services. Values are provided in 1994 dollars.
20. Interview with Altamaha Coastal Tours. September 28, 2013.
21. Interview with local fisherman by John Risher and Andy Cornwell. Darien, GA. October 18, 2013.
22. Ibid.

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GEORGIA INSTITUTE OF TECHNOLOGY CITY AND REGIONAL PLANNING STUDIO, FALL 2013

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ADDITIONALLY, WE WOULD LIKE TO THANK THE FOLLOWING:

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Kelly Spratt, McIntosh County Commissioner-At-Large

The fisherman of McIntosh County for sharing their personal experiences and helping to frame our understanding of commercial fishing in the state.

Blueprints for Successful Communities is an education and technical assistance program of the Georgia Conservancy designed to facilitate community-based planning across the state. The program is committed to achieving successful communities by creating sound conservation and growth strategies, and building consensus for action.

Georgia is home to an abundance of natural and cultural resources. Our development patterns over the last 50 years present a very real threat to these resources and to quality of life as a whole. Sprawling, decentralized development, where people must depend on automobiles, is expensive for local governments to serve and has a staggering effect on the environment. Vehicle emissions create toxic air pollution. Stormwater runoff from asphalt poisons rivers and streams. Thousands of acres of farms, woodlands, and open space are lost to wasteful, non-sustainable forms of development.

The Georgia Conservancy in partnership with the Urban Land Institute and the Greater Atlanta Homebuilders hosted its first *Blueprints for Successful Communities* symposium in 1995. Currently the Conservancy maintains an active partnership with thirteen organizations. These diverse organizations and their members provide a great deal of understanding and expertise in the relationships that exist between land use, public infrastructure, economic growth, and environmental quality.

Prior to the Working Waterfronts effort, *Blueprints* has addressed multi-jurisdictional watershed planning, heritage corridor preservation, location of commuter rail stations, inner city neighborhood issues, coastal sea level rise research and other planning opportunities all through a collaborative planning process.

BLUEPRINTS PRINCIPLES

Maintain and enhance quality of life for residents of the community	Employ regional strategies for transportation, land use, and economic growth	Consider the effect of the built environment on the natural environment as well as history and culture	Employ efficient land uses

Water – quality, quantity and/or access to – is a central issue within the State of Georgia and globally. All program areas at the Georgia Conservancy are working to address water challenges through statewide advocacy, education and research on coastal sea level rise, and advancing awareness through our stewardship trips and land conservation.

Coastal cities are vulnerable to many natural hazards - hurricanes, flooding, beach erosion, subsidence and sea level rise. There are many negative social and economic effects that may result from natural hazards on the coast such as loss of historic structures and communities, devastation of infrastructure, contamination of ground water by saltwater intrusion, and loss of important coastal wetlands and habitats. With over half of the world's population living less than 100 miles from the ocean, and with coastal cities having a population density that is three times higher than the global city average, these hazards pose a major threat to human civilization. Climate change will only exacerbate this.

The Georgia Conservancy, in partnership with Georgia Institute of Technology's College of Architecture conducted an city and regional planning studio to look at two working waterfronts on Georgia's coast. The studio focused specifically on the economic impacts storm surge, hurricanes, and sea level rise will have on these port towns. The studio included site visits, presentations, economic analysis, hydrological analysis and calculations to help develop a set of draft findings for consideration. These findings are supported by technical advisors and form the basis of this report.

Sea level rise is one of the biggest challenges facing coastal communities. Though sea level rise is a slow process, communities must plan well in advance in order to develop adequate adaptation strategies that will help mitigate future social, economic and environmental losses.

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