2.0 GARDEN CITY TERMINAL

The Garden City Terminal is the main container shipping terminal at the Port of Savannah, Georgia, and it is one of the largest and fastest growing container shipping terminals in the Southeastern United States. The terminal allows retail suppliers such as Home Depot, IKEA, and Target to bring overseas merchandise to American consumers from all over the world. Simultaneously, the terminal supports an even higher volume of exports by weight to Europe and other destinations, supporting numerous agricultural and manufacturing jobs in the southeastern United States. However, the port's economic links are not just related to the consumers and producers whose goods transit through it; the port also supports several thousand jobs onsite and many more jobs in the surrounding warehouses and distribution networks that carry freight to and from inland distributors, stores, and processors. As such, the port is an integral economic component of several scales: locally, it supports many households in and around Chatham County; regionally, the port supports wider distribution networks and regional agriculture and manufacturing; and the port serves as a gateway to global markets.

The Terminal has grown tremendously to become an economic powerhouse, but its location on the water to be accessible to ocean-going ships makes it potentially vulnerable to the sea level rise. Sea levels are projected to rise by approximately three feet over the next 100 years. While the rise will not inundate the port, it will decrease the dock heights relative to the water and may increase vulnerability to flooding under severe storms, salt water damage, or decreased efficiency. Sea level rise may also threaten off-site roads, rails, and warehouses that connect the port with inland customers. These changes may disrupt port operations or require expensive retrofits to maintain operations.

This project reviewed the likely economic effects of sea level rise at the Garden City Terminal over the upcoming 100 years. It draws on research from the Georgia Conservancy's previous *Blueprints* report (2012) and includes new tools for assessing the potential impacts on jobs, property, and other businesses. The intent is to provide actionable projections for business leaders, policy makers, and individuals in areas that will eventually have to respond to sea level rise effects. While port planning timelines generally occur over 10 years and some businesses have an even shorter timeline, it may be possible to mitigate or avoid negative impacts by accounting for long-term sea level changes early to build safety and resiliency into early design, policy, and business decisions.

2.1 CONTAINERIZED SHIPPING

INDUSTRY BACKGROUND

Containerization has emerged as a major force in growing international trade, integrating land and sea transportation modes, and transforming the economic dynamics of port communities. Containerization is a simple idea: it puts cargo of all types into standard-sized boxes that can be loaded onto ships, trucks, or trains with a standardized system no matter the types of cargo contained.

Freight shipping did not begin this way. Goods can be transported as dry bulk, liquid bulk, neobulk, breakbulk, or containerized cargo (Hoel et al. 2011). While commodities such as cement, automobiles, coal, petroleum products, and grain are transported in bulk, nearly all other commodities are transported as containerized cargo (Cudahy 2006). However, shippers did not always use standard containers to transport cargo. Up until the 1950s, the cargo that is containerized today was handled as breakbulk cargo — where goods were loaded on pallets and each pallet was individually transported from the warehouses to the ports. At the ports of origin, each pallet was carefully unloaded from truck and railcars and loaded onto the ship to minimize potential damage. At the destination ports, the pallets were carefully unloaded from the ship and loaded onto trucks or railcars that carried them to distribution centers. This made handling cargo a frustrating and time-consuming process (Hoel, et al. 2011). Often, items were unusual shapes or sizes that could not be palletized. Therefore, breakbulk shipping required armies of longshoremen worked at each port to load cargo of different shapes and weights into ships with an equal diversity of arrangements. Longshoremen learned to fit cargo into irregularly shaped spaces, to account for the order in which cargo would be unloaded at different ports, and to accommodate different types of commodities and packaging in a single ship (Levinson 2006). The breakbulk ships had lots of open space under deck to accommodate different types of cargo (Levinson 2006). Loading and unloading was labor intensive, but it sustained a large labor force and working class communities adjacent to ports.

While shipping in containers had existed since the early 1900s, different railroads and shipping companies used different sized containers and the practice was not widespread (Levinson 2006). The post-World War II shipping industry used large amounts of labor to accommodate cargo in break-bulk vessels, though the industry's protection from competition did not pressure it to increase efficiencies (Levinson 2006). The shipping industry's comfortable position began to change with pressure from the trucking industry, which had heretofore operated very differently from shipping companies.

In 1937, Malcom McLean, a truck company owner from North Carolina, became annoyed with the pace of the process when watching his shipment of cotton, along with other cargo, being slowly and painstakingly loaded onto a ship bound for Istanbul (Cudahy 2006). It was this frustrating event that led McLean to the idea that he could speed up the shipping process by loading truck trailers directly loaded onto ships (Cudahy 2006). These trailers would be loaded by the shipper at the origin and unloaded at the destination, thus reducing the handling of the cargo to two points. Later, in the 1950s, McLean acted on this transformative idea. McLean purchased a tanker company and retrofitted its ships with raised platforms, called spar decks that could be used to secure the truck trailers. Finally in 1956, the first containership, the Ideal X, was loaded in Newark with 58 trailers that he had made detachable from the chassis (Cudahy 2006; Levinson 2006). When the container ship arrived in Houston, the containers were unloaded from the ship and attached to running gear at the dock, thus marking the completion of the first containership voyage (Cudahy 2006). The new practice required new equipment, including a tanker ship retrofitted to carry containers, a new dockside gantry crane to handle containers, and trailer bodies that were detachable from the chassis.

Around the same time other shipping companies, including Matson on the West Coast, implemented similar containerization plans. Over the next several years, the U.S. Maritime Administration and standards organizations arrived at an enforced container size standards based on 10-foot length increments. Producers also developed a locking mechanisms that allowed cranes to attach to containers at its four corners automatically to be lifted onto trucks, trains, or ships. The locking mechanisms further sped container operations and reduced labor. Before containerization, only 20 tons of break-bulk cargo could be loaded per hour by a crew of 20. In comparison, 400 to 500 tons of containerized cargo can be loaded per hour using one crane and a crew of 10 workers (Hoel et al. 2011). This means that a break-bulk ship that would often take a week to unload and reload, could be unloaded and reloaded in only six hours as a containerized ship with the same amount of cargo (Hoel et al. 2011).

Containerization spread in several steps over the next decades:

Early 1960s: Containerization began to spread from McLean, Matson, and early adopters to a wider array of companies (Levinson 2006). Containerization created substantial efficiencies in ship utilization and cargo handling, in some cases reducing the cost per ton by nearly 90% (Levinson 2006).

Late 1960s: Containerization began to be adopted in Pacific shipping. This prompted container ship orders (Levinson 2006).

Late 1970s: Containerization and larger ships combined with truck and railroad deregulation in the late 1970s to reduce freight costs even further (Levinson 2006). Reduced transportation costs made it economical to ship raw and intermediate goods long distances to markets or further processing, which contributed to globalized supply chains (Levinson 2006).

As containerization spread, communities became increasingly reliant on their ports to connect them with global supply chains (Levinson 2006) even while containerization eliminated many — in some cases most — of the freight handling jobs at ports (Levinson 2006).

The early days of container shipping established a mechanism that facilitated global trade and managed freight flows efficiently at ports such as Savannah. Time and cost savings have allowed containerized shipping to grow tremendously over the past 50 years.

Containerization allowed shippers to provide a cheap supply of global freight movement that was soon met with an enormous latent demand. From 1980 to 2006 international cargo transported in containers grew from 36.4 million twenty-foot equivalent units (TEUs) to 442 million TEUs and by 2007, 50% of international water-transported cargo was containerized (Hoel et al. 2011). This trend of increasing demand for containerized shipping is expected to remain in the future (Hoel et al. 2011). Figure 2.1 below shows the exponential increase in containerized shipping that has occurred over the past decades.

The containerization movement has changed many aspects of the shipping industry, most notably port design. Before containerization, cranes onboard the ships loaded and unloaded cargo which was then stored in warehouses. Today, container ships do not have cranes onboard, and container ports have had to provide cranes at the dock for loading and unloading cargo. Additionally, with containerization, the need for warehouses was eliminated, so warehouses have been removed from container ports and replaced with open land for stacking containers (Hoel et al. 2011).

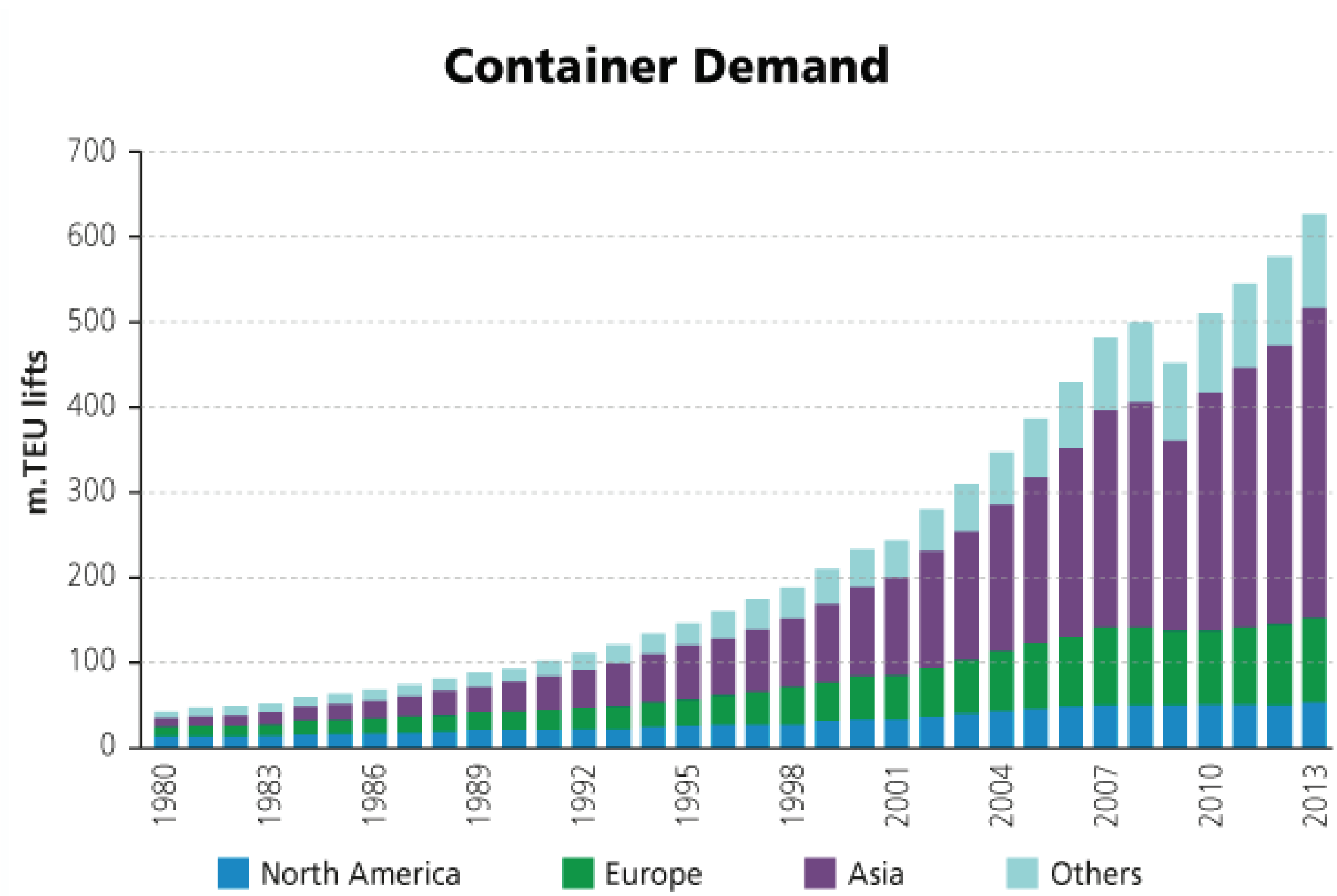


Figure 2.1: Containerized Freight Demand
Source: BIMCO 2012

FUTURE SHIPPING TRENDS

There are some future trends and activities that will also lead to many more changes in the shipping industry. One of these trends in containerized shipping has been the move to build larger ships. This is because the unit cost for transporting a container decreases with larger ship sizes. For example, an 8,000 TEU ship has an 18% to 24% cost savings over a 4,000 TEU ship which in turn has a 30% to 40% cost savings over a 2,500 TEU ship (Hoel et al. 2011). Ship sizes are expected to continue increasing as they have since the size of the largest container ships jumped to approximately 12,500 TEUs with the launch of the Maersk Emma class in 2006 (Rodrigue 2010a).

The trend of increasing ship size has some major implications for container ports. As these container ships continue to increase in size, ports will need to increase the size of on-dock cranes, the on-site container storage capacity, channel widths and depths, and the capacity of railroad and truck facilities. A current issue for East Coast and Gulf Coast ports in the U.S. is the inability of the Panama Canal to accommodate these larger ships. At present, only ships with a capacity of 5,000 twenty-foot equivalent units (TEU) or less are able to navigate the canal. These ships are called Panamax. However, the capacity limit is expected to change in 2014 (Hoel et al. 2011). A third set of much larger locks is being built to allow larger vessels to cross the isthmus and directly access the East Coast and Gulf Coast ports from Asia. Today, 30% of working ships and most of the ships on order are post-Panamax (Bank of America 2013). The completion of this project will place pressure on East Coast and Gulf Coast ports to expand capacity to accommodate the increased demand for containerized shipping (Hoel et al. 2011).

While the Panama Canal expansion is generally expected to increase the size of ships and general traffic volume to East Coast American ports such as Savannah, several eventualities could delay or derail the projected increases. Rodrigue (2010b) highlights the complexities involved in the global freight distribution system that make it prone to unexpected changes in flows. The shipping traffic configuration after the Panama Canal expansion will depend on how shipping companies rebalance the cost, time, and reliability criteria that providing shipping competitive advantage. This shipping reconfiguration may not be as straightforward as many analysts have predicted (Rodrigue 2010b). One of the reconfigurations that was predicted but no longer appears likely is the "Fourth Revolution" in global shipping (Ashar, 2006). The Fourth Revolution was supposed to follow the proliferation of containerization, intermodalism, and transhipment by creating a global east-west north-south grid of shipping services with intensive transhipment at a limited number of logistics hubs. This reconfiguration might have resulted in ports such as Savannah being served by smaller feeder ships from a nearby transhipment hub. However, high transhipment costs are holding off the Fourth Revolution and causing shipping companies to retain the existing configuration, in which container ships ply routes back and forth between major ports, such as Shanghai and Savannah (Ashar 2006).

Increasing wages in China may change container shipping configurations. China has been a primary production center for goods consumed in America and those shipped in containers to the Port of Savannah. Wages are already increasing in China, and China's domestic consumption is likely to significantly increase as well, which may cause producers to seek lower cost production sites, such as Southeast Asia, South Asia or Latin America (Rodrigue 2010b). Moreover, Rodrigue (2010b) asserts that weak American economic growth and an aging population may hinder the consumption growth that drives imports to U.S. ports.

Rodrigue (2010a) believes that predictions about future container shipping increases may be exaggerated and instead that container shipping is reaching maturity, after which it will be marked by slow growth. Past projections made by shipping companies proved overly optimistic, partially due to the 2008 recession, leaving the container shipping industry with a glut of capacity relative to demand (Reuters 2013). Organizations, including the Georgia Ports Authority and the Panama Canal Authority are making enormous investments on predictions of significant container traffic increases to U.S. ports. While these increases are likely, unpredictable economic factors will shape container shipping's future amounts and configurations.

Finally, climate change — the same phenomenon driving sea level rise — may ultimately impact long-term shipping configurations. Arctic ice has been melting at increasing rates since the 1970s, and Arctic summers may be ice free as early as 2020 (The Economist 2012; Borgerson 2013). Melting ice may open up the Arctic to shipping. The first ships began going between Europe and Northeast Asia by passing north of Russia in 2010 (Borgerson 2013) and the Northwest Passage above Canada is likely to become passable between 2040 and 2059 (Smith and Stephenson 2013). Both of these routes offer time savings compared with the Panama and Suez Canals, but they remain speculative (Panama Canal Authority 2006). Moreover, a survey by Pelletier and Lasserre (2012) of ocean carriers showed that most container shippers did not take the northern routes seriously because of the unreliability, remoteness, expense of changing shipping schedules each year, need for icebreaker escort, high insurance costs, and lack of intermediate stops.

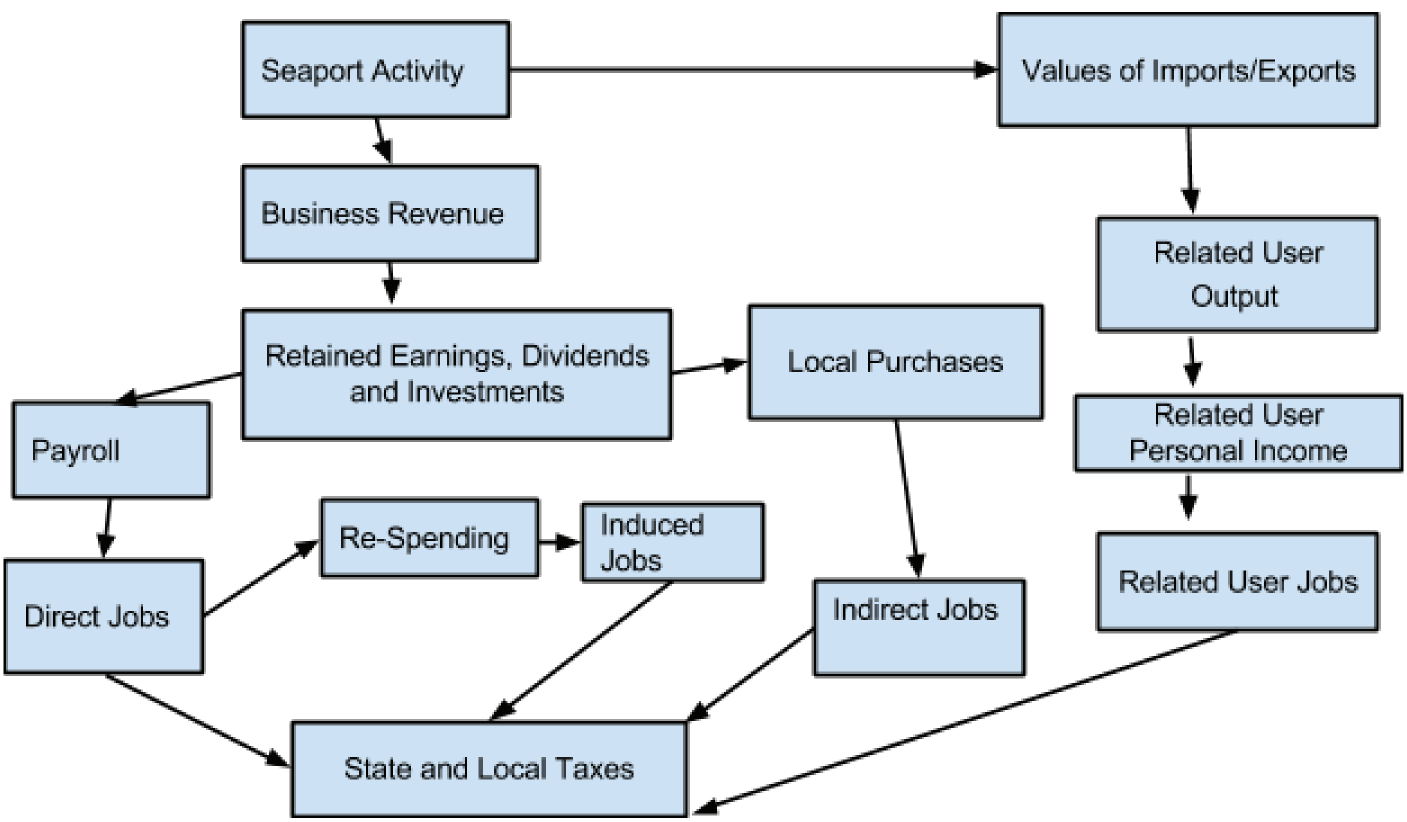


Figure 2.2: Seaport Impacts on Local, Regional, and National Economies
Source: Martin & Associates, "The Local and Regional Economic Impacts of the U.S. Deepsea Port System, 2007." June 6, 2008

Year	Sales (in billions)*	State Gross Domestic Product (in billions)**	Income (in billions)***	Employment (full and part-time)****	Taxes (federal, state & local, in billions)
2003	$35.4	$17.1	$10.8	275,968	$4.6
2006	$55.8	$24.8	$14.9	286,476	$6.3
2009	$61.7	$26.8	$15.5	295,443	$6.1
2011	$66.9	$32.4	$18.5	352,146	$7.0

Table 2.1: Georgia Deepwater Ports (Port of Savannah and Port of Brunswick)
Source: Economic Impact of Georgia's Deepwater Ports, FY 2011, Selig Center for Economic Growth, Terry College of Business, The University of Georgia.
*Gross receipts, plus or minus inventory.
**State GDP consists of employee compensation, proprietor income, other property income, and indirect business taxes.
***Income encompasses all forms of employment income, including wages, salaries, and proprietors' incomes. The income figure does not include nonwage compensation, transfer payments or unearned income (Humphreys 2012)
****Employment includes total wage and salary employees, and self-employed persons (Humphreys 2012).

2.2 SEA LEVEL RISE IMPACTS ON PORTS

As a society we depend on ports for the public goods they provide (Becker et al. 2013). Ports are a gateway to domestic and international trade, connecting individual countries and industries to the global economy. As noted previously, the advent of containerization and other technological advances in marine shipping over the last century have led to an explosion of marine traffic and a subsequent expansion of ports and port-related industries (Fitzgerald et al. 2008). In addition to playing a key role in trade, ports create jobs, generate wealth, and promote the expansion of related and nearby industries and cities. Industries locate near ports so that they are able capitalize on direct access to world markets through the port and on transit links extending from the port to inland rail and road networks. Port industry and port users rely on the efficiency of these inland transportation networks to move imports and exports to distribution centers across the country (Wright 2013).

Ports not only play a critical role in supply chain networks that move products to manufacturers and consumers, but they also generate substantial economic activity in the global economy. Ports are critical infrastructure that serve as engines of economic growth and development (Nursey-Bray et al. 2013). According to a study commissioned by the American Association of Ports Authorities (AAPA), deepwater seaports generated approximately 13.3 million jobs (471,089 direct jobs, 543, 638 induced jobs, 310,804 indirect jobs, and 12 million with importers, exports and port users), and $3.2 trillion dollars in total economic activity to the United States economy in 2007 (Martin & Associates 2008). Figure 2.2 graphically demonstrates how port activity impacts the local, regional and national economies (Martin & Associates 2008).

Ports are likewise critical infrastructure in Georgia. In addition to several small ports along Georgia's eastern coast, Georgia has two deepwater ports, the Port of Savannah (Garden City Terminal and Ocean City Terminal) and the Port of Brunswick, both of which significantly contribute to Georgia's economy. Over the past decade, Georgia Ports Authority (GPA), the quasi-governmental entity that owns both the Port of Savannah and Port of Brunswick, commissioned the University of Georgia's Selig Center for Economic Growth to conduct research on the ports' economic impact on Georgia's economy. A summary of the findings from 2003 to 2011 is shown in Table 2.1. Note that the figures are in constant dollars for the years shown and have not been adjusted for inflation.

According to Table 2.1, the total economic impact of the Port of Savannah and the Port of Brunswick on Georgia's economy in 2011 was $66.9 billion dollars, or 9.5% of Georgia's total economic output for the 2011 fiscal year. This amount represented the sum of the direct, indirect, induced economic impacts (Humphreys 2012). In the 2011 study, Humphreys of the Selig Center for Economic Growth noted that using sales as a measure of economic impact was problematic, however, because it included the value of inputs produced by other industries and therefore double counted some economic impacts. Humphreys suggested that GDP, income and employment figures are more realistic measures of economic impact (2012).

Turning again to Table 2.1, the Selig Center estimated that Georgia's deepwater ports contributed $32.4 billion in state gross domestic product (GDP) in 2011, and generated 352,146 full- and part-time jobs throughout the state in terms of direct, indirect and induced impact (2012). The employment figures were further broken down by county. According to the data, the two deepwater ports supported 37,319 full- and part-time jobs in Chatham County, Georgia where the Garden Terminal of the Port of Savannah is located. With the proposed dredging of the Savannah River to open the Port of Savannah to post-Panamax ships, Georgia's ports will continue to play an important role in the local, state and national economies.

2.2.1 THE EFFECT OF SLR ON PORTS

Climate change, and sea level rise specifically, threatens the viability of ports across the globe. According to a United Nations report on climate change, climate change may impact ports and areas beyond that are around or connected with ports because of the physical capital, employment, and supply chains that are linked with port operations (UN Report 2011). Ports will be particularly affected by rising sea levels because of their location in low-lying coastal zones. Considering that trade by water accounts for 90% of the world's freight shipments, the economic impacts of sea level rise will be significant at a local, national, and global level (Becker et al. 2011). Moreover, the strong interdependence between ports in developed and developing countries may become problematic in future years if ports fail to invest in the improvements and adaptation strategies necessary to prepare for rising sea levels and changing climatic conditions (Becker et al. 2013). A delay at one port, whether climate change-related or otherwise, can cause consequent delays in operations at ports around the world and substantially disrupt global logistics networks.

Sea levels will continue to rise at a quickening rate over the next century due to continued ocean warming and increased loss of mass from glaciers and ice sheets, and the rate of global sea level rise will "very likely" exceed the rate in past years (IPCC 2013). In Georgia, climate scientists have projected that sea level will rise by at least one meter along the Georgia coast over the next 100 years (Georgia Conservancy 2012). This one meter rise in sea level is similar to estimates used by researchers looking at the impact of sea level rise on international deep-water ports and global shipping (Hallegette et al. 2011). Though only a handful of studies have looked specifically at sea level rise's impact on ports and port activities, several recurring themes have emerged from these studies. Broadly speaking, trade, shipping, and the port communities will be impacted by increased sea levels (Wright 2013). More specifically, rising sea levels generally affects port infrastructure, operations, employment, and supply chains directly and indirectly in the following ways: (1) flooded or eroded infrastructure in and around the port; (2) decreased port operations and efficiency; (3) increased maintenance costs; (4) inadequate bridge clearance from rising sea levels; (5) increased susceptibility to storm surge; (6) groundwater contamination from chemicals stored near waterfronts; (7) compromised supply chains, including transit networks that extend into low-lying areas and port facilities; and (8) employment disruption or loss.

FLOODED OR ERODED INFRASTRUCTURE IN AND AROUND THE PORT

The most obvious impact of sea level rise will be on land or infrastructure that is permanently inundated (California Coastal Commission 2001). Structures and land that are partially submerged at high tide will likely be permanently inundated by a one (1) meter rise in sea level (California Coastal Commission 2001). Researchers in California recently conducted a study estimating the economic costs sea level rise will have on the state's ports, roads, rails and buildings. Specifically, the study looked at the Port of Los Angeles-Long Beach, which handles 45–50% of the containers shipped into the United States, and surrounding road, rail and power facilities (Herberger et al. 2011). To determine direct damage to buildings in the port and coastal areas, the California researchers used a Hazus model developed by FEMA. This model uses the economic value of buildings to estimate direct economic losses based on the repair and replacement of damaged or destroyed buildings and their contents, and includes: 1) cost of repair and replacement of damaged and destroyed buildings, 2) cost of damage to building contents, and 3) losses of building inventory (contents related to business activities) (Herberger et al. 2011). Hazus is discussed more fully below.

To determine the impact of rising seas on infrastructure, researchers estimated the miles of roadways and railroads at risk by overlaying the GIS inundation and erosion hazard layers with transportation data published by TeleAtlas (Herberger et al. 2011). The model used had to make many assumptions about the road and railroad networks because not much was known about the elevation of the actual road and rail infrastructure outside of what high resolution maps shows. The maps were produced by a system called Light Detection and Ranging, or LIDAR, in which light reflection determines ground characteristics such as elevation remotely. However, the LIDAR system used land elevation that did not account for long-term subsidence, which is the raising or sinking of land below average land elevation due to such factors as tectonics or aquifer mining. The model showed significant damage to rail and road infrastructure if sea levels rose by 1.4 meters, especially in San Mateo and Alameda Counties (Herberger et al. 2011).

Sea level rise may also impact port drainage systems. Port drainage systems could be overwhelmed by higher water levels and more recurrent flooding. If the drainage systems fail on the port property, or in areas surrounding the port, water may stagnate on the terminal and interfere with port operations or damage goods stored on the Terminal.

INADEQUATE BRIDGE CLEARANCE

Sea level rise may interfere with ships' bridge clearance and increase port susceptibility to storm surges from hurricanes. Because water levels will rise with time while the bridges remain static, clearance issues may become an issue in ports where bridges are relatively low. The rise in sea level could reduce the top clearance between ships and bridges. One study in California noted that sea level rise can reduce bridge clearance, thereby reducing the size of ships able to pass or restricting their movements to times of low tide. Bridge clearance may be an issue for boats accessing the Garden City Terminal in the Port of Savannah. Titus (2003) states that bridge clearance is less like to be a problem for small vessels passing under large bridges than for smaller vessels at smaller bridges because bridges outside of large ports are built with very high spans. However, there are instances of bridge heights limiting access to ports. The Bayonne Bridge outside of Port Newark in New Jersey allows an air draft of 151 feet and has been cited as a limiting factor in receiving some post-Panamax ships (Conway, CRE, & MAI, 2012). Increasing ship size coupled with sea level rise may exacerbate the problem.

INCREASED WATER DRAFT

The corollary of decreased air draft is increased water draft as sea level rise marginally deepens channels. However, the effect of slightly deeper channels is not expected to be significant because of its small size compared with overall vessel size (Titus 2003).

DECREASED PORT OPERATIONS AND EFFICIENCY

Sea level rise may also impact port operations and efficiency. Docks and piers built above the water will be closer to the water due to higher sea levels (California Coastal Commission 2001). Higher seas may cause ships to sit higher at the dock and cargo-handling facilities which could affect the loading and unloading of ships, and possibly result in less efficient port operations (Heberger et al. 2011). The horizontal elements of ports, including the decking of wharves, docks, and piers, will be exposed more frequently to uplift forces larger than those occurring now as a result of heightened sea levels (California Coastal Commission 2001). Furthermore, existing infrastructure with a long design life may eventually have to be raised, and new infrastructure may have to be built to higher standards to accommodate sea level rise. According to a 2008 report released by the U.S. Transportation Research Board, "sea level with respect to dock level is an important consideration at both wet and dry docks, general cargo docks, and container berths for clearance of dock cranes and other structures. Changes due to increased intense precipitation and sea level rise could require some retrofitting of facilities. At a minimum, they are likely to result in increased weather-related delays and periodic interruption of shipping services." (TRB 2008).

Moreover, thunderstorms and hurricanes already suspend port operations on occasion, which could increase due to sea level rise (Ng et al. 2013). If sea level rise exacerbates coastal flooding or storm surge effects, movement within the port may become difficult and goods stored in the port terminal may be more susceptible to flood damage (Wright 2013).

Additionally, increased sea level rise will mean that the elevation at which waves affect structures will increase, potentially undermining the structures per se and will increase the exposure of decks on docks and piers (Nursey-Bray et al. 2013). This could increase corrosion rates and material degradation. In a recent survey of port administrators, it was reported that sea level rise would change port infrastructure maintenance practices. For example, sea level rise would result in "higher salt-water splash zones" requiring more anti-corrosive paint. Paint and paving operations are expensive, yet routine operations at ports.

Finally, ports should also consider sea level rise's impact on the depth of water channels. Sea level rise may require additional dredging in the port area because of increased erosion around the port that will affect the depth of the navigable channels (Wright 2013). Thus, research points to different effects on water depth. Sea level rise would appear to automatically increase water depth in channels, but changes in water flow, erosion, and silt deposit make it harder to predict sea level rise's effects on channel depths in general.

SALT WATER INTRUSION

Sea level rise has also been shown in models and observation to push the saltwater and freshwater dividing line upstream in rivers (Bhuiyan & Dutta 2012)

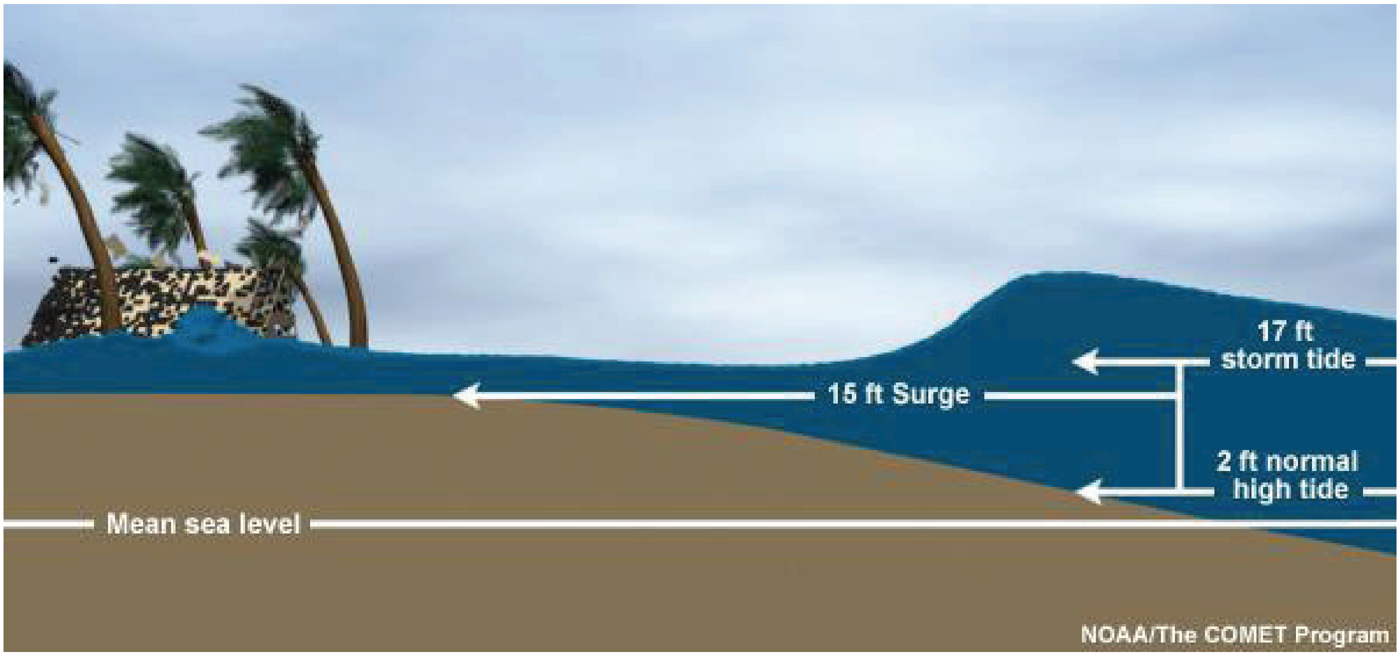


Figure 2.3: Diagram of Storm Surge and Storm Tide
Source: National Hurricane Center 2011

and to increase saltwater intrusion into groundwater (Chang et al. 2011). Salt water in rivers is likely to have several effects on ports and channels leading to ports. According to Titus (2003), salt water in rivers can change sediment deposits and change patterns of shoal creation. If saltwater reaches wooden piers or piles, it may also make them vulnerable to marine borers, a set of mollusks or crustaceans that digest wood (Marine Board 1987).

STORM VULNERABILITY

There is wide consensus that storms may become more intense due to climate change, and some models indicate increased frequency as well. As far back as 1987, the Marine Board suggested that the increase in the frequency and severity of storms may pose a larger threat to ports than sea level rise alone. Sea level rise will increase port's vulnerability to storm-related flooding even without increases in storm frequency or intensity. Some climate change models predict a decrease in global average hurricane frequency of between 6% and 34% even while average global intensity is projected to increase between 2% and 11% (Knutson et al. 2010). Likewise, the correlation between ocean surface temperature and storm intensity also suggests increasingly destructive storms along coasts (Emanuel 2005), and new satellite data analyzed by Emanuel suggests that both hurricane intensity and frequency may increase with climate change (Massey & ClimateWire 2013). Models by researchers at the University of Copenhagen have predicted up to a 1,000% increase in hurricane frequency if the climate warms by two degrees Celsius. When combined with higher sea levels, ports will be especially vulnerable. Depending on facilities' design life, higher sea levels and storm threats can be built into periodic port reconstructions because of the length of time required for significant sea level rise and warming (Titus 2003). However, ports will likely remain vulnerable to economic disruption due to storms and associated storm surge.

Storm surge is an abnormally high series of waves caused by the low pressure and wind in a hurricane which, according to the National Oceanic and Atmospheric Administration, constitute the biggest single threat in hurricanes (National Weather Service).

Different factors influence storm surge strength, including the slope of the continental shelf and contours of the sea or river bed, the coast's shape, and the existence of natural or manmade barriers (National Weather Service; Georgia Emergency Management Agency 2013). Storm tide refers to the observed height of water, which includes storm surge and lunar tides (Georgia Emergency Management Agency 2013). Figure 2.3 shows the relationship between storm surge, tide, and storm tide.

Even with preparations, hurricanes and accompanying storm surge can be economically devastating to ports. For instance, Hurricane Katrina destroyed one third of the Port of New Orleans. The port traffic recovered faster than many expected, with the first ship out two weeks after the storm, but recovery was still slow. The Port of New Orleans reached half capacity three and a half months after the storm and would not reach full capacity until much later (Sayre 2006). One of the challenges is in finding labor, including truck drivers and stevedores, whose homes were affected by storms (Sayre 2006). When Hurricane Katrina hit the Gulfport Port in Mississippi in 2005, the 7 meter storm surge knocked down container cranes, blew apart storage sheds, and pushed barges hundreds of feet inland (Wright 2013). Even after five years and more than $250 million in new investments, the Gulfport Port was still only operating at 80% of its pre-Katrina capacity (Wright 2013). In 2012 Hurricane Sandy shut down the New York-New Jersey container port for a week, resulting in economic damages that are estimated to reach $50 billion once all costs are fully calculated (Becker et al. 2013).

2.2.2 ARE PORTS PLANNING FOR SLR?

Port planning has difficulty accounting for climate change issues. Ports typically plan for short-term returns, not for conditions that could occur several years or decades into the future (Becker et. al 2013). Because ports operate on short planning horizons (typically 5 to 10 years), they tend to not account for climate estimates made on 80 to 90 year horizons. As noted previously, sea level rise projections are typically long-term projections, extending 90 to 100 years into the future. Despite the mismatched time frames, climate change might still affect the port outside of its planning window since most infrastructure lasts between 40 and 50 years.

A survey of port administrators found that few ports are planning projects to increase protection from increased storm activity or SLR and are still using current 100-year storm standards (Becker et al.). The survey showed that ports were more concerned with mitigation issues rather than adaptation issues. Thirty-eight percent of port administrators expected a SLR of .5 to 1 meter by 2100 and 15% expected more than 1 meter.

Thirty-nine percent of the administrators felt that a 0.5 to 1 meter would be problematic and 58% felt that 1 to 2 meters would be problematic for their port (Becker et al. 2013).

The costs of protecting or retrofitting port property will likely be significant, especially if ports have not prepared for sea level rise and are making ad hoc adjustments as they become apparent rather than strategically adapting their infrastructure based on a long range plan. The large infrastructure in ports, including cranes, gantries, warehouses and the like represent capital investments worth significant sums of money. It may be possible for ports to minimize costs associated with sea level rise through decisions in planning, budgeting, and designing future facilities.

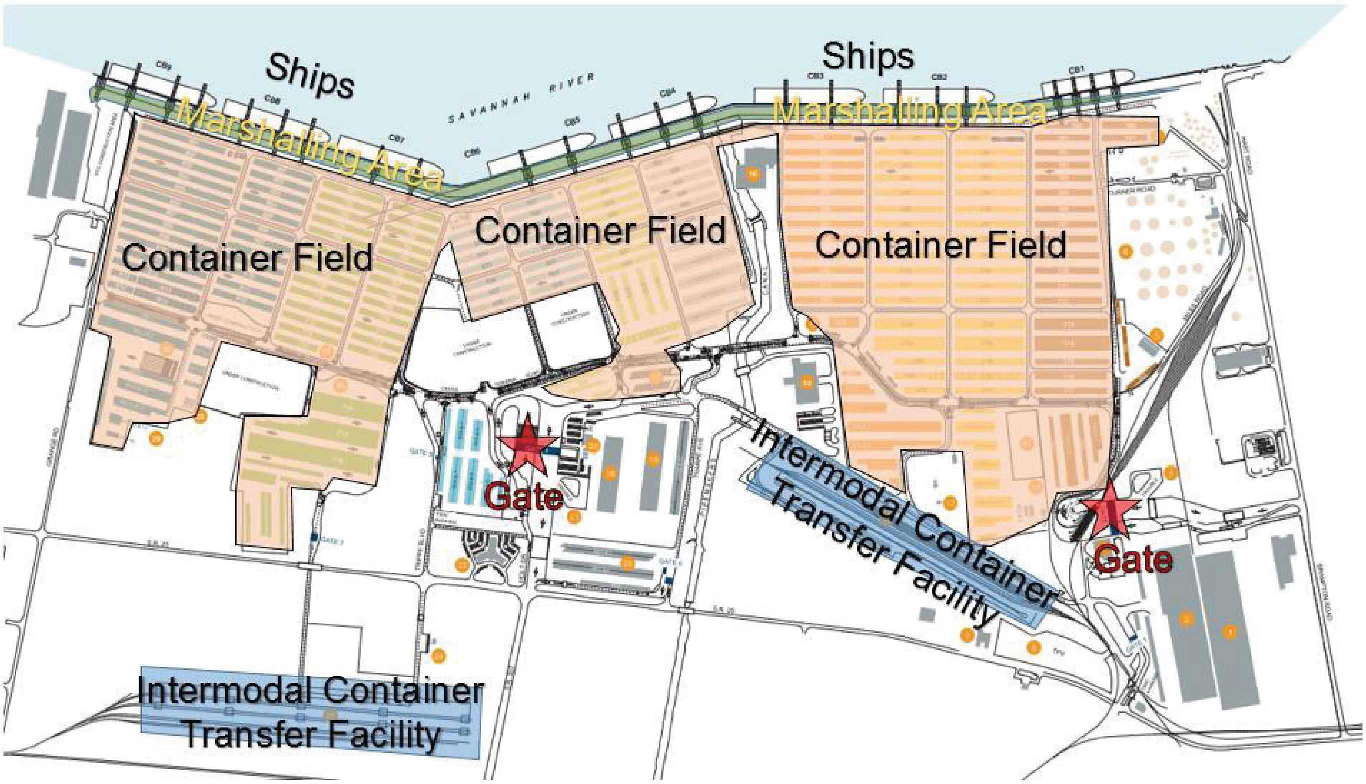


Figure 2.4: Garden City Terminal Facility Map
Source: Georgia Ports Authority

2.3 GEORGIA'S PORTS

The *Blueprints* team concentrated its analysis on the impacts of sea level rise to the Garden City Terminal near Garden City, Georgia, and the direct, indirect and induced economic impacts (definitions included in Section 5.3 of the Appendix) at the port and through the rest of the port's economic network. The project team has also applied previous research on sea level rise impacts to Garden City Terminal operations to estimate sea level rise's impact on State GDP and output.

CONTAINER SHIPPING

Much of the recent shipping growth has occurred in Asia. Indeed, 14 of the world's 20 largest container ports are in Asia. Much of this growth has been driven by containerized trade between northeast Asia and the United States, which has resulted in large ports on America's East and West Coasts to handling shipments. Georgia produces many exports of paper, clay, chickens and other commodities that go to market in Europe, Asia, or elsewhere by sea. As such, the Port of Savannah has grown into the fourth largest container port in the U.S. and the second largest on the East Coast behind New York-New Jersey (Hoel et al. 2011).

The Georgia Ports Authority owns and operates eight terminals in the State of Georgia. These terminals are located in four ports: two deepwater ports and two inland ports. The inland ports, Port of Bainbridge and Port of Columbus, each house one terminal. The two deepwater ports, Port of Brunswick and Port of Savannah, each house multiple terminals.

The Port of Brunswick is comprised of four terminals: Colonel's Island RoRo Terminal, Colonel's Island Agri-bulk Terminal, Mayor's Point Terminal, and Marine Port Terminal. These terminals handle breakbulk, agricultural products, and roll-on roll-off vehicles.

The Port of Savannah comprises two terminals: the Ocean Terminal and the Garden City Terminal. The Ocean Terminal handles breakbulk cargo next to downtown Savannah and the Garden City Terminal, the authority's largest facility and the location of the authority's headquarters, is "GPA's high-speed container terminal" (GDOT 2011). This section will focus solely on the Garden City Terminal.

Figure 2.5: A rubber-tired gantry crane moves a forty foot container in the container field

GARDEN CITY TERMINAL PORT OPERATIONS

The Garden City Terminal's primary purpose is to transfer containers from ocean vessels to trucks or rail for further shipping, or to receive containers from trucks or railroad operators for transfer to ship. However, organizing, inspecting, cooling and storing the containers between their inbound and outbound movements requires several specialized areas and equipment to transfer containers among them. Some of the key pieces of equipment are the following.


Figure 2.6: Jockey trucks preparing to unload in the marshalling area

- Container cranes: Load and unload containers from the ships.
- Rubber-tired gantry cranes: Stack containers in the container field for storage.
- Jockey trucks: Haul the containers among the marshalling area, the container field, the intermodal container transfer facility, and other areas on the port.
- Drayage trucks: Carry containers to and from nearby off-site facilities, including surrounding warehouses.
- The Garden City Terminal has several primary functional areas through with containers pass, which are visible in the diagram in Figure 2.4.
- Marshalling area: The small area adjacent to the

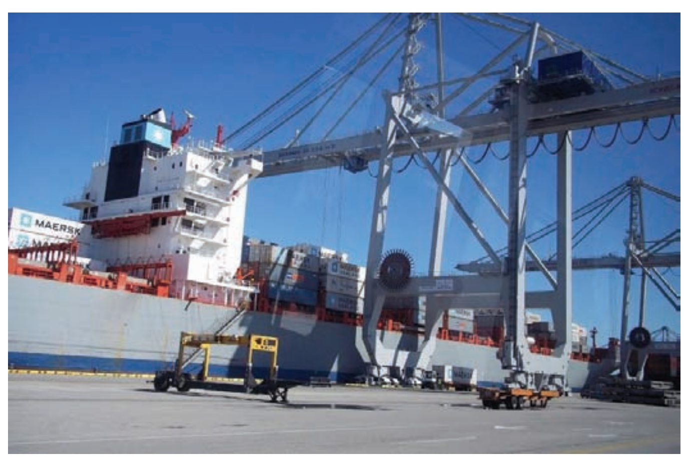


Figure 2.7: Container cranes above a container ship.

ship in which containers and transferred between the gantry crane and jockey trucks (Wong and Kozan, 2010).
- Container field: Flat, paved area in which containers are stacked in rows for temporary storage. They may have electrical outlets to maintain refrigerated containers at the appropriate temperature.
- Gates: Physical checkpoints through which trucks enter and leave the facility.
- Intermodal container transfer facility (ICTF): Areas where containers are transferred between trucks and trains.

The project team observed container movement at the Garden City Terminal, which was explained by a Georgia Ports Authority official. Moreover, Wong and Kozan (2010) explain container movements between the ship and container field in view of providing methods to increase jockey truck movement efficiencies.

Trucks with containers enter the Garden City Terminal through gates 3 or 4. Each gate provides a 'trouble' location for diverted trucks directly in front of the gate. After the trucks pass the gate, the containers are unloaded and stacked in the container field to await transfer to ship. Containers arriving by train are loaded directly onto jockey trucks and driven to the container field if the ship is not there for loading. Both of the terminal's intermodal container transfer facilities are located on-site. Figure 2.5 depicts a container field serviced by a rubber-tired gantry crane.

Jockey trucks move containers from the container field to the marshalling area, which is a narrow lane directly adjacent to the ship in which containers are loaded and offloaded (Figure 2.6, Figure 2.7, and Figure 2.8). Container cranes attach to holes on the containers' four and lift the container off the trailer chassis and into a container slot in the ship. Heavier containers are normally loaded lowest on the ship to improve stability.

Figure 2.8: A container crane preparing to stack a container on board a ship

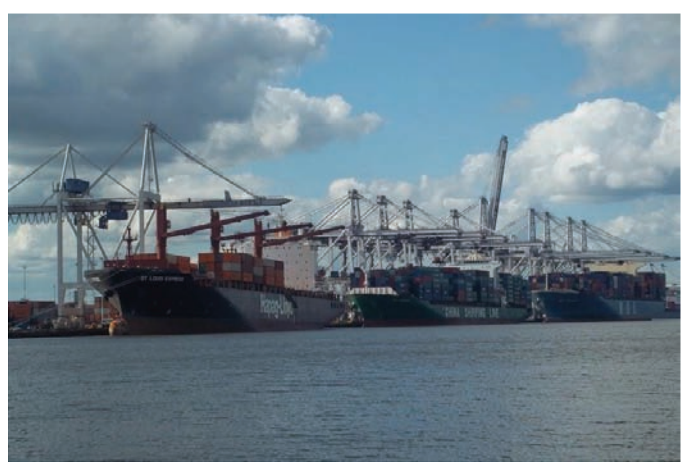


Figure 2.11: Ships lined up at dock at Garden City Termianl

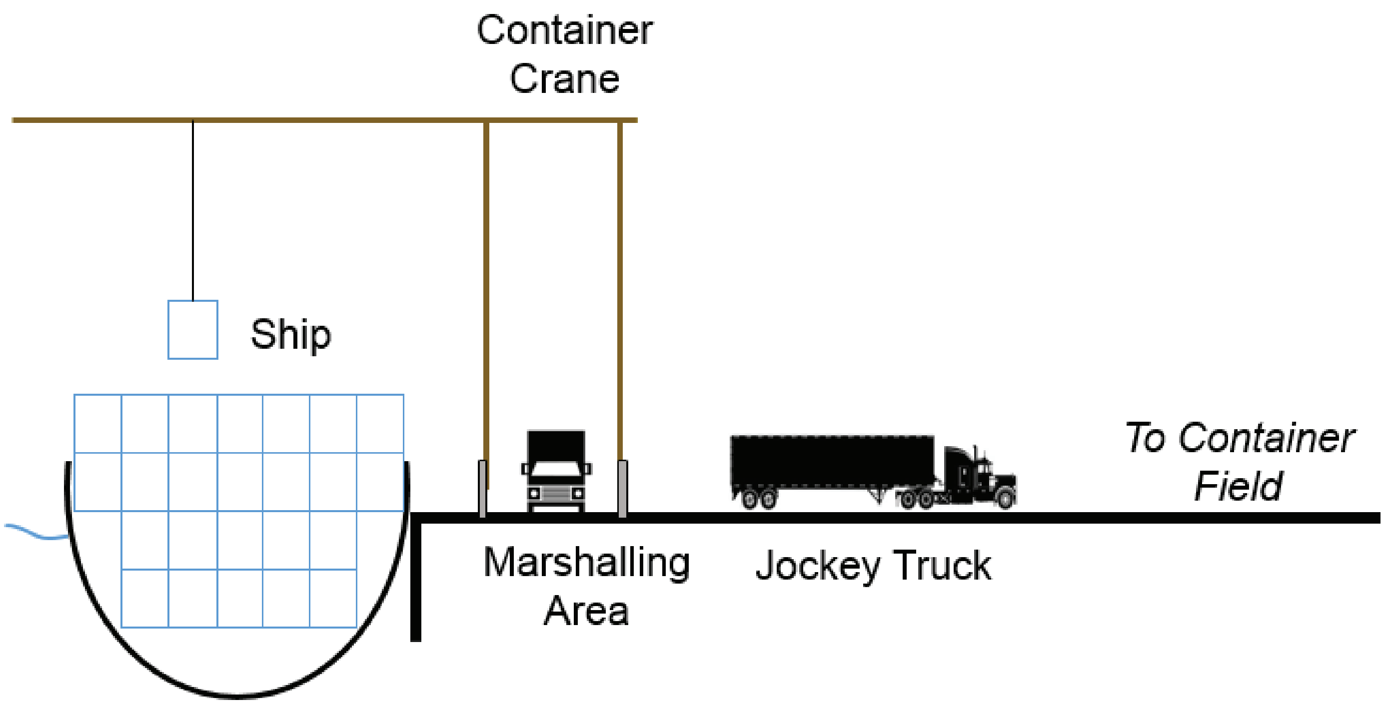


Figure 2.9: Container movement between the ship and the container field. Source: Modified from Wong and Kozan, 2010.

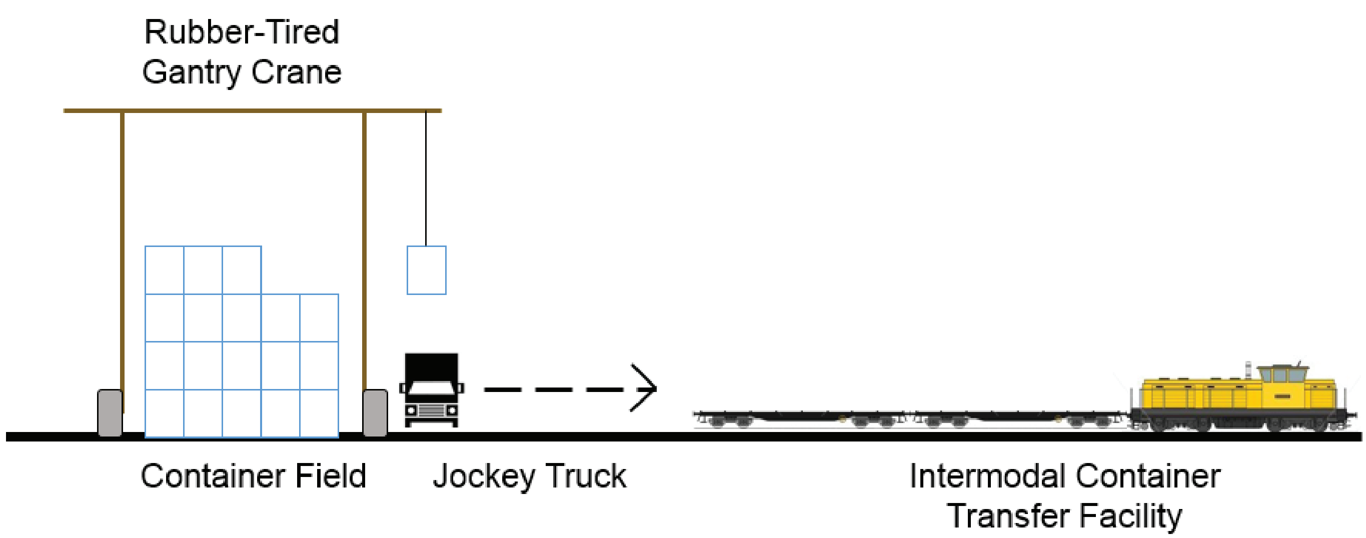


Figure 2.10: Container movement between the container field and the intermodal container transfer facility. Source: Modified from Wong and Kozan, 2010.

Containers arriving on ships follow a similar process. The container cranes lift containers out of the ship and load them one at a time onto jockey trucks, which drive them to the storage area. Toplifts raise the container off of the jockey truck and deposit into a container that may be up to seven containers high. There is a storage area where reefers (i.e., refrigerated containers) may be connected to electricity to maintain their cooling units. According to a Georgia Ports Authority representative, containers remain in the storage area for up to approximately seven days depending on agreements with the ocean carrier. They may be charged storage fees called demurrage after the agreed length of time. Eventually, the container are either transferred to trucks for shipment out of the port. Drayage trucks will carry containers on short hauls, such as to adjacent warehouses, or other trucks may carry the containers longer distances. Conversely, a jockey truck moves containers bound for the railroad to one of the intermodal container transfer facilities for loading onto one of the trains. Figure 2.9 and Figure 2.10 depict the steps in terminal container movement.

SPECIFICATIONS AND EQUIPMENT

The Garden City Terminal spans more than 1,200 acres along the Savannah River, inland of downtown Savannah (GPA 2013b). The shipping channel to the terminal is 500 feet wide and ranges from 42 feet deep at mean low water to 49.5 feet deep at mean high water. The lowest vertical bridge clearance along the channel is 185 feet at mean high water and the horizontal bridge clearance is unrestricted. The channel's turning basin, the King's Island Turning Basin, is located next to the terminal and is 1,500 feet by 1,600 feet (GPA 2013b).

The Garden City Terminal has nine container ship berths that total 9,693 linear feet of docking space. The channel depth at each of these container berths varies. Five are 42 feet deep at mean low water and four are 48 feet deep at mean low water. For all container berths, the dock is 15 feet above the mean low water line and 7.5 feet above the mean high water line (GPA 2013b). Figure 2.11 shows a section of the berth from near water level.

The Terminal also contains many facilities for the storage, handling, and transportation of containers on land. On site, there are 44 reefer racks with electrical hookups that have a capacity of 1,056 slots for refrigerated cargo (GPA 2013b). There are also paved container fields adjacent to each of the container berths that total 432.9 acres of paved area for the storage of containers. Additionally, the terminal houses a rapid dispatch facility that contains an extra 12 acres of paved area for storage (GPA 2013b).

As for equipment, the Georgia Ports Authority (2012) reports on its website that the terminal has 96 total rubber tire gantries, 24 five-high loaded toplifts, six four-high loaded toplifts, 16 seven-high empty stackers, and 48 forklifts, all equipment used for lifting and stacking containers on land. Although the website identifies only 23 container cranes (which transfer containers from ships to jockey trucks) an official with the GPA informed the *Blueprints* team that the terminal currently houses 27 container cranes and is planning on selling two smaller cranes and acquiring 10 additional cranes at a cost of $12 million apiece.

The Garden City Terminal maintains a competitive edge through its access to a robust network of transportation facilities. The terminal is served by two Class I railroads at its two intermodal container transfer facilities (ICTF): the Mason ICTF and the Chatham ICTF. The Mason ICTF has six working tracks and three storage tracks of 2,500 feet each and is operated by CSX (GPA 2013b). The Chatham ICTF has three working tracks just over 2,000 feet each and a storage track of 12,406 feet and is operated by Norfolk Southern (GPA 2013b). This railroad access connects the Garden City Terminal to

Figure 2.12: (a - left) Rail Network Accessible from Terminal
(b - right) Interstate Network Accessible from Termina
Source: GPA 2012.

major transportation hubs and population centers in the Southeast, Gulf Coast, and Midwest within a two to three day travel time (GPA 2012). Figure 2.12a shows the railroad network accessible from the Garden City Terminal.

The Garden City Terminal also boasts a close proximity to two Interstates. Interstate 95, the north-south link along the U.S. East Coast, is within 5.6 miles of the Terminal, and Interstate 16, which runs east-west and connects with Interstate 75 in Macon, GA is only 6.4 miles from the terminal (GPA 2012). Figure 2.12b depicts the Interstate network accessible by the Garden City Terminal and the major U.S. cities that can be reached within 5, 10, and 20 hours of the terminal via truck.

CURRENT CONTAINER VOLUMES

The leading exports by loaded 20-foot equivalent units (TEUs) for the Port of Savannah, which includes both the Garden City Terminal and the Ocean Terminal, are wood pulp, food, paper and paperboard, clay, and automotive commodities (GPA 2013a). The leading imports at the Port of Savannah are furniture, retail consumer goods, machinery, automotive items, and hardware/houseware (GPA, 2013). Exports from the Port of Savannah are most commonly destined for Northeast Asia, the Mediterranean, Southeast Asia, North Europe, and the Middle East (GPA 2013a). The imports into the Port most often originate in Northeast Asia, Southeast Asia, the Mediterranean, North Europe, and Southern Asia/India (GPA 2013a).

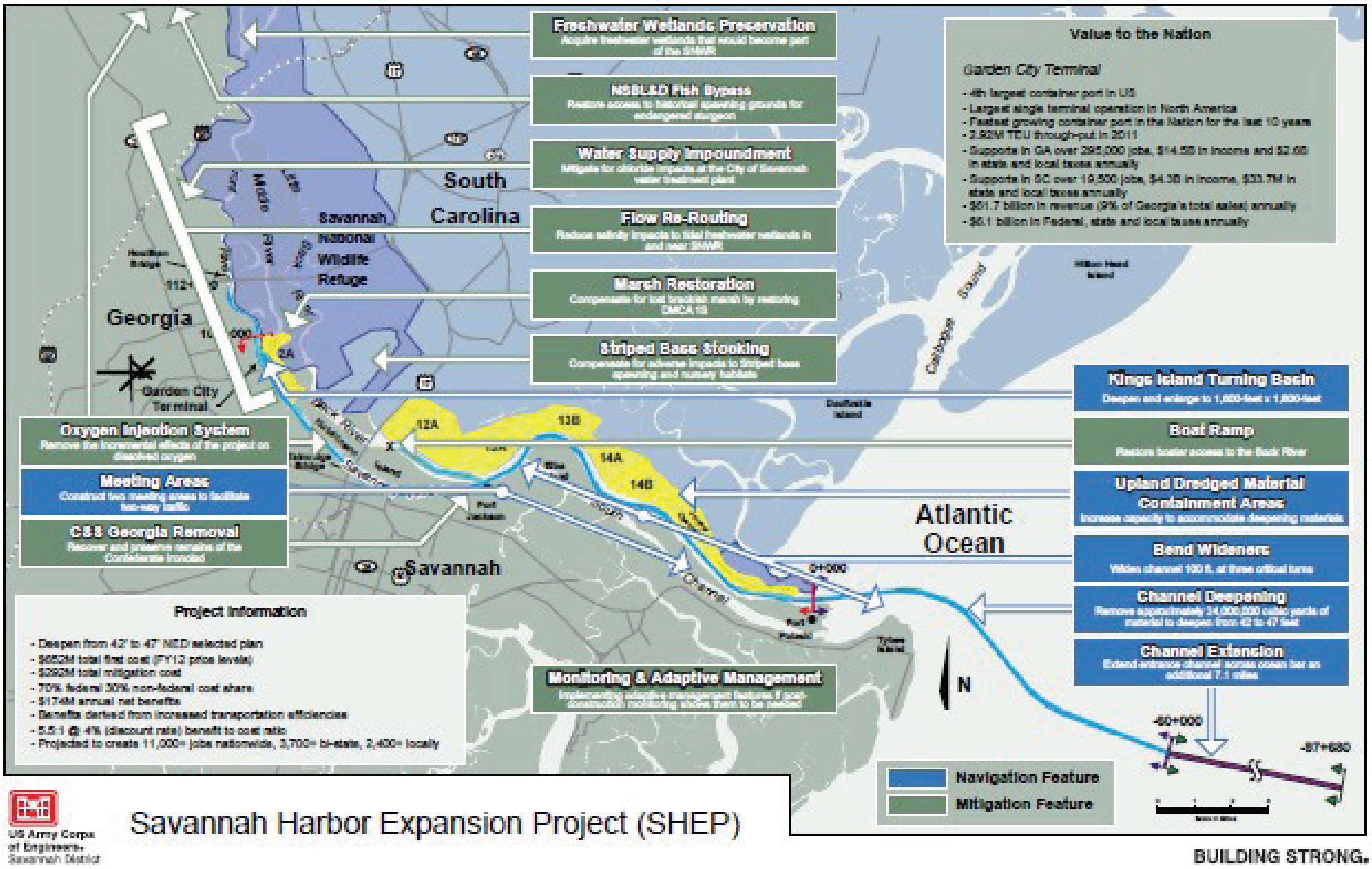


Figure 2.13: Savannah Harbor Expansion Project (SHEP)
Source: U. S. Army Corps of Engineers

FUTURE CONTAINER VOLUMES

Georgia Ports Authority is planning on container volume increases at the Garden City Terminal of between 5% and 7% over its ten year planning horizon (U.S. Army Corps of Engineers 2012, Appendix O). The Georgia Ports Authority is considering expansions to the terminal to accommodate the additional volume. One of its initiatives is to increase its existing space's productivity by increasing storage capacity from 3,512 TEUs per acre per year to 5,500 TEUs per acre per year through a variety of facility and operational improvements. It is also considering expanding its container processing facilities into adjacent properties. Improvements may allow the port to handle 3.85 million TEUs by 2019, which will be sufficient for future operations depending on the rate of container traffic growth. At a rate of 5% annual container growth, the port would still reach capacity by 2023, and with 7% growth capacity would be sufficient until only 2017 (U.S. Army Corps of Engineers 2012). Growth projections appear reasonable based on recent traffic figures. In April 2013, the port moved 258,951 TEUs, which was 4% more than the previous year (GPA 2013b).

2.4 THE SAVANNAH HARBOR EXPANSION PROJECT (SHEP)

The Savannah Harbor Expansion Project (SHEP) is a multimillion dollar, multiple-phase expansion project on the Savannah River. In 1999, Congress authorized the expansion Project in the Water Resources Development Act of 1999 (Public Law 106-53, Section 102(b)

(9)). Under the Act, the U.S. Army Corps of Engineers is authorized to deepen the entrance channel of the Savannah River to Garden City Terminal from 42 feet, its current depth, to 48 feet to accommodate the large container ships expected after the expansion of the Panama Canal in 2014. According to the Army Corps of Engineers' final report on the expansion project, the Corps has recommended deepening the Savannah River to 47 feet (USACE 2012). The Corps has estimated that the annual transportation cost savings from the expansion project will be $213 million per year (USACE 2012). A deeper shipping channel allows larger and fewer ships to move the same amount of goods at a lower transportation cost. To illustrate this cost savings, container ships currently using the Garden City Terminal on the Savannah River carry on average 5,000 twenty-foot equivalent units (TEUs) (GPA 2013). Once the SHEP is completed and the river is deepened to 47 feet, ships carrying 12,000 TEUs will be able to access the Garden City Terminal (GPA 2013). Moreover, a deeper channel means that larger ships can enter and leave the harbor with less delay in waiting for high tides (USACE 2012).

In addition to deepening a portion the Savannah River leading to the Garden City Terminal, the Army Corps is considering widening the Entrance Channel to create meeting areas at Long Island and Oglethorpe Ranges, widening and deepening of the Kings Island Turning Basin, and widening the channel at three bends in the Savannah River (USACE 2012). Figure 2.13 illustrates the U.S. Army Corps of Engineers (Army Corps) SHEP proposal.

The "first cost" for construction of SHEP is estimated at $652 million, which includes preconstruction engineering and design costs, construction costs and the real estate necessary for the project (USACE 2012). On October 23, 2013, the U.S. House of Representatives authorized funding for the Savannah Harbor Expansion Project in the Water Resources Reform and Development Act of 2013 in a 417-3 vote (Bohan 2013). The Act is expected to become law once the Senate and House of Representatives agree to a final bill (the two Houses of Congress passed different versions of the bill) and the President approves. The appropriations bill is crucial for the project to move forward since 70% of the funds for the SHEP project is coming from the federal government. The remaining 30% will be paid by the State of Georgia. Though the expansion project is costly, the U.S. Army Corps of Engineers has estimated that for every dollar invested in the harbor expansion project, the United States will see approximately $6 in return (USACE 2012). Moreover, the U.S. Army Corps has estimated that the SHEP will add $174 million annually to the U.S. economy (USACE 2012). President Obama and the Army Corps of Engineers have deemed the Port of Savannah a "nationally and regionally significant infrastructure project."

In 2010, the Savannah District, U.S. Army Corps of Engineers published its General Reevaluation Report (GRR) and Environmental Impact Statement (EIS) in the Federal Register and circulated for review and comment (USACE 2012). The studies evaluated the engineering, environmental, and economic acceptability of various alternatives for the present and future harbor conditions over a 50-year analysis period. (USACE 2010).

In its final GRR, the USACE briefly discussed sea level rise, noting that "[s]ea level rise uncertainty results in a minor level of risk" (USACE 2012). The Army Corps stated in its report that "[s]tructural features such as sills or plugs . . . carry minimal risk from sea level rise uncertainty." (USACE 2012). It also noted that a "structure's effectiveness could be reduced slightly with greater than projected sea-level rise rates, but this could be readily addressed through adaptive management of the mitigation features." (USACE 2012). Moreover the Army Corps has recommended several mitigation strategies to combat the potential environmental effects of the harbor deepening project: preservation of 2,245 acres of freshwater wetlands; restoration of 28 acres of brackish marsh; construction of a fish bypass around the New Savannah Bluff Lock and Dam near Augusta, Georgia; installation, operation, and maintenance of oxygen injection systems at three locations in the lower Savannah River; construction of boat ramp on Hutchinson Island; construction of a raw water impoundment for water withdrawn from Abercorn Creek by the City of Savannah; and data recovery, removal and conservation of the remains of the CSS Georgia (USACE 2010).

The SHEP has been embroiled in litigation since its proposal. Opponents to the expansion project have argued that the Army Corps failed to properly complete its environmental impact statement under the requirements of the National Environmental Policy Act (NEPA) and failed to mitigate potentially detrimental impacts on endangered species and wildlife habitat. Environmental organizations have alleged that harbor dredging will push salt water levels even further upstream, threatening the vitality of valuable tidal freshwater wetlands in the Savannah National Wildlife Refuge. Most recently, several environmental groups filed an injunction action against the U.S. Army Corps of Engineers and others to enjoin the project because the Army Corps had not applied for a South Carolina environmental permit. The environmental groups and the Army Corps reached a settlement agreement that requires significant environmental mitigation projects and conservation set asides on the part of Georgia, the U.S. Army Corps of Engineers and the Georgia Ports Authority (Landers 2013). Specifically, the Georgia Ports Authority has agreed to institute an evergreen fund for dissolved oxygen maintenance for $2 million over 50 years (Landers 2013). It is estimated that the mitigation costs from the settlement will add an additional $43 million to the project, most of which will be paid by the Georgia Ports Authority (Landers 2013). Overall, the SHEP will have significant impacts on the Georgia economy. The deepening and widening of the Savannah River will allow larger ships with more cargo capacity to enter and leave the Port of Savannah. The Port of Savannah is currently investing in capital improvement projects, including crane acquisition and road expansion projects surrounding the Port, to ensure that cargo can be quickly and efficiently transported through port facilities. As discussed above, sea level rise does not appear to be a major factor or concern in the expansion project as the Army Corps feels that any additional rise in sea level can be mitigated with proper engineering strategies.

2.5 ANALYZING THE ECONOMIC IMPACT OF SEA LEVEL RISE AT THE GARDEN CITY TERMINAL

This section of the report analyzes the economic impact of sea level rise on the Garden City Terminal. The section also addresses the impact of sea level rise on warehouses in Chatham County, employees commuting to and from the port, and regional road and railroad networks along Georgia's coast as impacts to these components will affect economic activity at the Garden City Terminal. First, the study team mapped projected sea level rise at the Garden City Terminal, and looked at how a one meter rise in sea level would affect the equipment, infrastructure and operations at the Garden City Terminal. The study team then extended its scope and identified areas that would be permanently inundated by a one meter rise in sea level, including warehouses in Chatham County, regional road and railroad networks and communities from which Terminal employees commute.

In the second part of its analysis, the *Blueprints* team explored the relationship between storm surge and sea level rise. The team first calculated the economic impact to the State of Georgia of hurricane events at the Garden City Terminal. The economic impact analysis

Figure 2.14: Inundation of the Garden City Terminal Under 1.0 Meter of SLR (Inundated areas shown in red)

uses economic inputs, such as State gross domestic product (GDP) and economic output attributable to operations at the Terminal, and information on average port recovery times to calculate the loss of economic activity to the State if operations at the Terminal are impaired for various lengths of time. The team then modeled storm surge with and without sea level rise to determine the physical impact of storm surge on warehouses and property in and around the Garden City Terminal. Finally, the *Blueprints* team used its analytical findings and broader information discussed in the literature review section to make recommendations regarding sea level rise preparedness for the Garden City Terminal, Chatham County and coastal Georgia.

PERMANENT INUNDATION FROM A ONE METER RISE IN SEA LEVEL

The *Blueprints* team first calculated the degree of permanent inundation at the Garden City Terminal. Our projections indicate that the Terminal is not at significant risk of permanent inundation by a one meter rise in sea level. The team uses "permanent inundation" to denote areas where water will permanently cover normally dry lands. The team differentiates areas that are permanently inundated from areas that will experience "episodic inundation" from storm surge events that are exacerbated by sea level rise. Storm surge events will be discussed in Part 2.7 of this section.

PERMANENT INUNDATION AT THE GARDEN CITY TERMINAL

The study team created a port facilities inundation map using the bathtub model to determine whether a one meter rise in sea level would affect port operations and physical infrastructure at the Garden City Terminal. 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. A description of the "bathtub model" is included in Section 5.1 Appendix. The study team overlaid the one meter sea level rise inundation map created by the previous studio (Georgia Conservancy 2012) on top of satellite imagery of the Garden City Terminal, shown in Figure 2.14, to examine the extent of impact the projected sea level rise would have on the terminal.

Figure 2.14 shows that a projected one meter rise in sea level would have a limited impact on the terminal facilities. While analysis suggests that the wharves themselves will remain above high tide, the stormwater drainage canal that runs through the center of the terminal to the Savannah River is a potential location where water stagnation or drainage-related flooding may occur. Minor flooding indicated in Figure 2.14 could change maintenance and cargo handling practices at the Terminal. This minor flooding can be properly mitigated for by certain improvements to infrastructure surrounding the canal. The costs of infrastructure improvements to mitigate for the increased sea levels and consequent flooding could be counted as a direct economic impact of sea level at the Terminal.

Assuming the Port does nothing to mitigate for increased sea level, however, permanent inundation around the stormwater drainage canal may erode paved surfaces and require repaving and additional maintenance. Paint and paving are routine, yet expensive, parts of port operations. According to the Georgia Ports Authority, paving and repaving costs represent one of the largest maintenance expenses at the Garden City Terminal (GPA 2013a). Similarly, if the water pools on the pavement around the canal, this could likewise disrupt movement of cargo around the Terminal as jockey trucks may not be able to move as efficiently on flooded surfaces. Moreover, the flooding along the stormwater drainage canal is close to the Class I CSX rail line. If the rail line is flooded, it could disrupt the cargo movement in and out of the Terminal. Overall, permanent inundation of any portion of the paved area at the Terminal will result in additional expenses for the Georgia Ports Authority.

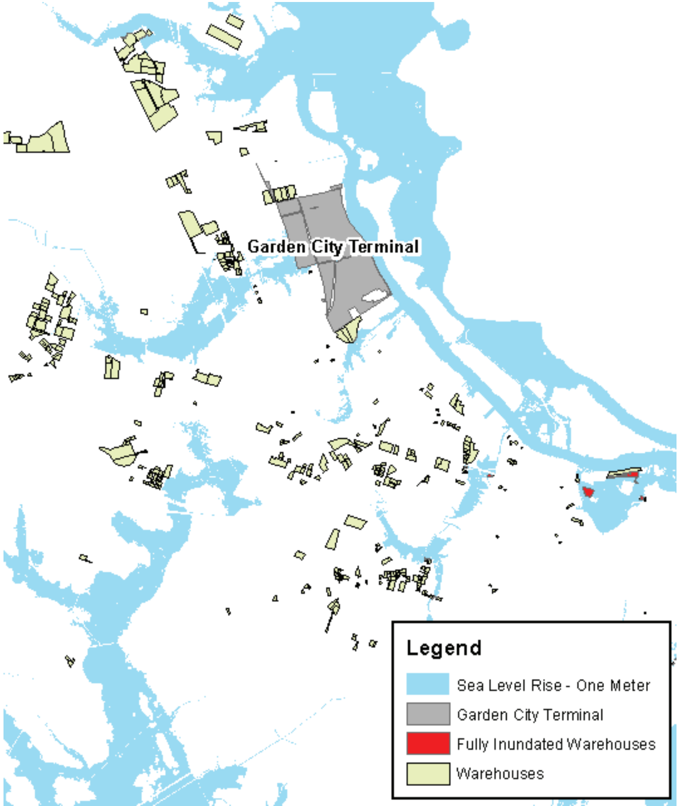


Figure 2.15: Warehouses in Chatham County Inundated by One Meter of SLR

	Chatham County Warehouses	At Least Partially Inundated	Fully Inundated	Percentage of Chatham County Warehouses
Number of Parcels	437	28	N/A	N/A
Land Area	2146.52 acres	105.10 acres	32.94 acres	1.50%
Total Building Value	$896,204,735	$51,474,247	16,133,367.34	1.80%
Total Land Value	$167,121,902	$10,946,053	3,430,777.61	2.10%
Total Assessment	$425,330,656	$24,968,120	7,825,657.98	1.80%

Table 2.2: Warehouse Properties in Chatham County Inundated by One Meter of SLR

Finally, the literature has suggested that higher water may also reduce port operations efficiency because ships will sit higher in the water. However, the literature does not specify the means by which higher water levels could degrade efficiency. Details from the Georgia Ports Authority would fill a gap in the literature on port operations and explain any site-specific operational challenges that sea level rise may pose to port efficiency.

WAREHOUSES IN CHATHAM COUNTY

Warehouses are an important part of the ship-to-consumer supply chain. Many Chatham County warehouses receive deliveries from the port that are repackaged and reshipped to inland locations for distribution, sale, or further processing. Thus, warehouses and distribution centers are port-related infrastructure even when they are located off-site.

The *Blueprints* team examined Chatham County warehouses to estimate which warehouses could be directly affected by one meter of sea level rise. The study team isolated parcels in Chatham County with data provided by the Chatham County Board of Assessors. There are 437 warehouse parcels in Chatham County with a concentration located between the Garden City Terminal and the I-95 corridor. While the data does not identify those warehouses with the most operational linkages with the port, the study team's interviews with a warehouse operator and port officials suggest that many warehouse operators locate in Chatham County to handle traffic to and from the Port of Savannah.

The study team used a spatial selection tool in ArcGIS, described in more detail in Section 5.7 of the Appendix, to locate warehouse parcels where a portion of the warehouse area is expected to be flooded by a one meter rise in sea level. There are 28 parcels that may be directly affected by one meter of sea level rise. However, these parcels are on average only 31% inundated, which suggests they could still be fully or partially operational even with projected sea level rise. Table 2.22 shows the building and land value for the portions of the affected parcels, calculated by multiplying the percent of the land area inundated by the entire parcel's value. The results show that approximately 2% of warehouse values are likely to be directly affected by sea level rise.

Figure 2.15 shows the location of warehouses in Chatham County, including those that may be partially inundated. Inundation is most likely in warehouses directly adjacent to the Savannah River or on very small sections of property along basins that drain into the river. The large warehouse parcels west and northwest of the port are unaffected by one meter of sea level rise. These parcels include the IKEA warehouse visited by the *Blueprints* team, as well as the adjacent Target distribution center and others whose location makes them advantageous for port-related distribution.

2.6 REGIONAL IMPLICATIONS OF SEA LEVEL RISE: EMPLOYEE COMMUTE PATTERNS AND ROAD AND RAIL NETWORKS

This section analyzes the impact of sea level rise on the Garden City Terminal from a regional perspective. Specifically, the section looks at the impact of a one meter rise in sea level on regional commute patterns and road and rail networks.

REGIONAL COMMUTE PATTERNS

An important asset for the successful operation of the Garden City Terminal is a strong employee base. Although one meter of sea level rise alone had minimal direct impact on the Terminal property and on warehouses, sea level rise in other areas of Georgia can have severe consequences for Terminal operations if Terminal employees reside in areas threatened by

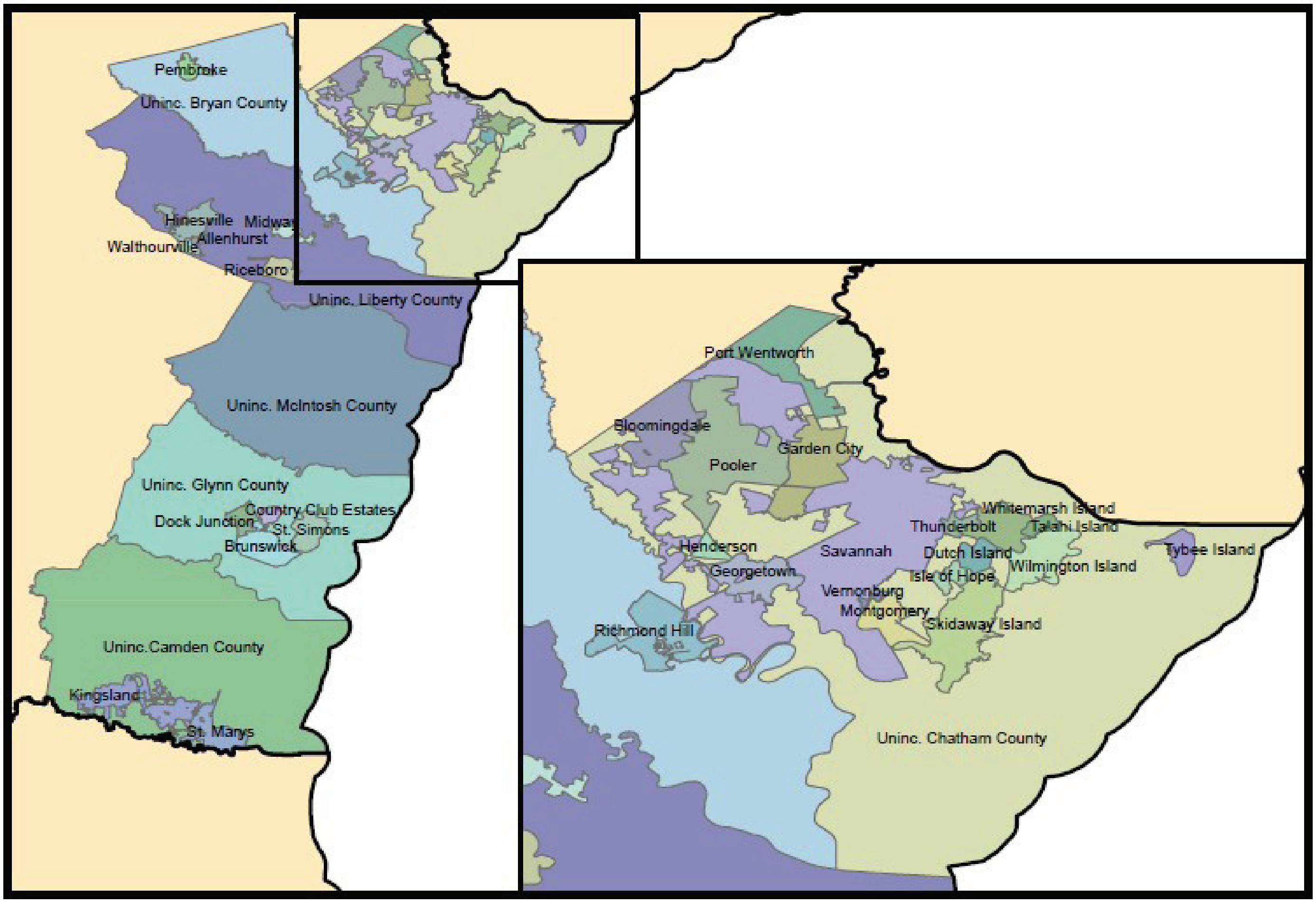


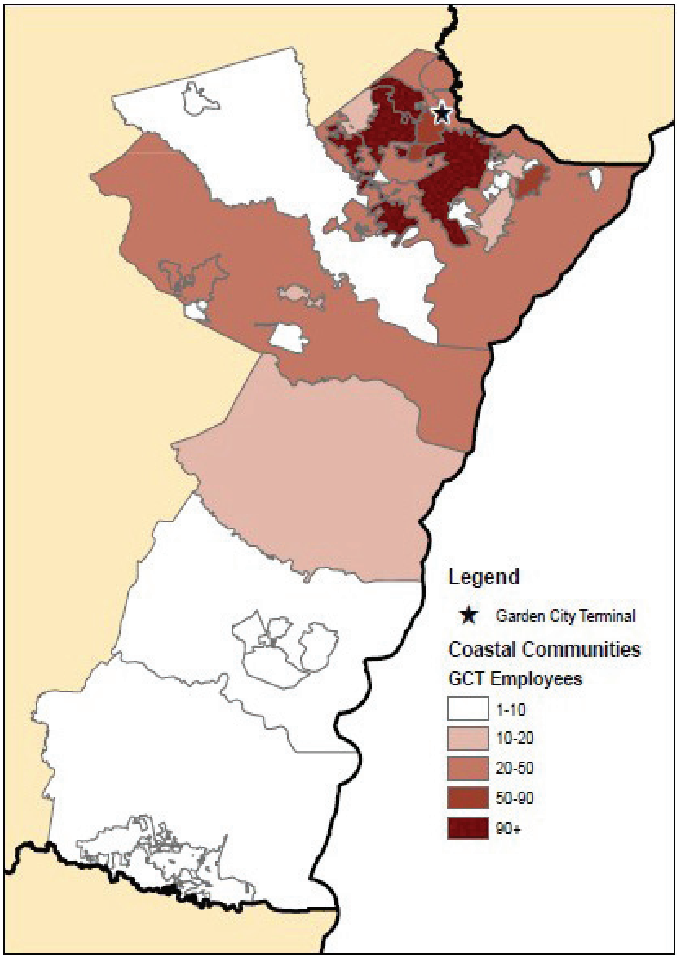
Figure 2.16: Map of Coastal Georgia Communities

rising sea level. This analysis will identify the most prominent locations where Garden City Terminal employees reside, and assess which of those areas are most vulnerable to sea level rise.

First, the *Blueprints* team examined where Garden City Terminal employees reside. The study team used data from Chatham County's tax assessor office in conjunction with the U.S. Census Bureau's online commuting pattern application, OnTheMap. Using this web-based application, the team found the cities and unincorporated counties where employees of the Garden City Terminal reside. Next, the study team identified the cities or unincorporated counties that were most vulnerable to sea level rise. The team overlaid inundation maps created by the previous studio (Georgia Conservancy 2012) with cities and unincorporated counties to determine the percentage of land area inundated by sea level rise.

The results of the commuter analysis are presented for the six coastal Georgia counties, although a number of employees come from other states and inland Georgia counties.

In the six coastal Georgia counties there are 36 communities, 30 municipalities and unincorporated areas in each of the counties. Figure 2.16 shows the locations of each of the 36 coastal communities examined in this analysis.



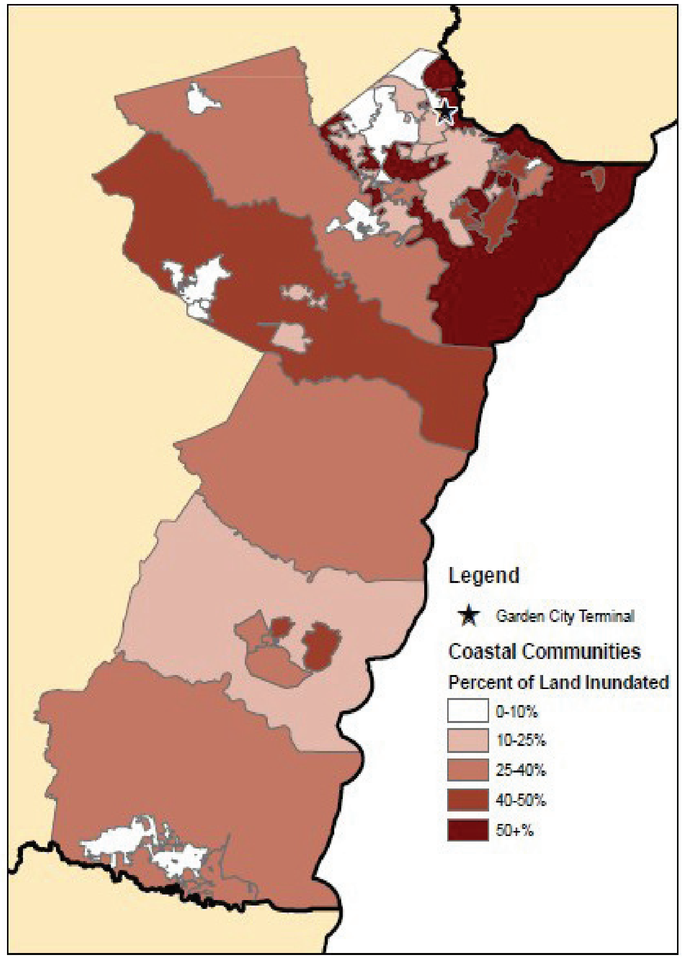


Figure 2.17: Commuter Analysis Results. (a) Garden City Terminal Employee Residences by Community. (b) Percent of Land Inundated by 1.0 Meter of SLR

Community	Employees	Percent Inundation
1 Savannah, GA	374	24.2%
2 Pooler, GA	92	1.9%
3 Garden City, GA	64	19.4%
4 Wilmington Island, GA	51	36.4%
5 Hinesville, GA	43	0.0%
6 Georgetown, GA	38	34.3%
7 Unincorporated Chatham County, GA	37	83.9%
8 Port Wentworth, GA	37	9.6%
9 Richmond Hill, GA	37	0.0%
10 Unincorporated Liberty County, GA	30	45.7%

Table 2.3: Top Ten Communities for Garden City Terminal Employee Residence

Community	Percent Inundation	Employees
1 Unincorporated Chatham County, GA	83.9%	37
2 Dutch Island, GA	61.8%	4
3 St. Simons, GA	48.8%	5
4 Montgomery, GA	45.9%	10
5 Country Club Estates, GA	45.8%	1
6 Unincorporated Liberty County, GA	45.7%	30
7 Skidaway Island, GA	42.8%	11
8 Tybee Island, GA	41.6%	13
9 Whitemarsh Island, GA	41.6%	13
10 Unincorporated McIntosh County, GA	39.4%	17

Table 2.4: Top Ten Communities with Highest Percentage of Land Area Inundated by Sea Level Rise

On the previous page, Figure 2.17 presents a map of the results for both parts of the commuter analysis. The map to the left, Figure 2.17a, represents the number of Garden City Terminal employees residing in each of the coastal communities. Communities with a darker shade of red contain a larger number of employees. As is seen in the map, communities in Chatham County contain the majority of employees that commute to Garden City Terminal. However, Terminal employees reside in communities in each of the six counties along Georgia's coast. As is expected, counties further from the Terminal, such as Camden and Glynn, contain fewer employees than counties nearer to the Terminal--McIntosh, Liberty, and Bryan. In Chatham County, the communities that contain the most employees are located further inland and clustered around the Terminal. The map to the right, Figure 2.17b, shows the vulnerability of coastal communities to sea level rise inundation. The counties are colored based on the portion of the community's land mass that is inundated by a one meter of sea level. The counties colored in darker red are the most vulnerable to sea level rise. The most vulnerable communities are primarily located in Chatham County along the Atlantic coast and the banks of the Savannah and Ogeechee Rivers. In addition to communities along the rivers, communities further inland are generally less vulnerable to inundation than those communities closer to the coast.

Detailed commuter data are included in the tables on the right. Table 2.3 is a list of the ten communities with the most Garden City Terminal employees. Table 2.4 is a list of the ten communities with the highest vulnerability, land area wise, to sea level rise impacts.

Looking at Table 2.3 and Table 2.4, Unincorporated Chatham County and Unincorporated Liberty County are popular locations for Garden City Terminal employees to reside and are extremely vulnerable to inundation from rising sea levels. Chatham and Liberty Counties are the only communities to find themselves on the top of both lists for number of Terminal employees and extent of inundation. In addition to Chatham and Liberty counties, Wilmington Island, Georgetown, Savannah, Garden City, Unincorporated McIntosh County, Whitemarsh Island, Skidaway Island, and Montgomery Island, also contain a large number of Terminal employees and will experience significant inundation from sea level rise. While this analysis identifies communities of interest for the Garden City Terminal with respect to sea level rise, data was not available for the analysis to identify the exact number of employees or the locations of employee residences vulnerable to sea level rise.

The Impact of SLR on Regional Transportation Networks: Road and Railroad

This section examines the length of roads and railroads that will be inundated by a one meter rise in sea level. The Garden City Terminal is heavily dependent on the rail and road networks along the coast of Georgia. Sea level rise will have a major impact on these rail and highway connections. The study team assumes that all vital infrastructure inundated by sea level rise will be rebuilt as bridges over the inundated areas due to the economic importance of the facilities. It is important to note that these impacts to the transportation network extend over the nearly 100 planning year horizon and do not necessarily occur at one point in time, since the effects of sea level rise are gradual. It is also important to note that rebuilding these facilities as bridges is only a temporary fix to the issue. Continuing sea level rise past the planning horizon will necessitate further rebuilding of inundated transportation networks.

The analysis for this section is divided into two pieces: the impacts to the road network and the impacts to the railroad network. The major findings of this analysis are as follows:

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials
Right Shoulder (in feet)	10-12	4-12	2-8	2-8
Left Shoulder (in feet)	4-12	0	0	0

Table 2.5: Range of minimum shoulder widths by functional classification. Source: FHWA 2007

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials
Lane Width (in feet)	12	12	10-12	10-12

Table 2.6: Range of Suggested Lane Widths by Functional Classification. Source: FHWA 2007

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials
Average Number of Lanes	5.59	4.70	3.43	2.37

Table 2.7: Average Number of Lane-Miles per Centerline-Mile on Georgia Roads by Functional Classification. Source: FHWA 2007

Span	Bridge Length	Cost (per sq. ft.)	Type of Bridge
Short	20'-45'	$80-$150	Pre-cast Concrete Slab Simple Span
Medium	45'-150'	$67-$140	Concrete Deck/ Pre-stressed Girder - Simple
Long	150'+	$67-$140	Concrete Deck/ Pre-stressed Girder - Simple

Table 2.8: Bridge Construction Costs per square foot for Bridges of Varying Lengths. Source: FDOT 2011

- 22.59 miles of major roads will likely be inundated under one meter of sea level rise
- Assuming all inundated major roadway segments are reconstructed as bridges,
- 336 bridges at a total cost of $350-922 million will need to be constructed.
- 14.04 miles of railroads will likely be inundated under one meter of sea level rise.

ROAD NETWORK

The *Blueprints* team began its analysis of sea level rise's impact on the road network by using the functional classification system used by Georgia Department of Transportation (GDOT) and Federal Highway Administration (FHWA) to determine the most important roads along Georgia's coast. The functional classification system divides roads into one of a number of categories: interstates, highways, other freeways and expressways, principal arterials, minor arterials, major collectors, minor collectors, and local roads. For purposes of this analysis, the study team examined only interstates, other freeways and expressways, and principal and minor arterials because of their traffic volume and regional importance. The *Blueprints* team overlaid the major roads with the inundation map created in the previous studio (Georgia Conservancy 2012) to identify segments that would be inundated based on the functional classification system. Next, the study team calculated the average number of lanes for each of the functional classifications in Georgia from the FHWA Highway Statistics Series (FHWA 2011) and identified the range

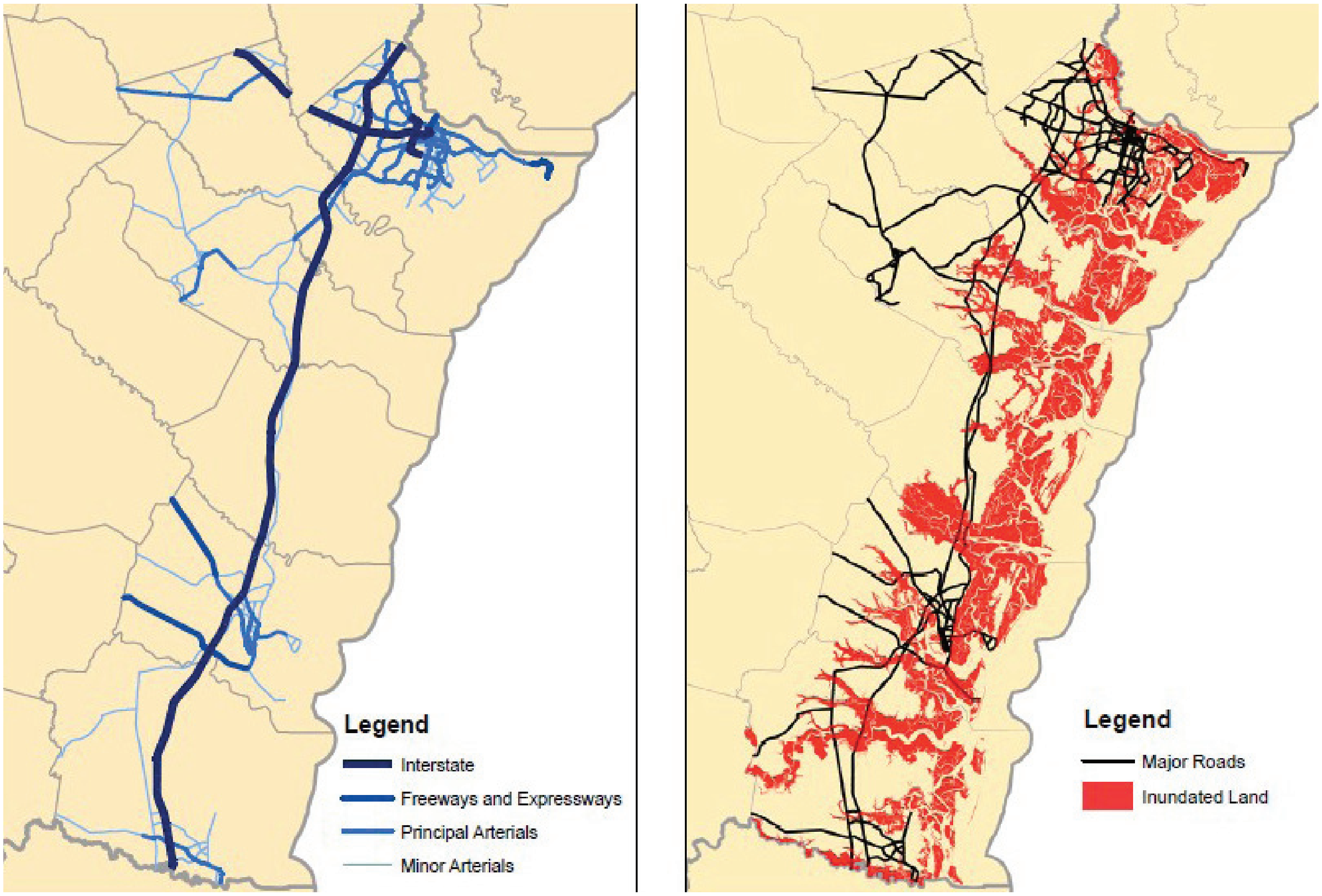


Figure 2.18: Georgia Coast's Major Road Network. (a) Functional Classification of Major Road Network. (b). Inundation of Major Road Network Under SLR.

of minimum shoulder widths and lane widths for each of the functional classifications from the FHWA's Mitigation Strategies for Design Exceptions (FHWA 2007).

Using these figures and the segment lengths, the study team estimated the range of the minimum bridge area for each of the functional classifications of roadways. As noted above, the study team is estimating bridge area because we assume that inundated roads will be rebuilt as bridges over the water. Table 2.5, Table 2.6, and Table 2.7 show the ranges of the minimum shoulder widths, the ranges of lane widths, and the average number of lanes for each functional classification that were used to calculate the range of the bridge areas that would need to be constructed to adapt to one meter of sea level rise. Next, the *Blueprints* team applied a per square foot bridge construction cost for each of the road segments that would be inundated with a one meter rise in sea level. The Florida Department of Transportation (FDOT 2011) publishes a range of bridge construction costs per square foot for bridges of varying lengths and types. FDOT classifies bridges into short span (20'-45'), medium span (45'-150'), and long span (150').

The *Blueprints* team assumed that short span bridges would be simple span bridges with pre-cast concrete

Span	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials	Total
Short Span (including shorter span bridges) (0’-45’)	19	4	37	24	84
Medium/Long Span (45’+)	52	22	111	67	252
TOTAL	71	26	148	91	336

Table 2.9: Number of Roadway Segments Inundated Under 1.0 Meter of SLR

Span	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials	Total
Short Span (including shorter span bridges) (0’-45’)	0.083	0.011	0.194	0.098	0.386
Medium/Long Span (45’+)	3.701	1.764	12.388	4.351	22.204
TOTAL	3.784	1.775	12.582	4.449	22.589

Table 2.10: Length of Road Network Inundated Under 1.0 Meter of SLR (in miles)

	Interstate	Other Freeways and Expressways	Other Principal Arterials	Minor Arterials	Total
Low	$108,933,319	$37,999,465	$162,083,152	$40,429,606	$349,445,541
High	$255,027,906	$89,842,873	$457,793,114	$119,462,091	$922,125,986

Table 2.11: Costs of Bridge Construction by Functional Classification to Adapt to SLR

slabs and that medium and long bridges would be simple span bridges with concrete decks and pre-stressed girders, as those were the cheapest options. Table 2.8 displays these construction costs for the varying span lengths.

Using these values, the study team found the range of construction costs for each of the segments by applying the appropriate construction costs to the bridge areas. FDOT did not publish information regarding the costs of elevating a section of roadway less than 20 feet long, so the study team applied the short span construction unit costs to spans under 20 feet as well. A more detailed explanation of the study team’s methodology for calculating bridge construction costs can be found in Section 5.2 of the Appendix.

GIS maps of Georgia’s coastal road network are presented in Figure 2.18. The map on the left shows the road network separated by its functional classification. This map shows that Chatham County and the area surrounding the port have the most robust road network. However, the map also shows that there are roads along the coast, particularly Interstates 16, 95, and U.S. 17, that are important links to other regions. Figure 2.19 shows the entire network of major roads (interstates, freeways/expressways, and arterials) overlaid with a map of the land expected to be inundated under one meter of sea level rise, according to the bathtub model used in the previous studio (Georgia Conservancy 2012). This map shows that the extensive road network in Chatham County and the critical highway facilities outside of Chatham County are vulnerable to the effects of sea level rise.

The geographic analysis of the road network produced a list of the major road segments along the Georgia coast that would be inundated along with the lengths of the segments.

Table 2.9 shows the number of segments that would be inundated by a one meter rise in sea level, broken down into the categories influenced by FDOT's bridge construction cost guidelines and the functional classification of the road. Table 2.10 shows the aggregated length of the segments broken down into short and medium/long span and the functional classifications.

In total, 336 segments of roadway could be impacted by sea level rise. Nearly half of the segments impacted by sea level rise are principal arterials; however, minor arterials and interstates are also largely impacted. For all road classifications, a majority of the segments are longer than 45 feet and will require a medium or long span bridge. Of the 336 roadway segments, only 84 will require a short span bridge whereas 252 will require the construction of a medium or long span bridge.

When considering the length of roadway impacted, the principal arterials still make up the most significant portion of the network impacted. In total, 22.589 miles of the roadway network will be impacted by one meter of sea level rise, and 12.582 of these miles will be on principal arterials. Minor arterials and interstates are also heavily impacted, with 4.449 miles of minor arterials and 3.784 miles of interstates inundated. As is expected, the majority of the length of roadway that will need to be reconstructed will require the construction of a medium or long span bridge to adapt to sea level rise; 22.204 miles of the total 22.589 miles of inundated roadway will be built in the form of medium and long span bridges.

Next, using the number and length of bridges along with the range of road widths and range of bridge construction unit costs, the study team calculated the lower and upper limit of bridge construction costs that would be required to adapt the major road network for a one meter rise of sea level. Table 2.11 includes the calculated costs broken down by functional classification.

Due to the variations in minimum shoulder width, typical lane width, and bridge construction costs, the expected costs of rebuilding the inundated road segments as bridges varies. The total cost of reconstructing the inundated segments of the roadway network as bridges is expected to be as low as $349 million and as high as $922 million, with these costs coming chiefly from interstates and principal arterials. It is important to note that this range of costs assumes current construction costs and the current roadway network. Construction costs are likely to rise and the road network is likely to expand over the study's 100-year time horizon, thus making the potential costs even greater than costs calculated in this report. It is also important to note that the gradual nature of sea level rise allows affected communities to plan ahead for sea level changes and to design infrastructure that accommodates such changes. While a strategy of rebuilding inundated roads as bridges will temporarily solve the issues associated with sea level rise, this is not a long term solution. Sea levels will continue to increase past the planning horizon examined in this study.

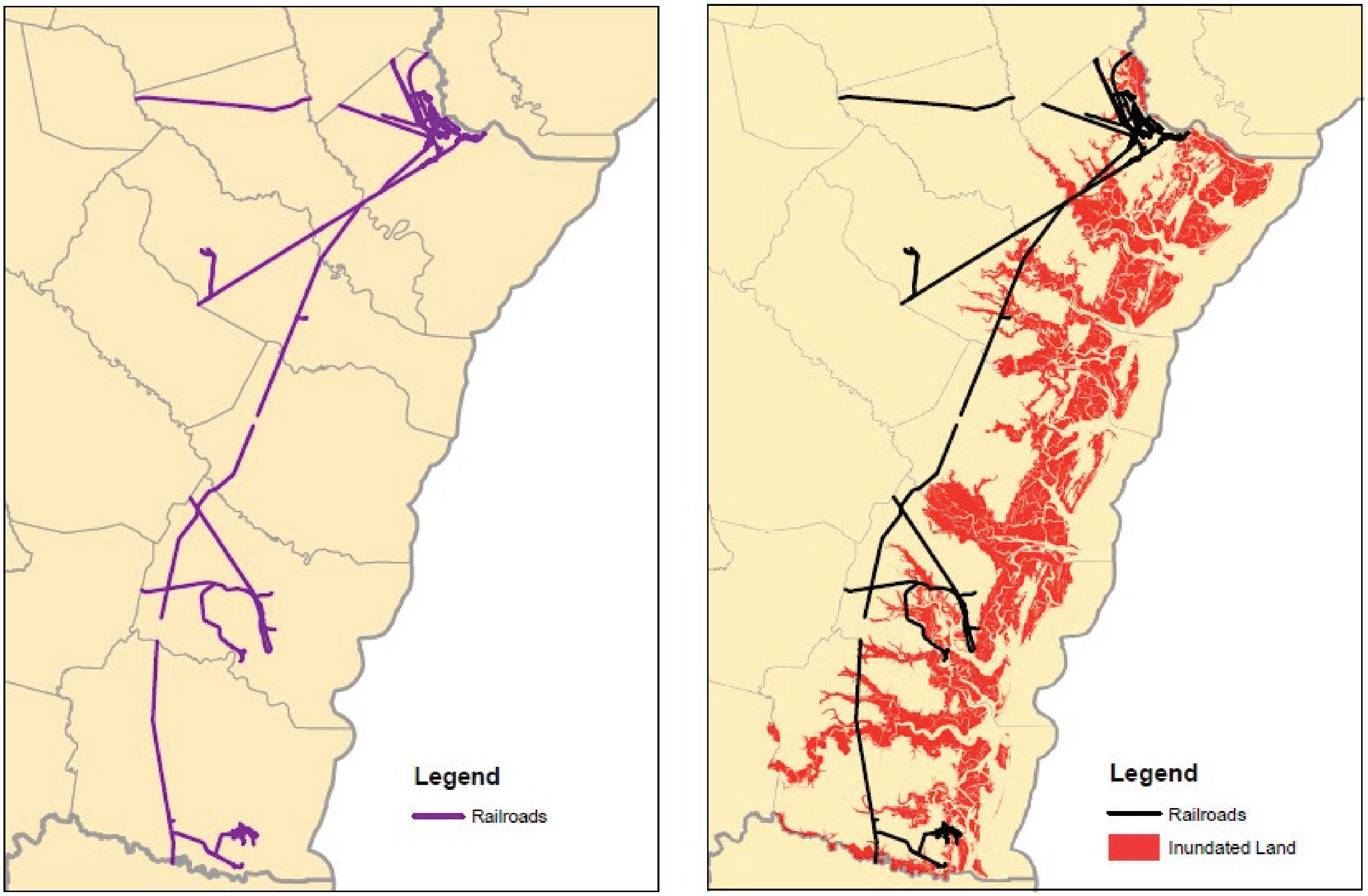


Figure 2.19: Georgia Coast's Railroad Network (a) Existing Railroad Network (b) Inundation of Railroad Network Under SLR

RAILROAD NETWORK

The *Blueprints* team used a GIS shapefile of the nation's railroad system provided by the U.S. Census Bureau to analyze the impact of sea level rise on rail networks in the coastal Georgia region. Only the rail infrastructure in the six county coastal Georgia region was examined in this section. The study team overlaid the sea level rise inundation map created in the previous studio (Georgia Conservancy 2012) on the coastal railroad infrastructure. The study team identified the number of segments and the length of each of the segments expected to be inundated under one meter of sea level rise. The team was not able to find reliable construction costs for railroad bridges. Therefore, the railroad network analysis does not include a calculation of the reconstruction costs for elevating rail networks due to sea level rise.

The GIS maps produced of coastal Georgia's railroad network are presented in Figure 2.19. The map on the left, (a), depicts the current railroad network. This map indicates that Chatham, Glynn, and Camden Counties have the highest concentrations of rail infrastructure along the coast. However, the map also shows that the other coastal counties contain rail lines that connect the coastal community to other regions in the Southeast, such as Florida, South Carolina, and inland Georgia. The map on the right, (b), shows the same railroad network overlaid with a map of the land expected to be inundated with one meter of sea level rise. This map visually depicts the extent railroad infrastructure along

Georgia's coast will be affected by a one meter rise in sea level.

According to the geographic analysis of the rail network, 84 segments may be inundated as a result of one meter of sea level rise. The length of these segments totals 14,036 miles. Due to the privatized nature of the railroads, the governments on the coast will likely not be responsible for adapting this infrastructure to sea level rise. However, it will be in the best interest of these communities to ensure that these connections are restored. As with the road network, it is important to point out the time horizon on this analysis. Since one meter of sea level rise is not expected until 2100, communities along the coast will be able to gradually adapt the infrastructure over several decades. Additionally, there is potential for further sea level rise after the 2100 planning horizon.

2.7 STORM SURGE

THE RELATIONSHIP BETWEEN SEA LEVEL RISE AND STORM SURGE

Storm surge from hurricanes threatens many coastal areas, especially when coupled with the fact that climate change is likely to increase storm intensity. Georgia's westernmost location on a concave Atlantic coastline and good fortune have combined to protect Georgia from direct hurricane strikes since 1989. Still, if there is a future hurricane strike, Georgia's shallow continental shelf and basin-like coastal shape will accentuate the resulting waves, giving Georgia "the potential for the second highest storm tide on the East Coast" (Georgia Emergency Management Agency 2013). Waves would not stop at the coast, but could also propagate up the Savannah River to the Garden City Terminal (Naval Research Laboratory 2008). Storm surge threatens to magnify the potential effects of sea level rise. Sea level rise will diminish the amount by which hurricane-driven waves have to rise to temporarily flood land and damage property since higher sea levels provide a higher base for storm surge. The water level associated with any given frequency of coastal storm or hurricane will grow, and communities will see waters reach new heights (Tebaldi et al. 2012). For instance, a "one meter rise in sea level would enable a 15-year storm to flood areas today that are only flooded by 100-year storms" (IPCC 1998). Storm surge levels will depend heavily on hurricane's frequency, size, strength, and path. While Georgia has not had any direct hurricane impacts in the past decades, a historical perspective back to 1800 shows that hurricane impacts are possible and suggests that the absence of hurricanes may be an anomaly rather than an enduring trend. Moreover, if predictions of stronger and potentially more frequent hurricanes accompanying climate change hold true, increased vulnerability to storm surge may represent one of the most significant sea level rise-related dangers to coastal communities.

In this section, the *Blueprints* team used several modeling techniques identified in the literature to assess the storm surge vulnerability with and without sea level rise for Garden City Terminal, Chatham County, and area warehouses. The purpose is to approximate the potential storm surge vulnerability increase due to sea level rise. The analysis does not account for climate change-related variations in storm intensity, but instead focuses on sea level changes alone.

ECONOMIC IMPACT AT GARDEN CITY TERMINAL

The *Blueprints* team conducted an economic impact analysis that calculates the loss of economic activity to the State of Georgia in the event of a hurricane to determine the economic impact of sea level rise from reduced operations at the port. Thunderstorms and hurricanes already suspend port operations on occasion. As noted above, the disruptive effects of these storms on port operations will increase as sea levels rise. Estimation of economic impacts after natural disasters requires two factors: (1) data inventory and (2) an appropriate methodology to analyze available data (Pan 2011). The team was able to locate much of the necessary economic data and information on physical infrastructure for this analysis through prior studies, U.S. Census information, tax parcel data from the Chatham County tax assessor, and from a tour of the facilities and infrastructure in and surrounding the Garden City Terminal. This report 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 rise in sea level at the Garden City Terminal ("UGA Study").[1] (Footnotes in Section 6.0: References)

The *Blueprints* team quantified the impact of sea level rise on the Garden City Terminal in terms of overall output and gross domestic product for the State of Georgia. In addition to output and State GDP, the team also addressed the impact of sea level rise on employment and income, though we did not quantify these estimates. Instead, we qualitatively described the potential effects of sea level rise on employment and income. The team qualitatively described these figures, rather than assigning each a specific cost, because in most instances any loss or disruption to income or employment is temporary and short term. Port employees are not likely to lose long term employment opportunities because of sea level rise, and will not likely lose a substantial amount of employment income because of sea level rise. Employment may be impacted in the short-term but the disruptions at the port would probably not cause permanent job loss in the long-term. However, this assumption may fail if the port is shut down for an extended period of time as in the case of the Port of New Orleans or Port of Gulfport after Hurricane Katrina. Since those ports operated at a significantly reduced capacity for several months, port employees (mostly wage-earning employees) left in search of other employment opportunities.

Salaried employees would likely continue to be paid even if the port is shut down. Thus, their income would not be impacted by a temporary port shutdown. A shutdown of the Garden City Terminal may have a larger impact on wage-earning employees (such as owner-operator trucks) because their income is tied to the number of hours worked. However, wage-earning employees would likely be able to make up any lost time and wages once the port resumes operations. Ships that were not able to access the port during a shutdown would use the Garden City Terminal once it reopened.

The *Blueprints* 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 rise in sea level 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. A detailed description of the study's methodology is found in Section 5.3 of the Appendix.

Output and State GDP at the Port of Savannah in 2011
The Garden City Terminal is a major economic engine in the State of Georgia.

- In 2011, the port industry at the Port of Savannah contributed $1.493 billion in total GDP to the State of Georgia, which included $975 million in direct GDP and $518 million in indirect and induced GDP.
- In 2011, the port industry at the Port of Savannah contributed $3.043 million in total output to the State of Georgia, which included $1.983 million in direct output and $1.060 million in indirect and induced output.

GPA Annual Economic Impact ($ Million)	Output			State GDP		
	Direct	Indirect/ Induced	Total	Direct	Indirect/ Induced	Total
Port Industry (All Ports)	$2,552	$1,363	$3,917	$1,242	$666	$1,907
Port Industry (Port of Savannah)	$1,983	$1,060	$3,043	$975	$518	$1,493
Proportion of Impact Attributed to Savannah	78%	78%	78%	79%	78%	78%
Port Industry	$36,702	$26,277	$62,980	$15,024	$15,495	$30,519
Port Users	$28,519	$20,436	$48,927	$11,794	$12,052	$23,893
Total Impact	$645	$455	$1,099	$270	$266	$537

Table 2.12: Output and State GDP at the Port of Savannah, FY 2011
Source: University of Georgia, Selig Center for Economic Growth, The Economic Impact of Georgia's Deepwater Ports, FY 2011.

Port industry data was specifically identified in the UGA study. However, data for the port users included economic activity at both the Port of Savannah and Port of Brunswick. In order to extract only Port of Savannah data, the team assumed that the proportion of port user output attributed to the Port of Savannah would be identical to the proportion of port industry output attributable to the Port of Savannah. This proportion was 78%. Using this figure, the team estimated port user impact on the State economy.

- In 2011, port users at the Port of Savannah contributed $48,927,275,977 in total output to the State of Georgia, which included $28,518,834,639 in direct output and $20,435,524,578 in indirect and induced output.

Like the output data, the port user data included economic activity at both the Port of Savannah and Port of Brunswick. In order to extract only Port of Savannah data, the team ran the same calculation for deriving impact to GDP as it did for output. The proportion calculation was approximately 78%.The team therefore assumed port user GDP attributable to the Port of Savannah was 78% of the total port user GDP.

- In 2011, port users at the Port of Savannah contributed $23,893,480,336 in total GDP to the State of Georgia, which includes $11,794,202,899 in direct impact to GDP and $12,051,666,667 in indirect and induced impact to GDP.

Next, the team had to determine what percentage of the output and GDP was attributable to the Garden City Terminal since the Port of Savannah information includes economic activity at the Garden City Terminal and the Ocean City Terminal. According to the Georgia Ports Authority, the Garden City Terminal handles 88% of all cargo that is shipped through the Port of Savannah. The team assumed the 88% cargo-handled figure attributed to the Garden City Terminal was identical to the percent of output and GDP attributable to the Garden City Terminal at the Port of Savannah. Since no additional information on the monetary value of each of the containers that came through the Port of Savannah (i.e. the average value of each piece of cargo handled) was available, the team could not definitively determine whether the 88% figure was also reflective of the total economic activity attributable to the Garden City Terminal.

AVERAGE WORKING WEEKS AND WORKING DAYS PER YEAR

The *Blueprints* team assumed the average number of working weeks at the Garden City Terminal is 52 weeks, and the average number of working days per year is 365 days. This comports with convention and with the UGA study where we attained much of our economic input data. Though the team used 52 weeks, the Garden City Terminal is only “open” to ships Monday through Friday, with some limited hours on Saturday (GPA 2013). Thus, the actual number of “working days” may be less than 365 and the actual number of “working weeks” less than 52 weeks. However, for the sake of convention and consistency with the UGA Study, the team used 52 weeks and 365 days as our annual “working days” count.

DIMINISHED PORT CAPACITY AFTER A HURRICANE

The final assumption the *Blueprints* study team had to make in the economic impact analysis involved the extent to which the port would be operating due to a hurricane based on the length of time the port remained in an impaired condition. The study team defined informed assumptions about how the extent of inundation and damage will limit the terminal’s handling capacity and the length of time this limited terminal capacity will persist. The extent of diminished operational capacity is expressed as a percentage of total operational capacity and was estimated based on recovery experiences at other ports after hurricanes. The time period for port shutdown is likewise estimated based on experiences at other ports in the United States and Caribbean. The team summarized the available data and was able to create an average hurricane recovery period, in terms of reduced capacity and recovery time for ports after Category 1, 3, and 5 hurricanes. The study team was able to estimate the associated economic impact of each hurricane scenario using this recovery information and the economic input data provided in the UGA Study.

The study team’s three post-hurricane recovery time lines are based on recovery time lines at different ports after particular hurricane events, though even ports affected by the same hurricane varied widely in their recovery time lines based on a variety of factors: (1) availability and extent of disaster relief assistance and resources; (2) damage to transportation networks, including road, rail and inland waterway networks; (3) effectiveness of the port’s hurricane preparedness and recovery plan, and the extent to which the plans were followed; (4) level of storm surge; and (5) damage to critical infrastructure within the port, such as container cranes, warehouses and navigational tools.

First, the authors looked at the Port of New York-New Jersey and the impact Superstorm Sandy had on the container terminal within the Port. The New York-New Jersey container terminal is the busiest container terminal on the East Coast and the third busiest container terminal in the United States. The authors chose to look at the impact of Sandy on the Port of New York-New Jersey because it includes a container terminal similar to the Garden City Terminal and because sufficient information was available on the Port’s recovery after Sandy to construct a reasonable recovery time line. Next, the team looked at Hurricane Rita’s impact at the Port of Port Arthur in Port Arthur, Texas and the impact of Hurricane Ivan on the Port of St. George’s in Grenada. The impacts of Hurricane Rita are somewhat conflated with the impacts Hurricane Katrina imposed on the port. However, because Hurricane Katrina had less of an impact on Port Arthur than it did on ports in Louisiana and Mississippi, the authors believe the impacts of Hurricane Rita can be reasonably estimated. The Port of St. George’s is a smaller port that is vital to Grenada’s economy. In September of 2004, Category 3 Hurricane Ivan struck the Port of St. George’s and caused substantial disruption to the Port’s operations. However, due to generous outpourings of support from the international community and relief organizations, the Port returned to pre-hurricane levels fairly quickly. Finally, the team looked at Hurricane Katrina’s impact on both the Port of New Orleans (including its large container terminal) in Louisiana and the Port of Gulfport in Mississippi.

Hurricane Katrina was a Category 5 hurricane, but quickly dissipated to a Category 3 storm upon landfall. Though the storm weakened upon landfall, its disastrous impact on Gulf Coast ports makes it an appropriate proxy for a Category 5 hurricane for the purposes of this study.

PORT RECOVERY PERIOD: 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). Sandy disrupted operations at the Port of New-York and New Jersey, and specifically disrupted operations at the Port's container facility for an extended period of time due to power outages and substantial flooding. The Port of New York-New Jersey includes the third busiest container terminal by number of TEUs handled in the United States. The container terminal was shut down for approximately a week, and regained full operations after four weeks. A more detailed description of the storm and its impacts on the container terminal are included in Section 5.4 of the Appendix.

Table 2.13 summarizes the average port recovery time for a Category 1 hurricane.

Disruption Characteristics	End of Week 1	End of Week 2	End of Week 3	End of Week 4
Extent of Capacity Reduced	90%	25%	10%	0%

Table 2.13: Estimated Disruption at the Garden City Terminal due to a Category 1 Hurricane

PORT RECOVERY PERIOD: CATEGORY 3 HURRICANE

To estimate damage from a Category 3 Hurricane, the study team looked at the impact of Hurricane Ivan on the Port of St. George's in St. George's, Grenada and the impact of Hurricane Rita on Port Arthur in Port Arthur, Texas. 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, which allowed the Port of St. George's to reach pre-hurricane operations after four weeks. Hurricane Rita hit made landfall as a Category 3 hurricane on the Louisiana and Texas border on September 24, 2005. The port's emergency management team was permitted to enter the city on September 28 to start cleaning up the Port. In August of 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). A more detailed description of the storms and their impacts on the Port of St. George's and Port of Port Arthur are included in Appendix 4.

Table 2.14 summarizes the average port recovery time for a Category 3 hurricane.

Disruption Characteristics	End of Week 1	End of Week 2	End of Week 3	End of Week 4	End of Week 5
Extent of Capacity Reduced	90%	50%	25%	10%	0%

Table 2.14: Estimated Disruption at the Garden City Terminal due to a Category 3 Hurricane

Disruption Duration (in weeks)	1	2	3	4	8	12	16	20	24	28	32
Extent of Capacity Reduced	100%	90%	85%	80%	65%	55%	45%	35%	25%	10%	0%

Table 2.15: Estimated Disruption at the Garden City Terminal due to a Category 5 Hurricane

GPA Annual Economic Impact ($ Million)	Output			State GDP		
	Direct	Indirect/ Induced	Total	Direct	Indirect/ Induced	Total
Port Industry	$1,745	$933	$2,678	$858	$456	$1,314
Port Users	$25,097	$17,983	$43,056	$10,379	$10,605	$21,026
Total Impact	$26,841	$18,916	$45,734	$11,237	$11,061	$22,340
Economic Impact of Reduced Capacity ($ Million)						
Port Industry	$42	$22	$64	$21	$11	$32
Port Users	$603	$432	$1,035	$249	$255	$505
Total Impact	$645	$455	$1,099	$270	$266	$537

Table 2.16: Garden City Economic Outputs, Category 1 Hurricane

RECOVERY PERIOD: CATEGORY 5 HURRICANE

Finally, the *Blueprints* team estimated a port recovery period for a Category 5 hurricane using Hurricane Katrina's impact on the Port of Gulfport in Gulfport, Mississippi and the Port of New Orleans in New Orleans, Louisiana. Hurricane Katrina was the most devastating hurricane that has ever hit the United States in recordable history, both in terms of human lives lost and economic impacts. The total number of fatalities directly and indirectly attributable to Hurricane Katrina was 1,833 deaths, and estimates of its total economic damage total approximately $81.2 billion (Pan 2011). The team is aware that Hurricane Katrina was unique in the extent of its damage. Failures outside the Port of New Orleans and Port of Gulfport, such as levee failures and an anemic initial response by the government, made the economic impacts of Hurricane Katrina unique and more difficult to generally apply to other ports. However, the authors are confident that the port recovery periods after Hurricane Katrina can still be used to estimate potential economic impacts at the Garden City Terminal. Though Hurricane Katrina destroyed one-third of the Port of New Orleans (Grenzeback & Lukmann 2008), the Port recovered to pre-hurricane capacity in just six months (U.S. Department of Commerce 2006).

When Hurricane Katrina hit the Gulfport Port in Mississippi 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). Reports indicate that even after five years and more than $250 million in new investments, the Port of Gulfport was still only operating at 80% of its pre-Katrina capacity (Wright 2013). A more detailed description of Hurricane Katrina and its impact on the Port of New Orleans and Port of Gulfport is included in Section 5.4 of the Appendix. Table 15 summarizes the average port recovery time for a Category 5 hurricane.

ECONOMIC ANALYSIS CALCULATIONS AT THE GARDEN CITY TERMINAL

The following sections analyze the economic impact of Category 1, 3, and 5 storms at the Garden City Terminal on Georgia's economy. The economic impact

	Direct	Indirect/ Induced	Total
Output	$645,231,117	$454,713,020	$1,099,371,223
State GDP	$270,117,754	$265,896,795	$537,021,699

Table 2.17: Economic Impact of a Category 1 Hurricane on the Garden City Terminal, Summary

	Direct	Indirect/ Induced	Total
Output	$903,323,564	$636,598,228	$1,539,119,712
State GDP	$378,164,855	$372,255,513	$751,830,379

Table 2.19: Economic Impact of a Category 3 Hurricane on the Garden City Terminal, Summary

is measured in terms of reduced output and State GDP. A qualitative discussion regarding a hurricane's impact on employment and income and taxes was discussed above. This report used economic inputs provided by the University of Georgia's Selig Center for Economic Growth in its 2012 Report, "Economic Impact of Georgia's Deepwater Ports, FY 2011." The economic input data and methodology employed by the University of Georgia is found in Section 5.3 of the Appendix 3.

ECONOMIC IMPACT OF A CATEGORY 1 HURRICANE AT THE GARDEN CITY TERMINAL

This section examines the economic impact of a Category 1 hurricane at the Garden City Terminal. As noted above, the economic impact is measured in terms of reduced output and State GDP. Table 2.16 shows the economic outputs attributable to the Garden City Terminal and the Economic Impact of the Reduced Capacity based on the port recovery the team created for a Category 1 hurricane.

Looking at Table 2.16, the economic impact of reduced capacity was calculated by multiplying the economic output at the Garden City Terminal for each category by the reduced capacity of the Terminal. The reduced capacity of the Terminal encompasses both the extent of reduction in operational capacity (percentage figure) and the length of time that the port is operating at such reduced capacity. Table 2.17 summarizes the total economic impact of reduced capacity after a Category 1 hurricane. It should be noted that this economic impact analysis only calculates the economic impact of operational delays at the Garden City Terminal.

Looking at Table 2.17, the total direct economic impact of a Category 1 hurricane on Georgia's economy in terms of output is $645,231,117. The total indirect and induced economic impact on Georgia's economy in terms of output is $ 454,713,020. Adding the direct and indirect/induced output totals together produces a total economic impact of $1,099,371,223 on Georgia's economy in terms of output in the event of a Category 1 hurricane. The total direct economic impact of a Category 1 hurricane on Georgia's economy in terms of State GDP is $270,117,754. The total indirect and induced economic impact on Georgia's economy in terms of State GDP is $265,896,795. Adding the direct and indirect/induced State GDP total together produces a total economic impact of $537,021,699 on Georgia's economy in terms of State GDP in the event of a Category 1 hurricane.

ECONOMIC IMPACT OF A CATEGORY 3 HURRICANE

This section examines the economic impact of a Category 3 hurricane at the Garden City Terminal. As noted above, the economic impact is measured in terms of reduced output and State GDP. The economic impact was found using the same methodology employed in calculating the impact of a Category 1 hurricane, but included a longer recovery period. Table 2.18 shows the economic outputs attributable to the Garden City Terminal and the Economic Impact of the Reduced Capacity based on the port recovery the team created for a Category 3 hurricane.

Garden City Terminal Annual Economic Impact ($ Million)	Output			State GDP		
	Direct	Indirect/ Induced	Total	Direct	Indirect/ Induced	Total
Port Industry	$ 1,745	$ 933	$ 2,678	$ 858	$ 456	$ 1,314
Port Users	$ 25,097	$ 17,983	$ 43,056	$ 10,379	$ 10,605	$ 21,026
Total Impact	$ 26,841	$ 18,916	$ 45,734	$ 11,237	$ 11,061	$ 22,340
Economic Impact of Reduced Capacity ($ Million)						
Port Industry	$59	$31	$90	$29	$15	$44
Port Users	$845	$605	$1,449	$349	$357	$708
Total Impact	$903	$637	$1,539	$378	$372	$752

Table 2.18: Economic Output at Garden City Terminal, Category 3 Hurricane

Garden City Terminal Annual Economic Impact ($ Million)	Output			State GDP		
	Direct	Indirect/ Induced	Total	Direct	Indirect/ Induced	Total
Port Industry	$ 1,745	$ 933	$ 2,678	$ 858	$ 456	$ 1,314
Port Users	$ 25,097	$ 17,983	$ 43,056	$ 10,379	$ 10,605	$ 21,026
Total Impact	$ 26,841	$ 18,916	$ 45,734	$ 11,237	$ 11,061	$ 22,340
Economic Impact of Reduced Capacity ($ Million)						
Port Industry	$515	$275	$790	$253	$135	$388
Port Users	$7,408	$5,309	$12,710	$3,064	$3,131	$6,207
Total Impact	$7,923	$5,584	$13,500	$3,317	$3,265	$6,595

Table 2.20: Economic Output at Garden City Terminal, Category 5 Hurricane

Table 2.19 summarizes the total economic impact of reduced capacity after a Category 3 hurricane. Looking at Table 2.19, the total direct economic impact of a Category 3 hurricane on Georgia's economy in terms of output is $903,323,564. The total indirect and induced economic impact on Georgia's economy in terms of output is $636,598,228. Adding the direct and indirect/induced output totals together produces a total economic impact of $1,539,119,712 on Georgia's economy in terms of output in the event of a Category 3 hurricane. The total direct economic impact of a Category 3 hurricane on Georgia's economy in terms of State GDP is $378,164,855. The total indirect and induced economic impact on Georgia's economy in terms of State GDP is $372,255,513. Adding the direct and indirect/induced State GDP total together produces a total economic impact of $751,830,379 on Georgia's economy in terms of State GDP in the event of a Category 3 hurricane.

ECONOMIC IMPACT OF A CATEGORY 5 HURRICANE

This section examines the economic impact of a Category 5 hurricane at the Garden City Terminal. As noted above, the economic impact is measured in terms of reduced output and State GDP. Table 2.20 shows the economic outputs attributable to the Garden City Terminal and the Economic Impact of the Reduced Capacity based on the port recovery the team created for a Category 5 Hurricane. The economic impact was found using the same methodology employed in calculating the impact of a Category 1 and 3 hurricane, but included a longer recovery period.

	Direct	Indirect/ Induced	Total
Output	$7,923,438,121	$5,583,875,885	$13,500,278,613
State GDP	$3,317,046,014	$3,265,212,641	$6,594,626,469

Table 2.21: Economic Impact of a Category 5 Hurricane on the Garden City Terminal, Summary

Hurricanes	Max Storm Surge above Mean Tide (ft.)
Category 1	13.6
Category 2	17.2
Category 3	21.4
Category 4	24.9
Category 5	28.1

Table 2.22: Storm Surge Predicted by the SLOSH Model at the Garden City Terminal (given existing sea levels) Source: Naval Research Laboratory, n.d.

The recovery period for a Category 5 hurricane is substantially longer than for a Category 1 or 3 Hurricane. Because Category 5 hurricanes have only made landfall on a few occasions in recent history, data and information on the devastating impact of these storms was limited. This report used information from Hurricane Katrina's impact on the Port of New Orleans and the Port of Gulfport. The extended delays in reopening the ports to full capacity were confounded by breached levees, and thus massive flooding, poor planning, massive destruction to infrastructure outside the port, and a mass outflux of available labor. The team is aware that these additional storm-related occurrences may have exacerbated the port's recovery period. However, a Category 5 storm would cause incredible destruction at the Garden City Terminal and communities surrounding the Terminal and may create the same kind of flooding, infrastructure damage and outflux of labor that Hurricane Katrina caused in New Orleans, Louisiana and Gulfport, Mississippi. Moreover, it is unclear whether the Terminal has an updated an effective hurricane plan in effect in the event of a massive hurricane. If the Terminal does not have a hurricane recovery plan in place, the recovery period could extend beyond eight months. Table 2.20 summarizes the total economic impact of reduced capacity after a Category 5 hurricane.

Looking at Table 2.21, the total direct economic impact of a Category 5 hurricane on Georgia's economy in terms of output is $7,923,438,121. The total indirect and induced economic impact on Georgia's economy in terms of output is $ 5,583,875,885. Adding the direct and indirect/induced output totals together produces a total economic impact of $13,500,278,613 on Georgia's economy in terms of output in the event of a Category 5 hurricane. The total direct economic impact of a Category 5 hurricane on Georgia's economy in terms of State GDP is $3,317,046,014. The total indirect and induced economic impact on Georgia's economy in terms of State GDP is $3,265,212,641. Adding the direct and indirect/induced State GDP total together produces a total economic impact of $6,594,626,469 on Georgia's economy in terms of State GDP in the event of a Category 5 hurricane.

PHYSICAL PORT DAMAGE FROM STORM SURGE

Storm-surge related damage to the Garden City Terminal depends on both the frequency of storm surges and the height of the surge. The National Oceanic and Atmospheric Administration (NOAA) maintains a software tool that predicts storm surge based on different hurricane scenarios, topography, and water basin characteristics. The model, called the Sea, Lake and Overland Surges from Hurricanes (SLOSH), produces storm surge inundation maps, which can then feed models predicting disruptions to economic activity or infrastructure damage (National Hurricane Center, 2013). A detailed description of SLOSH is included in Section 5.6 of the Appendix. The Naval Research Laboratory, Marine Meteorology Division, used the

Category of Hurricane	Occurrences since 1850*
Category 1	15
Category 2	5
Category 3	2
Category 4	1
Category 5	0

Table 2.23: Hurricane Occurrences affecting Georgia since 1850 by Category of Storm
Source: Georgia Emergency Management Agency, 2013.
*A majority of the 23 hurricanes occurred before 1900

SLOSH model to estimate water heights at the Garden City Terminal under hurricane categories one through five (Naval Research Laboratory 2008). The results of the SLOSH model predict a storm surge ranging from 13.6 feet to 28.1 feet above mean tide (Table 2.22). The tidal range at the Garden City Terminal is 7.5 feet, meaning that resulting storm tide could be 3.75 feet higher or lower depending on the astronomical tide at the moment of hurricane impact. As previously stated, the piers at the Garden City Terminal are 7.5 feet above mean high tide, which equates to 11.25 feet above mean tide, indicating that even a Category 1 storm would likely flood much of the terminal, even at current sea levels.

Hurricanes have not struck Georgia directly in the past decades. The last hurricane to impact the Georgia coast directly was Hurricane David in 1979 (Category 2). However, storms have occurred more frequently over Georgia's history. Since 1800, 31 storms have impacted Georgia, 23 of which were after 1850. According to the Georgia Emergency Management Agency, Category 1 storms account for the majority of hurricanes (2013). No Category 5 storms have directly struck the Georgia coast since 1851. Table 2.23 shows the number of storm occurrences since 1850 and the derived probability per year based on the 163 years of observation.

The Port of Savannah could minimize damage by preparing for hurricanes. The U.S. Navy does not consider docks at the Garden City Terminal to be safe for ships during a hurricane, and the Coast Guard inspects port preparation with facility operators 48 hours before the expected arrival of gale force winds and closes the harbor no later than 12 hours in advance (Naval Research Laboratory 2013). The Coast Guard also recommends that all seagoing vessels leave the port to avoid the storm (U.S. Coast Guard 2013). While the Georgia Ports Authority has a mobile command center that can direct port operations remotely in case of storm (Georgia Ports Authority 2013), the Coast Guard requires a suspension of port cargo operations during severe storms (U.S. Coast Guard 2013). A strong hurricane plan might further increase port preparedness.

SLOSH AT THE COUNTY LEVEL

The study team produced results quantifying property exposure for each hurricane Category with and without storm surge at the level of the county as a whole, with particular focus on the Garden City Terminal and Chatham County warehouses. The results include the following variables:

- Area (acres and percentage)
- Building value (value and percentage)
- Land value (value and percentage)
- Max flood height (feet)
- Mean flood height (feet)

SLOSH METHODOLOGY

The study 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. 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. A more detailed SLOSH methodology is provided in Section 5.6 of the Appendix.

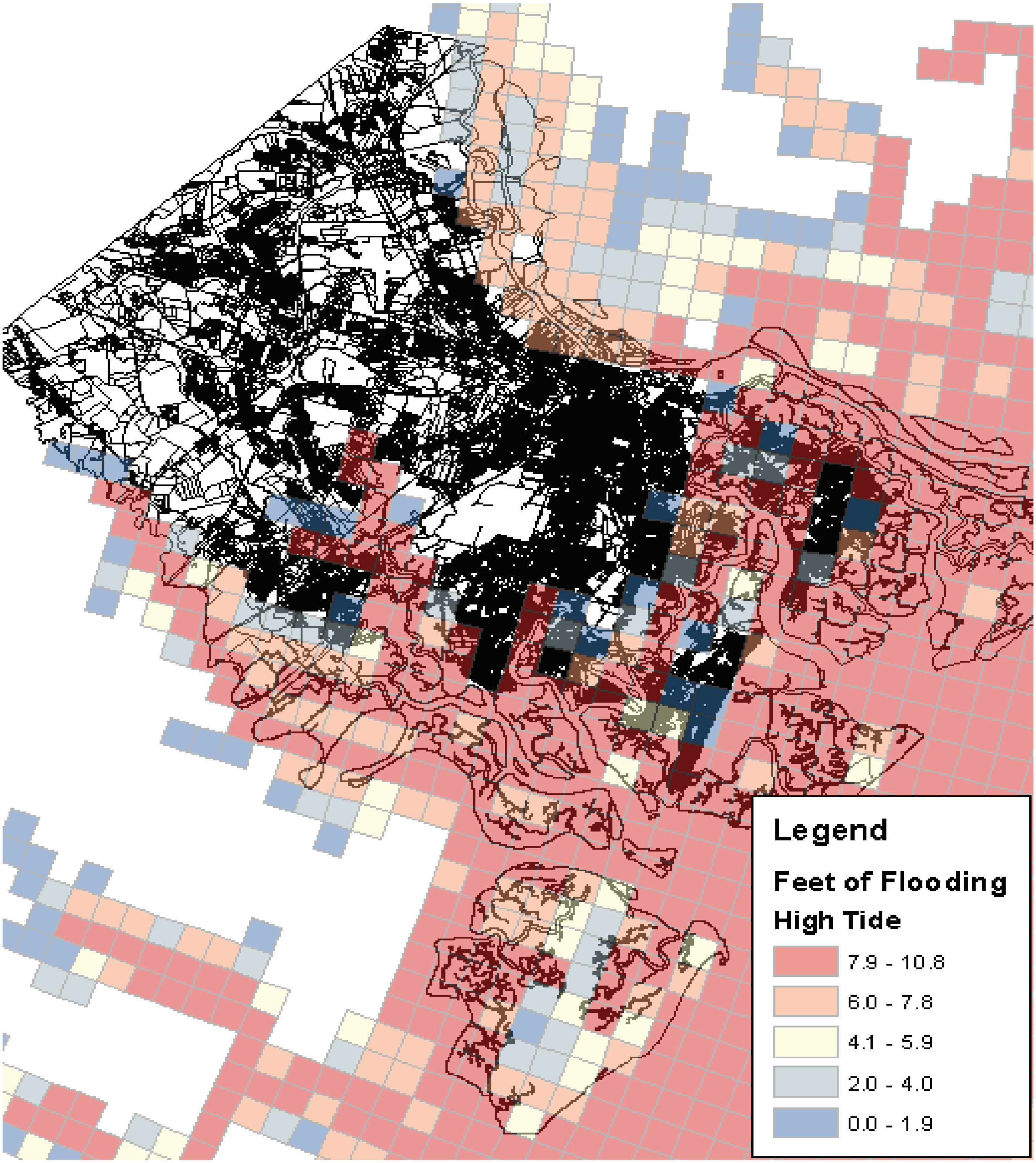


Figure 2.20: Storm Surge with Category 1 Hurricane in SLOSH, Chatham County

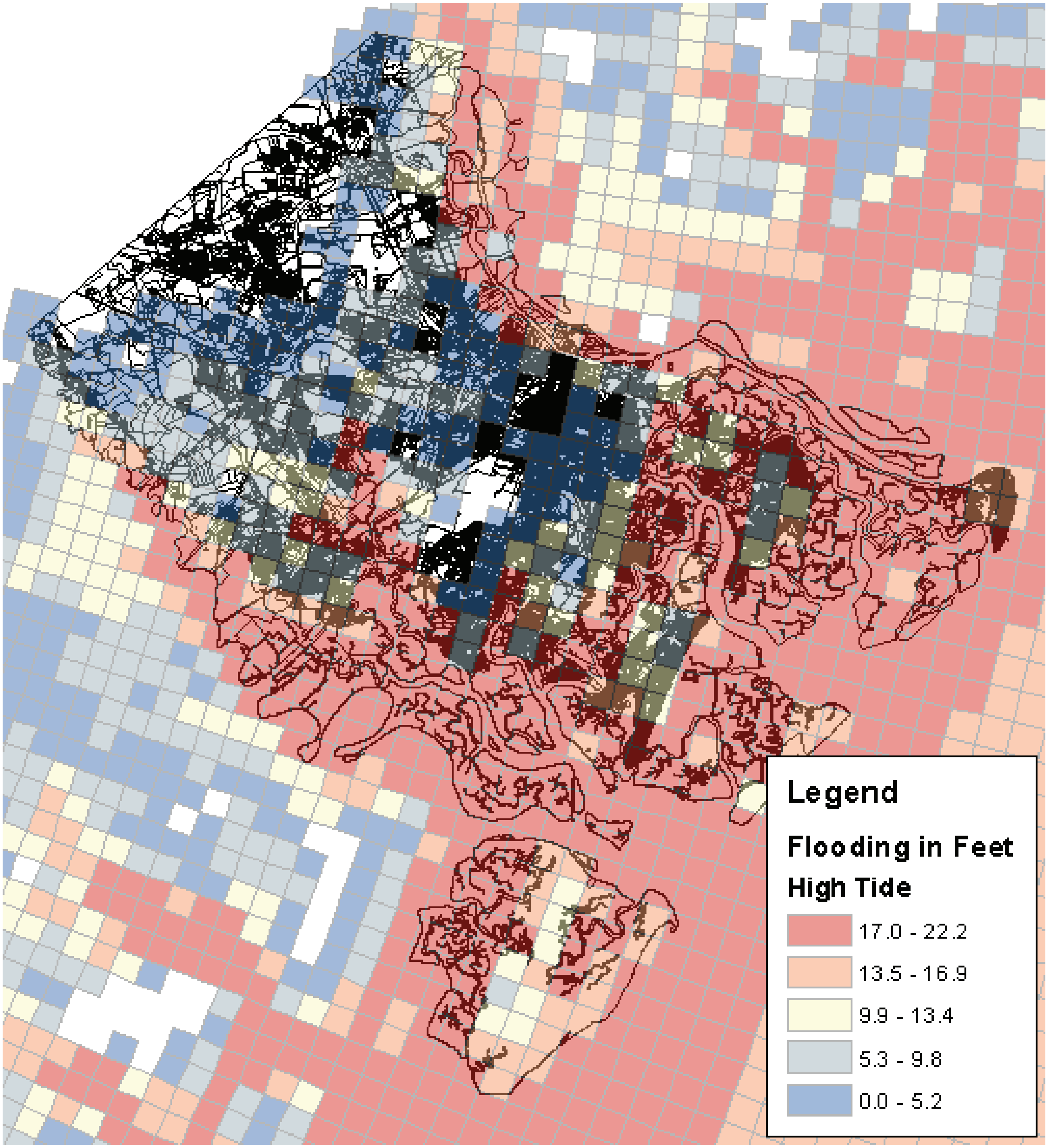


Figure 2.21: Storm Surge with Category 3 Hurricane in SLOSH, Chatham County

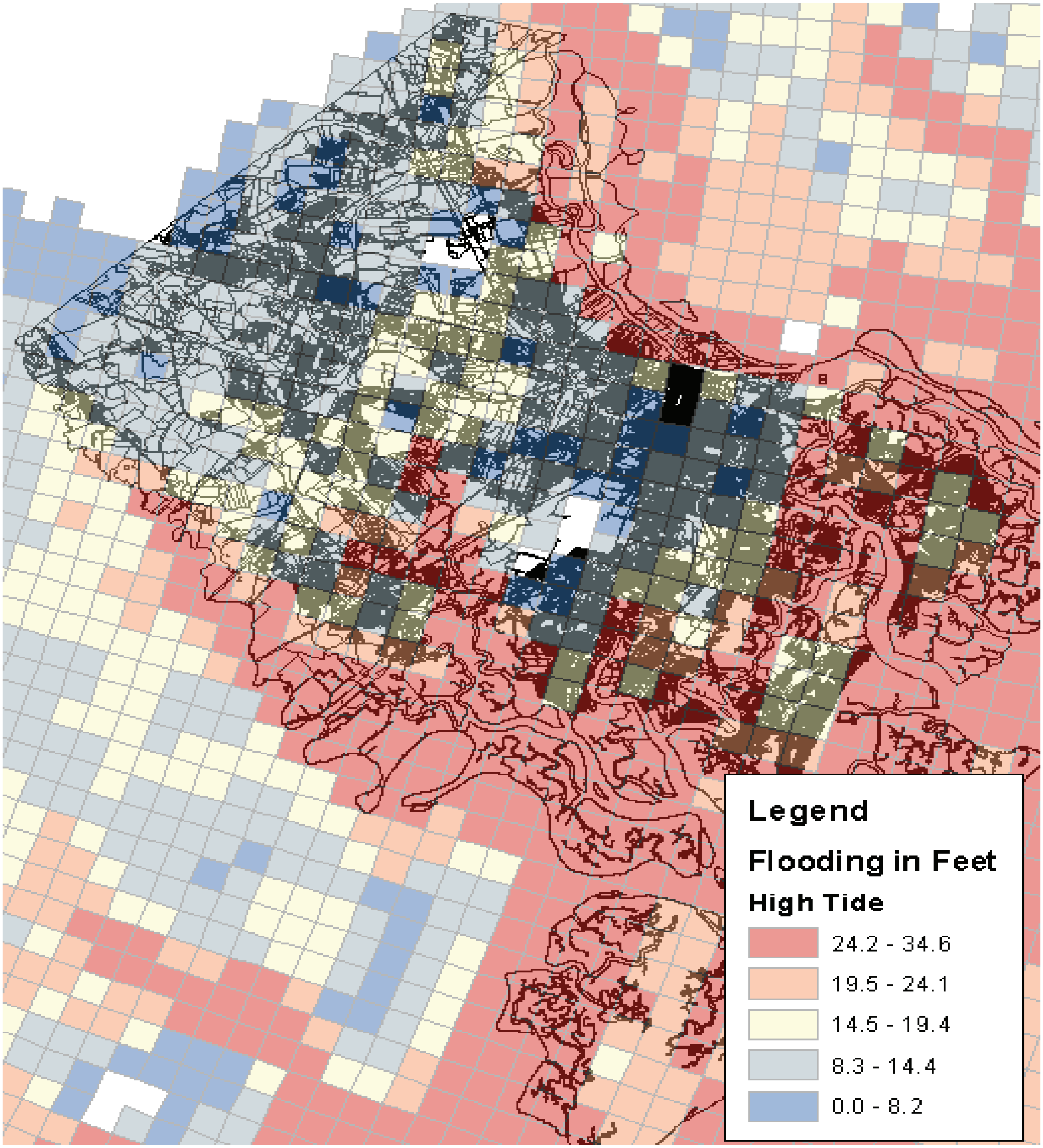


Figure 2.22: Storm Surge with Category 5 Hurricane in SLOSH, Chatham County

CHATHAM COUNTY

The study team first analyzed SLOSH output at the scale of Chatham County because Chatham County contains the Garden City Terminal, the majority of nearby warehouses, the largest number of port employees, and the closest vulnerable transportation links. The analysis revealed the coastal and riverside areas to already be very vulnerable to storm surge from lower category hurricanes, and all but the highest elevation areas vulnerable to storm surge from higher category hurricanes. Those high elevation areas include the bluff upon which the historic downtown is built and the high ground at the Savannah regional airport. However, many residential areas and transportation links are located in much lower elevation areas with increased storm surge risk.

The study team overlaid SLOSH flooding output with parcel data to display the areas most vulnerable to storm surge at current sea levels. Figure 2.20 shows that a Category 1 storm would cause flooding along the coast and the counties' rivers. The Savannah River, along which the Garden City Terminal is built, would experience limited flooding. Figure 2.21 shows that flooding is much more widespread for a Category 3 hurricane. Indeed, most of the county is flooded, and flooding is severe along the coast and the Savannah River. A Category 5 storm in Figure 2.22 would flood nearly all of the county, with extremely severe flooding along the Savannah River, with water levels on the river as much as 34 feet above normal.

Sea level rise is expected to increase the entire county's vulnerability to storm surge by making all storm surges

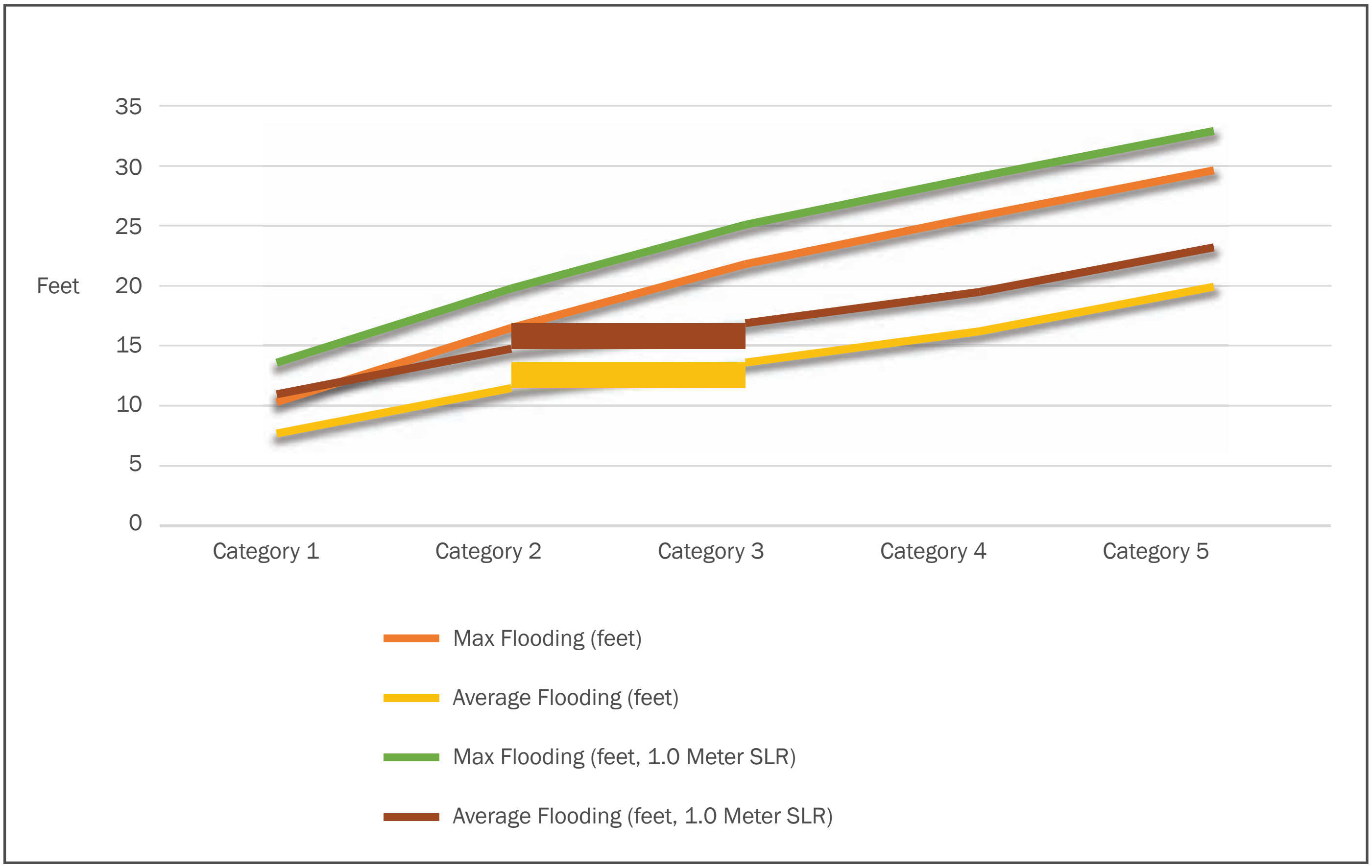


Figure 2.23: Storm Surge Related Flooding in Chatham County

approximately one meter higher relative to land in 100 years. Sea level rise will increase flooding's reach in the county and make it more severe. Figure 2.23 shows the expected impact that sea level rise will have on average flooding and maximum flooding for different storm categories. For a Category 5 storm, sea level rise will push maximum flooding over 30 feet above ground level and will produce average flooding over 20 feet above ground level in Chatham County.

Higher sea levels will increase the number of properties in Chatham County affected by storm surge, especially for Categories 1, 2, and 3. Category 4 and 5 storms would flood most of the county even at sea levels, so sea level rise causes a more modest increase in the number of parcels flooded. Still, sea level rise would increase flooding severity by approximately one meter over all flooded parcels (Figure 2.24), increasing damage to buildings, infrastructure degradation, and threats to human life.

Today, a Category 1 hurricane in the Savannah area would produce an average storm surge of approximately 7.7 feet and a maximum storm surge of 10.3 feet, which would rise to 13.3 feet with three feet of sea level rise. The sea level rise would increase the number of Chatham County parcels affected from 24,988 to approximately 43,509. These parcels' economic value can be summarized by the appraised value of the land that they occupy and the value of the buildings on them. The fully or partially flooded parcels' aggregate land value would increase from $3.6 billion for a Category 1 storm at current sea levels to $4.7 billion with one meter of sea level rise (Figure 2.25).

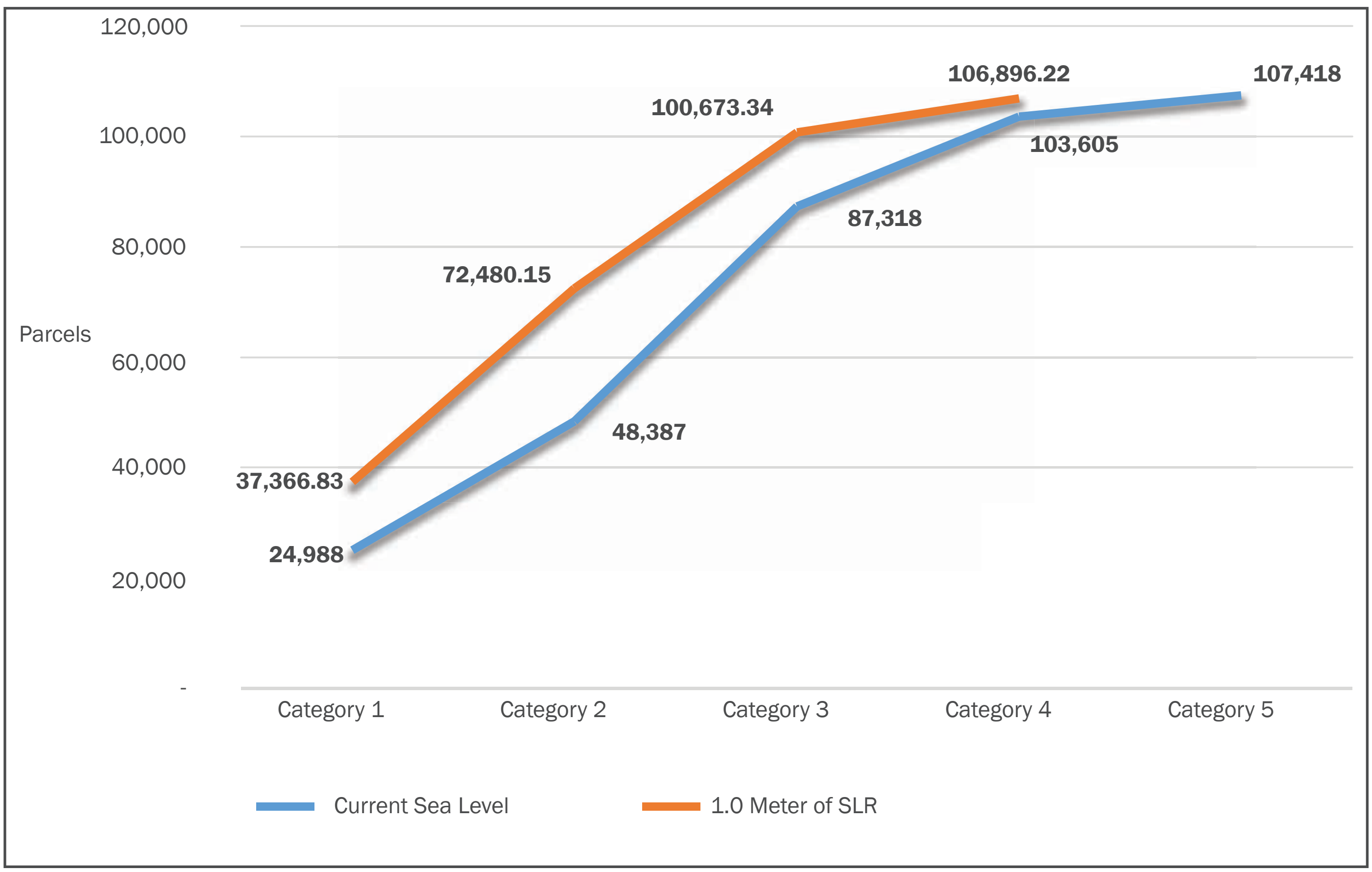


Figure 2.24: Number of Parcels Affected by Storm Surge

Storm surge from a Category 1 storm at current sea levels threatens to damage or destroy $5.2 billion worth of buildings in Chatham County, which would increase to $8.2 billion worth of buildings with one meter of sea level rise (Figure 2.26). The building value is particularly important because it is the property most easily damaged in a hurricane and because people who do not leave the county take shelter in buildings during hurricanes. Thus, sea level may significantly increase the building stock's susceptibility to flooding and hurricane damage even with low category hurricanes. The same increases hold true at higher storm categories too. Sea level rise may increase the affected parcels in a Category 4 storm from 103,605 with a building value of $17.7 billion to 106,623 parcels with a building value of $18.1 billion dollars. By comparison, Chatham County's entire building stock is worth $20.5 billion, meaning that a Category 4 hurricane with sea level rise would threaten up to 88% of the county's building stock by value.

Section 5.9 of the Appendix provides a table of Chatham County's direct economic vulnerabilities to hurricanes with and without sea level rise.

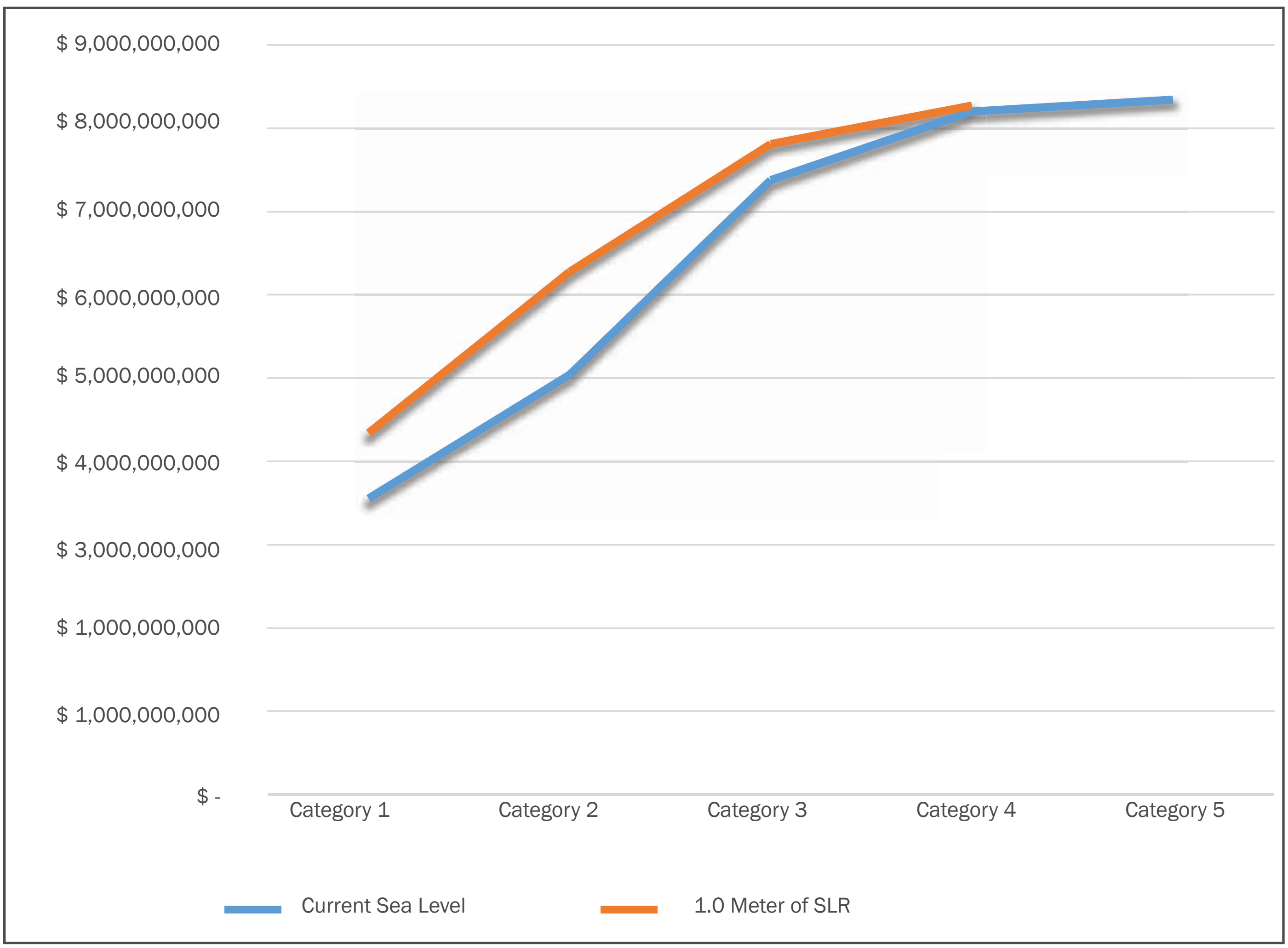


Figure 2.25: Land Value of Parcels Affected by Storm Surge, Chatham County

THE PHYSICAL IMPACTS OF STORM SURGE

The Garden City Terminal is directly adjacent to the Savannah River. While the location is necessary for operations, the river's adjacency makes the Terminal very vulnerable to storm surge. The Garden City Terminal's wharves are just 7.5 feet above high tide, or roughly 11.25 feet above mean tide. The Terminal is predominantly flat, offering little protection from waves. Moreover, the basin's shape allows waves to propagate up the river. The container crane, gantry cranes, electrical infrastructure, stored containers, jockey trucks, buildings, and other equipment are worth tens of millions of dollars and may not all be able to be moved or adequately protected from storms. In addition to the building and equipment value, damage to the port may temporarily require its closure, negatively affecting the employees and industries that work in and depend on the port in Chatham County and the must border region. Thus, increasing port flooding is a major economic threat.

A Category 1 hurricane today at high tide would cause waves 13.6 feet above mean tide in the Savannah River adjacent to the Garden City Terminal (Naval Research Laboratory n.d.). These waves would likely overtop the wharf heights, which are 11.25 feet above mean tide. The SLOSH model output confirmed that a Category

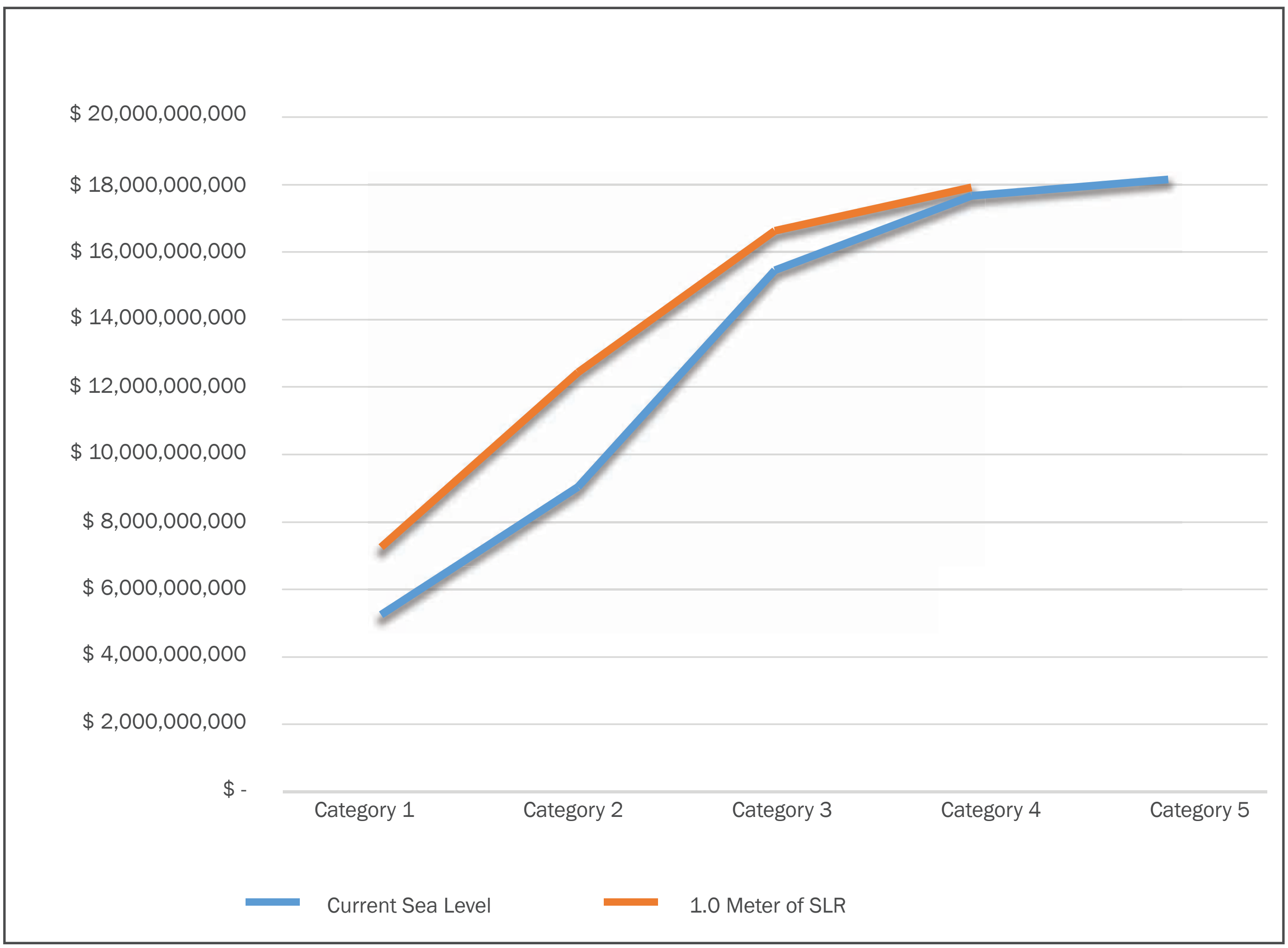


Figure 2.26: Building Value of Parcels Affected by Storm Surge, Chatham County

1 storm would likely flood portions of the Garden City Terminal even at current sea level. One meter of sea level rise would cause Category 1 storm surge to rise to approximately 16.6 feet above mean tide. If port infrastructure is not prepared appropriately, the rise in wave height would worsen port inundation.

Figure 2.27 below shows maximum storm-induced flooding at a representative site in the Garden City Terminal for different hurricane categories with and without sea level rise. Sea level rise increases flood height by approximately 30% for Category 1 storms. Category 5 storms without sea level rise could see more than 25 feet of flooding at current sea levels, which sea level rise may increase to nearly 30 feet. Such severe flooding would cause immense devastation at the terminal.

The port areas most endangered by storm surge are directly adjacent to the river, where the large container cranes are located, and along the storm water drainage basin that bisects the port. One meter of sea level rise would raise the wave level from 6.8 feet to 10.08 feet, making widespread port flooding much more likely even with the lowest category storms. The effect is more pronounced for Category 2 storms, which would increase port flooding from an average of 1.4 feet above ground to 4.68 feet above ground, flooding approximately 94% of the Terminal.

Figure 2.28 shows how sea level rise may increase the percent of the port that is flooded. Storms above Category 2 would flood the entire terminal, and sea level rise will increase the water level and result in more severe damage and longer port closures. To illustrate,

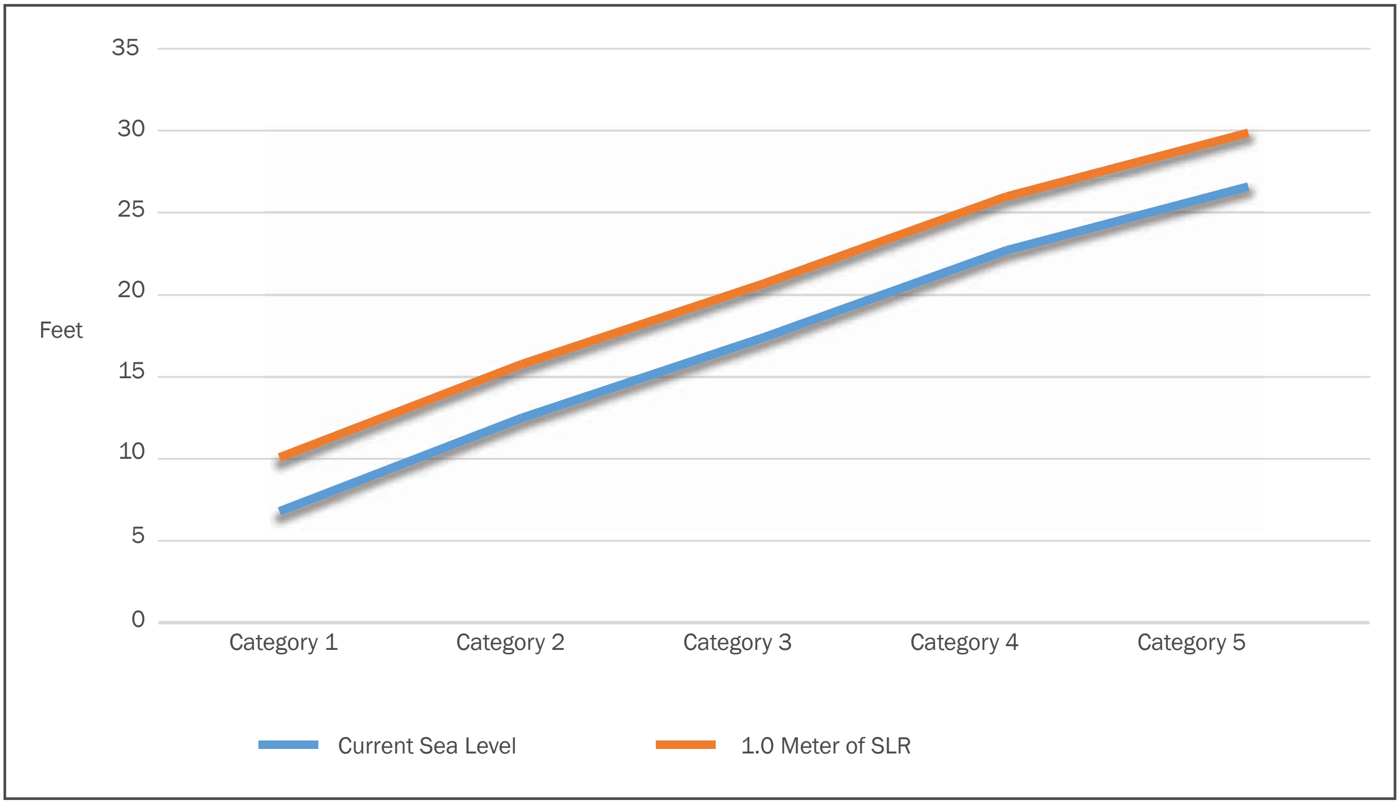


Figure 2.27: Height of Storm Surge Above Sample Ground Level at the Garden City Terminal

a Category 5 storm with sea level rise risks flooding the terminal with 19.2 feet of water, which would cause very significant damage to all infrastructure and equipment at the Garden City Terminal.

The Appendix includes detailed flood height and extent statistics derived from the SLOSH model.

WAREHOUSE DAMAGE IN CHATHAM COUNTY

Chatham County contains 2,147 acres of warehouses owned by a large variety of company types, as shown in Table 2.24. These warehouses have buildings worth $896 million and are built on land worth $167 million. While not all warehouses have direct port-related activity, many — particularly in west Chatham County — receive deliveries from the port, process these deliveries, and ship the final product to customers in the Southeast. Port-related supply chains depend to a large degree on these warehouses functioning. Table 2.24 provides warehouse value and coverage statistics derived from a database provided by the Chatham County Board of Assessors.

Today's Category 1 storms are likely to cause storm surge flooding of part of 8% of the county's warehouse acres, mostly located near the coast and the Savannah River. It is important to note that some of the largest

Total Warehouse Area (acres)	**2,147**
Total Warehouse Building Value	**$896,204,735**
Total Land Value	**$167,121,902**

Table 2.24: Warehouses in Chatham County

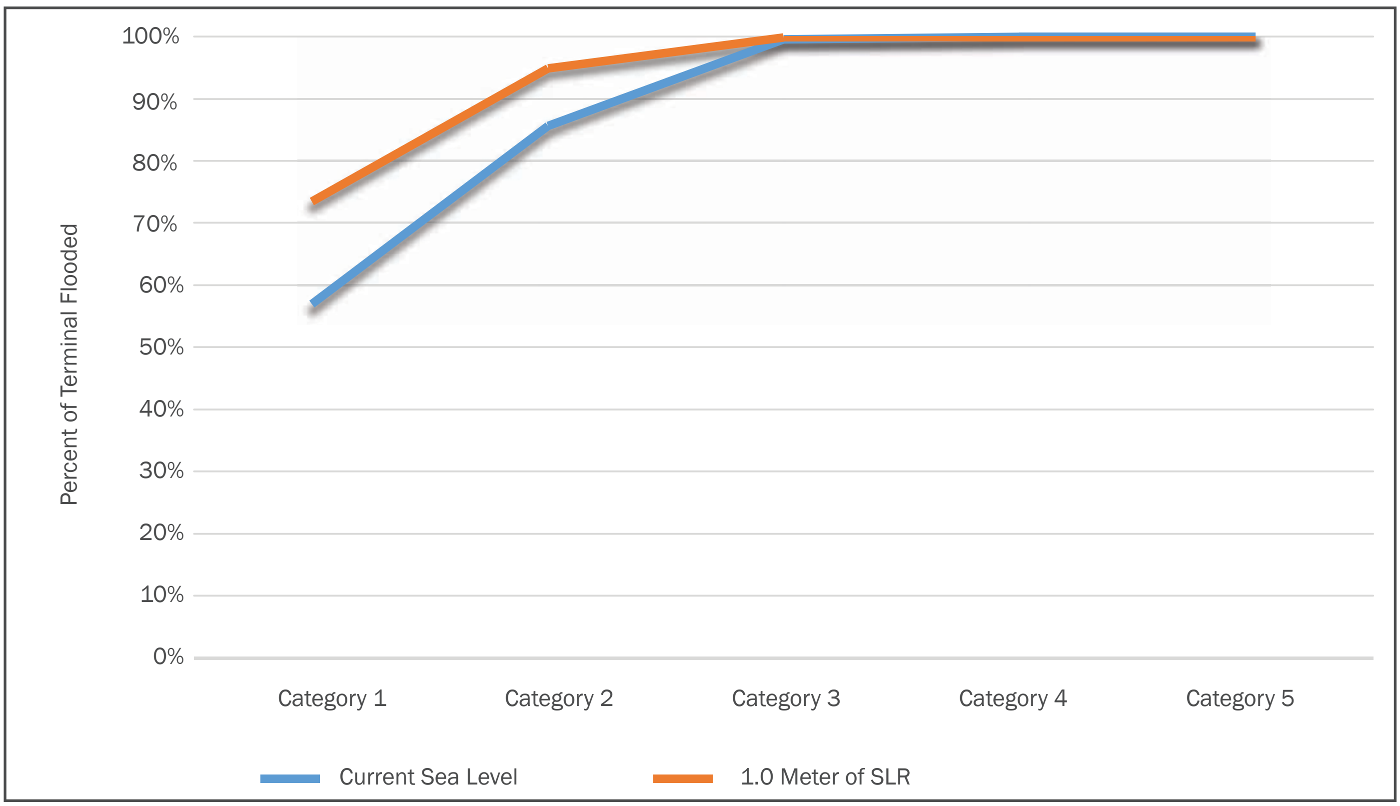


Figure 2.28: Percentage of Garden City Terminal Flooded Due to Storm Surge

warehouses are located in low lands in northern Chatham County within approximately half a mile of the Savannah River with few natural barriers. This includes large warehouses operated by IKEA and Target. Sea level rise is likely to increase the percentage of acreage flooded in a Category 1 storm from 72 acres to 432 acres, or from 8% to 20% of total warehouse acres in Chatham County.

Figure 2.29 and Figure 2.30 below show how sea level rise will increase the warehouse parcels affected by inundation by acres. Sea level rise has the biggest impact for Category 1, 2, and 3 storms. By Categories 4 and 5, nearly 100% of the county's warehouses would be fully are partially inundated by storm surge at current sea levels. Sea level rise will increase storm surge's damage severity for higher category storms even if it does not increase the number of warehouses affected.

Sea level rise is also likely to increase a Category 1 storm surge's effect. This impact would affect buildings worth $112 million to buildings worth $235 million. Figure 2.31 and Figure 2.32 on the following page illustrate the warehouse building value that may be exposed to storm surge a current sea levels and with one meter of sea level rise. The increase is similar to the warehouse acreage exposure. Sea level rise has the biggest effect for increasing the number of buildings exposed to storm surge for categories 1, 2, and 3. Category 4 and 5 hurricanes are likely to flood most warehouses in the county with or without sea level rise, though sea level rise will aggravate the damage. The building stock vulnerable is worth nearly $900 million.

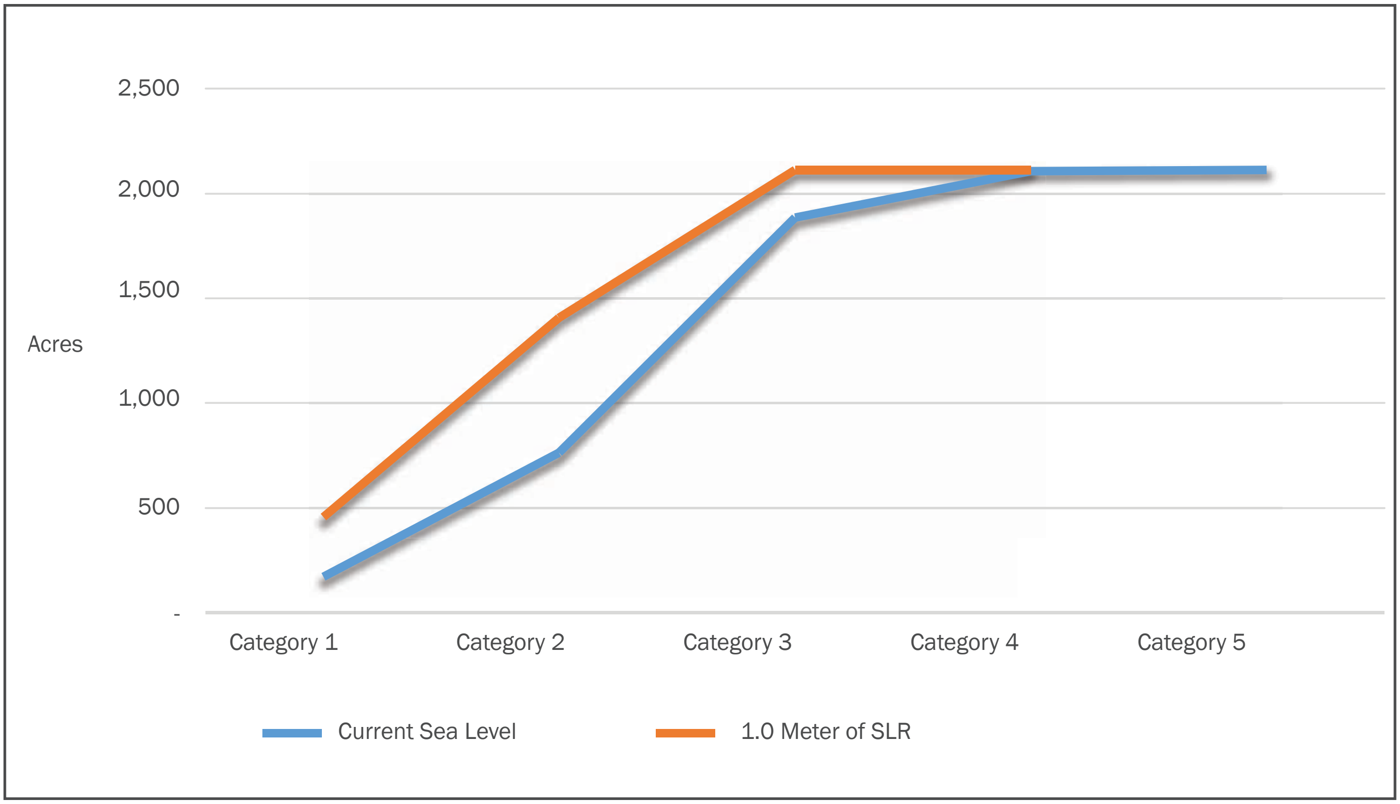


Figure 2.29: Acreage of Warehouses Affected by Storm Surge

Figure 2.33 on page 64 illustrates the maximum storm surge flooding seen at warehouses and the increase caused by one meter of sea level rise. Maximum flooding at warehouses for Category 5 storms with sea level rise may exceed 30 feet above ground.

The Appendix includes detailed tables with warehouse vulnerability by value and acreage.

CONCLUSIONS

Increased vulnerability to storm surge is one of the greatest threats to port-related economic activity posed by sea level rise. It threatens the economy in two regards. First, storm surge will damage the very expensive capital investments made in Chatham County, necessitating reinvestment in rebuilding the physical capital stock instead of other productive investments. Chatham County parcels have buildings assessed at a value of nearly $21 billion, which are potentially vulnerable to storm surge damage. The Garden City Terminal's value is at least $105 million according to the Chatham Board of Tax Assessors. This figure does not even include the 27 container cranes and the eight new cranes valued at approximately $12 million each. Warehouses in Chatham County have buildings worth $896 million, most of which higher category hurricanes with sea level rise will threaten.

Second, storm surge may close the port, dislocate workers, damage highways and railroad tracks, damage port equipment, or flood warehouses, all of which may hinder the Terminal's ability to function at full capacity. A partial port closure, which is common with hurricane strikes, will result in lost productivity and disrupted freight flows with a very real economic cost throughout the coastal region and State of Georgia.

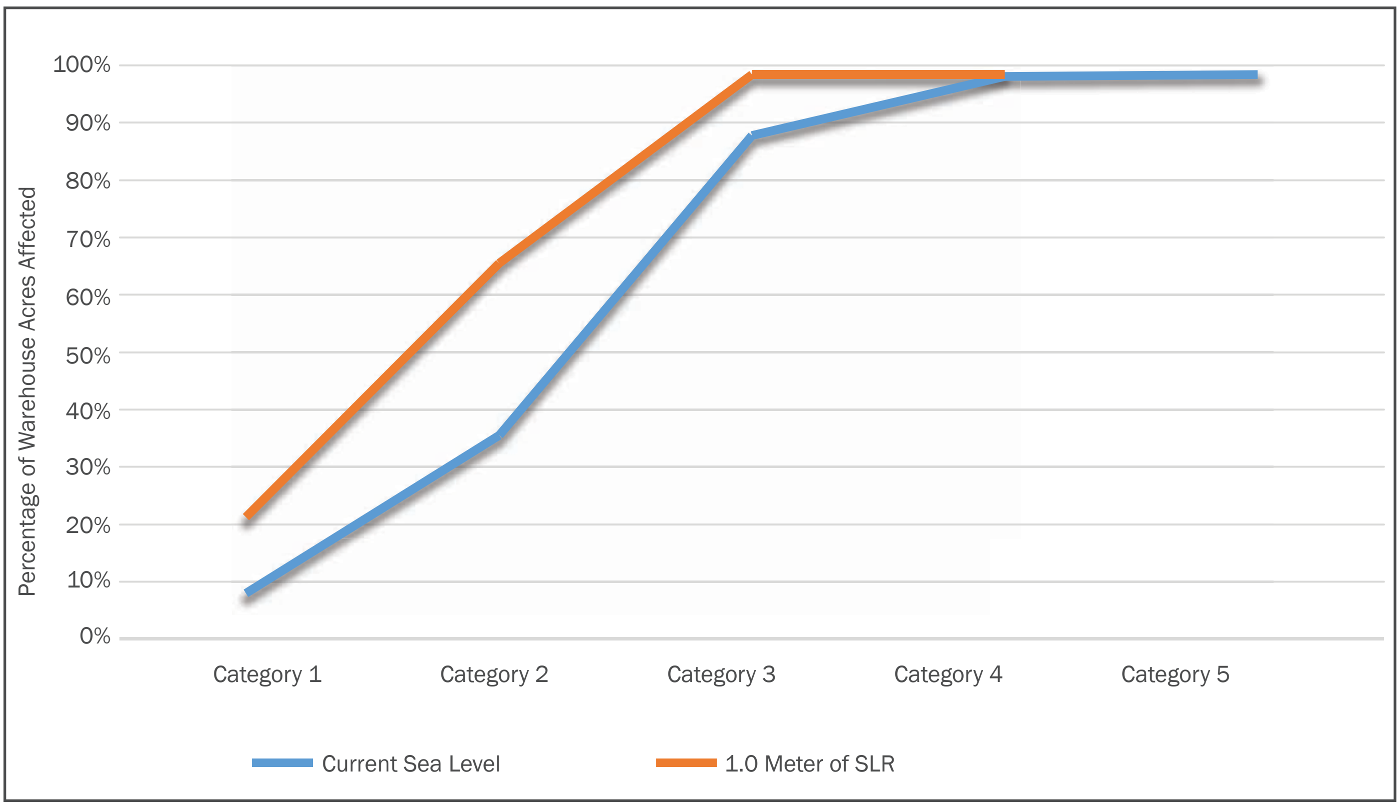


Figure 2.30: Percentage of Warehouse Acres Affected by Storm Surge

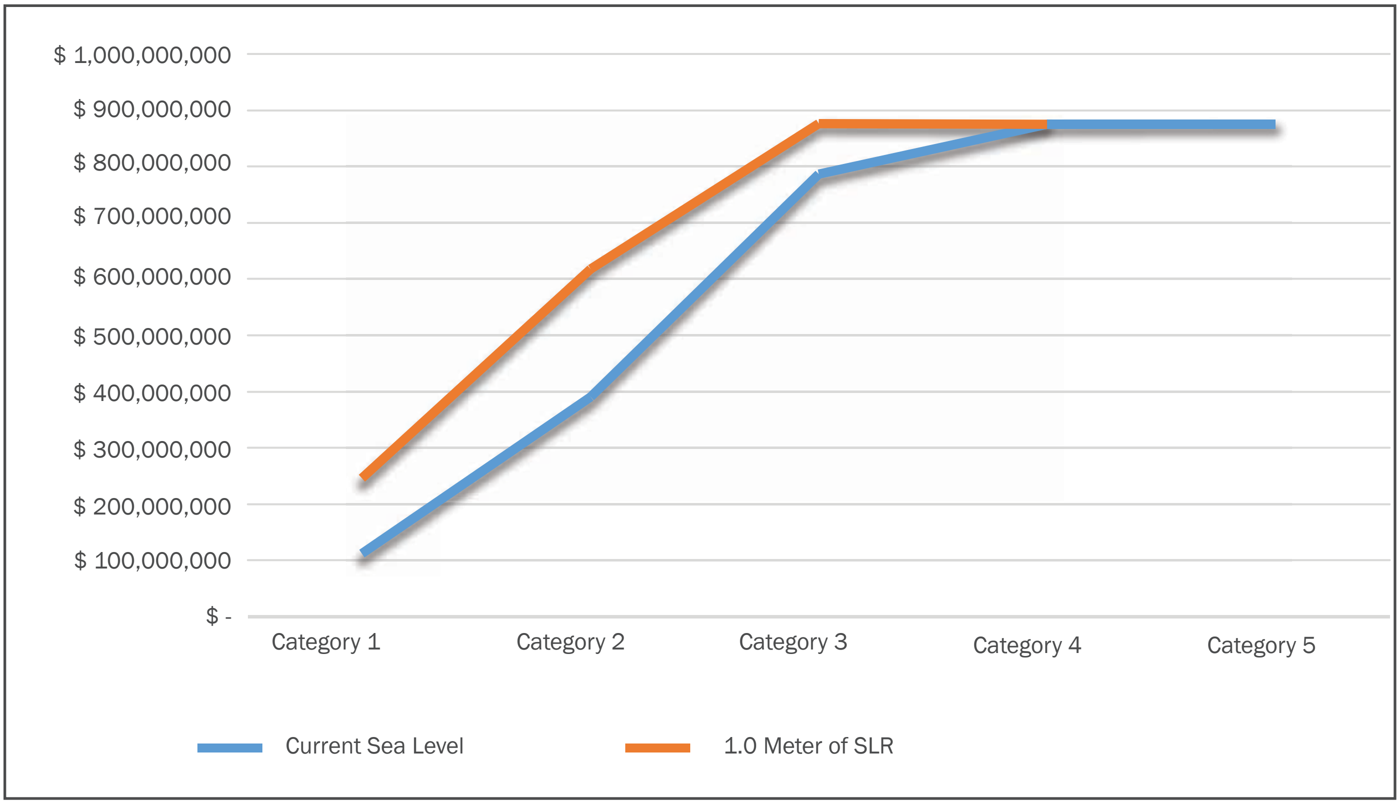


Figure 2.31: Building Value of Warehouses Affected by Storm Surge

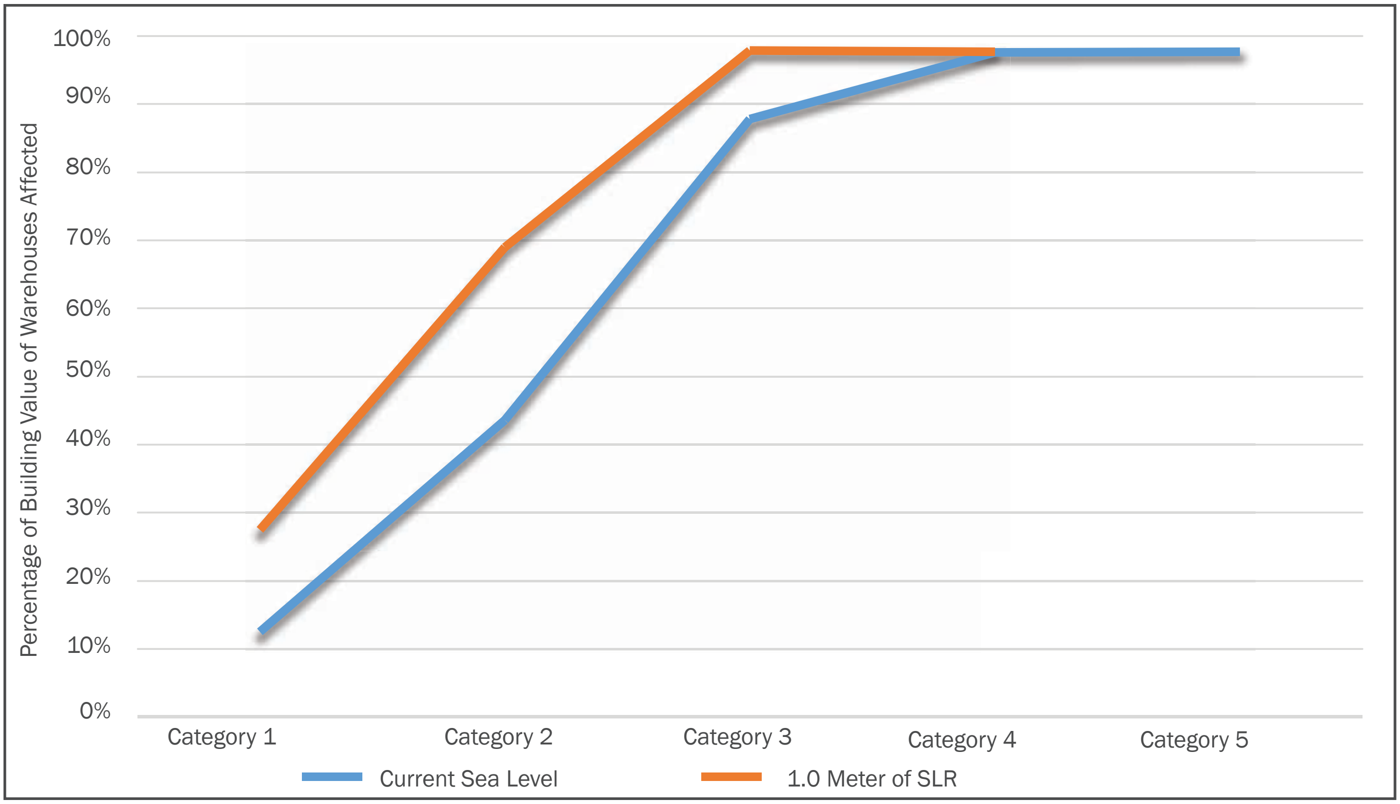


Figure 2.32: Percentage of Building Value of Warehouses Affected by Storm Surge

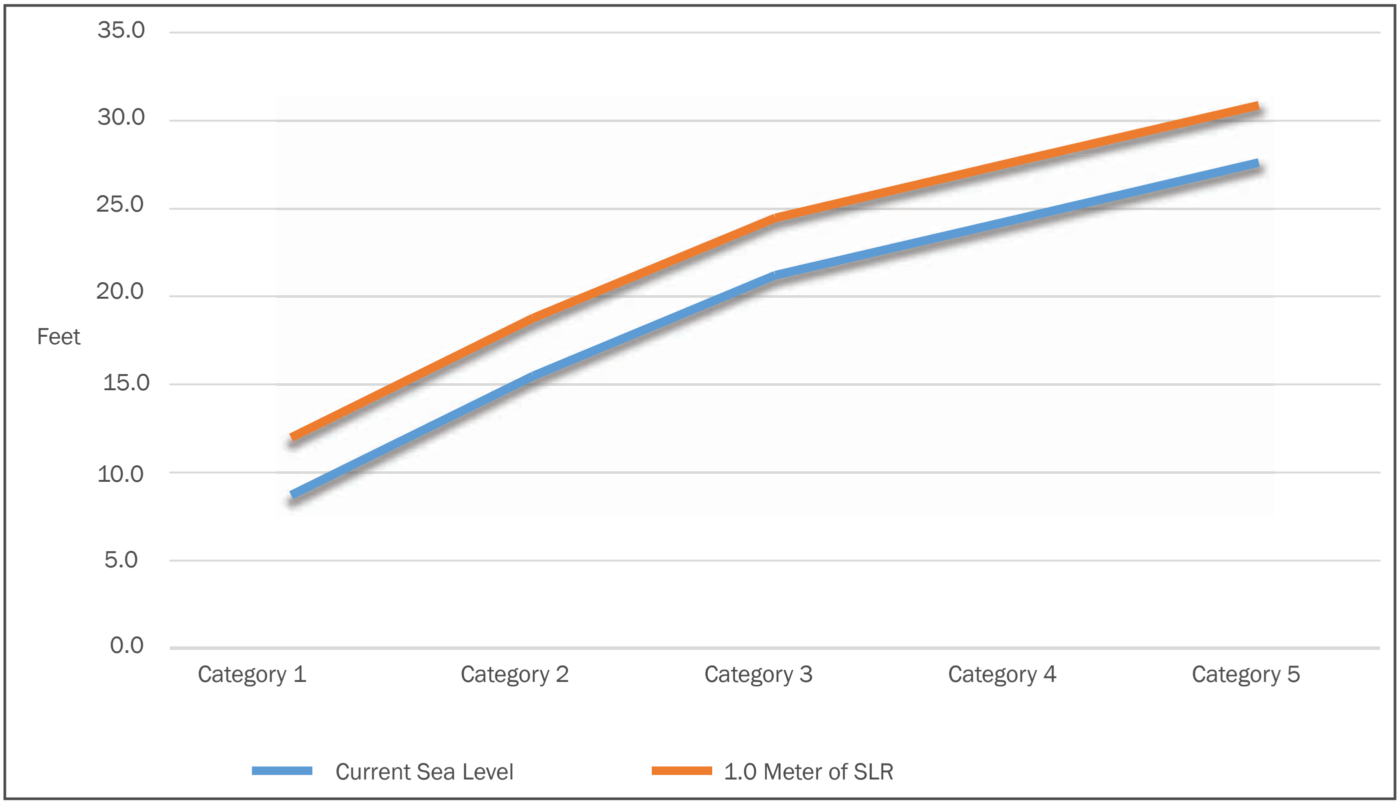


Figure 2.33: Maximum Storm Surge Flooding in Chatham County