SEA LEVEL RISE, GREEN INFRASTRUCTURE AND RESILIENCE ALONG THE EXTANT BRUNSWICK-ALTAMAHA CANAL

by

LISA EMILY BIDDLE

(Under the Direction of Jon Calabria)

ABSTRACT

Recent projections of sea level rise indicate that global mean sea levels could rise up to 2.0 meters (6.6 feet) by the end of this century. Coastal communities need to respond with innovative design strategies to adapt to uncertain changes in water levels and precipitation. This research-design thesis identifies green infrastructure as an adaptable design strategy that could enhance the resilience of coastal communities to adapt to sea level rise and increased flooding risk. This thesis suggests green infrastructure to attain these objectives, yet realizes limitations to its application in coastal protection. Green infrastructure is applied in a site design that specifically addresses sea level rise on the extant Brunswick-Altamaha Canal in Glynn County, GA.

INDEX WORDS: Sea level rise, green infrastructure, Brunswick-Altamaha Canal, Glynn County, adaptation, soft coastal protection, landscape architecture, design

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CHAPTER 1

INTRODUCTION

Sea level rise threatens coastal communities across the United States. According to the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report, sea levels globally are predicted to rise by 0.18-0.59 meters by 2100 (Solomon et al., 2007). However, more recent evidence suggests that those numbers may underestimate the potential for sea level rise. More recent projections show global mean sea levels rising on the magnitude of 2.0 meters by 2100 (NOAA, 2012a; Pilkey & Young, 2009; Rahmstorf, 2012). Sea level rise will have dramatic impacts on coastal communities and ecosystems, including permanent inundation, increased flooding from storm surge, rising water tables, saltwater intrusion, and shifting habitats and ecological systems. Coastal communities must find ways to adapt to these changing coastal conditions through planning and design strategies that are adaptable to uncertainties of the future.

One method of design that is adaptable and resilient is green infrastructure. Initiatives such as the Sustainable Sites Program and the Landscape Architecture Performance Series are building research and case studies that quantify the benefits of green infrastructure through performance based design metrics (Calkins, 2012; Landscape Architecture Foundation, 2013). In the coastal United States, these green infrastructure networks are often called "soft" coastal protection measures because they use natural elements like wetlands to provide critical ecosystem services along urban coastlines. They provide a soft edge along waterfronts that historically have been channelized and armored. In contrast to hard infrastructure solutions, such as sea walls and storm surge barriers, green infrastructure is a coastal adaptation method that might provide other benefits in addition to protection. These additional benefits may include ecological and community resilience (Benedict & McMahon, 2006; Gill, Handley, Ennos, & Nolan, 2009; Odefey et al., 2012; Watson & Adams, 2010).

However, there are limitations to the use of green infrastructure solutions as a coastal protection measure, especially in coastal areas with critical infrastructure and high-density human settlements that need protection at all costs. The IPCC has defined a spectrum of adaptation solutions for coastal management due to climate change, including protection from rising waters and storm surge, accommodation to a new normal, and retreat from coastal areas (IPCC Working Group III, 1990). Green infrastructure is one of an array of coastal adaptation measures that fall under these three categories. This thesis will discuss all three adaptation methods, but will focus on green infrastructure as a "soft" protection technique.

Like all coastal regions, coastal Georgia is vulnerable to sea level rise. While some coastal communities are initiating the adaptation planning process, the majority of coastal Georgia still lacks an adaptation plan (NOAA Coastal Services Center, 2012). Sea level rise threatens all of coastal Georgia, not just real estate along beaches and barrier islands. The effects of sea level rise will be felt along inland lagoons, tidal creeks, and rivers that connect to the sea. In coastal Georgia these intertidal zones are significant due to the large estuaries and marsh systems along the Atlantic Coast.

One specific tidal coastal waterway is the subject of the design portion of this thesis. Yellow Bluff Creek, located in Glynn County, GA is an impaired tidal creek along the Turtle River that is vulnerable to sea level rise. It connects to the historic Brunswick-Altamaha Canal, a 12-mile transportation canal built in the 1850s that has been unused for the past 150 years. The canal is a significant historic feature in the cultural landscape of Glynn County, although presently degraded and underutilized. The canal currently operates as a de facto stormwater drainage system for urban runoff in Glynn County and is hydrologically impaired (Brunswick-Glynn County Joint Planning Commission, 1981). Preliminary plans by Glynn County have identified the potential for reutilization of the canal into a recreational greenway and blueway trail. As the planning stages of the canal are still underway, there is an opportunity to address sea level rise projections in the reutilization planning and design. The reutilization of the Brunswick-Altamaha Canal could become a case study in the state of Georgia for how communities can plan to adapt to sea level rise. Recognizing this potential, this research-design thesis investigates the impacts of sea level rise both on the 12-mile canal corridor and a specific site along the corridor. Using information from the inventory, a design is proposed for a public park and trailhead along the canal.

Research Objectives

This thesis asks the following research question: What is the potential role of site-scale green infrastructure in adapting coastal communities to sea level rise and flooding? Sub-questions include: What are the benefits and limitations to using green infrastructure for coastal sea level rise adaptation? What are the unique impacts and sea level rise projections specific to the Georgia coast? What are precedent examples of designs, either conceptual or built, that use green infrastructure for climate change adaptation? The design application portion of this thesis synthesizes the findings to these sub-questions and strives to provide one example of how a green infrastructure approach might by utilized at the site-scale in coastal Georgia to adapt to an uncertain future.

The purpose of this research is to further understanding of the uses of green infrastructure as a coastal adaptation tool that specifically addresses sea level rise and flooding. While focused on the benefits of a green infrastructure approach, this thesis also illustrates limitations to a green infrastructure approach and provides areas for further research. It explores how and where green infrastructure might best fit into an array of planning and design tools to mitigate and adapt to climate change. In the site inventory, this thesis synthesizes an array of scientific projections and illustrates ways that designers can incorporate publically accessible data and interactive maps of coastal hazards and sea level rise into the design process. Through the design application, this thesis provides one example of what abstract concepts such as “sustainability,” “resilience,” and “adaptation” might look like at the site-scale and through time.

Methodology and Thesis Structure

The methodology of this thesis combines literature reviews, precedent studies, multi-scale inventory and analysis, and a design application. This thesis combines literature reviews on sea level rise projections, anticipated impacts on coastal regions, coastal adaptation strategies, and green infrastructure. Precedent design studies that specifically address sea level rise and green infrastructure are chosen to inform the design application. The design application works at two scales. The first is the regional scale of the Brunswick-Altamaha Canal. Direct observation of the canal corridor during two site visits, secondary descriptions, and online sea level rise map viewers are used to inventory the canal corridor and predict the impacts of sea level rise on the water level and vegetation of the corridor. After defining possible changes to the canal corridor and analyzing its vulnerabilities to sea level rise, the thesis moves further down in scale to the level of a 21 acre site. For the design application, the thesis uses online map viewers and GIS tools to inventory and analyze the impacts of sea level rise on the site. It then synthesizes the findings of the literature review, the regional inventory and analysis, and the site inventory and analysis to propose a site design.

The thesis is organized into six chapters. Figure 1 provides a graphic representation of the thesis structure. Chapter 2 reviews the scientific and coastal hazards literature to understand climate change projections, specifically sea level rise and storm events, and then reviews the impacts associated with these changes. This chapter also reviews the coastal management literature to extrapolate adaptation approaches that are used in coastal adaptation planning and design.

Chapter 3 focuses on green infrastructure, its definition, and similarities to “soft” coastal protection measures. It discusses the associated benefits and limitations of using green infrastructure specifically in coastal environments for sea level rise adaptation. Chapter 3 also provides precedent design examples from competitions, exhibitions, artistic works, and built landscapes that specifically address the needs of sea level rise and flooding that are site-specific.

Chapter 4 introduces the larger context of the Brunswick-Altamaha Canal, including its history, present condition, and future visions for reutilizing the corridor as a greenway and blueway. An inventory of the impacts of sea level rise on the entire 12-mile canal corridor is presented using screen shots from online, interactive mapping viewers developed by NOAA and the University of Georgia’s Skidaway Institute of Oceanography. The feasibility of the canal reutilization in light of sea level rise is discussed.

Chapter 5 then introduces a site-specific design application for a proposed trailhead park along the canal corridor. The design will analyze the impact of various sea level rise scenarios on the chosen site and include a site design that incorporates green infrastructure as the primary method to build adaptable frameworks to sea level rise. It provides an opportunity to test a small-scale, site-specific design strategy in the context of sea level rise and evaluates the use of green infrastructure as an adaptation technique.

Lastly, Chapter 6 provides a conclusion to the thesis and offers potential for further research explorations on the topic.

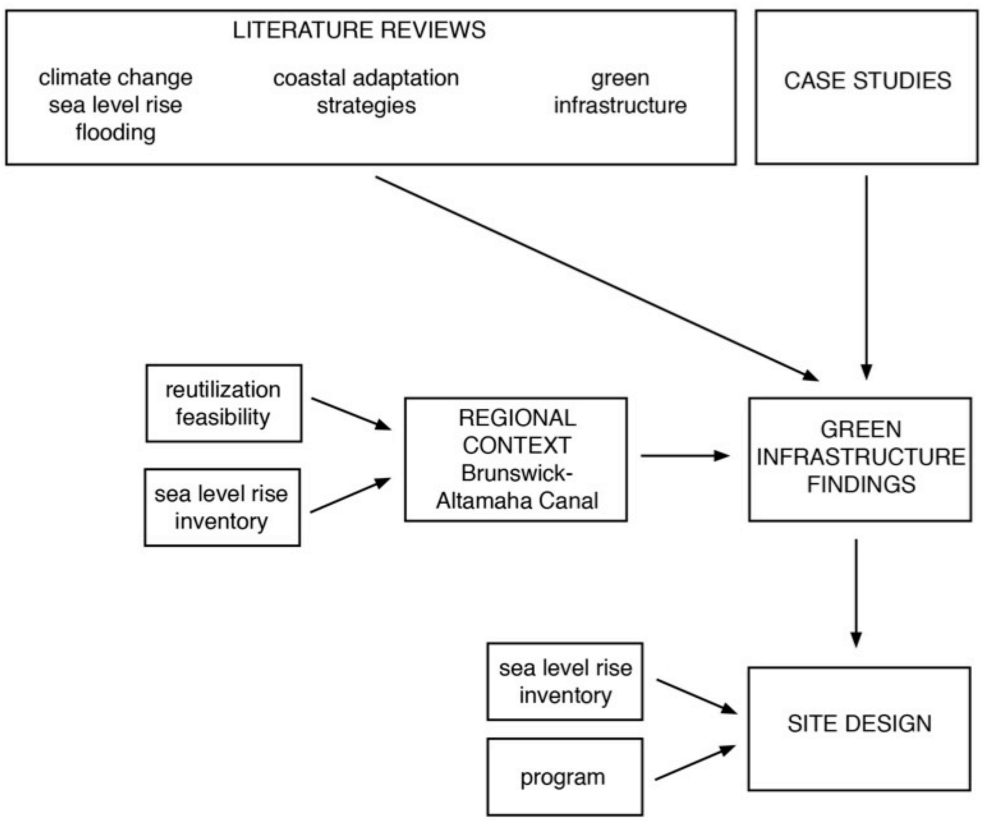


Figure 1: Thesis Structure Diagram

CHAPTER 2

SEA LEVEL RISE PROJECTIONS AND COASTAL ADAPTATION STRATEGIES

Accelerated sea level rise due to climate change is a global threat, but its impacts will be experienced at the local level. The U.S. Global Change Research Program states that an increase in sea level rise and likelihood of increased hurricane intensity and resulting storm surge are likely to, "be among the most costly consequences of climate change for this [the Southeast U.S.] region" (2009, p. 114). Recent projections for sea level rise predict between a 0.2-meter and 2.0 meter rise in mean global sea level by the end of this century (NOAA, 2012a). The impacts of this amount of water rise will be significant and threaten cities, towns, communities, and entire coastal regions.

This chapter reviews the scientific literature and synthesizes global sea level rise projections and impacts, then narrows in scope to focus on Georgia. Characteristics of the Georgia coast make it unique in planning and adapting to sea level rise, including the vast acreage of salt marshes and potential hurricane threats. Coastal management literature suggests methods that coastal communities might consider to adapt to coastal hazards using varying strategies such as accommodation, protection, and retreat. These scientific findings and adaptation strategies gleaned from this chapter will provide grounding as subsequent chapters move toward a site design that incorporates rising sea levels into the design process.

<u>Global Sea Level Rise Projections</u>

Global sea level rise is caused by two principal factors, thermal expansion of water due to ocean warming and melting of land-based ice (glaciers), both of which are influenced by climate change (NOAA, 2012a; Solomon et al., 2007).

The Intergovernmental Panel on Climate Change (IPCC) is a scientific intergovernmental research body established by the United Nations, and is responsible for global projections of climate change. In the most recent report, the IPCC estimated that global average sea levels are projected to rise by 0.18-0.59 meters by 2100 (Solomon et al., 2007). However, there is growing scientific agreement that the projections from this IPCC report may have seriously underestimated sea level rise (NOAA, 2012a; Rahmstorf, 2012; Watson & Adams, 2010; Weiss, Overpeck, & Strauss, 2011). There are several reasons for this. First, the 2007 projections are over five years old at the time of this thesis writing. During these five years, global greenhouse gas emissions have been at the higher-end of the spectrum of scenarios modeled by the IPCC in 2007. This means we are more likely to experience the higher-end rates and magnitude of global sea level rise (NOAA, 2012a; Rahmstorf, 2012). Second, the IPCC's 2007 projections did not account for the melting of the Greenland and West Antarctic ice sheets, which contribute to a rise of water levels (Solomon et al., 2007). More recent reports that account for observed greenhouse gas emissions trajectories and current ice sheet melting trends indicate that the 2007 IPCC recommendations are likely to be exceeded in the next century.

A more recent peer-reviewed sea level rise study is a 2012 U.S. interagency publication produced for the U.S. National Climate Assessment. This interagency task force is charged with advising the federal government with projections for climate change, including sea level rise. The report surveys several recent studies and comes up with the result with "very high confidence" (greater than 9 in 10 chance) that global mean sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100 (NOAA, 2012a). A chart of the scenarios, from lowest to highest, with two intermediate scenarios is provided in Figure 2.

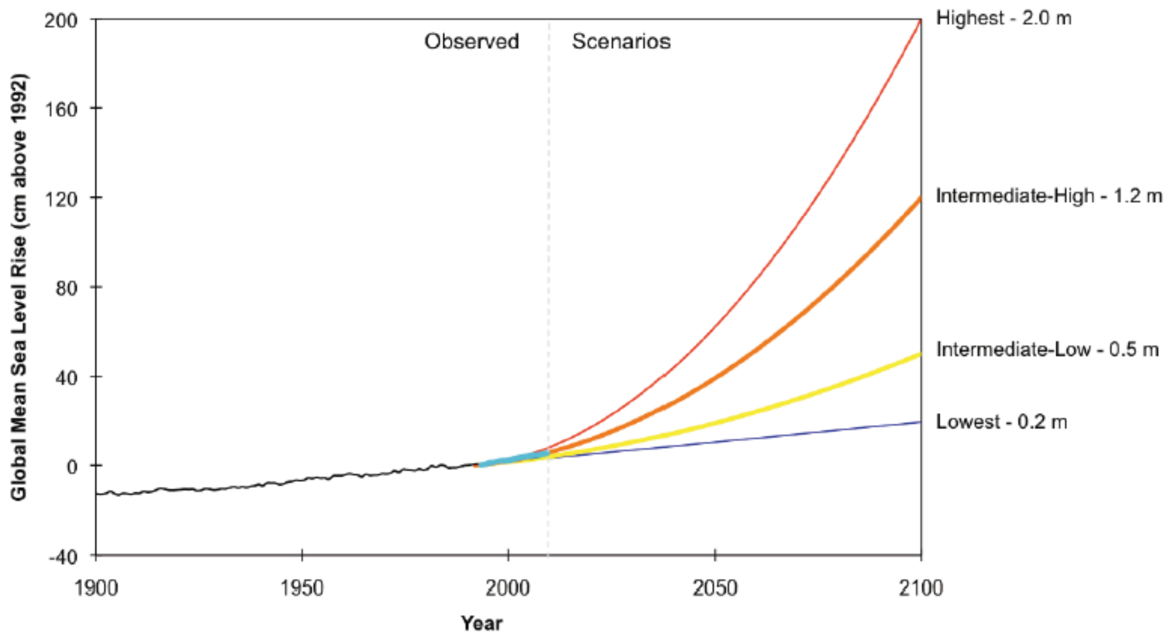


Figure 2: Sea level rise scenarios produced for the U.S. National Climate Assessment Report. The graph shows four alternative future scenarios that range from a 0.2 m to 2.0 m global mean sea level rise by 2100 (NOAA, 2012a).

Sea level rise will continue to trend upward in the coming centuries as well. The IPCC projects that even if greenhouse gas emissions were stabilized within 100 years, seas would still continue to rise for centuries due to climate processes and feedbacks (Solomon et al., 2007). This fact means that even if the lower-end projections prove true, coastal communities could still face threats at higher levels in coming centuries. It also means that even with aggressive mitigation, adaptation is likely the only strategy that will allow for some form of coastal use in the future. If decision-makers follow the precautionary principle, then a 2-meter rise in sea level by 2100 should be the benchmark for adaptation planning (NOAA, 2012a; Pilkey & Young, 2009). Cities along coastal edges must consider adaptation planning now in order to be prepared once sea level rise accelerates and becomes a real, tangible threat.

Storm Events

Compounding sea level rise threats are projections that climate change will bring more frequent, intense storms (NOAA, 2012a; Solomon et al., 2007; U.S. Global Change Research Program, 2009). These changes will impact coastal regions. Storms are forecasted to bring more intense bursts of rainfall and higher peaks in stormwater runoff, causing flooding, erosion, and damage to rivers and stormwater control structures. Coastal cities will also experience higher storm surges and wind speeds during tropical storms and hurricanes that can overtop and damage coastal infrastructure (Watson & Adams, 2010). However, some analyses indicate that while the frequency of large storms will increase, small storm events might remain unchanged (Hirschman, Caraco, & Drescher, 2011). These uncertainties in the amount and duration of precipitation will impact the ability of stormwater control structures to meet water quality and quantity standards.

While the complexity of storm system predictions remains uncertain, there is some evidence to suggest that the "new normal" in terms of rain events may be very different than what we experience today, especially in coastal Georgia. Two studies using NOAA's tidal gauge data, collected daily over decades, suggests very alarming trends for increased flooding in coastal Georgia.

Tebaldi (2012) conducted a nationwide study of tidal gauge data to develop sea level rise projections at 55 NOAA gauges nationwide (Tebaldi, Strauss, & Zervas, 2012). They combined these projections with historic patterns of extreme high water events to understand the impact of sea level rise on local extreme high water events. They find the most significant increase in the frequency of current “extreme” water events in areas where the difference in height between presently common and rare water levels is small. Georgia is one of these areas where they anticipate the greatest increase in storm return frequency of extreme high water events. They suggest coastal Georgia’s 100-year storm could occur as often as every year (Tebaldi et al., 2012).

Data available online through NOAA’s Coastal Services Center Sea Level Rise Impact Viewer supports Tebaldi. The web viewer provides a chart that estimates that the occurrence of coastal flooding events and coastal flooding duration will increase significantly under a 0.5m and a 1m sea level rise scenario (Figure 3) (NOAA Coastal Services Center, 2013). In Figure 3 the number of coastal flooding events per year rises from only a few events occurring per year currently, to over 150 events per year with 0.5m sea level rise, to over 600 events per year with a 1m sea level rise.

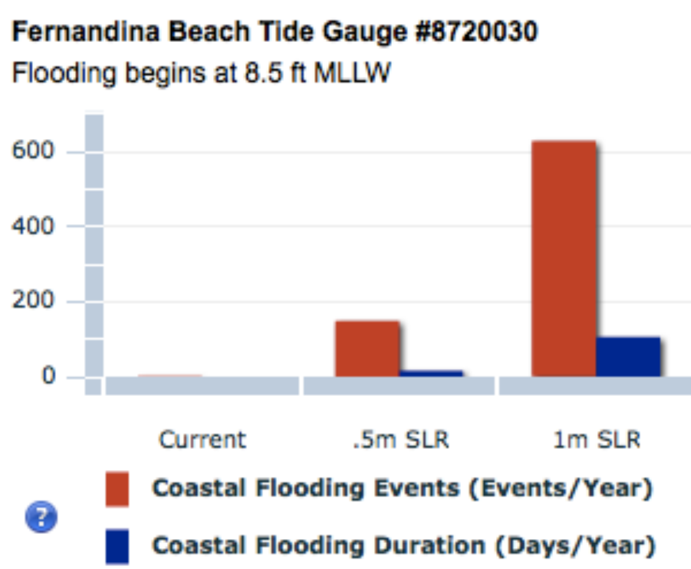


Figure 3: Impacts of a 0.5m or 1.0m sea level rise on coastal flood frequency and coastal flood duration at the NOAA Tide Gauge at Fernandina Beach, FL. Graph shows increases to the frequency of coastal flooding events per year and longer flooding duration (NOAA Coastal Services Center, 2013).

Impacts of Sea Level Rise and Storm Events

Sea level rise and changes in storm events are predicted to impact the built and natural environments of the coast in significant ways. Some impacts of a rising sea level are permanent inundation, more frequent temporary flooding, higher storm surges, erosion, and intrusion of salt water. When coupled with the prediction that climate change will bring more intense and frequent storms and thus high winds and storm surges, damage to coastal communities will only increase. Table 1 summarizes the impacts of sea level rise and flooding on the physical and socioeconomic systems.

Table 1: Sea Level Rise Impacts. The impacts of sea level rise and more frequent storm events, and their potential effects on society and environment (SF BCDC and NOAA CSC, 2012).

Climate Change Prediction	Impacts associated with change	Potential effects on society and built and natural environments
Sea level rise	• Higher high tides cause temporary and permanent inundation • Increased shoreline erosion • Saltwater intrusion	• More frequent temporary flooding and permanent inundation of low lying land • Flooding of critical infrastructure • Loss of transportation accessibility during inundation events • Increased number of people at risk for flooding and hurricane hazards • Loss of economic industries, especially natural resource-based, such as agriculture, fisheries, forestry • Mobilization of contaminants at flooded sites • Increased shoreline erosion • Habitat and vegetation migration • Salinity damage to built structures and infrastructure, both above and below ground • Increased salinity of estuaries and aquifers contaminates drinking water sources
More frequent storms and increased intensity	• More frequent flooding events • Longer flooding duration	• Coastline erosion • Damage to built infrastructure during high wind and storm events • Damage to homes, buildings, and development • Overwhelmed coastal stormwater infrastructure • More injuries and loss of life • More repeat-loss claims and higher insurance rates due to greater flood risk

Sea level rise and more frequent storm events will cause coastal flooding to reach further inland and to occur more often. Historically rare floods could become routine, with implications for FEMA floodplain mapping, insurance policies, and the design of stormwater control structures and coastal protection measures (Hirschman et al., 2011). Storm surge, an abnormal rise of water generated by a storm over and above the predicted astronomical tide, will also affect coastal communities (Watson & Adams, 2010). Storm surge heights will increase as base heights of mean high water increase due to sea level rise. This will cause more overtopping of protective barriers during storm events and higher levels of inundation along inland waterways.

In low-lying coastal areas that are currently dry, permanent inundation may occur as higher daily tides reach farther inland. In developed areas, this could lead to permanent inundation of critical infrastructure such as highways, bridges, airports, ports, water and wastewater treatment facilities, and other structures deemed critical by local governments (Grannis, 2011). In developed regions without critical infrastructure, such as residential areas, permanent or more frequent temporary inundation will cause significant damage to structures and properties, not to mention the emotional and financial burden placed on owners of these houses.

Inundation in natural areas will cause inland migration of intertidal and upland natural environments, such as marshes, tidal flats, and dunes (Craft et al., 2009). While these habitats are naturally equipped to deal with change and disturbance, without adequate space for these features to migrate these environments could be fractured or lost all together. Hard coastal defenses such as sea walls or levees prevent the habitat from migrating, leading to devastating loss of species and habitat as well as loss of vital ecosystem services such as storm surge buffering, nutrient cycling, and water quality provided by these habitats (Craft et al., 2009).

In addition to inundation, sea level rise will also cause saltwater intrusion into coastal groundwater and aquifers (FitzGerald, Fenster, Argow, & Buynevich, 2008). Another significant impact along shorelines will be wave erosion causing changes to shorelines and barrier islands (FitzGerald et al., 2008).

Sea Level Rise on the Georgia Coast

While global sea level rise projections are important to understand larger climatic trends, local measurements and projections are needed for realistic local planning and design efforts (NOAA, 2012b; Rahmstorf, 2012). Local, or relative, sea level rise uses global sea level rise projections and adjusts them considering a variety of local factors such as topography, geology, vertical land motion (subsidence or uplift), weather, and ocean circulation patterns (NOAA, 2012b; Rahmstorf, 2012). Every city and region will experience sea level rise differently, and the state of Georgia is no exception.

The Southeast United States has some of the most vulnerable lands to sea level rise, due to their low-lying nature and frequent occurrence of hurricanes and tropical storms (Weiss et al., 2011). While not as low-lying as its coastal neighbors of Florida and North Carolina, Georgia is still vulnerable to sea level rise and is home to millions of people and vacationers each year.

Georgia-specific sea level rise trends indicate that sea levels in Georgia are generally accelerating in line or slightly below the global average of 3.1mm/year cited by the IPCC AR4 2007 report. The two tidal gauging stations closest to Georgia are the Fort Pulaski station near Savannah, GA and the Fernandina Beach, FL station, near the Florida/Georgia border. At Fort Pulaski, GA current sea level rise trends indicate a 2.98 mm/year rise, while data from Fernandina Beach, FL indicates a slightly lower than average sea level rise, a 2.02 mm/year rise in sea levels from 1890 to present (NOAA, 2012c). Figure 4 compares the two stations, and illustrates the upward trend of the charts, showing that sea level rise is already a real and quantifiable threat.

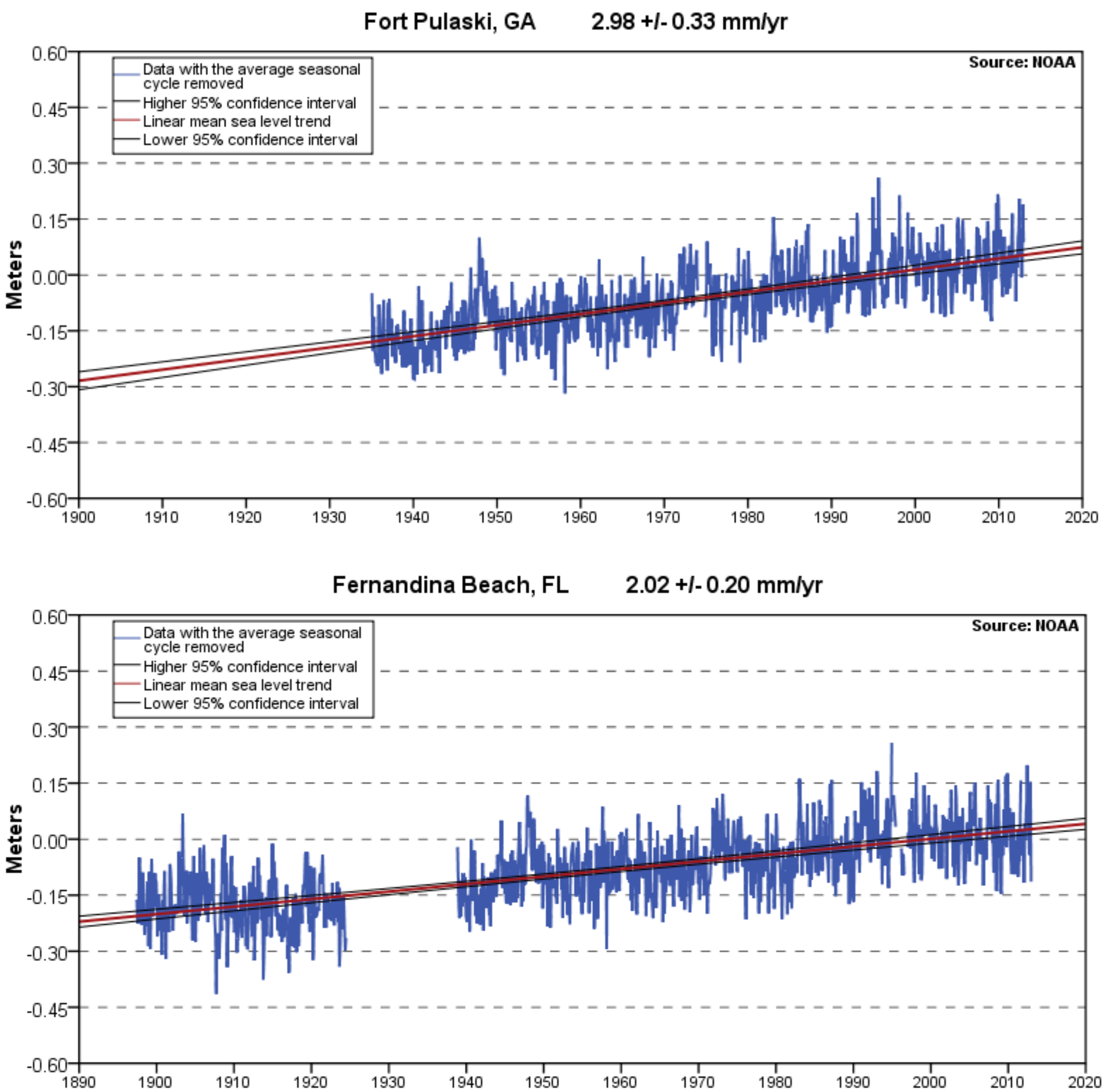


Figure 4: Sea level rise trends based on tidal gauge data. The two closest locations to Georgia are shown, Fort Pulaski, GA and Fernandina Beach, FL (NOAA, 2012c).

While no comprehensive study of sea level rise projections and impacts specific to the state of Georgia has been conducted, there are a few national studies that can provide some insight into Georgia-specific trends. Tebaldi (2012) looked at tidal gauge data from 1959-2008 and projected sea level rise to 2050. For Fort Pulaski and Fernandina Beach they calculated estimates of 0.15m and 0.13m, respectively, by 2030 and 0.34m and 0.30m, respectively, by 2050 (Tebaldi et al., 2012). The non-profit organization, Climate Central, has also provided state-by-state predictions for sea level rise. These predictions are not peer-reviewed scientific findings, but do provide some level of local projections to supplement global trends. Climate Central projects that sea level rise in Georgia will be between 5" and 24" (0.13 and 0.61 meters) by 2050, citing a 90% confidence range in their methods (Climate Central, 2012a). While these predictions are helpful, more robust and localized scientific studies should be undertaken to inform climate adaptation planning specifically for the Georgia coast.

There are some unique physical and hydrologic characteristics of the Georgia coast that affect its vulnerability to sea level rise and increased storms. These characteristics offer local challenges and opportunities to sea level rise adaptation.

The Georgia coast is often described as more sheltered from hurricanes than the other southeastern Atlantic states due to its bathymetry and coastal hydrography. The coast of Georgia sits along the South Atlantic Bight, a wide, flat continental shelf that curves from Florida to North Carolina (Figure 5). Sitting at the westernmost apex of the bight, Georgia's coast is relatively sheltered from frequent hurricane landfall, although far from "hurricane proof". Between 1851 and 2004, a total of 20 hurricanes hit Georgia (Figure 5) (Southern Environmental Law Center, 2007).

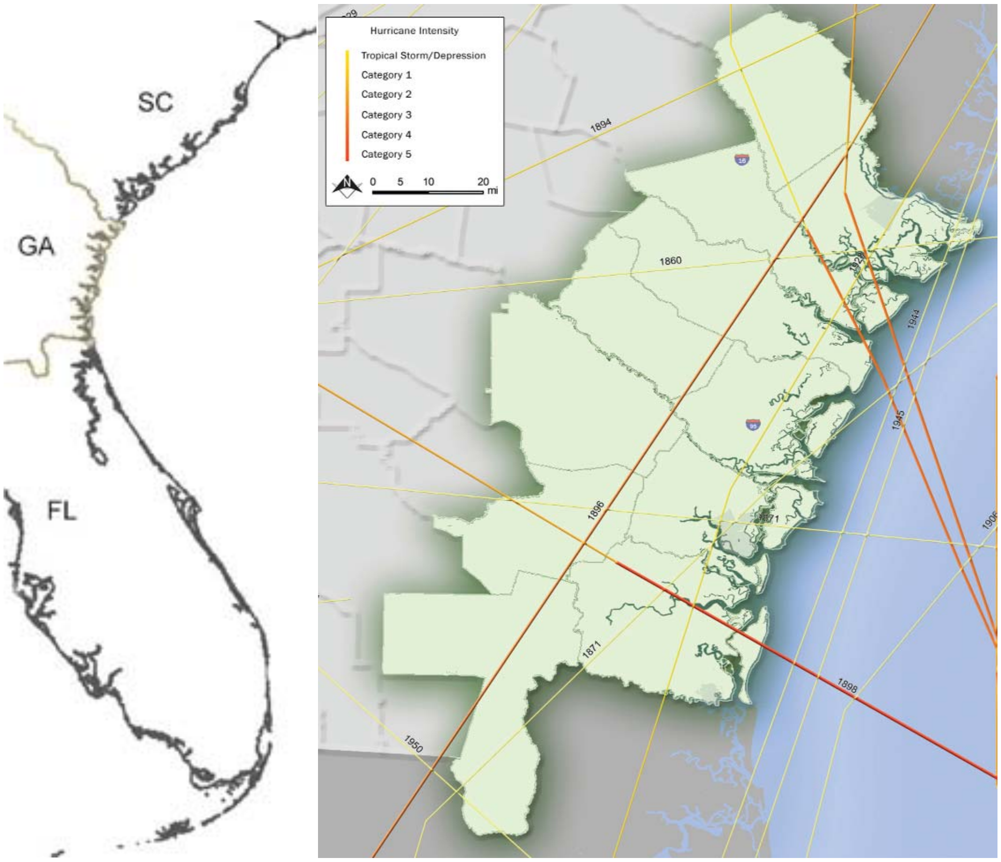


Figure 5: The shape of Georgia's coastline (left) and hurricane tracks along the Georgia Coast from 1851-2004 (right) (Southern Environmental Law Center, 2007).

The location of the Georgia coastline also allows Georgia to experience some of the widest tidal fluctuations on the Atlantic coast (Seabrook, 2012). Combine these tidal waters with the vast river systems such as the Altamaha River, and an exceptionally large volume of water is exchanged tidally each day. For nearly every acre of wetland, 1.3 trillion gallons of water is exchanged in each tidal cycle (Seabrook, 2012). The wide estuary networks that are formed create some of the most highly productive ecosystems in the nation, the Southeastern Atlantic salt and freshwater marshes, and Georgia has about one third of them (Seabrook, 2012). These marshes provide valuable ecosystem services and buffering capacity, protecting the Georgia coast from wave and wind action.

While the location of Georgia along the coastline and its vast marshes may shelter it from direct hurricane hits, those factors actually make the coast more vulnerable to higher storm surge should a hurricane strike (Southern Environmental Law Center, 2007; Tebaldi et al., 2012). The funnel-like shape of the Georgia coast, tucked between Florida and South Carolina, acts to focus and increase tidal energy during storm events, while the wide, shallow waters of the continental shelf provide a long distance for energy to increase. The low elevations along the large tidal estuaries place thousands of acres of coastal land in vulnerable low-lying areas. These estuary systems stretch inland for miles, creating a path for both rising seas and storm surge to reach far inland. Storm surge inundation maps, such as the Glynn County map in Figure 6, illustrate the area of inundation that occurs during a large storm event. This map shows that even a Category 1 Hurricane (Category 5 is the highest) reaches about 12 miles inland from the coast in Glynn County, GA. Higher storm surges from a Category 5 storm leave almost the entire county under water.

These maps also illustrate the point that oceanfront property will not be the only areas damaged by sea level rise or hurricanes; the land connected to the sea by creeks, inlets, and nearby low-lying areas will be damaged as well. In Georgia, this amount of connected land is significant. Should sea levels rise further, and the possibility of intense storms and hurricanes increase, Georgia will find that it will need to consider new management strategies not only along shorelines but also along entire coastal and tidal regions.

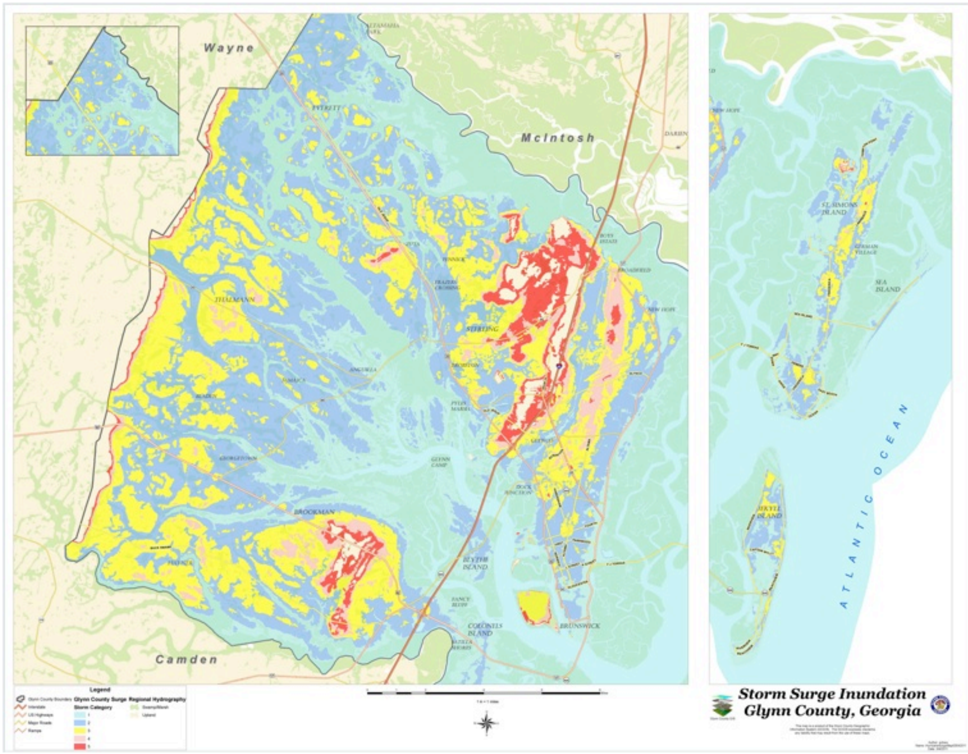


Figure 6: Storm surge inundation map for Glynn County, GA. Much of Glynn County will be inundated by a Category 1 storm (light blue) and almost the entire county is inundated in a Category 5 storm (red) (Glynn County GIS Department, 2013).

Adaptation Approaches to Sea Level Rise

In light of these projections of sea level rise and its impacts, it is critical that coastal areas prepare to adapt to a "new normal" of higher sea levels, higher tides, and increased flooding. There are several strategies for how coastal areas can adapt. The most widely used categorization of strategies is outlined in the IPCC First Assessment Report by the Coastal Zone Management Subgroup (Linham & Nicholls, 2010). The report outlines three broad adaptive response strategies: protection, accommodation, and retreat (Figure 7) (IPCC Working Group III, 1990). While the later chapters of this thesis consider protection strategies, in particular "soft" strategies more in depth, it is important to make the distinction between all three approaches and recognize the value and necessity of each for coastal adaptation to sea level rise.

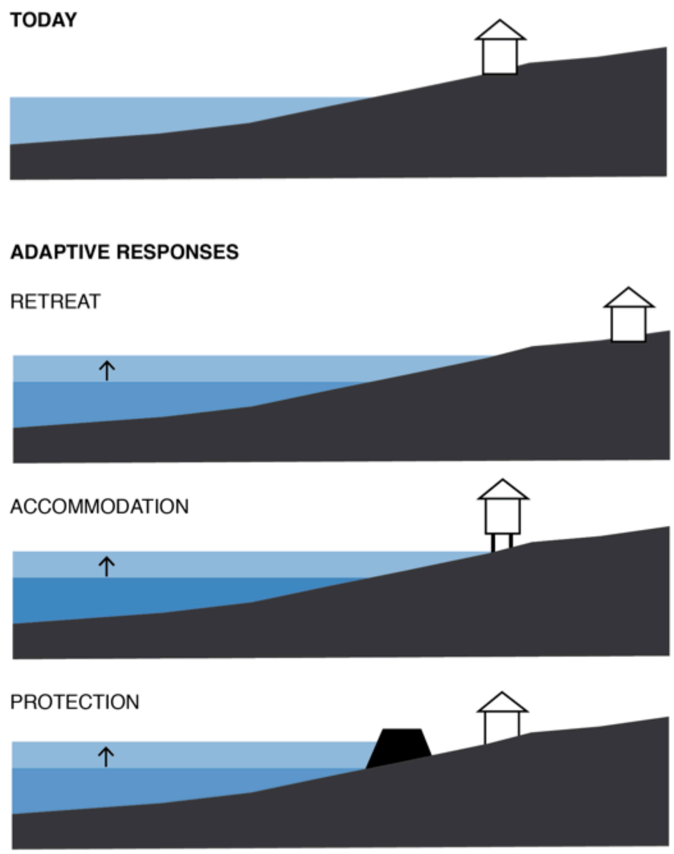


Figure 7: Diagram of coastal adaptation responses to sea level rise: retreat, accommodation and protection (adapted from IPCC Working Group III, 1990).

Protection

Protection involves hardening and/or buffering the coast in order to protect vulnerable areas so that existing land uses can continue (IPCC Working Group III, 1990). The strategies involve an array of “hard” and “soft” infrastructure solutions that can be applied alone or in combination. Hard protection measures take a more technological, engineered form that literally blocks or stops water. Soft protection measures usually consist of simulated natural features such as beaches and wetlands (IPCC Working Group III, 1990). Specific options for each protection measure are provided in Table 2.

Table 2: Comparison of hard and soft structural options for coastal protection (IPCC Working Group III, 1990).

Hard Structural Options	Soft Structural Options
Dikes, levees, and floodwalls	Beach filling and beach nourishment
Seawalls, revetments, and bulkheads	Artificial sand dunes and dune rehabilitation
Groins	Wetland and mangrove restoration, creation, and enhancement
Detached Breakwaters	Other solutions
Raising Existing Defensive Structures	
Infrastructure modifications	
Salt water intrusion barriers	
Floodgates or tidal barriers	

The "other solutions" category within the soft structural options is vaguely referenced in the IPCC 1990 report to include "increasing resilience and reducing vulnerability" (IPCC Working Group III, 1990). More recent studies and design strategies suggest the use of natural materials and habitats to take advantage of natural processes and ecosystem services. New technologies and greater understanding of natural processes have contributed to the use of a wide range of "soft" protection measures such as habitat restoration, artificial reef creation, bioinfiltration, detention basins, Low Impact Development (LID), and green infrastructure, among others (ICLEI-Local Governments for Sustainability, 2012; The Museum of Modern Art, New York, 2011).

The hard and soft approaches to coastal protection each have their strengths and weaknesses. In general, soft infrastructure can mitigate some of the environmental and social degradation associated with hard infrastructure, but is inadequate for providing protection of critical coastal areas and maintaining full coastal use. Strengths of a hard infrastructure approach include the continued use and protection of the coast and urban areas. This ensures the maintenance of property values and existing economic and social activities (ICLEI-Local Governments for Sustainability, 2012). However weaknesses of the hard infrastructure approach include expense, annual maintenance, erosion, ecological degradation and loss of social and aesthetic links to the waterfront (ICLEI-Local Governments for Sustainability, 2012).

Soft infrastructure provides environmental benefits, including preserving or increasing habitat, reducing the intensity of flooding, and reducing water pollution and increasing groundwater recharge. Weaknesses to this approach include uncertainty in the protective capacity of soft systems, annual maintenance, extensive land requirements, and the time to establish habitat (ICLEI-Local Governments for Sustainability, 2012).

Accommodation

In an accommodation scenario, people continue to occupy the land but make adjustments in order to adjust to a "new normal" (Blanco et al., 2009). They do not attempt to prevent land from being flooded, and consequently learn to accommodate and live with varying degrees of flooding (IPCC Working Group III, 1990). Examples of accommodation strategies include elevated grade surfaces, elevating structures on piles, floating structures, designing floodable developments, and designating buffers and setbacks.

Strengths of accommodation strategies are that they provide for the removal of development from immediate flooding threat, allowing residents and businesses to remain where they are. However, weaknesses include the high expense of retrofitting existing buildings, the need to provide accessibility to elevated structures, and the change of character of the streetscape. Also, the long-term cost of allowing structures to flood and the impact of salt water on these flooded structures are currently still being understood (ICLEI-Local Governments for Sustainability, 2012).

Retreat

Retreat is defined by the IPCC as “the abandonment of land and structures in vulnerable areas, and the resettlement of inhabitants” (IPCC Working Group III, 1990). In this scenario, either the land is prevented from development in the first place, or development is allowed to take place under the condition that it will be abandoned if necessary. This adaptation strategy is highly complex and controversial. It reaches across all spectrums of society, from government, science, insurance, policy, citizens, economics, and planning and design among others. It is an emotionally charged topic as well, as sense of place, home and community are meaningful in the daily lives of people who live on the coast. To manage this connotation with the word retreat, the term “managed retreat” is often used to offer a greater sense of autonomy over the future.

Strengths of using a managed retreat strategy include creating new space for habitats and recreation, as well as increased access to the shoreline (ICLEI-Local Governments for Sustainability, 2012). Weaknesses of managed retreat are property owner opposition and public perception, expense (especially in high density urban areas) and the unknown legal, insurance, and policy framework for the management of wide-scale retreat (ICLEI-Local Governments for Sustainability, 2012).

Discussion: Diverse Approaches to Coastal Adaptation Planning

These three adaptation methods are not mutually exclusive. Protection, accommodation, and retreat should each be assessed and incorporated in a sea level rise adaptation plan (Watson

& Adams, 2010). An adaptation plan is a document that assesses a city or community's climate change vulnerabilities and risks through a plan with goals, implementation, and evaluation measures (ICLEI-Local Governments for Sustainability, 2012). The strategies can be combined and prioritized based on a tiered system of solutions: first, non-structural protection methods (including public outreach and education), then structural methods, and lastly accommodation and retreat (Watson & Adams, 2010).

All three strategies can be implemented at varying phases of planning and as various thresholds of risk are met. For example, soft infrastructure might be able to protect an urban area to a low degree threshold such as a few inches of sea level rise, but a hard infrastructure strategy or elevating a house might be necessary for dealing with many feet of sea level rise or a storm surge. Then, as sea levels rise by the end of the century and vulnerability increases, another threshold will be reached that protection and accommodation can not meet, signaling that retreat may be the only way to provide safe places for living.

Many U.S. states and cities are preparing adaption plans that utilize these three strategies. New York City, San Diego, Boston, Norfolk, Virginia Beach, Charleston, and Punta Gorda, FL are all examples of cities that have created adaptation plans recently. Currently, the state of Georgia has no unified climate change adaptation plan, much less a sea level rise specific plan (Climate Central, 2012b). While there is a lack of statewide climate change adaptation planning, some coastal communities in Georgia are beginning to prepare themselves. The City of Tybee Island near Savannah, GA is working to develop a sea level rise adaptation plan of their own, and are one of the first Georgia coastal communities to quantify the damages and adaptation costs (NOAA Coastal Services Center, 2012).

Conclusion

In 2007, Jonathan Barnett and Kristina Hill wrote in Harvard Design Magazine on sea level rise that, “we don’t know how to relate apocalyptic visions to current problems and solutions” (2007, p. 14). A 2.0m rise in sea level, plus several feet of storm surge, can certainly be viewed as an “apocalyptic vision.” The way we plan and make decisions is critical to protect the health and safety of American citizens. But these threats can also be viewed as an opportunity to create more resilient ecosystems and communities that are able to adapt to changing environmental conditions. By recognizing the risks, uncertainties and vulnerabilities that a coastal community faces in the future, communities can plan their own response and develop their own direction for growth in the future. By combining a strategy of coastal management that combines hard and soft infrastructures, accommodation, and retreat, communities can alter their built and natural environments to attain a resilient future. Design professions such as landscape architecture are poised to lead these discussions and develop creative solutions to these apocalyptic problems. New and innovative strategies in the planning and design fields will help to address these unprecedented changes to our modern society.

CHAPTER 3

GREEN INFRASTRUCTURE AS A RESILIENT SEA LEVEL RISE ADAPTATION STRATEGY

Using natural approaches to water management is a concept that has been increasingly referenced in landscape architecture, engineering, and other design fields in recent decades. A shift in emphasis is underway in the design fields, a shift away from hard, structural methods of controlling nature and the coastline, toward a more natural approach that recognizes ecosystem services and the adaptive capacity of the landscape. Recent disasters in coastal areas such as Hurricane Katrina in New Orleans, and, most recently, Superstorm Sandy in New York and New Jersey, have revealed just how vulnerable our built environment is to hazards, especially along our coasts. Climate scientist Michael Oppenheimer emphasizes the necessity of reframing our water management strategies to be inclusive of water rather than exclusive of water by saying,

> "Despite our best efforts, the city and the water remain one organism. As the sea rises and the storms intensify, the water will break down the boundary again and again. The question is whether we should build faster and harder to keep it out, or find a way to gently merge ourselves with the water once again, transforming the hard boundary into a continuum, a smooth transition, a commingling rather than a battle zone" (The Museum of Modern Art, New York, 2011, p.17).

Green infrastructure is one method of utilizing the soft, absorptive powers of nature to manage water from both stormwater runoff and seawater. Unlike hard infrastructure that is based on the principle of building higher and stronger vertical elements (sea walls, bulkheads, etc.), green infrastructure relies on the horizontal nature of wetlands to buffer storm surge and sea level rise. Essentially, it flips the traditional, vertical approach to coastal management with a horizontal approach (Barnett & Hill, 2007). It takes a vertical problem (rising water levels) and treats it with horizontal solutions, creating what one coastal scientists calls "vertical levees" (Costanza et al., 2008).

This chapter explores, in greater depth, the coastal adaptation strategy of "soft" protection and situates it within the larger realm of green infrastructure. These natural approaches recognize the inherent value of ecosystem services, and provide benefits beyond simply protection, including social, ecological, and economic benefits. They offer the opportunity to introduce resilience into design thinking for sea level rise, another topic defined in this section. Examples of green infrastructure in current built projects, competitions and exhibits are explored in order to extract design themes and characteristics to inform the site design in Glynn County, GA.

Green Infrastructure Defined

Green infrastructure is a term that is appearing more and more frequently in discussions of sustainability across the United States (Center for Watershed Protection, 2009). Green infrastructure has become a popular stormwater management tool as a growing number of practitioners are applying its techniques to site designs, and long-term monitoring results are contributing to research quantifying its benefits (Calkins, 2012; Odefey et al., 2012). The profile of green infrastructure for urban stormwater management has also been raised, as major metropolitan cities such as Philadelphia, Chicago, New York, Seattle, and Portland adopt comprehensive green infrastructure plans in order to meet water management goals in urban areas. These practices are also being adopted in countless smaller urban areas, cities, towns, and people's own back yards (Robbins, 2012).

The precise definition of green infrastructure, however, remains ambiguous. As green infrastructure becomes more prevalent, there are several nuanced definitions that are being used. Perhaps the broadest definition of the term defines it at the scale of landscape conservation and protection as, “an interconnected network of natural areas and other open spaces that conserves natural ecosystem values and functions, sustains clean air and water, and provides a wide array of benefits to the people and wildlife” (Benedict & McMahon, 2006). This definition takes a landscape ecology approach to protecting and enhancing ecological systems across multiple scales, from watershed to neighborhood to site scale, preferably before development occurs (Benedict & McMahon, 2006; US EPA, 2010). Other definitions lean more toward the application of green infrastructure for stormwater and wet-weather management. These can be applied as retrofits in existing urban areas or in new developments. The EPA defines green infrastructure in the context of wet-weather systems as “an approach to wet weather management that uses natural systems — or engineered systems that mimic natural processes — to enhance overall environmental quality and provide utility services” (Odefey et al., 2012). As this thesis is more aligned with the goals of water management rather than conservation management, the latter definition is used in this thesis.

Green infrastructure shares many characteristics to other terms used in coastal adaptation, climate change, and hazard literature. Terms such as soft protection, soft infrastructure, soft coastal engineering, and living shoreline are commonly used in coastal literature (Grannis, 2011; IPCC Working Group III, 1990). While these names might differ from “green infrastructure” they all stem from the same philosophy - using natural materials and natural processes to perform ecological services. One definition of soft coastal protection highlights these similarities, defining it as, “projects that replenish or mimic natural buffers, such as beach nourishment, living shorelines, or wetlands restoration" (Grannis, 2011). While the stormwater management literature tends to use the term "green infrastructure" and the coastal hazards and sea level rise literature uses the term "soft infrastructure" or "soft protection," they are fundamentally the same. Coastal green infrastructure might take the form of sand bars, salt marshes, and wetlands, whereas inland green infrastructure might take the form of forests, riparian buffers, and freshwater wetlands, but they are essentially nested under the same ecosystem services-based approach that defines green infrastructure. For the purposes of this thesis the term green infrastructure will also apply to all manner of soft protection, soft infrastructure, and living shorelines, recognizing that each is situated within the wider realm and definition of green infrastructure.

There are many types of green infrastructure, depending on the scale at which it is being used. The types range from small-scale site design features, commonly called Low Impact Development (LID) techniques, to landscape conservation agendas (Center for Watershed Protection, 2009). A compiled list of green infrastructure techniques and practices is found in Table 3.

Table 3: Green infrastructure types (adapted from Center for Watershed Protection, 2009; IPCC Working Group III, 1990; North Carolina State University, 2009).

Green Infrastructure Type	Examples
LID Techniques	• Natural areas • Riparian buffers • Land conservation • Cluster Building • Reduced impervious area • Site assessment and design
LID Practices	• Bioretention • Bioswales • Stormwater wetlands • Stormwater ponds • Constructed wetlands • Rainwater harvesting • Green roofs • Permeable pavement • Filtration practices (sand or vegetated filter strips) • Infiltration practices (infiltration basins & trenches)
Coastal Green Infrastructure Practices/Restoration	• Sand dunes • Salt marshes • Wetlands • Organism-based habitats (oyster reefs, oyster beds, mussel beds) • Submerged aquatic vegetation

Green Infrastructure as a Climate Change Adaptation Strategy

Green infrastructure is increasingly mentioned in the climate change literature as a method for both mitigating greenhouse gas emissions and adapting to the realities of climate change. Studies are concluding that green infrastructure, by increasing green space and natural land cover, can help manage flooding, temper the urban heat island effect, provide cleaner air and water, and increase human health through increased recreational opportunities and interaction with nature (Gill, 2007; Gill et al., 2009; Odefey et al., 2012). Many examples exist of cities recognizing not only the stormwater management benefits of green infrastructure, but also its use as a climate change adaptation tool. In 2011 the City of Philadelphia adopted an aggressive green infrastructure plan to deal with combined sewer overflow (CSO) problems. The City considers the investment in green infrastructure as not only a win for water management, but also as contributing to mitigation and adaptation to climate change (Kessler, 2011; Philadelphia Water Department, 2011). The landscape architecture profession also recognizes green infrastructure as a climate change tool. In the policy statements of national associations of landscape architects, such as the American Society of Landscape Architects (ASLA) and The Landscape Institute in the United Kingdom, the organizations advocate for the use of green infrastructure as a climate change mitigation and adaptation technique (ASLA 2008; The Landscape Institute, 2008).

Water management and the water cycle will be particularly impacted by climate change, necessitating new methods of design, as well as management of existing and new infrastructure (Hirschman et al., 2011). Sea level rise and flooding are two byproducts of an altered climate state that will have tremendous effects on typical urban water management and infrastructure. Green infrastructure is a possible solution that can help adapt our urban infrastructure to be more resilient to disturbances due to climate change.

Benefits of Green Infrastructure Approach

There are many benefits to using green infrastructure for sustainability. The benefits go beyond simply conveyance of water or protection of shorelines to providing benefits that encompass the entire environmental, social, and economic realms. Sustainability is often defined by this triple bottom line. The EPA takes this approach to communicating the benefits of green infrastructure (Table 4). But sustainability can also be defined by landscape performance. Research undertaken by the Landscape Architecture Foundation and the Sustainable Sites

Initiative focus on how landscapes perform – and this guides whether or not they are sustainable (Calkins, 2012; Landscape Architecture Foundation, 2013). This type of categorization first focuses on the ordering system (transportation, flood protection, air quality, etc.) and then groups these into broader topics (habitat, materials, water, etc.). These topics can then be generalized into the broad triple bottom line topics (environment, economy, and social). Table 5 summarizes the Landscape Architecture Foundation's Landscape Performance Series categorizes into broad classifications of sustainability. These two categorization techniques, triple bottom line and performance, together provide justification for the benefits of green infrastructure in the landscape. They combine to support the holistic definition of sustainability that encompasses all aspects of the natural and built systems, and the processes and flows that drive those systems.

Table 4: Green infrastructure benefits classified using the triple bottom line categories of sustainability (environmental, economic, social) (adapted from US EPA, 2010).

Benefit	**Type**
Environmental	• Increase carbon sequestration • Improve air quality • Efficient land use • Flood protection • Replenish groundwater • Improve watershed health • Protect or restore wildlife habitat • Reduce sewer overflow events • Restore impaired waters • Meet regulatory requirements for receiving waters
Economic	• Reduce hard infrastructure construction costs • Maintain aging infrastructure • Increase land values • Encourage economic development • Reduce energy consumption and costs • Increase life cycle cost savings
Social	• Additional recreational space • Improve human health • Drinking water source protection • Educate the public about their role in stormwater management

Table 5: Green infrastructure benefits classified using the Landscape Architecture Foundation Landscape Performance Series Case Studies subtopics and topics (left and center columns). The author re-categorized the topics into broader triple bottom line sustainability categories (right column) (adapted from Landscape Architecture Foundation, 2013).

Subtopic	Topic	Triple Bottom Line
Transportation	Land	Environment
Land efficiency/preservation		
Soil creation/restoration		
Stormwater management	Water	
Water conservation		
Water quality		
Flood protection		
Other water		
Habitat preservation	Habitat	
Habitat creation/restoration		
Energy use/ emissions	Carbon, Energy, and Air Quality	
Air quality		
Temperature/Urban heat island		
Carbon storage/sequestration		
Reused/recycled materials	Materials and Reuse	
Local materials		
Waste reduction		
Green waste		
Property values	Economic	Economic
Operation and management savings		
Economic development		
Job creation		
Other economic		
Recreation and social value	Social	Social
Public health and safety		
Educational value		
Noise mitigation		
Scenic quality/views		
Food production		
Other social		

These categorizations of the benefits of green infrastructure above are helpful to understanding sustainability at the broad, theoretical scale, but need clarification at the local and practical scale. When studying a specific threat (such as sea level rise and flooding) these broad benefits can be discussed at a more detailed level. Also, impacts of sea level rise such as increased saltwater intrusion, permanent inundation, and habitat migration are typically not accounted for in discussions of green infrastructure for urban water management. The solutions to these problems will require an extension of the testing and quantitative methods that define the traditional benefits of green infrastructure. Using a green infrastructure approach for sea level rise adaptation requires special considerations that specifically address these issues.

Using a natural and ecosystem-based approach may provide multiple benefits that a "hard" infrastructure approach to armoring the coast might not. Many strategies of green infrastructure have been described as "no-regrets," meaning that taking steps to implement them now has few drawbacks – they are relatively low cost and offer a variety of benefits (Chou, 2012). In short, "no regrets" options can only strengthen coastal systems rather than harming them.

However, "no-regrets" solutions certainly do not offer complete protection from any future climate change event. As described in chapter 2, a mix of hard structural solutions, soft infrastructure, accommodation strategies, and eventual retreat are a necessary part of coastal adaptation to climate change. Green infrastructure should be a targeted approach that is incorporated into the larger coastal adaptation planning goals and that responds to the specific site assessment and performative capacities. Green infrastructure is likely to benefit more naturalized coastal regions, or low density coastal settlements that have the land required to implement green infrastructure practices and that do not have critical infrastructure such as ports, airports, and concentrated population and development centers. In these areas, sea walls and storm surge barriers will be more appropriate to protect the health, safety, and welfare of the coastal communities. Green infrastructure can help to a point, but will be unable to completely stop rising waters from infiltrating into developed areas and damaging infrastructure and human life. The exact tipping point between green infrastructure providing benefits and green infrastructure being inadequate is unknown. It is likely that only as sea level rise occurs, and design responses address the threat, that knowledge and case studies of the benefits will be more understood.

The following section describes some of the unique challenges and possible benefits of applying green infrastructure to manage and adapt to sea level rise and flooding under uncertain future scenarios. The discussion focuses on using a green infrastructure approach to coastal adaptation to sea level rise that other strategies such as hard protection might not afford. These topics include: adaptability and resilience, vegetation and habitat shifts along salinity gradients, aesthetics, and visualization of risk.

Adaptability and Resilience

By working "with nature's capacity to absorb and control impacts," green infrastructure has the potential to provide systems that are adaptable and flexible to uncertain future conditions (Odefey et al., 2012). With the large levels of uncertainty regarding the exact rate and height of sea level rise, a flexible and adaptable approach is one method to design in the present but be prepared for future conditions. This approach can provide some level of action today, but still allow for adaptability and changes in the future.

Resilience theory is one way that adaptability might be approached. Resilience is defined as, "the ability of a system to absorb disturbance and still retain its basic function and structure" (Walker & Salt, 2006). Resilience has been championed as a new paradigm of design thinking that adopts lessons from nature and ecosystem services to mitigate impacts of flooding, extreme weather and climate change (Watson & Adams, 2010). Watson and Adams outline eight "lessons from nature" that are applicable to design and construction: absorption, buffering, core protection, diffusion, rapid response, redundant circuits, storage capacity, and waste/nutrient recycling (Watson & Adams, 2010). The principles of green infrastructure can fit into this mold, as they use natural materials such as plants, soil, and water in dynamic processes. By working to mimic or enhance these natural processes, plants and species can migrate, undergo succession, and follow restoration trajectories that gain function and benefits with time. By implementing green infrastructure now, a restoration trajectory can be started that will ultimately benefit all forms of coastal adaptation, be it accommodation, protection, or retreat.

Green infrastructure is a spatially flexible approach to design that can be used at multiple scales. This flexibility may prove especially beneficial considering the uncertain future conditions of sea level rise. A green infrastructure approach can be used at multiple scales from a large landscape scale to a site scale (Benedict & McMahon, 2006; United States Environmental Protection Agency, 2010). Green infrastructure principles can be applied at the site scale by using flexible frameworks of interconnected treatment and storage structures. Evidence suggests that in the face of climate change, a distributed network of small-scale storage and treatment devices might be better suited for the stormwater management of the future (Hirschman et al., 2011). As our understanding of design storms changes, a smaller system is easier to adapt to new conditions than a larger, centralized system (Hirschman et al., 2011). An example of the power of connected small-scale systems is in Philadelphia, where the city is implementing green infrastructure on a large scale by way of small, incremental designs at the block and house scale. The city has quantified the costs and benefits of using green infrastructure versus the expansion of underground tunnels to manage CSO capture over time. In the study, the green infrastructure approach not only provided maximized benefits in the long run, but also saw earlier and higher benefits, as capacity of the pipes lagged due to design and construction (Figure 8) (Philadelphia Water Department, 2011). Since each green infrastructure project is smaller and less costly, they can be planned, designed, and installed more rapidly. This study illustrates the adaptable nature of small-scale interventions of green infrastructure to make large impacts.

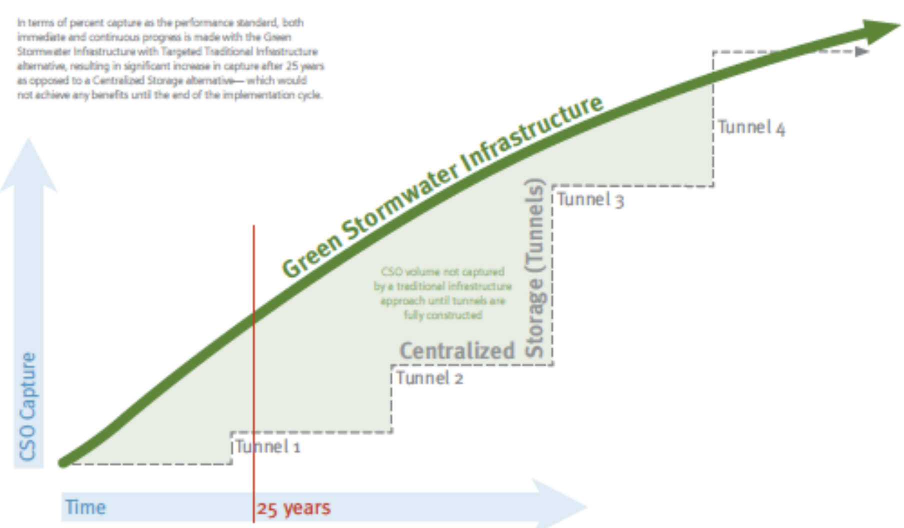


Figure 8: A conceptual comparison of CSO capture over time for green infrastructure compared to a traditional grey infrastructure system (Philadelphia Water Department, 2011).

This example illustrates the ability of green infrastructure to be a resilient and adaptable strategy that is flexible to the uncertainty associated with climate change. As Guy Nordenson writes in the introduction to “On the Water/Palisade Bay,” soft infrastructure is “an adaptable solution that adjusts to varying climatic conditions and urban demands by balancing environmental, technical, and economic priorities” (Nordenson, Seavitt, & Yarinsky, 2010). By layering these frameworks into a comprehensive strategy, green infrastructure can be the backbone that supports a more resilient coastal system.

Vegetation and habitat shifts along salinity gradients

Sea level rise will impact the typical materials of green infrastructure -- soil and vegetation – causing profound changes to the coastal environments. Coastal plant communities respond to subtle, gradual shifts in elevation, nutrient levels, water levels and salinity gradients. This can be illustrated by the fine gradients that exist in tidal wetlands between the tidal flat, low marsh, high marsh, and upland areas (Figure 9). Often these habitats can change within a few inches of vertical elevation, as they are tied to the tide elevations. Coastal wetlands (including salt marshes, brackish marsh, and fresh tidal marsh) in particular provide vital ecosystem services such as storm buffering, nutrient cycling, and habitat (Costanza et al., 2008; Craft et al., 2009; FitzGerald et al., 2008; Odum, 1988). By acting as "horizontal levees" wetlands are able to protect areas from storm surge, and also provide ecosystem services that typical vertical levees cannot (Costanza et al., 2008).

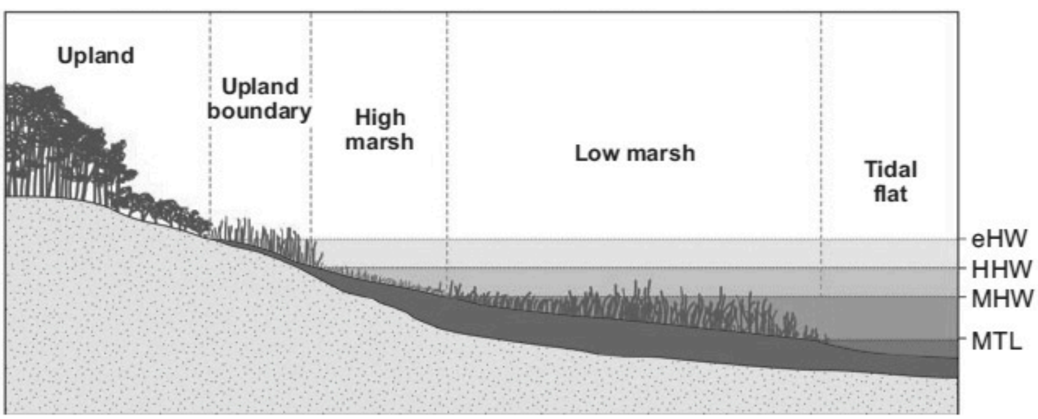


Figure 9: Morphologies of tidal wetlands and corresponding habitats. Marsh zones are shown relative to mean tide level (MTL), mean high water (MHW), mean spring high water (HHW) and extreme high water (eHW) (FitzGerald et al., 2008).

As sea level rises, existing plant communities will shift, or migrate, further inland to keep pace with the inundation and salinity levels (Baldwin & Mendelssohn, 1998; Craft et al., 2009; FitzGerald et al., 2008; Linham & Nicholls, 2010; Sharpe & Baldwin, 2012). Low-salinity, salt-sensitive vegetation found in tidal freshwater habitats will exhibit stress or mortality as salinity levels increase for longer durations (Baldwin & Mendelssohn, 1998; Jiang, Gao, & DeAngelis, 2012). Models predicting ecosystem change in coastal Georgia suggest that as salt water intrudes farther inland, tidal freshwater marshes will decline in area and brackish marshes will migrate inland to replace them (Craft et al., 2009). Called "marsh migration," these shifts in habitats will affect existing landscape patterns as well as typical ecosystem services along the coast (Craft et al., 2009).

Marsh migration will prove especially troubling along developed coastlines, where large acres of marsh might be lost. When hard defenses such as sea walls are present, inland migration halts as sea walls block the migration of coastal habitats. This can cause drastic reductions in the extent of habitats found in the coastal zone. A conceptual illustration of the effect of hard defenses on marsh migration is shown in Figure 10 (Linham & Nicholls, 2010). Responding to sea level rise with approaches that are sensitive to the migration of vegetation provides opportunities to not only maintain existing habitats but also enhance and facilitate their migration.

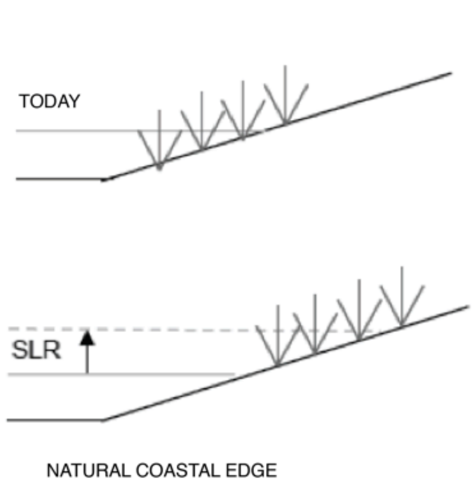


Figure 10: The process of coastal squeeze. Where hard defenses are not present, as shown on the left, marshes are able to migrate freely with sea level rise. Where hard defenses are present, as shown on the right, they block migration, thereby reducing habitat area (adapted from Linham & Nicholls, 2010).

Ecological restoration efforts are one method of helping vegetation move along this new trajectory. Although highly complex, examples of salt marsh and other marsh restoration are proving successful in disturbed ecosystems (Boumans, Burdick, & Dionne, 2002; Bowron, Nancyvan, Lundholm, & Graham, 2011; Casagrande, 1997; Green, Jacobs, & Reichelt-Brushett, 2009; Stagg & Mendelssohn, 2010; Van et al., 2005; Williams & Orr, 2002). One example of a salt marsh restoration in New Haven, Connecticut illustrates the added human benefits that a restoration can bring to a community. The project explicitly involved local participation in the restoration. After removing a series of floodgates and thus restoring tidal flow back into the West River the salt marsh was restored, providing increased ecological habitat, but also increased social benefits because of the local participation. The restoration was a success in re-connecting people with their ecosystems by empowering them to action (Casagrande, 1997).

Other examples of green infrastructure for habitat enhancement are seen in places experimenting with natural materials or living organisms to provide services typically associated with hard protection measures, such as shoreline erosion. A study using constructed oyster shell reefs in Louisiana found them successful to prevent shoreline retreat in low wave energy environments (Piazza, Banks, & La Peyre, 2005). Designers such as Kate Orff are experimenting with using a large network of restored oyster beds to protect and clean water from Palisades Bay in New York (The Museum of Modern Art, New York, 2011). These ecologically based designs not only recognize the natural abilities of green infrastructure to protect coastal environments, but also enhance the ecosystem services of that area. Their use may be one way to help create resilient ecosystems that can naturally respond to shifts in salinity and water level.

Aesthetics

Aesthetics are also a critical element of sustainability. Whereas the typical "triple-bottom line" approach to sustainability highlights the environment, economy and community aspects, aesthetics is a key component that impacts the human understanding and awareness of sustainability (Meyer, 2008). However, understanding what makes a certain type of place or vegetation beautiful or attractive to different groups of people is difficult. If coastal communities are to sustainably adapt to sea level rise, then a consideration of coastal aesthetics and their impacts on human behavior and understanding is important.

Aesthetics are particularly important at the site scale, especially when designed to be ecologically performative landscapes. Nassauer argues that ecological landscapes need to exhibit signs of care in order to be understood, because ecological function is not an easily recognizable element in the landscape (Nassauer, 1995). Designing ecological spaces within certain cultural norms, such as a mowed strip next to a wider, open meadow, signals that the landscape is not neglected and thus messy and disorderly, but rather maintained and cared for (Nassauer, 1995).

Exhibiting signs of care in ecological landscapes is part of what Gobster calls, the "perceptible realm," or the scale at which humans perceive and experience landscapes (Gobster, Fry, Daniel, & Nassauer, 2007). By making nature accessible and aesthetically rich at this site-scale level, then loftier goals such as awakening environmental understanding and increasing human receptivity to natural landscapes can be achieved.

Research on the public perception of attractiveness of restored nature is equally complicated. One study in the Netherlands looked at hikers' perceptions of attractiveness for different plant community types in a restored environment and a natural environment (van Marwijk et al., 2011). The study found that the most attractive landscape contained views of water with mature forest, whereas the least attractive landscape was young deciduous and coniferous landscapes, regardless of whether the landscape was restored or naturally occurring (van Marwijk et al., 2011). These findings, while targeted to a forest ecosystem, might have relevance in a coastal ecosystem where views of open water and early successional forests are common. Efforts to restore natural functions to the landscape might not be as "unsightly" as some may suppose, if the restoration effort falls in line with visual preferences.

Georgia coastal landscapes exhibit a distinct aesthetic character. Vegetation and open water are two critical aesthetic elements of the Georgia coast. Marshes and long sweeping views of salt marshes and water are iconic to the Atlantic coast. Vegetation, particularly coastal vegetation such as salt marshes, contributes to "place character" and the coastal identity of people who live and visit the coast (Green, 2010). This is illustrated by the salt marshes of Glynn County, GA, immortalized in the 1878 Sidney Lanier poem, "The Marshes of Glynn." The towns and barrier islands of the Golden Isles are surrounded by salt marshes, contributing to the sense of place and the unique identity for residents and visitors. The marshes and Lanier's poem are ingrained in the cultural fabric of the place, adorning historical plaques, street names, restaurant names, and promotional materials for the region. The marshes of Glynn County are integral to the understanding and enjoyment of place on the Georgia coast. The marshes are part of Gobster's "perceptible realm," creating a human reaction and experience that connects people to place.

These site-specific understandings of beauty and perception are tied into a wider discourse on beauty and sustainability. In Elizabeth Meyer's manifesto, "Sustaining Beauty: Performance of Appearance," she argues that sustainable landscape performance does not just involve the engineering and technical aspects of a design but also the emotional and ethical connection of humans to nature and dynamic processes (Meyer, 2008). She believes that beauty can alter an individual's consciousness in ways that can lead to greater care for the environment. Other designers such as Lance Hosey have echoed these sentiments on the subject of aesthetics. Hosey, like Meyer, argues that sustainability and aesthetics are not opposed to each other, but rather should be intricately bound together (Hosey, 2012). He distills research on the aesthetics of ecology into his own manifesto. He researches how patterns, shapes, color, light and other elements commonly found in nature can attract and connect us to sustainable design. Ultimately Hosey argues that it is the human perception of a design that makes it ultimately successful.

Framing the discussion of climate change within Gobster's "perceptible realm" or human-scale might lead to better engagement and understanding of the risks involved with climate change. Tacit values such as sense of place and beauty have been found to be the most influential to stakeholder involvement in coastal management decisions, as they have strong influence over human behavior (Anthony et al., 2009). And widening the notion of aesthetics to include recognition of change is critical as well. Landscape architect Kristina Hill, in an interview with ASLA, advocates that developing an aesthetic that values process and change will ultimately allow for greater acceptance of the realities of climate change stating, "if humans see change as beautiful, adaptation will be easier" (ASLA, 2013). In designing for sea level rise adaptation, aesthetics are a critical component of the design process that should not be overlooked. As sea level rise is complex, uncertain, and tethered to the meaning of place, perhaps beauty is one way that design can help make those uncertainties of the future more bearable and understood.

Visualization of risk

Another method of framing the discussion of sea level rise at a more human scale is through visualization of risk. Visualization of the consequences of sea level rise is one method of educating the public and decision makers about risk. While the use of visualization techniques for sea level rise planning is fledgling, they have the potential to be a very powerful tool to communicate risk. Several real-life adaptation projects are synthesizing complex data streams and communicating the results through 3d rendering programs such as Sketchup, Community Viz, ArcSCENE, Google Earth, and Visual Nature Studio, as well as 2d photorealistic renderings such as Photoshop (Sheppard et al., 2011).

Images such as those in Figure 11 not only visualize the impacts of sea level rise or flooding but also provide renderings of the visual character of the adaptation approaches at the site scale (Shaw et al., 2009). For example, a city where the buildings are raised on stilts looks and operates very differently from our cities today. Similarly, a view of a concrete sea wall from your back porch is very different from an ocean view. Providing visualizations of risks as well as possible design solutions in the planning process can help show the community what abstract planning policies will look like, ultimately educating them so they can make informed decisions about the future of their communities.

Figure 11: Visualizations of sea level rise and adaptation scenarios in British Columbia (image by David Flanders as cited in Sheppard et al., 2011).

Visualization techniques can also help communities understand the time scales involved with sea level rise. Sea level rise is predicted to be a gradual, incremental change in water level over many decades. Because of its slow nature, the risks of sea level rise may be harder to perceive than the risks from an intense, one time event like a hurricane. While we can conjure images of a hurricane-ravaged coastline in our head, the threat and danger of an imperceptible daily shift in water levels is less dramatic.

Theories of risk communication point to some lessons that could be applied to sea level rise design. Signage is one way that planners typically used to communicate risk in coastal areas. Markers on bridges or poles showing the level of water height during various floods or hurricanes are a common sight in American cities. Studies suggest that might be a tool to increase risk perception (Morrow, 2009). A synthesis report produced for NOAA by a social scientist provided case studies and expert interviews about risk management and risk visualization (Morrow, 2009). Two examples of effective risk-management tools regarding communication of flood risk were described. The first, in Pinellas County, Florida describes a public education technique used by the Emergency Management Agency staff. They bring a 24-foot high storm surge banner to community meetings, where they attach it to a fire truck that raises it vertically. People are able to stand in front of it, realizing what a 24-foot storm surge would look like at a personal scale (Figure 12). This brings a low-probability, but high-risk situation into the perceptible realm of the audience. They can understand just how high water levels would be and compare that to personal understanding, such as the height of their house.

Figure 12: Storm surge signage examples. Life size storm surge banner in Pinnella Co, Florida (left) and historic flood awareness signage in Lewes, Delaware (Morrow, 2009).

Another example of a successful risk communication campaign is in Lewes, Delaware. The city has created a signage system that uses a measuring stick and images of historic floods in the community to illustrate the vulnerability of the area by recalling previous events. The signs are displayed around low-lying areas (Figure 12). What makes this case unique is that rather than reacting against the signs, for fear of risk and negative effects on commerce, the city has embraced the signs and even started putting them in surrounding neighborhoods. The people are receptive to the signs and appreciate the educational awareness (Morrow, 2009).

These examples of computerized renderings and educational signage help the public to visualize coastal risk, but are only successful as part of a wider public awareness program. The state of Oregon has a successful educational campaign that focuses on tsunami awareness along the coast. The program includes signage at coastal sites, targeted print and web media, interactive maps, and research that is housed on a publically accessible clearinghouse website (State of Oregon, 2012). This type of broad communication across a wide variety of outlets helps to prepare coastal communities for hazards. As coastal communities begin to experience sea level rise and flooding, it will be necessary to update their educational programs to address the vulnerabilities, risks, and actions that are specific to sea level rise, storm surge, and localized flooding. Designers can play the crucial role of translating complex scientific models into visuals that the public can understand either through computer modeling or landscape design. Designs that are sensitive to communication of risk might play a crucial role in developing a community awareness model for sea level rise adaptation.

Limitations of a Green Infrastructure Approach

While there are many benefits of using a natural approach to coastal management for sea level rise, there also are limitations to their use. Green infrastructure will not be a panacea for all climate change problems. Charles Waldheim has said, "green infrastructure alone [will] not be sufficient. We need a mix" (Ireland, 2011). He is referring to the mix of hard and soft approaches as well as accommodation and retreat (Ireland, 2011). A summary of identified limitations to using green infrastructure for adaptation to climate change on the coast include:

- Inability to protect critical infrastructure
- Limited data and modeling for quantifying green infrastructure as a protection measure
- Extensive land requirements and time to establish habitats and plants
- Ongoing maintenance and monitoring requirements

Inability to protect critical infrastructure

While green infrastructure may be a "no-regrets" option in the short term, in the long-term "no-regrets" solutions may not be sufficient to provide adequate protection under radical changes to today's sea level and weather patterns. They are also not sufficient to protect critical infrastructure such as highways, bridges, airports, ports, water treatment facilities or other facilities that are critical to the health and safety of a community (Grannis, 2011). In these cases, engineering approaches such as raising a highway or building a barrier or sea wall might be necessary to protect these critical assets. Major global cities such as London, Venice and Amsterdam have chosen to spend billions of dollars on storm surge barriers and dikes because the critical infrastructure those barriers protect is worth billions more. New York City is in the process of deciding what critical infrastructure is vulnerable to sea level rise and storm surge and weighing the possibility of installing a storm surge barrier, or series of barriers to protect the city (Klinenberg, 2013). In major global cities like New York or London these strategies may be cost effective, but there are countless small towns and coastal regions that may not have the money to adequately protect their critical infrastructure. It is in these small cities that critical decisions must be made in the coming decades.

Limited modeling and quantification of green infrastructure as a protection measure

Green infrastructure suffers from a limited amount of tested models on reliability, especially as a coastal protection measure (Grannis, 2011). While knowledge is growing, few models exist to quantify the strength and buffering capacity of green infrastructure techniques such as wetlands, making their protection ability difficult to quantify (Costanza et al., 2008). Whereas the Army Corps of Engineers has complex models, equations, and tests for the design and construction of sea walls, levees, and barriers - models quantifying the reliability and capacity for green infrastructure are lacking.

Due to the lack of hard data, this may lead to a perception by the public that green infrastructure is not as safe or does not provide the same protective qualities that a hard element like a seawall might. This perception is understandable, as a swath of wetlands does not look as protective as a tall, concrete wall. However, there is evidence that the perception of safety provided by hard infrastructure can actually increase future risk and vulnerability, called the “levee effect” or “safe-development paradox” (U.S. Global Change Research Program, 2009). The theory suggests that a levee that is designed to provide protection from a low or medium intensity storm surge will increase real and perceived safety in that area and thereby encourage development. However, when a large intensity storm hits, as happened with Hurricane Katrina in New Orleans, the damage is catastrophic, as development has been allowed in these risky environments. How green infrastructure such as wetlands is perceived as a risk-management tool for protection is an emerging area of research and would benefit from a more thorough review.

Extensive land requirements and time to establish habitats and plants

Another disadvantage to green infrastructure is the more extensive land requirements as compared to linear protection strategies. When taking a horizontal approach to flood protection, more land is needed to act as a buffer to hold the same volume of water as a vertical system (Barnett & Hill, 2007; Costanza et al., 2008). Also, a significant amount of time is needed to establish and restore new habitats and plants if their ecosystem services value is to be fully realized. Restoration of coastal environments remains a complex undertaking with many variables such as species and material choice that can impact the effectiveness of a restoration (Borsje et al., 2011). Considering the projections of marsh migration due to sea level rise, more research will need to be undertaken to understand the time scales needed for marsh ecosystems to migrate and establish, and steps that can be taken to facilitate this change (Borsje et al., 2011).

Ongoing maintenance and monitoring requirements

Related to the unknown time scales of habitat establishment, ongoing maintenance and monitoring is another area of limited knowledge for green infrastructure. Data on long-term maintenance requirements and costs of green infrastructure has only begun in the past ten years, limiting the ability to calculate the real costs of green infrastructure and compare against other coastal adaptation strategies (Odefey et al., 2012; SPUR, 2011). Also unknown are the uncertainty of best management practices specific to sea level rise. For example, as green infrastructure is based on the principle of infiltration, what effect will rising water tables or salt-water intrusion have on the effectiveness of a rain garden to adequately infiltrate runoff? What effect do artificial reefs have on the surrounding environment? These are just some questions that might arise from using green infrastructure on the coast that are, as yet, untested.

More research and understanding is needed to fully predict the hydrologic and hydrographic impacts of sea level rise on coastal systems, and then apply those findings to quantitative, long-term research in green infrastructure specifically in coastal environments. As coastal communities make decisions today about their adaptation plans, long-term maintenance and performance estimates are critical to their decision-making. Initiatives such as the Sustainable Sites Initiative will help to establish a more robust knowledge base of best practices for sustainable site design and management, but more research should be focused on specifically looking at sustainable sites within our changing coastal landscapes.

Design Precedents

The following are some design precedents that have addressed sea level rise as a design concern, and specifically incorporated green infrastructure into a site-scaled design. While many of the designs may take a large-scale, decentralized approach, they illustrate the capacity of connected site-level responses to sea level rise. These precedents capture the current state of thinking by designers as to how sea level rise can be planned for at a site scale and how those site elements can aggregate into large scale adaptation.

The chosen precedents are located within the United States and the Netherlands.

While the planning and climate change literature in the United States has recognized the critical need for design solutions that are adaptable to sea level rise, examples of built landscape architecture works that explicitly address sea level rise in the United States are lacking (Ireland, 2011). One reason for this might be that sea level rise has only been taken seriously in America in the past few years, and that many cities are just now looking at developing adaptation plans, much less contracting and building projects (Ireland, 2011). While the political will to implement design solutions to sea level rise is lacking in the United States, there have been a number of design competitions and exhibits that have furthered design ideas about sea level rise and green infrastructure. This section looks at a few significant US design precedents that use green infrastructure approaches to sea level rise adaptation. These include work from the 2009 MOMA Rising Currents Exhibit and the San Francisco Bay Rising Tides Competition in 2009.

Other precedent designs come from the Netherlands, arguably the gold standard for sea level rise adaptation. The Netherlands has battled the sea and reclaimed land for centuries, as much of its territory lies below sea level. The Netherlands is an insightful case study in the limitations of "hard" approaches and the new emerging design ethic of bringing water back into the cities by integrating soft solutions as well. Two projects, one artistic in nature and the other a newly developed urban district not only deal with water but also embrace it as a reality and something to be celebrated.

MOMA Rising Currents Exhibit, 2009

The most high profile sea level rise design project was the 2009 Museum of Modern Art (MOMA) exhibit in New York City called Rising Currents. Five interdisciplinary design teams made up of architects, landscape architects, urban designers, ecologists, and planners gathered for an 8-week intensive design workshop in New York City. Tackling different areas of the Manhattan waterfront, each team designed an area of the waterfront specifically using a soft approach to sea level rise design. Building on existing research of the vulnerabilities and impacts of sea level rise on the New York Waterfront in "On the Water: Palisades Bay," the design products of the MOMA exhibit were vibrant, innovative, and visionary approaches to design that brought together the ecological and social realms to face future challenges. Table 6 summarizes the types of green infrastructure used be each project.

Table 6: Classification of green infrastructure practices in the MOMA Rising Currents 2009 Exhibit

Project	Firm	Green Infrastructure Type
New Urban Ground	ARO and dlandstudio	• Bioswales • Stormwater wetlands • Salt marsh wetland restoration • Porous pavement
Water Proving Ground	LTL Architects	• Wetland restoration along shoreline • Bioremediation ponds • Constructed wetlands and habitat islands
Oystertecture	SCAPE	• Oyster reefs • Stormwater retention pools • Rain barrels • Constructed wetlands
Working Waterline	Matthew Baird Architects	• Reefs made of recycled glass • Salt marshes
New Aqueous City	nARCHITECTS	• Floating wetlands

One project from the MOMA exhibit, in particular, highlighted how coastal and inland green infrastructure can be combined to form new systems of urban water management. New Urban Ground is the title of the design by ARO and dlandstudio that envisions a new green infrastructure for the city that integrates an interior porous street network and a shoreline marsh system to manage daily tidal flow and storm surge. The plan adds 2 miles of created shoreline, mostly in the form of wetlands used to diversify the urban edge and soften and absorb storm surge. Geo-textile tubes covered in marsh plantings create a system of breakwaters along the lower tip of Manhattan (Figure 13). A series of green streets continue in zones based on inundation levels into Lower Manhattan. The design of low lying city streets proposes the use of salt tolerant wetland plants along the street corridors that are subject to daily tidal flooding and occasional storm surges. In the more inland zones, the purpose shifts to stormwater management, as existing utility lines are relocated to waterproof vaults, and the streetscape utilizes porous pavement and bioswales to infiltrate stormwater runoff. One unique feature to the design is a proposal for a sunken forest to hold storm surge that is modeled after the sunken forests found on Fire Island in Long Island (Figure 13). This design especially shows how coastal and inland green infrastructure can combine to deal with both fresh and salt water.

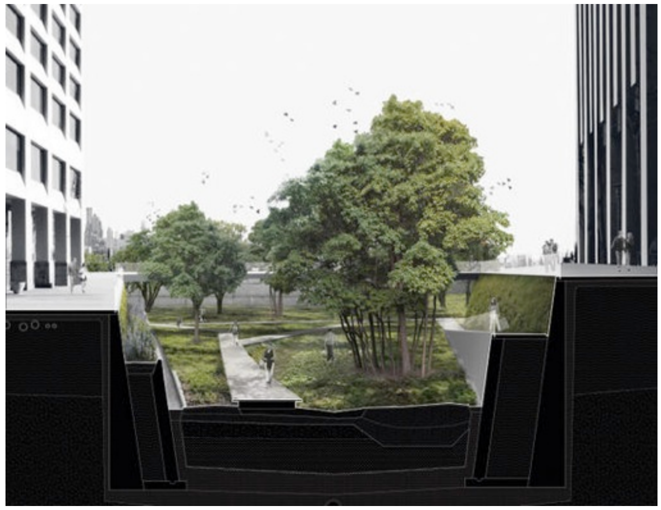


Figure 13: ARO and dlandstudio's "New Urban Ground". A design for New York's waterfront, part of the New York Museum of Modern Art's 2009 "Rising Currents" exhibit. Green streets (above left), sunken forests for storm surge catchments (above right) and geotextile shorelines (bottom) are all examples of green infrastructure practices in the proposal (Cassell, Drake, & Yarinsky, 2010).

San Francisco Rising Tides Competition, 2009

Another high-profile sea level rise design was a competition called Rising Tides held in San Francisco in 2009. While not specifically geared toward soft infrastructure, as the MOMA Exhibit was, the winners and honorable mentions for the Rising Tides competition did exhibit many soft infrastructure approaches. Recognizing the complexity of the problem at hand and the need for multiple solutions to sea level rise adaptation, the judges picked six winners. Two projects most illustrated the site-scale green infrastructure approach.

One winning project, “Topographical Shifts at the Urban Waterfront” utilizes green infrastructure on land and shoreline (Figure 14). The design approach sets up an adaptable framework in the water and on land that involves bioswales, bio-retention, and living shorelines. Floating wetlands create a diverse urban edge that then extends to natural areas on land, allowing for migration of vegetation with rising sea levels. A system of bioswale streets creates an on-land approach to collect and treat stormwater runoff, manage flooding, and create ecological and cultural corridors that act as floodplains when the sea level rises.

Figure 14: "Topographical Shifts" poster, Rising Tides Competition. A winning submission to the San Francisco Rising Tides competition. The design integrates stormwater and coastal management through porous street networks on land that extends into the San Francisco Bay (SF BCDC 2010).

A second design from the competition, called the RAYdike, is not a design solution, but rather more of an art installation that explores the power of the visual. It uses a series of laser beams illuminated off the fog of the San Francisco Bay to create a 30' tall dike along the shoreline of the bay (Figure 15). The result is a striking visual element in the landscape thats power lies in the communication of an abstract future, hopefully awakening political and social engagement to the threat of sea level rise (SF BCDC 2010).

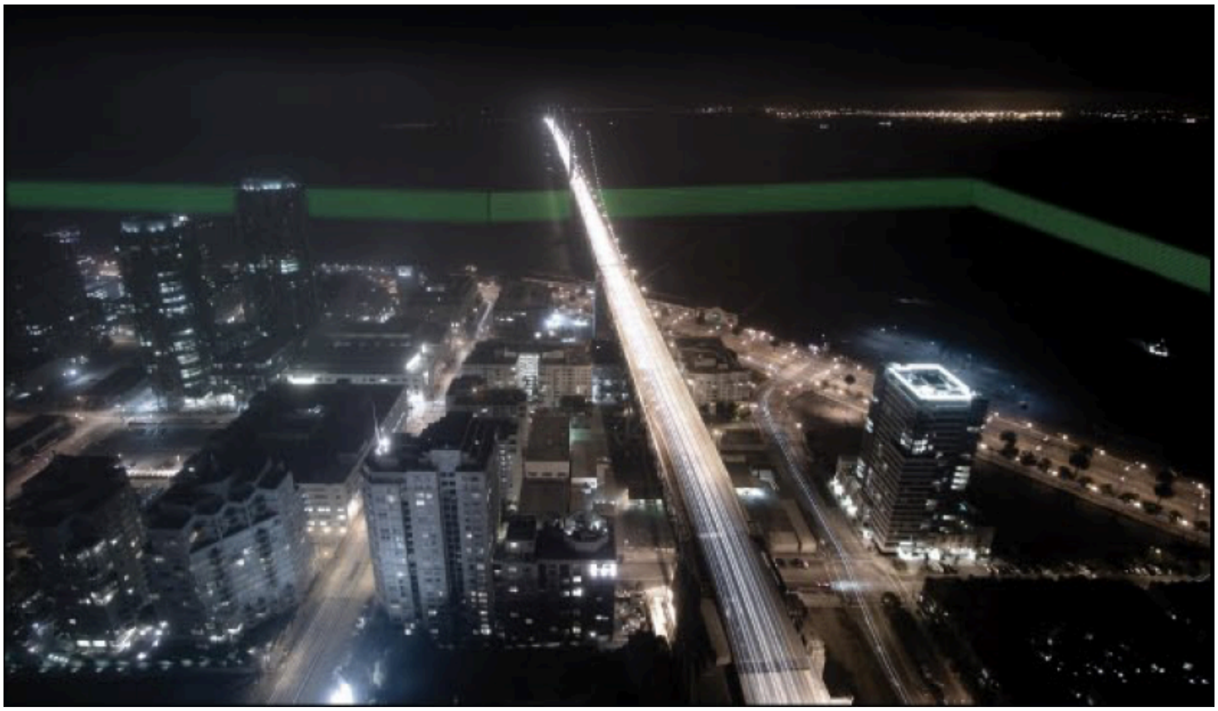


Figure 15: The RAYDike, Rising Tides Competition. This design uses lasers to project an earthen dike on the San Francisco Bay, seen in green in the image (SF BCDC 2010).

Flood Management and Sea Level Rise in the Netherlands

The Dutch have been building dikes to hold back the sea since the 12th century. Over 50% of their country lies below sea level, lying on land reclaimed using a complex system of dikes and pumps to create polders, or areas of reclaimed land protected by the dike and storm surge barrier systems. This massive infrastructural system, called the Delta Works, blocks the estuaries of the Netherlands and includes internationally known projects such as the Oosterscheldekering, or Eastern Scheldt Storm Surge Barrier. In the past 30 years the Dutch have been moving away from a reliance on technical, hard engineering solutions to water management and flood protection and integrating more comprehensive solutions based on landscape and a mix of hard and soft solutions (Hofland & Meeuwsen, 2011). The restructuring of design solutions is due in part to the realization in recent years that the solely structural system has left the natural estuary systems of the Netherlands in ecological disrepair (Hofland & Meeuwsen, 2011). The water policy of the Dutch in the last ten years has been exemplified by the slogan, “building with nature, living with water” (Metz & Heuvel, 2012). By accepting that water is no longer something to be kept out, and instead inviting it back in to urbanized areas, the Dutch are pioneering strategies to water management that bring an emotional and physical connection back to the water that surrounds the country. Two site-scale precedent projects, one in the Netherlands and one in nearby Germany show the new ethic to experiment with water as an element in the human landscape.

This first precedent is an artistic work that explores temporal and spatial changes at work in the Delta. Zeeland artist Dieuwke Parlevliet created a project called the Picnic Sea Spot, by placing a picnic table made of wood in the middle of the tidal delta (Figure 16). The table is submerged at high tide and exposed at low tide, allowing for access to the picnic table. The project invites people to interact with the dynamics of the place and recognize the vertical change in the landscape during the tides.

Figure 16: The Picnic Sea Spot. This artistic work by Dieuwke Parlevliet places a picnic table in the middle of an estuary, limiting access to only certain times of day. The work makes water level change visible in the landscape and invites interaction with the water (Metz & Heuvel, 2012).

The second example of a new water culture with sea level rise is in the district of HafenCity, a 126-hectare area outside of Hamburg, Germany. HafenCity is located on the Elbe River, which is not protected by storm surge barriers or dikes. This means that the city is subject to daily tides of over 3 meters, spring tides, and, every few years, storm surge flooding. Despite these conditions, or maybe because of them, HafenCity has become one of the most popular new urban developments, complete with housing, offices, museums, parks, plazas, and a metro line (Metz & Heuvel, 2012). HafenCity employs a variety of adaptation techniques in order to protect people in this new aqueous environment. All buildings are raised to 8 meters, a system of parking garages double as flood control during storm surges, raised roads are used, and natural and recreational amenities are placed along the waterfront. HafenCity will not be completed until around 2025.

HafenCity does not employ an elaborate system of green infrastructure, instead choosing to accommodate to rising seas through elevation of buildings and infrastructure, but it is a unique example of a new urban district being built wholly around the concept of water and daily water level fluctuations. This city brings residents in visible contact with the water every day, reinforcing that they live in a dangerous area. But public education is a priority for the project as well, preparing residents for any dangers (Metz & Heuvel, 2012). HafenCity can be a model for how to integrate urban use into a vulnerable area that is subject to flooding by turning people toward the water instead of against it.

These five case studies utilize different types of adaptation strategies and prioritize different aspects of sustainability. Table 7 provides a framework for comparing these five case studies. In this chart, each case study is assessed based on the adaption strategies (protect, accommodate, retreat) discussed in Chapter 2, and the sustainability strategies (environment, economy, society, aesthetics) discussed earlier in Chapter 3. As shown in the table, some case studies such as the New Urban Ground project and the Topographical Shifts project used a wide range of adaptation strategies and sustainability strategies in the design; others, such as the RAYDike and the Picnic Sea Spot focused on the aesthetics and visual elements of design. HafenCity combines all three adaptation strategies, but the focus of the urban design is on economic and social development.

Table 7: Case study comparison chart.

Case Study	Adaptation Strategy			Sustainability Strategy			
	Protect	Accommodate	Retreat	Environment	Economy	Society	Aesthetics
New Urban Ground (MOMA Rising Currents Exhibit)	X	X	X	X	X	X	X
Topographical Shifts (Rising Tides Competition)	X	X	X	X	--	X	X
RAYDike (Rising Tides Competition)	--	--	--	--	--	--	X
The Picnic Sea Spot	--	X	--	--	--	--	X
HafenCity	X	X	X	--	X	X	--

X = Prioritized in design
-- = Not prioritized in design or not a design element

<u>Conclusion</u>

This chapter has outlined and discussed some of the key strengths to using green infrastructure for sea level rise adaptation, and also some of the limitations. The categorization of sustainability in terms of the triple bottom line -- environment, economy, and society – provides a framework for understanding sustainability. Adding landscape performance to the notion of sustainability creates a framework for understanding the breadth and depth of deep sustainable thinking. Using green infrastructure for coastal management is one strategy that can benefit all aspects of sustainability.

The coast offers a unique approach to urban stormwater management, as storm and coastal waterways are in such close proximity. Due to this intimate relationship that coastal communities already have with the water, the typical discussion of green infrastructure as a stormwater management strategy has been expanded to include benefits and unique conditions of its use for coastal sea level rise adaptation. Conditions such as marsh migration, adaptability, visualization of risk and aesthetics are all unique ways that green infrastructure can provide additional amenity value to coastal protection and accommodation. However, there are limitations to relying on green infrastructure as well, such as the uncertainty and difficulty in quantifying its ability as a protection strategy, the time scales involved with restoration and establishment, and the uncertainty of how saltwater intrusion and other expected impacts will affect the absorption and infiltration abilities fundamental to green infrastructure.

Design competitions in the United States such as the MOMA Rising Currents exhibit and the San Francisco Rising Tides Competition are beginning to explore how to design for rising sea levels. However, built projects that specifically target adapting to rising sea levels are lacking in US cities. Nonetheless, the design exhibits and competitions reviewed in this chapter provide a window into the thinking of designers at the edge of innovation and application of green infrastructure on the coast. The changing perceptions of water and flood management in the Netherlands provide opportunities to understand the cultural shift underway that is bringing water back into cities for flood control, restoring ecological health to urban waterways, and providing amenity value to water management. Systems of greenways and waterfront recreation areas are reclaiming the waterfront edge as the realm for public space and reconnecting people with the water that surrounds and sustains them.

These design precedents provide insight into design thinking for sea level rise and new methods of flood management. Understanding gained from them will be applied to the site design along the Brunswick-Altamaha Canal. The next chapter introduces the historic Brunswick-Altamaha Canal, a vision for its reutilization, and analysis of the impacts of sea level rise on the canal.

CHAPTER 4

THE BRUNSWICK-ALTAMAHA CANAL & FEASIBILITY OF ITS REUTILIZATION

The Brunswick-Altamaha Canal is a historic feature located in Glynn County, GA. The canal was dug in the 1850s, and intended to be used as a transportation canal to connect the port of Brunswick to commerce along the Altamaha River. Despite being complete for almost its entire 12-mile stretch, financial difficulties and other impediments delayed the construction of the canal long enough that the railroad rendered the waterway canal obsolete by 1860. For the past 150+ years the canal has degraded and acts to drain stormwater in Glynn County, with little to no improvements to the original construction. A task force in Glynn County has expressed interest in reutilizing the canal as a greenway and blueway corridor (Batiwalla, 2011). The reutilization effort is currently in the planning and fundraising stages.

The Brunswick-Altamaha Canal is a potential case study of how to plan for the long-term impacts of climate change on the coast of Georgia. Because the canal's original lock structures are deteriorated, both the northern and southern ends are open to tidal influences, making the canal reutilization effort a case study in sea level rise design for coastal greenways. This chapter provides a description of the past, present and potential future of the canal and discusses opportunities and constraints to the implementation of a reutilization plan for the Brunswick-Altamaha Canal. An inventory of the impacts that sea level rise will have on the canal helps frame the discussion of feasibility of the proposed reutilization.

History of the Brunswick-Altamaha Canal

The primary body of work on the history of the Brunswick-Altamaha Canal is a 1981 report prepared by the Brunswick-Glynn County Joint Planning Commission with assistance from Robinson Fischer Associates and Hussey, Gay and Bell (Brunswick-Glynn County Joint Planning Commission, 1981). The original design and engineering of the canal is documented in Loammi Baldwin's 1836, "Report on the Brunswick Canal and Rail Road" which provides insight into the original intended design of the canal (Baldwin, 1836). These two sources provide the following historical description of the canal and its construction.

The Brunswick-Altamaha Canal was constructed to act as a transportation canal between the harbor at Brunswick, Georgia and the Altamaha River during the mid-nineteenth century. The canal stretches approximately 12 miles in a north/south direction from its northern terminus at Six Mile Creek, a tributary to the Altamaha River, to its southern terminus at Academy Creek near the Brunswick harbor and Turtle River (Figure 17). The canal connects to the South Branch of the Altamaha River by way of Six Mile Creek.

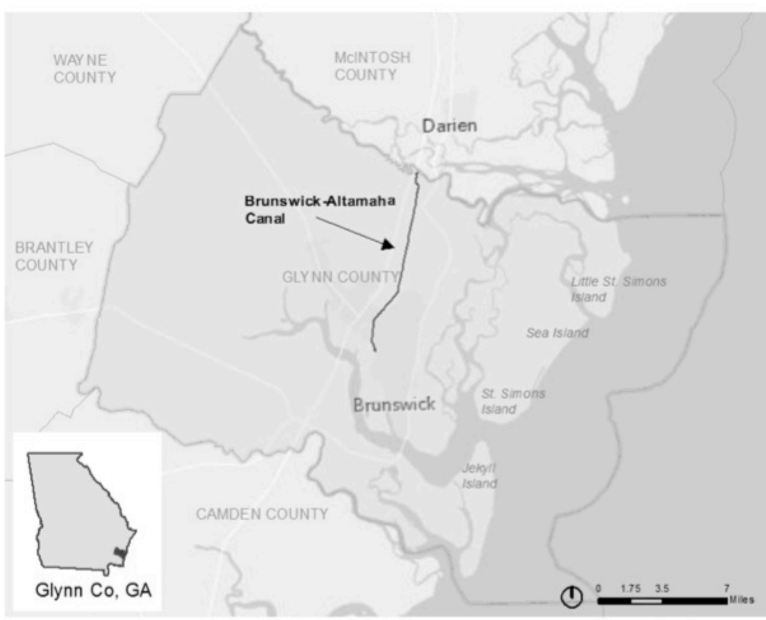


Figure 17: Location map of Brunswick-Altamaha Canal in Glynn County, GA.

Canals were a popular method of transportation and commerce during the early and mid-nineteenth centuries. Inspired by the success of other canals such as the Erie Canal in New York, many state governments, including Georgia, proposed constructing canal systems to speed the riverine transport of timber, rice, and cotton by boat. The Brunswick-Altamaha Canal was designed to act as a critical link in the trade route between inland Georgia and the coast. The canal as designed would have provided a direct link between the Altamaha River and the harbor at Brunswick, instead of the longer route through Darien to Savannah, as shown in Figure 18.

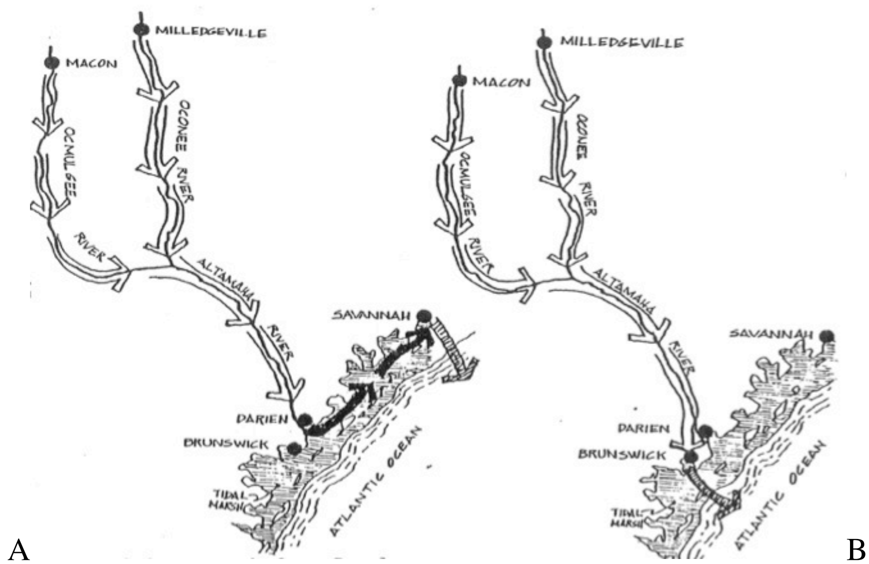


Figure 18: Early 19th century trade routes between Central Georgia and the Georgia Coast, (A) before the contructiion of the Brunswick-Altamaha Canal, and (B) proposed trade route after the canal (Brunswick-Glynn County Joint Planning Commission, 1981).

Construction of the canal began in 1836, but was interrupted several times due to labor disputes, difficult construction conditions in the marshes, and financial difficulties. Over five hundred slaves and Irish workers dug the canal by hand. The canal was engineered to be a saltwater canal, unaffected by tidal influences. Two locks, one at the southern terminus and one at the northern terminus would act to control the influx of fresh water from the Altamaha and estuarine water from the Turtle River. A supply sluice located at Yellow Bluff Creek, near the southern portion of the canal, would regulate water levels, essentially keeping the water level of the canal at mean high tide. The canal was designed to be 6 feet deep, with a 35’ wide base and 53’ wide at water level (Figure 19). A towpath of 12’ width was specified to be along the eastern side of the canal (Baldwin, 1836). Baldwin surveyed many potential lines for the canal, encountering many difficulties due to swamps, high water tables, creeks, and rice fields. The routes and profiles from Baldwin’s report are shown in Figure 20.

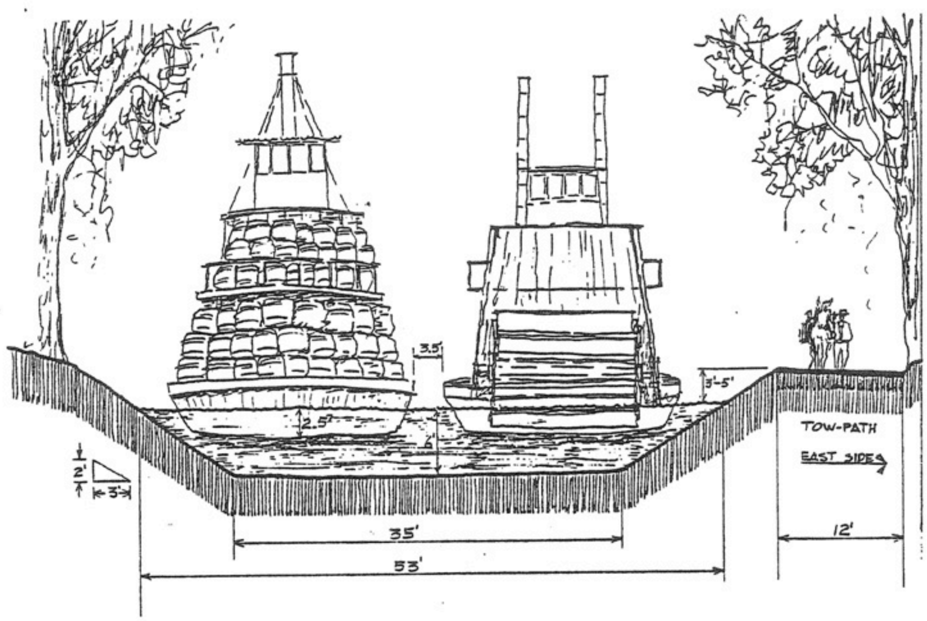


Figure 19: General canal dimensions as designed (Brunswick-Glynn County Joint Planning Commission, 1981).

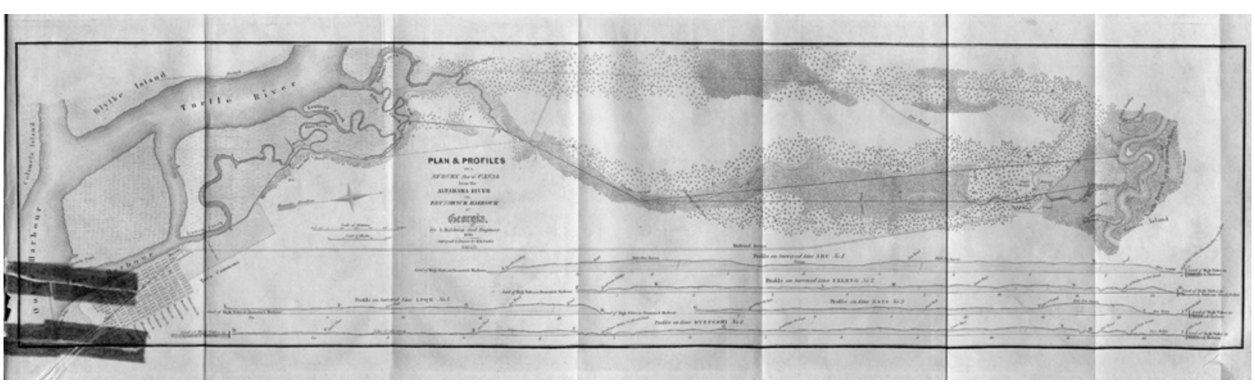


Figure 20: The original routing plan and profiles produced by the engineer, Loammi Baldwin for the Brunswick-Altamaha Canal in 1836 (Baldwin, 1836).

The canal opened in 1854, but was only in use for about six years. Reasons for the failure of the canal are twofold. First, the far northern section of the canal was not completed as engineered, leaving a 1.4-mile stretch along the naturally meandering Six Mile Creek, which prevented steamboats from navigating the canal. But this detail was ultimately rather insignificant due to the advent of the railroad. By the late 1850s the railroad had overtaken canals as the dominant form of transportation in much of the United States. The Central Railroad of Georgia provided the direct link between Macon and Savannah that the Brunswick Canal speculators originally sought, rendering the new canal obsolete for transportation (Figure 21). By 1860 the canal was completely abandoned. Two attempts to make the canal functional again failed, leaving the canal to degrade to its present condition over the next 150 years.

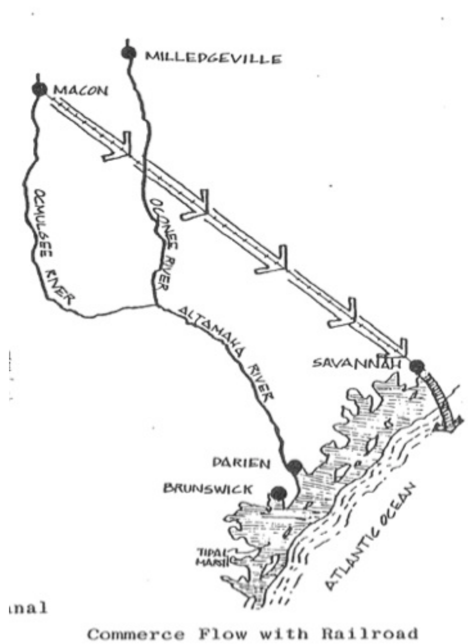


Figure 21: Impact of railroad on commerce flow, rendering the Brunswick-Altamaha Canal obsolete by 1860 (Brunswick-Glynn County Joint Planning Commission, 1981).

Present Condition of the Canal

Hydrology

The canal today has been largely unmaintained and has deteriorated over the past 150+ years. Hydrography of the canal today reflects some historical incompletions (like at Six Mile Creek), but also the deterioration of the canal since its abandonment some 150 years ago. Today, only the northern lock is still visible. The southern lock is not visible, presumed to be buried under fill and refuse from nearby development (Brunswick-Glynn County Joint Planning Commission, 1981). Because of the lack of functioning locks, the canal's waters are tidally influenced, ranging from hypo-saline to saline, especially along the northern and southern terminuses (Brunswick-Glynn County Joint Planning Commission, 1981). The central portion of the canal is dominated by freshwater discharge from surrounding wetlands, swamps, and suburban development. There is severe stagnation along much of the canal's length due to numerous impediments to natural drainage and tidal flow, such as siltation, overgrown aquatic plants, logs, branches, and debris (Brunswick-Glynn County Joint Planning Commission, 1981). Also impeding flow are several culverts along major road and rail crossings. Major road crossings exist at SR 303, US Route 25/341, Old Jessup Highway, Hwy 25/Golden Isles Pkwy, Glynco Pkwy, Harry Driggers Blvd, and SR 99/Grants Ferry Rd. In total there are three bridges, nine culverts, two filled areas, and one trestle span along the 12-mile canal corridor (Brunswick-Glynn County Joint Planning Commission, 1981).

Today, the canal acts as a stormwater drainage way for Glynn County, especially along the central portions of the canal (Fakour, 2010). This area is general characterized by residential land use as well as an airport and federal training facility. Conflict over jurisdiction, maintenance, and drainage began in 2008 when drainage was impeded by a series of beaver dams, causing flooding in the neighborhoods (Hawkins, 2008b). A battle between the US Army Corps of Engineers, environmentalists and Glynn County over permitting to clear debris from the canal resulted in an increased awareness of the canal and its neglect (Hawkins, 2008a). Figure 22 shows one of these beaver dams along the canal between Harry Driggers Blvd and SR 99.

Figure 22: Beaver dams along the Brunswick-Altamaha Canal north of Harry Driggers Blvd looking south (Nightingale, 2009).

A site visit by the author in May 2012 and February 2013 confirmed that portions of the canal waterway and towpath are either overgrown or otherwise visually blocked, while other parts are scenic and easily navigable by either boat or foot along the towpath. Figures 23, 24, 25, 26 and 27 are site photos taken along the canal that provide insight into the visual character of the corridor. The photos are presented in order from north to south along the canal corridor.

Figure 23: The Brunswick-Altamaha Canal towpath looking south from Hwy 99. This portion of the canal is cleared and used by County maintenance vehicles. It is known as Shell Rd. Photo by author, February 15, 2013.

Figure 24: The Brunswick-Altamaha Canal at Harry Driggers Blvd looking north. Photo by author. February 15, 2013.

Figure 25: The Brunswick-Altamaha Canal towpath at Harry Driggers Blvd. A cleared canopy is visible, but undergrowth impedes access to towpath. Photo by author, February 15, 2013.

Figure 26: The Brunswick-Altamaha Canal at Glynco Parkway looking north. The airport lies to the eastern side of the canal. Photo by author, February 15, 2013.

Figure 27: The Brunswick-Altamaha Canal at Old Jesup Rd bridge looking north. Picture is taken around low tide, but otherwise the canal is clear and navigable. Photo by author, February 15, 2013.

Archaeology

Three archaeological sites exist along the canal reach and surrounding land (Brunswick-Glynn County Joint Planning Commission, 1981). Prehistoric Indian mounds have been found at the northern section of the canal near Six Mile Creek at the historic Evelyn Plantation. Some of this land is now a housing subdivision. An archaeological field study conducted in 1980 unearthed two other archaeological sites, both located just north of the southern terminus of the canal. Ceramic shards were found in these sites (Brunswick-Glynn County Joint Planning Commission, 1981). Today, both of these sites are degraded and filled by development, leaving further archaeological exploration difficult.

There are also other historical sites along the canal. At the north end near the site of the former Elizafield Plantation there are tabby ruins of a sugar cane mill, and three historic cemeteries. At the far southern end of the canal near Seldon Park there are two more cemeteries. Also of note is that during the original excavation of the canal in 1838, a number of fossil shells and bones of extinct mammals were unearthed, including the Mammoth, Mastadon, and Megatherium (Brunswick-Glynn County Joint Planning Commission, 1981).

Proposed Reutilization of the Canal

Recognizing the historical significance of the canal and the opportunity to restore the canal to a useful state and manage the current flooding issues, Glynn County has expressed interest in reutilizing this canal into a recreational greenway and blueway (Fakour, 2010). A committee of county officials and environmental experts is working to construct a master plan and secure funding at this time (D. Hainley, personal communication, February 15, 2013; Fakour, 2010). The task force has identified reutilized planning principles as follows (D. Hainley, personal communication, February 15, 2013):

1. Perform the reutilization in accordance with all archeological and environmental standards.
2. Perform the reutilization with the least impact to the environment.
3. Incorporate access and design features for people with a wide range of physical abilities and interests.
4. Incorporate design features to avoid conflicts between cars and pedestrians, cars and boaters, and boaters and pedestrians.
5. Restore adequate flow ability to the canal.
6. Develop the canal as an ecotourism destination.

Further design goals of the canal restoration include clearing the canal to be navigable by non-motorized boats (canoes and kayaks) from the Altamaha River to Yellow Bluff Creek at a proposed reutilization depth of water at 42”. A multipurpose, ADA accessible path will follow from SR 99 to SR 303. ADA compliant bridges, facilities, and structures will replace some existing drainage structures and small bridges. They also want the canal to connect to regional coastal blueway and greenway trails and have several venues along its route (D. Hainley, personal communication, February 15, 2013). Spatial mapping using Geographic Information Systems (GIS) performed by the author reveal some significant opportunities and constraints in the reutilization effort. Complete maps and results of this analysis of connectivity of the canal to surrounding community assets are included in Appendix A.

Opportunities for Canal Reutilization

Opportunities exist to enhance the community, environment, and economy of Glynn Co through reutilization of the canal. As a recreational corridor the canal could provide for the health and well being of residents of Glynn County as well as visitors to the Golden Isles. The reutilization of the canal using sustainable site design methods could not only restore hydrologic function to the canal and help reduce local flooding, but also provide increased ecological health and natural amenity to the area. The historic value of the canal could bring additional users who are interested in the history and cultural landscape presented by the canal and its surrounding land uses.

In terms of connectivity, the canal corridor is connected to a wide variety of existing community assets within a one-mile area. These sites include parks, historic sites, shopping centers, public and private schools, residential neighborhoods and other proposed paddle and greenway trails (Appendix A). By providing well-designed and accessible connections to these amenities, the overall value and use of the canal greenway/blueway could be increased.

Constraints to Canal Reutilization

A number of constraints were also identified in the mapping inventory. These included adjacent land uses that might conflict with recreation, a nearby Superfund site, general degradation of the canal bed and surrounding environment, and permitting and regulatory constraints.

Located adjacent to the canal are two major facilities in Glynn County, the World War II-era Glynco airport (now called Brunswick Golden Isles Airport) and the Federal Law Enforcement Training Center (FLETC). They both lie adjacent to the central portion of the canal and could cause conflicts due to noise, safety, access, and security with recreational users of the canal. Collaboration among Glynn County, the airport and FLETC officials should ensure that the safety and well being of the users of the greenway are not compromised due to these facilities -- and conversely, that the users of the canal do not impede the operations and security of these critical service facilities.

Mapping also identified a nearby EPA Superfund site, the former LCP Chemical Site (EPA ID: GAD099303182), one of four superfund sites in Glynn County (US EPA, 2012b). This site is located near the southern portion of the canal along Academy Creek in the City of Brunswick. While Academy Creek is hydrologically disconnected from the Brunswick Canal due to infill, the LCP site lies adjacent to the marshes of Turtle River, which share the same tidal waters as Yellow Bluff and the Brunswick-Altamaha Canal. The EPA is scheduled to conduct a remedial investigation/feasibility study to determine what long-term threats to ground water and marshland may exist at the site (US EPA, 2012a). This thesis does not explore this Superfund site in depth, but recognizes that it may be a constraint to the reutilization of the canal, especially if the EPA finds evidence of contamination near the canal or along Yellow Bluff Creek.

As identified earlier in this chapter, the quality of the canal is generally degraded. Reaches of the canal are not navigable by boat or foot in their present state. If a water depth of 3.5' is desired for the canal to be accessible to non-motorized boats, then significant dredging of the canal will need to occur. Along the tow path, significant clearing and in some places, grading or boardwalks might be necessary to restore a pedestrian pathway along the canal.

Lastly, regulatory and permitting issues will pose significant barriers to the reutilization of the canal, especially if dredging will occur along portions of the 12-mile corridor. As previous attempts at dredging the canal to clear beaver dams has shown, there are a number of local, state, and federal agencies that might claim jurisdiction over the canal, complicating permitting and management (Hawkins, 2008b). The Army Corps of Engineers will be a key player in this regulation, both for dredging permits and wetland mitigation permitting. Another impediment to converting the towpath into a greenway will be the permitting and regulation of stream buffer widths, controlled by local and state ordinances. For any clearing or surfacing of the path for walking or biking, these activities would need to be permitted and designed in accordance with stream protection buffer widths and other environmental protection and sustainable sites strategies.

Reutilization Planning and Sea Level Rise

Sea level rise is another significant condition that could impact the canal. While the impacts of sea level rise may be decades away, planning for those potential impacts now will save time and money later as areas might be inundated. As the planning for the canal is still in its infancy, tremendous opportunity exists for the reutilization of the canal to be a case study for redeveloping in a coastal area while anticipating and planning for sea level rise.

Due to the deterioration of the locks on the north and south end of the canal, both ends of the canal are open to their surrounding tidal waterways, Yellow Bluff Creek and Six Mile Creek. Assuming no engineered barrier is built to protect Brunswick or Darien from high tide and storm surge (like the Thames Barrier in London), the canal will experience increased water levels due to sea level rise. Images captured from NOAA's interactive web viewer show the expected water level changes between today and with a 6' rise in sea level (Figure 28) (NOAA Coastal Services Center, 2013).

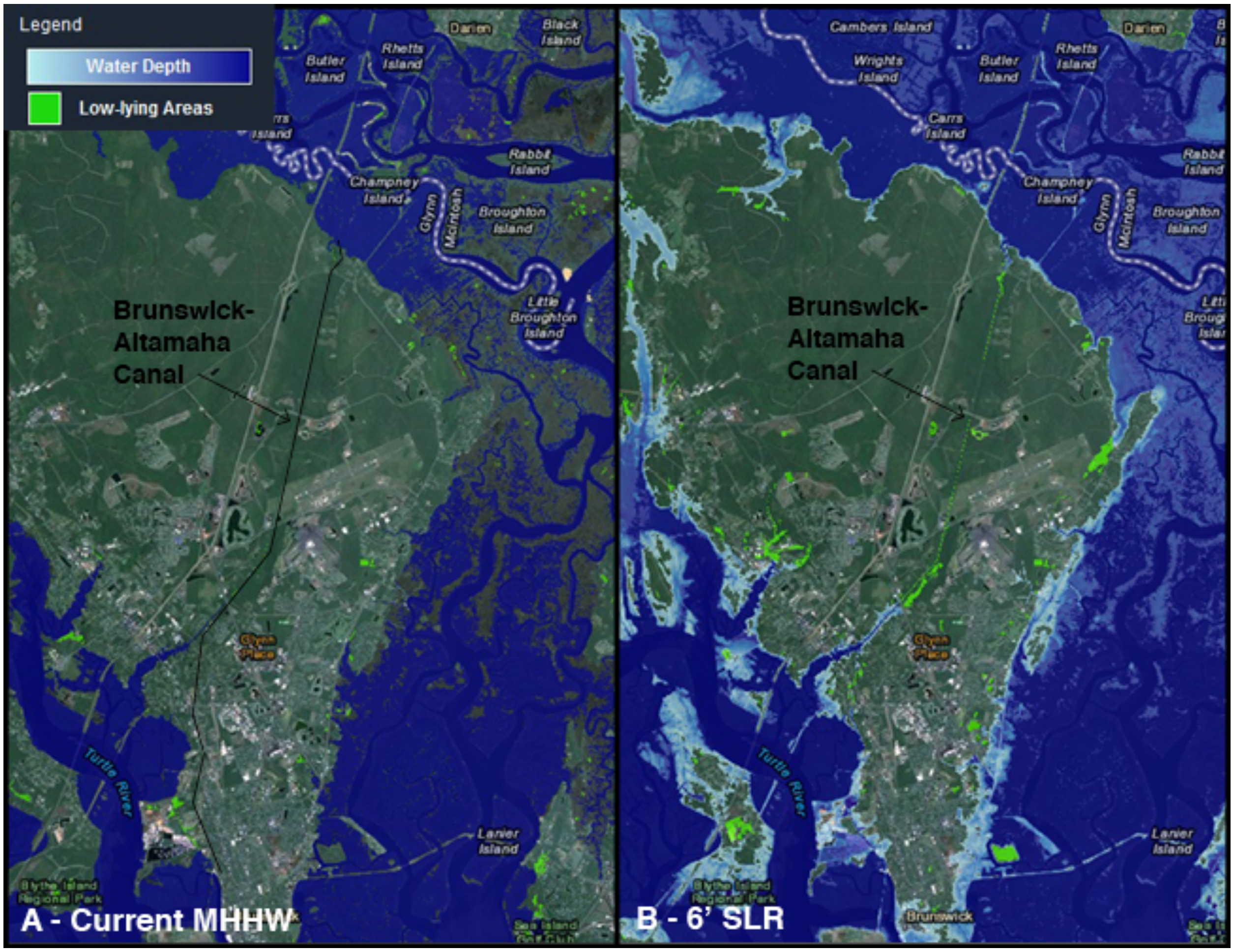


Figure 28: Sea level at current MHHW and with a 6' rise. The drainage way created by the canal is visible in green. Screen shots captured using online web map viewer (NOAA Coastal Services Center, 2013).

Sea level rise might not look dramatic along the entire reach of the canal, but upon closer examination there are some significant impacts along several reaches of the canal. Figure 29 provides a closer view of the middle and upper reaches of the canal at a 6' mean higher high water (MHHW) mark. Here several impacts become visible. First, the area of the canal northeast of Yellow Bluff Creek is clearly impacted. It is low lying and directly connected to an estuarine system of salt marshes along Yellow Bluff Creek and the Turtle River. Second, the northern end near Six Mile Creek also appears to be inundated, possibly impacting some of the historic sites at the historic Evelyn and Elizafield Plantations. Lastly, the interior region of the canal is shown in green as “low-lying land.” NOAA identifies these areas in green as being hydrologically ambiguous as to whether they are connected to waterways or not. By clearing the canal to restore flow for the reutilization, the green areas on the map will become connected to larger hydrologic tidal systems, likely becoming inundated (blue) too. Looking at the map as if the green areas are blue reveals the conduit created by the canal for tidal waters to reach deeper into inland portions of Glynn County. This creates a low lying area for future storm surge and flooding during regular storm events due to the higher waters in the canal.

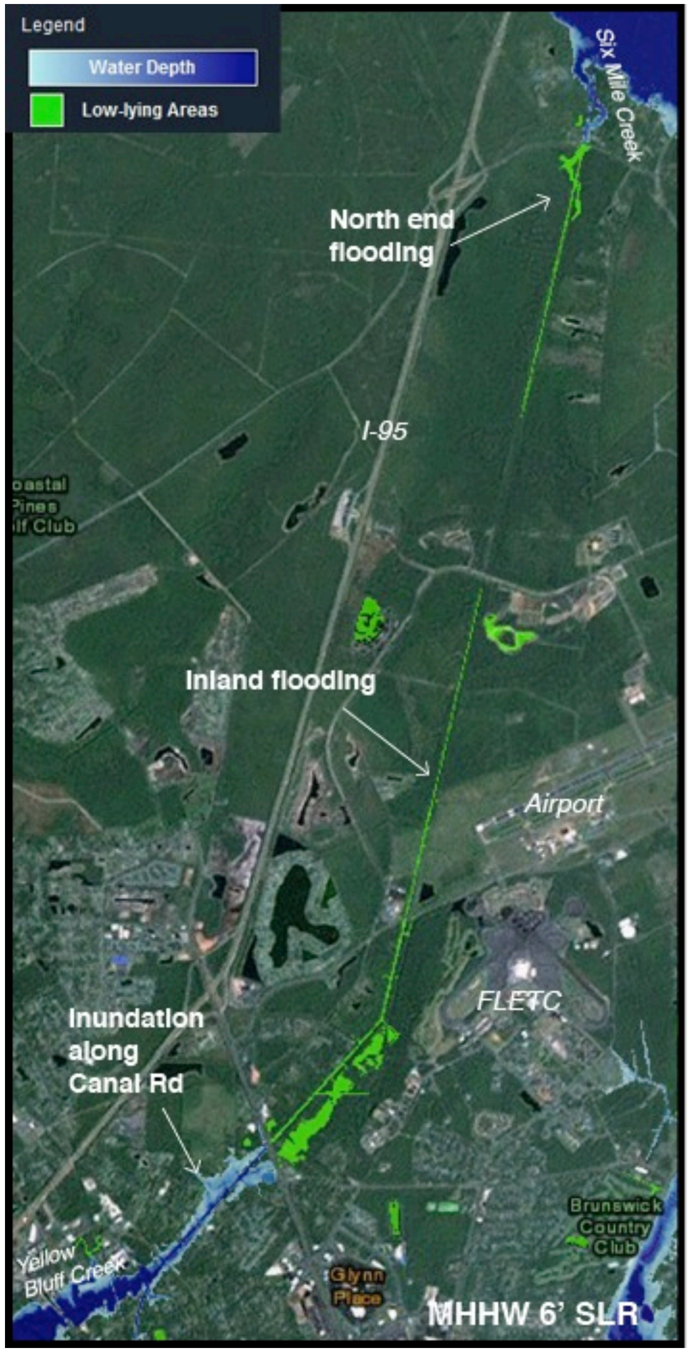


Figure 29: Zoomed view, sea level at current MHHW and with a 6’ rise. Flooding and inundation will increase along the canal near Yellow Bluff Creek and Six Mile Creek, increasing inland flooding as well. Screen shots captured using online web map viewer (NOAA Coastal Services Center, 2013).

With rising salinity levels, vegetation shifts will also begin to occur along the canal corridor. Historically three main plant communities characterized the canal corridor: estuarine marsh, freshwater wetland, and oak-pine upland (Brunswick-Glynn County Joint Planning Commission, 1981). Today these communities are still present although successional plant communities and pine plantations are now present (Appendix B). And sea level rise will further change these plant communities. Figure 30 shows anticipated vegetation changes under various sea level rise scenarios using Sea Level Rise Affecting Marshes Model (SLAMM) outputs accessed through the Georgia Coastal Hazard Portal online viewer provided by the UGA Skidaway Institute of Oceanography (Skidaway Institute of Oceanography, 2013). The SLAMM models show the expected changes to vegetation and land cover under a 1-meter sea level rise scenario by 2100. The shift of regularly flooded marsh along the canal, especially near the Yellow Bluff Creek outlet, is clearly visible. Salt marshes will reach further inland along the southern portion of the canal. The changes along the Altamaha River, while not indicating significant flooding or inundation, show a critical shift toward higher salinity. With a 1-meter rise in sea level, the inlet to the canal along Six Mile Creek will transition from a tidal freshwater marsh to an irregularly flooded marsh, contributing more saline water into the northern canal area. This saline water in the northern end will affect the interior reaches of the canal as the vegetation changes from swamp to tidal swamp. These vegetation changes mean that the future vegetation and thus character of certain reaches of the canal will change as sea levels rise.

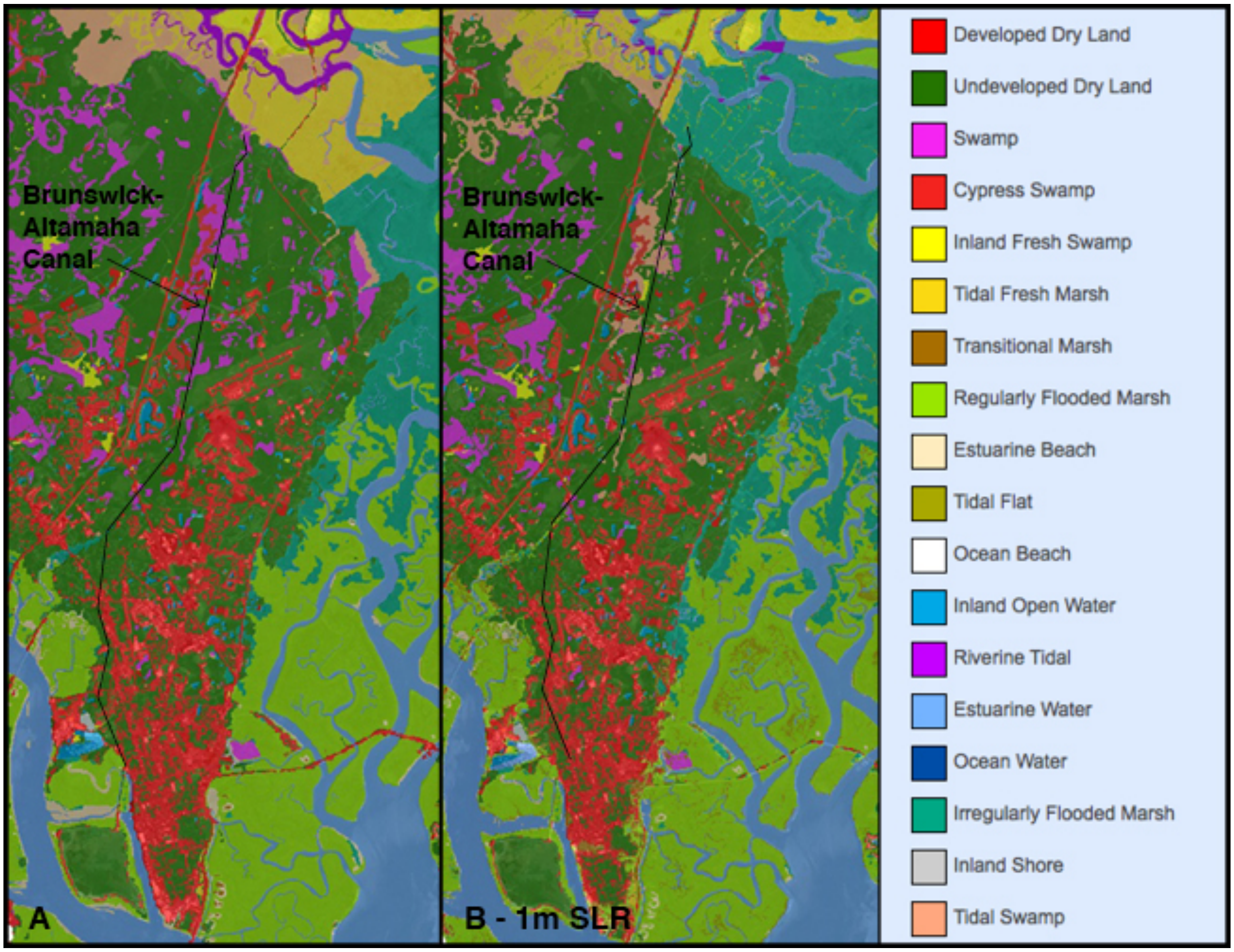


Figure 30: SLAMM Output showing vegetation changes from (A) current vegetation land cover to (B) land cover at 1m sea level rise by 2100. Significant impacts include the transition of the Altamaha River marshes from tidal freshwater swamps to irregularly flooded marsh, contributing more saline waters into the interior reaches of the canal. In the interior, current swamps will transition to tidal swamps. Along the southern portion of the canal, salt marshes will migrate further into the canal corridor. Screen shots captured using online web map viewer (Skidaway Institute of Oceanography, 2013).

One upshot to the rise in sea level is that dredging of the canal bed might be limited, as a rise in sea level might naturally help gain the 42” of base flow desired in the canal. Increased water levels due to sea level rise would also possibly help clear stagnation of some of the middle stretches of the canal, improving drainage of these interior reaches. However, while rising water levels might benefit the flow of water in the canal, the other impacts including inundation, more frequent flooding, and the change of vegetative character along the canal corridor are more striking. The planning of the canal needs to take into account these possible future changes. When planning trailheads, towpaths, and facilities, inundation maps of potential sea level rise and floodplain changes should be critical in the planning process. Otherwise critical features of the Brunswick-Altamaha Canal Reutilization might be inaccessible after a few decades. By assessing the impacts of sea level rise on the Brunswick-Altamaha Canal, the long term use and stewardship of the canal and the ecosystem and community benefits it provides can be ensured.

Conclusion

The Brunswick-Altamaha Canal is a historically significant feature in Glynn County and coastal Georgia. While its use as a canal was limited to a brief period, it is nonetheless a significant feature in the landscape and eligible to be listed on the National Register of Historic Places. Despite its degradation over the past 150 years it is still visible in the landscape and currently acts as a stormwater drainage way for Glynn County. The potential is great for a reutilization of the canal into a recreational greenway and blueway that would provide recreational amenity to residents and visitors to Glynn County as well as restore ecological function to the area, although significant barriers to the repurposing of the canal exist.

Opportunity exists now to plan for future changes such as sea level rise and flooding due to the timing of the canal reutilization. The inventory provided shows that sea level rise may alter the hydrography and hydrology of the canal, especially near the north and south tidal zones. Widening of the canal width, vegetation shifts, salinity changes, and more frequent flooding could be experienced along portions of the 12-mile canal. Taking steps now to look further into the impact of sea level rise on the future of the canal will prevent placement of critical services such as trails, trailheads, parking lots, and facilities within future flood zones. Careful analysis and foresight toward adaptive planning will ensure the long-term viability and use of the canal greenway and blueway for decades to come.

CHAPTER 5

DESIGN APPLICATION

This thesis applies the findings and discussions on sea level rise and green infrastructure from previous chapters to a design for a site-specific section of the Brunswick-Altamaha Canal. The goal of the design is to provide a conceptual vision of what the application of green infrastructure in an area vulnerable to sea level rise might look like at the site-design scale. The design aims to increase the ecological resilience of the site through the use of green infrastructure and also increase the social resilience of the community surrounding the site by emphasizing the visualization of landscape change over time through the site design.

Site Selection

The chosen site is located in Glynn County, GA and lies along the southern reach of the Brunswick-Altamaha Canal. The site is located on Old Jesup Rd between the cross streets of Walker Rd and Canal Rd (Figure 31). The site is currently in use as a mobile home park, called Driftwood Mobile Home Park. Approximately 77 trailer homes are located here, although during a site visit in February 2013, it appeared that many lots are vacant and many mobile homes appear vacant. Adjacent land uses include single-family residential houses and a church, Emmanuel Baptist Church. The church also supports a private school, Emmanuel Christian School, with approximately 100 K-12 students enrolled.

This site was chosen for a design application that specifically addresses green infrastructure and sea level rise for several reasons. First, the site is located near the confluence of Yellow Bluff Creek (YBC), a tidal creek, less than a quarter mile downstream from the site. This means that this section of the canal is tidally influenced and thus will be one of the first reaches of the canal to be affected by sea level rise. Second, because of its close connection to YBC, it is at the intersection of a natural system and the altered system of the canal. The site juxtaposes the natural qualities of a meandering tidal creek with the linear geometry of the canal corridor. It offers an opportunity to interpret and respond to each of these conditions. Third, YBC is listed on the Georgia Draft 2012 Integrated 305(b)/303(d) list as an impaired coastal stream for dissolved oxygen, although the 2008 and 2006 reports also list fecal coliform as an impairment type (US EPA, 2013). Due to this impairment, treating the water that drains into YBC, such as the site's watershed, will improve water quality in YBC. Applying green infrastructure at the site provides an opportunity to improve the waters of YBC and Turtle River.

Other reasons for choosing this site include that this region of the canal, although not this particular site, has been identified by the canal task force as a possible location for a trailhead. Lastly, the mobile home park is located in a vulnerable area, with some trailers currently located within the 100-year flood plain. Based on projections of the intensification of once-rare storms, discussed in chapter 2 of this thesis, it is likely this entire site will be vulnerable to flooding in the future. In order to adapt to climate change with social equity, safe housing must be provided for all residents of a community. Although outside the scope of this thesis, it is encouraged that an off-site affordable housing complex be constructed in a less physically vulnerable and low-lying area for displaced residents of the Driftwood Mobile Home Park.

Design Process and Site Inventory

This design uses research on the site and inventory/analysis of the impacts that sea level rise will have on the site. The process focuses on water management and looks specifically at how to integrate green infrastructure into the site. The author conducted a site visit to Glynn County, GA in May 2012 and February 2013. The site visit provided opportunities for pictures, ground truthing, and site sketches. Figure 32 provides site photos taken during these visits. The design process included an inventory of the site using Geographic Information Systems (GIS) data from Glynn County, including a 1' contour digital elevation model (DEM) provided by the Glynn County GIS department. This high-resolution data was integral in developing a design that recognizes the subtle shifts in topography that will occur with sea level rise.

The design process also utilized online public interactive maps provided by NOAA and UGA's Skidaway Institute of Oceanography. Inventory mapping using NOAA's Sea Level Rise Web Viewer, and SLAMM models accessed through the Georgia Coastal Hazards Portal provided inventory data on inundation, predicted sea level rise, vegetation change, and other regional coastal data that was not accessible through GIS. These online web viewers increase the access to data and knowledge at the regional scale, but are not a substitute for rigorous studies at the local level. The outputs of these online models are used conservatively in the inventory of the site and only used as general possibilities, not definite truths.

A site inventory diagram illustrates some of the findings of the site analysis (Figure 33). Some findings, like the nearby Superfund site and EPA stream impairment of Yellow Bluff Creek, as described previously in this chapter, provide justification for targeting green infrastructure practices at this site. There are two wet ponds that lie parallel to the canal along the site. The site has a slightly sloping topography that drains toward the canal, with a forested canopy of mature live oak and pine trees. There is little understory growth in the mobile home section of the site with most groundcover that is cleared or in lawn. However there is significant understory growth along the buffer between the mobile homes and the canal. A fence currently separates the mobile home community from the canal, blocking access to the canal from the site. A bridge crossing at Old Jesup Rd provides views of the canal but does not have sidewalks or bike lanes, limiting non-motorized traffic from safely accessing these views.

The design of this site specifically states the goal of applying green infrastructure to a site that will be impacted by sea level rise. To meet these goals, an inventory of diagrams showing projected sea level rise inundation at three height intervals (current mean sea level, 3' sea level rise, and 6' sea level rise). These sea level rise heights were chosen based on predicted sea level rise projections from chapter 2. Figure 34 shows the maximum extent of daily tidal inundation of water levels on the site. The figure use mean higher high water (MHHW) as the justification for the highest typical daily reach that water levels will have at this elevation. This does not mean that water will always be at this level throughout the day, but it will mean that tidal marshes and salinity will be affected in this area, at least for portions of each day.

Tidal range is an important factor in a sea level rise inventory, as it determines the elevation of highest water for each day and average mean over time. Tidal gauge data from NOAA's website can provide a baseline of expected tidal range in a given region. The closest tidal gauge station to the site is located at Howe St Pier, located in Brunswick, GA about 5 miles from the site. This tidal gauge data reveals that the average mean tidal range is 7.13' at this station (NOAA Tides and Currents Website, 2012). However, because tidal influence diminishes with increasing distance inland, it is assumed that tidal influence at this site along the canal will be less significant than at the tidal gauge station. Photos and ground-truthing from the site visit reveal that indeed the canal is tidally influenced, somewhere on the magnitude of a three foot range. Without access to a specific tidal gauge station at this site, the author uses a daily tidal range of 3 feet as a conceptual range that may be appropriate at this site.

Results from the sea level rise inventory suggest that the widths of the canal will be altered with sea level rise. In particular, the width of current MHHW and future MHHW will contribute to a wider channel width of the canal. Current width of the canal in this section is between 40’ and 60’ at mean tide level. With a 6’ rise in sea level the canal width will expand to between 100’ to 230’ at mean tide level. The two stormwater wet ponds located adjacent to the canal will be inundated at high tide with a 3’ rise in sea level, and inundated completely with a 6’ rise in sea level. These changes will undermine the current use of the wet ponds as stormwater drainage and control measures, as they will be filled to capacity with estuarine water and no longer able to buffer increased stormwater. This finding further legitimizes the additional uses of green infrastructure practices to help regain function lost by the wet ponds.

Site Design

The design of the site specifically addresses the goal of applying green infrastructure at a site scale to help increase sustainability and resilience to coastal climate change impacts of sea level rise and flooding. Using background information from the literature review on sea level rise projections, the standard of a 6’ rise in sea level is chosen to be the basis for future water levels on the site. The design figures show the concept, adaptation strategies used in the design, a site plan and section at current mean water levels and a site plan and section with a 6’ rise in mean sea level (Figures 35-39).

Program

The site is redesigned as a public park that functions as a trailhead, day use park, and overnight camping location for through-paddlers travelling along the Brunswick-Altamaha Canal. The flat topography, abundance of mature live oaks and pine trees, and the open nature of the understory due to its use as a housing development, already provide a park-like quality to the site. The site is accessed off Old Jesup Rd with a parking lot, nearby restroom, and day use pavilion. A boat rental (canoes and kayaks) facility is located near the boat launch ramp, and would be designed as an open-air structure and elevated structure to accommodate possible flooding. The southwestern portion of the site is converted into an overnight camping area designed to accommodate paddlers. The campsites are for tents only, not RVs. Camping pads, a restroom, check-in/fees kiosk, and access road are located at the campground sites.

Clearing the undergrowth from the site near the wet ponds and creating a series of boardwalks that run parallel and perpendicular to the canal create access to the waterfront. The main pedestrian path is a fixed, curvilinear wooden boardwalk that runs along the length of the canal. This boardwalk allows for a more intimate connection with the canal and its surrounding vegetation. Bike traffic and pedestrians who wish to divert from the scenic boardwalk can use the multi-use path that lies on the upland area of the site, paralleling the road. Secondary paths include walking trails through the flat forest landscape and floating boardwalks that are placed in the wet ponds. Figure 39 illustrates the location, width, and qualities of each path type.

Green Infrastructure Applications

The design accomplishes the goal of utilizing green infrastructure by using an array of practices, including bioswales, wetlands, permeable paving, green roofs, and rainwater harvesting. The main goal of the site is to allow adequate area for the migration of coastal vegetation, and to facilitate the migration with sea level rise. The ecological approach to the design creates a series of bioswales that change their function through time to act as stormwater conveyance today and tidal inlets with sea level rise (Figure 41). The swales are cut into the landscape as part of the initial design, and function as swales for the treatment and conveyance of stormwater runoff. As sea level rises, the swale topography makes them the first areas to be inundated by the rising water. With time, and possibly intervention and restoration, the swales will transition from the grass swale mix into a mix of salt-tolerant plant species such as, *Spartina alterniflora, Spartina patens, and Juncus roemerianus*. The swales will then function as tidal creeks, bringing water, sediment, and nutrients into the interior of the site and restoring natural drainage functions and patterns to the site. Figure 42 shows a vignette of the swales at the site.

Visualization of landscape change

The second major design goal is to make sea level rise, both experienced and predicted, a visible feature in the landscape. To accomplish this, graphic water markers are placed on the site to visibly connect visitors to the coastal topography and water levels. The markers follow one-foot topographic contours, but their spacing between and among each other is random. They are meant to hint at the general topography, but not be a literal interpretation of it. In this way the markers serve as a way to make the subtle, changing topography of this coastal landscape visible and exaggerated.

High water markers are common in coastal landscapes and would not be an interesting design feature, however this design multiplies and abstracts the water markers, removing them from their literal context. Instead of placing just one vertical marker on the site, there are dozens.

The markers would be made of metal, a resistant material, and would be sized at a uniform 2' width and 6" depth, and a variable height between 2-20' tall. Figures 42-43 provide vignettes of the markers at various areas of the site that show the form, color and placement of the tidal markers in the landscape. The varying heights of the markers provide visual interest as well as the ability to make large fluctuations in water level visible. The exaggerated height of the markers make small changes on the ground a dramatic feature in the landscape, reorienting the topography to be at eye level rather than on the ground place. In this way, the topography of the site is raised from the ground plane into the vertical plane. In a coastal area, where small changes in topography are critical, the markers will help illustrate just how important small shifts in water level are to coastal ecosystems.

Instead of marking heights at different intervals, as is typical of high water markers, the designed markers will read only one number, the elevation at which the marker lies in the ground. This number will be cut out from the metal, minimizing the amount of maintenance required to make the numbers legible year after year. The markers are also colorful, designed so that different colors correspond to different landscape elevations (for example, red markers are placed at the 1' contour line, orange markers at the 2' contour line). The heights of the actual marker may vary within their color coordination, but the elevation that the marker represents is consistent.

The markers are static features in the landscape. Once installed they are left in place and do not move. However, the water level and landscape around the markers will change with time. As sea level rises, or daily tides rise and fall, the color on the markers is inundated or revealed. For example, a 1' rise in tide will inundate the red markers, but the base of the orange markers will still be visible on the ground. As water rises to 2', the orange markers are also inundated;

leaving only an orange tip that is visible in the landscape. Eventually, markers that once were on dry land will be surrounded by water, further revealing the change that is occurring in the landscape.

While the markers span both land and water, they also will cross into the plane of the boardwalk in places, as shown in the vignette in Figure 43. Through a hole cut into the boardwalk, some markers will pierce through the boardwalk and rise toward the sky. They will become part of the experience of walking along the boardwalk. These markers will add to the dramatic quality of the site and act as a startling interruption to the sinuosity of the boardwalk, serving as a reminder that sea level rise is not a distant notion but a real and tangible threat.

Design Discussion

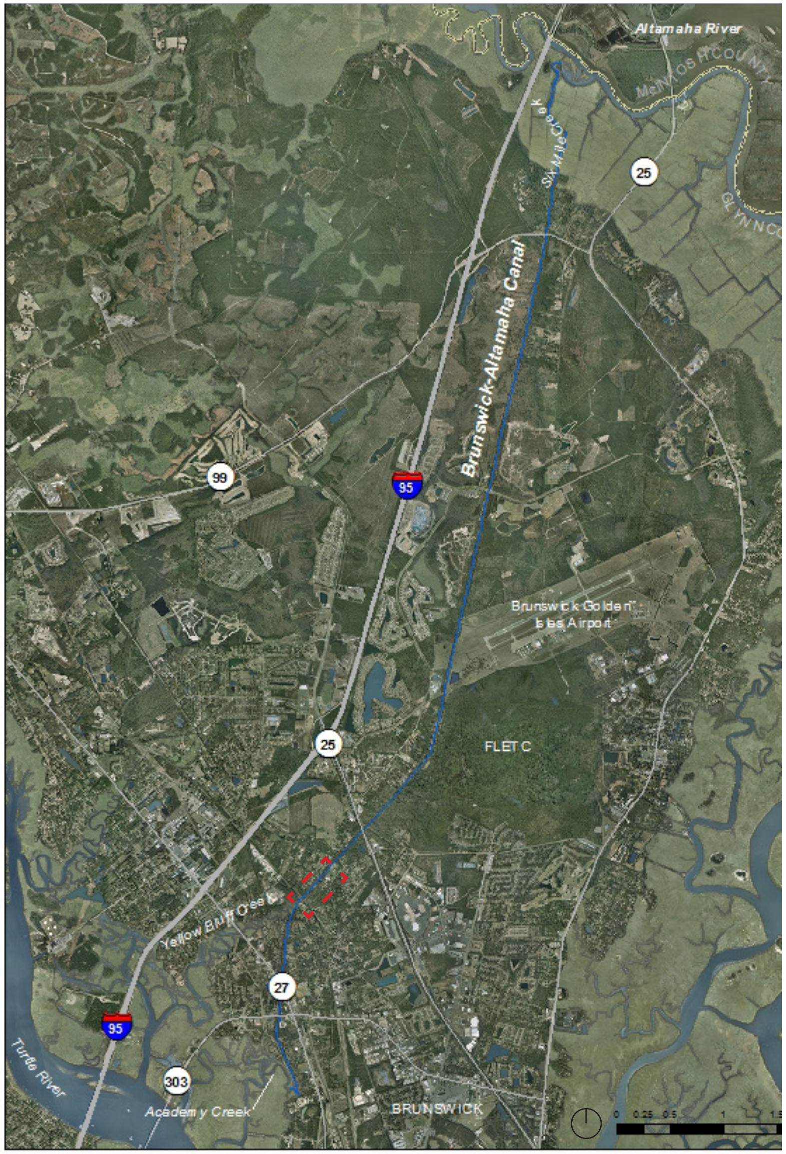
The design of the site attempts to create a framework of green infrastructure that can accommodate and facilitate the adaptation of rising water levels and vegetation shifts predicted with sea level rise. While the ecological function of the bioswales could improve the ability of the site to be resilient to small disturbances (i.e. a low level of sea level rise), their function in the case of a large coastal storm is not calculated or understood. The design makes no claim that the green infrastructure applied to the site will protect the boardwalks, structures, camping sites, vegetation on the site or the surrounding properties from large storm events or high storm surges. The design is meant to be a conceptual intervention into the landscape that could help bring resiliency and function to the site and to the Brunswick-Altamaha Canal and its surrounding water bodies.

Returning to the other adaptation strategies outlined in chapter 2, such as accommodation and retreat, this site design can allow for a certain measure of integration among these strategies.

The buildings on site could be designed to accommodate raising the structures and occasional flooding. And structures such as the kayak and canoe storage facility could be designed as open to the air and would accommodate occasional flooding. Simple structures such as the restrooms, day use pavilion and kiosks could be designed to be elevated at a later date, as threats of rising waters become more apparent. And camping pads that are currently placed on the ground could be elevated into camping platforms that are accessible by water or ramps.

The process of coastal retreat would also be set in motion by this design. First, the vulnerable populations living in vulnerable housing would be relocated already into safe, accessible housing on higher ground, removing the risk of having residents on the site. Secondly, the system of bioswales begins to enable a trajectory of ecological restoration back to a more natural state. The swales would provide conduits for water to migrate, similar in function to natural salt marshes. In the case of total abandonment of this coastal community, the site design would provide for some level of ecological restoration that otherwise would be lacking in the landscape of today.

While the proposed site design does not protect the site and surrounding region from apocalyptic predictions of large-scale sea level rise, frequent hurricanes, and extreme storm surge, it does accomplish the stated objectives of using green infrastructure and visualizing landscape change due to sea level rise. The design applies the principles of green infrastructure to a specific site, and the system of bioswales establishes a framework to enhance the ecological functions of the site. The colorful water level markers create an artistic and dramatic visual element in the landscape that reveals the changing levels over time. The overall design for the park provides services such as trailhead access, boat launches, rental facilities, and camping access that would contribute to the vision of the Brunswick-Altamaha Canal greenway and paddle trail as a vibrant public amenity in Glynn County.



LOCATION Old Jesup Rd between Canal Rd and Walker Rd
Glynco Area, Glynn County, GA
31°13'13.42"N, 81°30'18.80"W

AREA 21 acres

Figure 31: Site Location Maps

Driftwood Mobile Home Park entrance

Empty lot at Driftwood Mobile Home Park, with Brunswick-Altamaha Canal in background

Driftwood Mobile Home Park, live oak and pine canopy character

Yellow Bluff Creek

Brunswick-Altamaha Canal at Old Jesup Rd (southwest view) near high tide

Brunswick-Altamaha Canal at Old Jesup Rd (southwest view) near low tide

Figure 32: Site Photos

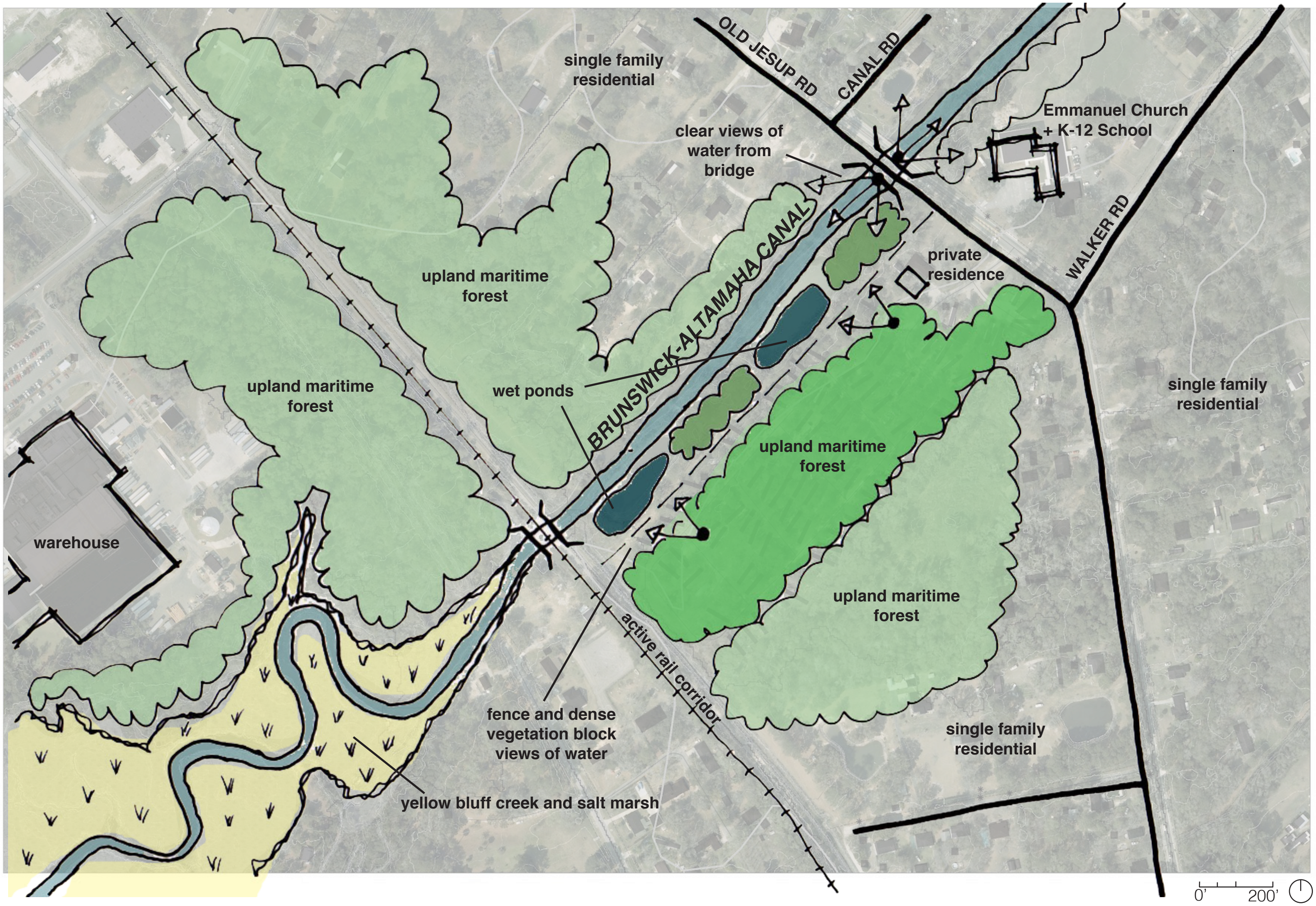


Figure 33: Existing site conditions and site inventory

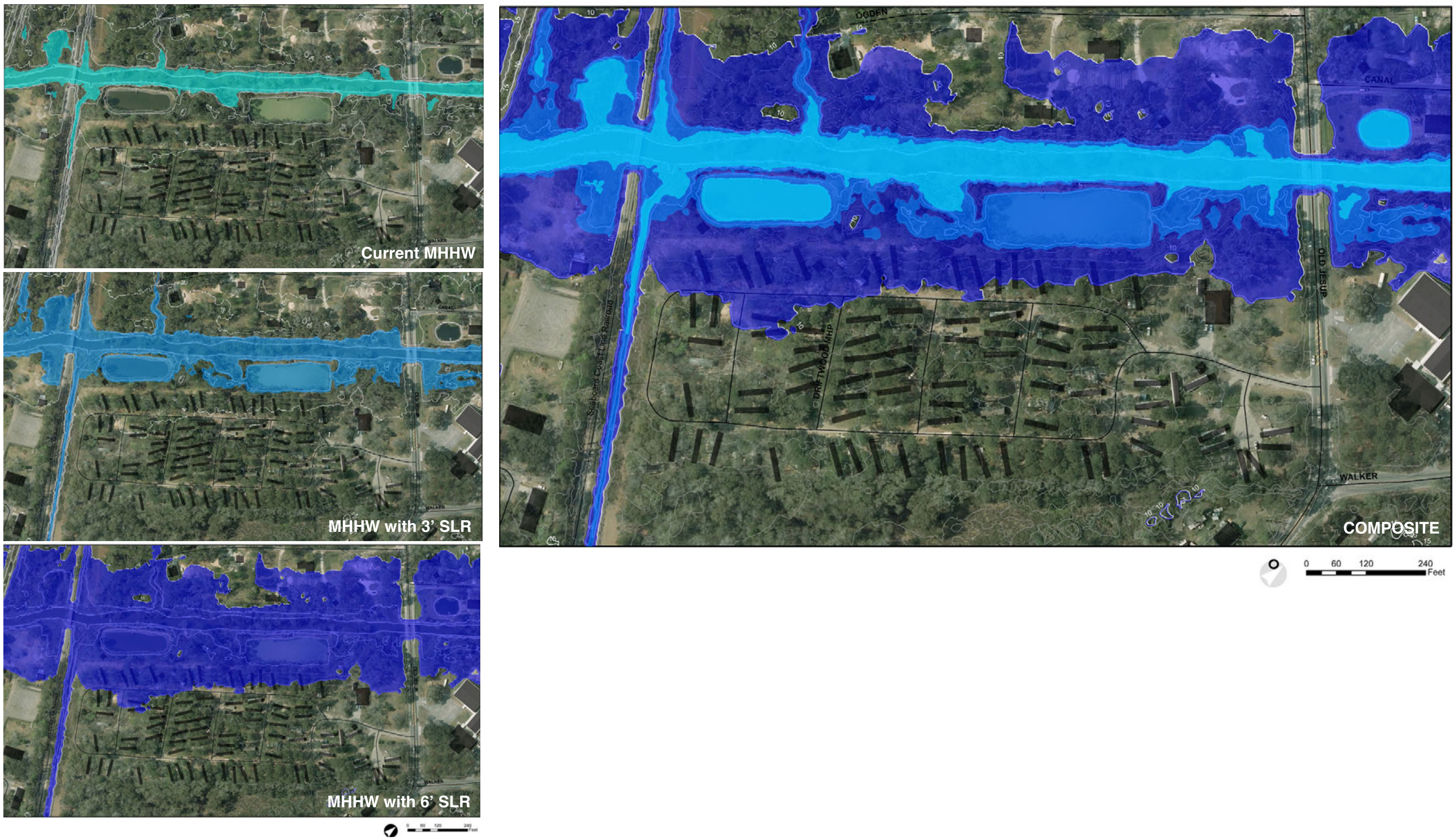


Figure 34: Sea level rise inventory maps. Maps of inundation levels at site with a 3' and 6' rise in sea level, with composite.

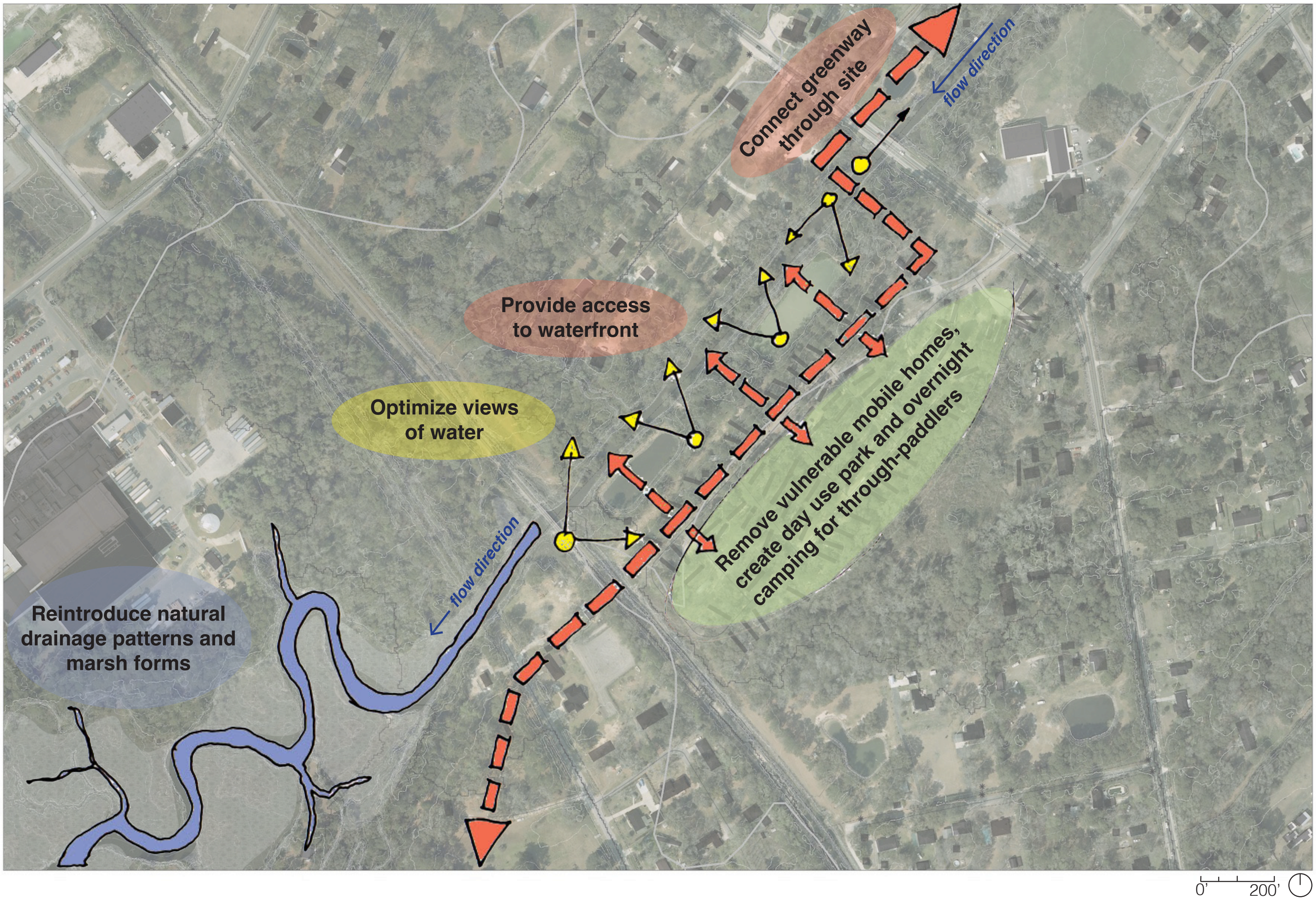


Figure 35: Site Concept Plan

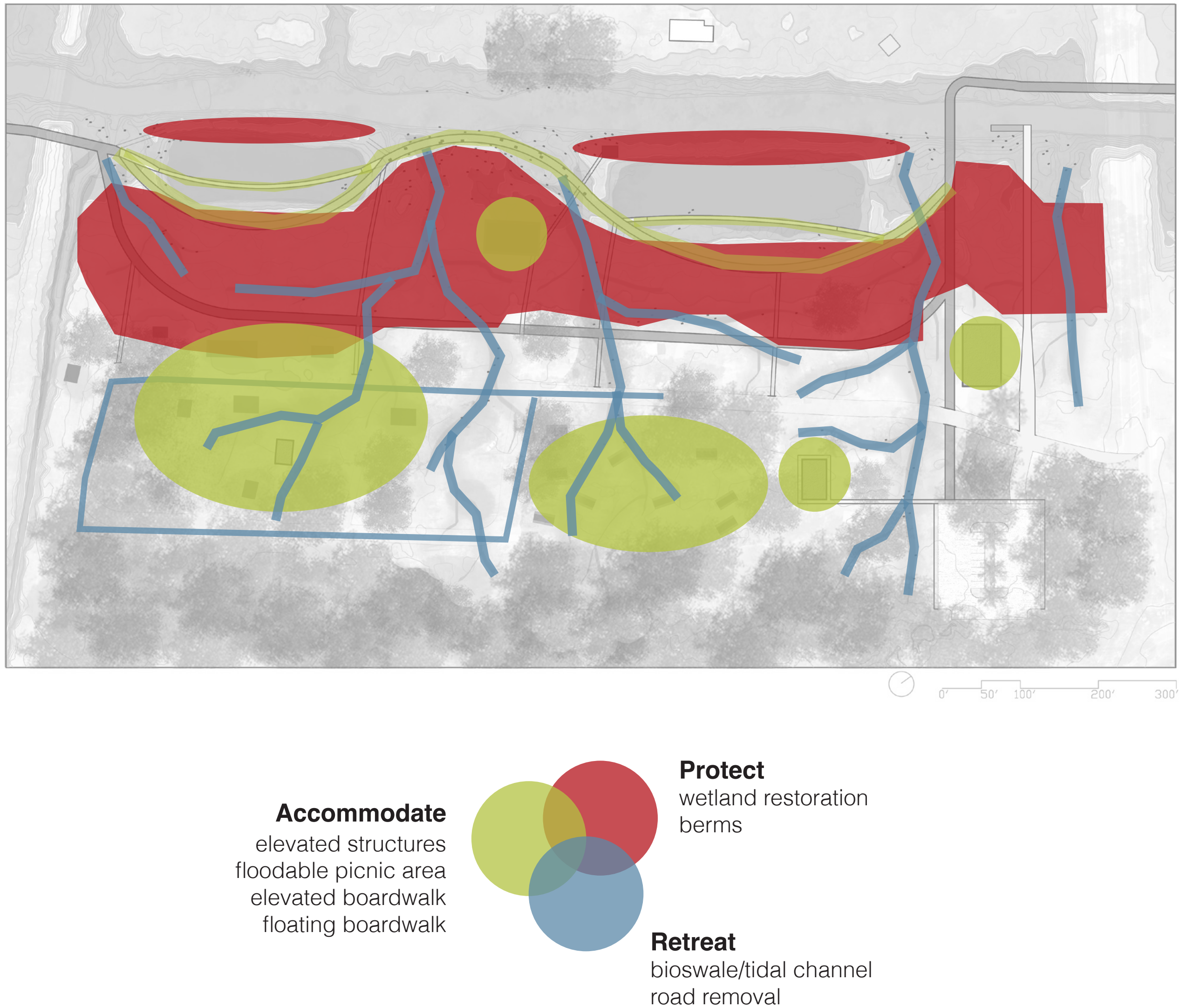


Figure 36: Diagram of applied adaptation strategies

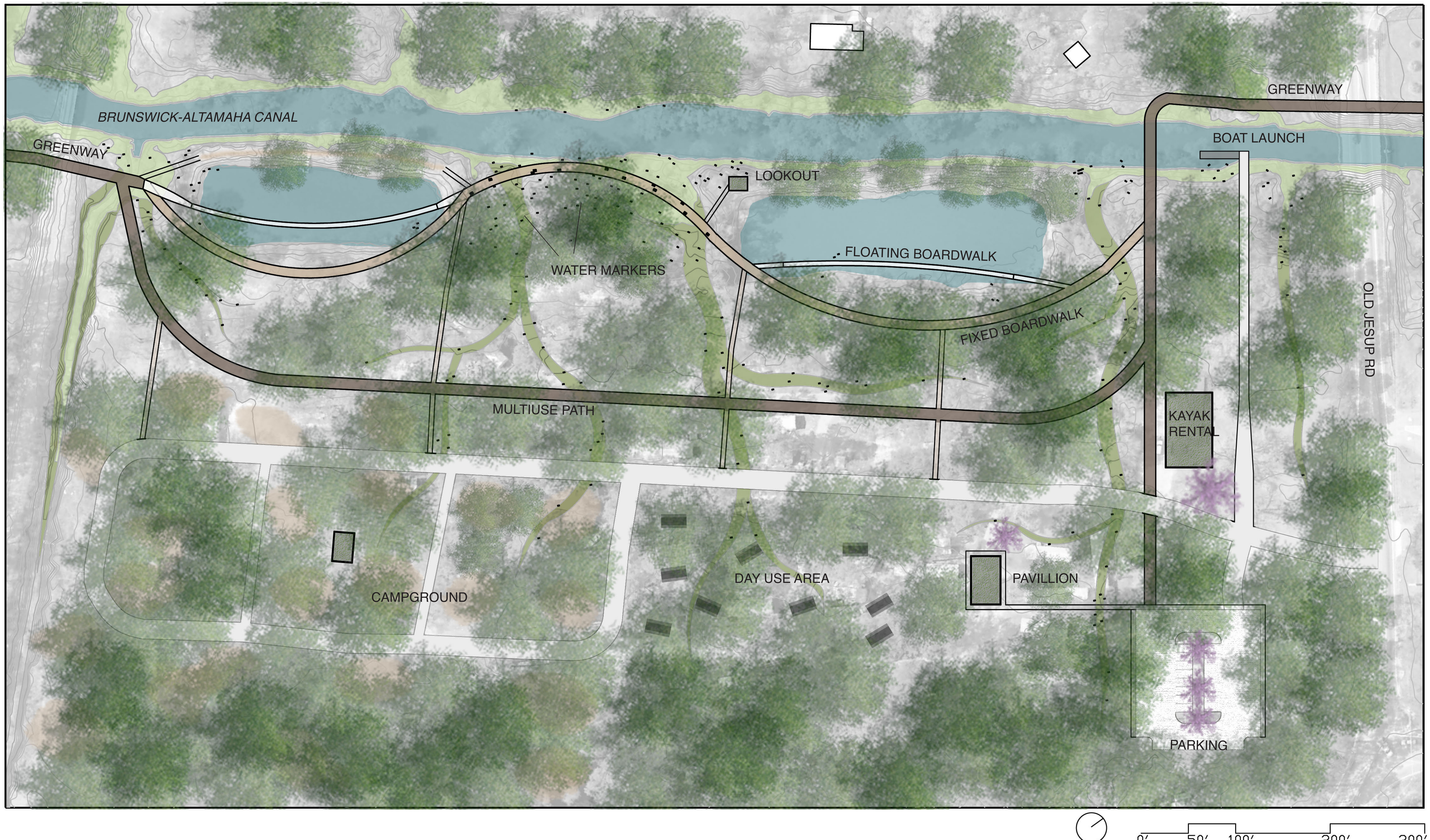


Figure 37: Site Plan - Current Sea Level

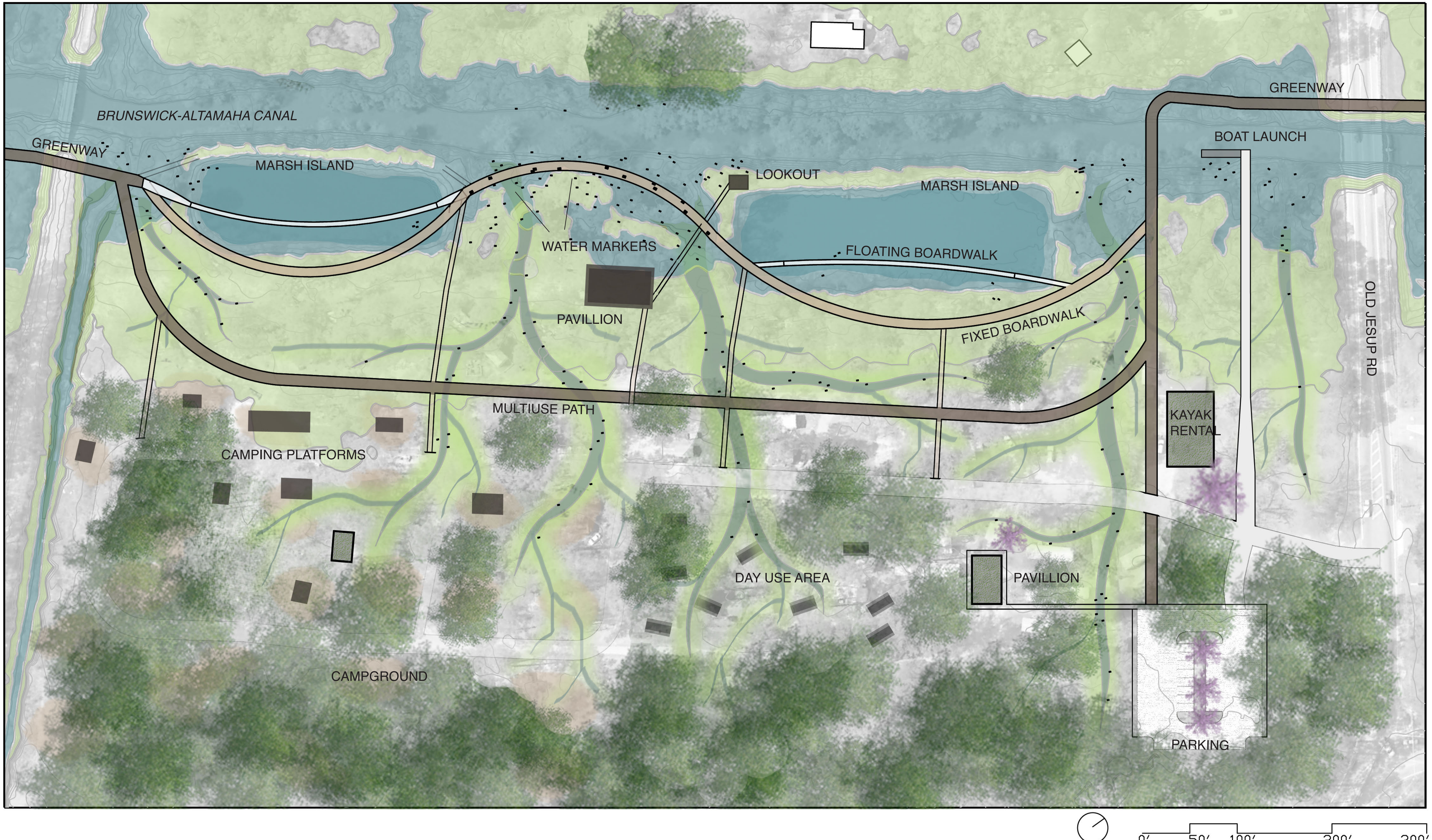
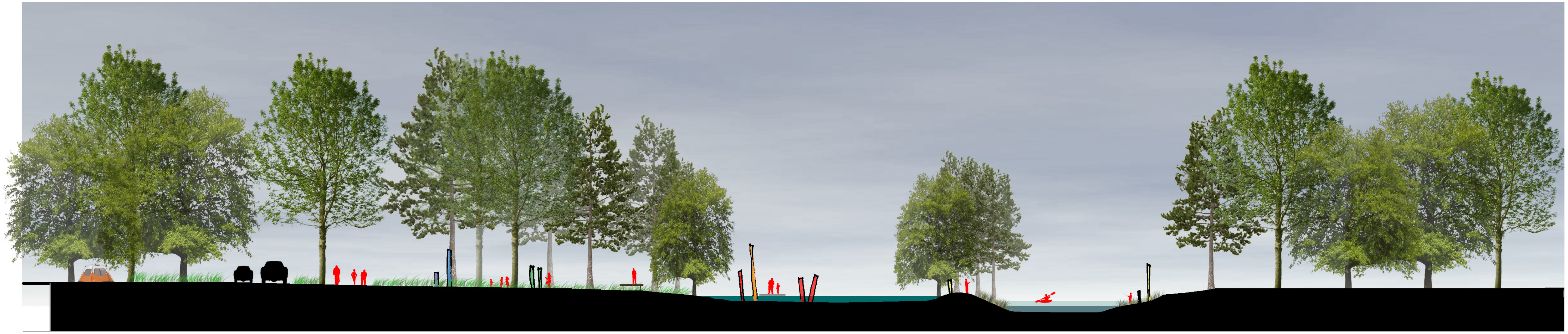
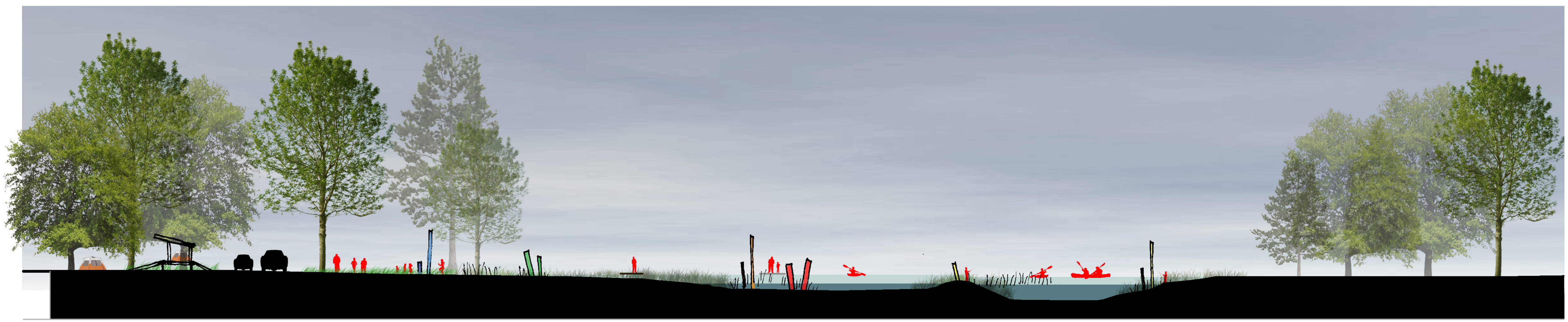


Figure 38: Site Plan - 6 foot sea level rise



SECTION - current site conditions
1"=50'



SECTION - 6 foot sea level rise
1"=50'

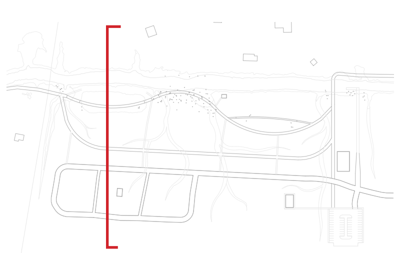


Figure 39: Site Sections - current mean water level (top) and 6' rise in sea level (bottom)

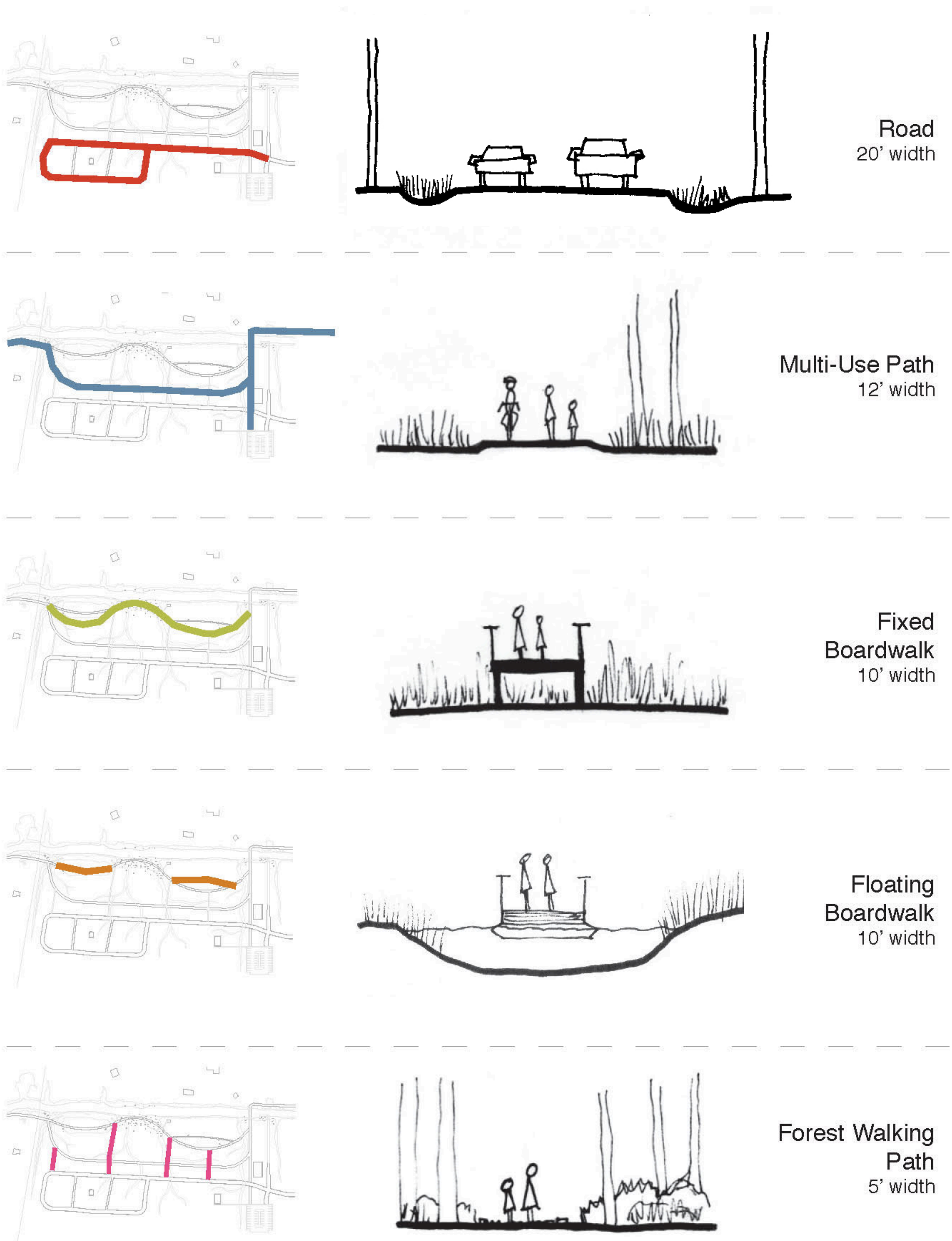


Figure 40: Diagram of Path Types

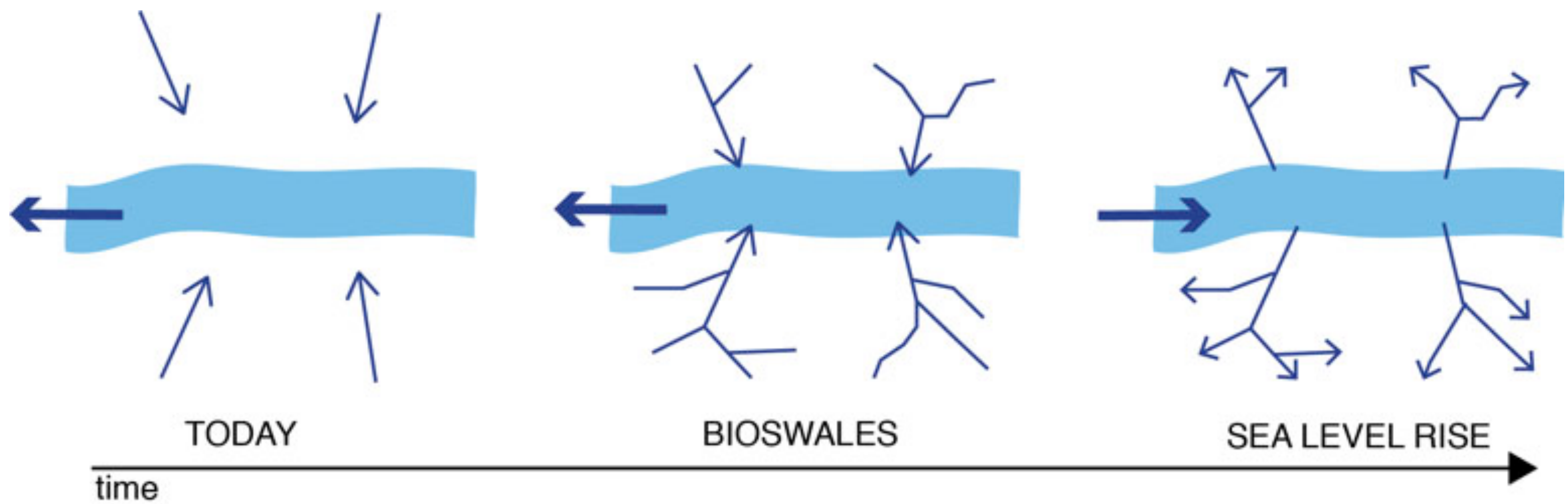


Figure 41: Diagram of swale function. This diagram illustrates the function of the swales over time. Today the stormwater runoff travels directly into the Brunswick-Altamaha Canal. The bioswales would create a treatment and conveyance network to slow urban runoff draining from the site. As sea levels rise, the function of the swales reverses to let water into the site, functioning as a tidal creek system and facilitating marsh migration.

Figure 42: Vignette of bioswales and multi-use path - today (top)
and with 6’ sea level rise (bottom).

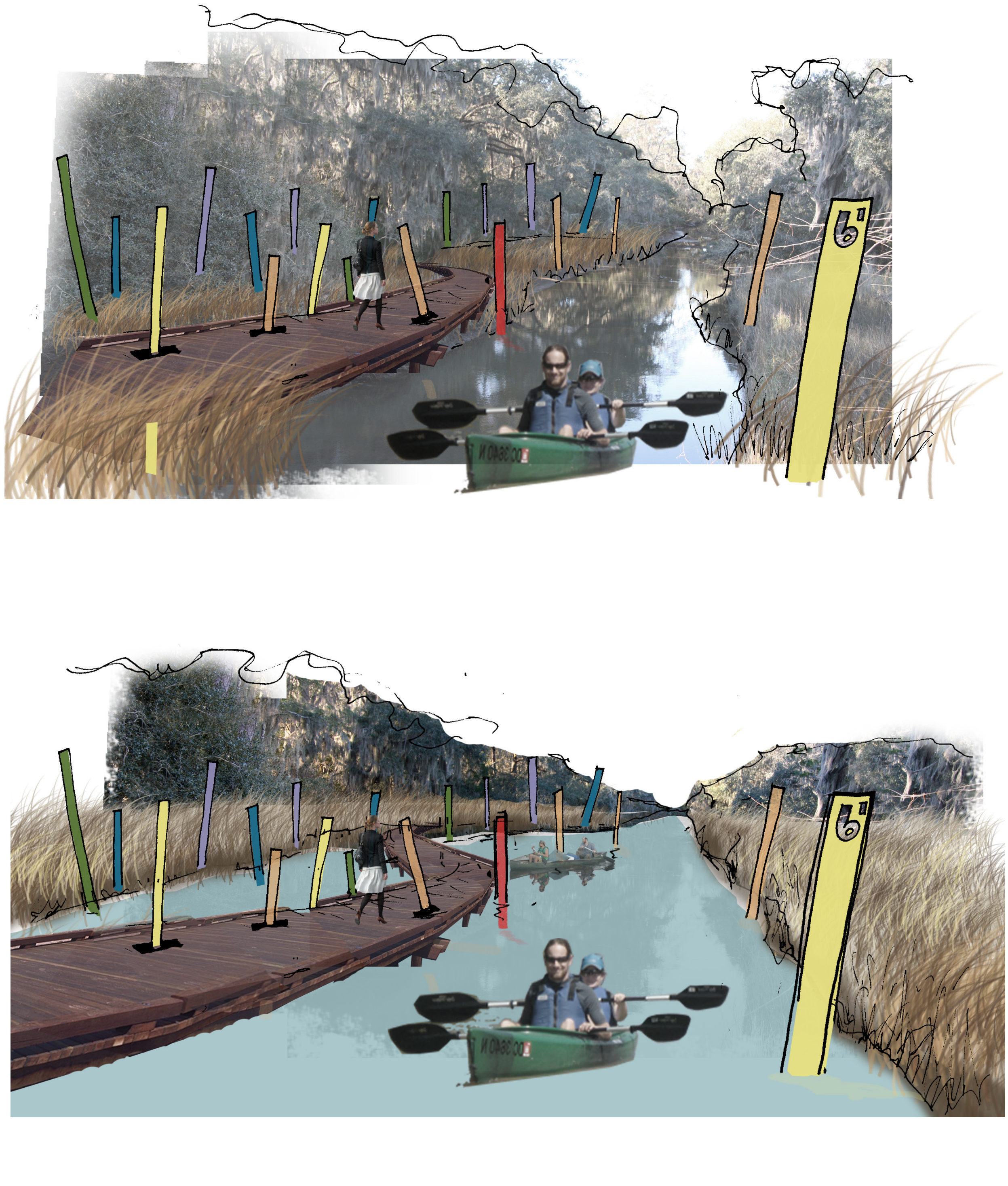


Figure 43: Vignette of canal and boardwalk - today and with 6’ sea level rise

Figure 44: Vignette of camping area - today (top) and with 6’ sea level rise (bottom)

CHAPTER 6

CONCLUSION

With global predictions of climate change and sea level rise threatening the future of US coastal areas, planning and design solutions that protect and adapt our coastal communities from rising waters are rapidly becoming a necessity. Major U.S. cities such as New York, San Francisco, and Boston, as well as countless smaller coastal regions, are now discussing strategies about how best to protect against rising waters. Green infrastructure practices such as wetland restoration, bioswales, green roofs, and rainwater harvesting/reuse are some strategies that could be implemented in coastal regions that would provide benefits to stormwater management today and sea level rise management in the future. By working with, rather than against, natural systems, materials and processes, green infrastructure can assist in buffering capacity for increased storm surge and rising water levels. In addition to discussing direct water management measures, this thesis has argued that green infrastructure might provide benefits to a broader definition of sustainability and contribute to increasing resilience in urban coastal areas. However, knowledge of how green infrastructure will perform over time due to changing hydrology, salinity changes, and vegetation shifts caused by sea level rise is uncertain. Due to these uncertainties and limitations of green infrastructure for protection, green infrastructure should be applied as part of an array of planning and design strategies, including protection, accommodation, and managed retreat. A combination of all these strategies will provide the adaptation methods needed for highly vulnerable coastal areas.

The implementation of green infrastructure, as part of a wider adaptation plan, should be encouraged in coastal communities, especially those that are seeking low cost methods of adapting to small changes in sea level rise today and in the near future. Landscape architects can be advocates for its use as an adaptation strategy and can further the discussion of designing for future uncertainty and resilience. By providing site-specific designs at the human scale, landscape architects can also contribute to greater public awareness about the threats and risks of sea level rise.

This thesis identifies the potential for reutilization of the Brunswick-Altamaha Canal, and the importance of planning for resilience to future changes. Opportunities exist to plan and design the existing canal into a greenway and paddle trail that enhances the environment, economy, and communities in Glynn County, GA. But these opportunities could be threatened by climate change. This thesis provides an initial inventory of the canal corridor that reveals that portions of the canal and surrounding communities will be effected by sea level rise. The design application inventory provides an example of site-specific inventory of sea level rise impacts. And lastly, the design of the trailhead park and campground is one example of how green infrastructure practices can be applied to a coastal site and how the landscape can reveal subtle changes to topography and hydrology as water levels rise and vegetation shifts through time.

Throughout the process of this thesis, several areas of further research needs have been identified. Many of the limitations of pursuing green infrastructure on the coast are the unknowns associated with its capacity to protect and provide ecosystem services in a changing climate. First, more research and case studies are needed that specifically address the impacts of sea level rise on coastal green infrastructure and the long-term quantification, monitoring, management and performance of green infrastructure landscapes in coastal communities. The potential effects of projected changes to coastal hydrology and groundwater are particularly critical to understand due to their implications to the underpinnings of green infrastructure, such as absorption and infiltration. Second, the design fields can contribute to a greater body of work on design solutions for sea level rise thorough a review of case studies and precedent designs that specifically address sea level rise both nationally and internationally. Third, on the Georgia coast there is a critical need to start sea level rise adaptation planning now, before Georgia's beautiful coastal communities are threatened even further.

This thesis has used the methods of literature review, precedent design study, inventory, analysis, and design application to answer the research questions provided in the Chapter 1 of this thesis. The thesis has shown that green infrastructure can be a viable adaptation strategy for coastal sea level rise adaptation planning, but that it has its limitations. Further scientific research is needed to define the exact quantification of the capacity of green infrastructure to protect against rising water levels and increases salinity. In the mean time, green infrastructure can be a cost-effective way to make small, incremental changes to increase future resilience in coastal communities. By working with nature's services, green infrastructure might provide some level of protection, while also benefiting ecological and community health. At a time when action is needed to protect our coastal communities and resources from climate change, every small step in increasing resilience is beneficial. Green infrastructure can provide those small steps, and by nature is flexible and adaptable. Facing uncertain future scenarios of water level and storm events, coastal communities will need strategies that can mitigate and adapt to a variety of possible future conditions. By increasing sustainability and resilience today, green infrastructure is a powerful tool that landscape architects and planners can use to help our coastal communities adapt to sea level rise and flooding, despite uncertainties in exactly what that future may hold.

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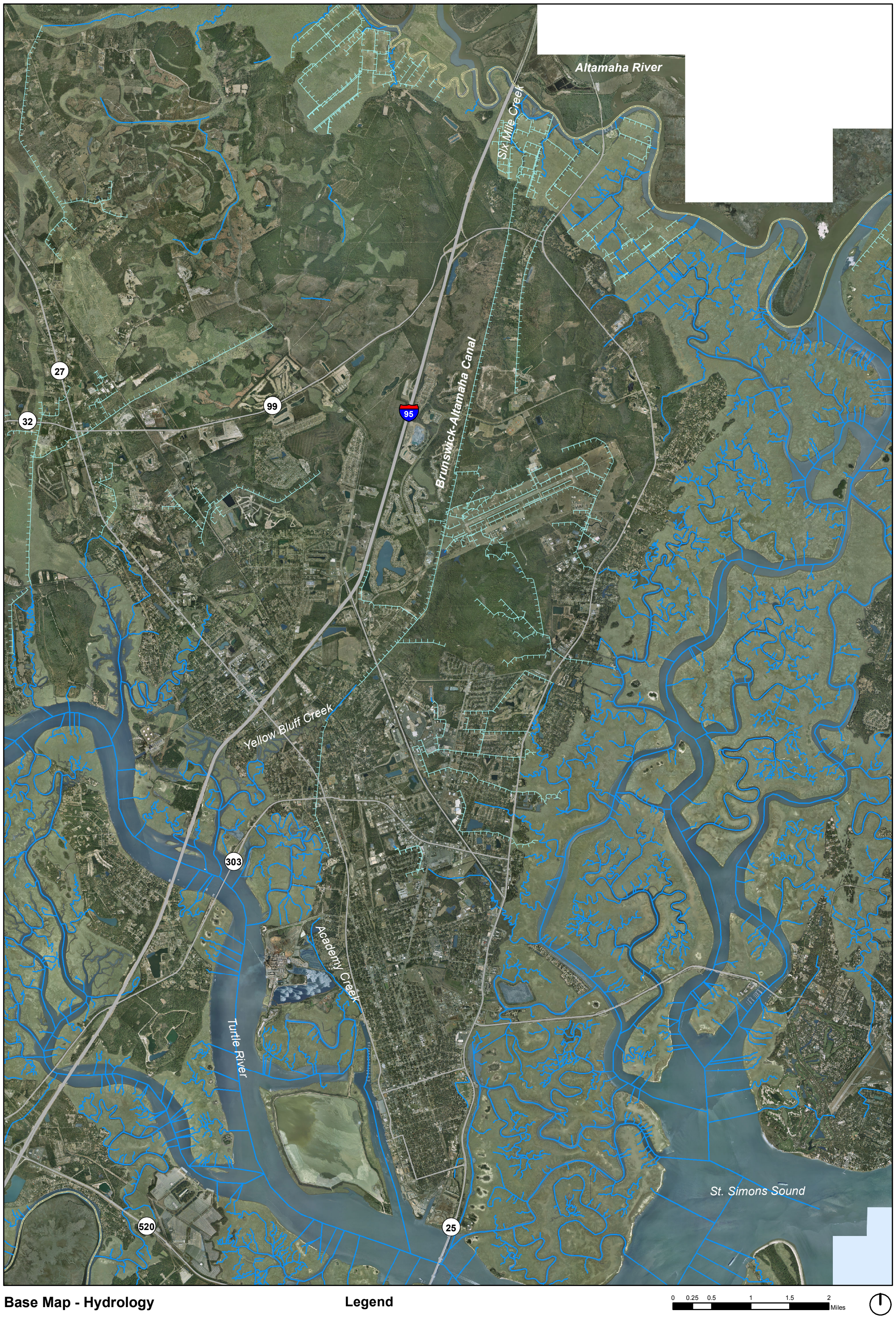
APPENDIX A

BRUNSWICK-ALTAMAHA CANAL CONNECTIVITY STUDY

The following tables and maps were created by the author as an inventory and analysis of the Brunswick-Altamaha Canal corridor for reutilization as a greenway and recreational blueway.

Summary Table: Inventory of existing community assets within a one-mile radius of the Brunswick-Altamaha Canal corridor.

Topic	Feature
County Parks	• North Glynn Recreational Complex • Ballard Park • Ells Point Park • Waverly Pine Parks
Historic Features	• Hofwyl-Broadfield Plantation State Historic Park
Shopping Centers	• Golden Isles Plaza • Glynn Place Mall
Public and Private K-12 Schools	• Needwood Middle School • C.B. Greer Elementary School • Emmanuel Christian School • Heritage Christian School • Morningstar Treatment Services/Youth Estate
Proposed Greenways	• Coastal Georgia Greenway • East Coast Greenway
Proposed Paddle Trails	• Coastal Georgia Blueway (with sites near the Blythe Island Regional Park and Marina campground, Altamaha River and Two Way Fish Camp)
Churches	• Bible Baptist Church • Emmanuel Bible Church
Residential Neighborhoods	• Several residential neighborhoods

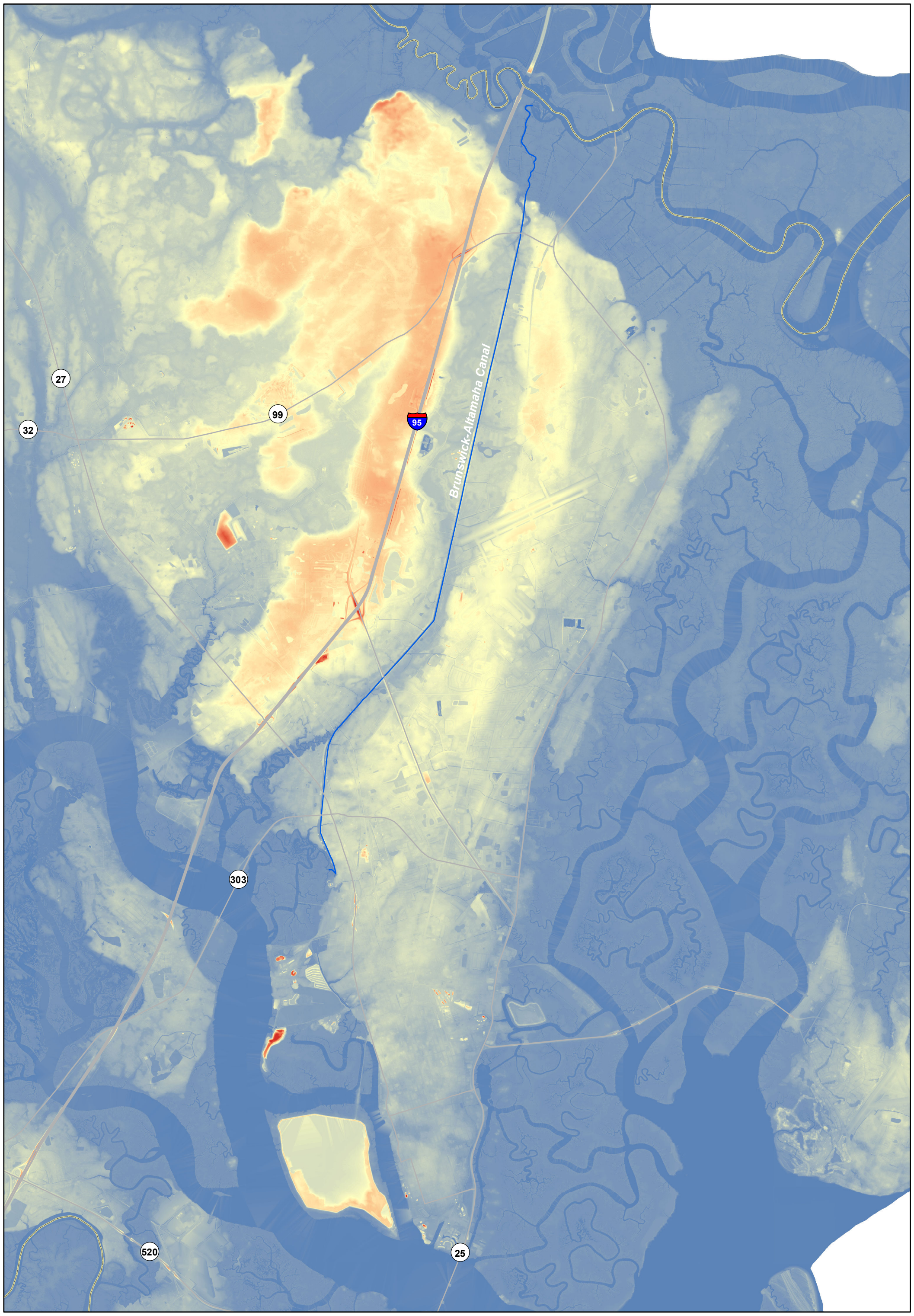


Base Map - Hydrology

Legend

- Stream/River
- Canal/Ditch
- Marsh
- Water

Brunswick-Altamaha Canal Reutilization Study
DRAFT February 2013
Prepared by: Lisa Biddle, Graduate Student, UGA



Elevation

Legend

Elevation (DEM)

High : 87'

Low : -6'

Brunswick-Altamaha Canal Reutilization Study
DRAFT February 2013
Prepared by: Lisa Biddle, Graduate Student, UGA

FEMA Floodzone Designations firm 11-5-08

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Legend

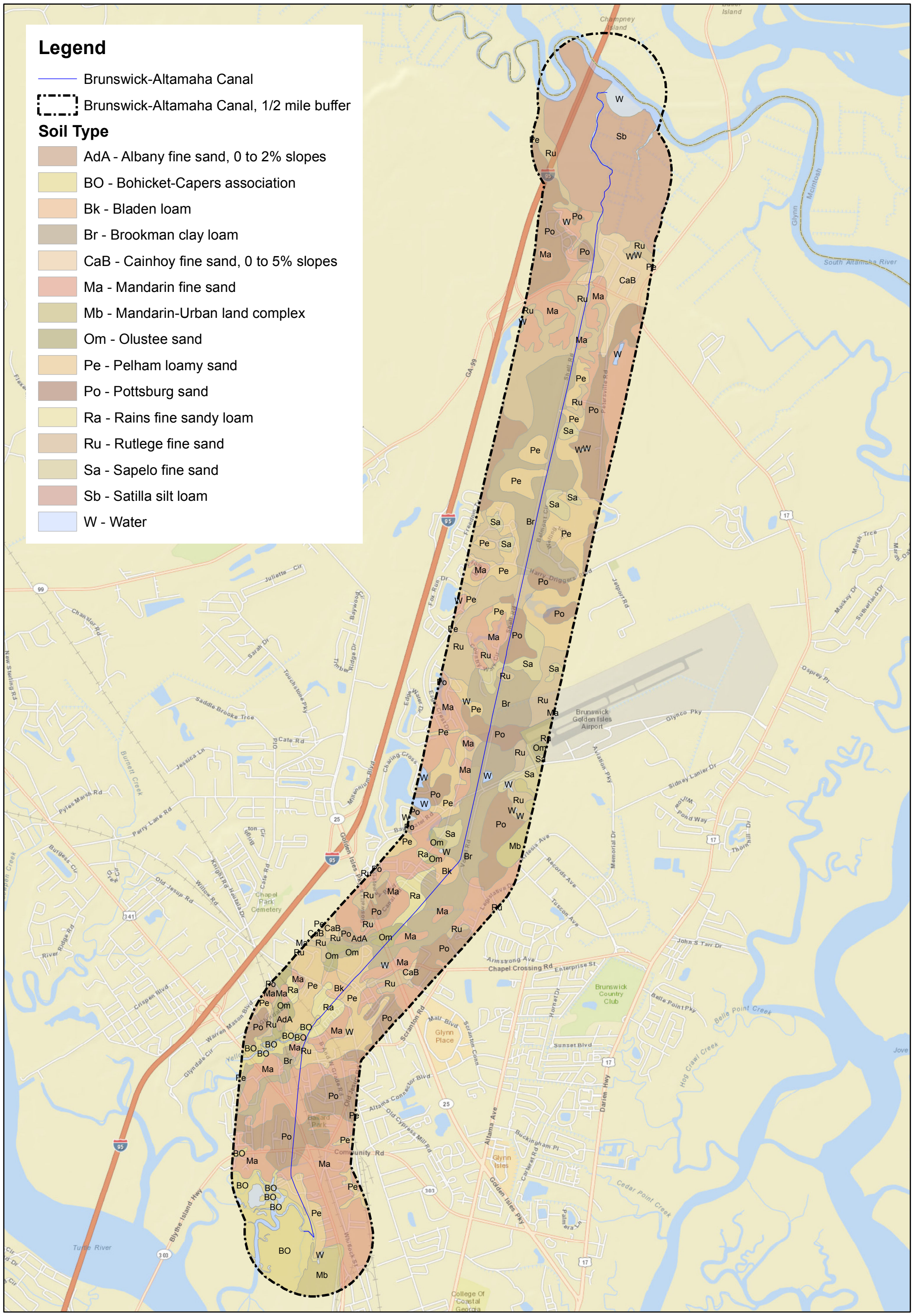
Brunswick-Altamaha Canal

FEMA Flood Zone Designation

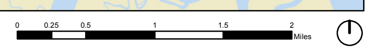
X (UNSHADED)
0.2 PCT - X (SHADED)
AE 10-15
VE 13-20
OPEN WATER

0 0.25 0.5 1 1.5 2 Miles

Source: Glynn County data: firm 11-5-08



Soils within 1/2 mile radius of Brunswick-Altamaha Canal



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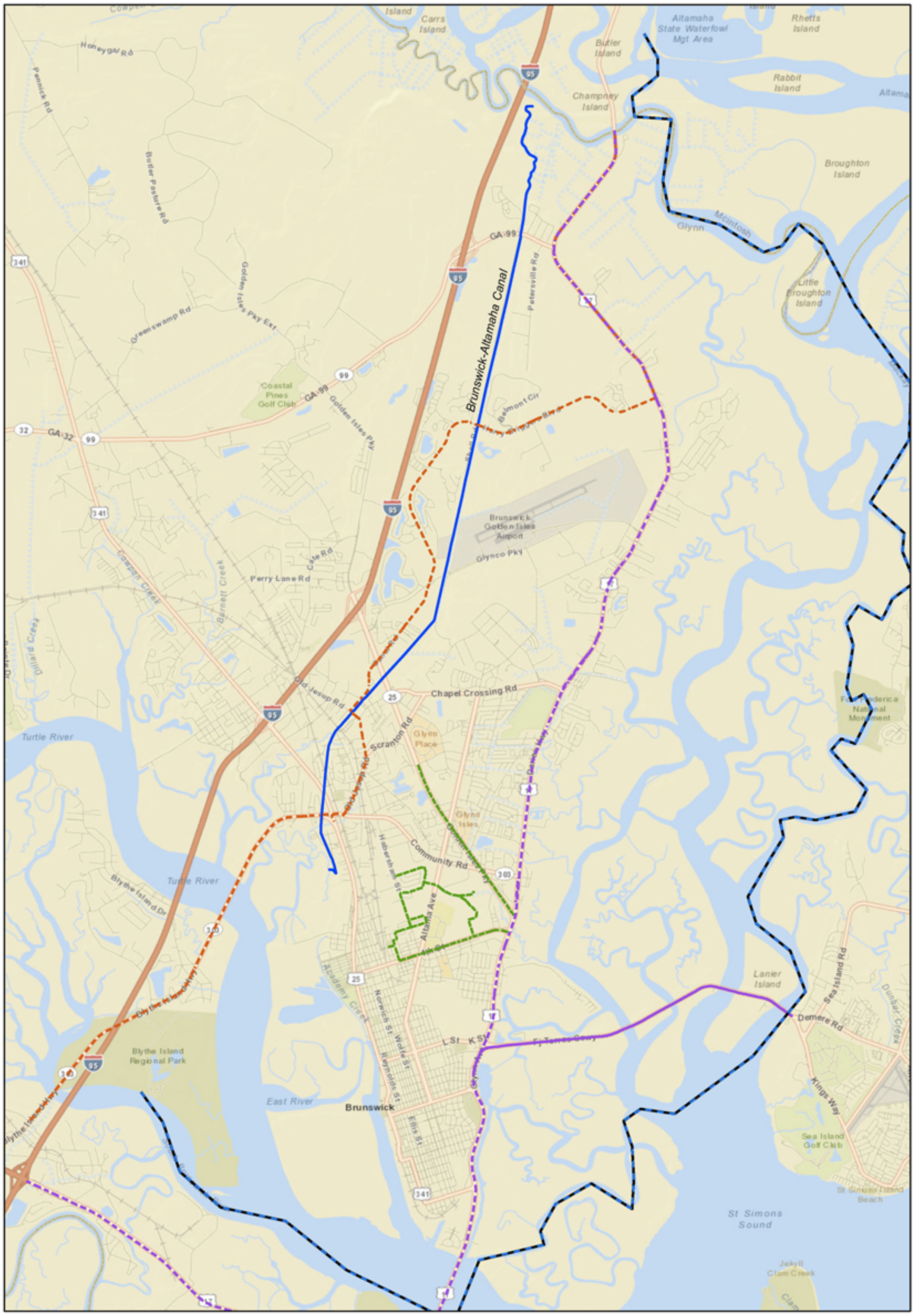

Regional Greenways and Blueways

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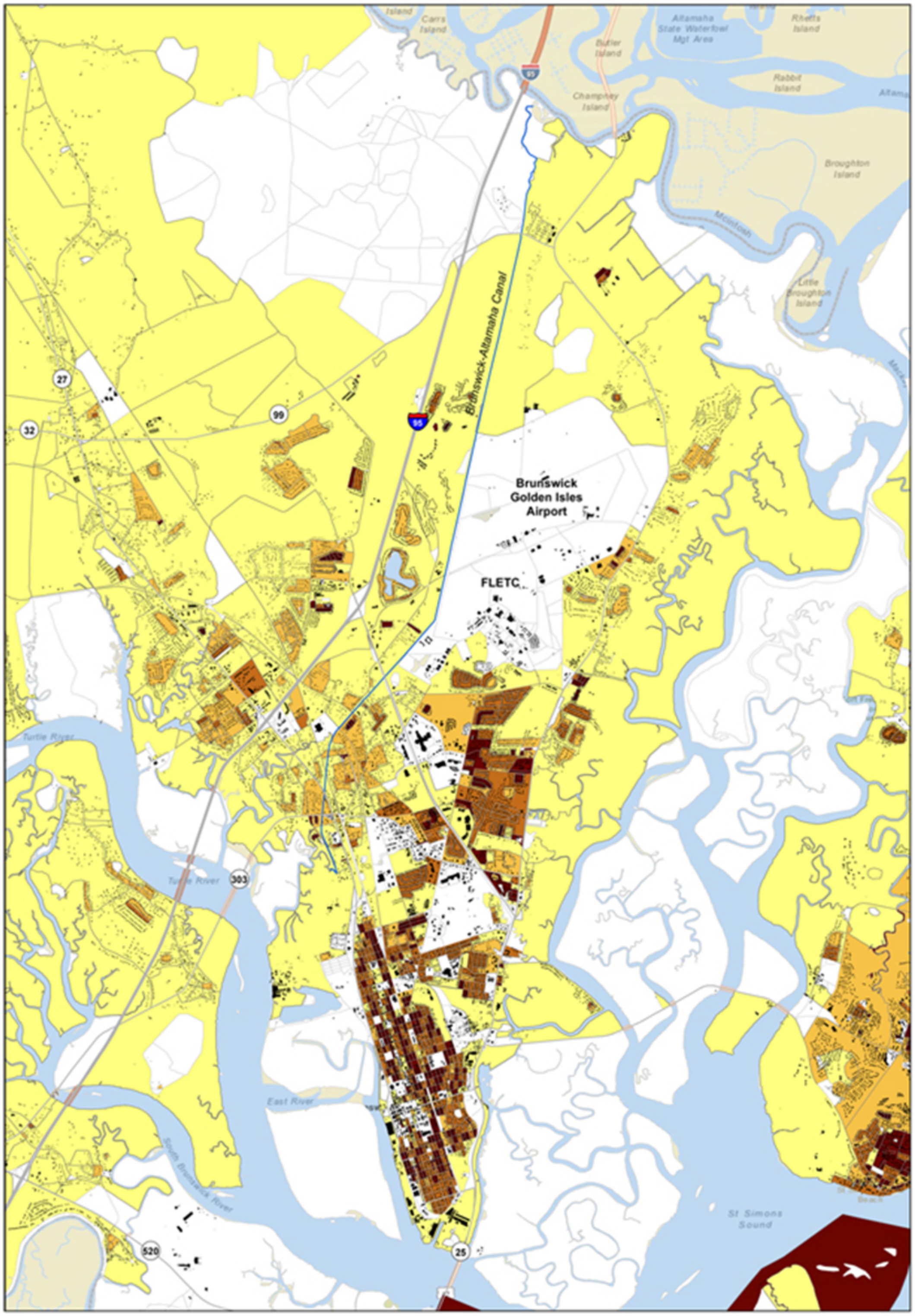
Legend

Greenways
- East Coast Greenway - Proposed
- Coastal Georgia Greenway - Existing
- Coastal Georgia Greenway - Proposed
- Altama Community Transformation District Greenway - Proposed

Blueways
- Coastal Georgia Blueway-Proposed

0 0.25 0.5 1 1.5 2 Miles



Population Density
Housing Units/Acre of Land

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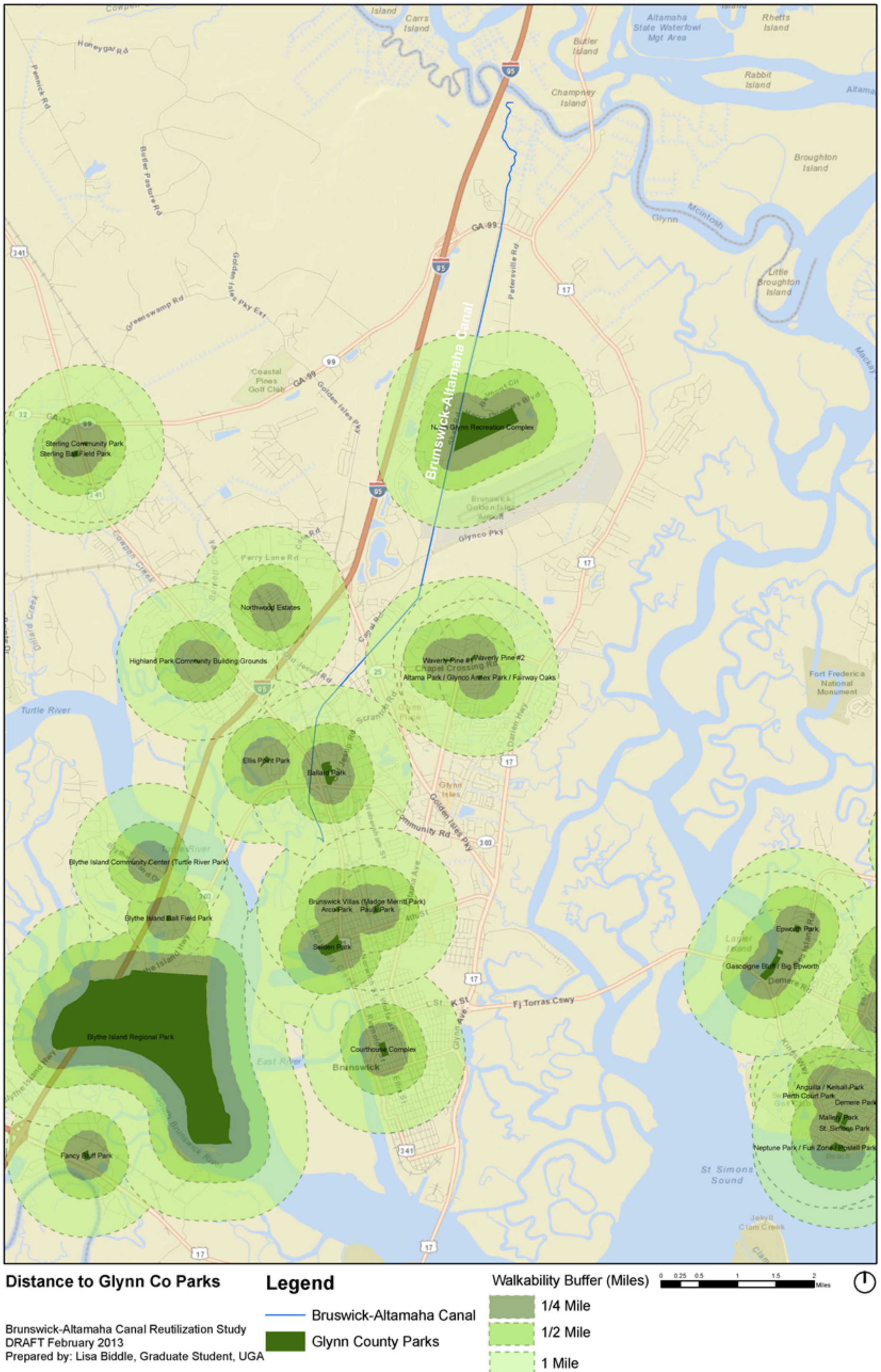
Legend Total Housing Units / Acres Land

- 0
- 0 - 1
- 1 - 2
- 2 - 4
- 4+

Source: Census data by block, Glynn Co, 2010



Brunswick-Altamaha Canal
North Glynn Recreation Complex
Sterling Community Park
Sterling Ball Field Park
Northwood Estates
Highland Park Community Building Grounds
Waverly Pine #1
Waverly Pine #2
Altama Park / Glynco Annex Park / Fairway Oaks
Ellis Point Park
Ballard Park
Blythe Island Community Center (Turtle River Park)
Blythe Island Ball Field Park
Brunswick Villas (Madge Merritt Park)
Arco Park
Paulk Park
Selden Park
Blythe Island Regional Park
Courthouse Complex
Fancy Bluff Park
Epworth Park
Gascoigne Bluff / Big Epworth
Anguilla / Kelsall Park
Perth Court Park
Demere Park
Mallery Park
St. Simons Park
Neptune Park / Fun Zone / Postell Park
Turtle River
East River
Brunswick
St Simons Sound
Fort Frederica National Monument
Altamaha State Waterfowl Mgt Area
Distance to Glynn Co Parks
Legend
Bruswick-Altamaha Canal
Glynn County Parks
Walkability Buffer (Miles)
1/4 Mile
1/2 Mile
1 Mile
0 0.25 0.5 1 1.5 2 Miles
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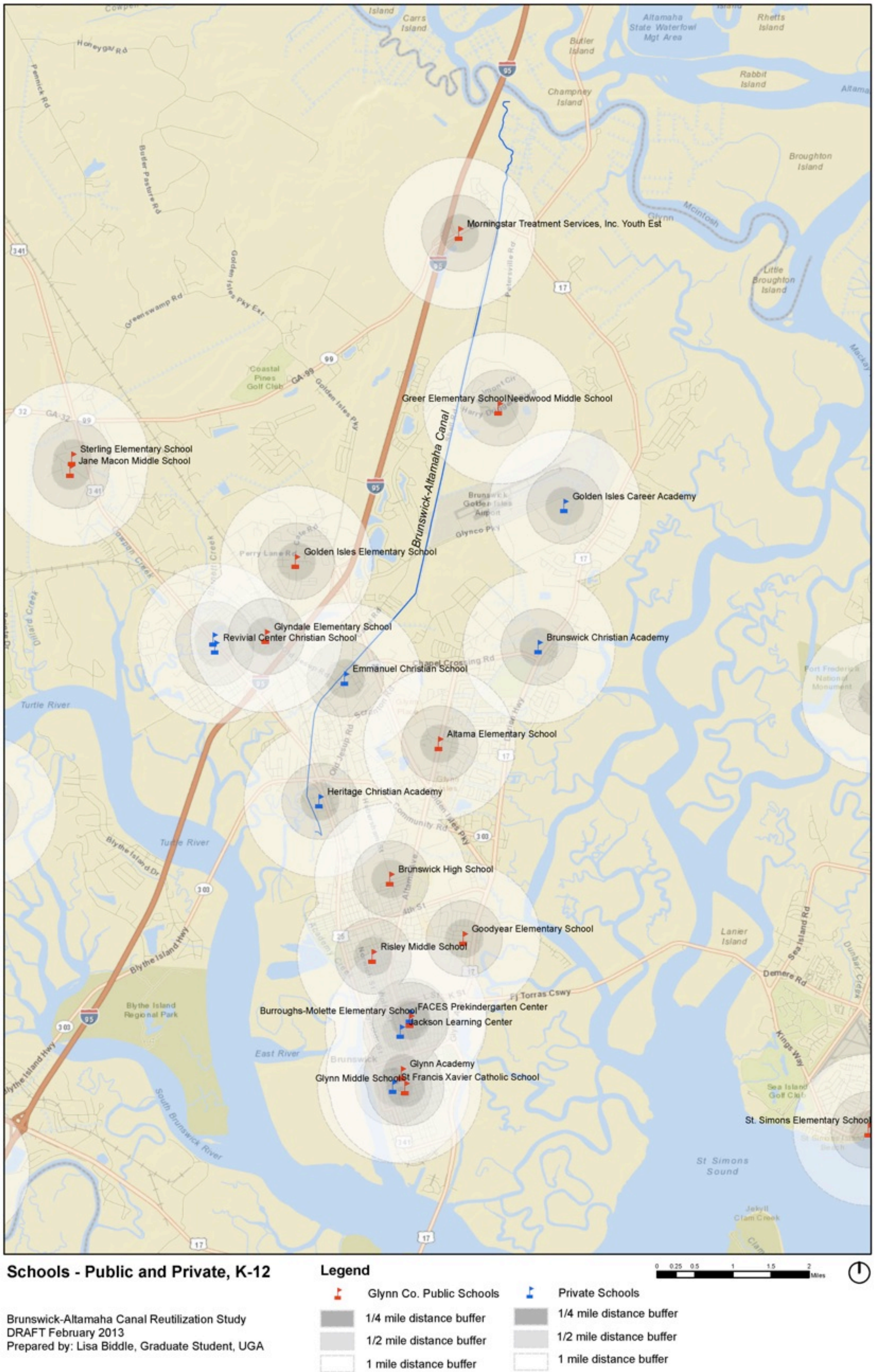

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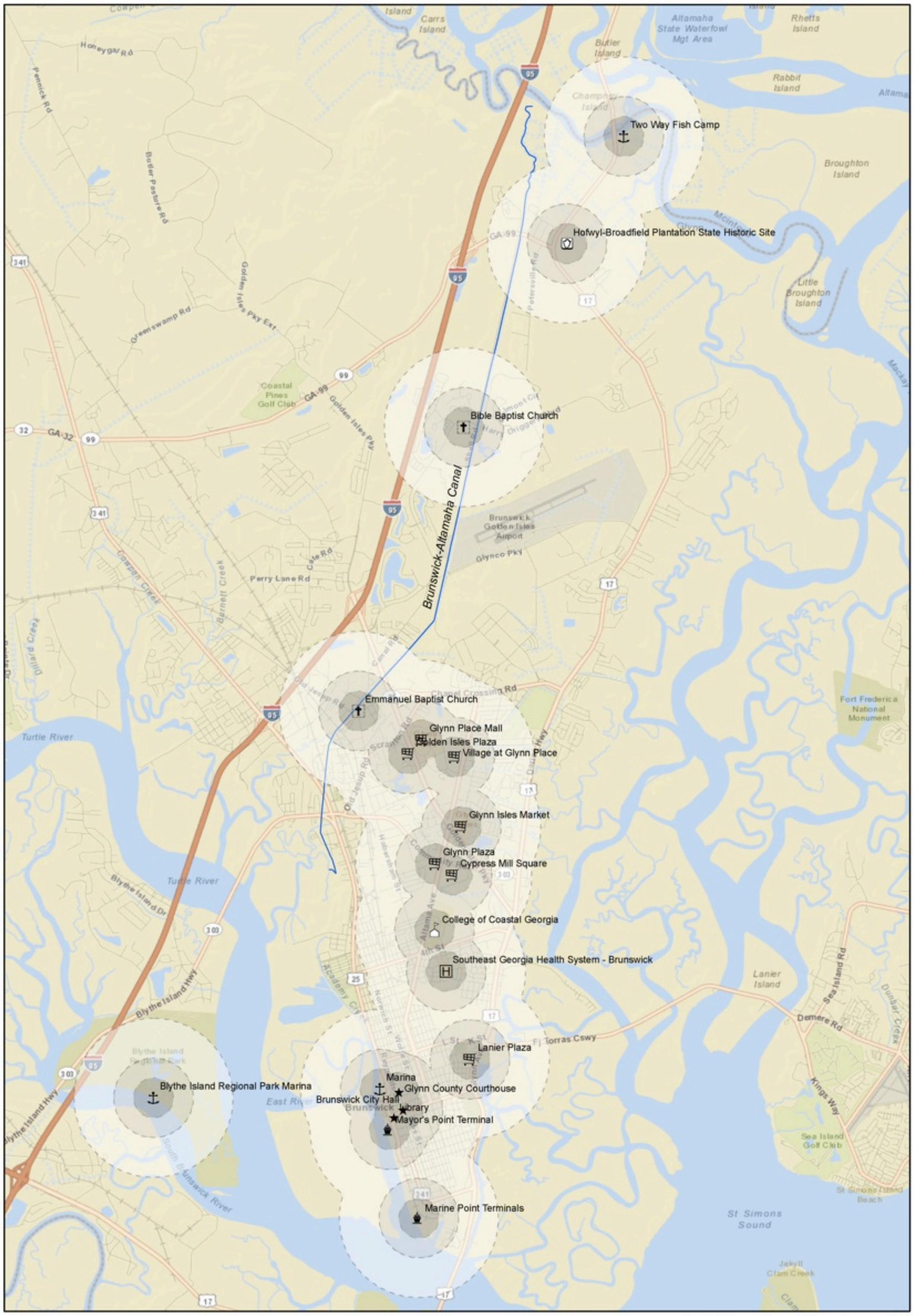

Points of Interest Opportunities

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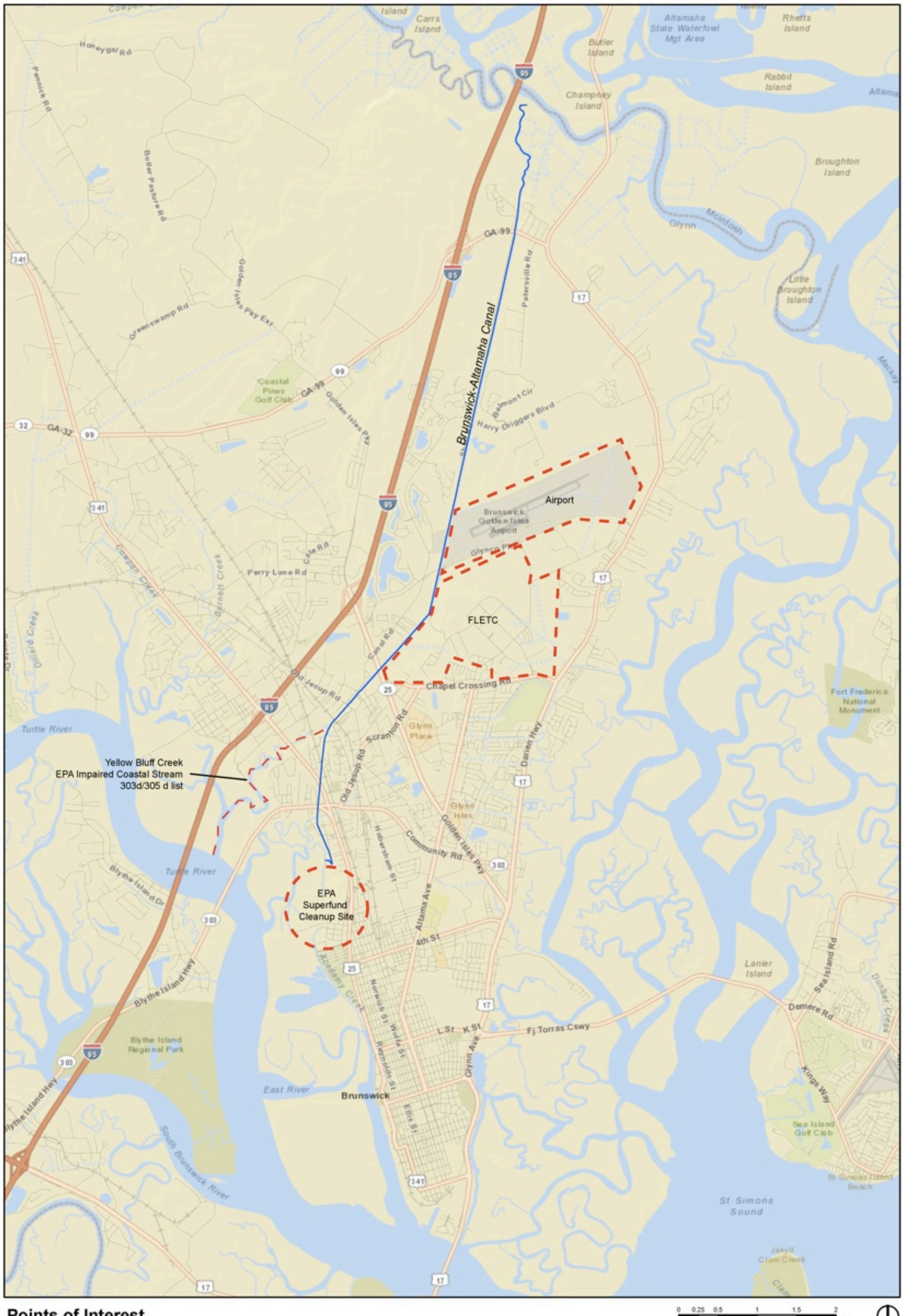
Legend

Point of Interest

- Church
- Civic
- College
- Hospital
- Marina/Fishing
- Port
- Shopping
- State Historic Park

- 0.25 mile distance buffer
- 0.5 mile distance buffer
- 1 mile distance buffer

0 0.25 0.5 1 1.5 2 Miles



Points of Interest
Constraints/Conflicting Uses to Greenway

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APPENDIX B

BRUNSWICK-ALTAMAHA CANAL VEGETATION STUDY

This appendix includes inventory and analysis of the vegetation and land cover along the Brunswick-Altamaha Canal watershed, and was conducted in EDES 6270: Geographic Information Systems (GIS) studio course by MLA student Wes Ryals in spring of 2012. All graphics contained in this appendix are the original works of Wes Ryals, produced as part of coursework for a University of Georgia, College of Environment and Design. The graphics contained below are reproduced in this thesis with his written permission.

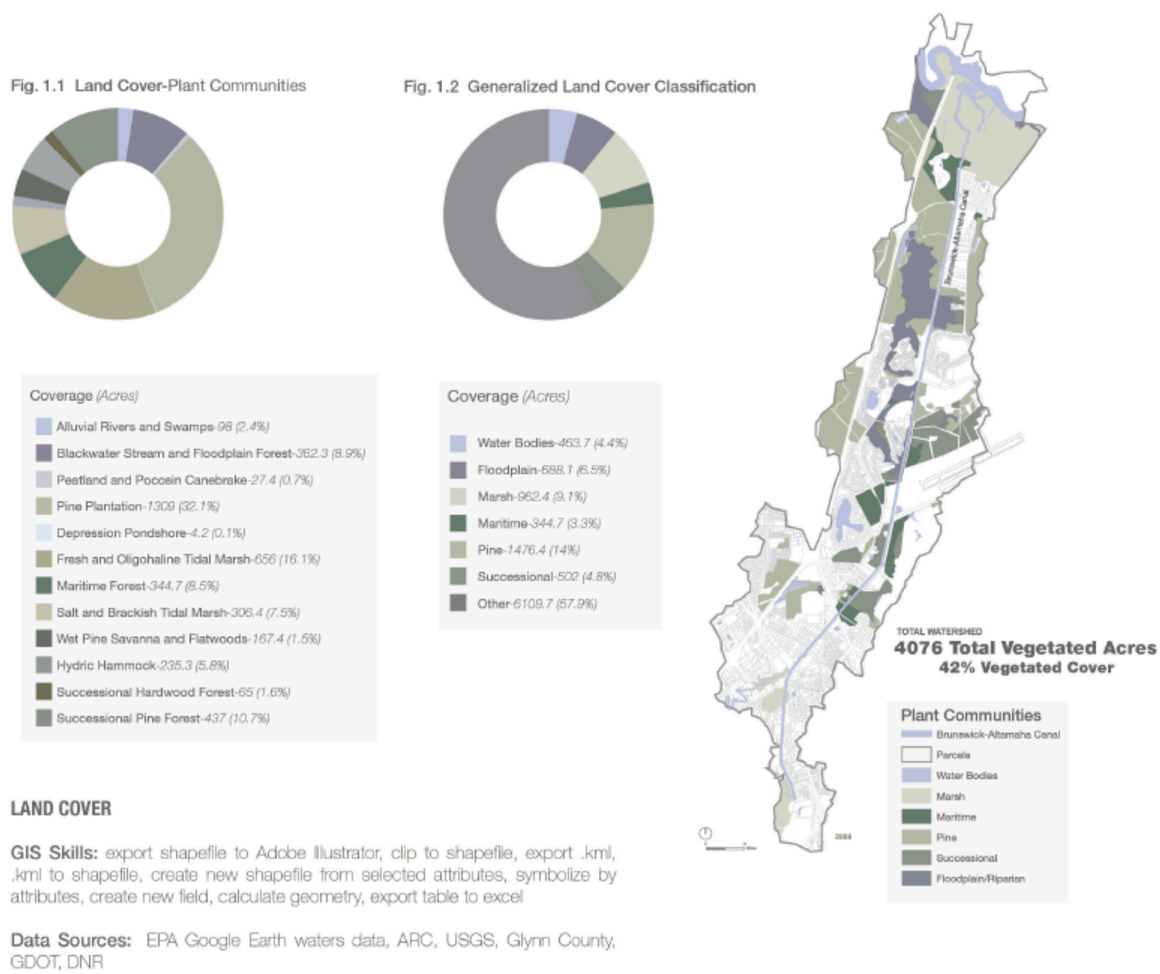

Figure courtesy of Wes Ryals.

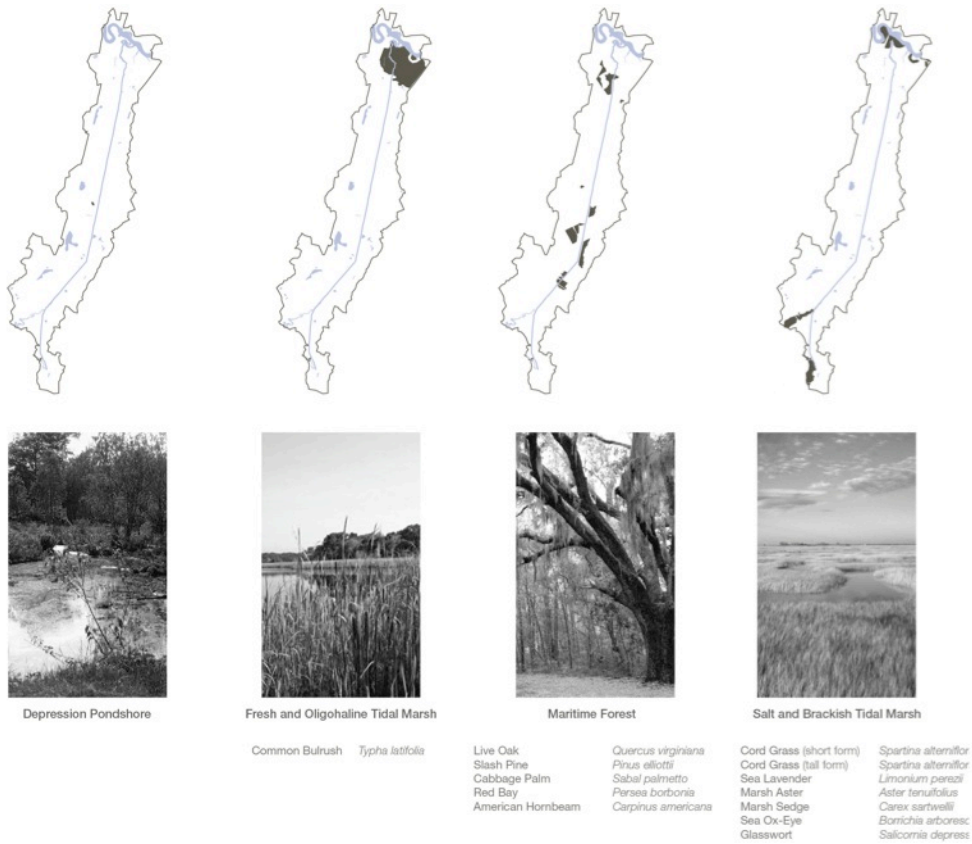

Figure courtesy of Wes Ryals.

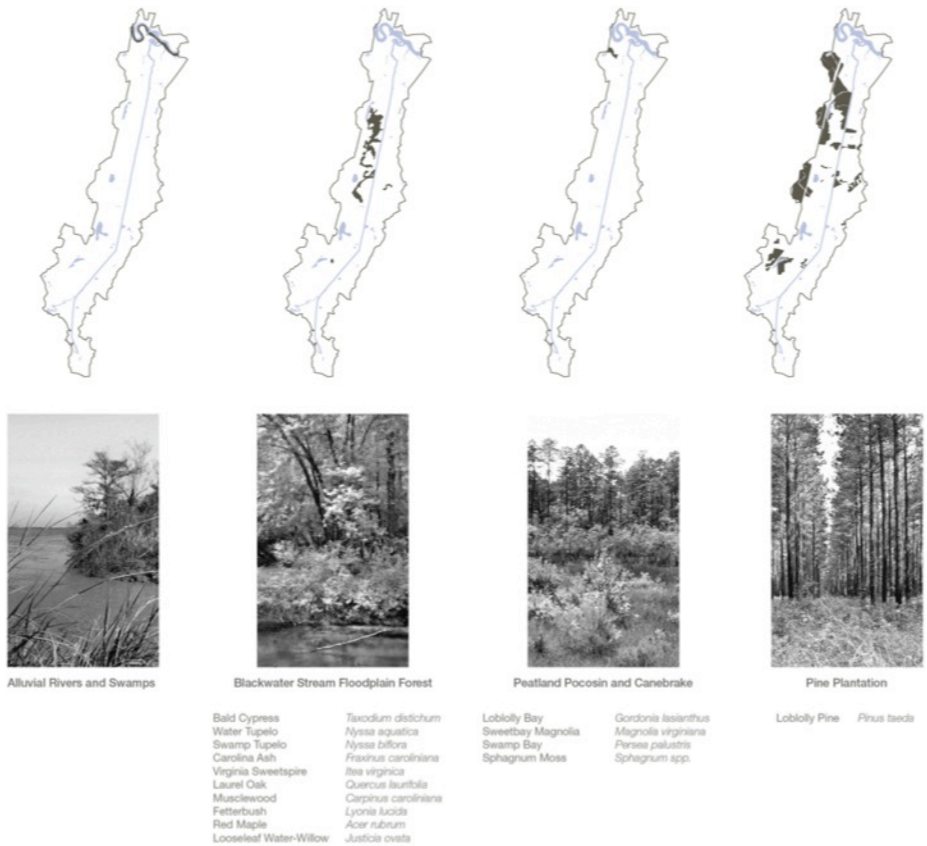

Figure courtesy of Wes Ryals.

Figure courtesy of Wes Ryals.