ANALYSIS OF CLIMATE ADAPTATION STRATEGIES FOR SOUTHEAST U.S. COASTAL CITIES

By

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Abstract

The realities of climate change are no longer future predictions to address in years to come. Impacts to Southeast coastal communities from rising sea levels, strange weather, and stronger storms caused by a warming planet are occurring today. Trends in scientific measurements clearly indicate that temperatures are rising, sea ice is melting, and storm intensity is increasing. The Southeast coastline is particularly vulnerable to these changes and local communities are the first to feel the impacts and address the needs. Yet many conversations about adaptation to climate change impacts are only occurring at high levels of government concerning international issues. Local decision-makers in the Southeast U.S. need tools to identify strategies that will provide adequate protection to their citizens as well as to manage environmental quality and prepare for any uncertainties.

This Master's project identifies primary and secondary climate change impacts to coastal areas of the Southeast U.S. A preliminary analysis was conducted to identify the societal implications incurred from impacts and the specific sector of society to which those impacts correspond. A resiliency criterion analysis was then created to qualitatively examine climate adaptation response strategies through three core evaluation mechanisms: adequate adaptive capacity, environmental sustainability, and the win-win nature of measures. To test the usefulness of the resiliency criteria, sea level rise response strategies were analyzed. Methods for this project included an extensive literature review of scientific findings as well as in-depth interviews with nine professional experts in the fields of government, academia, and coastal environmental non-profit organizations.

The results of the criteria analysis indicate that measures receiving a "very high" ranking thoroughly meet the resiliency goals of maximizing human safety, community protection, environmental sustainability, and flexibility. Measures ranking "low" or "very low" fail the resiliency criteria in two or more categories and likely contribute to environmental degradation. Reviewing adaptation strategies for resiliency is an effective determination of strategic response initiatives. Creating communities resilient to climate change will require local officials to utilize tools such as this to choose optimal adaptation strategies.

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This Master's project is dedicated to my niece Sofia Davin Reeves… You are the brightest change this planet could hope for. And in loving memory of my mother, Molly, whose love of, dedication to, and enjoyment of our natural world is why I care so much.

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CHAPTER ONE: Overview

Introduction

Global warming impacts to southeast coastal cities of the United States are anticipated to bring profound changes to quality of life in the region. Sea level rise and hurricanes are two of the most notable impacts from a warming planet that will dramatically alter coastlines in the next 50 years.[1] Additionally, the greatest majority of the Southeast population centers are on the eastern shoreline. Current policy responses and dialogue, if any, focus predominantly on mitigation of anthropogenic greenhouse gases (GHGs). Very few cities in the Southeast are proactively embracing adaptation initiatives to safeguard their communities from the impacts of global warming.

Yet scientists believe that even if atmospheric concentrations of GHGs were stabilized today, the impacts of global warming pollution already in the system will still cause substantial and possibly severe changes to our weather patterns, natural landscapes, and therefore the built environments of human civilization around the world for years to come. Greenhouse gases have atmospheric lifetimes ranging from 5 to 50,000 years, therefore impacts from pollutants emitted today and even hundreds of years ago will have a lingering effect on global warming long into the future.[2] Policy responses to adapt to these coming consequences are essential if we are to protect our treasured ecosystems, human health, economies, and cities of the Southeastern United States.

While all of the Southeast is vulnerable to the impacts of global warming, the coastal areas are literally the front lines for threats from sea level rise (SLR), storm surges, extreme hurricanes, and inundation of densely populated areas and water resources. Scientists predict upward trends in the intensity and unpredictability of North Atlantic hurricanes in correlation to global warming.[3] The Southeast coastal states, and even many inland states, are considered part of "hurricane alley" as they are first in line for the severe consequences of extreme Atlantic tropical storm and hurricane events. Over half of the U.S. population lives in close proximity[4] to our Atlantic and Gulf coastal areas with 12% of the U.S. population living directly on those coastlines.

The Southeast U.S. is also one of the fastest growing regions in the nation, with a 21.7 percent increase between 1990 and 2006. The Carolinas, in particular, has doubled in growth

since the 1950s and in the five years between 2003 and 2008, the Southeast coastal population is expected to grow by 1.1 million.[5] Burgeoning population growth in the region bodes poorly for disaster preparedness. More people equate to greater development pressures on coastal resources and more complicated transportation and land use planning for emergency preparedness as well as adaptation to rising seas and subsequent inundation to built areas.

Many local planning departments and governmental services in communities along the Southeast coastline are not adequately prepared for climate impacts in coming years.[6] There is a great need for guidance and resources to augment existing plans to address the strategic initiatives necessary to face sea level rise and emergency preparedness in the face of more intense hurricanes and tropical storms such as those predicted to occur in the region. Long term planning for public education, land use, emergency evacuation, and community preparedness efforts are essential to avoid large losses of life, spread of communicable diseases, and infrastructure devastation. Currently, many residents living in threatened coastal areas are ill prepared for, or resistant to, evacuation. Many do not even know the location of the nearest evacuation shelter or the actual ability of their own home to withstand a storm.[7] A recent report by the Center for American Progress found that hurricanes could also be a potential source of invasive agricultural pests and human diseases – a factor that must be accounted for in financial and long-term planning.[8]

The Southeast is also disproportionately vulnerable to the aftermath of hurricanes on societal systems and infrastructure. Devastation to communication, energy systems, housing, and business infrastructure will shut down expected and normal functions, creating the collapse of emergency response systems and unsanitary shelter situations, just as residents experienced after Hurricane Katrina in 2005. The Superdome evacuation site for Hurricane Katrina victims became the location of a level of violence, disease, and suffering unbeknownst to most Americans. But these experiences may become an unfortunate reality of the future as the region faces a more intense hurricane future. Southeast cities must be prepared to prevent or adequately respond to worst-case scenario disasters.

Coastal development and investment in tourism infrastructure in the Southeast is also unprecedented and unique to the region. Storms, flooding, and sea level rise threaten the vast and dense human inhabitation of the Southeast coastal region. Insurance rates are likely to skyrocket as subsequent damage to homes, businesses, and industrial infrastructure increases.

Transportation infrastructure in the region is uniquely threatened with a simultaneous pressing need to adequately accommodate emergency response needs to sudden storm damage, as well as the steady rise of sea level causing erosion and inundation over time. Additionally, land use planning systems must account for the multitude of impacts beginning to occur. Construction zone easements and development buffers to account for sea level rise are savvy responses for Southeast planners as is the consideration of more robust construction requirements to protect homes and buildings from stronger storms.

Lastly, our health care systems in the Southeast are the frontlines for the earliest onset of tropical disease migrations. With rising temperatures, Florida, Georgia, and the Carolinas are predicted to be the perfect climates for tropical diseases like malaria, dengue fever, cholera, and typhoid fever. Currently our medical systems are ill prepared for such health care emergencies and without proper planning we could experience rapid spreading of these unfamiliar sicknesses to Americans. Moreover, with the predicted hurricane intensification, communicable diseases are also very likely to plague disaster zones without improved evacuation capabilities, proper emergency sanitation, energy systems, and clean water.

Mitigation is often the first measure of response mentioned in climate adaptation plans. Cities and countries already looking at the need to prepare their communities recognize that they must also make significant reductions in their GHG emissions in order to truly be part of the solution to this global crisis and prevent further impacts. By reducing emissions of global warming pollution, predominantly from fossil fuel usage, Southeastern cities can become leaders in innovative measures to prevent the growth of atmospheric concentrations of GHGs. Another critical and increasingly recognized approach to addressing climate impacts is that of adaptation strategies, which seek to protect communities from the known impacts associated with a warmer planet. Climate change impacts and the corresponding adaptation strategies are the focus of this research project.

Objective

The purpose of this Masters project is to provide an analysis tool and example of a process for which a local agency might utilize to review impending climate impacts and identify and evaluate adaptation response strategies. To do this, the primary and secondary climate impacts facing southeast U.S. coastal cities are first reviewed and then analyzed for the societal implications and corresponding sectors of society these impacts affect. The report specifically analyzes how global warming will impact the Southeast coastal region between now and 2100 (with several earlier waypoints). A resiliency criteria analysis was created as a means by which local decision-makers might identify the most strategic adaptation response strategies for southeast coastal cities, with resiliency meaning 1) sensitivity to environmental sustainability, 2) adaptive effectiveness and 3) the flexibility and effectiveness of the measure in the face of scientific uncertainty. To test the usefulness of the resiliency criteria, sea level rise response strategies were analyzed.

Specifically, the four key global warming impact areas were analyzed as well as possible adaptation initiatives in the sea level rise impact area for the Southeastern coastal United States. The primary impact categories include rising temperatures, sea level rise, stronger storms, and changes in precipitation as these are the most significant impact areas affecting the coastal region. The secondary impacts categories include, among many others, emergency preparedness, human health (disease, safety, air pollution, etc.), threats to infrastructure (residential and commercial buildings, transportation), tourism and recreation, water supply and quality (salt-water intrusion, storm surges), agriculture, aquaculture, energy systems, and related coastal development issues. Those impacts are then linked to the corresponding sector of society they affect and the specific societal implications. This process of first systematically identifying the primary and secondary impacts followed by the sectors and societal implications is intended to serve as an example of how local officials might begin the process of identifying the issues they need to address and set the stage for the analysis of adaptation response strategies.

In response to concerns about the projected impacts of climate change, many European countries and agencies, as well as a few U.S. cities, like Seattle, have developed climate adaptation policy strategies to prepare their communities. While many of these policies have yet

to be implemented, particularly in the U.S., they provide strategic guidelines in directing decision-makers toward the necessary processes and priority components to include in adaptation initiatives. Certain elements of adaptation strategies are necessary for most geographic areas and those overarching recommendations will be highlighted for inclusion in broad policy recommendations. There are certainly positive affects of climate change for certain sectors of our communities that could be explored, however this report will focus on the implications and disruptions to existing resources, operations, services to society, and our ecosystems.

The report will include:

- A review of the current state of climate adaptation conversations and why action at the local level matters;
- Thorough review of projected southeast coastal global warming impacts (sea level rise, stronger storms, rising temperatures, and changes in precipitation) and the secondary impacts such as storm surges and salt-water intrusion;
- Tables clearly linking the secondary impacts to the sectors of society they affect and the specific societal implications such as emergency preparedness, human health (disease, safety, air pollution, etc.), threats to infrastructure (residential and commercial buildings, transportation), tourism and recreation, storm water management issues, agriculture, aquaculture, energy systems, and other coastal development issues;
- A summary of broad-reaching, high-level community adaptation strategies for addressing global warming impacts;
- Specific adaptation initiatives for response to the impacts of sea level rise;
- A resiliency criteria analysis for the primary category of sea level rise climate change impacts and the individual adaptation initiatives;
- Summary of the most resilient strategies for sea level rise;
- Conclusions.

Methods

Literature Review

For this report an in-depth literature review was conducted of the various climate impacts expected in the Southeast United States, specific sector implications from climate change, and adaptation initiatives both in the U.S. and worldwide. A full breadth of literature was consulted to offer as comprehensive and wide-ranging input as possible given the immense scope of the topic – primarily relying on peer-reviewed publications. All research and literature used is cited in the endnotes of this report.

Interviews

Extensive voluntary interviews were conducted with various representatives of southeast coastal cities in Miami and Wilmington, non-profit environmental organizations, government agencies, and academic institutions over the course of several months in early 2008. Research was conducted using approved *interview procedures.* Approval from the Duke University Institutional Review Board was received in December, 2007. Verbal information was collected from professionals who work and focus on the adaptation issue or whose line of work will be directly impacted by climate change impacts. Queries were based on experience, knowledge of the adaptation and global warming impacts subject area, and input on the report objectives. Interview responses are attributed with citations in the report as pertinent to the findings and consent for citation or quotation from our conversation was acquired verbally.

Resiliency Criteria Analysis

The resiliency criteria analysis is based on three primary categories deemed essential components of resilient adaptation efforts based on research and interview findings: 1) adequate adaptive capacity (e.g., the effectiveness of the measure to safeguard citizens and communities from the climate impacts); 2) environmental sustainability (this analysis reviews whether the ecosystem will be harmed more from the adaptive measure than by leaving it alone or whether the adaptation initiative contributes to another environmental challenge); and 3) the ability of the adaptation initiative to serve as a win-win strategy in the face of climate uncertainty (i.e., does the initiative still serve the community if the climate change projections are wrong?). Given the scale and complexity of the issues at hand, and for purposes of simplification, the initiative either

meets or fails the criteria on a Yes/No basis. Since this was a qualitative analysis, a number of measures whose evaluation was not clear-cut were encountered, and therefore were left as *inconclusive*. Determination as to whether or not the initiative meets the resiliency criteria is the personal view of the author influenced by research findings, for example:

- *Adaptive Capacity (essential):* Measures clearly providing some form of adaptive or protective capacity from the climate impact listed receive a *Yes*. Initiatives that questionably address the climate change implication or do not offer adaptive or protective capacity receive a *No.*
- *Environmental Sustainability (optional):* Measures that create an alternate environmental problem while addressing the impact receive a *No.* Initiatives that address the climate impact without creating additional environmental stress receive a *Yes.*
- *Win-win Initiatives (optional):* Measures that are sensible regardless of climate change impacts, create new economies, solve alternate environmental issues or otherwise provide a win-win or "no regrets" solution receive a *Yes.* Other initiatives that only address the immediate problem at hand receive a *No.*

All three criteria are analyzed for each adaptation measure listed.

The table below is the key for how measures are ultimately rated as having *very high, high, medium, low* or *very low* resiliency.

TABLE 1: Resiliency Criteria Analysis Definitions

Adequate Adaptive Capacity	**Environmental Sustainability**	**Win-Win Ability Given Uncertainty**
The effectiveness of safeguarding citizens and communities from the impacts of climate change. Yes, No, or Inconclusive?	Will the ecosystem be harmed more from the adaptive measure than by leaving it alone, or does the adaptation initiative contribute to another environmental challenge? Yes, No, or Inconclusive?	The ability of the adaptation initiative to serve as a win-win (or "no regrets") strategy in the face of climate uncertainty. Yes, No, or Inconclusive?

TABLE 2: Resiliency Criteria Analysis Key

Adequate Adaptive Capacity	Environmental Sustainability	Win-Win Ability Given Uncertainty	Results
Yes	Yes	Yes	Very High
Yes	Yes	No	High
Yes	*Inconclusive*	No	Medium
Yes	No	No	Low
No	No	No	Very Low

These criteria are by no means absolute and there are many alternative views for each of them. They are simply intended to serve as an example of how a city might determine whether or not an initiative is a resilient adaptation strategy. Explanation of the criteria choices is offered in supplemental text. The resiliency criteria analysis does not take into account political feasibility, cost, and fairness or equity – all of which are significant matters of consideration, but depend uniquely on the existing local, state and federal policies as well as community receptiveness.

CHAPTER TWO: Why Adaptation?

Current State of Adaptation Conversations

Present day conversations around climate change in the United States are largely oriented toward mitigation efforts for greenhouse gases both in federal level policy debates and state level initiatives.[9] The focus of climate adaptation conversations is predominantly geared internationally in federal level discussions of how to allocate financial resources acquired through carbon emission reduction efforts. For example, policy discussions include questions of how to distribute carbon cap and trade allocations to provide financial resources for climate adaptation to lesser-developed countries (LDCs). The premise for these discussions aimed at the international issue of extreme climate impacts is quite appropriately that more developed countries' (MDCs) greenhouse gas emissions contribute disproportionately to the impacts of climate change in less fortunate and low-lying areas.

Climate change effects are truly global in nature, and since MDCs such as the U.S. produce the majority of GHG emissions (the U.S. contributes 25% of the global carbon dioxide emissions[10]), it is appropriate for MDCs to assume a greater level of responsibility to aid LDCs in their climate adaptation efforts. However, the focus on international adaptation has created a gap in our national research, understanding, and strategic action necessary to prepare locally for the inevitable impacts of climate change that are certain to occur despite the most aggressive mitigation efforts. While attention to the issue is increasing slowly, there are limited conversations occurring among local decision-makers about how best to address impending impacts to their community.

In the Southeast, the Miami-Dade Climate Change Advisory Task Force is the most notable and visible initiative to comprehensively address both mitigation and adaptation of climate change for the city and county area. They are a leader in the field of adaptation and their work is a great example for other cities wishing to begin dialogue around preparing for climate impacts. In other instances, piecemeal attention is being paid to adaptation, yet it is a subject, which requires a comprehensive and coordinated approach in order to fully address the breadth of the implications.

Why Local Governments Matter

"The battle for climate change will be won or lost on the local level."

– Scott Shuford, Visiting Scientist to the National Oceanic and Atmospheric Administration

For the purposes of this report, a focus on the strategic response initiatives was chosen to address climate change adaptation for those on the front lines of global warming impacts – our local communities. Given the lack of dialogue among our national decision-makers on domestic climate adaptation issues, the onus is shifted onto our state and local officials to aggressively pursue protection of our and future generations' well being. Despite the fact that global warming is a worldwide phenomenon, the most immediate and pressing consequences are entirely local and will require the full attention of local government officials.

Moreover, climate change impacts are not just future trends – we are beginning to experience these realities in our communities today. Harvey Ruvin of the Miami-Dade Climate Change Advisory Task Force stated, *"We've already brought [upon ourselves] decades of sea level rise, extreme weather events, tropical disease, and a range of other impacts due to the emissions we have emitted since the Model T Ford."*[11] We are not likely to act fast enough to avoid all of the threatening events to both society and our ecosystems,[12] but the responsible thing now is to come up with logical, proactive steps we can take to make us more resilient to the coming impacts.[13]

The officials in charge of vulnerable local communities must begin planning today in order to safeguard the quality of life and economic vitality. According to *Preparing for Climate Change,* local officials are at a greater advantage to tailor policies to the specific needs of their area given their unique climate impacts. Unlike higher levels of government, which inherently create more broad and wide-reaching policies, localities can design preparedness strategies to meet very individualistic concerns.[14] Of course, there is a need for the federal and state governments to proactively support the efforts of local governments by providing funding, overarching support, and coordination.

Communities have the unique ability to understand their own adaptive capacity to deal with climate change and therefore determine what must be addressed on the local level versus what they will need assistance with and coordination from regional, state, and federal levels.

Mendelsohn (2001) also identifies that there is a role for the market sector in 'private adaptation', where sole beneficiaries, (e.g., companies, individuals, or industries) take adaptive actions. Although private adaptation initiatives are fundamental elements of an overall adaptation strategy, this report will focus on 'public adaptation' where the strategies proposed will benefit multiple parties in local communities.[15]

A further analysis on adaptation strategies might delve more deeply into the role of specific government agencies for which specific response initiatives. Throughout this research effort, a number of measures were identified for consideration at the local government level. However, many of these strategies may be better suited for implementation at a higher level of government, such as state, federal, or within a specific agency. For example, in 2007 the Coastal States Organization prepared a report for Congress about the role of the state Coastal Zone Management Programs (CZMPs) in adaptation initiatives.[16] CZMPs provide an excellent resource for local planners in coastal communities as they begin dialogue around adaptation. Coordination is the key to avoiding duplication of efforts and appropriately housing policies where they will be most effective in addressing climate adaptation needs.

CHAPTER THREE: Southeast Coastal Impacts

Primary Impacts

"Few regions have the combination of special characteristics and vulnerabilities [to climate change] found in southeastern coastal areas." **– *Burkett, et al (2001) p.156***

The Southeast is arguably the most vulnerable location in the continental U.S. to the impacts of global warming both in physical and economic threats.[17] Four primary impacts of global warming affecting the region were reviewed:

1) Rising temperatures,

2) Sea level rise,

3) Stronger storms and hurricanes, and

4) Changes in precipitation patterns.

Each threat from climate change uniquely affects the Southeast coastal region in profound ways unlike other parts of the U.S. and therefore demands specialized attention from local decision makers. Ocean acidification is another direct impact of global warming that will create challenges for coastal communities, particularly those dependent on fisheries and tourism for revenue, however it is beyond the scope of this research effort and will only be addressed briefly.

According to Burkett, et al., (2001) by 2100 the Southeast will experience a greater heat index increase than any other region of the U.S.[18] The low-lying coastal shores combined with miles of expensive beachfront properties leave this region at a proportional disadvantage to sea level rise and stronger tropical storm intensity.[19] In the United States, tropical storms and hurricanes predominantly make landfall in the Southeast region of the country, therefore as intensity increases, those in this region will bear the brunt of adapting to fiercer storms. And while the Southeast typically receives more rainfall than any other region of the country, projections indicate a likelihood that substantial increases in extreme precipitation will occur under various climate scenarios.[20] Lastly, despite increases in strong rainfall events, there are likely to be marked by periods of prolonged dry spells creating drought conditions foreign to southeast citizens.[21]

Rising Temperatures

The Intergovernmental Panel on Climate Change (IPCC) 2007 report found that temperatures rise in direct correlation to the concentration of greenhouse gases in the atmosphere. If humans are able to limit GHG concentrations at or below 450 parts per million (ppm), we may hold global warming to roughly 1°F by 2100 (warming at 0.18°F per decade would still occur even if all GHGs were stabilized in 2000).[22] If we allow emissions to increase with continued use of fossil fuels to levels of 850 ppm and beyond, temperatures will rise in direct response, reaching disturbing increases of 6.1°F to even 12.6°F and higher by 2100.[23] Given the current steady increasing emission trends, the IPCC predicts in the most conservative of scenarios, that for at least the next two decades, we will experience an annual average of about 0.36°F per decade of warming.[24]

A range of projections exists specifically for southeast regional temperature increases between now and 2100. One model (the Hadley Centre Climate model) projects a mean annual increase of 1.8°F by 2030 to 4.1°F by 2100, whereas the Canadian Centre climate model ranges from 3°F by 2030 to 10°F in 2100. Compared to other regions of the nation, the overall temperatures in the Southeast will rise less drastically, although, the heat index (humidity and temperature combined) is projected to rise between 8° and 15°F or over 15°F by 2100 depending on the model.[25] These heat index temperature increases are greater than any other region of the U.S. and will significantly affect the quality of life for those living in the Southeast in years to come.

Dangerous positive feedback loops are also of great concern in driving further global warming. As warming increases and temperatures rise, previously frozen landmasses (e.g., permafrost) thaw, releasing more carbon dioxide and methane into the atmosphere, which in turn cycle back to increased warming.[26] It is also significant to note that of global temperature averages, eleven of the last twelve years (from 1995–2006) rank among the 12 warmest years in the record of global surface temperature (since 1850).[27] For the purposes of adaptation to climate change, the significance of the temperature increases is quite simply that increased warming affects every other primary impact of global warming addressed in this report. As temperatures rise, sea levels rise, hurricanes strengthen, drought and storms worsen, and ocean acidification increases.

Sea Level Rise

Sea level rise (SLR) is a combination of rising sea temperatures, which cause thermal expansion in the ocean as well as melting land ice such as polar ice sheets, glaciers, and ice caps, which increase the sheer volume of the ocean. The consistent expansion of oceans is often referred to as eustacy.[28] The eustatic sea level rise expected in the Southeast region of the U.S. is consistent with nationwide projections from the IPCC and other models, however there is a wide range of uncertainty concerning exact increases.

Sea levels have historically risen throughout the past 15,000 years and continue to gradually do so.[29] The IPCC found that since 1961, sea levels have risen at an average rate of 1.8 mm per year and since 1993 rates increased to an average of 3.1 mm per year.[30] In 2001 the IPCC concluded that sea levels would rise between .09 and .88 meters (0.3 – 2.8 feet) by 2100, yet many now believe this to be a conservative projection.[31] In 2006 German researchers reported new sea level rise projections for the world of 0.5 – 1.2 meters (1.6 – 4 feet) by 2100 in *Science.*[32] With the very recent observed melting trends in polar-regions throughout 2006, 2007, and 2008, scientists are alarmingly concerned that rates of melting are increasing much more rapidly than expected.[33] Florida-based scientists believe 1.5 – 2 feet of SLR by 2050 is more likely than other projections.[34] And if the global warming feedback loops described above play out fully, sea levels could reach catastrophic heights of 20 feet or more by 2100.[35]

Additionally, many parts of the Southeast coastline (especially North Carolina and south Florida) lie at very low elevations with areas just a few feet above sea level and miles of flat, expansive land that are much more vulnerable to inundation from rising seas than the steep, rocky shores of the Pacific or Northeastern coasts.[36, 37] Low-lying southeast coastal areas also experience high rates of subsidence, or sinking of landmass below sea level. Subsidence exacerbates the effect of sea level rise on coastal areas as it increases the rate and amount of saltwater intrusion on landmass. According to Leatherman, et al (2001), the average subsidence level on the East Coast of the U.S. is 12 cm. When coupled with the average sea level rise of 18 cm, the relative sea level rise is nearly one foot every century.[38] Human activity contributes to the rates of subsidence – particularly through ground water withdrawals and canal dredging in marshes and barrier islands.[39]

Stronger Storms and Hurricanes

Powerful evidence exists to support the claim that global climate change will exacerbate hurricanes and tropical storm intensity in the future.[40,41] In fact, Atlantic-based hurricanes that directly affect southeast coastlines have already seen a marked increase in intensity over the last few decades.[42] The increases in storm intensity result from rising sea surface temperatures (hurricanes need surface temperatures of 81°F to gain momentum) and changes in wind patterns – both of which are side effects of global warming.[43] Scientists have found a direct causal relationship in rising sea surface temperatures over the past 30-35 years with increasing greenhouse gas emissions and thus, human-induced climate change.[44] Models show that with 4°F of warming of sea surface temperatures, hurricane wind strength could increase by 5 to 10 percent, which correlates to a 25 percent increase in destructive power of winds.[45]

While debate is still ongoing as to whether or not climatic changes will affect the frequency of storms, atmospheric scientists released new research in 2007 on the topic. They found that Atlantic storms have already increased in frequency over the last century with twice as many storms forming each year on average as compared to 100 years ago.[46] This trend in frequency also has a direct correlation to the changing climate and rising sea surface temperatures. Stronger tropical storms also tend to bring with them greater precipitation outfalls.[47]

Scientists are also finding that the Atlantic Ocean seems to be exhibiting trends toward more frequent and stronger hurricanes than other oceans around the world because generally its temperature is cooler. Even slight variations upward in sea surface temperatures can cause a more favorable environment for the creation of super storms.[48] Changes in the El Niño and La Niña weather patterns as they are affected by climate change will also impact the intensity of hurricanes. Typically, El Niño patterns decrease hurricane tendencies, whereas La Niña years encourage cyclonic activity.[49]

The majority of the time when people think of stronger storms in correlation to climate change, they think of hurricanes. Yet for the northeastern seaboard of the United States and portions of the Southeast coastline, there are also other storms of significance to consider. Extra tropical cyclones, or "nor'easters" are winter storms that often wreak havoc on coastal development and ecosystems, and in certain cases do more damage than hurricanes.[50] The Southeast coastline may expect numerous nor'easters each winter with a handful of them being

of significant intensity.[51] The worst nor'easters tend to form in the Southeast ocean waters in the Gulf of Mexico or off Florida or Cuba and are believed to have a similar relationship as hurricanes do to rising sea surface temperatures.[52] In 2001, the IPCC reported that extra tropical cyclone activity had increased since the mid-century in the Northern Hemisphere.[53] As the Gulf Stream becomes warmer at the equatorial equilibrium, the storms will increase in intensity just as tropical cyclones will. In El Niño years (which are expected to increase in a warmer climate), extra tropical cyclones are stronger and more frequent.[54] While the Southeast does not typically experience the same impacts as the Northeast from the nor'easters, these storms are of great concern to North Carolina in particular and must be factored into coastal planning.[55]

Precipitation Changes

Rainfall projections vary quite substantially for the region as the global climate changes, making certainty and planning for all affected sectors challenging. Typically the Southeast is the wettest region in the U.S. and according to certain models it will remain so despite other changes to climate trends.[56] Under the Hadley model, precipitation increases 20% by 2090, yet the Canadian model simulates a decrease in precipitation of 10% from today's levels by 2090, which would contribute to drought conditions.[57] According to the Max Planck Institute climate model, El Niño patterns are likely to increase in frequency as the world warms and these weather patterns often bring substantial rainfall to the Southeast.[58]

Another scientific finding around changes in rainfall is that over the past century, the U.S. as a whole has seen an increase in the frequency of storms that have heavy or extreme precipitation. As temperatures rise, atmospheric moisture content rises, which correlates to increases in storm formation and heavy rainfall events (a 1.8°F rise in temperature will increase atmospheric moisture by 7 percent).[59] So, as a result of climate change, we will likely see an increase in both storms and the amount of rainfall (or intensity of precipitation) in those storms – particularly in temperate regions of North America, which is most of the United States. For the Southeast U.S., we are relatively familiar with intense summer storms bringing heavy rainfall, which means we have a higher minimum threshold than many parts of the country. These studies find a 15% increase in the region in extreme precipitation events in the last century and predict a growing trend that cannot be ignored.[60]

As weather trends change in the Southeast, another possible result is that the rising surface temperatures will increase evaporation and induce more frequent and prolonged droughts.[61] Southeastern cities and communities are historically unfamiliar with dealing in drought conditions and are ill prepared to accommodate long-term dry spells such as were seen in 2007. In particular, coastal communities are often more dependent on groundwater resources and in drought conditions, groundwater is even more taxed with a depletion in rainfall and soil moisture. Groundwater depletion from drought combined with saltwater intrusion from rising seas could spell disaster for many community water supplies.

There are many secondary implications from these varying precipitation change scenarios to be addressed later in this report. Communities will need to think of the most flexible means of accommodating these conflicting and uncertain predictions that offer win-win solutions in both water shortage situations as well as floods.

Ocean Acidification

Our oceans are huge absorbers of the excess carbon dioxide emissions humans are pumping into the atmosphere. With a daily uptake of 22 million tons of carbon dioxide, excess buildup of carbon dioxide in the atmosphere contributes directly to increasing acidification in ocean waters.[62] Acidic waters most significantly affect our coral reefs and the subsequent economies, which depend on them – so in the Southeast, Florida's tourism economy is most at stake. In addition, shellfish and pteropods (small snails that are an important food source for mackerel, herring, and cod) are particularly vulnerable, so the marine food chains could be significantly disrupted as well as the human-seafood web. For the purposes of this report focus will be maintained on the land-based impacts from global warming as the strategic response options for adaptation are analyzed and evaluated. It is important that fishing-dependent coastal communities in addition to tourism-based economies understand and be prepared for changes in our ocean's ecosystem due to increasing acidity levels.[63]

Secondary Impacts and Sector-Specific Implications

"Most of global warming's perils are familiar problems, only magnified."

— Christopher Swope, Governing Magazine, December 2007

The primary impacts outlined above cause subsequent secondary impacts of global warming on various sectors of our society. Global warming will affect absolutely every sector of our economies and societies that we can imagine. Obviously, this reality makes planning, predicting, and paying for adaptation an enormous challenge. Most cities are familiar with land-use, natural-hazards, and disaster planning. Adaptation takes each one to another level of sophistication.[64] The first step is outlining all the anticipated impacts and connecting them with the appropriate sectors. In the charts below the most anticipated or severe secondary impacts of climate change were chosen and connected to the corresponding sector, then the expected implications to society as a result were outlined.

For the purposes of this section, the secondary climate impact is correlated with the most appropriate of the following sectors of society:[65]

- Medical/public health
- Business
- Agriculture
- Biodiversity
- Aquatic ecosystems
- Water resources
- Forests
- Recreation
- Infrastructure
- Transportation
- Coastal resources
- Emergency response
- Energy systems

Rising Temperatures Secondary Impacts

As temperatures rise, a number of secondary impacts can be expected, including increased heat stress for humans, prolonged and intensified smog and ozone episodes, more attractive climates for insects and pests, decreases in soil moisture content, and warmer river and lake waters that threaten fish and other aquatic species. The range of societal implications is extensive. Agriculture threats range from changes in growing conditions as temperatures increase to new challenges from unfamiliar pests. Likewise, human health and the medical sector will be

challenged as citizens and medical professionals struggle with treating and preventing tropical diseases brought in from foreign and invasive insects like mosquitoes and ticks.

Table 3 below describes the effects of rising temperatures.

TABLE 3: Rising Temperatures – Secondary Impacts		
Secondary Impacts	**Affected Sectors**	**Societal Implication**
Invasive species and pests	• Medical/public health • Biodiversity • Agriculture	Threats to agriculture, forestry, overall ecosystem health, death of native species, and increased competition from invasive species. Warmer temperatures and higher humidity levels expand the range of tick populations – Lyme disease infections are more frequent in seasons with above-average total precipitation.[66]
Tropical and vector-borne disease migration	• Medical/public health	Warmer temperatures move disease-carrying mosquito breeding grounds northward and increase human health risks from malaria, typhoid, dengue fever, etc.[67]
	• Medical/public health • Business	Increased pressures on public health systems, demand new knowledge, treatments, and infrastructure to limit the spread of infectious diseases.[68]
Reduced air quality and heat waves	• Medical/public health • Forests	More smog and ozone air exceedances: Air pollution-related sickness and death, more asthma attacks, emergency room visits, lost workdays and impacts to forest ecosystems from ozone. Heat stress and risk of heat-related illness and even death, especially among the elderly and young.[69]

Agricultural and growing impacts	• Agriculture • Forests	Increased risk of heat stress to crops. Changes in crop yields, increased risk of pests, weeds, and invasive species.
Increasing water temperatures	• Aquatic ecosystems • Recreation • Business	Warmer waters threaten cold-water dependent species, less fly-fishing possible.[70]
Decreased runoff	• Aquatic ecosystems • Water resources • Recreation	Lower water flows contribute to reduced water quality, reduced dissolved oxygen content that leads to massive fish kills and algal blooms.[71]
Decreased soil moisture	• Agriculture • Forests • Water resources	Increased drought conditions lead to a lack of viable water resources that stress crops and forests.

Sea Level Rise Secondary Impacts

Secondary impacts from sea level rise promise complex challenges in addressing climate change adaptation for local coastal communities. Slow, but steady inundation of rising seas over land areas, beaches, urban areas, salt marshes, wetlands, estuaries, water supplies, and other human developments of all kinds (including harbor infrastructure) demand unique and thoughtful adaptation strategies. As saltwater intrudes into ground water supplies, the risk of contamination increases and simultaneously forces the water table to rise.[72] "Sea level rise causes sandy beaches to retreat."[73] Whether or not tropical cyclones increase in intensity or frequency, "…sea level rise alone will increase the propensity for storm surge flooding in virtually all southeastern coastal areas."[74]

Table 4 below describes the effects of rising sea levels.

TABLE 4: Sea Level Rise – Secondary Impacts

Secondary Impacts	Affected Sectors	Societal Implication
Saltwater intrusion	• Water resources	Less available drinking water as salt water intrudes coastal aquifers, inland and upstream waterways, ground water

		contamination increases.[75]
Loss of land, beaches, coastal wetlands, and natural habitat	• Coastal resources • Recreation • Business	Fewer tourist destinations, disruption of natural ecosystem processes, creation of "ghost swamps", ecological collapse of tidal wetlands occurs when marsh grasses cannot accrete fast enough to keep abreast of rising sea level in locations where inorganic sediment inputs are low.[76]
	• Aquatic ecosystems	Loss of near-shore habitats and coastal wetlands for breeding, impacts to prime fishing zones, etc.[77]
Loss of transportation infrastructure	• Infrastructure • Transportation • Business • Emergency response	Disappearing roadways lead to problems with transportation needs: food, economic operations, quality of life, commerce, and emergency response.[78]
Private properties at risk from flooding, damage, and inundation (loss of land)	• Coastal resources • Infrastructure • Water resources • Business	Insurance claims and reinsurance risks increase, human displacement and economic threats from loss of businesses, reclamation/disposal costs and environmental risks from abandoned buildings. Loss of livable human coastal areas.[79]
Pollution from coastal hazardous waste	• Coastal resources • Infrastructure • Water resources • Aquatic ecosystems	Hazardous waste leaks as rising water levels threaten toxic storage locations and sewage treatment plants.[80]
Cultural and historical sites threatened	• Coastal resources • Recreation • Business • Infrastructure	Loss of treasured historic or cultural buildings, infrastructure, sites, etc.[81]

Stronger Storms Secondary Impacts

Stronger storms create myriad challenges for all of the sectors of society that their wrath touches. From higher winds, increased rainfall, and associated storm surges, the impacts touch nearly every sector of our economy. Sea level rise alone contributes to greater impacts from hurricanes and tropical storms – with higher water levels, storm surges associated with even low-intensity storm systems have a greater potential for flooding and inundation. Flooding events increase and stress urban water systems, higher winds and storm surges impact the human built environment (transportation and building infrastructure), and emergency situations demand greater planning in order to save lives, provide adequate health care response, and pre-evacuate the bulk of the population.

Table 5 below describes the effects of stronger storms.

TABLE 5: Stronger Storms – Secondary Impacts

Secondary Impacts	Affected Sectors	Societal Implication
Storm surges	• Infrastructure • Medical/public health • Coastal resources • Business	Private properties and public at risk from sudden flooding, wind and wave damage, storm water systems inundated, loss of life and risks to human health and safety. Loss of beaches, tourist destinations, barrier islands, waterfront parks, etc.[82]
Increased flooding	• Water resources • Medical/public health • Infrastructure • Emergency response	Threaten storm water management, sewage overflow, spread of disease, loss of life, property (loss and damage), need for evacuation, and displacement of populations.[83]
	• Aquatic ecosystems • Biodiversity	Loss of near-shore habitats and coastal wetlands, fishing zones, etc.[84]
Infrastructure damage and destruction	• Infrastructure • Business	Insurance costs, reclamation, and disposal costs skyrocket. Environmental risks from building debris.[85]

	• Transportation • Emergency response • Infrastructure	Stranded individuals and communities as roads wash out. Inability to provide rescue and emergency services, food, water, etc. Environmental risks from building debris.[86]
	• Emergency response • Infrastructure • Business	Downed telephone, television, and other transmission lines affect the ability for communities to effectively communicate, esp. during critical emergency periods.[87]
	• Emergency response • Infrastructure • Energy systems • Business	Downed energy/electricity transmission lines affect the ability for communities to effectively provide essential services (heat, water, A/C) esp. during critical emergency periods.[88]
Loss of life, injuries, and disease	• Emergency response • Medical/public health	Increased demands on emergency management systems and personnel.[89]
Commercial fishing losses	• Business • Infrastructure • Coastal resources • Aquatic ecosystems	Hurricanes and storms churn up critical habitat for fish, and damage fishing infrastructure.[90]
Damage to forests	• Forests • Biodiversity • Business	Hurricanes destroy forest resources with high winds, storm surges, and subsequent flooding. Downed forests impact the timber industry as well as ecosystem health for many species.[91]
Population displacement	• Business	As storms become more frequent and severe, the likelihood of coastal community residents relocating inland increases – coastal communities must plan for loss of tax base.[92]

Precipitation Changes Secondary Impacts

The extreme prediction discrepancies in precipitation changes in the Southeast create unique challenges in planning for adaptation measures. The range of secondary impacts from both increased precipitation and decreased rainfall result in contradictory societal implications – from extreme short-term flood episodes to scarce water resource availability. These varying impacts on certain sectors and societal functions require divergent planning efforts. Below Table 4 correlates the secondary effects of too much rainfall and the results of decreased rainfall with the subsequent implications.

Models predicting a decrease in annual precipitation project one of the secondary impacts will be a decrease in runoff to coastal waters by 80%.[93] Decreased freshwater inflows to coastal waters could hinder estuarine flushing, which causes salinity increases (particularly of brackish waters), and increases the vulnerability of shellfish to diseases. Likewise, decreased water flows result in a decline of freshwater drinking supplies, agricultural water supplies, availability of water for nuclear and coal-fired power plants, and water for natural ecosystem functions.

Conversely, not enough runoff causes excess runoff from upstream watersheds to the coastal plain. Extreme and heavier rainfall events create runoff, which causes an increase of sediments, nutrients and contaminants from upstream agricultural pollution. Heavy sedimentation and toxic runoff affects available light for aquatic plants, increases eutrophication, and causes toxins in the to water build up and bioaccumulate.[94] The Hadley Model shows an increase in precipitation, and a subsequent potential runoff increase of more than 60% by 2090.[95] For urban and sometimes rural areas, heavier rainfall events lead to storm water infrastructure failures and flooding events, which threaten human development and lives.

Table 6 below describes the effect of precipitation changes.

TABLE 6: Precipitation Changes – Secondary Impacts

Secondary Impacts	Affected Sectors	Societal Implications
SCENARIO **Drought: Decreased Precipitation**		

Decreasing drinking water supplies	• Water resources • Medical/public health	Drives the need for water rationing, affects public health services, decrease in water quality, etc.[96]
Loss of water for power plants	• Water resources • Energy systems • Business • Aquatic ecosystems	As water for cooling at power plants decreases, there is an increased likelihood of power failures, brown/blackouts, and operational risks (esp. nuclear plants).[97]
Agricultural and growing impacts	• Agriculture • Aquatic ecosystems	Increased demand from crops in longer and warmer growing seasons combined with less availability for water resources results in agricultural challenges.[98]
Lower summer stream flows	• Water resources • Biodiversity • Aquatic ecosystems	Lower water flows contribute to reduced water quality, and reduced dissolved oxygen levels that leads to massive fish kills and algal blooms. Fish and wildlife as well as industries discharging effluent have less available clean, fresh water for dilution.[99]
SCENARIO **Increased Precipitation**		
Flooding	• Water resources • Infrastructure • Aquatic ecosystems • Medical/public health • Emergency response	As heavier precipitation and more prolonged and extreme rainfall events occur, flooding increases pollution runoff, which in turn poses a great risk to public health and welfare. Emergency preparedness and storm water management are concerns.[100]
Increased Runoff	• Coastal resources • Aquatic ecosystems • Agriculture • Biodiversity	Increases in sedimentation and nutrient and contaminant runoff lead to decreased available light for aquatic plants, eutrophication from nitrogen runoff and toxic water pollution.[101]

CHAPTER FOUR: Adaptation Strategies

Universal Adaptation Strategies

"This isn't a conversation that people have to have all the answers to right away, we just need to start the conversation and look at what we're doing right now in the face of climate change – see if our decisions make sense in a climate impacted world."

– Lara Whitely Binder, Climate Impacts Group, University of Washington

A guiding principle that many experts and community leaders working on adaptation are embracing is the concept of *resiliency*. Resiliency refers to the extent to which a measure provides flexibility and true adaptive capacity to the impacts associated with climate change. Planning with resiliency and a win-win outcome in mind will aid communities in overcoming the uncertainties of climate science. A number of climate adaptation strategies and policies have been identified in this research that are both resilient in nature and are universally wise for any level of government or entity to consider when planning for community preparedness to climate change. The strategies in this section encourage over-arching adjustments in the traditional ways we think about, plan, and prepare for the future in our cities and communities. These broader strategies will be discussed before covering the resiliency criteria analysis for specific response initiatives to sea level rise to provide a high-level backdrop for local decision-makers.

The concept of resiliency is one that many adaptive planning efforts already embrace and ought to be fully incorporated into any initiative. While we do not know the precise outcome for each locality under climate change, we do know that the science indicates massive changes to our way of life and basic operations in the Southeast regardless of the specificity. Working toward climate resilient communities means creating cities and towns that can ebb and flow with the changes afoot to our weather, our landscape and environment, our property, public health, and our livelihoods.

In the list below a number of measures have been identified that research indicates are necessary in addition to specific policies addressing explicit problems, which will be examined later in this report. These recommendations are provided for any agency working on increasing adaptive capacity.

1. Given the current lack of specific data for many localities, cities and towns must begin to increase their sophistication to incorporate climate modeling into planning initiatives.[102] Adequate modeling of impacts, particularly of consequences like sea level rise, inundation, and storm surge potentials, are an essential component of any planning effort around adaptation.[103] For example, light detection and ranging data (LIDAR)[2] is incomplete for the entire Southeast coastline, so knowing what is most vulnerable is extremely difficult, which makes planning even more so. Leatherman, et al. (2001) reference a tool called "airborne laser monitoring" that aids in providing high-resolution contour maps that are especially useful in detailed coastal mapping. Accessing quality modeling tools should be a priority for local governments and collaboration with universities or higher levels of government to utilize such tools may offer a cost-effective solution. Through high-tech modeling, governments can develop a range of scenarios on which to base planning for the future instead of relying on predictions.

2. Conducting sensitivity analyses of a community's vulnerability to climate change is an important activity in understanding the most urgent issues to address through adaptation.[104] This exercise highlights the ability of the area to naturally adapt to the impacts, whether or not the particular resource in question is already stressed due to other factors (e.g., overpopulation). Vulnerability assessment leads to the next logical review process of determining what the ability of the community is to sustain and absorb impacts, for example, the adaptive capacity.

3. Also, understanding a community's 'adaptive capacity' is an essential component of knowing what one government is capable of handling as they move to undertake adaptation efforts. Adaptive capacity is a term that Mendelsohn (2001) refers to as the wide range of available resources, technology, and human capital: institutional structure; property rights; the ability to spread risks; information management and decision making; public willingness in the face of climate change impacts.[105] Later in this report the specific adaptive capacity of certain adaptation response measures will be analyzed and will in essence utilize the term for a specific action rather than for the overarching capacity of a city or government.

4. Historical record of our weather patterns, floods, and droughts dominates the way in which we plan today for water supply and flood zone management, storm water operations and wastewater treatment. However, in a world affected continuously by a changing climate, relying on historical events for decision making to plan our policies and operations is a mistake; we need

[2] Light Detection and Ranging (LIDAR) is a remote sensing system used to collect topographic data.

to look to scientific modeling rather than historical observation.[106] While history may provide valuable information for how we are to respond to extreme events, we must not root all planning decisions there any longer as the past is no longer a good benchmark.[107]

5. There is a need to identify efforts already underway in the local communities that qualify as adaptive management efforts in confronting climate change impacts. For example, many coastal areas are already addressing sea level rise through the development of coastal barrier infrastructures, or consciously choosing to allow for the natural movement of beaches – both have different implications as seas rise and storms strengthen. It is important to make sure that sea level rise predictions are being incorporated to adequately accommodate future predictions, not just immediate needs.

Also, integrative planning efforts must be initiated to promote proper coordination between mitigation and adaptation efforts to ensure mutually beneficial strategies are pursued. Communities are very likely to experience conflicting priorities between today's environmental response efforts and tomorrow's adaptation needs.[108] For example, coastal cities that are emphasizing urban density and downtown revitalization efforts to assist in lowering carbon emissions may find that those initiatives directly compete with an adaptation strategy to avoid construction in a projected flood or inundation zone from sea level rise or storm surge. Many coastal communities, such as Charleston, S.C., have historic downtowns that are located in potential SLR inundation zones. Likewise, the hardened infrastructures or "sea walls" are often the least desirable option for addressing rising waters from an environmental and long-term economic perspective. However, many coastal cities have significant infrastructure and high value properties to guard in vulnerable areas and the pressures among decision makers to protect those investments are powerful.[109]

6. Through cooperative integration of planning efforts, there may be opportunities to identify adaptation measures that carry net benefits for the community independent of climate change. The goal of mutually beneficial initiatives in future planning may offer solace to decision makers who are concerned with the elements of uncertainty about climate change impacts. Later in the analysis, specific initiatives will be valuated for this win-win, or "no regrets" aspect, which increases resiliency.

7. Engage regional planning organizations (or councils of governments) for assistance and cooperation in preparing local adaptation policies and strategies. These higher-level

development organizations are often "above the fray" of the urgent demands of a city councilperson or mayor, and have the ability to address longer-term priorities, consider research more thoroughly, and think at more macro levels. Intergovernmental cooperation may also be more feasible through regional planning organizations. Many challenges of climate change will require cross-pollination of thinking through city-to-city and regional information and resource sharing.[110]

8. Modeling population growth projections on the community and incorporating adequate planning simultaneously with adaptation initiative development is critical. Additional considerations for long-term adaptive planning must include the increasing pressures that population growth places on the coastal regions of the Southeast U.S. Between 1970 and 1990, the Southeast "sunbelt" grew 32% with most of this growth in coastal counties.[111] These same areas are projected to increase in population 41% by 2025 adding significant burden on local communities to both adapt to climate change impacts and accommodate this rapid growth. Careful and innovative forethought must go into land use and urban planning, water resources management, emergency response, and human health and medical services in order to adequately serve and design climate resilient communities.

9. The incorporation of vulnerability assessments and risk management for existing infrastructure and any new construction is an important component to all government adaptation considerations. Understanding the vulnerability to specific buildings, residences, and transportation infrastructure will help guide community planning and may lead to requirements for any future construction that managing risks from impending climate change impacts is an essential component to development.[112]

While overarching adaptive management strategies are offered here, many other more specific measures must connect directly to land use planning, water resources management, adequate public health and transportation infrastructures, coastal zone management, and ecosystem management. All of these are fundamental components of a preparedness plan for a southeast city, and there are unique impacts of global warming on each of these systems in our region that need to be specifically addressed. For example, salt-water intrusion in fresh water aquifers seriously threatens many public water systems in our region. Due to the low-lying coastal plain geography, salt-water intrusion is a very real threat more so in the Southeast than in other regions. This next section addresses more of these specific issues.

Strategic Adaptation Initiative Analysis

"Adaptation means we need to know where to move back to – not how to stay there."

– Dr. Stanley P. Riggs, Distinguished Research Professor, East Carolina University

The benefits of proactively adapting to climate change outweigh the costs. In the 2007 Working Group 3 Assessment Report, the IPCC stated with high confidence: *"Adaptation costs for vulnerable coasts are much less than the costs of inaction."* The report elaborates that the damage costs for most developed coasts (accounting for property and human life losses) are higher than the anticipated costs of adaptation.[113] Many post-event, non-market impacts on communities are unaccounted for in traditional disaster accounting, thereby making the case that adaptation can assist in averting the worst market and societal impacts of the high-end sea-level rise scenarios and other climate change impacts such as increased storm intensity.

Yet, the single biggest challenge for local communities in preparing for climate change is often finding the financial resources, will, and ability to look beyond the immediate, pressing problems all cities and towns face daily to plan for the long term. Caught in a "catch-22" situation, local decision makers are known for their inability to incorporate future time horizons in planning efforts, in part because election cycles are so short, resources are often tight, and the most pressing issues require immediate responses.[114] Most notably, in coastal areas, development and long-term planning have been conducted in piecemeal fashion, with little coordination among government entities.[115] But in the face of climate adaptation, cross-fertilization between agencies and various levels of government must increase substantially. Adaptation planning must be closely coordinated and with existing planning efforts to ensure a thorough and responsible approach to new initiatives. Local decision makers must rise to prepare their communities to the climate challenges and bring the necessary players from all affected sectors together to begin the conversation locally and in the nearby region.

In order for local decision-makers to make the most of limited time and resources, they need to be able to selectively identify the response measures that are most strategic and resilient. For the purposes of this report, *strategic adaptation initiatives* have been defined as those with the highest level of *resiliency* to the long-term possibilities of various climate scenarios.[3] The

[3] In King County, Washington, they are terming such initiatives as "no regrets policies;" policies that make sense for the community even if the climate projections turn out wrong. (Swope, 2007)

three qualitative criteria chosen for evaluating *resilience* include 1) adequate adaptive capacity, 2) environmental sustainability, and 3) the ability of the adaptation initiative to serve as a win-win, or "no regrets", strategy in the face of climate uncertainty. See Methods section. Issues relating to the cost of implementation of the measures, political viability, and public acceptance are essential overlays for decision-makers to consider. This analysis separates the fundamental factors that equate to resiliency in an effort to spotlight the essential considerations of adaptation planning.

To test the usefulness of the resiliency criteria analysis, the most common strategies to address sea level rise were selected based on those that arose through research. There are countless other response strategies to sea level rise that could be explored in this analysis. One of the greatest challenges with adaptation initiatives is determining which of the myriad options make most sense for a given community. It is beyond the scope of this report to offer an exhaustive list of options or to conduct the resiliency criteria analysis for all the primary and secondary climate impacts reviewed earlier. For the purposes of illustrating the criteria analysis and demonstrating the types of considerations necessary, the response strategies to sea level rise are applied to the criteria and evaluated in the chart below.

Strategies for Rising Sea Levels

"A strong, healthy ecology has a direct correlation to safe and resilient communities."

– **Todd Miller, Executive Director, North Carolina Coastal Federation**

Strategies to address and adapt to sea level rise will likely need to vary quite dramatically from urban to rural coastal areas as well as from outer shorelines and barrier islands to inner bay shores.[116] The IPCC (1996) offered three primary adaptation strategies to address SLR: retreat (prevention of development and rolling easements), accommodation (elevate land surfaces and structures), and protection (armoring shorelines).[117] The measures analyzed here for sea level rise fall under all of these categories.

Coastal systems are inherently impermanent, with a natural fluctuation and migration of beaches, marshes, estuaries, barrier islands, river mouths, and other features of these ecosystems.[118] Shoreline erosion is already happening today and the natural migration of wetlands and marshes is part of allowing the system to regenerate itself in the face of rising seas. Wetlands, estuaries, and marshes are essential ecosystems that humans depend on both directly and indirectly for human quality of life. They are breeding grounds for edible fish, natural buffers to the storms that come ashore, and filtration systems for pollution, among many other services. The ability of humans to adapt most resiliently to the forces of rising sea levels will depend upon our ability to allow, as much as possible, for nature to take her course – or at least the nature humans have created which is climate change.

The existing infrastructure and development investments in heavily urbanized areas along the Southeast coast may have already caused the desecration of natural shoreline habitats and therefore, protecting shorelines through armoring may be the only viable solution to preserve communities.[119] Likewise, in heavily developed areas, wetlands and marshes may already be subject to the "urban squeeze" and have very little room to migrate naturally and adapt to SLR. However, in a world of rising seas, we must give the coastline the ability to breathe as much as possible to avoid losses of natural ecosystem functions – particularly in the rural and less developed parts of the coastline where we still have the ability to do so. The attempts of humans to permanently stop the powerful forces of the ocean only with hardened structures will

ultimately be met with failure and severe environmental consequences. Poorly planned approaches to rising seas could result in the loss of critical marshes and wetlands, sea walls that may never be high enough, and the eventuality that the seas can ultimately reach any setback.[120]

It is of fundamental importance that local communities in the Southeast region enhance their ability to predict more exact rates of shoreline retreat and land loss. The rates of erosion will vary depending on existing topography and the underlying geography. Likewise, assessment of urban development (inundation projections) and biological impacts (due to habitat/ecosystem changes and loss) are essential for planning purposes.[121] Simultaneously, overlaying increasing population dynamics is also of utmost importance, given that nearly all parts of the Southeast coast already face profound population pressures.[122] The pressures that urban development place on the fragile coastal ecosystems is profound – from homes to roadways to storm water and sewage systems – the land surface is systematically hardened and modified, preventing the natural movement of this landscape.[123] It is of great urgency that we begin to overlay a lens of climate adaptation planning to our existing practices and efforts of development on the coast.

Strategies to adapt to rising sea levels will inevitably need to consider the political and private property legal issues that exist. Titus (2000) recommends that governments seek to protect coastal property values, for "…any policy that fails to do so is likely to be unfair and inefficient, and to engender opposition sufficient to prevent implementation on the scale necessary to have a lasting effect."[124] Titus also suggests "a combination of density restrictions, setbacks, and rolling easements would probably be more successful than relying on any single option."

In Table 7 below, the multiple options for response strategies to salt water intrusion, loss of land, specific private property issues, loss of transportation infrastructure, and threats to cultural and historic structures are evaluated for their resiliency. The evaluation criteria are qualitative and inherently subjective, but the exercise serves as an example of how a local decision-maker might consider an initial review of whether or not certain measures serve to make the community resilient to climate change adaptation.

TABLE 7: Resiliency Criteria Analysis of Sea Level Rise					
Sea Level Rise Strategies	**Response Strategies and Measures**	**Adequate Adaptive Capacity?**	**Environmental Sustainability**	**Win-Win Ability Given Uncertainty**	**Overall Resiliency Rating**
Salt Water Intrusion	1) Construction of desalination plants in areas heavily reliant on groundwater for drinking water.[125]	**Y**	**N**	**N**	**Low**
	While desalination plants may adequately provide drinking water to communities in need of alternative sources, this is an incredibly energy-intensive process using up to 29,500 kilowatt hours of energy per acre-foot (kWh/AF),[126] which would likely contribute to increased GHGs since over 60% of the energy produced in the Southeast U.S. comes from coal-fired power plants.[127] For every 100 gallons of seawater in, a range of 15-50 gallons of freshwater is returned and the resulting waste brine is highly saline and possibly toxic. Given the uncertainties around sea level rise, less environmentally intrusive alternatives are likely to provide greater flexibility.				
	2) Innovative rain water collection and reuse systems on houses and buildings.[128]	**Y**	**Y**	**Y**	**Very High**
	Rainwater collection systems are low-impact environmentally, make more efficient use of rainfall through distributed collection systems, are relatively inexpensive, and can serve many household and irrigation needs throughout society.[129] These ideas provide both adequate adaptive capacity and flexibility in the face of climate uncertainty – a sure win-win strategy.				
	3) Water efficiency and reuse (gray water) efforts – reclaim water for irrigation and other uses.[130]	**Y**	**Y**	**Y**	**Very High**

	Like rain water collection, gray water reuse and water efficiency increase adaptive capacity of a community by utilizing more wasted water and increasing the efficiency with which we use water on a daily basis – ensuring that more water is available in any scenario. These water use measures are also very low-impact on the environment and thus are highly resilient.				
Loss of land, beaches, coastal wetlands, salt marshes, estuaries and natural habitat	1) Beach renourishment with trucked-in sand or sand bags.[131]	***I***	**N**	**N**	**Low**
	The extent to which artificial sand dunes and sandbagging actually protects people and infrastructure is quite variable, but in certain instances (e.g., Miami) it has performed adequately in the past – particularly in the short term – and is thus inconclusive for adaptive capacity.[132] However, it is not a sound environmental solution as the sand bags themselves are often made of non-biodegradable material and create hardships for wildlife, especially sea turtles who dig deep in beach sand for nesting and egg laying.[133] Also, trucking in sand from elsewhere simply displaces the ecological burden. Beach renourishment does not adequately provide for the wide range of SLR uncertainties and really only serves as a short-term, low sea level rise response strategy.				
	2) Construction of sea walls, dikes, wooden concrete bulkheads, rock revetments, groins, sills (rock) – in urban areas only.[134]	**Y**	**N**	**Y**	**High**
	Placement of hardened structures along estuarine shorelines often leads to loss of valuable wetlands and natural buffers, which may increase erosion on adjacent shorelines, thus it is not an environmentally sustainable alternative.[135] However, a caveat is placed here that this strategy be reserved for use in urban, more populated areas, which are likely to already have dramatically altered the natural ecosystem of the shoreline. In this instance, sea walls or other hardened structures may be the best means to provide adequate adaptive capacity to protect the populations and infrastructure in dense, urban areas with significant commercial and residential development.[136] It is also a response measure that will provide a fair level of protection given the uncertainties of SLR. However,				

Loss of land, beaches, coastal wetlands, salt marshes, estuaries and natural habitat, continued…	sea walls are likely not a viable response strategy for cities in which a rise of the water table is expected with SLR (e.g., locations with limestone geology).[137]				
	3) Limit development of hardened and permanent structures to allow for natural ecosystem response, predominantly in rural and underdeveloped areas[138]	**Y**	**Y**	**Y**	**Very High**
	In rural areas and places with less development it is in nature and humanity's best interest to allow the ocean to follow its natural course of expansion and creation of new coastal ecosystems. We must preserve ecological buffer zones to allow for inland beach migration and the room for the sea level to rise in places where nature has the capabilities to absorb it; otherwise we will fight an ongoing battle to harden every inch of coastline, an impossible, expensive, and environmentally insensitive task.[139] When combined with proper infrastructure response strategies, this is a highly resilient means of adapting to SLR.				
	4) Retreat: move structures away from inundation zones to more inland, sheltered locations.[140]	**Y**	**N**	**Y**	**High**
	Planned retreat from inundation zones does provide adequately for health and human safety, however, the environmental footprint of developing two separate locations for one dwelling or business is high. For existing structures, retreat does allow for uncertainty, as properties would simply be relocated as sea levels encroach on development and not before. Historically, homes were actually built on skids, which allowed for easy relocation to dry land.				
	5) Abandonment of properties.[141]	**Y**	***I***	**N**	**Medium**
	Abandoning properties on one hand ensures safety for individuals, but could create secondary environmental disasters as buildings break down and disintegrate. However, demolition is often coupled with abandonment, in which the structure would be completely removed, thus creating a win for the environment.[142] Eventually, though, allowing the sea level to rise and				

	ecosystems to naturally recover is better for the coastal ecosystem than hardened structures.[143] Additionally, abandonment is not a strategy that offers much flexibility for landowners; it should be a last resort for properties with no other alternatives and governments will need to offer compensation if they are to incentivize the leaving of properties.				
Loss of transportation infrastructure	1) Plan for increased navigation via water and air.	**N**	**Y**	**N**	**Low**
	This response strategy is likely only viable in the case of emergency response and management preparedness in the event of washed out roads for evacuation, so it provides little adaptive capacity for daily operations. In terms of climate uncertainty, it is not truly a win-win strategy and is relatively neutral from an environmental sustainability perspective.				
	2) Rebuild damaged roadways and increase maintenance frequency.[144]	**N**	**N**	**N**	**Very Low**
	Continuously repairing roadways that are in flood and inundation zones vulnerable to rising sea levels is a less than ideal response strategy. The costs to society are high, the likelihood of the road washing out again are high, and the environmental impact to the area affected from repeated washout with a hardened structure on top is much higher than allowing the area to reclaim itself naturally. This strategy is also not an adequate adaptive strategy because it has a likelihood of failing in an emergency and does not provide flexibility for a community given the predictions of sea level rise.				
	3) Be prepared to lose threatened roadways and do not rebuild in same location. Identify and map alternative roadways and move roads back from coastal zone.[145]	**N**	**Y**	**Y**	**High**
	While this is a highly resilient response strategy from an environmental perspective, and does allow flexibility given the uncertainties of climate change (once a road is lost, avoid rebuilding), it is likely only a strategy for rural or sparsely populated areas. From an adaptive capacity perspective there are				

	challenges in that a simultaneous retreat must be planned for both residential infrastructure and the roadways or there will be significant challenges for inhabitants of areas with washed out roadways. Temporary roads to allow for relocation for an area may work well.				
Private property response strategies	1) Utilize building setbacks for construction – prevent or restrict construction within a certain high-tide range.[146]	**N**	**Y**	**Y**	**High**
	Building setbacks only work for prevention of future construction in projected inundation zones, so from an adaptive capacity perspective, it does nothing for existing infrastructure and inhabitants. It is a protective policy for the environment, but only allows for uncertainty if setbacks are established early on to accommodate the full scope of sea level rise projections.				
	2) Rolling easements[147]	**Y**	**Y**	**Y**	**Very High**
	A rolling easement is a highly resilient policy, which is particularly good for the environment, as it prevents the property owner from constructing a hardened structure to protect their property. Government ownership rights follow the high tide line as sea level rises. Once the property is overcome, the government takes it back and presumably demolishes it and compensates the landowner for their loss. The strategy allows for flexibility to adapt in direct response to actual sea level rise (not just predictions), and provides adequate adaptive capacity to protect the citizens one by one for their unique location.[148]				
	3) Strengthen building codes to accommodate higher water levels (e.g., stilts), storm surges, and flooding.[149]	**Y**	**Y**	**Y**	**High**
	Building codes to create stronger, more resilient buildings to the impacts of climate change like sea level rise, stronger storm winds, and storm surges is a common-sense approach to adaptation. The resiliency rating is high as this measure provides adequate adaptive capacity. New, more durable and protective construction replaces older buildings. This is a sensible approach regardless of the varying projections for sea level rise, and may be a sustainable				

	environmental option as buildings last longer.				
	4) Transfer of development rights.[150]	**Y**	**Y**	**Y**	**Very High**
	Transferring new development rights from oceanfront properties to properties further away from the shoreline to avoid future inundation issues is also a sensible and highly resilient response when viewed through these criteria. This approach provides adequate adaptive capacity, but again only for new construction projects, not existing property.				
Cultural and historical sites threatened by inundation	Inventory all vulnerable historic infrastructures or areas. Prioritize sites based on vulnerability and historic or cultural significance. Develop relocation strategies for critical structures.	**Y**	***I***	**Y**	**High**
	It is difficult to predict the environmental impact associated with protection of historic structures, thus the *inconclusive* ranking here. If properties are identified early in the process of developing adaptation response strategies, then many of the above measures are viable consideration for these structures and will provide adequate adaptive capacity and are smart strategies despite climate uncertainty.				

CHAPTER FIVE: Conclusions

Conclusions

Impacts from climate change will affect absolutely every sector of coastal communities in the Southeast region of the U.S. From sea level rise and stronger storms, to rising temperatures and changes in precipitation, the implications to all sectors of society and our economy are vast, and we must be prepared to adapt to these impending changes. Indeed, the changes are already occurring, and thus demand urgent attention from decision-makers. Resiliency is an increasingly common term used in discussion of climate adaptation. Therefore, evaluation of response strategies to determine if they are resilient is a useful means of determining which strategies offer greatest flexibility and meet both human and environmental protection needs. It is of particular importance that the environment be included in evaluation of adaptation strategies because in certain cases, the response measure may ironically contribute to increasing global warming pollution.

Response strategies vary in their levels of resilience depending on the nature of their application. In a perfect world only the highly resilient strategies would be used. However, given the realities of cost, political support, and the urgency of implementation (none of which were within the scope of this project), it is highly likely that actual adaptation initiatives will be comprised of a combination of those measures outlined above and many more. In fact, measures will ideally be used in combination with each other in order to truly maximize community resiliency. For example, with the property rights strategies, they must be used simultaneously because certain strategies address new construction only, while others, such as rolling easements, will work with existing infrastructure.

Also, given the significant variability in coastal topography and existing development, certain measures make better sense in urban areas than others. As shown in the analysis of hardened shoreline structures as a response strategy, urban areas require a very different approach as compared to rural areas for resilient sea level rise adaptation. There will need to be compromises in order to adequately protect the populations and infrastructure of the built environment and simultaneously consider natural environmental sustainability. We must factor in the realities of existing ecosystem challenges and develop plans concurrently with the

adaptation needs driven by pressing changes to our climate and the corresponding societal implications. One critical reason to combine conversations immediately is that current planning efforts could directly contradict necessary adaptation measures, resulting in wasted time, money, and effort of the local community.

The conclusions above about the resiliency analysis lays the foundation for a larger conclusion, which is that planning agencies and local decision-makers must begin the dialogues immediately about adaptation because these response strategies are so intricately tied with the ways in which we are currently planning for our future. Early preparedness is a critical component of developing a resilient community. From Miami, Florida to the Outer Banks of North Carolina, the Southeast coastline is more vulnerable than many other parts of our nation to climate change, which begs the need for urgent adaptation conversations to begin.

The resiliency criteria analysis tool created in this report is just one of many means by which a local official might begin to evaluate response strategies, but it is a useful guide to initiate thinking in this direction. Resiliency is a useful trend in the adaptation world and offers a common-sense approach to identify win-win and "no regrets" strategies for climate adaptation. A thorough, more in-depth analysis conducted for a specific community and looking at all of the response strategies for each impact area would create a comprehensive review of resilient measures.

Lastly, local governments are but one piece of the political puzzle to addressing climate adaptation. Many of the response strategies that reviewed for resiliency could be better implemented by state, regional, or federal level government policies. The research and interview findings led to the conclusion that local governments are often politically incapable of establishing and enforcing the kinds of measures necessary to address serious impacts of climate change. For example, coastal area management agencies may be the best ones to enact and enforce large land use policies affecting set backs and building restrictions. Thus, all levels of government must be brought together to establish the dialogue about appropriate distribution of policy-making to maximize effectiveness. Local governments must initiate the dialogue because they will understand the implications for their community and economy better than anyone.

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