A CASE STUDY COMPARATIVE OF CHALLENGES AND OPPORTUNITIES FOR GREEN INFRASTRUCTURE IMPLEMENTATION IN COASTAL REGIONS

by

SONIA C. LINTON

(Under the Direction of Stephen J. Ramos)

ABSTRACT

As storm size and intensity increases in the future along with the rise in sea levels, coastal regions are set to experience greater damage to their social, economical and environmental spheres. With grey infrastructure failing under the pressure of sever storm events, the implementation of green infrastructure is being looked to to successfully mitigate the damage of storms to urban and metro environments. As an integral part of a planned response to climate change, this thesis proposes adapting to long-term rising sea levels in a manner that supports coastal locations by assessing the challenges and opportunities associated with green infrastructure in coastal regions. To this end this thesis proposes using green infrastructure to better support coastal communities but with a need of regulation and policy to allow for effective implementation, and to give policymakers time to prepare for the possibility of a managed retreat from the coastline.

INDEX WORDS: climate change, sea-level rise, grey infrastructure, green infrastructure, coastal resilience, comparative matrix

A CASE STUDY COMPARATIVE OF CHALLENGES AND OPPORTUNITIES FOR GREEN INFRASTRUCTURE IMPLEMENTATION IN COASTAL REGIONS

by

SONIA C. LINTON

B.A., Saint Louis University, 2011

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

MASTER OF ENVIRONMENTAL PLANNING AND DESIGN

ATHENS, GEORGIA

2018

© 2018

SONIA C. LINTON

All Rights Reserved

A CASE STUDY COMPARATIVE OF CHALLENGES AND OPPORTUNITIES FOR GREEN INFRASTRUCTURE IMPLEMENTATION IN COASTAL REGIONS

by

SONIA C. LINTON

Major Professor: Stephen J. Ramos

Committee: Rosanna G. Rivero
Brian A. Orland
Justin Vandever

Electronic Version Approved:

Suzanne Barbour
Dean of the Graduate School
The University of Georgia
May 2018

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

> *As the coasts become increasingly populated, more and more people are placed in harm's way. Thus far, science has not found effective ways to reduce most hazards. Therefore, citizens must look to strengthening communities. Building safer buildings and strengthening infrastructure are important steps, but it is the manner in which societies are built that largely determines disaster resilience. A vital part of effective disaster planning—whether for mitigation, preparation, response, or recovery—is an understanding of the people and institutions that make up each community, including their strengths and their weaknesses, as a basis for developing policies, programs, and practices to protect them. In the end, it is human decisions related to such matters as land use planning and community priorities that will build stronger, safer, and better communities.*
>
> – said by H. John Heinz III at Center for Science, Economics and the Environment, 2002, Human Links to Coastal Disasters (Siders 2013)

Climate change will be one of the most consequential impacts that the earth will have to face, and major future decisions – both policy and individually based – will be affected by it. Rising tides and stronger storms will have an influence on where retirees choose to buy homes, how values in property will fluctuate, the studies and career paths younger generations will take, and how we will come to invest in the future. Disaster resilience depends now more than ever on planning and policy change for the future continuation of coastal cities and safe communities.

The global trends of urban sprawl and fragmentation are complex and intersecting meaning that many coastal cities around the world looking to acquire resiliency techniques and designs to protect their developed areas and communities from the wrath of nature. The fear is that by failing to contain or mitigate the effects of climate change, the pressure put on environmental systems by urban development will ultimately have such negative economic impacts on coastal living and end up having adverse effects on national and international GDP.

Cities differ widely in terms of population, size (area), density, demographic and economic conditions, and their relationships to the environment. These are key variables when it comes to assessing the environmental impacts of urbanization on coastal regions; this is a wicked problem because they cannot be solved by the traditional processes (Camillus 2008) due to the complexity of gathering data (what data should be looked at) and defining issues more clearly (something very hard to do when we do not even wish to address the idea of relinquishing control of the coast). It is not feasible to aim for a single solution when it comes to providing resiliency for cities by mitigating the effects of climate change because of how storm size and intensity are set to grow in the future; in addition to the fact that cities like Miami, New York and New Orleans are such prominent cites that it is almost impossible to imagine that they might cease to exist in the next century.

A 2013 study, "Hurricane Sandy Inundation Probabilities Today and Tomorrow," by NOAA researchers explored the impact of sea-level rise on storm surge. That analysis found that Superstorm Sandy-level inundation will become commonplace in the future as sea-level rise projections continue to grow. The U.S. National Oceanic and Atmospheric Administration notes, "The record-setting impacts of Sandy were largely attributable to the massive storm surge and resulting inundation from the onshore-directed storm path coincident with high tide" (Romm 2016). This means that storm surge and sea-level rise will be perceived as "business as usual" versus the odd occurrence. The idea that storm surges and flooding will become more commonplace in the near future must drive home the need for in-depth analysis of current coastal resiliency policy and the possibility of using green infrastructure in coastal regions as people try to continue their day-to-day lives in high storm impacted areas.

Historically, coastal cities have recorded some of the highest human and economic losses in disaster events, but this is not a trend that necessarily need continue in the future due to the evolving accuracy of science. The predicted rate of greenhouse gas emission by 2100 has NASA projecting that as ice sheets respond to the warming air, sea level could rise from 0.2 meters to 2.0 meters, or up to six feet. Here NASA uses its five coastal centers and facilities as examples:

> *Even under lower sea level rise scenarios, the coastal flood even that currently occurs on average once every 10 years is projected to occur approximately 50% more often by the 2050s in the Galveston/Johnson Space Center area; 2 or 3 times as often near Langley Research Center and Kennedy Space Center; and 10 times more frequently in the San Francisco Bay/Ames Research center area. NASA coastal centers that are already at risk of flooding are virtually certain to become more vulnerable in the future* (NASA 2017).

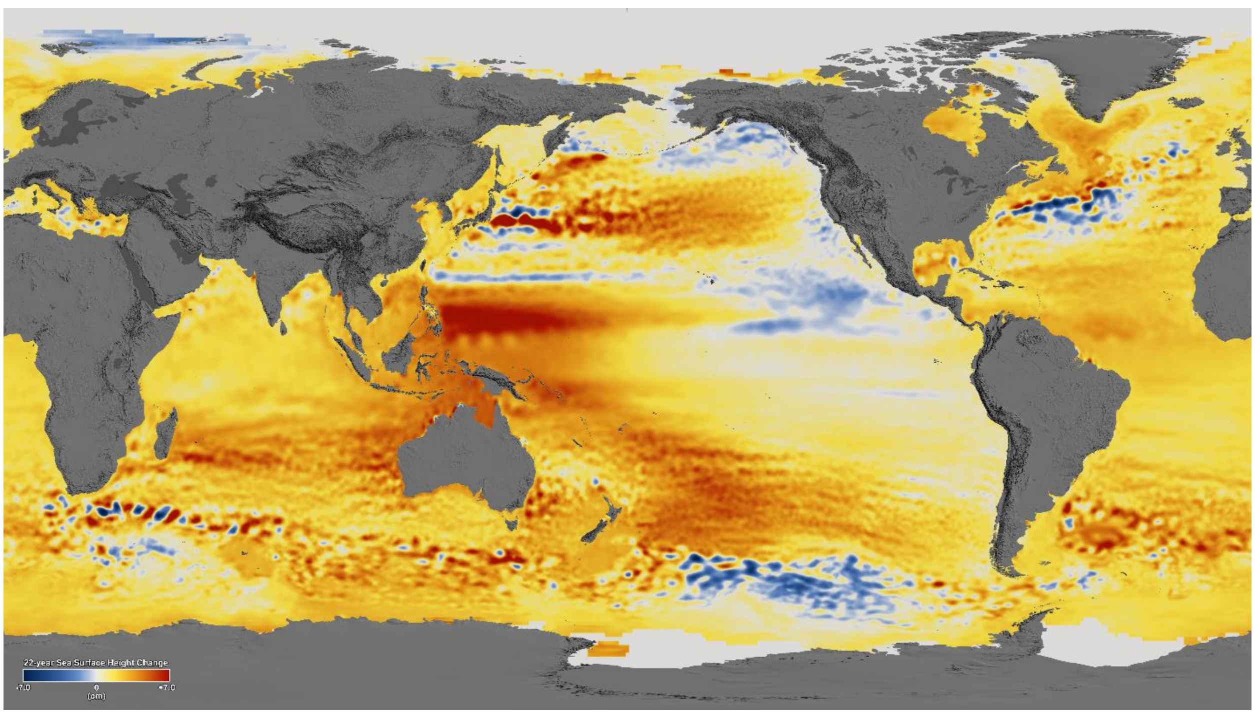

Figure 1.1 NASA recorded sea level changes 1992-2014, -7 cm to +7 cm
(Source credit: https://svs.gsfc.nasa.gov/4345)

Additionally, the Intergovernmental Panel on Climate Change, or IPCC, shows data where the intensity of future typhoons and hurricanes will likely increase, as well as heat waves and heavy precipitation from the year 2090 through 2099.

> *Anthropogenic warming and sea level rise would continue for centuries due to the time scales associated with climate processes and feedbacks, even if greenhouse gas concentration were to be stabilized* (Intergovernmental Panel on Climate Change 2007).

The IPCC reports are important documents providing the scientific basis for global climate agreements and coastal planning around the world, and are updated about every six years, so it is important to note that only a few years ago three feet used to be the "high-end" estimate for sea-level rise by 2100 (Church 2013). This shows just how difficult it is to predict future storm events and what sea-level rise could look like in the future. While science has become more accurate and informative in the climate change data that it can provide, there are still variables that can only be calculated a few years out, such as the function of economics, technology and population growth – all which have an impact on the concentration of carbon dioxide put into the atmosphere which influences the rate of global warming.

Scientists can look at accumulated data like that in Figure 1.1 from NASA that shows the rise and fall in sea levels over a 10-year period to make educated predictions on what will follow in another 10 years, but this may not be completely accurate due to socio-economic and technological fluctuations. With these considerations in mind, anyone living in low-lying coastal regions, the difference between three feet in sea-level rise and six feet can be equated from a soggy but livable city to a submerged one, or from a manageable coastal crisis to a decades-long refugee disaster.

Purpose

In the following thesis I will address the challenges and opportunities for the implementation of green infrastructure in coastal regions. In the past twenty years the coastlines of the United States have experienced severe damage caused by extreme storm events and there is steady move towards building greater coastal resiliency through green infrastructure to protect the social and economic aspects of coastal regions. Through our need to create our own type of environment that better suits out human needs we have generated pressure on coastal environmental systems that were once natural barriers to storm events. This has made it imperative to look at the opportunities that coastal green infrastructure could provide to mitigate the damage caused by the increased intensity and damaging capacity of storms before coastal cities are literally wiped off maps due to overreaching and poor planning.

Green infrastructure is more commonly thought of in relation to stormwater management systems, but for this thesis green infrastructure will be used for coastal urban and metro environments and how to implement it to make these regions more resilient. While green infrastructure and resilience are commonly criticized for being too theoretical, conceptual, and even too impractical for operational use in managing real systems as they constantly evolve and change (Schultz 2016), this thesis hopes to fill in the gap and allow for real world application by showing how, when, where and why green infrastructure was used for coastal resiliency.

With this thesis I intend to look comparatively at grey and green infrastructure in coastal regions by looking at coastal resiliency efforts and issues in Florida, New York, Louisiana and Rotterdam to assess the region's conditions, strategies used, challenges and successes in the implementation of green infrastructure. The logic behind this purpose is to help other government bodies and policymakers make educated decisions for their own planning in coastal resiliency to see what has worked, what has not and what strategies would best suit their own resiliency needs. Once they can they can visually see how others have used green infrastructure, they will improve their ability to adapt to climate change and sea-level rise and to protect valuable assets with greater certainty.

Method and Outline

The methodology in this thesis comes from the work of Robert Yin and his case study method. This method was beneficial in the writing of this thesis because it allows the four cases study areas – Florida, New York, Louisiana and Rotterdam – to be comparatively assessed for the conditions of each region, the strategies, challenges and successes they faced in the implementation of green infrastructure and where this is now leading them (Yin 2014).

Throughout this thesis, grey and green infrastructure will be looked at in relation to its implementation along coastal regions with research to describe its uses and impacts. In Chapter 2, this thesis presents the evolution of green infrastructure, along with a triple-bottom-line evaluation of it to then help discuss its impacts and criticisms. This chapter also investigates the U.S. Army Corps of Engineers assessment of coastal green infrastructure to mitigate the effects of sea-level rise and the funds required to implement then in relation to grey infrastructure. As stated earlier, for the context of this thesis green infrastructure will be referred to in relation to coastal resiliency as opposed to stormwater management. This chapter concludes with analysis of the National Flood Insurance Program (NFIP) as well as the Community Rating System for NFIP participating communities and what it means for properties in flood prone areas.

Chapter 3 uses a comparative matrix for Florida, New York, Louisiana and Rotterdam to inspect what each region is experiencing in terms of storm damage, and what their governments and policymakers are doing in reaction to sea-level rise and mitigating damage from future weather events. Each section begins with a description of the state and why they have been strategically chosen for this thesis, what strategies they are using for sea-level rise, their challenges and successes, as well as what this could mean for their future.

Chapter 4 discusses the difficulty in evaluating green infrastructure from a cost-benefit approach and looks back to previous chapters to analyze and think through the challenges and opportunities faced by the implementation of grey and green infrastructure in coastal regions. The comparative matrix from all four case studies will be discussed to unpack what this means in terms of general policies and conclusions that can be drawn for the implementation of green infrastructure along coastal environments. Chapter 5 concludes with a comprehensive summary of what climate change will entail for coastal regions in the future and what this comparative study has shown in the way of the opportunities in the use of green infrastructure along coastal regions due to its social, economic and environmental benefits. This will also elaborate the challenges in its implementation due to the limited data, experience and regulations of its use. The incentives and challenges with coastal green infrastructure assessed in this thesis will help to establish what planning in the future will entail for urban and metro coastal regions.

Reasoning for Research

A rough estimate places 200 million people worldwide live along coastlines within 5 meters of sea level. By the end of the 21^{st} century this figure is estimated to increase by another 200 to 300 million people (Pelling 2013). This necessitates an analysis of the challenges facing coastal water management and urban development everywhere, and understanding the interactions between human occupation, infrastructure networks and physical conditions. The current view is that existing urban development needs protection but there is little discussion coming from stakeholders and policymakers regarding what it means the future of living along coastal regions entails and the possibility of a managed retreat from the coast, out of harm's way from damaging flood waters and high winds.

Whether for newly planned areas or developed cities, the question stands as how to: 1) minimize costs, destruction, degradation, deterioration, lack of value, and accessibility of property and safety through land use planning; and 2) should the areas subject to flooding be left as open spaces or for recreation use with minimal development above the projected flood plain? All communities will face hazards at one point or another, but what is needed is how to prevent a short-term hazard from becoming a long-term disaster that affects the population as a whole (National Oceanic and Atmospheric Administration 2017); particularly as seen with the ongoing after-effects of Hurricane Katrina on the state of Louisiana.

The vulnerability of an area to rising tides and stronger storms needs to be discussed for two reasons: 1) it puts the emphasis on the ability of a system to deal with a hazard, absorbing the disturbance or adapting to it, and 2) it is forward-looking and helps explore policy options for dealing with uncertainty and future change (Schultz 2016). Coastal cities are predominately caught up now with the concept of making their built environments less susceptible to storm damage by focusing on coastal resiliency. The ability of the community to "bounce back" from hazardous events like hurricanes, coastal storms and flooding is certainly a much-improved goal than simply reacting to impacts after the fact which generally means dealing with greater damage to areas that were unprepared for storm surge and flood damage.

However, while incorporating resilience into human-environment systems has been an effective way to cope with change characterized by surprises and unknowable risks, there is also the difficulty of developing long-term coastal resiliency efforts when considering the uncertainties of predicting future circumstances and impacts. In a world where respected scientists are stating that sea-level rise by 2100 could be six feet or more, designing resiliency projects for current levels looks either startling naïve or incompetent.

By considering the challenges and opportunities that are involved with implementing green infrastructure on a large coastal scale, will help to assess the social, economic and environmental benefits to coastal regions. Due to the limited data and experience on the use of green infrastructure in coastal environments, the research for this thesis has shown that there is more exploration to be done on coastal green infrastructure to make it a good investment and allow for improved future planning in the wake of climate change. We must begin to think systematically about climate change because we cannot predict what the next extreme storm event will entail and looking at both the challenges and opportunities of green infrastructure will help to give policymakers and stakeholders incentives and solid reasons to invest in their future.

CHAPTER 2

GO GREEN WITH GREEN INFRASTRUCTURE

Introduction

Chapter 2 reviews the background and evolution of green infrastructure and discusses its impacts and criticisms with the help of a triple-bottom-line approach to look at green and grey infrastructure from social, environmental and financial standpoints. The chapter will also look at the coastal green infrastructure from information provided by the U.S. Army Corps of Engineers to assess the financial differences between grey and green infrastructure. The chapter will conclude with a descriptive assessment of the National Flood Insurance Program (NFIP) and its relation to the Community Rating System (CRS) that is provided by FEMA for participating communities. While green infrastructure is commonly referred to in the form of green spaces, their interconnecting pathways and as stormwater management that improves the environmental functionality of cities and towns, for this thesis, green infrastructure will be used to describe mitigation and adaption techniques implemented by coastal urban and metro environments under threat of sea-level rise.

Background of Grey and Green Infrastructure

When managing flooding risks, government planning agencies have generally defaulted towards man-made infrastructure, such as building levees and dredging rivers. Compared to green infrastructure, the grey variety currently has a clearer asset life, depreciation and return on investment. Green infrastructure differs from conventional approaches to land conservation and natural resources protection because it looks at conservation in concert with land development and man-made infrastructure planning. While other conservation methods typically are undertaken in isolation from and even in opposition to development, green infrastructure provides a framework for conservation and development that acknowledges the need for providing places for people to live (Benedict 2006). Taking a green infrastructure approach facilitates systematic and strategic planning activities that can be applied to communities beyond jurisdictional and political boundaries.

In 2002, a study published by *Science* concluded that the destruction of habitat costs the world the equivalent of $250 billion each year. It was also estimated that a network of global habitat conservation would provide an annual net benefit of over $4.4 trillion (Balmford 2002). This type of study pushes home the protecting natural systems and biodiversity is an important goal of green infrastructure, but it can also be used as a tool to facilitate protection of coastal development from flooding and erosion without depending on engineered structures such as sea walls (Benedict 2006).

Whether taking a green or grey infrastructure approach, each has its challenges. The most common challenges faced by green infrastructure come from the difficulty in measuring return on investment, risk management, and its effectiveness in urban areas. Current regulation – or rather absence of regulation – at the federal and local levels also presents obstacles because green infrastructure projects do not fit traditional infrastructure models meaning that there is an uncertainty in how they are to be implemented. A common issue that will be seen later in Chapter 3 of this thesis is that when implementing green infrastructure, it is most commonly associated with high income communities and areas with high property value. Challenges surrounding grey infrastructure commonly stem from funding and public investment, maintenance, and increased urbanization (Gale 2015). Urbanization has presented water management challenges because of hard surfaces increasing runoff and decreasing infiltration into the ground.

Another consideration is the timeframe in which green infrastructure begins to protect from flooding and erosion. Wetlands and living shorelines take time grow and be restored, and the maturation period can be affected by pollutants in the water and storm events that damage new vegetation and other organic materials. Additionally, once these areas have matured they must then be monitored and maintained (NOAA 2017). In contrast, once a seawall is built it is expected to have a structural lifetime of 20 to 30 years. It is only recently, due to heavy rains, tropical storms and hurricanes, that seawalls have begun to fail (Coastal Construction 2018). Although grey infrastructure, like a seawall, can only survive for a finite amount of time, coastal cities will still choose to go for these types of short-term solutions because the time frame which they can be installed and how long they will last is a known factor.

Even though implementing green infrastructure approaches presents challenges due to its scale and lack of traditional aspects, after consistently looking for newer and better ways to manage and take control of nature, green infrastructure is beginning to emerge as a beneficial way to work *with* nature and is becoming a subject of significant influence for city and regional planning. With the increase in quantity and intensity of storm events, planners and politicians are looking for other ways to protect the communities that are right on the frontlines of damage from hurricanes and flooding.

Green infrastructure is not a new concept and its formative years can be traced back to the work of Frederick Law Olmsted in the nineteenth century. Olmsted's philosophy not only addressed the ties between ecosystem services and human well-being, but also how integral green infrastructure could be in the evolution and resiliency of cities. Influenced by the negative effects the Industrial Revolution was having on human health and happiness, Fredrick Law Olmsted considered and used the green benefits that he saw in English parks and brought them back to be used in the United States. The most notable project to be implemented from this idea of a social and democratic greenspace was Olmsted's proposal for Central Park in New York City. Following this successful merging of human health and green space, he took the concept of green space and evolved it into functional use as green infrastructure with a reconstructed tidal marsh for Boston's Back Bay area (Eisenman 2013). In Back Bay, the area had formerly been a marshy wetland, but with the increase of human development the landscape soon began experiencing the negative effects of stagnant water and flooding.

Not only did Olmsted return the land to its pre-existing form through a wetland design, but he also encouraged a functioning natural ecosystem which was able to effectively mitigate the impact of storm water and flooding; without negatively affecting the surrounding properties.

Figure 2.1 Central Park, New York City
(Source credit: Getty Images)

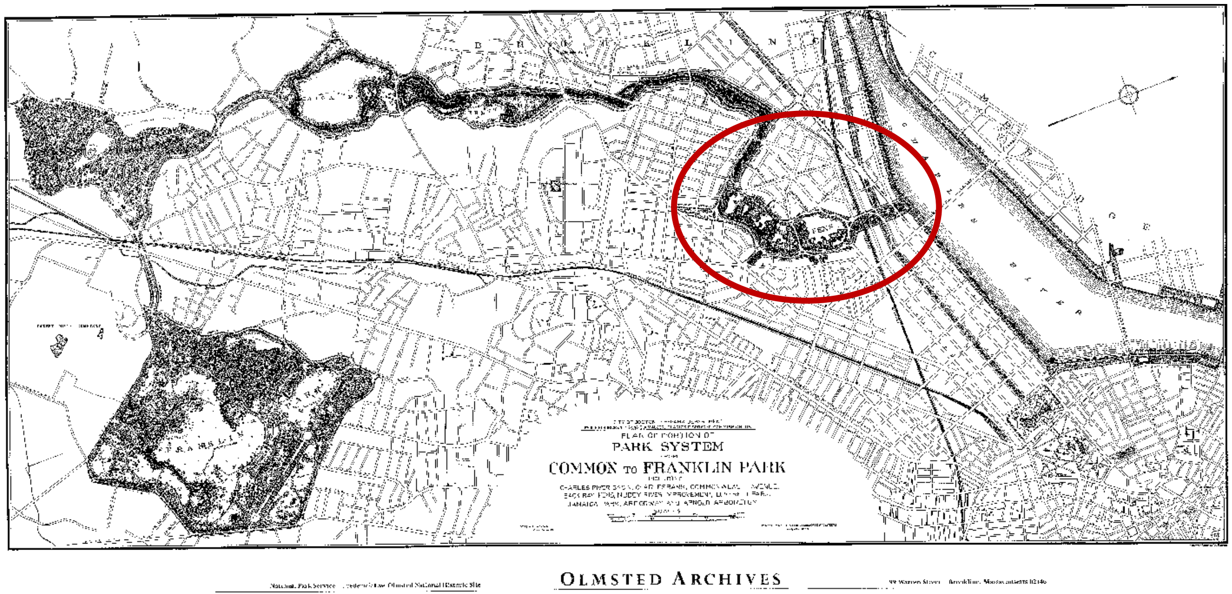

Figure 2.2 Back Bay, Boston
(Source credit: http://www.muddyrivermmoc.org/restoraton-overview/)

As time progressed, green infrastructure moved from the intrinsic character of the land guiding in how it should be used, to conserving natural places for future generations in the 1950s, and landscape and suitability analysis in the 1960s where landscape ecology became the focus of interactions between biological communities and the physical environment. This was also around this time that Rachel Carson published *Silent Spring*, bringing to attention the impact that humans were having on nature. It was finally in the 1980s and 1990s that green infrastructure began to be looked at as a needed process to guide complex land-use planning by taking in the importance of ecological features (Benedict 2006). Unfortunately, human activities had already generated great pressure on coast environmental systems, so the idea of sustainable and resilient development was something difficult to work into existing built environments. With climate change exacerbating the effects of storms, even though the public was slowly gaining greater awareness of the potential value of green infrastructure to meet these new challenges, there was limited information on the implementation process and no financial support from government agencies.

There are limited incentives to facilitate the use of green infrastructure, and this dissuades policymakers and community members from implementing green polices along coastal regions. While there is existing information which indicates that green infrastructure can be less expensive than grey infrastructure (Naumann 2011), the long-term benefits on the social, economic and environmental are not as clear. The benefits are often assessed in purely qualitative terms as there is much less quantitative evidence of the ecosystem services provided by green infrastructure projects.

Although the benefits of green infrastructure are much less understood and documented than the financial costs, studies have shown that the benefits and opportunities coming from the implementation of green infrastructure include: increased recreational opportunities through access to parks, improved exercise and walking, increased water quality and quantity through best management practices, better connection to nature through engagement and access, and increased real estate values of property around open space (Abunnasr 2013). However, the complete set of opportunities to come from green infrastructure is still not clearly known and there is a need for further data accumulation and evaluation over the coming years.

Implementation of Grey and Green Infrastructure

It is certainly true that flooding is a frequent and destructive occurrence that has been making an impact on civilizations for centuries. One group that probably managed climate change and the rising seas better than most was the Calusa, a Native American tribe who lived in South Florida until they were wiped out by smallpox brought by the Europeans in the eighteenth century. The ancient capital of the Calusa, translated as "fierce people" in their language, lived on what is what is now Mound Key Archeological State Park.

The remarkable thing about this island is that it is entirely artificial, an island built up by the Calusa from their discarded seashells. No one knows exactly how long the Calusa lived in the region, but it was likely a thousand years. This shell midden, basically a well-engineered dump, shows just how good the Calusa were at engineering *with* water. They built canals, with locks to control the water, as well as big water courts that functioned like a city square (Thompson 2018). And when storms and hurricanes came through destroying their homes, they just rebuilt them as it was accepted as part of their lives – with their world changing every day, their sense of permanence was not the same as what we perceive in modern times.

Figure 2.3 Mound Key Archeological State Park
(Source credit: https://www.trailoffloridasindianheritage.org)

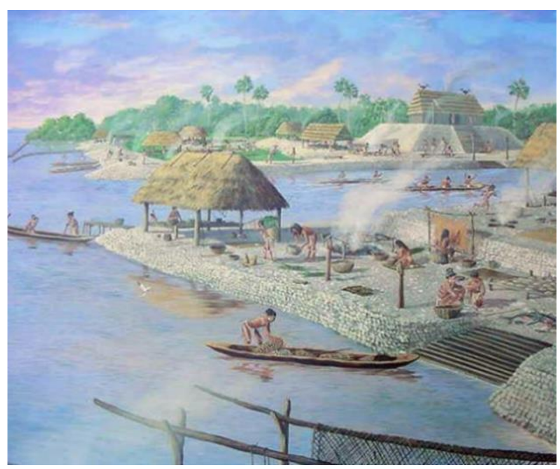

Figure 2.4 Calusa Indians representation
(Source credit: www.ancientpages.com)

Living shorelines are a means of controlling erosion using natural ecosystem services. These natural barriers improve shoreline resilience and provide services such as water filtration, slowing erosion and being able to comeback from damaging storm events at little financial cost – aspects that should be taken into deep consideration due to how natural coastal ecosystems that are wiped out by coastal development (Ewel 1998). Of the "natural" or ecological adaptation measures, mangroves are considered to be the most effective for shoreline protection (Mazda 1997). Mangrove forests reduce erosion by binding soil together and because as mangroves grow, the soil around them also "grows" vertically. This literally keeps up with sea-level rise and in some cases, reduces the impacts of wave energy by up to 20 percent.

A side effect of grey infrastructure like seawalls and pump systems is that it has encouraged development in vulnerable areas, as well as caused flooding and erosion to nearby areas. Post-disaster relief from the government has also emphasized rebuilding houses, reconstructing infrastructure, rehabilitating and restoring the area where the disaster occurred to pre-disaster conditions. The current governance tools to protect people and infrastructure may only offer short-term protection because of increased rates of sea-level rise and the consequent increased intensity of storm surges, flooding and erosion (Lewis 2012). As sea-level rise will cause land to disappear permanently, decision makers will need to balance trade-offs when deciding how to protect people regarding the cost of building erosion and flood control infrastructure, the value of the threatened property and long-term cost maintenance of the land.

Coastal locations have always had interest to humans because access to water meant access to food, transportation and trade. As villages and towns turned into major cities with economic clout, humans created grey infrastructure such walls, barriers and pumping systems to protect themselves from the tides and winds. However, the use of grey infrastructure is certainly more of an avoidance technique and less financially viable as cost increases each time cities rebuild and replace grey infrastructure to stem the destruction from stronger storms (Benedict 2006). Citizens are slowly beginning to realize the value of green infrastructure to help protect their homes and assets, because although it is not perfect fix to the rising seas, it does limit the financial damage caused by storm surges and flooding and keeps the community together – something that is of high value to people who have lived on the coast for many years.

The effects that flooding and storm surge has on coastal communities makes the homes unlivable and drastically decreases property value. The irony that regardless of the destruction and danger that coastal residents experience, people do not want to leave their homes behind and because they pay taxes, they expect their government to maintain and rebuild the washed-out infrastructure and protect them overall from severe storms. The money to constantly rebuild and maintain these types of grey infrastructure systems must come from somewhere, and while residents along coastal areas do not care to abandon their homes, there will also be a limit to how much they are willing to be taxed in order to fund repair work.

Flooding is the most common natural disaster in the United States with low-lying cities around the world experiencing an increase in "clear-sky flooding". In these instances, streets or entire neighborhoods are temporarily washed out by high tides and storm surges. Due to development and construction, parts of Washington now experience flooding 30 days out of the year, a figure that has roughly quadrupled since 1960 (Mooallem 2017). In many urban areas, natural resources such as streams, floodplains and wetlands have been replaced by development and natural hydrological processes has been disrupted by fill and impervious surfaces. This is what happened to Miami following Hurricane Irma when the pumps failed, and ground water flowed upwards onto the streets. As sea levels rise, it no longer takes a strong storm or hurricane to cause coastal flooding; all that is needed is a high tide to wash out streets and flood buildings.

Figure 2.5 Clear-sky flooding in Miami-Dade County
(Source credit: http://www.miamiherald.com/news/local/environment/article72070677.html)

It is by no means easy to go back and replace what has been lost through human development, but we can take note of what Fredrick Law Olmsted accomplished by rehabilitating the landscape to function as it did before. Flooding and storm surge in coastal environments can be greatly reduced by setting aside land or returning parts of built environments to their original natural wetland, riparian and floodplain states. We can pat ourselves on the back for helping natural ecosystem services to once again thrive, while also protecting and mitigating against the full impact of storm surges on coastal communities. Wetlands can give water that could potentially flood built areas on the coast, a place to go and tidal marshes can limit the impact of waves and limit the effects of erosion.

Figure 2.6 Wetland
(Source Credit: https://www.worldwildlife.org/habitats/wetlands)

Figure 2.7 Tidal marsh
(Source credit: https://www.worldwildlife.org/habitats/wetlands)

When impacts from climate change occur, they will happen regardless of city boundaries and socio-economic standing. As an ecological approach of environmental planning, green infrastructure is a network of green spaces where the purpose to conserve ecological values and functions of the environment while simultaneously providing benefits to human populations. The functionality in the application of green infrastructure approaches is great as it can range from the scale of individual buildings, lots and neighborhoods to entire cities and metro regions (Cameron 2016).

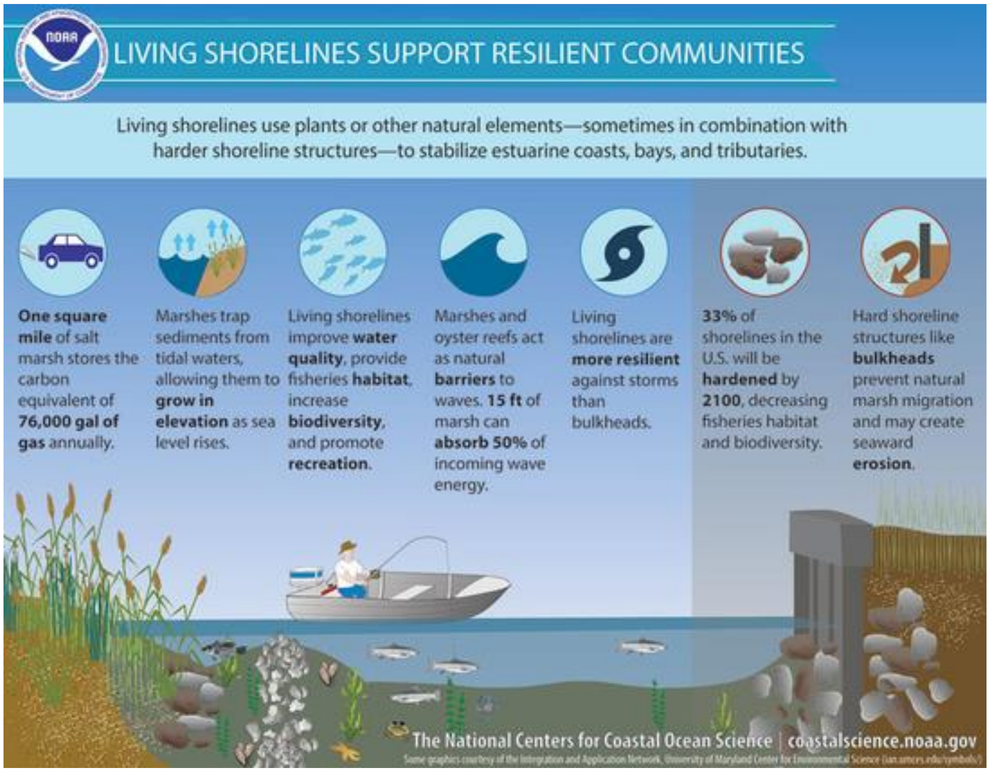

Figure 2.8 Benefits of living shorelines
(Source credit: https://www.fisheries.noaa.gov/insight/living-shorelines)

Unlike a concrete seawall or other hard structure, living shorelines allow for the growth of plants and animals and, as the name describes, grows over time. Not only do these natural structures provide aesthetic green space that is low-maintenance, but evidence also shows that it will perform better during major storm events than a hardened shoreline due to their ability to absorb the impact and recover naturally. According to the U.S. Army Corps of Engineers, the cost of hard shorelines, for example bulkheads, tend to cost more than living shorelines which they have estimated initial installation fees from $1,000 to $5,000 per linear foot. Maintenance of living shorelines will typically cost less than $100 per linear foot annually (NOAA 2018).

Community implementation of green infrastructure particularly helps local governments to achieve environmental, sustainability and adaption goals within their jurisdictions; as well as saving half the amount of money that will be spent on projects costing over $200 million to implement which will most likely be damaged by a stronger storm. Although there are local governments and communities who are using green infrastructure to achieve a variety of environmental and economic goals, including resilience to climate change, application of green infrastructure solutions is not yet widespread as adaption best practices due to the shock of the sticker price.

The writer, Herbert Muschamp, called infrastructure “the connective tissue that knits people, places, social institutions, and the natural environment into coherent urban relationships… It is shorthand for the structural underpinnings of the public realm.” We should take note of how we continue to build and associate with nature because by the 2024, the population in the United States is expected to increase by 48 million people and have an almost fifty percent increase from that in 2050 (Elmer 2014). Much of this growth will be accommodated in areas without streets, roads, schools, sanitary sewers – predominately at the edges of existing metropolitan areas. Climate change effects have enormous implications for infrastructure and major local responses are critical to address mitigation and adaption needs.

National Flood Insurance Program and Community Rating System

In the United States, virtually all flood insurance is provided through the National Flood Insurance Program, or NFIP, which was created in 1968 in the wake of Hurricane Betsy, which caused massive flooding in the Gulf states. Not surprisingly, in the aftermath of the storm event many commercial insurers refused to sell insurance to people who lived in flood zones. To fill the gap, and to give protection to the often-poor homeowners who lived in low-lying areas, the NFIP was born.

For the NFIP, flood risks are determined by the Federal Emergency Management Agency, which draws up maps of areas likely to flood based on ground elevations and other factors. Every building within those flood zones that has a mortgage backed by Freddie Mac or Fannie Mae – that is two government-sponsored agencies that securitize mortgages made by banks and other lenders – must carry flood insurance. For practical purposes, this means that every building with a mortgage in a low-lying area near the coast or a river must carry flood insurance. Right now, the maximum allowable coverage under NFIP is $250,000 for residential properties and $500,000 for commercial properties (United States Government Accountability Office 2017).

NFIP was a good idea at the time, but it has grown into a bureaucratic, outdated, mismanaged program that subsidizes insurance rates for homeowners who live in high-risk areas. Whatever its virtues, the program has encouraged building in flood-prone areas and conditioned a generation of American homeowners into thinking that a cheap rate for flood insurance is their natural-born right as U.S. citizens. The NFIP has also encouraged homeowners to rebuild their homes in high-risk areas regardless of the increasing damage from severe storms. In 2012, Congress passed bipartisan legislation to reform the program, including several measures that would allow insurance rates to rise to better reflect the true cost of risk involved by living in a low-lying area. Since then, Congress has tinkered some of the rules, but the program is still woefully outdated, using flood maps that have only a vague connection to reality and does not even factor in the possibility of a six-foot sea-level rise in the future. Not to mention, the program is also $23 billion in debt (United States Government Accountability Office 2017).

When thinking about the future of South Florida, flood insurance is a scary concept. Currently Florida has the most flood insurance policies in America: that's 1.7 million people in the state alone and those policies cover roughly $428 billion in property value. Looking at the cost of storm damage across the United States from Hurricane Katrina in 2005 to Hurricane Irma in 2017, overall damage comes out to almost $300 billion in commercial and residential properties (FEMA 2018).

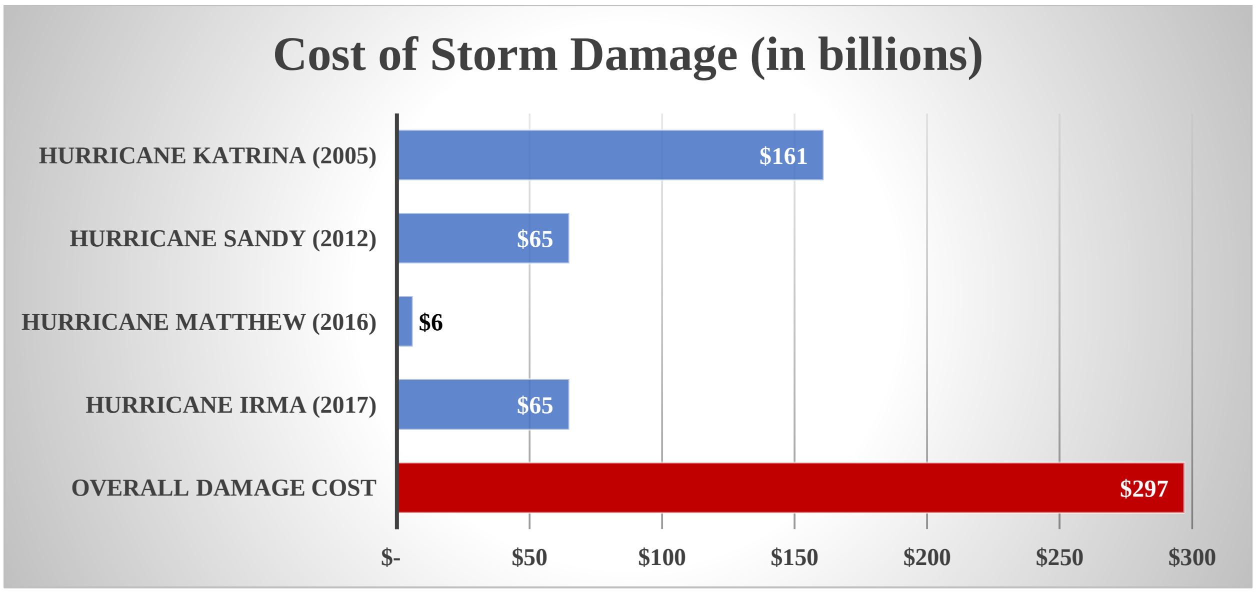

Figure 2.9 Cost of storm damage
(Source credit: USA Today, illustration by: Sonia Linton)

In Miami-Dade County alone there are 346,742 policies, which protect about $74 billion in assets. As an example, in South Florida for a house that is worth $350,000, a homeowner might pay $2,500 a year in flood insurance. If rates go up by 18 percent a year, which is the maximum allowed by the current law, then in ten years, the homeowner will be paying more than $11,000 for insurance. At the same time, higher premiums decrease the value of the home. If rates went up 18 percent a year, a home that was worth $350,000 in 2016 would lose $172,000 in value and only be worth $177,000 in 2026. This would essentially kill the real estate market and any reason to invest in the area (Goodell 2013).

Recently Congress allowed modest reforms in the NFIP, and insurance rates have started to go up, which is still not fast enough to make the program solvent. Still, rising rates are a big challenge for people who own property in flood zones. To make matters worse, the rates are dependent on some mix of luck, bad mapping, and political influence (FEMA 2018). While the future cost of land in flood prone coastal regions could become cheaper as risk increases, being able to rebuild and maintain properties and grey infrastructure that cannot cope with the increased intensity of storms is not a feasible option.

The negative financial impact on property owners with the threat of sea-level rise can, however, be mitigated by participation in the NFIP's Community Rating System. This system recognizes and encourages community floodplain management activities that can exceed the minimum NFIP standards. Depending upon the level of participation, flood insurance premium rates for policy holders can by reduced by up to 45 percent (FEMA 2018). Besides the benefit of reduced insurance rates, the system has the capacity to reduce damages to property and public infrastructure, enhance public safety, avoid economic disruption and losses, reduce human suffering, and protect the environment.

Even with the beneficial aspects of the Community Rating System (CRS), the current cost of flood insurance and the climate change predictions by IPCC and NASA create possibilities for green infrastructure to be looked at as a viable strategic and spatial approach to landscape and urban planning. Green infrastructure has the opportunity to work in tandem with CRS as a form of mitigation and adaption planning to focus on coastal urban and metro environments. CRS already has a framework to gain points and reduce flood insurance premiums for homeowners, and a green infrastructure framework could be used to supplement the floodplain management activities to greatly reduce the threat of flooding.

As coastal communities continue to face the ever-increasing intensification of flooding and storm surges, the survival and evolution of cities is tied to the understanding of resiliency and economic risk. Because of this, emerging adaption plans ought to be set forth as a series of multi-tiered and multi-objective measures to address the dangers of climate change (Abunnasr 2013). As sea levels become more elevated, flooding increases, causing more damage to aging and obsolete grey infrastructure, incurring greater cost to governments and coastal residents who do not have an endless supply of money to spare.

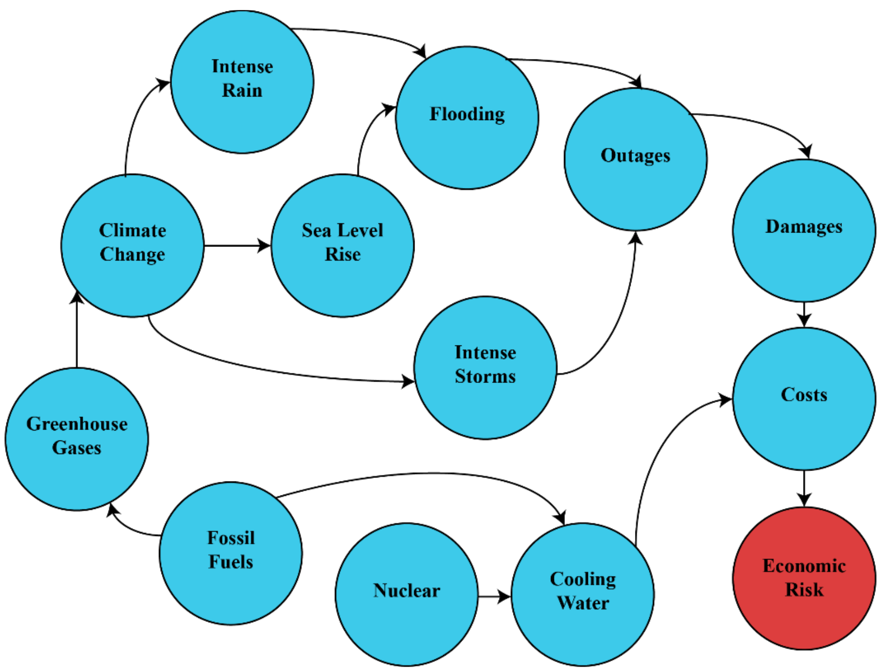

Figure 2.10 Resilience's connection to economic risk
(Source credit: Urban Land Institute, illustration by: Sonia Linton)

Conclusion

Green infrastructure projects along the eastern seaboard in the United States have been using sustainability and ecological urbanism to pave the way for the implementation of resiliency into many urban development plans. These projects are now combinng a variety of sectors – government, business, non-profit and community organizations – to better understand how environmental and human-made vulnerabilities have left cities and regions at risk to climate change (Rebuild by Design 2017). The advantage of resiliency planning is that it not only looks at the possible future dynamics of social and ecological systems, but that it also allows for proactive reimagining of how cities and people can be better prepared for extreme weather events.

Table 2.1 Comparative matrix of grey and green infrastructure *(Source credit: Sonia Linton)*

	Grey Infrastructure	**Green Infrastructure**
Defined As	Human-engineered	Strategic use ecosystem services to benefit human populations
Implementation Cost	Certain	Certain
Life-Cycle Assessment	Clearly defined	Difficult to measure due to lack of comprehensive data
Challenges	Finite life, inflexible	Lacks regulatory systems, relatively untested on large coastal scales, when used it is predominately associated with areas of high property value
Opportunities	Combine with green infrastructure design to support coastal urban and metro environments	Combine with CRS to support floodplain management, socio-economic and environmental benefits

The differences between grey and green infrastructure mostly stem from the availability of conducting a full life-cycle assessment. The valuations and assessments of grey infrastructure are more clearly defined, as are the costs and benefits. On the other hand, green infrastructure is hard to quantify and because it is relatively new in use to coastal planning strategies and policies, deducing the full range of applications and benefits provided by this process are limited.

Resilient urban systems are able to bounce back from impacts due to their flexibility, diversity, sustainability, adaptability, self-organization, self-sufficiency and learning (Ramyar 2017). However, as with green infrastructure, community resilience and climate adaption are difficult to assign value, given uncertainties about future climate impacts and the subsequent difficulty in knowing when a community is adequately "adapted". Multiple goals and no regret policies centered on green infrastructure can offer measurable benefits regardless of how climate changes.

Whether considering beach front property and tourism, or residential neighborhoods and everyday living, adaption strategies for climate change are incredibly important points to take note of. The complexity of contemporary environmental problems means that traditional approaches – like grey infrastructure – to planning, design, governance, policymaking and decision making must now be combined and looked at with a green infrastructure and multi-scale approach. Five adaption principles can be summed up from the plans and designs listed in this section previously: 1) vulnerability of an area and prioritizing those most vulnerable to climate change; 2) building strong partnerships and creating overlap in governance; 3) using the best science available and flexibility in decisions; 4) having a multi-scale approach and maximizing mutual benefits; and 5) continuous monitoring and evaluating the performance (Tengnagel 2017).

The correlation between an increase in cost with flood insurance by 18% per year means that the cost to own a property along the coast will eventually not be the investment to build or buy land there. The increase in sea-level rise over the next century only means that insurance companies will continue to raise their rates not only to make money from coastal properties, but to also be prepared for mass destruction caused by severe weather events. There is huge potential in creating a co-funding model where municipalities, utility companies, and external foundations simultaneously finance flood mitigating measures and recreational urban design. This type of co-funded, landscape-based resiliency management system can be used, among other things, as a driver to upgrade neglected urban areas and provide cities with the potential to simultaneously create more livable streets and more resilient cities.

The overall approach of incorporating and including several potential projects in an area at the same time – construction of central heating, implementation of cloudburst solutions, and general architectural lift to the area – not only saves money but also reduces the hassle to the local citizens. Additional opportunities can be realized in the economic partnership that can drive and increase cooperation between the investing parties and a local anchoring by including residents and other local parties. These partnerships can further lead to increased understanding between groups and to the implementation of innovative concepts and designs that only multidisciplinary teams can create.

Green infrastructure can thus become a multi-scale planning approach to the conservation and protection of land. It is possible to identify underlying features, common principles and characteristics of all the disciplines that use the term "green infrastructure." The opportunities of implementing green infrastructure not only address the inconvenience associated with storm surge such as flooded roads and eroding coastlines, but also the economic aspects of saving millions in flood insurance and construction of hardscapes that will eventually fail as storms become bigger and stronger.

Accommodating climate change impacts as an adaption strategy that may be implemented by decision makers with the goal of intentionally absorbing impacts by designing communities in ways that aim to minimize damage rather than prevent it. Examples include local building codes in flood zones that mandate raising buildings or bridges above current and future flood-levels or requiring that first floors be “floodable”.

Some municipalities are intentionally designing roads as flood canals to channel water away from downtowns to increase their flood resilience or establishing park and recreation land in town-centers as “green” floodways for when local rivers overtop their banks. However, many communities either are unaware of the opportunities of green infrastructure to begin with or believe it is more expensive or difficult to implement than traditional grey approaches. Meanwhile, communities that have embraced green infrastructure may not have connected that it could be a beneficial adaption to climate change, let alone possessing the necessary financing and know-how to plan and implement solutions.

The largest structural component of green infrastructure in urban areas regards the health of the green infrastructure framework. Post-storm surveys have shown that the reason for most green infrastructure failings during storm events could have been prevented through the maintenance, monitoring and in aiding of the natural processes. (American Planning Association 2014) With the potential that green infrastructure has to reduce the damage from natural disasters, it is unfortunate that cities have been unable to look past a quick, and expensive, fix for long-term resilience. The preservation and restoration of mangroves, marsh, dune and floodplains; and the creation of living shorelines and oyster reefs can increase community resilience while providing multiple environmental, economic and social benefits. The qualitative and quantitative benefits – social, economic and environmental opportunities – of green infrastructure are beginning to show through, bringing resilient and feasible designs to the forefront.

CHAPTER 3

COMPARATIVE CASE STUDIES OF COASTAL REGIONS

Introduction

In the built environment, the primary purpose to understanding disaster resilience is to evaluate the baseline conditions, adverse impacts and factors that inhibit effective responses to develop good management plans. Unfortunately, the uncertainty in forecasting weather events and future predictions on the extent of climate change is a difficult business. In Chapter 3, the purpose of the following case studies on Florida, New York, Louisiana and Rotterdam is to look at them with the help of a comparative matrix to assess what they have experienced in terms of storm damage, their successes, challenges and how policymakers and governments are looking to navigate the future. These four coastal regions are important to this thesis because they are at the forefront of climate change, having all experienced serious damages from flooding. While all are using versions of green infrastructure implementation, they have had different experiences and success rates that will allow for overall comparison later in this thesis. Each section begins with a description of the state and why they have been strategically chosen for this thesis, what strategies they are using for sea-level rise, their challenges and successes, as well as what this could mean for their future.

Florida

When it was first colonized by the Spanish in the 16th century, the explorers already knew that Florida would be an excellent gateway to the New World and port location to travel with goods across the Atlantic back to Europe. Since then Florida has grown with economic prosperity based predominately on tourism and the draw of coastal living, along with foreign investment. According to the U.S. Department of Commerce, Florida now ranks as the fourth largest economy in the United States as of the second quarter in 2017 (Bureau of Economic Analysis 2017). This means that a lot is riding on the state's ability to regain its footing after storms like Hurricane Irma for investment to continue in the region and to help support the overall U.S. gross national product.

Back in the 1890s Miami Beach first started to take shape when Carl Fisher – a Mid-western entrepreneur who got rich from his patent and manufacturing of the first mass-produced automobile headlight, helped to create the Indianapolis Motor Speedway and the first transcontinental highway – saw the potential of transforming Miami Beach into America's winter playground. Fisher hired hundreds of black laborers to hack away the palmetto and mangroves native to the region. He then filled in the marshy land with sand dredged from the bottom of Biscayne Bay. Colossal steel-hulled dredgers were brought in to push the sandy bay bottom to the surface. To keep it all from washing away, hard borders were created through the use of pilings and wooden timbers attached with steel cables. Along with thousands of tons of rock used the support the new land, this area became a soup of rotting algae and marine, and it took six months for the smell to dissipate (Paul S. 1999).

Following the draw of financial investment a few miles up the coast in Fort Lauderdale, Charles Green Rhodes was beginning to dredge a new series of canals along the New River. The

West Virginia coal miner then used the fill to create rows of small peninsulas that stretched into the river so that every lot on the street could be sold as waterfront property. Rhodes named the development the Venice of America. This technique of "finger-islanding" quickly caught on, and it took years before anyone realized that the canals had become stagnant cesspools and that the development had destroyed wildlife habitat (Sanders 1989). Not surprisingly, homes also began to sink into the muck, and with sea-level rise in the twenty-first century, the hastily constructed *Venice of America* title took on a whole new meaning.

In 1916, Carl Fisher's company sold $40,000 worth of real estate, and just nine years later the company sold nearly $24 million worth of property. By then, there were 56 hotels with 4,000 rooms in Miami Beach, 178 apartment houses, 858 private residences, 308 shops and offices, 8 casinos and bathing pavilions, 4 polo fields, 3 golf courses, 3 movie theaters, an elementary school, a high school, 2 churches and 2 radio stations (Paul S. 1999).

Of course, this boom would eventually go bust. Not only were con artists and scandals exposed, but in September 1926, a Category 4 hurricane slammed into the newly minted paradise. A ten-foot storm surge flooded Miami Beach, destroying or damaging 5,000 homes and killing 113 people (Paul S. 1999). None of this is surprising because while on the way to make a quick buck, no one was thinking about resiliency or considering the consequences of building a city where mangroves forests had originally existed *and* locating an urban environment right in a major hurricane pathway. With poor construction forethought given to homes and bridges, it is also unsurprising that an earthen dike that was holding back Lake Okeechobee in the central part of the state, would be washed away flooding land and killing hundreds of people (Grunwald 2006).

Eventually the City of Miami would pass the first building code in the United States – this would in turn later become the basis for the first nationwide building code – that required roofs to be bolted down, building frames to be securely attached to foundations, and windows to have hurricane glass. While more resistant to hurricanes than ever before, the legacy of cheap building and poor forethought to coastal planning in South Florida continues.

Today, more than three quarters of the population of Florida lives on the coast, where virtually everything – roads, offices, condos, electrical and water lines, sewer pipes – are vulnerable to storm surges and high tides. As the seas rise in the coming years, the majority of infrastructure will have to be rebuilt or removed. According to a Report by the Risky Business Project, between $15 billion and $23 billion worth of Florida real estate will likely be underwater by 2050. By 2100, the value of the drowned property could go as high as $680 billion (The Risky Business Project 2017). As can be seen in Figure 3.3, the area of Miami-Dade County dominates the Atlantic coastline with developed urban and metro land. There is little or no natural vegetation to absorb the impact of storm surges and decrease flooding in these built up areas.

Figure 3.1 Current land cover for Florida and zoomed in to Miami-Dade County
(Source credit: USGS, edited by: Sonia Linton)

Down by the Gulf of Mexico in South Florida, residents have been, and continue, to adapt to a "new normal" of preparing for the next king tide. Residents park their cars on higher ground and "No Wake" signs encourage drivers to slow down so as not to flood nearby lawns. Although residents have been complaining about the water damage to city officials for years, they end up paying for repair work themselves – one request called for $20,000 from each person living in the area that would involve increasing the height of seawalls and raising the roads (Alvarez 2016). While both the northeastern and southeastern coasts of the United States are buffeted by storm surges and damaging floods, all property owners agree that they will continue to stay in the area and rely on flood insurance to pay for the incurred damages.

As the city has developed without any real land use planning and ordinances to protect it against developers, Miami has created a situation where it is poorly suited to deal with sea-level rise. The city's core business is real estate and tourism that depends upon the quality of and access to the coast, so wealthy investors will take their money elsewhere if the view degrades or if they no longer have access to the shoreline. Another issue is that there is no state income tax in Florida, as state and local governments are largely funded by property taxes. In Miami-Dade County for example, about one third of the county's operating budget comes from property taxes, which means that this form of taxation is incredibly important to keeping schools open and police officers paid. For all intents and purposes, there are only two ways to raise property tax revenue: increase the tax rate or build more expensive real estate. In Florida, which prides itself as a low-tax state, talk of raising tax rates would likely be a career-ender for any politician to suggest it. Therefore, there is an incredible incentive for policymakers to stay quiet, so buildings can keep going up and investors continue to stay happy with the belief that their oceanfront condo is safe.

There is also a third issue of no one wishing to spend money to build a more resilient city because literally nobody owns the risk. This is because soon after a building is completed by the developer, it is passed off to the condo association; and since most condo owners only keep their units for four to five years – about a long as it takes to get their money's worth – there is no long-term concern for what will happen to it in the next century, let alone in the next twenty years (Nehamas 2017).

Home mortgages have a similar problem. Banks give out thirty-year loans, but in most cases, they are quickly sold off and nobody will hold a mortgage for more than a year or so before swapping it with some other bank or financial firm. In Miami, most of the cash is from overseas. In 2015, foreign nationals bought nearly $6 billion worth of real estate in Miami-Dade, Broward, and Palm Beach counties, more than a third of all local home spending there (Nehamas 2017). Being tied to foreign investment makes the Miami condo market different from the markets in other places in that it largely depends on the strength of foreign markets.

Florida is in a predicament because even though the effects that flooding and storm surge has on coastal communities makes the homes unlivable and drastically decreases property value, the irony is that regardless of the destruction and danger that coastal residents experience, people do not want to leave their homes behind and because they pay taxes, they expect their government to maintain and rebuild the washed-out infrastructure and protect them overall from severe storms. To deal with these issues, back in 2013 engineers for the city decided to consider what could have the biggest impact on a city facing higher tides and rising seas. In many areas of the city, flooding was caused by seawater backing up through the wastewater drainage pipes and bubbling up in the streets through manholes and sewer grates. To fix this, one-way check valves were installed on drain pipes that would stop water from backflowing into the streets, in addition to installing big pumps in low-lying areas of the city to drain the water that did accumulate. To finance this, the city commissioners pushed through $100 million in bonds by raising the stormwater fees on residents' utility bills by $7. Yet this was only a down payment as the final price tag for the city's flood abatement plans will likely rise to $500 million (Mazzei 2014).

Another strategy followed with raising a few streets in Miami Beach. The hope would then be that over time, owners of the buildings on the street would raise or rebuild the structures at new, higher levels on their own dime. By the end of 2016, about twenty blocks had been elevated with newly engineered pumps and drainage system below that were supposed to keep the low areas dry during big rains or high tides. However, a few weeks before the king tides in 2016, Hurricane Matthew rolled up the East Coast. The neighborhood flooded just as it had before from the torrential rains, and during the king tides a few weeks later, the new pump and drainage system was overwhelmed (Nunez 2015). The money to constantly rebuild and maintain these types of grey infrastructure systems must come from somewhere, and while residents along coastal areas do not care to abandon their homes, there will also be a limit to how much they are willing to be taxed in order to fund repair work that has minimal benefits.

After these failed attempts at trying to control nature, the Local Office Landscape Architecture, based out of New York, was brought with the goal of working with nature, not against it. Plans were drawn up for the redevelopment of Arch Creek Basin in north Miami. There they have proposed to tear down houses that had been built in a low-lying neighborhood that had been a natural slough – a swamp connecting the Everglades to the sea – and building new housing on higher ground. "The idea is to reduce the risk by relocating people, but doing it locally, so that families and neighborhoods are not disrupted," says landscape architect Walter

Meyer. With the natural slough being resorted, water would be allowed to collect and drain along the natural contours of the land (Local Office Landscape Architecture 2018). The effectiveness of green infrastructure implementation in this area will only be able to be experienced overtime to see how it benefits the community. However, while initial measurements of success cannot be immediately measured, there will be clear social benefits in that the neighborhood will be supported in the process of relocation with better and improved economic standing.

Florida has also recently begun to look to its wetlands to minimize damage urban and natural environments. Renowned for its national parks – Everglades and Biscayne Bay – with its miles of beaches and hundreds of thousands of acres of wetlands, the state is looking to regulate, restore and use acquisition programs for additional wetland areas (Cox 2017). In addition to engineering projects, such as pumps and seawalls, officials in Miami-Dade County are turning to "nature-based infrastructure solutions" to aid climate adaptation. (Robert 2008) Green infrastructure is now more closely being looked at as an important part of resiliency planning. Although vegetation is itself damaged by storms, there is evidence that proves it recovers relatively quickly; unlike grey infrastructure which must be rebuilt by humans. These include coral reefs, wetlands and dunes, which help absorb floodwaters and buffer coastal zones against wave energy. In particular, mangrove ecosystems in Biscayne National Park represent effective, self-sustaining green infrastructure option because of their resiliency in both hurricane and non-hurricane years (Wdowinski 2016).

Figure 3.2 Mangroves at Miami Beach
(Source credit: https://www.instagram.com/gravelmonkey14/)

The effective ways in which the ecological resilience of wetlands can reduce damage from cyclones and hurricanes, is beginning to be appreciated and greatly valued by planners and policymakers as the frequency and intensity of tropical storm events will most likely increase in the coming decades (Davis 2015). As grey infrastructure continues to fail, new designs and implementation practices will need to be generated for urban and metro coastal regions.

Table 3.1 Comparative matrix of Florida *(Source credit: Sonia Linton)*

	Florida
Conditions	¾ of population lives on coast, dependent on tourism, rapid development with little initial planning
Strategies Used	Pump and drainage systems; regulate, restore and acquire wetlands; relocate low-lying neighborhoods
Challenges	No state income tax, people do not want to leave their homes
Successes	Not clear as implementation is still in design phase
Future Projections	Even with the protection and acquisition of wetlands, neighborhood relocation may be the way of the future

An awareness of what is to come regarding the effects of climate change is slowly percolating through the consciousness of property owners, real estate investors, planners and policymakers. In response to projected sea-level rise and extreme weather events, urban areas are developing adaptive strategies to mitigate the effects of changing environmental conditions. As a low-lying community, Miami-Dade County is extremely vulnerable to climate change: i.e. sea-level rise, higher storm surges and more frequent and intense hurricanes. The key economic drivers to the area, tourism and agriculture, are incredibly weather dependent. According to a recent study, Miami is currently ranked first out of 200 cities in the world for total assets exposed to coastal flooding during 1 in 100-year storm surge (Miami-Dade County Government 2015).

Florida has become well known for as a play area for the rich and wealthy, and with this money the state has a strong influence on the economic standing of the United States. For Florida to have investors and tourists continue to spend money on the peninsula, the state has reconsidered its use of pump and drainage systems to defend against nature and is now looking to give and work with the natural environment. Since idea of using wetlands in lieu of grey infrastructure is a relatively new concept, the government needs to develop regulatory policies to make sure the greatest benefit is achieved from acquiring and restoring wetlands, as well as relocating communities to higher ground. The policymakers of Florida have the opportunity to ensure that homeowners are protected financially and legally in their relocation and that the application of green infrastructure to support coastal urban development but also the socio-economic and environmental aspects of the peninsula.

New York

As another coastline colonized in the 16th century, this time by the French, this vast area was deemed to have a "deep delta in which every kind of ship could pass." (Centro Studi Storici Verrazzano 2018) It is no wonder that New York became a major port for the shipment of goods and was the third largest American port at the time of the American Revolution. By the mid-1800s, New York had achieved trade domination. (Encyclopedia Britannica 2018) Although the economy of New York has slowed down since the recession in 2009, the state still ranks as the largest economy in the United States as of the second quarter in 2017 (Bureau of Economic Analysis 2017). As with Florida, the world is watching to see how well New York is able to provide sufficient and feasible resiliency to the coastline. New York is one of the most well-known and invested in parts of America, so a lot is riding on how well policymakers and the citizens can adapt to climate change in their implementation of new policies and designs.

In the early 19th century there was little in the way of rational planning for the city and it was not until the city zoning ordinance of 1916 that any attempt was made to control density and the regulation of land use. By this time though, New York was already a largely built up environment with little room for editing. (Encyclopedia Britannica 2018) As can be seen in Figure 3.4, vast swaths of the New York coastline show its built urban environment.

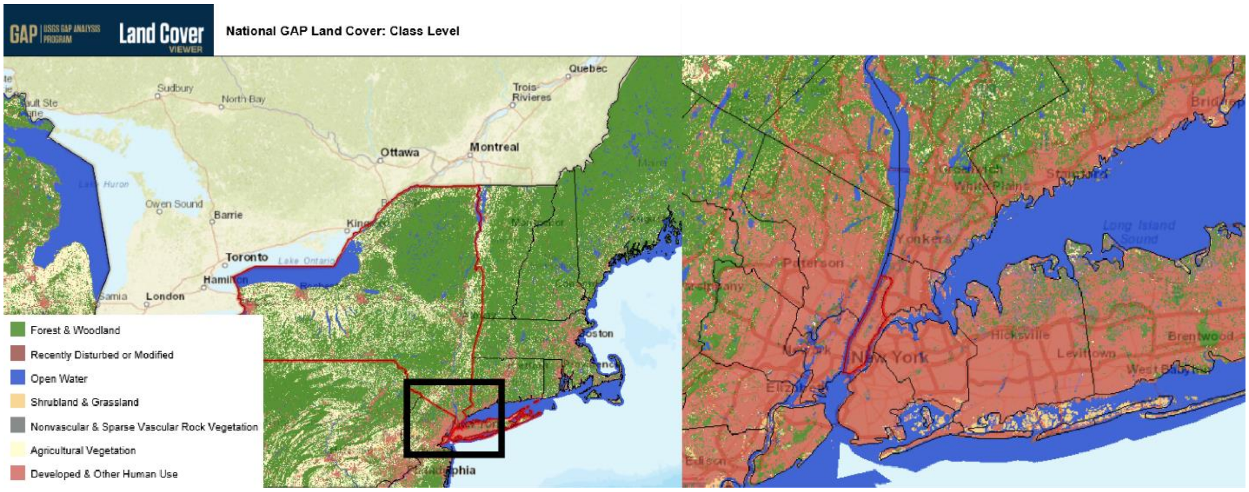

Figure 3.3 Current land cover for New York State and zoomed in to New York City
(Source credit: USGS, edited by: Sonia Linton)

This meant that when Hurricane Sandy hit New York City in October 2012 – with no place for the water to go – more than 88,000 buildings were flooded, 44 people were killed and over $19 billion in damages and lost economic activity occurred. Not only did this reveal how vulnerable a prominent and rich modern city is to a powerful storm, but it also gave a preview of what the city could face in the future. Although climate science can still only predict what sea-level rise will look like, these projections are becoming more alarming as time progresses.

Following the storm event, proposed flood protection designs were studied, and extensive fieldwork was conducted by the U.S. Geological Survey and the New York City Department of Parks and Recreation. Future predictions and simulations showed the coastline's susceptibility to flooding, even with the inclusion of reconstructed dunes along existing shoreline and current mitigation efforts were shown to be having little to no impact (Horstman 2009). In an effort to ready themselves for the future of climate change, in April 2015 New York became part of the 100 Resilient Cities effort set up by the Rockefeller Foundation to:

> *…prepare for and respond to adverse events like Hurricane Sandy, deliver basic functions and services to all residents, and emerge stronger as a community – with the goal of eliminating long-term displacement from homes and jobs after shock events by 2050. The city will upgrade private and public building to be more efficient and resilient to the impacts of climate change; adapt infrastructure like transportation, telecommunications, water, and energy to withstand severe weather events; and strengthen [their] coastal defenses against flooding and sea level rise* (Rockefeller Center 2017).

The Rebuild by Design group is working with 100 Resilient Cities to bring collaborative research and design approaches to cities around the world. It ranges from aiding governmental processes of sea-levels and flooding, to helping agencies make informed decisions. Far from an effort to reduce the destructive effects of a global carbon economy and the planetary urbanization that has unfolded in parallel, resilience strategies are founded first and foremost on calculations of financial risk and insurance – as in the case of a city like New York this means protecting valuable chunks of real estate. It should come as no shock that many insurance experts are directly involved in several of the Rebuild by Design teams, and that many teams have located areas of high vulnerability and risk through complex calculations of geography, geology, hydrology, climate modeling *and* property value. The amount of real estate at risk in New York is mind-boggling: 72,000 buildings that are worth over $129 billion are located within current flood zones (Office of the New York Comptroller 2014). Climate change has now lead resilience to be measured in terms of a cost – without the benefit – analysis for governments over the short-term (Adams 2014).

There is nothing like a catastrophe and threats to property values to emphasize the need to plan for future hazard and climate change impacts. While coastal communities in New York have considered planning for long-term recovery and resilience, on the path to achieving such a great feat there have been challenges in identifying the most beneficial tools, data and resources to inform local planning and decision making. The primary complication is that making big decisions causes big impacts which can have negative effects on people who are outside the sphere of influence.

The task of bringing together the urban planners, stakeholders from coastal communities, architects and real estate moguls is made difficult by their values and the multiple levels at which they interact. So, the theory behind the Rebuild by Design projects is that they are bringing around the concept of global environmental change and making it palatable for everyone. This is at least being done visually. There is no such thing as immediate resilience in a world where climate scientists already have a hard time predicting when the next big storm event will happen. Risk reduction is also costly, requiring substantial investment in infrastructure planning; and as seen in the projects from Rebuild by Design, the ideas that won out were awarded between $10 million and $335 million (Rebuild by Design 2017); no small amount of money.

All this money is going towards projects aimed at resisting the impacts of storm, storing the energy and discharging it safely. One of the most innovative proposals to come out of it was called Living Breakwaters. In relation to the more expensive projects that were part of the competitions, this one is on the “cheaper” side with being awarded $60 million federally. The project was designed by SCAPE, a design firm in New York City founded by Kate Orff, who gained notoriety a few years ago with a bold proposal to clean up New York City’s harbor by reintroducing oysters. Her Living Breakwaters project, which will be built on the south shore of Staten Island near the town of Tottenville, is a four-thousand-foot-long system of breakwaters located about a thousand feet from shore and aims at reviving the natural ecologies of the landscape to protect the coastal residents (New York State 2018). While the project is not designed to stop sea-level rise, it’s purpose is rather to slow and soften waves before they hit the coast, lessening the impact of storms and slowing erosion.

The breakwaters themselves will be built with ecological features like textured concrete units that make healthy habitats for young fish. They will also be seeded with oysters to help further slow and clean the water. So instead of cutting the community off from the waterfront with a fortress like wall – big infrastructure that would block views and just redirect the force of storm surges elsewhere – Orff wants to engage the community with the coastline again. Among other things, SCAPE hopes to work with schools to help garden oysters and start collection programs for shells that could be added to the breakwater to strengthen its growing ecosystem. "Sustainability and resiliency can be built, but by reconnecting with our shorelines, not walling off 500-plus miles of the city's coastline" (Orff 2015).

Perhaps the boldest proposal for protecting New York City was the Blue Dunes project, a forty-mile chain of islands that a group of scientists and architects proposed building in the shallow water about ten miles off the coast. From the city, the dunes would have been visible, and together they would have formed a protective necklace of sand running from Staten Island up to Long Island. Like SCAPE's Living Breakwaters, the Blue Dunes were designed to absorb the wave energy of the Atlantic before it hits the city and lower the impact of the tides, as seen in Figure 2.9. This in turn would buy the city time to recalibrate for sea-level rise.

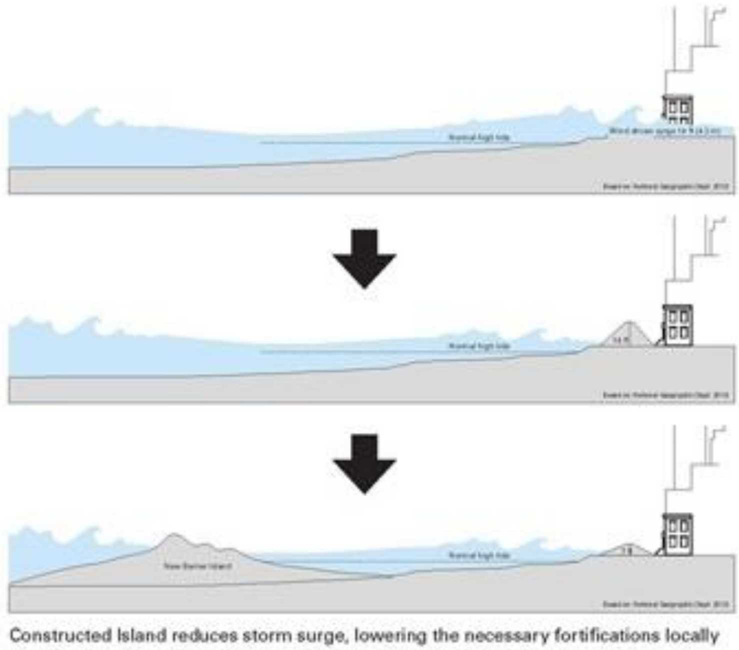

Figure 3.4 Predicted reduction in storm surge from Blue Dune project
(Source credit: http://www.west8.com/projects/blue_dunes_the_future_of_coastal_protection/)

Yet whereas Living Breakwaters is modest in ambition and human in scale, Blue Dunes which was proposed by a group headed by Dutch landscape architect Adriaan Geuze, would have reshaped the entire coastline of New York City. The tides and water would have to go somewhere, and by creating a barrier to strong tides, their effects would be channeled elsewhere. Possibly affecting coastal regions in new and negative ways than previously.

The theory was that Blue Dunes would not save the city from sea-level rise, but rather might save New Yorkers from *fearing* sea-level rise, showing them that there are ways, as Geuze put it, of "working with nature, bending its will, rather than trying to punish it." The Blue Dunes provoked a lot of discussion during the Rebuild by Design competition, but in the end, the project was not funded – the final estimated cost of $31 billion for the full island concept did not help (West8 2014).

Figure 3.5 Blue Dune project location
(Source credit: http://www.west8.com/projects/blue_dunes_the_future_of_coastal_protection/)

The idea may have been to provide coastal communities with new planning tools and resources to help them adapt and change overtime, but this ambitious concept was not very sustainable where there are not current legal and regulatory ways to support the implementation. And even with the possible protection effects from the Blue Dunes project, the multi-billion price tag is difficult to vouch for even with decreases in insurance premiums that could be afforded through the National Flood Insurance Program's Community Rating System.

Yet designs like Living Breakwaters and Blue Dunes show how green infrastructure can be implemented via large centralized public "macro" projects or smaller decentralized "micro" applications on private property (Cameron 2016).

Another successfully chosen project from the Rebuild Design competition is Living with the Bay which was awarded $125 million. In this proposal, the team envisions a “buffered bay” approach where the ecosystems that provide natural protections from storm surge will be protected (Rebuild by Design 2018). Yet this process of disaster mitigation and reconceptualization of large coastal regions into integrated systems leads to questions of feasibility, long-term effectiveness, and whether the marketing imagery of such projects will hold true. Resiliency and mitigation feasibility has its limits and will not be effective when basic safety requires more than what can be provided in a cost-effective way, and at times, without governmental help. The funding broken down in Figure 3.3, in this case, is provided by the New York State Governor’s Office of Storm Recovery.

BREAKDOWN	COST
Planning	$3,750,000
Pre Development	$8,750,000
Construction	$106,250,000
Program Delivery	$6,250,000
Total Allocated Budget	$125,000,000

Figure 3.6 Living with the Bay implementation breakdown
(Source credit: https://stormrecovery.ny.gov/living-bay)

Figure 3.7 Living with the Bay resiliency plan illustration
(Source credit: http://www.rebuildbydesign.org/our-work/all-proposals/winning-projects/ny-living-with-the-bay)

Figure 3.8 Living with the Bay stormwater park illustration
(Source credit: http://www.rebuildbydesign.org/our-work/all-proposals/winning-projects/ny-living-with-the-bay)

Within the concept of Rebuild by Design, resilience is being applied as a social-ecological system where humans and nature are having balanced and reciprocal interaction, as shown in the illustration in Figure 3.4 and Figure 3.5. While this could certainly have social and environmental benefits in the future, these plans and proposals put forth by design firms are underscoring the necessity to learn from past events. Walls and buffers to protect against current levels of storm surges only create an illusion of protection against the acceleration of sea-level rise. And the unfortunate thing is that to accommodate an additional 6 feet in sea-level rise means that costs go up exponentially on top of already pricey projects. As Rebuild by Design and the 100 Resilient Cities projects show, coastal location with highly immovable assets will turn to the mitigation of sea-level rise by investing in expensive protection and accommodation strategies to protect luxury lofts and prized views.

Table 3.2 Comparative matrix of New York *(Source credit: Sonia Linton)*

	New York
Conditions	Valuable property in current flood zones, rapid development with little initial planning
Strategies Used	Joining 100 Resilient Cities to initiate resilient designs, visually appealing proposals
Challenges	Proposed designs are expensive and focus predominately on communities with high incomes and where property values are high, no regulatory bodies, expensive implementation costs
Successes	Not clear as implementation is still in design phase
Future Projections	Limited feasibility due to cost and sole focus on financially important areas

For New York to succeed in its implementation of resiliency methods, it needs to look to provide a standard policy framework and methodology for choosing design parameters that come from ensuring cost-effective investments and providing support to all members of the urban coastal environment. Already considered a leader in planning and development, New York can have a great and positive impact on the implementation of flexible adaption strategies like green infrastructure to support its environment, economy and people.

Louisiana

If New Orleans is culturally and culinary unique among American cities, it is also uniquely vulnerable – half the city lies below sea level, and sinking, and the buffer of protective wetlands that can absorb the force of incoming hurricanes is eroding away. Climate change threatens to make these problems far worse than what they already are. The rising oceans that are strengthening storm surges and increasing moisture in the atmosphere will add to the drenching rains that regularly overwhelm the city's aging drainage system (Schwartz 2018).

Since the early 18^{th} century, the construction of levees on the Mississippi and the closing of is distributaries have altered natural hydrology and stifled land-building silt deposits from spring floods. Property owners and government regulators have allowed the degradation of swamp and marshland: first for farming and cyprus-logging, followed by exploration for oil and natural gas. Prospectors first discovered oil in Louisiana 117 years ago, over 57 thousand wells have been drilled in 10 coastal parishes (Sack 2018). Louisiana is rich in petroleum and natural gas and the state ranks as the fourth largest economy in the United States as of the second quarter in 2017 (Bureau of Economic Analysis 2017) with 18 oil refineries accounting for nearly one-fifth of the nation's refining capacity – processing more than 3.3 million barrels of crude oil per day (U.S. Energy Information Administration 2018). Averaging at $64.69 a barrel as of stock prices on 27 March 2018, that is the equivalent of over $213 million worth of crude oil per day (Bloomberg Markets 2018). This amount of money alone shows just how influential Louisiana is as a whole for the United States. If Louisiana were to be lost due to sea-level rise, the economy of the U.S. could take a noise dive once access was lost to the petroleum and natural gas reserves.

To gain entry to these natural resources, thousands of miles of canals have been dredged through marshes and they broaden each year from erosion caused by boat traffic and storm currents. After years of laissez-faire regulation, some consequential finger pointing has begun in the courts, where parish governments and private landowners are now suing energy companies to rebuild their land. To date that burden has fallen mostly on tax payers, even when property being repaired is owned by oil and gas interests, as shown in examination of state records (Schwartz 2018).

When the Louisiana coast was battered in succession by Hurricane Katrina, Rita, Gustav and Ike in 2005 and 2008, a fourth of the state's wetlands ceased to exist, and state planners believe another 2,000 square miles could be overtaken in 50 years as the land sinks, canals widen, and sea levels rise (Schwartz 2018). Although the recession of Louisiana's coast has somewhat slowed this decade, a football field's worth of wetlands still vanishes every 100 minutes. That is one of the highest rates on the planet and accounts for 90 percent of such losses on the continental United States (Couvillion 2017).

As can be seen from Figure 3.6, New Orleans technically has a "buffer" of vegetation and grassland that could in essence be protecting the parish from flooding, but due to the devastating impact human engineering has had on the wetlands, the U.S. Geological Survey predicts that in 200 years the state's wetlands could be gone altogether. Additionally, the Gulf Restoration Network, a nonprofit conservation group, calculates that there are currently 358,000 people and 116,000 houses in Louisiana census tracts that could be swamped in the surge of a devastating hurricane by 2062 (Couvillion 2017).

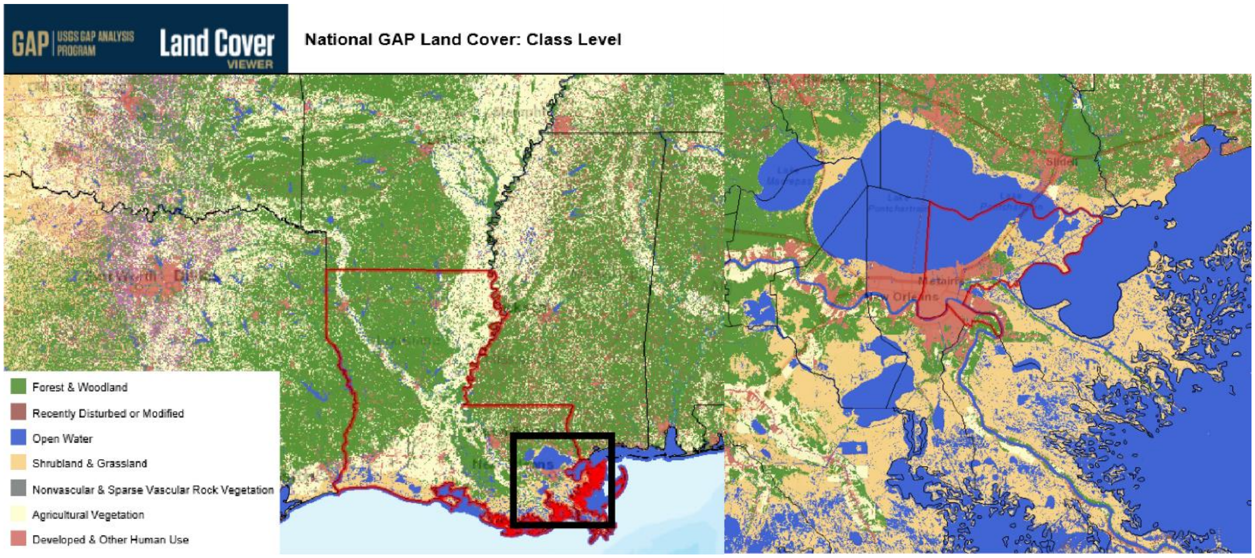

Figure 3.9 Current land cover for Louisiana and zoomed in to New Orleans
(Source credit: USGS, edited by: Sonia Linton)

The area of New Orleans is uniquely linked to water as both an asset and a hazard. Although the City of New Orleans gained national attention following the devastation brought by Hurricane Katrina in 2005, the entire region continues to face the threat of storms, flooding, subsidence and rising sea levels. To ensure that the region remains economically competitive following the disastrous failure of its structural flood defenses, the Greater New Orleans, Inc. alliance is now supporting a multi-line defense strategy that includes not only coastal restoration and engineered flood protection, but also natural design solutions within the urbanized areas (Greater New Orleans Inc. 2015).

The plan provides site-specific redesign recommendations and a regional vision for creating and connecting larger green infrastructure components across jurisdictional boundaries. By implementing the plan’s vision with an estimated $6.2 billion in investments, the Greater New Orleans, Inc. estimates that the regions will reap $22.4 billion in economic benefits over the next 50 years through job creation, increases in property values, reduced insurance premiums, and reduced flooding and subsidence damage (Greater New Orleans Inc. 2015).

With many areas that were once streams, floodplains and wetlands having been replaced by development, the natural hydrological processes were disrupted by fill and impervious surfaces. The conventional stormwater approach prior to Hurricane Katrina dealt with the grey infrastructure of levees to keep water out of residential and commercial areas. With the force of the storm surge and winds brought by the hurricane, these defense mechanisms failed terribly (American Planning Association 2014). The move away from levees and floodgates has signaled a significant change in flood-defense tactics to a focus on more natural solutions, as well as the conservation and restoration of these areas.

However, last year Louisiana officials acknowledge for the first time that even with a vast restoration program for the wetlands, even with tens of billions of dollars they do not have, they no longer believed they could build land fast enough to offset the losses. Plotted on a map, their projections show 40-mile swaths splashed in red to denote that without action, those areas will disappear within decades (Sack 2018). The crisis has become existential with policymakers confronting choices about which communities they can afford to rescue.

As a stark example, a $43 million federal grant is being used to relocate nearly 100 residents of Isle de Jean Charles, a narrow spit in lower Terrebonne Parish that has lost 98 percent of its land over 60 years. In a national experiment, the money will be used to buy land and build homes for those willing to move to higher ground about 40 miles north (Kailath 2018).

Figure 3.10 Katrina's flood waters spill into Ninth Ward
(Source credit: New York Times)

The worry now is that the 100-year flood, or one percent flood, is becoming a five percent or 20-year flood. By this logic, the 500-year flood will become a 100-year flood, and so on. The U.S. Army Corps of Engineers has repeatedly acknowledged that the new system to protect against 100-year floods is simply insufficient for an urban area that is certain to face more powerful storms. The deal under the George W. Bush administration was that New Orleans would remain eligible for federal flood insurance if the system could be brought up to the 100-year level, i.e. the protection needed for insurance eligibility in what the government defines as a flood zone. Though the Army Corps of Engineers produced a 4,000-page report with a host of alternatives, it offered no recommended course of action. That, along with the financing, fell predominately to a state still reeling in the aftermath of the costliest storm on record (Kailath 2018).

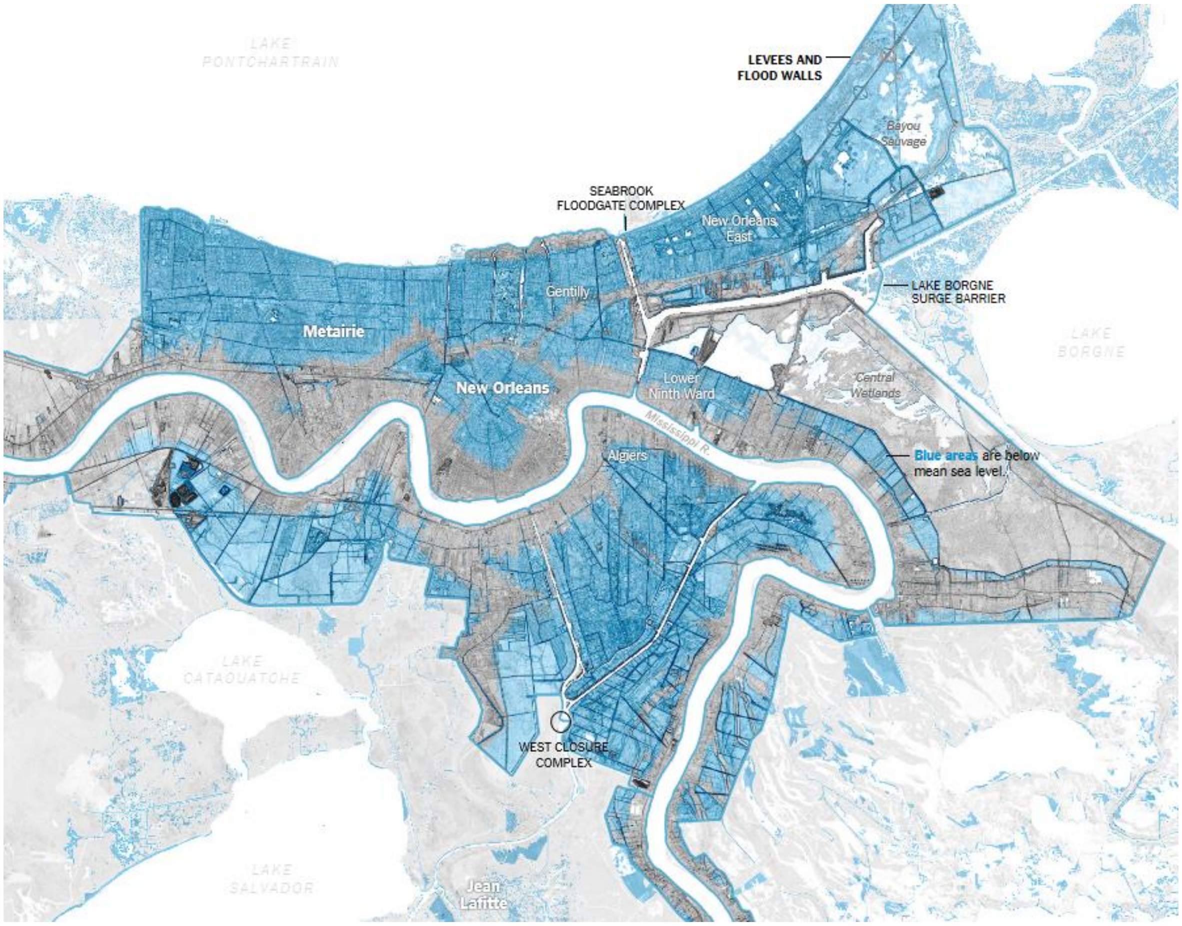

Figure 3.11 Areas of New Orleans below sea-level, represented in blue
(Source credit: U.S. Army Corps of Engineers)

By 2012, the state of Louisiana's Coastal Protection and Restoration Authority had already issued two versions of its own master plan, the later calling for Katrina-level or greater protection for New Orleans. However, when the third plan was released in 2017, predictions for the effects of climate change had outstripped ambitions and it was concluded by the authors that the seas were rising so fast, that with its $50 billion price tag for greater New Orleans and the South Louisiana coast, the desired and needed protection was just too far out of reach; not to mention that the money might never become available (Sack 2018).

Having already been aware that the clear majority of New Orleans is below sea-level, see Figure 3.8, Hurricane Katrina drove home the point that the flood walls and earthen levees were not high enough to stop the storm surge.   So, the Army Corps of Engineers responded by building in features intended to keep them standing – including erosion-fighting measures like concrete “splash pads” to prevent overflow from washing away supporting soil. Deeper pilings were added with the intention to help the walls stay upright and gates to the north to keep Lake Ponchartrain from pouring in; which in theory means there will be less water to pump out after a storm (Schwartz 2018).

Table 3.3 Comparative matrix of Louisiana *(Source credit: Sonia Linton)*

	Louisiana
Conditions	Losing land at rates faster than can be replenished, a lot of land below sea level
Strategies Used	Levees to hold back waters, relocation of small communities
Challenges	Multiple billions of dollars a needed to implement wetland restoration (state does not have the money), levees are failing with no recommended course of action from U.S. Army Corps of Engineers
Successes	Not yet clear as relocation is still new
Future Projections	The state is going underwater faster than it can be restored, relocation the greater option

Yet flooding could still be severe because during a 500-year flood, as five feet of water can cover half the city because it sits below sea level. In August 2017, a thunderstorm dumped six and nine inches of rain over parts of the city within a three-hour period, overwhelming the antiquated pumps (with some dating back to 1912) and causing extensive flooding; to update the drainage system, it will cost at least $1 billion (Sack 2018). The idea that providing protection against a 500-year flood as the status quo is a tall order, considering the estimated cost and that many areas do not even have 10-year flood protection levels.

Louisiana is strategically important to the United States because of the natural resources it provides, but due to mismanagement of land, no set regulations and rules on how to use the land, the state is disappearing faster than the government can find the funds to support adaption strategies, green or grey. At this point in time, even if Louisiana was to find a way to acquire the funds needed to implement a massive wetland restoration project and creating green connections as suggested by Greater New Orleans, Inc., the green infrastructure designs could not be realized in enough time to mitigate the effects of rising seas. As the parishes begin to go underwater regardless of the levees and dikes, the cost and timeframe to use green infrastructure will mean that the government will need to begin considering using the money for more relocations to higher ground.

Rotterdam

Strategically located on the Rhine about thirty miles from the North Sea, Rotterdam is the largest port in Europe with a city full of old canals and wooden boats. Flooding is a well-known threat here as the city sits on a plain that absorbs outflows from the Scheldt, Meuse, and Rhine Rivers, which makes it vulnerable to inundation from extreme rainfalls, as well as sea-level rise and storm surges that move up the Rhine. What is so strategically important about incorporating Rotterdam into this thesis is because of its long history in dealing with flooding and how it has evolved from avoidance techniques to keep the waters at bay to accepting and adapting to the inevitable rise in sea levels.

People in the Netherlands have been living with water for a thousand years and some of the oldest laws in the country are about controlling and protecting themselves from water. Reclaiming land from the sea can be said to be the origin tale of the Netherlands as seventy percent of the country lies below sea level. Back in 1997, at the cost of $5 billion, the Department of Waterways and Public Works completed the Delta Works project. With its implementation of barriers, sluices, locks, dikes and levees, the risk of flooding was reduced to 1 in 10,000-years (Water Technology 2018). This massive grey infrastructure chain of flood protection came about following a flood in 1953 that swept in from the North Sea during high tide, killing 8,361 people and flooding nine percent of Dutch farmland (Metz 2012).

Although the nation has long felt protected by walls and dikes against the forces of the sea, the 1953 flood was a wake-up call to the risk they faced in the future. The Dutch government responded with an all-out engineering effort to defend the nation from the sea, launching the Delta Works project that was a massive feat in possibilities of grey infrastructure. This meant raising dikes, rerouting rivers, and in some cases, moving villages out of harm's way. The centerpiece of the Delta Works is the Maeslant Barrier, about 15 miles from Rotterdam, where the Rhine enters the sea.

The Maeslant Barrier is designed to protect the Rotterdam from a big storm surge coming up the Rhine and inundating the city, while at the same time keeping the Rhine open for shipping – an incredibly important economic aspect for all of Europe as the Port of Rotterdam has an approximately €710 million turnover, over $880 million (Port of Rotterdam 2018). When a storm is coming, two enormous gates swivel out from hinges on the riverbanks and close off the river from the ocean, holding back both the flow of the Rhine and the surge of the incoming ocean. The gates, held by 52,000 tons of concrete buried in the ground, are designed to roll with the waves. However, despite the size of the barrier, it can only stay closed for about twelve hours before the stress on the joints and the foundation becomes too much and the gates must be open.

Figure 3.12 Maeslant Barrier
(Source credit: https://www.holland.com/global/tourism/holland-stories/land-of-water/the-maeslantkering -storm-surge-barrier.htm)

The barrier, which was completed in 1997, cost $450 million to build. In the twenty years it has been in operation, the barrier has only been used once (Water Technology 2018). Keeping the city safe while at the same time keeping it open to the sea is a difficult trick, and with a three-foot sea-level rise, the Maeslant will not be very helpful. Unless walls and levees are raised for many miles around Rotterdam, water will come in from other directions, making closing and opening the gate a moot point. Dutch engineers have let on though that the primary use here is not to solve the problem, but to buy time so they can better figure out how big the problem really is and what can feasibly be done. What is interesting here is that while U.S. coastal regions have continued to use grey infrastructure to avoid the impacts of flooding quite similarly to the Dutch, European thinking has moved to employing this type of infrastructure to allow them to come up with more resilient options for their built environments.

The Dutch look at water as much in cultural as in engineering terms due the centuries old need to work together for protection. Engineers are looking now not how to fight the water, but how to live with it and adapt to it. To meet these principles, they have come up with quite a few innovative ways to deal with flooding in Rotterdam, including pioneering the use of "water parks," which are public squares that double as catch basins for excess water (Metz 2012). This essentially creates storage ponds that keep the water from draining into streets and flooding neighborhoods. During big rainstorms, the catch basin will funnel the water into the stormwater discharge system, sending it out into the river.

Quite like what some projects from the Rebuild by Design competition are looking to create, the Dutch version has fashioned successful urban infrastructure the can function in both dry and wet states. When the pools are dry, they function as recreational spaces providing social meeting places. When there is a heavy rain, the water can accumulate away from the neighborhoods (Figure 3.10) and be redirected safely to the river (Figure 3.11) keeping homes and businesses protected.

Figure 3.13 Waterplein Benthemplein (Water Square)
(Source credit: https://land8.com/waterplein-benthemplein-reveals-the-secret-of-versatile-water-squares/)

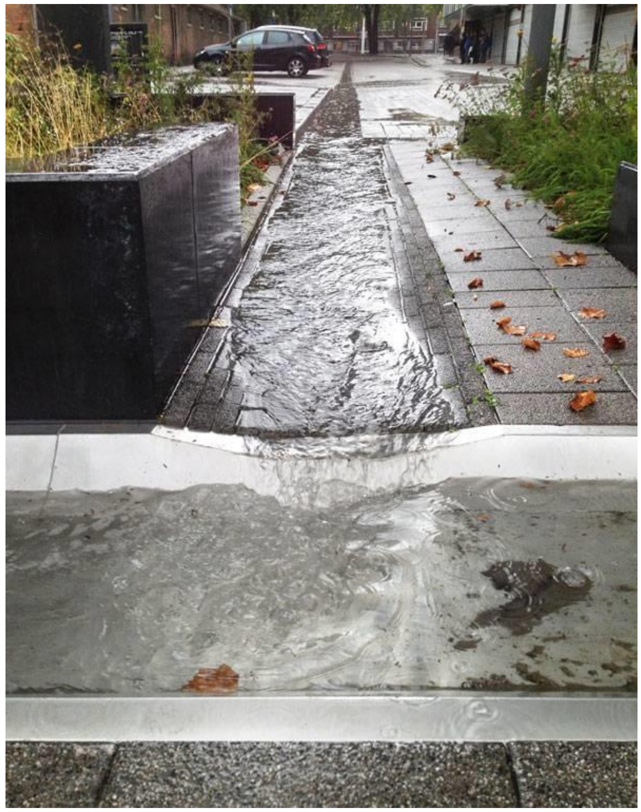

Figure 3.14 Water being funneled to discharge system
(Source credit: https://land8.com/waterplein-benthemplein-reveals-the-secret-of-versatile-water-squares/)

While the Dutch are looking to climate adaption strategies that turn every conceivable area into water storage and protection of infrastructure – from underground parking garages capable of holding 2.5 million gallons of rainwater to green roofs and green facades that are capable of absorbing water, as well as moving all electrical lines up to the second floor of buildings – despite all the innovative sponging and water storage and keeping assets out of harm's way, they do not have full protection from floods. It is not possible to seal off neighborhoods during storms because of the dense population in the city (Braw 2013). No longer are the Dutch combating sea-level rise, but rather seeking alternative means of living with the rising tides by building floating neighborhoods as seen in Figure 3.12.

Figure 3.15 Floating pavilions in Rotterdam
(Source credit: https://www.theguardian.com/sustainable-business/rotterdam-flood-proof-climate-change)

Table 3.4 Comparative matrix of Rotterdam *(Source credit: Sonia Linton)*

	Rotterdam
Conditions	Majority of land lies below sea level, multiple rivers feed into region
Strategies Used	Massive chain of grey infrastructure, some relocation, green infrastructure in the form of green roofs and "water parks"
Challenges	Mixed use of grey and green infrastructure is not proving enough to stop rising tides, costly projects
Successes	The Dutch have a change of mindset to living *with* water, use of grey and green infrastructure has given engineers time to come up with alternative methods
Future Projections	Alternative means to live with water could mean living on the water in floating pavilions, the Dutch cannot just get up and leave as there is nowhere to go

Made of a plastic that is a hundred times lighter than glass with rounded domes for structural integrity, these floating pavilions have a futuristic appeal. Since there is an overall acceptance that the streets in Rotterdam will eventually flood regardless of the grey infrastructure that has been implemented to keep out the rising tides – and because the Dutch know they cannot easily retreat since there is nowhere else to go – so why not float (Braw 2013). Their land is already below sea level and the melting icecaps will outmatch the Dutch flood protection system in the long run. By 2040 the city anticipates that as many as 1,200 homes will float in the harbor (National Geographic Magazine 2013). Due to the limited space that the Netherlands sits on, and because the majority of the land is below sea level, the Dutch have realized that a mixed use of grey and green infrastructure in their cities can only work to such an extent when flooding and sea-level rise will continue regardless of effort and money.

Conclusion

When looking at the comparative matrix for each coastal region, many areas already lie below sea level, or are on there way there. Three of the regions – Florida, New York and Rotterdam – still have the opportunity to implement green infrastructure and create regulatory systems to manage existing and future ecosystem services. Louisiana is unfortunately past the point of no return. Human engineering has caused the wetland areas to disappear much sooner than what could have happened with a monitoring system on how natural resources could be accessed.

To show just how important it is to have a method of acquiring and protecting natural ecosystem services can be seen in the Charles River Basin near Boston, Massachusetts. In the 1960s, urban planners began to recognize that wetlands buffer regional infrastructure and housing against flooding. More recently, wetlands began to be seen as an effective means to manage the more intense and frequent precipitation events expected under climate change conditions, including reducing peak flows and the intensity of flood events in urban areas. In 1978, the Army Corps of Engineers began purchasing land and acquiring development easements to preserve wetlands in the Charles River Basin area (Boston Government 2017).

By 1983, 75% of wetlands in the basin, around 8,000 acres, had achieved protected status at an estimated cost of $100 million (about $618 million today). Without protection, the Corps estimated that 40% of all existing wetlands at the time would have been lost to development by 1990. Since their purchase the wetlands have protected downstream communities on numerous occasions in recent decades, and they prevented an estimated $40 million in flood damages every year. For contrast, communities in neighboring basins without intact wetland systems continued to suffer flood damages with growing financial detriment (Boston Government 2017).

In effectively protecting the wetlands, managing them and limiting development, the U.S. Army Corp of Engineers was able to provide protection on multiple levels to communities who could have been in dangerous flood zones without it. With the ongoing concerns of vulnerability to sea-level rise, this means that cities in especially low-lying elevations will be the most at risk of storm surge and flooding. Even though the opportunities and challenges in the implementation of green infrastructure are relatively new to many coastal regions, it is clear that that valuable benefits to start the use of green infrastructure before there is nothing to build off of.

As seen with Louisiana, if the decision to implement green infrastructure along with guideline and regulations to monitor it comes too late, relocation of urban and metro environments will be the next step. Or, there is the option to the be like Rotterdam that has decided not to continue to solely use a mix of grey and green infrastructure, and instead has moved to new and futuristic ideas that allow them to stay not in the city, but rather on top of it in floating bubbles. No longer trying to spatially complement the built environment and provide counterbalances to its negative effects (Foster 2011) with forms of green infrastructure but are instead taking a whole new look at living with rising tides and climate change.

CHAPTER 4

ANALYZING GREY TO GREEN INFRASTRUCTURE

Introduction

People have been flocking to coastlines around the world, and according to report published by the National Oceanic and Atmospheric Administration, the coastal populations in the United States will have grown to 165 million people; this is a 50% increase since 1960. Governments often do not manage or keep track of coastal development, leaving sprawling urbanization and poorly planned coastal developments that not only disrupt and degrade the ecosystem (Tibbetts 2002) but also leaves communities unprotected and uninsured from natural disasters. Neither grey nor green infrastructure is a perfect approach to climate change: green infrastructure currently lacks ways to measure its effectiveness, return on investment and any type of regulatory body for its implementation; on the other hand, grey infrastructure encourages increased urbanization in areas that cannot truly support a built environment and requires a good deal of maintenance to keep it functioning effectively.

The hope with sea-level rise is that if it progresses slowly enough, it will erode the politics of denial and inspire innovation and creative thinking, and the whole crisis might just become manageable. People who do not want to live with the risk of higher water can move to Denver, while the people who want to experiment with a platform city and new ways of living with water can remain behind. Becoming pioneers in a watery urban renewal.

In the very near future, coastal cities face a twofold threat of inexorably rising oceans that will gradually inundate low-lying areas, and higher seas that will extend the damaging reach of storm surges. The threat will never go away and only worsen as time progresses. By the end of the century a hundred-year storm surge like Hurricane Sandy's might occur every decade or less. Using a conservative prediction of half a meter, or 20 inches, of sea-level rise, the Organization for Economic Co-operation and Development estimates that by 2070, 150 million people in the world's largest port cities will be at risk from coastal flooding. This is on top of the $35 trillion of property – about 9 percent of the global GDP – that could be in danger. (Organization for Economic Co-operation and Development 2007).

The feasibility of coping with this amount of damage to the economy world-wide while losing value to property and continuing to rebuild grey infrastructure is out of the question. To adapt to present climate change conditions, it has been estimated that between $448 billion and $944 billion would have to be spent to upgrade grey infrastructure for water and wastewater (Berkes 2007). Even with potential future opportunities in the way of social, economic and environmental benefits to urban and metro environments, the challenge of implementing such an upgrade lies in the extent and willingness of government bodies. As stated earlier in this thesis, the uncertainty in climate change predictions means that renovating infrastructure systems is to advance them for an unknown future of severe weather.

Building levees and storm barriers as has been done for the past few decades to keep the storms out entails millions of dollars will have to be spent every in half the amount of time that grey infrastructure is supposed to last. The intensity and frequency of storm events will come to dictate the life expectancy of man-made infrastructure. The opportunities envisioned from green infrastructure – slowing off erosion, mitigating storm surge damage, creating connections between humans and nature – comes from the knowledge that ecosystem services associated with mangrove forests, wetlands and living shorelines have been surviving and regenerating from storm events for millions of years. Policymakers, design firms and stakeholders are looking to implement green infrastructure in regions that had once been natural habitats for these ecosystem services, so there is the expectation that wetlands and mangrove forests will be able to operate successfully once they protected and restored.

The challenges though for the implementation of green infrastructure lie in the funding required, the lack of any regulatory laws for implementing it, and how well ecosystem services will be able to do what coastal regions hope they will do. With limited comprehensives studies and reports having been done to support the implementation of green infrastructure in coastal regions, there is an uncertainty in reaching out into the expensive unknown. The concept of implementing green infrastructure is quite new to the coastal regions researched in this thesis: Florida only began considering protecting, restoring and acquiring wetlands in 2016, and that was after trying to use massive systems of grey infrastructure that failed following Hurricane Matthew in 2016; New York decided to join 100 Resilient Cities back in 2015 after the devastating effects of Hurricane Sandy in 2012, and as part of their "resiliency goals" they created Rebuild by Design to come up with new and greener ideas to protect their urban coastline; Louisiana may have been severely impacted by Hurricane Katrina back in 2005, but it was not until 2012 that they considered investing funds to reconstruct their wetlands, which at this point is a losing battle; and Rotterdam has never quite moved away from using grey infrastructure to keep out flood waters and has decided instead to use a mix of green and grey methods to keep the land above the tides.

When looking at a comparative matrix of all the coastal regions, none of the areas have any clear success stories to tell due to the newness in their ideas to implement green infrastructure. The majority of literature on green infrastructure that supports its use and has quantified cost-benefit analyses focuses on inland areas by streams and low-lying areas in need of stormwater management; not expanses on coastline where erosion, hurricanes and storm surges are of primary concern. The lack of any initial planning and forethought in areas that lie below or at sea level has left the below urban and metro environments without any clear vision in which to implement green infrastructure.

Having experienced the failings of grey infrastructure and the damage that followed from storm events, there is a rush to try new strategies and adaption techniques to mitigate sea-level rise. Without any regulations and laws to deem how green infrastructure will be funded and implemented in these coastal regions, there is no guarantee of its success and protection of the coastline as is being envisioned. Louisiana has already acknowledged that the cost to restore its wetlands is too great and is now looking to relocate communities in immediate danger of going underwater; and Florida may be soon to follow once the financial implications of such a venture are assessed. New York will have to reconsider its plans to primarily protect financially important areas to be more inclusive of the whole urban area, and Rotterdam will now have to deal with the regulatory implications of implementing new forms of infrastructure to live on top of the tides.

Overall it is still too early to tell what the opportunities and benefits are that can be provided by green infrastructure to urban and metro coastal environments. The plans to implement this form of nature-based infrastructure is somewhat of a last-ditch effort to reinforce the safety and prominence of coastal living and create visually appealing resiliency efforts that work with natural ecosystems. Grey infrastructure has essentially become obsolete with the onset of vastly fluctuating storm intensity and frequency. At this point engineers cannot predict what level of strength and design is needed for levees and seawalls to be efficient and good investments for urban and metro coastal environments with rising sea levels and stronger storm surges.

Table 4.1 Comparative matrix of all coastal regions *(Source credit: Sonia Linton)*

	Florida	**New York**	**Louisiana**	**Rotterdam**
Conditions	¾ of population lives on coast, dependent on tourism, rapid development with little initial planning	Valuable property in current flood zones, rapid development with little initial planning	Losing land at rates faster than can be replenished, a lot of land below sea level	Majority of land lies below sea level, multiple rivers feed into region
Strategies Used	Pump and drainage systems; regulate, restore and acquire wetlands; relocate low-lying neighborhoods	Joining 100 Resilient Cities to initiate resilient designs, visually appealing proposals	Levees to hold back waters, relocation of small communities	Massive chain of grey infrastructure, some relocation, green infrastructure in the form of green roofs and "water parks"
Challenges	No state income tax, people do not want to leave their homes	Proposed designs are expensive and focus predominately on communities with high incomes and where property values are high, no regulatory bodies, expensive implementation costs	Multiple billions of dollars a needed to implement wetland restoration (state does not have the money), levees are failing with no recommended course of action from U.S. Army Corps of Engineers	Mixed use of grey and green infrastructure is not proving enough to stop rising tides, costly projects

Successes	Not clear as implementation is still in design phase	Not clear as implementation is still in design phase	Not yet clear as relocation is still new	The Dutch have a change of mindset to living *with* water, use of grey and green infrastructure has given engineers time to come up with alternative methods
Future Projections	Even with the protection and acquisition of wetlands, neighborhood relocation may be the way of the future	Limited feasibility due to cost and sole focus on financially important areas	The state is going underwater faster than it can be restored, relocation the greater option	Alternative means to live with water could mean living on the water in floating pavilions, the Dutch cannot just get up and leave as there is nowhere to go

The most damaging aspect of a hurricane is the storm surge, and in a 2012 study a consistent record was made of large storm surge events in the Atlantic over the previous nine decades. It found the worst storms surges "can be attributed to landfalling tropical cyclones." The study also found that the worst storm surges "also correspond with the most economically damaging Atlantic cyclones" (Aslak 2013). In summary, hurricanes cause the biggest storm surges, and hurricanes with storm surges caused the most destruction. Studies like this along with an analysis from Reuters showing $1.4 trillion in property lying within 660 feet of the U.S. coast (Wilson 2014) has created a drive to quickly develop new techniques to combat the threat of sea-level rise.

As with new medicines that are put out on the market, a coastal implementation of green infrastructure is an untested and expensive method that has coastal regions placing their hopes and continued existence. The National Oceanic and Atmospheric Administration and the U.S. Army Corps of Engineers have done the math to see what the initial and managing costs of coastal green infrastructure would entail, and scientific studies have found that there is structural integrity and resiliency in natural ecosystems after destructive storm events. So, with this combined data it can be believed that if urban and metro coastal regions take the initiative to implement green infrastructure as protection, they will see beneficial results – from reduction in coastal erosion and less flooding, to overall improvement in social well-being and economic stability.

Evaluation of Coastal Living

What no one really wants to consider is that the potential of a 6-foot sea-level rise will not be limited solely to areas directly on the coast, but rather that water will travel miles inland to pool in low-lying areas. As seen in the maps at the end of this chapter from data collected by Climate Central: Miami becomes a watery floodplain, New York loses its financial districts, New Orleans ceases to exist, and the Rotterdam is washed away. As the years pass, the oceans will rise and limit the potential of grey and green infrastructure. Waters will rise above levees and flow over wetlands. According to the U.S. Geological Survey, sea level on an iceless Earth would be as much as 216 feet higher that it is today (National Geographic Magazine 2013).

Without any support from the Community Rating System, as it stands if a homeowner were to start out paying $2,5000 in flood insurance, with an 18 percent increase as the market standard, by the time 10 years had passed, they would be paying $11,000. The need for flood insurance and the long-term payment of premiums also means that property value will decrease by half due to the home being in a flood prone area.

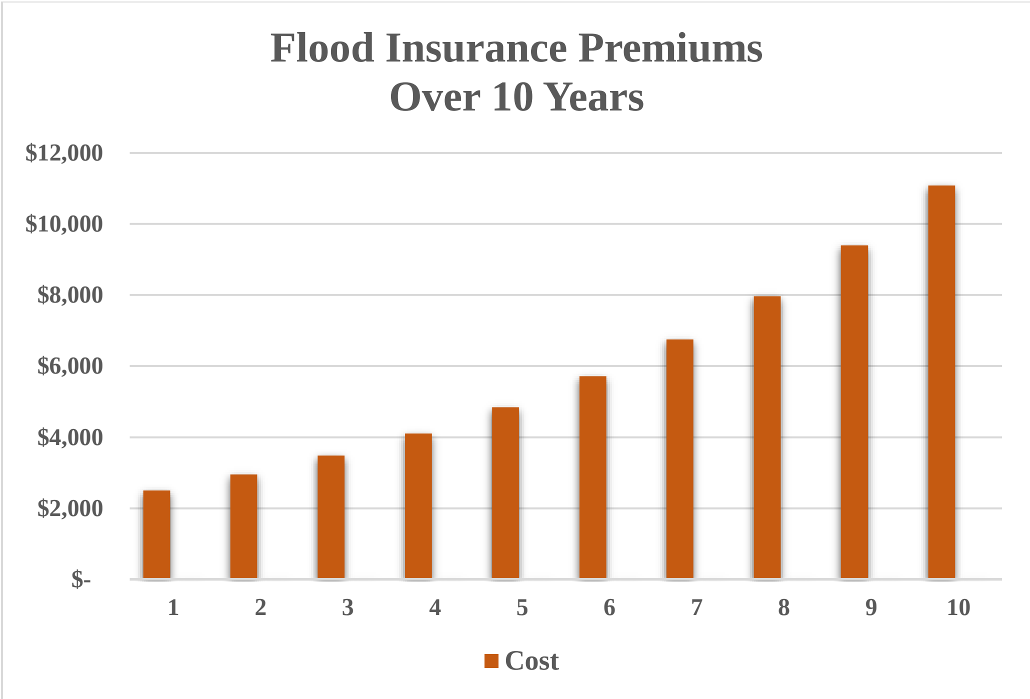

Figure 4.1 Increase in flood insurance premiums
(Source credit: FEMA; illustration by Sonia Linton)

To show how a well grey infrastructure, like a seawall, versus green infrastructure, in this case a living shoreline might protect the above-mentioned homeowners and lower their flood insurance premiums, the below graphs were created. For sake of argument, consider a mile long stretch of coastline that a community sits on, or 5,280 feet. Previously stated in Chapter 2, the U.S. Army Corps of Engineers estimates that the implementation of a seawall can cost anywhere between $5,000 and $10,000 per linear foot, with over $500 per linear foot to maintain on an annual basis. In contrast, a living shoreline costs $1,000 to $5,000 per linear foot to implement and only $100 per linear foot to maintain annually.

As seen in Figure 4.2, which represents the lowest amount per linear foot that can be spent, setting up a seawall along a mile stretch of beach starts at $26.4 million. Assuming that the seawall will be maintained on an annual basis as suggested by the Army Corps of Engineers, that means an additional $2.6 million will be spent each year for upkeep of the seawall to repair any structural damage. By the end of the tenth year of use, $52.8 million will have been spent. In contrast to this, the cost of a miles worth of living shoreline will start out at $5.2 million with a $528,00 maintenance fee each year. Ten years later, the overall amount of money spent will be $10.5 million.

In Figure 4.3, representing the highest amount per linear foot that can be spent, initial costs along a mile of coast line starts at $52.8 million. The fees will remain the same as before at $2.64 million. Ten years later, a total of $79.2 million will have been spent on the seawall. As for the living shoreline, the initial cost will be $26.4 million, once again at the same $528,000 in maintenance fees annually. After ten years, $31.6 million will have been spent.

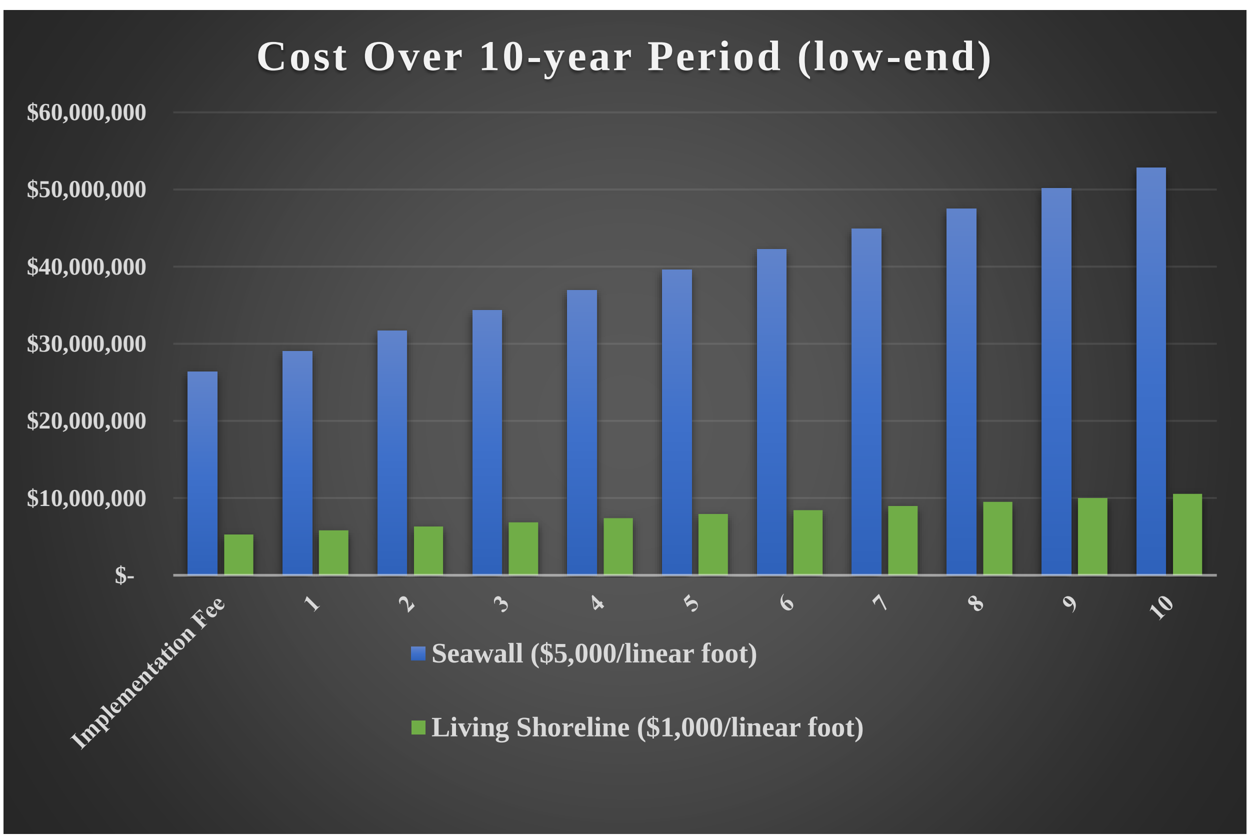

Figure 4.2 Cost comparison between a seawall and living shoreline (low-end)
(Source credit NOAA; illustration by Sonia Linton)

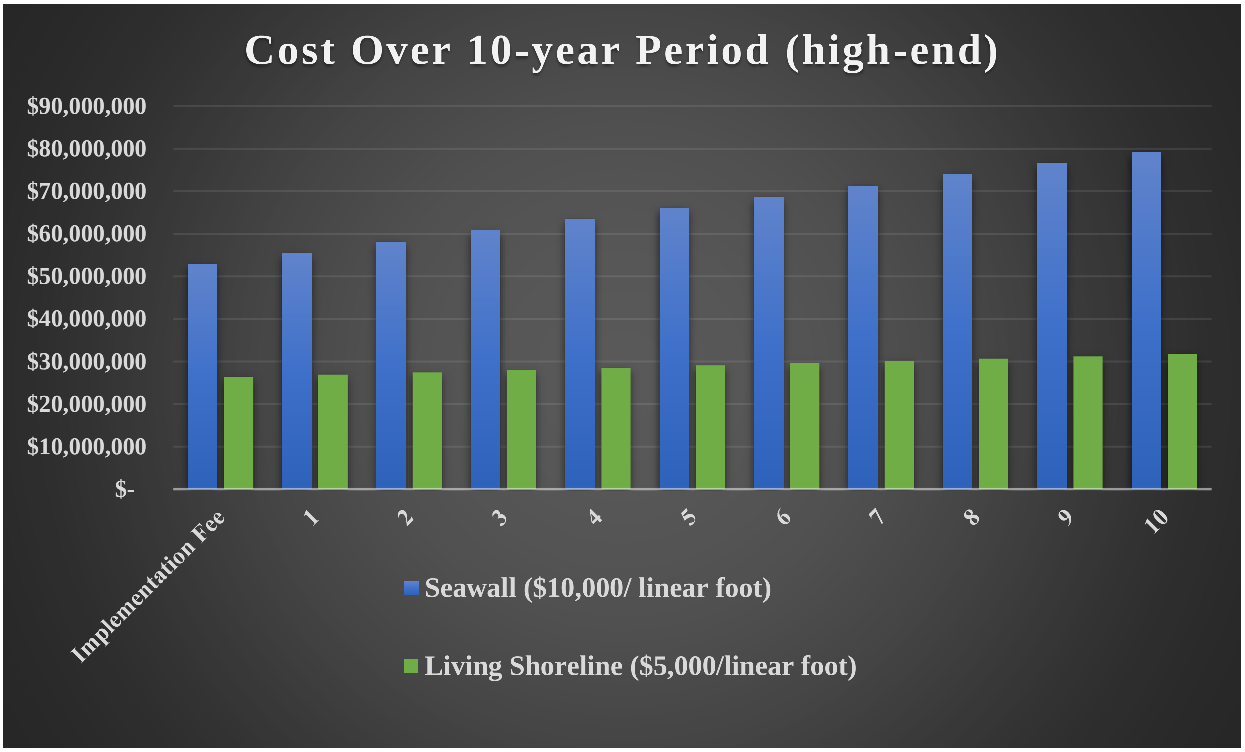

Figure 4.3 Cost comparison between a seawall and living shoreline (high-end)
(Source credit NOAA; illustration by Sonia Linton)

The costs of establishing and maintain green infrastructure are known for most projects, but the benefits are much more difficult to value. Benefits are often assessed in purely qualitative terms and there is much less quantitative evidence of the ecosystem services provided by green infrastructure, and of the value of these services. The lack of evidence and support of ecosystem service delivery makes it difficult to speculate on what green infrastructure is worth in terms of social, environmental and economic benefits (Naumann 2011).

Overall, the evidence does suggest that green infrastructure projects give rise to certain and readily estimated costs, as well as a wide variety of benefits – the extent and quality of habitats and ecosystems, change in the level of reduction of flood risk and number of recreational users of the green space, and socio-economic changes such as impact on employment and gross domestic product. A large portion of costs can relate to capital costs, which are incurred up-front, while benefits may be expected to accrue long into the future (Jacobs 2004). The assessment of costs and benefits over longer time horizons can be expected to enhance the measured viability of green infrastructure projects and to support their implementation.

Figure 4.4 Costliest hurricanes
(Source credit: NOAA)

Conclusion

While a major critique of green infrastructure is whether these "clever and conscientious" strategies promise more than "eternal summer and healthy bodies," as is implied in the marketing imagery (Neocleous 2013), with great focus on the integration of community and economic development. Thinking in a resilient way is like integrating complex adaptive systems where you need to recognize that ecosystems have multiple states of being (Donner 2008). For resilience thinking to work for urban coastal regions it must be constantly changing and consider renewal and reorganization as opposed to stable states.

With billions upon billions of dollars being spent on grey infrastructure to defend coastal communities against climate change, the feasibility of maintaining and repairing such structures in the wake of storms like Katrina, that caused $161 billion in damage (see Figure 4.4), goes down drastically. FEMA and the U.S. government does not have bottomless pockets to supply properties with continual flood insurance and pay for infrastructure that will eventually fail, so while there are challenges in implementing green infrastructure, the opportunity to save over $40 million by using a living shoreline versus a seawall, is a larger driver and incentive to coastal regions – flood insurance premiums can be alleviated and even as an untested means, green infrastructure could prove fruitful in its use where grey infrastructure has failed.

The challenges and opportunities seen in green infrastructure makes policymakers and stakeholders tentatively step around the idea of its implementation, but also have them looking at this form of adaption techniques to sea-level rise as a last-ditch effort to not abandon their homes. When looking at coastal locations and what the natural habitats used to be: Florida had forests of mangroves protecting the coast from erosion and wetlands holding back storm surges, New York had oyster beds buffering the coast from strong waves, and Louisiana had miles upon miles of natural wetlands that have been wrecked by human-engineering.

By mimicking what the natural landscape used to be through artificial reefs, restored wetlands and living shorelines, these green features can hopefully help to mitigate the effects of sea-level rise. And even with minimal data on what the implementation of large scale coastal green infrastructure means, the current interest in providing sustainable and resilience infrastructure to mitigate the effects of climate change is a strong drive to try a variety of techniques. While coastal green infrastructure cannot be constructed like a seawall in a matter of months, once established there will be the ability to test how this nature-based infrastructure is fairing and to observe how beneficial it is to the land, the people and the economy.

As can be seen from the figures on the following four pages, the images created by Climate Central to visually represent what 6 feet of sea-level rise could look like in Miami, New York, New Orleans and Rotterdam. As the polar icecaps melt, the seas will continue to rise whether there is green infrastructure along the coastlines or not. The previous chapters in this thesis have laid out the challenges and the opportunities in the use of green infrastructure by assessing how coastal regions are responding to climate change. The means needed to build and maintain grey infrastructure are beginning to outweigh its benefits in the eyes of policy makers as they move from failing pump and drainage systems to natural ecosystem services.

How we chose to manage and invest in resiliency for coastal developments is what is important, and green infrastructure cannot only be implemented at a lower cost, but it also has a natural resiliency of its own that has allowed it to "bounce back" since the dawn of evolution. This can in turn allow coastal communities time to find financially viable alternatives to coastal living. As the century progresses, large numbers of people will have to abandon coastal regions all around the world. There has been a belief that cities like Miami and New York have always been here and it will continue to be so, but as the climate changes and infrastructure systems either fail or are unable to perform to the extent coastal urban regions require, human populations will have to consider alternate means of living with the water or moving farther inland.

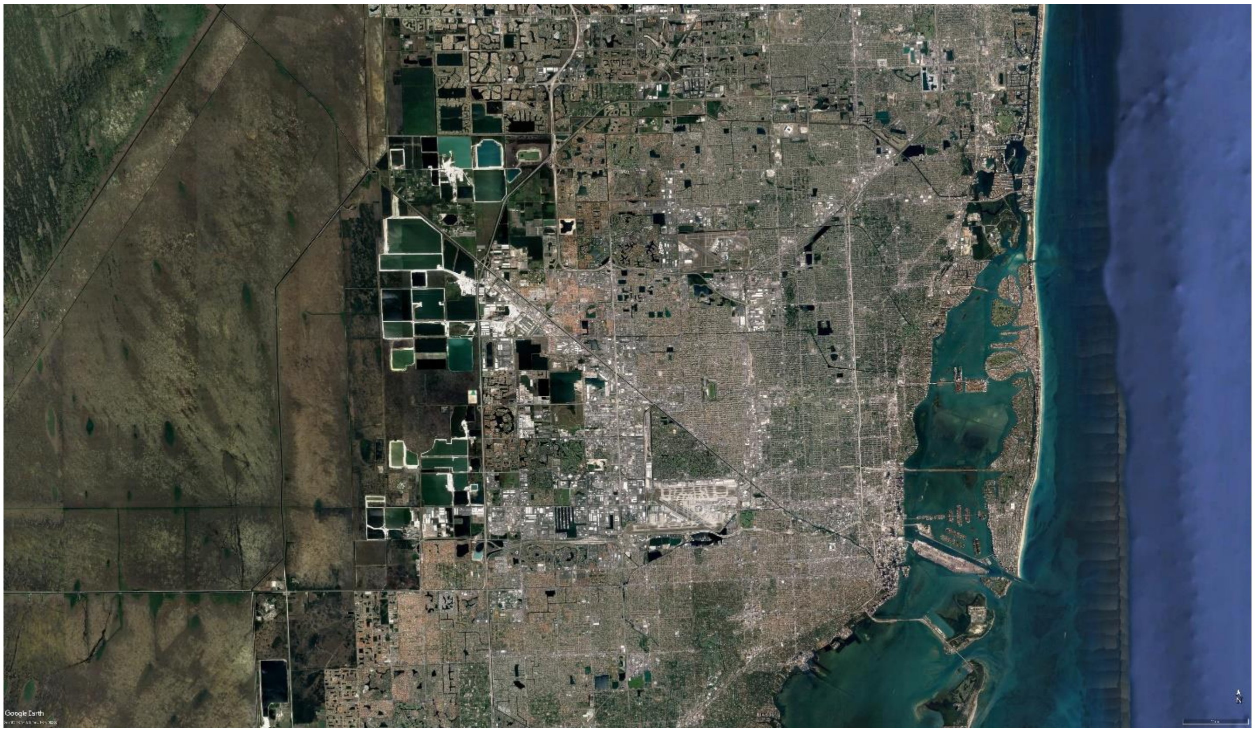

Figure 4.5 Miami today
(Source credit: Google Earth Pro)

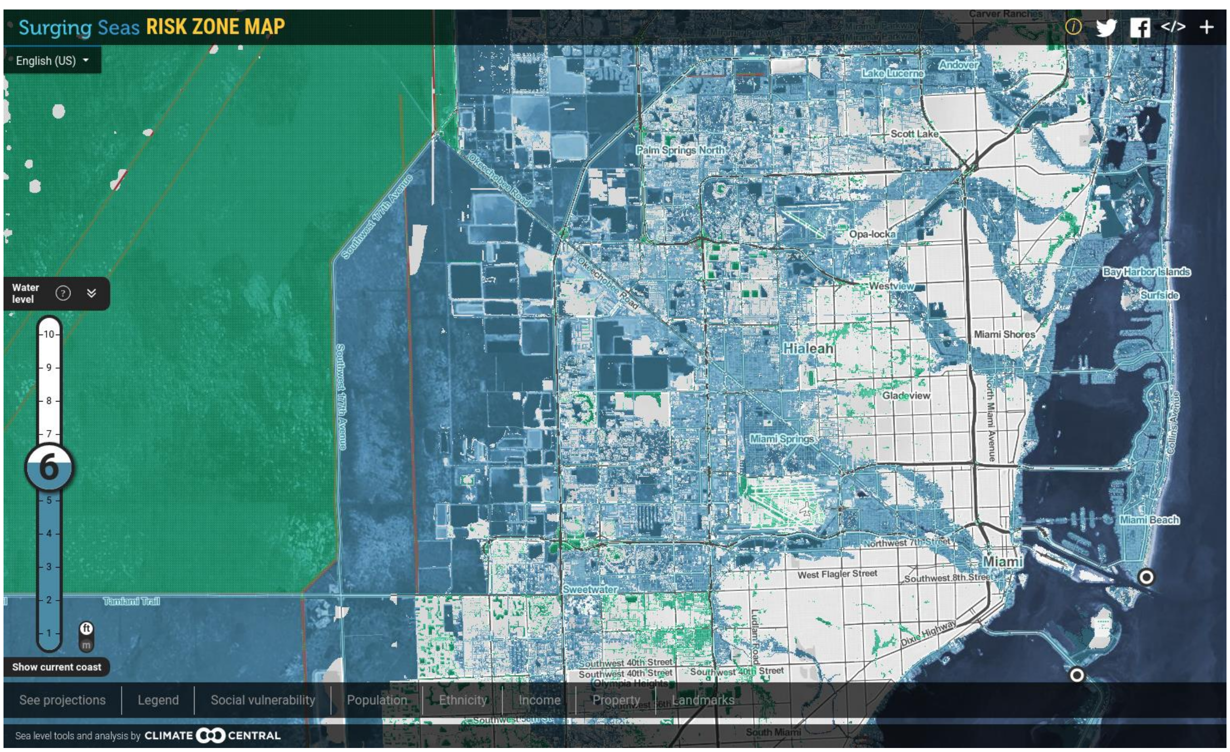

Figure 4.6 What 6 feet of sea-level rise could look like in Miami, blue is below water level
(Source credit: Climate Central)

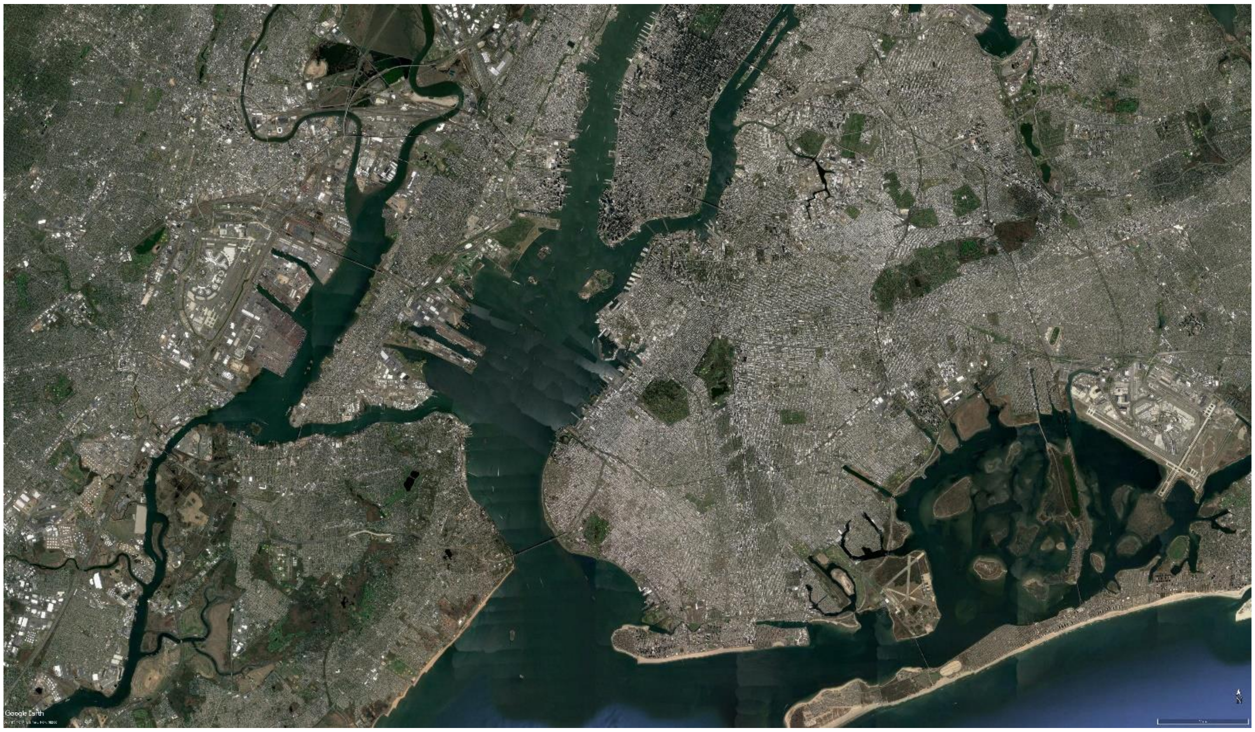

Figure 4.7 New York today
(Source credit: Google Earth Pro)

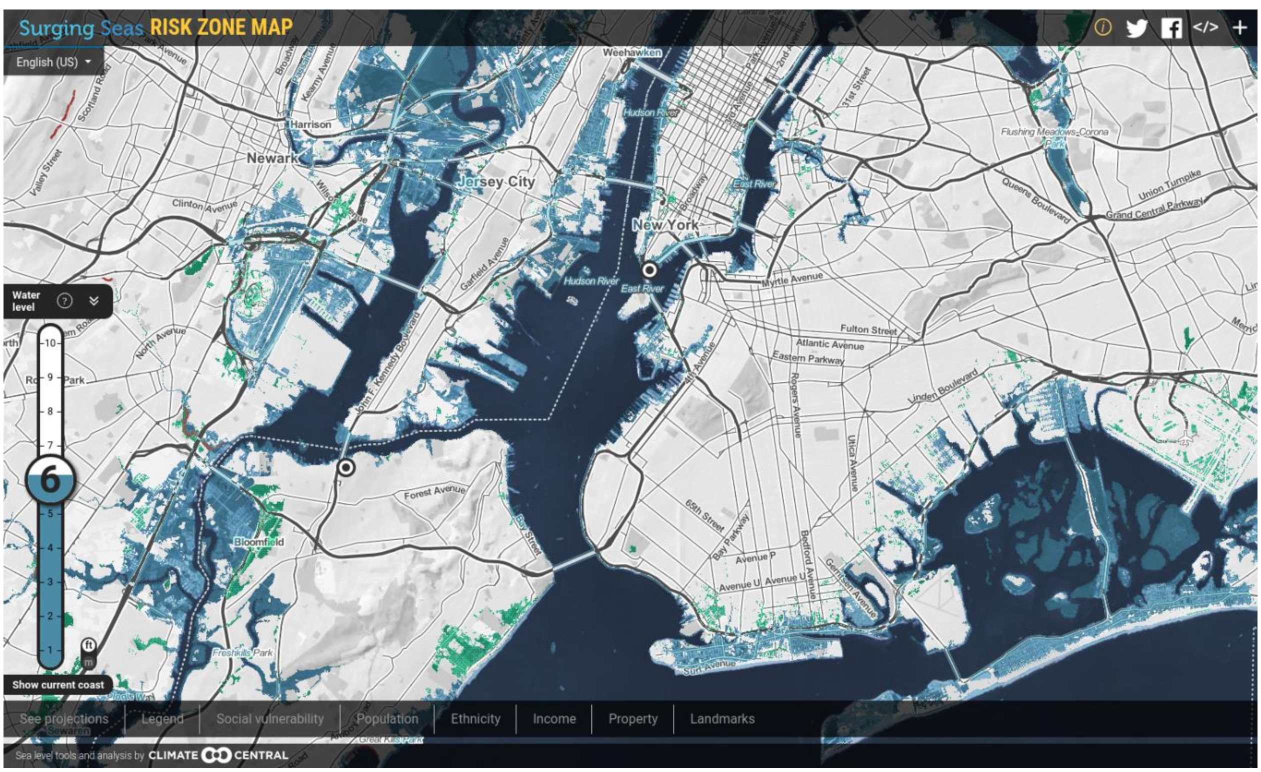

Figure 4.8 What 6 feet of sea-level rise could look like in New York, blue is below water level
(Source credit: Climate Central)

Figure 4.9 New Orleans today
(Source credit: Google Earth Pro)

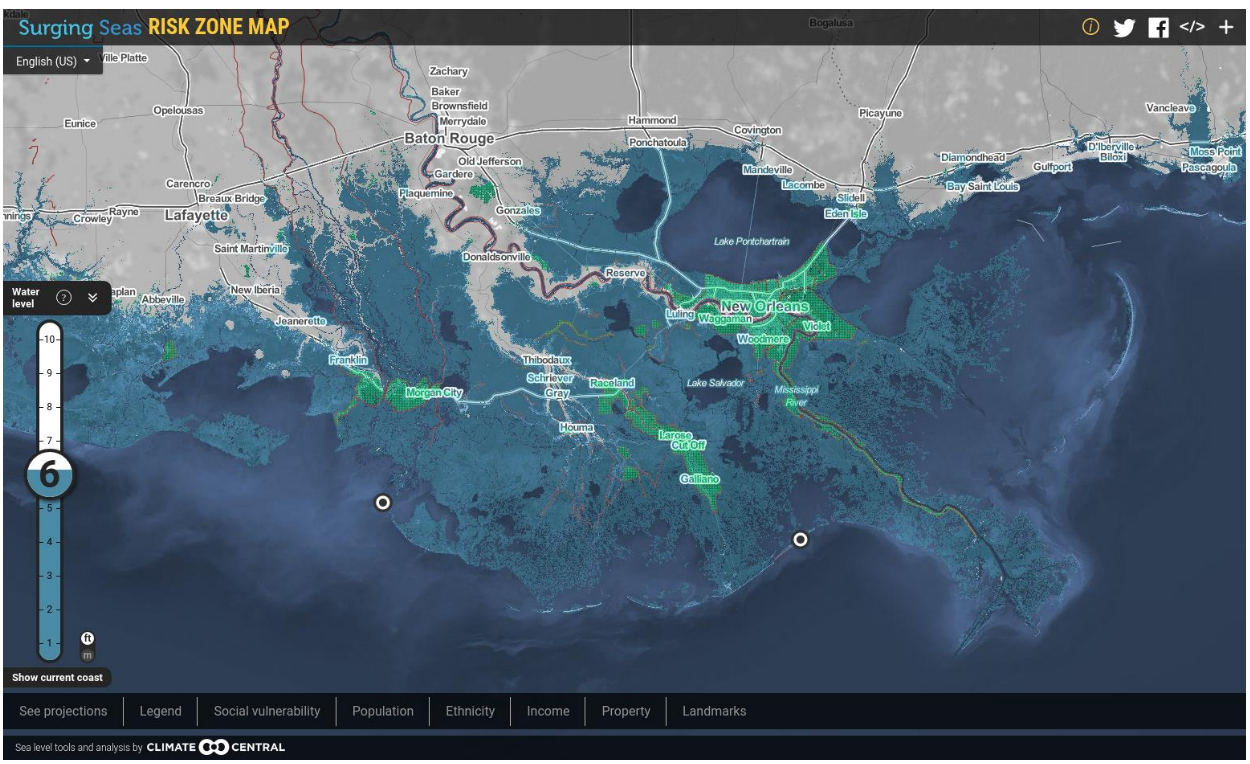

Figure 4.10 What 6 feet of sea-level rise could look like in New Orleans, blue is below water level
(Source credit: Climate Central)

Figure 4.11 Rotterdam today
(Source credit: Google Earth Pro; edited by Sonia Linton)

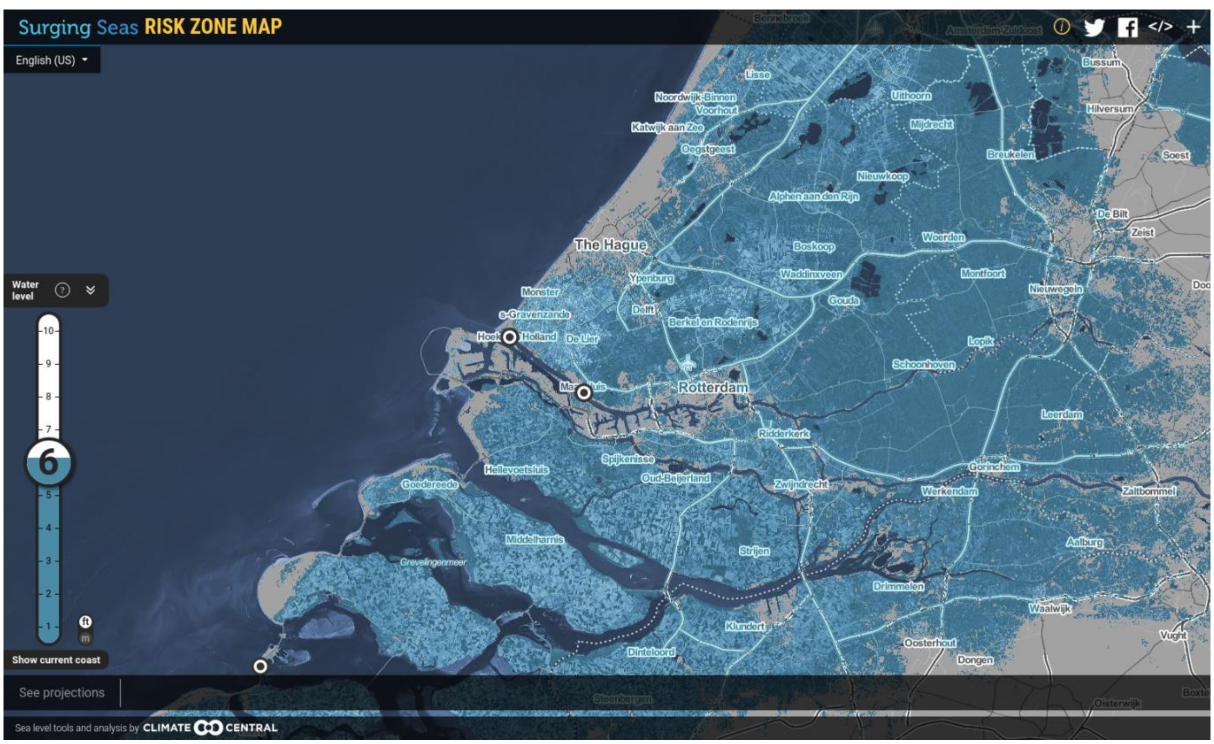

Figure 4.12 What 6 feet of sea-level rise could look like in Rotterdam, blue is below water level
(Source credit: Climate Central)

CHAPTER 5

THE FUTURE OF COASTAL PLANNING STRATEGIES

As the denial fades over what sea-level rise means for urban coastal regions, many are skipping the anger stage and moving on to bargaining. The issue for most people is not whether their coastal homes will be underwater soon, but how long they should stick around for. In a winning scenario, civic leaders address the risk of sea-level rise in a proactive way, lobbying hard for state and federal funds and demonstrating enough political courage to raise taxes so that the city will have the money to elevate streets and causeways, invest in better sewer systems, and keep low-lying airports and commercial areas functioning smoothly. In this case, foreign investors do not panic, and property values do not plummet. Population declines, and some buildings are abandoned, but innovation flourishes and new ways of living with water emerge – houses float, canals replace streets, rooftops host gardens, living coastlines become the status quo. The water keeps rising and people continue to leave, but it is a slow and stable retreat buffered by innovation and civility.

In the losing scenario, the more investors understand the risk of sea-level rise to buildings and infrastructure, the less willing they will be to invest in the region. As people sell, the supply of houses and condos will go up while the prices drop, and property tax revenues will decline. Even a modest drop will have enormous consequences for the city and county budgets. This means that there will not only be cuts in teachers, police and firefighters, but also less money to buy pumps, fix roads, build seawalls and all other infrastructure needed to deal with rising seas.

With no money for repairs or upgrades, infrastructure falls apart, which in turn causes more people to sell, and people with money to leave.

Informed people such as John Van Leer, an oceanographer at the University of Miami, worry that one day they will no longer be able to insure or sell their houses. "If buyers can't insure it, they can't get a mortgage, you can only sell to cash buyers," Van Leer says (National Geographic Magazine 2013). That is particularly true in a place such as Miami where conventional efforts to deal with sea-level rise, such as sea wall and barriers, will not work because South Florida sits above a vast and porous limestone plateau.

Despite the reality of accelerating sea-level rise, coastal properties are increasing in many places. One of the most vulnerable spots in the developed world to both sea-level rise and storm surge is Miami. However, between the first quarter of 2013 and the same period in 2014, Miami property values were up 19%. The sales price for luxury homes – the top 10% of the market – jumped even more to 34% (Goodell 2013). By itself, the United States appears to be in a coastal real estate bubble of over one trillion dollars. Florida is literally ground zero because it leads the country with $484 billion in "property covered by the National Flood Insurance Program, often at below market." The Miami area is so flat that even with a slight 3 feet of sea-level rise, "more than a third of Southern Florida will vanish; at six feet, more than half will be gone" (National Geographic Magazine 2013).

Many coastal cities still seem to believe that if it gets *bad*, then the federal government will bail them out, but with the National Flood Insurance Program experiencing money issues and little thought or planning being given to regulatory policies to manage sea-level rise is coastal urban and metro environments, this is unlikely to happen. Having seen the devastating impact Hurricane Katrina caused Louisiana, and the lack of regional thinking shown by most

Americans, each individual homeowner would rather undertake the individual and expensive work of protecting themselves against flooding. There is a lack of a regional approach to protect whole areas successfully from storm surges and rising tides. And because of this, at some point, it will be almost impossible to get flood insurance, property values will drop, and there will be nowhere to go.

Cities and their coastal zones are dynamic human and natural environments, and this is the sort of study that is needed to address the rapidly and constantly changing environment; especially since climate change is becoming increasingly unpredictable. When problems fail to respond to solutions, we tend to intensify our efforts, which in turn produce unintended consequences that can show up later in time and in other places. It is necessary to acknowledge that the implementation of green infrastructure in coastal regions is untested on a grand scale and that we can only surmise at this point that there will be benefits from its use.

Yet because there is information that has been collected from the research by ecologists and engineers that has shown that natural ecosystems like wetlands, tidal marshes and living shorelines have withstood severe storm events and been able to come back, we should feel confident that coastal green infrastructure has merit. As seen with the Rebuild by Design projects, it will take time and money to establish clear benefits and opportunities in green infrastructure's implementation. Once established, this nature-based infrastructure can be assessed to see how valuable it is to the social, economic and environmental aspects of urban and metro coastal regions which will help to support its implementation and adaptive use elsewhere.

When it comes to considering and implementing resiliency, it can be adequately put as "our ability to predict [social and ecological systems] future dynamics" is never complete (Emanuel 2005). We must reduce reservations about the use of green infrastructure through the creation of means to regulate it and improve the outcome of future events with it. For me as a planner, resiliency is a discursive topic that seems to pick up where others like sustainability and ecological urbanism leave off; but like green infrastructure, resiliency lacks clear implementation strategies and regulations to keep it in check. Resilience has come to be our "newest fetish" (Neocleous 2013) where architects, planners, urban designers, engineers, climate scientists, marine ecologists and university bodies can all come together to provide environmental restoration and economic development. The promise of scientifically tuned proposals for climate remediation continues to fuel commercial development in areas prone to severe storms without giving check to the challenges associated.

Climate change will alter the way humans live in our built environments and is one of the biggest drivers for global change. The environment will no longer be a static condition, a certainty upon which other variables depend. Instead, it will be a variable itself, and it will make planning for the future an incredibly difficult task. The already visible effects of change along coastlines – rising seas and more frequent hurricanes that leave cities looking apocalyptic – that present a dynamic environment that threatens infrastructure that has long been deemed safe. Governments, scientists and planners have taken note that cities are ill-prepared for the foreseeable future. As a planner in today's constantly changing environment, there are many challenges to create policies and regulations that will guide coastal regions to reduce future risk, namely lack of information in the implementation of green infrastructure on such a large scale. But there is a need to come up with initiatives to keep the spending of money in check, well-rounded support of all coastal regions regardless of wealth, and to implement programs and projects that are feasible and viable to regions at risk of going underwater.

Disaster relief in America functions by giving lots of incentives to rebuild but few incentives to rebuild differently, let alone to rethink the long-term future of cities and towns along the coast. By the end of 2016, the State of New Jersey alone had spent $4.6 billion on Sandy recovery efforts, 95 percent which came from the federal government (State of New Jersey, Office of the State Comptroller 2018). In effect, people in Kansas and Iowa and Washington – people who will most likely never see a Jersey beach – paid for the reconstruction.

In a world of quickly rising seas, the rationale for encouraging people to move out of harm's way is straightforward in that it saves money and saves lives. But for government officials to *not* encourage people to move out of the path of danger means to ask for something time-consuming, something that costs money and means they probably will not get re-elected. When it comes to new development, many cities have created incentives to encourage people to build on higher ground. Zoning ordinances and restrictions on how close you can build to water are the simplest. Some cities, including Miami, are considering levying impact fees on developers who want to build in low-lying areas to fund clean energy and climate adaption projects.

With all this "new scientific" and "planned" focus on built environments along the coast, it is important to remember that humans have long been occupants of many of the world's coastal environments. The connection indigenous peoples have had to the coast is notable for multiple reasons: as long-term inhabitants, they have observed and interpreted the coastal processes and resources, garnering ecological knowledge of their environment (Mulrennan 2014). Having been able to inhabit some of the world's most remote and dynamic environments, indigenous peoples have shown a high degree of resilience to environmental change and variability. These early peoples did not necessarily live in harmony with the environment, but rather had to adapt and readjust to survive.

When it comes to building resilience for the present times, it is necessary to prepare for the future predominately means being able to adapt – as the Dutch are doing with their floating pavilions – in order to have infrastructure guiding regulations that can be a foundation for cities when the year 2100 rolls around and sea-levels have risen 6 feet or more. This will require innovation and new technologies, but also hard decisions. Some areas will be too vulnerable due to their vicinity to the coast or having been built in a floodplain.

With it being too early to make clear statements on how coastal green infrastructure will perform, it will be useful to have a combined implementation of grey and green infrastructure in coastal metro and urban environments. Grey infrastructure has been engineered to withstand severe weather and protect coastal regions from damage, and with a combined use of green infrastructure this will allow for the wetlands and living shorelines to become established until they can be seen to actively mitigate storm damage to either aid or take over from grey infrastructure.

And as opposed to continue to build – and rebuild – for better resiliency, an orderly surrender to the rising tides may be necessary. Coastal implementation of green infrastructure will not only help to reestablish the natural landscape, but also give urban and metro environment a chance to intelligently plan a managed retreat. Moving away from the threat of rising tides, more intense and frequent storms and opening the shoreline could ultimately benefit natural ecosystems and the human population

Managed retreat options are expected to be less expensive, over the long term, than protection and accommodation strategies. The implementation of retreat is also flexible in response to the current uncertainty regarding [sea level rise] predictions, as retreat action is not required until sea levels reach a designated critical point. Managed retreat has historically *been recommended to maintain coastal settlements and ecosystems vulnerable to development pressure and erosion, prior to wide recognition of climate change impacts* (Alexander 2012). Through the search for new methods in mitigating sea-level rise, the challenges and opportunities in the implementation of green infrastructure are encouraging coastal regions to consider relocating communities to higher ground. The uncertainties in the potential success of green infrastructure and the financial cost are discouraging aspect, but it is still being looked at as a step prior to ultimately abandoning homes and property.

Green infrastructure and its application in coastal environments certainly needs to be studied in a more in-depth fashion, and planners and policymakers need to devise regulatory methods for implementation, management and overall use of this strategy. As a planner I can see the value that is placed in oceanfront property and the difficulty in relocating whole coastal regions farther inland. These are my drivers to find ways to structure the use of green infrastructure in partnership with grey infrastructure so that its feasibility may become better known. While the information considered in this thesis from the four cases studies shows that it is still too soon to tell the concrete benefits and opportunities in the implementation of nature-based infrastructure, this does demonstrate that urban and metro coastal regions are willing to take a leap of faith in untested large-scale designs and methods. And once coastal green infrastructure becomes established, this will allow for the generation of information to support the development of future adaption strategies. When grey and green infrastructure finally fail to mitigate the effects of sea-level rise, we must decide to either to retreat from the coastline in a managed fashion or have create new ways to coexist with coastal environments.

REFERENCES

Abunnasr, Yaser F., “Climate Change Adaptation: A Green Infrastructure Planning Framework for Resilient Urban Regions” (2013). *Open Access Dissertations*. 775. http://scholarworks.umass.edu/open_access_dissertations/775.

Adams, Ross Exo. “Notes from the Resilient City.” *Log*, no. 32 (2014): 126-39.

Alexander, K. S., A. Ryan, and T. G. Measham. "Managed Retreat of Coastal Communities: Understanding Responses to Projected Sea Level Rise." *Journal of Environmental Planning and Management* 55, no. No. 4 (2012): 409-33.

Resilience Thinking." *Natural Hazards* 41 (2007): 283-95.

Alvarez, Lizette and Frances Robles. “Intensified by Climate Change, King Tides Change Ways of Life in Florida.” Accessed December 2, 2016. shttps://www.nytimes.com/2016/11/18/us/intensified-by-climate-change-king-tides-change-ways-of-life-in-florida.html.

American Planning Association. 2014 “Green Infrastructure and Post-Disaster Recovery.” Accessed November 27, 2017. https://planning-org-uploaded-media.s3.amazonaws.com /document/post-disaster-paper-10-green-infrastructure.pdf.

Aslak, Grinsted, Moore John C., and Jevrejeva Svetlana. 2013. "Projected Atlantic hurricane surge threat from rising temperatures." *Proceedings Of The National Academy Of Sciences Of The United States Of America* no. 14: 5369. *JSTOR Journals*, EBSCO*host* (accessed March 5, 2018).

Balmford, Andrew, author, author Aaron Bruner, author Philip Cooper, author Robert Costanza, author Stephen Farber, author Rhys E. Green, and author R. Kerry Turner, et al. 2002. “Economic Reasons for Conserving Wild Nature.” *Science* no. 5583: 950. *JSTOR Journals*, EBSCO*host* (accessed March 26, 2018).

Benedict, Mark A., Edward McMahon, and Va.) Conservation Fund (Arlington. 2006. *Green Infrastructure: Linking Landscapes and Communities*. Washington, DC: Island Press, 2006. *eBook Collection (EBSCOhost)*, EBSCO*host* (accessed March 26, 2018).

Berkes, Fikret. “Understanding Uncertainty and Reducing Vulnerability: Lessons from Resilience Thinking.” *Natural Hazards* 41 (2007): 283-95.

Bloomberg Markets. 2018. “Markets: Energy.” Accessed March 27, 2018. https://www.bloomberg.com/energy.

Boston Government. 2017. “Coastal Resilience Solutions for East Boston and Charlestown: Executive Summary.” Accessed December 6, 2017. https://www.boston.gov/sites/default/files/coastalresiliencesolutions_eastbostoncharlestown_executivesummary.pdf

Braw, Elizabeth. “Rotterdam: designing a flood-proof city to withstand climate change.” *The Guardian*, November 18, 2013. Accessed March 16, 2018. https://www.theguardian.com/sustainable-business/rotterdam-flood-proof-climate-change.

Bureau of Economic Analysis – U.S. Department of Commerce. 2017. “Gross Domestic Product by State: Second Quarter 2017.” Accessed March 26, 2018. https://www.bea.gov/newsreleases/regional/gdp_state/qgsp_newsrelease.htm.

Cameron, Ross W. F., and Tijana Blanuša. 2016. "Green infrastructure and ecosystem services – is the devil in the detail?" *Annals Of Botany* 118, no. 3: 377-391. *Food Science Source*, EBSCO*host* (accessed November 27, 2017).

Camillus, John C. Harvard Business Review. May 2008. “Strategy as a Wicked Problem.” Accessed January 15, 2018. https://hbr.org/2008/05/strategy-as-a-wicked-problem.

Centro Studi Storici Verrazzano. 2018. “1524, The Voyage of Discoveries.” Accessed March 26, 2018. https://web.archive.org/web/20090415202640/http://www.verrazzano.org/en/index2.php?c=viaggioscoperte

Christina Nunez, “As Seas Rise, Are Coastal Nuclear Plants Ready?” *National Geographic*, December 16, 2015.

Church, John and Peter Clark et al. *Climate Change 2013: The Physical Science Basis Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Accessed February 28, 2018. http://www.ipcc.ch/report/ar5/wg1/.

Coastal Construction. 2018. “Seawalls.” Accessed March 26, 2018. http://go2coastal.com/seawalls/.

COX, KELLY J., and RAFAEL J. ARAÚJO. 2017. "Friends or Foes? The Problem of South Florida's Invasive Mangroves." *Pace Environmental Law Review* 34, no. 2: 463-487. *Environment Complete*, EBSCO*host* (accessed October 23, 2017).

Couvillion, B.R., Beck, Holly, Schoolmaster, Donald, and Fischer, Michelle, 2017, Land area change in coastal Louisiana 1932 to 2016: U.S. Geological Survey Scientific Investigations Map 3381, 16 p. pamphlet, https://doi.org/10.3133/sim3381.

Davis, Jenny L., Carolyn A. Currin, Colleen O’Brien, Craig Raffenburg, and Amanda Davis. 2015. "Living Shorelines: Coastal Resilience with a Blue Carbon Benefit." *Plos ONE* 10, no. 11: 1-18. *Food Science Source*, EBSCO*host* (accessed October 2, 2017).

Donner, William, Rodr, xed, Havid guez, and xe. "Population Composition, Migration and Inequality: The Influence of Demographic Changes on Disaster Risk and Vulnerability." *Social Forces* 87, no. 2 (2008): 1089-114.

Eisenman, Theodore S. 2013. “Frederick Law Olmsted, Green Infrastructure, and the Evolving City.” *Journal of Planning History* 12, no. 4: 287-311. *America: History & Life*, EBSCO*host* (accessed November 28, 2017).

Elmer, Vicki, Adam Leigland. *Infrastructure Planning and Finance: A Smart and Sustainable Guide for Local Practitioners.* New York, NY: Routledge, 2014.

Emanuel, K., “Increasing Destructiveness of Tropical Cyclones over the Past 30 Years,” *Nature* 436 (2005): 686-688.

Encyclopedia Britannica. 2018. “New York City.” Accessed February 16, 2018. https://www.britannica.com/place/New-York-City.

Ewel. Katherine C., author, author Robert R. Twilley, and author Jin Eong Ong. 1998. "Different Kinds of Mangrove Forests Provide Different Goods and Services." *Global Ecology and Biogeography Letters* no. 1: 83. *JSTOR Journals*, EBSCO*host* (accessed October 2, 2017).

FEMA. 2018. “Policy Information by State.” Accessed February 14, 2018. https://bsa.nfipstat.fema.gov/reports/1011.htm.

Foster, Josh, Ashley Lowe, Steve Winkleman. Center for Clean Air Policy. “The Value of Green Infrastructure for Urban Climate Adaption.” Accessed November 26, 2017. http://ccap.org/assets/The-Value-of-Green-Infrastructure-for-Urban-Climate-Adaptation_CCAP-Feb-2011.pdf.

Gale, Sarah Fisher. Water World 2015. “Bold and the Beautiful: How Complementing Gray

Infrastructure with Green Helps Ease Pressure on Stormwater systems While Beautifying Dense Urban Environments.” Accessed April 10, 2018. www.waterworld.com/articles/print/volume-31/issue-8/features/bold-and-the-beautiful-how-complementing-gray-infrastructure-with-green-helps-ease-pressure-on-stormwater-systems-while-beautifying-dense-urban-environments.html.

Goodell, Jeff. “Miami: How Rising Sea Levels Endanger South Florida.” Rolling Sone, June 20, 2013. Accessed February 12, 2018. https://www.rollingstone.com/politics/news/why-the-city-of-miami-is-doomed-to-drown-20130620.

Greater New Orleans Inc.- Regional Economic Development. 2015. “The Great New Orleans Urban Water Plan.” Accessed November 28, 2017. http://gnoinc.org/initiatives/the-greater-new-orleans-water-plan/.

Grunwald, Michael. 2006. *The Swamp: The Everglades, Florida, and the politics of paradise*. n.p.: New York: Simon & Schuster, 2006.

Horstman, E. M., K. M. Wijnberg, A. J. Smale, and S. J. M. H. Hulscher. "Long-Term Coastal Management Strategies: Useful or Useless?". *Journal of Coastal Research* (2009): 233-37.

Intergovernmental Panel on Climate Change. 2007. “Projections of Future Changes in Climate.” Accessed February 16, 2017. https://www.ipcc.ch/publications_and_data/ar4 /wg1/en/spmsspm-projections-of.html.

Jacobs (2004). “Environment Group Research Report: An Economic Assessment of the Costs and Benefits of Natura 2000 Sites in Scotland, 2004 Final Report, The Scottish Government.” Accessed March 29, 2018. http://ec.europa.eu/environment/nature/

info/pubs/docs/nat2000newsl/nat29_en.pdf
http://www.scotland.gov.uk/Resource/Doc/47251/0014580.pdf.

Kailath, Ryan. "Louisiana Tries Defense Against Floods: People Move to Higher Ground." NPR, January 29, 2017. Accessed February 28, 2018. https://www.npr.org/2017/01/29/512271883/louisiana-tries-new-defense-against-floods-move-people-to-higher-ground.

Lewis, David A. 2012. "Relocation of Development from Coastal Hazards through Publicly Funded Acquisition Programs: Examples and Lessons from the Gulf Coast, The [article]." *Sea Grant Law and Policy Journal* no. 1: 98. *HeinOnline*, EBSCO*host* (accessed March 26, 2018).

Local Office Landscape Architecture. "Projects." Accessed March 3, 2018. http://www.localofficelandscape.com/projects/.

Mazda, Yoshihiro, Michimasa Magi, Motohiko Kogo, and Phan Hong. 1997. "Mangroves as a coastal protection from waves in the Tong King delta, Vietnam." *Mangroves & Salt Marshes* 1, no. 2: 127. *Complementary Index*, EBSCO*host* (accessed October 23, 2017).

Mazzei, Patricia. "Federal Judge Signs Agreement for $1.6 Billion in Miami-Dade Sewer Repairs." *Miami Herald*, April 15, 2014.

Metz, Tracy, and Maartje van den Heuvel. 2012. *Sweet & Salt: water and the Dutch*. n.p.: Rotterdam: NAI Publishers, 2012.

Miami-Dade County Government. 2015. "Greenprint: Our Design for a Sustainable Future." Accessed November 23, 2017. http://www.miamidade.gov/GreenPrint/.

Mooallem, Jon. 2017. "THE DELUGE." *New York Times Magazine* 36-40. *MasterFILE Elite*, EBSCO*host* (accessed June 12, 2017).

Mulrennan, Monica E. "On the Edge; a Consideration of the Adaptive Capacity of Indigenous Peoples in Coastal Zones from the Arctic to the Tropics." *Special Publication - Geological Society of London* 388 (2014): 79-102.

(NASA), National Aeronautics and Space Administration. 2017. "Sea Level Change – Observations from Space." Accessed December 1, 2017. https://sealevel.nasa.gov/understanding-sea-level/projections/empirical-projections.

National Geographic Magazine, September 2013. "Rising Seas." Accessed March 12, 2018. https://www.nationalgeographic.com/magazine/2013/09/rising-seas-coastal-impact-climate-change/.

National Oceanic and Atmospheric Administration. 2017. "What Is Resilience?" Accessed 3 December 2017. http://oceanservice.noaa.gov/facts/resilience.html.

Naumann, Sandra, McKenna Davis, Timo Kaphengst, Mav Pieterse and Matt Rayment. "Design, implementation and cost elements of Green Infrastrucutre projects, Final Report – 16 December 2011." Accessed March 28, 2018. http://ec.europa.eu/environment/enveco/biodiversity/pdf/GI_DICE_FinalReport.pdf

Neocleous, Mark. "Resisting Resilience." Radical Philosophy, March/April 2013. Accessed April 23, 2017. https://www.radicalphilosophy.com/commentary/resisting-resilience.

New York State. "Living Breakwaters: Tottenville." Accessed March 2, 2018. https://stormrecovery.ny.gov/living-breakwaters-tottenville

The New Yorker. March 2017. "When is it Time to Retreat from Climate Change?". Accessed April 24, 2017. http://www.newyorker.com/tech/elements/when-is-it-time-to-retreat-from-climate-change.

Nehamas, Nicola. "Buying a Home in Miami-Dade Is So Expensive It Could Hurt the

Economy." *Miami Herald*, February 9, 2017. Accessed February 28, 2018.

NOAA. 2017. "Living Shorelines." Accessed February 28, 2018. https://www.fisheries.noaa.gov/insight/living-shorelines

Office of the New York Comptroller, October 2014. "On the Front Lines: $129 Billion in Property at Risk from Floodwaters." Accessed March 6, 2018. https://comptroller.nyc.gov/wp-content/uploads/documents/Policy_Brief_1014.pdf.

Orff, Kate. "Adapt to the Future with Landscape Design." *New York Times*, October 28, 2015.

Organization for Economic Co-operation and Development. February 2007. "Climate change could triple population at risk from coastal flooding by 2070, finds OECD." Accessed March 12, 2018. http://www.oecd.org/general/climatechangecouldtriplepopulationatrisk fromcoastalfloodingby2070findsoecd.htm.

Paul S., George. 1999. "The Pacesetter: The Untold Story of Carl G. Fisher, Creator of the Indy 500, Miami Beach & The Lincoln Highway Jerry M. Fisher." *The Florida Historical Quarterly* no. 1: 108. *JSTOR Journals*, EBSCO*host* (accessed March 5, 2018).

Pelling, Mark, and Sophie Blackburn. *Megacities and the Coast: Risk, Resilience and Transformation*. Abingdon: Routledge, 2013.

Port of Rotterdam. 2018. "About the Port Authority." Accessed March 27, 2018. https://www.portofrotterdam.com/en/port-authority/about-the-port-authority.

Ramyar, R., and E. Zarghami. 2017. "Green infrastructure contribution for climate change adaptation in urban landscape context." *Applied Ecology and Environmental Research* 15, no. 3: 1193-1209. *CAB Abstracts*, EBSCO*host* (accessed November 24, 2017).

Rebuild by Design – in Partnership with 100 Resilient Cities. 2017. "Rebuild by Design." Accessed December 1, 2017. http://www.rebuildbydesign.org/.

Rebuild by Design – in Partnership with 100 Resilient Cities. 2018. “Living by the Bay.” Accessed February 8, 2018. http://www.rebuildbydesign.org/our-work/all-proposals/winning-projects/ny-living-with-the-bay.

The Risky Business Project, June 2017. “Risky Business: The Economic Risks of Climate Change in the United States.” Accessed March 5, 2018. https://riskybusiness.org/site/assets/uploads/2015/09/RiskyBusiness_Report_WEB_09_08_14.pdf

Robert, Costanza, Pérez-Maqueo Octavio, Martinez M. Luisa, Sutton Paul, Anderson Sharolyn J., and Mulder Kenneth. 2008. "The Value of Coastal Wetlands for Hurricane Protection." *Ambio* no. 4: 241. *JSTOR Journals*, EBSCO*host* (accessed September 30, 2017).

Rockefeller Center. 2017. “100 Resilient Cities.” Accessed November 28, 2017. http://www.100resilientcities.org/strategies/city/new-york-city#/-_/.

Romm, Joseph J. 2016. *Climate change: what everyone needs to know*. n.p.: New York: Oxford University Press, 2016.

Sack, Kevin and John Schwartz. “Left to the Tides and Fighting for Time.” *The New York Times*, February 25, 2018.

Sanders, Beth Duff. “Affluent Area Has Problems and Squabbles Too.” *Sun Sentinel*, April 26, 1989. Accessed March 5, 2018. http://articles.sun-sentinel.com/1989-04-26/news/8901210759_1_four-islands-venice-waterway.

Schultz, Martin T., and Ernest R. Smith. "Assessing the Resilience of Coastal Systems: A Probabilistic Approach." *Journal of Coastal Research* 32, no. 5 (2016): 1032-50.

Schwartz, John and Mark Schleifstein. “New Orleans, Fortified but Still In Peril.” *The New York Times*, February 25, 2018.

Siders, Anne. Columbia Law School – Center for Climate Change. "Mangaged Coastal Retreat: A Legal Handbook on Shifting Development Away from Vulnverable Areas." October 2013. Accessed April 2, 2017. https://web.law.columbia.edu/sites/default/files/microsites/climate-change/files/Publications/Fellows/ManagedCoastalRetreat_FINAL_Oct%2030.pdf.

State of New Jersey, Office of the State Comptroller. 2018. "NJ Sandy Transparency Funds Tracker." Accessed February 29, 2018. http://nj.gov/comptroller/sandytransparency/funds/tracker/

Tengnagel, Michael Fabritius. "Cloudburst Projects Transform Urban Living, Prevent Flooding." *Stormwater Management* 5, no. 1 (2017): 12-13.

Thompson, Victor D., William H. Marquardt, Karen J. Walker, Alexander Cherkinsky, Amanda D. Roberts Thompson, Lee A. Newsom, and Michael Savarese. n.d. "From Shell Midden to Midden-Mound: The Geoarchaeology of Mound Key, an Anthropogenic Island in Southwest Florida, USA." *Plos One* 11, no. 4: *Science Citation Index*, EBSCO*host* (accessed February 15, 2018).

Tibbetts, John. "Coastal Cities Living on the Edge." *Environmental Health Perspectives* 110, no. 11 (2002): A674-A81.

United States Government Accountability Office. "Gao Report to Congressional Committee: High Risk Series, February 2017." Accessed March 4, 2018.

U.S. Energy Information Administration. 2018. "Louisiana, State Profile and Energy Estimates." Accessed March 27, 2018. https://www.eia.gov/state/?sid=LA

Water Technology. 2018. "Delta Works Flood Protection, Rhine-Meuse-Scheldt Delta, Netherlands." Accessed March 16, 2018. http://www.water-technology.net/projects/delta-works-flood-netherlands/.

Wdowinski, Shimon, Ronald Bray, Ben P. Kirtman, and Zhaohua Wu. 2016. "Increasing flooding hazard in coastal communities due to rising sea level: Case study of Miami Beach, Florida." *Ocean and Coastal Management* 126, 1-8. *ScienceDirect*, EBSCO*host* (accessed November 20, 2017).

West8. 2014. "Blue Dunes: The Future of Coastal Protection." Accessed February 28, 2018. http://www.west8.com/projects/blue_dunes_the_future_of_coastal_protection/.

Wilson, Duff, Ryan McNeill and Deborah J. Nelson. "Special Report: Why metro Houston fears the next big storm." *Reuters*, November 24, 2014. Accessed March 5, 2018. https://www.reuters.com/article/us-sealevel-fixes-galveston-specialrepor/special-report-why-metro-houston-fears-the-next-big-storm-idUSKCN0J81IM20141124.

Yin, Robert K. 2014. *Case Study Research: Design and Methods*. Los Angeles, California: Sage Publications.