COASTAL POLICY SIMULATIONS: A GIS FRAMEWORK TO ANALYZE THE RELATIVE DIFFERENCES IN COASTAL POLICIES

By

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Thank you to my PhD committee for supporting me for so many years, pointing me in the right direction, and always pushing me to do well. Thank you to my family for not complaining too much about my time in graduate school.
# TABLE OF CONTENTS

ACKNOWLEDGEMENTS........................................................................................................ 3  
LIST OF TABLES ................................................................. 6  
LIST OF FIGURES ........................................................................... 7  
ABSTRACT ............................................................................................ 9  

CHAPTER

1 INTRODUCTION ..................................................................................11  
  Overview ..............................................................................................11  
  Problem Statement ...............................................................................12  
  Objectives ............................................................................................14  
  Organization of the Dissertation .........................................................14  
  Background .........................................................................................15  

2 GIS-BASED MODELING OF SEA LEVEL RISE’S EFFECTS ON COASTAL PROPERTY MANAGEMENT POLICIES .........................................................26  
  Sea Level Rise ....................................................................................29  
  Policy Options Overview ....................................................................31  
  Methods ...............................................................................................34  
  Results ..................................................................................................38  
  Discussion ............................................................................................40  
  Conclusion ...........................................................................................44  

3 A GIS MODEL OF ROLLING EASEMENT POLICIES IN PINELLAS AND SARASOTA FLORIDA.................................................................52  
  Background ........................................................................................57  
  Methods ...............................................................................................62  
  Results ..................................................................................................68  
  Discussion ............................................................................................69  
  Conclusion ...........................................................................................75  

4 UNCERTAINTIES IN VALUING COASTAL REAL PROPERTY: ANALYZING REAL PROPERTY LOSSES AND ROLLING EASEMENT COMPENSATION PAYMENTS DUE TO SEA LEVEL RISE: SENSITIVITY ANALYSIS ..........82  
  Background ........................................................................................84  
  Methods ...............................................................................................91  
  Results ..................................................................................................94
# LIST OF TABLES

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>Results of armoring prohibition scenario in Key West</td>
<td>45</td>
</tr>
<tr>
<td>2-2</td>
<td>Results of the armoring prohibition scenario in Pinellas, FL</td>
<td>45</td>
</tr>
<tr>
<td>2-3</td>
<td>Results of armoring scenario in Key West, FL</td>
<td>45</td>
</tr>
<tr>
<td>2-4</td>
<td>Results of armoring scenario in Pinellas, FL</td>
<td>45</td>
</tr>
<tr>
<td>2-5</td>
<td>Results of rolling easements Scenario in Key West, FL</td>
<td>46</td>
</tr>
<tr>
<td>2-6</td>
<td>Results of rolling easements scenario in Pinellas, FL</td>
<td>46</td>
</tr>
<tr>
<td>3-1</td>
<td>Attribute table showing the percentage of inundation of each parcel</td>
<td>77</td>
</tr>
<tr>
<td>4-1</td>
<td>Sea level rise estimates at 2.1 m</td>
<td>103</td>
</tr>
<tr>
<td>Figure</td>
<td>Description</td>
<td>Page</td>
</tr>
<tr>
<td>--------</td>
<td>-----------------------------------------------------------------------------</td>
<td>------</td>
</tr>
<tr>
<td>2-1</td>
<td>Study areas</td>
<td>47</td>
</tr>
<tr>
<td>2-2</td>
<td>Process map of armoring prohibition scenario</td>
<td>48</td>
</tr>
<tr>
<td>2-3</td>
<td>Process map of armoring scenario</td>
<td>48</td>
</tr>
<tr>
<td>2-4</td>
<td>Process map of rolling easements scenario</td>
<td>49</td>
</tr>
<tr>
<td>2-5</td>
<td>Property values and inundation percentages in Key West study site under the armoring prohibition scenario</td>
<td>50</td>
</tr>
<tr>
<td>2-6</td>
<td>Property values ($) and beach loss percentages under the armoring scenario in Key West</td>
<td>50</td>
</tr>
<tr>
<td>2-7</td>
<td>Rolling easements scenario at 0.30 m, 0.60 m, and 1.20 m for Pinellas</td>
<td>51</td>
</tr>
<tr>
<td>2-8</td>
<td>Rolling easements scenario at 0.30 m, 0.60 m, and 1.20 m for Key West</td>
<td>51</td>
</tr>
<tr>
<td>2-9</td>
<td>Results of rolling easement model in Key West study site</td>
<td>51</td>
</tr>
<tr>
<td>3-1</td>
<td>Locations of Pinellas County and Sarasota County</td>
<td>77</td>
</tr>
<tr>
<td>3-2</td>
<td>Elevation maps</td>
<td>78</td>
</tr>
<tr>
<td>3-3</td>
<td>Overview of GIS model workflow</td>
<td>78</td>
</tr>
<tr>
<td>3-4</td>
<td>Three SLR inundation steps in Pinellas</td>
<td>79</td>
</tr>
<tr>
<td>3-5</td>
<td>Three SLR inundation steps in Sarasota</td>
<td>79</td>
</tr>
<tr>
<td>3-6</td>
<td>SLR-related property inundation in Pinellas County</td>
<td>80</td>
</tr>
<tr>
<td>3-7</td>
<td>Mean rolling easement compensation payments in Pinellas County</td>
<td>80</td>
</tr>
<tr>
<td>3-8</td>
<td>SLR-related property inundation in Sarasota County</td>
<td>81</td>
</tr>
<tr>
<td>3-9</td>
<td>Mean rolling easement compensation payments in Sarasota County</td>
<td>81</td>
</tr>
<tr>
<td>4-1</td>
<td>Overview of study area</td>
<td>103</td>
</tr>
<tr>
<td>4-2</td>
<td>Elevation map</td>
<td>104</td>
</tr>
<tr>
<td>4-3</td>
<td>Comparison of rolling easement compensation payments with varying buy-in percentages in Pinellas</td>
<td>105</td>
</tr>
</tbody>
</table>
4-4 Comparison of rolling easement compensation payments with varying buy-in percentages in Sarasota................................................................................................ 106

4-5 Comparison of beta values in Pinellas.................................................................................. 107

4-6 Comparison of beta values in Sarasota.................................................................................. 107
Florida faces a substantial threat from sea level rise (SLR) over the next century because of its low and flat topography in addition to its populous coastlines. With only a one foot future water level rise, most of Florida’s natural beaches will disappear; with a four-foot rise, millions of acres will be lost. Given that 80% of Florida residents live in coastal counties, local policymakers must begin acting now to prevent widespread losses due to SLR inundation. This study analyzes the relative differences between three SLR coastal policies using digital elevation models and county parcel datasets in a GIS environment. A coastal policy simulation prototype was developed to simulate armoring, armoring prohibition, and rolling easements using SLR estimates from 0.15 m to 1.35 m in 0.15 m steps in Key West, FL and Pinellas County, FL. This prototypes indicated the feasibility of the rolling easement policy and highlighted the need for a better rolling easement compensation estimation model. A negative exponential function of SLR inundation risk was proposed to calculate rolling easement compensation payments. The rolling easement model was applied on SLR scenarios ranging from 0.30 m to 2.1 m with 0.30 m steps. The calculation of easement payments to home owners is performed based on the percentage of
people accepting an easement, a friction coefficient to control how quick the rolling easement payment will be reduced, and an overall monetary discount of property value. A sensitivity analysis was conducted on the model parameters. Large uncertainties in home owners selecting to participate in the rolling easement program are addressed using Monte Carlo analysis. In this analysis, the model is run 100 times with different randomly selected properties each time the model is run. The results for Pinellas County, FL and Sarasota County, FL show that acceptance of a rolling easement policy is dependent on physical features such as topography. For example, compensation payments in low-lying and densely built Pinellas ($200k at 1.2 m) were about 16 times more expensive than Sarasota ($12.5k at 1.2 m) using the same model parameters. The sensitivity analysis performed on three of the rolling easement compensation parameters highlighted the effect of the buy-in ratio as a key parameter controlling the policy cost. In general, changing the friction coefficient values affected the rolling easement payments by tens of millions. On the other hand, the buy-in percentage had a much stronger influence on the rolling easement payment (hundreds of millions of dollars). Moreover, the buy-in percentage has a strong connection with social perception of SLR, which suggests the need for social science studies and programs to understand the interaction among the rolling easement parameters and human behavior.
CHAPTER 1
INTRODUCTION

Overview

Sea level rise is widely accepted in the scientific community (Climate Change 2007: Working Group II: Impacts; Vermeer & Rahmstorf, 2009). Its effects have yet to be fully determined but they are expected to inundate thousands of square miles of land, place roughly 100 million Americans along the coastline in jeopardy of losing their homes, and destroy significant portions of barrier islands and natural habitats in the U.S. as well as abroad. (Stanton & Ackerman, 2007; Zhang, Li, Liu, Rhome, & Forbes, 2013). While we cannot stop SLR, we can prepare for it. Evaluating the policies to address sea level rise is crucial so the government can develop and implement plans before SLR’s effects are fully realized1. This study analyzes coastal policies with respect to SLR through Geographic Information System (GIS) models to compare several coastal policies, estimate the costs of applying a rolling easement policy, and measuring the effects of the rolling easement policy parameters through a sensitivity analysis.

Two primary objectives of county government are to “to promote social and economic development” and “promote a safe and healthy environment” for all of their citizens (Heyman, 1991, p. 517). SLR presents a clear threat to the well-being of many coastal areas but many policymakers are not acting to counter SLR because they lack the understanding and the tools to make sound, unbiased assessments of policy implementation (personal correspondence with counties).

While there is a substantial body of coastal policy literature, it is broadly divided between legal issues that examine policy solutions by studying case law, regulations and statutes and the

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1 Authors widely agree that the longer we wait to address SLR, the more costly it will be to implement the proper coastal policies (Caldwell & Segall, 2007; Titus & Richman, 2001).
technical studies that model sea level rise and storm surge using GIS-based simulations. Furthermore, coastal policy research has not progressed to the point where relative differences between coastal policies are analyzed. Both fields have been of limited use to policymakers and other stakeholders because the legal theory of coastal policy has de minimis value for purposes of creating coastal plans in a community while technical simulations provide little guidance when only modeling do-nothing scenarios and ignoring how each policy affects a community.

The research presented in this dissertation fills a research gap in coastal policy technical modeling using GIS-based simulations. It is important to fill this gap because policymakers in many states are already struggling to address SLR-related problems but lack the tools to make meaningful decisions about the future of their communities.

**Problem Statement**

Despite the fact that Florida is especially vulnerable to climate change (Douglas, Kearney, & Leatherman, 2000; Penland & Ramsey, 1990; Ross, O'Brien, & Sternberg, 1994), the best coastal policies to address sea level rise remains unclear. Even the largest and most vulnerable counties in Florida have not adopted a forward-looking approach to threats posed by SLR in any of their master plans, sometimes refusing to acknowledge that these threats exist.

Numerous state agencies, local governments, and public universities have created SLR projections for the rising waters that surround Florida. Research published by scientists in Florida Atlantic University estimated SLR in Florida between 0.61 m and 1.22 m by 2100 using a quadratic equation formula (Heimlich, Bloetscher, Meerooff, & Murley, 2009). The U.S. Army Corps of Engineers, in a 2009 guidance document, estimates SLR between 0.5 m and 1.44 m by 2100 (Hennecke, Greve, Cowell, & Thom, 2004). The newest projection, adopted by four South Miami counties, estimates the seas in South Florida will rise between 0.23 m and 0.61 m by 2060 (Bin, Poulter, Dumas, & Whitehead, 2011). Local tide station readings in Key West, Florida,
from 1913-1999, support these predictions. Using the Key West tidal data, The U.S. Army Corps of Engineers linearly projected a rise of 0.06 m by 2030, 0.13 m by 2060, and 0.23 m by 2100. While these estimates do not take into account the increasingly sharp acceleration of SLR, they demonstrate that SLR has already begun.

About half of the world's population lives within 200 kilometers of a coastline and the average population density in coastal areas is 80 persons per square kilometer, twice the world's average (Sutton, Roberts, Elvidge, & Meij, 1997). If the current IPCC projections prove to be accurate, the world faces over $1 trillion dollars by 2050; New York, Miami, and New Orleans alone are expected to suffer over $6 billion in losses (Hallegatte, Green, Nicholls, & Corfee-Morlot, 2013). The global costs of protecting the coast with dikes are significant with annual investment and maintenance costs of $12 – $71 billion in 2100 (Hinkel et al., 2013).

Sea level rise presents a variety of threats to Florida including inundation of low-lying coastal areas, saltwater intrusion into coastal estuaries and freshwater aquifers affecting the availability of drinking water, and significantly greater damage caused by the storm surge generated by hurricanes (Harrington, 2008). The potential damage caused by these threats is exacerbated from the fact that 80% of Florida residents live in coastal counties and the majority of the state’s 87 million tourist, which generated $67 billion in 2011, flock to its beaches (Facts).

Florida, with its development and population concentrated in the densely populated South Florida communities, is particularly vulnerable to SLR. In fact, Florida is one of the four most vulnerable states along the Atlantic and Gulf coasts (Titus & Richman, 2001). Approximately 4,500 square miles (of the total 66,000 square miles) in Florida are within 4.5 feet of sea level (Harrington, 2008). With a rise of less than three feet, $156 billion worth of property will be lost, 840,000 people in about 300,000 homes will be displaced, and 2,120 square miles of land could
disappear below the water (Central, 2013). Even with a one foot rise, most of Florida’s beaches are expected to vanish (EPA, 2002). Finally, with only a 0.49 foot rise, SLR would cause substantial flooding in South Florida, where the downtown streets already turn into rivers during high tide (Hazell, 2013).

**Objectives**

The research presented here had three objectives:

1. Create GIS computer models that simulate coastal policy options;
2. Analyze and model the rolling easement policy at the county level on a larger parcel dataset; and
3. Perform a sensitivity analysis on three rolling easement policy parameters.

**Organization of the Dissertation**

This dissertation consists of five chapters based on three research articles. Chapter 1 introduces the reader to the dissertation and provides an overview of Chapters 2, 3, 4, and 5. Chapters 2, 3, and 4 are standalone research articles. Chapter 2 proposes a GIS simulation of three coastal policy options: armoring, armoring prohibition, and rolling easements. A case study compares each policy option in terms of land area loss, real property value loss, home removal costs, and rolling easement compensation payments in a limited number of parcels in Key West, FL and Pinellas County, FL. Chapter 3 focuses on the rolling easement policy option and tests the model on about 500,000 parcels in Pinellas County, FL and Sarasota County, FL. Chapter 4 is a sensitivity analysis on three parameters used to model the rolling easement compensation payments. Chapter 5 concludes by providing an overview of the models, explaining their limitations, and suggesting areas of further research.

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2 Chapter 2 is an exact reproduction of previously published peer-reviewed articles. Chapters III and IV are based on two articles that have not yet been published.
Background

Sea Level Rise Projections and Effects

It is difficult to predict how much sea level will rise in the twenty-first century but several approaches allow scientists to approximate it. The Intergovernmental Panel on Climate Change estimated that global sea level rise to be between 0.18 and 0.59 meters (Intergovernmental Panel on Climate Change, 2007). Other authors have calculated more substantial rises, ranging from 0.90 m to 2.00 m (Jevrejeva et al., 2008; Vermeer and Rahmstorf, 2009). In Florida, a research team from Florida Atlantic University estimated SLR in Florida between 0.61 m and 1.22 m by 2100 (Heimlich et al., 2009), The U.S. Army Corps of Engineers estimated SLR of 0.5 m and 1.44 m by 2100 (U.S. Army Corps of Engineers, 2009), and four South Florida counties estimated SLR between 0.23 m and 0.61 m by 2060 (Broward, 2010).

SLR predictions for Florida, according to NOAA and the Army Corps of Engineers, are even grimmer. According to NOAA, the Cedar Key Tide Station #8727520 (NOAA, 2014a) shows a positive trend of 1.80 mm/year rise with a 95% confidence interval of +/- 0.19 mm/year based on the monthly mean sea level data from 1914 to 2006; this is equivalent to a level change of 0.59 feet in 100 years. The Key West Tide Station #8724580 (NOAA, 2014b) shows a positive rising trend of 2.24 mm/year with a 95% confidence interval of +/- 0.16 mm/year based on the monthly mean sea level data from 1913 to 2006; a level change of 0.73 feet in 100 years. These two examples show past sea level rise, but scientists agree that the rate of SLR will only increase in the future (Climate Change 2007: Working Group II: Impacts; Vermeer & Rahmstorf, 2009). The predictive tools are important because they allow policymakers and other stakeholders to model the damaging effects of SLR using projections of future events.

The U.S. has 12,400 miles of coastline with 5.2 million acres of estuarine wetlands (Titus, 1998). Rising waters and increasing intensity and severity weather patterns put much of
this land in danger by eroding beaches, destroying wetlands (they will become open water) and leading to an increase in coastal flooding (Higgins, 2008). A four foot rise in the next century inundates 7000 square miles of once dry land (Titus et al., 1991). Even if the lowest IPCC estimates are correct, a substantial amount of the Chesapeake Bay wetlands may be destroyed (Morris, Sundareshwar, Nietch, Kjerfve, & Cahoon, 2002). If we assume 50% IPCC levels (~ 1 m), most wetlands in mid-Atlantic region (New York to North Carolina) will also be lost (Burkett & Kusler, 2000). Sandy beaches that account for a large percentage of tourist dollars in several states are also at risk (Shivlani, Letson, & Theis, 2003).

Florida is particularly vulnerable to SLR due to its large population living near the coast and considerable amounts of land at or near sea level (Harrington, 2007). In fact, about 4,500 square miles of coastline are at or below the 4.5 feet of sea level. Even with a one foot rise, erosion of up to 200 feet on many Florida beaches is likely a reality (E.P.A., 2002). In terms of the environment, mangroves, brackish water and a portion of the Everglades are at risk (Davis, Childers, Lorenz, Wanless, & Hopkins, 2005). Many future mangrove swamps are within 1-2 feet of sea level; existing freshwater wetlands are 2 to 4.5 feet above sea level (Davis et al., 2005). Projections show that their destruction due to saltwater intrusion and with salt water “flushing” is a distinct possibility (Andersen, Mercer, & White, 1988; Smith, 1993). In terms of direct impact to Florida residents, the Biscayne Aquifers which supplies a large portion of drinking water to south Florida is at risk because it is recharged by freshwater Everglades (E.P.A., 2002).

Not only are environmental sites targets of sea level rise, but also personal property. As shorelines slowly move farther inland, home sites on the coast and bays are losing acreage. Sometimes these properties lose land quickly during hurricanes but slow the process of shoreline
erosion is growing with the rate of sea level rise. Contention between private land owners and state conservation easements (submerged lands) is also likely increase as more properties are affected over the next century.

**Policy Options**

The policy choices that local communities make today will affect the vulnerability of those communities for decades to come. Today, these policymakers may to choose four broad options: protect, accommodate, retreat, or do nothing. Protection includes hard armoring using seawalls, riprap, groins or other similar manmade structures or soft armoring through beach nourishment or dune stabilization (Titus & Richman, 2001). Accommodation includes a variety of policies including zoning, build code modification, comprehensive community plans, and using existing regulations, such as in floodplains, to reduce the vulnerability of the community (Grannis, 2011). Retreat is a set of policy choices that do not attempt to hold back the sea; instead, retreat acknowledges the inevitable and seeks to make the transition as easy as possible (Alexander, Ryan, & Measham, 2012).

**Armoring**

Coastal armoring is widespread along our nation’s coastline and is only expected to increase in response growing threats from over-development, sea level rise, and flooding. Methods for hardening the coast include hard armoring using seawalls, jetties, and rip-rap as well as soft armoring methods such as beach nourishment and dune restoration (Schlacher et al., 2007). Hard armoring has traditionally been the choice of property owners and others to hold-back the sea and maintain property values. But given the detrimental effects to adjacent property and marine life, as well as the value of the beach, the use of soft armoring methods to maintain sandy beach has exploded in previous decades.
Hard armoring is a widely accepted method of holding back the sea (Cardiff, 2001; Hanak & Moreno, 2012; Titus, 1998). Hard armoring using devices such as seawalls, jetties, and rip-rap is widely used along our nations developed coastlines (Giles & Pilkey, 1965; Neal, Pilkey, & Kelley, 2007; Pilkey & Wright, 1988). Its advantages include stabilizing upland areas from flooding and storm surges, protecting infrastructure such as homes and businesses, and importantly, maintaining property values (Kriesel & Landry, 2004). Unfortunately, hard armoring often alters the flow of sediment which leads to increased erosion in adjacent beaches as well as the loss of dry land along the seawall itself (Dugan, Hubbard, Rodil, Revell, & Schroeter, 2008). As the beach adjacent to and surrounding the seawall shifts, reductions and losses of marine habitat have also been observed (Dugan et al., 2008). In California, over 136 miles of the 1100 mile ocean coastline is armored (Titus, 1998). As of 1990, almost 20% of Florida’s coastline is armored; as of 2004, about 50% of Florida’s developed coastline is armored (Bush, 2004).

The ability of a coastal property owner to armor his property varies widely from state-to-state and county-to-county (Byrne, 2010). Political entities can limit coastal armoring in two ways: either by limiting or denying public funds build hard structures and/or by enacting regulations that prohibit or restrict property owners from building the structures themselves. In California, the California Coastal Commission (CCC) enacted a statute that limits the building of hard armoring devices…”required to serve coastal-dependent uses or to protect existing structures or public beaches in danger from erosion.” The language used by the CCC is well-written because it limits the political dangers by allowing existing, grandfathered, properties to be protected; this is a good way to phase-in an armoring prohibition program (CCC, 1995). Similarly, North Carolina essentially prohibited hard armoring along its coasts in 1985 when the
state passed the North Carolina Coastal Zone Management Act (Pilkey & Wright 1998). As a result, only about 3%-6% of North Carolina’s coasts is armored, a substantial reduction from 30 years ago (Kittinger 2010).

Florida is another great example of armoring prohibition policies. There are only a limited number of armoring permits are granted at the state level and some counties have applied even more stringent prohibition policies (Christie, 2012). Coastal armoring in Florida is regulated at the state-level in two ways. First, Florida State law requires property owners to obtain permits from the Department of Environmental Protection for any construction seaward of the Coastal Construction Control Line (essentially defined by the 100-year storm surge predictions) or within 50 feet of the mean high tide (MHT) line as defined by the Beach and Shore Preservation Act (Wyman, 2010). Second, the Florida Department of Environment Protection has instituted a second layer of hard armoring regulations which requires the denial of a permit if (1) the structure is vulnerable to erosion, (2) the structure cuts-off public beach access, or the construction will results in significant adverse impacts to the shore. However, the state legislature passed a law allowing for easier armoring permitting for undeveloped land.

Some Florida counties have enacted much more rigorous requirements for hard armoring structures. In Sarasota, per the county’s Coastal Setback Code, coastal armoring is banned in all but the most extreme circumstances by virtue of a permitting requirement that property owner prove that the new structure will not affect his neighbors.

Soft armoring strategies such as beach nourishment and dune stabilization have become increasingly popular as people see the numerous disadvantages of hard armoring but are still trying to “hold back” the ocean (Dean, 2002; Valverde, Trembanis, & Pilkey, 1999). Beach nourishment projects have been widely accepted in many coastal areas because they maintain
beautiful beaches for tourism, a major income source for places such as Miami Beach, FL and Siesta Key, Sarasota, FL, while protecting valuable coastal real estate (Houston, 1995, 1996).

The advantages of this policy option include wide, picturesque beaches while providing a natural defense against erosion and coastal flooding which makes tourism and property owners happy (Jones & Mangun, 2001). Beach nourishment projects are also incentivized by the federal government\(^3\) though funding schemes where the federal government may pay up to 75% of the costs to nourish a beach (Klein, Osleeb, & Viola, 2004). Given the advantages of this method, combined with state and federal subsidies, beach nourishment is only expected to increase (Klein et al., 2004).

The two major disadvantages are cost and maintenance (Jones & Mangun, 2001). The ten-year cost of maintaining a one-mile stretch of beach ranges of $2 million to $15 million; factors such as the type of sand, distance of sand from project site, and frequency of major weather events cause the 10-year costs to vary widely (Daniel, 2001). Despite these high costs, studies have shown the benefits usually far outweigh the costs. For example, Miami Beach, FL increased its tourism revenues to $290 million the first year after it began nourishing -- five times the amount of its $51 million investment – the first year after it began nourishing (Houston, 2008). The federal government also derives substantial profits from beach nourishment. A 2002 study showed that for every $1 the federal government spent to nourish beaches, it gained $570 in tax revenues from beach tourism (Marlowe, 1999).

While beach nourishment may be popular, its long-run feasibility is suspect given SLR projections. SLR should lead to substantially more sand will being required to maintain a

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\(^3\) Millions of federal, state, and private dollars have been expended annually on shore armoring and protection, which can cost anywhere from $1,800 to $7,600 per linear foot of coast (Griggs, 2005).
disappearing beach. However, some authors believe soft armoring will continue to be “the most cost effective and environmentally acceptable approach” to protecting coastlines because the white beach will serve as a (semi)-natural buffer (American Shore and Beach Preservation Association, 2006). Another study, examining the most populous 2,000 miles of coasts along the Eastern U.S. found that it would still be cost-effective to nourish the beaches around densely-populated areas, despite the $3 billion to $9 billion price tag (Leatherman, 1989). None-the-less, shrinking deposits of near-by sand and increased costs associated with raising beach elevations higher and higher are likely to cause governments to re-think the economics of beach nourishment (Hinkel et al., 2013; Jonkman, Hillen, Nicholls, Kanning, & van Ledden, 2013).

Adaptation

Adaptation to coastal vulnerabilities includes a wide variety of policy choices (Grannis, 2011). It is the most difficult category of coastal policy making because choosing the “right” combination of policies requires assessing both the long-term risks of climate impacts and also how those impacts will be affected by the chosen amalgamation of adaptation policies. Adaptation policies may be categorized into (i) regulatory tools, (ii) spending tools, and (iii) marked-based tools (Grannis, 2011).

Regulatory tools are enacted by statute or ordinance at the county or city level of government. The four most popular regulatory policy tools are comprehensive plans, zoning ordinances, subdivision ordinances, and building codes (Grannis, 2011). Given that local governments have exercised their power to zone communities, set building standards, and regulate land use, these tools are usually the “most expedient solution” (Maryland Department of Natural Resources). But if major power-holders, such as coastal land owners oppose new policies, there may be little political will to make difficult choices.
Comprehensive plans, created by local planning departments, provide a vision of what the community will look like in many years or decades by establishing a general growth plan (Locke & Rissman, 2015). These plans, unlike zoning laws, are usually not legally enforceable (Locke & Rissman, 2015). None-the-less, they are very important because many of the new zoning regulations are created based on their comprehensive plans. These plans can be a powerful coastal management tool because they allow planners to identify and study how SLR may impact their community and then choose which areas should be protected and which areas may not be worth saving. Once these decisions are made, policies such as armoring prohibition can be chosen that conform to the choices made in the comprehensive plans.

Local governments have significant powers to control development through zoning. Throughout the country, Zoning ordinances categorize each district in the community (residential, commercial, or industrial), its density (R-1, R-2, etc.). Planners then specify design requirements and specific regulations for each district (building size, height, location, and floor space). Planners, using **overlay zoning**, may also add supplemental regulations to areas with special characteristics. Overlay zoning is performed in three steps: (1) establish the purposes for creating the district, (2) map the district, and (3) establish the regulations to achieve the purposes for creating the district. Current examples include historic properties or beach-front homes, but overlay zoning could just as easily be used to place stricter requirements on lots based on SLR vulnerability.

Floodplain regulations are a very good option for local policy makers because the federal government, acting as a partner with the local community, provides incentives for their cooperation. The National Flood Insurance Program (NFIP) provides discounts for flood insurance policies based on how much the local community cooperates to reduce flood
vulnerabilities. One program requires the communities to adopt and enforce floodplain management ordinances that meet minimum program requirements for regulating new construction in “Special Flood Hazard Areas” (SFHAs). To become a partner, the local community merely has to adopt and the model language, as written by the Federal Emergency Management Agency (FEMA), to receive substantial NFIP discounts. Although the FEMA flood maps do not consider SLR or increased storm surge, proper floodplain regulation is a good tool to set stricter building requirements and limit development in areas of high vulnerability.

Governments typically regulate the construction and design of structures through state or local building codes. These codes could be drafted by local communities. But an easier solution would be to apply the NFIP building codes to lower-risk areas. An example would be applying the building codes of V-zones (very high risk) to every parcel in A-zones (medium risk).

Alternatively, building code requirements, either written by the community or adopted from the NFIP, could be required in areas designed as high-risk using the county’s own GIS vulnerability analysis. Building codes are typically enforced only when the structure is first-built or requires “substantial repairs,” so existing properties are not required to immediately conform to the new regulations.

**Retreat**

Coastal policy choices under the umbrella of retreat allow natural habitats, such as beaches, marshes, and wetlands, to naturally migrate landward as the sea slowly inundates the once-dry land. Retreat is a viable option when it is coupled with sound policies like limiting development in the most vulnerable areas and removing hard-armoring structures and preventing new ones. But retreat becomes more difficult to adopt when areas are already densely built, such as coastal downtown areas, or when there is nowhere for existing developments to “retreat to,” such as on barrier islands. Retreat policies may be created by the local communities through
local regulations such as zoning and land use, requiring property owners to cede a property interest in exchange for permission to armor or rebuild their structures, or purchasing conservation easements.

The purpose of retreat is to protect properties along the shoreline by reducing their vulnerability to coastal hazards such as sea level rise and storm surge (Siders, 2013a). The results of a successful retreat policies is a community that avoids repetitive coastal losses during major weather events (Siders, 2013a), unlike the 12,000 homes that FEMA has re-built at least four times in past years ("Houses wrecked repeatedly by sea rebuilt with taxes," 2014). While some argue that retreat places overly-restrictive limits on their property, the end-result is quite the opposite (Titus, 2011). Retreat often allows for property owners un-restricted use of their property, with the exception of building hard-armoring structures to hold back the sea.

Retreat is not a single policy; it is a combination of them that may include armoring limitation or prohibition, rebuilding restrictions, land use restrictions, acquisitions, and different types of easements. Armoring prohibition is an essential retreat policy; either the state or local government may severely restrict or prohibit new hard-armoring structures from being newly constructed or rebuilt, which allows the sea to naturally retreat landward. Courts in Oregon, North Carolina, and Florida, three states with strict state-wide prohibition regulations, have found the policy to be constitutional. Without limiting the ability of coastal owners to armor, retreat cannot take place. Rebuilding restrictions are a viable option for limiting coastal vulnerability because often the most vulnerable structures are required to be rebuilt again-and-again. Limited resilient rebuilding policies “require that damaged structures be replaced by more resilient structures, be built at higher elevations, or be moved further from the coast” (Siders, 2013b). Conditional rebuilding allow the owners to rebuild only if they agree to certain land-use
related caveats, such as removing their seawall or limiting the number of times they may rebuild. One such caveat may be agreeing to a conservation easement where the owner is allowed to use his property any way he sees fit, with the exception being that he may not hold-back the sea in any way. Conservation easements may also be acquired through state-purchases from property owners. Finally, acquisitions, eminent domain, and buyouts may be a good option for the most vulnerable properties but their prohibitive costs justly them in only the most expensive of situations.
The effects of coastal climate change are being felt across the United States (Noss, 2011). Flooding from New York to Florida, disappearing beaches, and threatened ecological systems are consistently reported and only expected to increase in the future (Noss, 2011). Some communities and land owners are reacting to the phenomenon by building ever higher seawalls which are exacerbating existing problems and leading to narrower beaches with even less buffer between the structures and the water (Landry & Hindsley, 2011). If climate change predictions are correct, the coastline will face even greater threats in the future which may only be overcome if stakeholders are prepared about new coastal policies and about ways to implement strategies of choice, tailored to their own communities (Titus, 2011). Choosing the best strategy for an individual community is difficult because in addition to fixed variables such as the loss of property area and corresponding value, threats to infrastructure and flooding issues, combined with other considerations such as liability, are difficult to estimate due to the current lack of information and research. A review of the successes and failures of current policies in different communities can help address some of the concerns, but many policy options are so recent that long-term application and information on outcomes are not yet available. Nonetheless, relocation and accommodation policy options have been implemented in several counties in the United States and the United Kingdom, and they show great promise.

There are three types of policies: protection, adaptation, and relocation. Protection includes hard armoring such as seawalls, groins, and jetties and soft armoring such as beach nourishment and dune stabilization. Adaptation includes updating zoning ordinances, building plans, rebuilding restrictions, and floodplain regulations. Relocation includes conditional
development, conditional improvement programs, acquisitions and buyouts, and rolling easements.

The intent of this paper is to provide municipal, county or state coastal planners and managers with a GIS based modelling tool to test various scenarios in their jurisdictions related to sea level rise in Florida. Given the numerous policy options available to today's local governments, comparing the different options in order to make informed decisions is integral to preparing for coastal sea level rise caused by climate change. To accomplish this goal, local governments should be urged to consider implementing site-specific coastal plans by combining different policies in order to craft a solution that fits the needs of their own community.

Unfortunately, there is a disconnect between the research centered on legal aspects of coastal climate change and the research predicting the effects of climate change using GIS. For over a decade, researchers have created GIS models to estimate the effect of sea level rise on coastal areas (Frazier, Wood et al., 2008; Frazier, Wood et al., 2010). These models have been very useful in predicting the effects of sea level rise and storm surge because they visualize the predicted effects of sea level rise (SLR) and have steadily improved by adding new components, considering parameter interactions (i.e., SLR and storm surge), and using higher resolution data (Zhang, 2011; Zhang, Wu, Zhen, & Shu, 2004; Zhang, Dittmar, Ross, & Bergh, 2011). But with only a few exceptions (Ackerman & Stanton, 2008), predictions have not moved beyond the “do-nothing” scenarios.

More recently, legal researchers have addressed the tension between the Sovereign and private property owners as waters continue to rise. Locating the boundary between the two, usually meaning high water (MHW) or mean low water (MLW), is difficult because MHW and MLW are well-defined legally but hard to locate physically (Titus et al., 1991; Sax, 2009).
Coastal policy research articles address many topics, including mechanisms to help local governments understand their options (Levina, 2007), constitutional issues such as Takings (Titus, 2011), which occur when the Government unlawfully acquires private property, and novel policy solutions to prepare for the inevitable (Bryne, 2009; Sax, 2009).

Geographers and land surveyors have recognized GIS’s ability to simulate SLR and storm surge along the coast as a means to relate the estimates of climate change to their impacts on a specific community (Wu et al., 2002; Zhang et al., 2004). Many of these models have been relatively simple because they only simulated a “do-nothing” scenario (Allison et al., 2009, Snow & Snow, 2009). Over the past five years, technical papers commissioned by local and state governments predicted the impact of climate change on their regions in terms of the impacts on various groups of stakeholders, including property owners, tourism, and businesses (Harrington & Walton, 2008; Whitehead et al., 2008). The scope of these reports was much more comprehensive than that of previous journal articles, yet applied the same methodology of overlaying SLR projections with digital elevations models. Some studies have added demographic data or used a hedonic model to better predict real estate pricing, but very few have considered different policy options.

Ackerman and Stanton (2008) examined the climate change outcome's potential cost for Florida, comparing two scenarios: one proactive (lawmakers adopt climate change legislation) and the other not proactive (lawmakers do nothing). The purpose of the paper was to provide a comprehensive review of climate change threats to Florida.

The current study intends to fill the gaps of previous analysis in terms of the methodology used to estimate real property losses in terms of model inputs and criteria measured. For example: Stanton used 1:250,000 Digital Elevation Model (DEM) map to
determine which properties were below 1.5 m in elevation; those properties below the 1.5 m threshold were considered inundated.

In addition to failing to consider the way in which various policy options will affect modeled simulations, the resolution of the data and the size of the study areas were major shortcomings in the past studies. Considering how slow sea levels are rising (a few millimeters a year), models that use digital elevation with a vertical accuracy of several meters risk misrepresentations and a misinformation for the end-users (e.g. counties and property owners), who may assume the results can be relied upon for specific locations.

The goal of this study is to simulate results of different policy options under different SLR scenarios. An incremental approach to rising waters was adopted from Zhang (Robertson, Zhang et al., 2007). In order to measure the relative policy differences, an ArcGIS Model Builder iteration loop was used to simulate the primary factors of each policy option. The data used for the study areas is publicly available and can be easily substituted with data relevant to other areas in other counties. Also, the methodology and computer programming code can be modified and improved to account for more variables. The results show that managed relocation strategies work well for areas that are gradually inundated by SLR. However, without more land to allow the water to “roll back,” land and property quickly disappears. Considering that Florida’s elevation is only 6 feet, not only are coastal cities as risk, but much of the entire state.

Sea Level Rise

It is difficult to predict how much sea level will rise in the twenty-first century, but several approaches allow scientists to approximate it. The Intergovernmental Panel on Climate Change (2007) estimated that sea level rise will be between 0.18 and 0.59 meters by 2100. IPCC sea level predictions are widely accepted by the scientific community, having been cited thousands of times, but questions regarding the study’s methodology have led to other authors
calculating more substantial rises. For instance, Rahmstorf (2007) correlated IPCC surface temperatures with a rise of 3.4 mm/year per degree Celsius. This led to a prediction of a 0.5- to 1.4-meter rise over the same time period, almost triple the IPCC predictions. Similarly, predictions of 0.75-1.9 m by Vermeer and Rahmstorf (2009), 0.8-2.0 by Pfeffer et al. (2008), and 0.8-1.3 by Jevrejeva et al. (2010) have been estimated between 2000 and 2100.

As previously mentioned, Florida is particularly vulnerable to SLR due to its large coastal population (Hinrichsen, 1999) and considerable area of land at, or near sea level (Harrington & Walton, 2008). In fact, about 4,500 square miles of coastal areas sit at, or below 4.5 feet of sea level (Harrington & Walton, 2008). Even with an estimated one-foot rise, erosion of up to 200 feet on many Florida beaches is likely (EPA, 2009).

SLR predictions for Florida, according to NOAA and the Army Corps of Engineers, are even grimmer. According to NOAA, the Cedar Key Tide Station #8727520 (NOAA, 2014a) shows a positive trend of 1.80 mm/year rise with a 95% confidence interval of +/- 0.19 mm/year based on the monthly mean sea level data from 1914 to 2006; this is equivalent to a level change of 0.59 feet in 100 years. The Key West Tide Station #8724580 (NOAA, 2014b) shows a positive rising trend of 2.24 mm/year with a 95% confidence interval of +/- 0.16 mm/year based on the monthly mean sea level data from 1913 to 2006; a level change of 0.73 feet in 100 years. These two examples show past sea level rise, but scientists agree that the rate of SLR will only increase in the future, therefore, predictive tools remain at the level of estimates.

The stability of our nation’s coast is in decline and continues to be threatened on several fronts (Titus, 2011). As the population grows and the demand of waterfront real estate rises, new development is causing coastal areas to become more vulnerable to erosion, Sea Level Rise (SLR), and storm surge (Zhang et al., 2011). Many people believe natural events such as
hurricanes are the biggest threats to our coast, but when these natural events are combined with increased ocean levels, the combined effects can have dramatic consequences (Snow & Snow, 2009; Zhang et al., 2011). Property owners are responding to this threat with different protective actions such as widespread armoring, which only delay the inevitable changes to our beaches while negatively affecting the coastal ecology and providing a false sense of security (Titus et al., 1991). Considering a four-feet rise of the water level in the next century in Florida?, which is not out of the realm of possibilities, it is estimated that 7000 square miles of once dry land will be covered with water (Titus, 1998). A rise of only two feet could result in the loss of between 17 and 43 percent of U.S. wetlands (Smith & Tirpak, 1989).

It is imperative that local governments act now to forestall the medium and long-term effects associated with SLR because coastal policies take years or decades after implementation to prove their efficiency. Coastal Commissions struggle to choose policies to address climate impacts for a variety of reasons, including: (i) the demand to meet short-term needs as opposed to making long-term plans; (ii) concerns about private property rights, businesses and property owners; (iii) political pressure from climate change skeptics; (iv) lack of data about the effects of different policy options (especially more progressive policies); and most importantly, (v) uncertainty as to how climate change will affect their community.

**Policy Options Overview**

Coastal policy options can be categorized in several ways, but the U.N. framework of *Protect, Accommodate, or Relocate* is a widely accepted standard (Klein et al., 2001; Few, Brown et al., 2007). *Protection policies* include hard armoring of the coasts by building protective structures, such as seawalls and jetties, intended to stop the landward migration of the ocean and soft armoring techniques such as beach nourishment, dune creation and restoration, sand scraping, and dune reshaping. *Accommodation* involves making choices to reduce the
sensitivity and/or exposure to coastal impacts. Policy choices include revising building codes, re-zoning vulnerable areas and imposing minimum elevations to buildings so the property is able to withstand flooding (Alexander et al., 2012). Relocate allows for the use of vulnerable lands to continue, as long as the policies do not attempt to prevent flooding or inundation with shoreline protection; the owners can do anything they want to their property except hold-back the sea. (Titus, 2011)

Today, protective armoring policies are favored in many highly developed areas, but other communities, such as Sarasota County and Miami Beach, have understood that the results of coastal barriers are less than ideal because of the adverse effects to the coastlines adjacent to the seawalls\(^1\). Many state and local governments have limited or prohibited coastal armoring by private property owners because local governments are realizing that armoring has adverse impacts on the surrounding coastlines. Hence, Florida became one of the first states to embrace armoring prohibition; in 1985, the State adopted a policy prohibiting coastal armoring in areas where no seawalls existed. Today, the Florida Department of Environmental Protection and local planners consider the issuance of hard-armoring permits on an individual basis; stricter regulations vary by county. Similarly, Rhode Island embraced non-structural methods for controlling erosion, such as stabilization with vegetation and beach nourishment, while denying armoring permits until after the owner exhausts all reasonable and practical alternatives, including but not limited to the relocation of the structure and nonstructural shoreline protection methods dune stabilization (Save the Bay, 2013).

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1 “Instead of slowing erosion,” observed a journalist in the 1980s, “the solid beach structures hastened the loss of sand” (1985). Cabinet should say “No” to new coastal armoring. Miami Sun Sentinel.
Accommodation involves making long-term decisions now before the full effects of climate change alter the coastal landscape. These strategies include prohibition or removal of hard protection, revising infrastructure, permitting, zoning regulations, and land acquisition/trading programs, among others (Nicholls, 2009). These policies require implementation in the medium and long term, before the full effects of climate change begin (Titus, 2011). As an example, towns and cities in the U.S., such as several in New York State, including East Hampton, began prohibiting armoring along the ocean and bay shores (Rather, 2000). Other communities adopted similar measures. Southampton, for example, banned “new bulkheads, steel walls, seawalls, rock revetments and other hardened erosion-control structures along its fabled ocean shores” in 2003 (Rather, 2003). Armoring prohibition is also implemented by several states, including Florida and New York.

Relocation policies allow low-lying coastal areas to give way to the sea by allowing the sea to naturally “roll in” and inundate coastal areas. There are many ways by which the sea is “allowed” to inundate coastal property. For instance, property owners could be prohibited from armoring their land through regulations. Second, the government could prohibit that existing seawalls be replaced. Third, the government could purchase the most vulnerable lands in fee-simple from property owners; this could be done now or after a major storm damages the properties. Fourth, the government could purchase a conservation easement from property owners today (year zero) in exchange for a covenant on their property that prohibits the owners from building any structure to hold-back the ocean; this is the most viable relocation option because it eliminates the threat of litigation due to a taking. Rolling easements are also seen as the best alternative because they put off many taking for several decades and also provide a type of forewarning to property owners, in contrast to new laws that take effect immediately and
impede the use of private property. Several local governments have implemented relocation policies over the past few decades. The first examples were in the UK, where an 8000 m² area at Northey Island, Essex, in 1991 was a success (Dagley, 1995), followed by Tollesbury and Orplands in 1995 (Lowe, Gregory et al., 2001).

Methods

Study Area

Two study areas, Pinellas County in the Tampa Bay region and Key West (Monroe County) in Southern Florida, were included in this research. A subset of parcels in each county was selected, representing different areas in Florida in terms of land size, population density, and coastal hazard preparedness.

Key West (Fig 2-1 top) is highly susceptible to climate change and is probably one of the most at-risk areas in the United States. The small island has a total land area of 17.2 km², and a population of 25,000. Its average elevation is 1.8 m, but many coastal areas are much lower. The low elevation leaves little area for relocation (Zhang et al., 2011).

Pinellas County (Figure 2-1 bottom) has a total area of 1574 km² and a population of a just below 1 million people, with highly developed and protected coastal areas, including high beach dune elevations.

Data

A high quality digital elevation model (DEM) is one of the most important pieces of data when constructing a GIS elevation model. The DEM used for Key West in this study is a topographic/bathymetric hybrid, created from a combination of LiDAR observations and ocean soundings, which covers all of the Keys. It was created by NOAA in 2000 with a spatial resolution of 1/3 arc second horizontal accuracy of less than 1 meter, and vertical accuracy of between 0.18 m and 0.36 m. The DEM for Pinellas has a spatial resolution of 2 m, horizontal
accuracy of 75cm at 1 sigma, and vertical accuracy of 20cm at 1 sigma. Both data sets are available for download at NOAA’s Digital Coast website.

The land parcels layer of each site outlines the geographic boundary of each property and includes attribute data such as the owner’s name and address, different property evaluations for several years, structure type, and zoning type. This type of data set has been used in many SLR studies (Ackerman & Stanton, 2008; Whitehead et al., 2008; Zhang, 2011). The parcel polygons are used to determine the inundation percentage of each parcel, as well as the loss of property value. The two parcel data sets were obtained from the counties’ property appraiser websites.

**Policy Option Modeling**

Three policy options were modeled and compared in this study: hard armoring, armoring prohibition, and rolling easements. Each policy option was simulated using a combination of existing GIS tools and custom programmed Python scripts. In each simulation, the different Python module scripts created in ArcGIS Model Builder and representing the modeling criteria were seamlessly run in a single package. This modular approach allows for new criteria to be added as needed. The only drawback with this approach is that each custom Python script must be validated by itself before it can be added to each of the three Model Builder policy scenarios as a quality control measure. While not necessarily a drawback, because each component is tested by itself first, the constant testing and search for error messages can be time consuming.

**Armoring prohibition policy modeling.** The armoring prohibition scenarios, shown in Figures 2-1 and 2-2, were the simplest of the three to model. Land area loss and the associated loss in property value were evaluated. First, an inundation polygon was created using the DEM and ArcGIS Raster Calculator. Second, each parcel is divided into 1 m cells using the build

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attribute table function. Third, each 1 m cell, linked to a parcel ID, is overlaid on top of the SLR Inundation raster; then the Tabulate Area function determines the percentage of inundation for each parcel. Fourth, a custom Python script determines the associated loss in property value: if less than ten percent (10%) of a parcel is inundated by water, then the level of inundation is multiplied by the value of the land. For example, if a parcel is valued at $100,000 and it is 5% inundated, then the parcel is now worth $95,000 (100,000 – (5% * 100,000). If more than ten percent of the parcel is inundated, then the parcel is considered worthless. For example, if 200 of 800 pixels of a parcel are inundated, then the parcel inundation script would calculate a 25% (200/800) inundation for this parcel. Since parcel inundation is above the 10% threshold, its new value is zero.

**Armoring policy modeling.** The armoring scenarios, in Figures 2-3 and 2-4, use the same land area and property value criteria as the armoring prohibition scenario but also accounts for the cost of building a seawall and associated value losses with the loss of sandy beaches. The seawall, costing an average of $2 million per mile, is modeled by raising the elevation up to 1.35 m, the highest inundation scenario. Additionally, the premium of a sandy beach in front of the parcel is calculated by overlaying the inundation scenario on top of the beach area, the same process used to calculate property area loss, with a different value loss formula applied. The cost of building the seawall is calculated by multiplying the average cost-per-mile by the length of the beach in the study area.

Deciding on the cost-per-mile and maximum height proved to be very difficult. Like any other coastal engineering estimate, the costs of seawalls vary substantially based on site-specific factors such as: desired seawall type (sea wall, jetty, etc.), construction material, beach slope, and soil type. Therefore, after corresponding with several coastal engineers, $2 million per mile was
chosen as an average cost in the South Florida area. The maximum sea wall height was also
difficult to determine because various other factors, such as drainage problems, occur well before
the sea wall reaches its maximum construction height. A maximum seawall height of 4.25 m was
chosen after corresponding with the same experts who helped determine cost-per-mile. Since the
SLR inundation “steps” only went as high as 1.35 m, it was assumed the seawall would hold
until the last scenario. Another shortcoming in determining the costs associated with hard
armoring was that property values are adversely affected by hard armoring structures (Fletcher,
Mullane et al., 1997; Caldwell & Segall, 2007); this loss-of-value was not modeled.

**Rolling easements policy modeling.** The rolling easement scenario proved to be the
most complicated to create of the three policy scenarios. In addition to the land area and
associated value loss calculations, other criteria, including the cost of compensating property
owners in exchange for a conservation easement [comp] (Titus, 2011), waterfront property gains
that occur when a landlocked property becomes waterfront due to inundation [waterfront gains]
(Landry & Hindsley, 2011), and the cost to remove the house after the property has been
inundated [building demolition] (Landry & Hindsley, 2011) had to be considered and modeled.
The rolling easements model, Figure 2-4, is based on the idea that the ocean will slowly inundate
coastal property without any hard or soft armoring to stop the gradual “rolling-in” of the water.
But there are no built-in functions or series of tools in ArcGIS that depict this behavior.
Therefore, custom models and python code utilizing standard ArcGIS geo-processing tools, such
as the buffer, intersect, and join functions, as well as raster calculator operations, were
developed.

First, an inundation polygon was created using the DEM and ArcGIS Raster Calculator.
Second, each parcel was divided into 1 m cells using the build attribute table function. Third,
each 1 m cell, linked to a parcel ID, was overlaid on top of the SLR inundation raster (Figure 3-5); then the Tabulate Area function determined the percentage of inundation for each parcel. Fourth, and a custom Python script determined the associated loss in property value: if less than ten percent (10%) of a parcel is inundated by water, then the level of inundation is multiplied by the value of the land. Fifth, water gains were calculated by determining if a parcel was landlocked in the previous scenario but now is bounded on at least one side by water. If yes, then the property value is increased by 73%. Sixth, if a parcel is over 10% inundated by water, then a one-time charge (negative gain in property value) is added for $14,000. Seventh, a one-time payment from the county to the property owner is calculated. Since this easement is assumed to be purchased in year zero (today) based on the property’s value and SLR vulnerability; the more vulnerable the property, the more the county pays for an the easement.

Results

Two study areas, Pinellas County and Key West, were analyzed using three SLR policy options. The Key West study area totaled 0.52 km² with an average elevation of 1 m and a corresponding property value of $232 million. The study area on the mainland coastline of the Pinellas County area included 0.25 km of land area, with an average elevation of 9 m and a total current property value of $70.8 million. Pinellas County differed from Key West in two ways: that the average elevation was higher and the mainland lots were larger. Therefore, the results were expected to be quite different.

In the armoring prohibition scenario, as seen in Table 2-1, corresponding to Figure 2-5, Key West would only lose 0.001% of land area at 0.15 m SLR level. At a 0.30-m rise, 0.04% of the land area would be inundated and $635,000 of property will be lost. At 0.45-m rise- a tipping point- 2.3% of land would be lost with a corresponding $25.5 million property loss. In this simulation of relatively small site, the steep trend begins to level out around 0.90 m, with a
potential property loss of $170 million, and the slower loss continues with a $203 million loss at 1.05 m, a $223 million loss at 1.20 m, and finally a $232 million loss at 1.35 m.

In the Pinellas study site, Table 3-2, only a small percentage of the land would be lost (0.55% at 0.15 m, 0.98% at 0.90 m), but a significant trend begins to emerge at 1.05 m with a 1.67% estimated loss and continues until almost 4% of the study area would potentially be inundated in the 1.5-m scenario.

Figure 2-6 and Table 2-3 show property values and beach loss percentages under the armoring scenario in Key West. In this scenario, no property loss was attributed to rising waters until the 4.25 m seawall was breached, which would potentially result in the total loss of the study area and an associated value loss of $232.5 million. Similar results are noted for the Pinellas study site as shown in Table 2-4. Although no property values would be lost due to rising waters before the threshold, other factors such as loss of tourism and property values due to the huge seawall and drainage issues would cause significant losses well before the seawall sea breach.

Figures 2-7 and 2-8 show a map of the SLR inundation at 0.30, 0.60 and 1.20 m SLR in Pinellas and Key West study sites. Figure 2-9 and Table 2-5 present added value due to new waterfront property, compensation paid to property owners, and the cost to remove homes from inundated properties at each SLR step of the rolling easement model implementation. Beginning at 0.30 m, no waterfront value would be gained, but $2 million would potentially be paid in easement compensation, and only one house estimated to be removed, at a cost of $14,000. As with property losses of the same study site, 0.60 was a tipping point where $29 million would be gained from added waterfront property values, only $1.3 million in easement compensation, but 142 homes would be demolished. This trend continues in the scenario with 263 homes at 0.75 m,
370 homes at 0.90 m, 438 homes at 1.05 m, 463 homes at 1.20 m, and 475 homes at 1.35 m, until the entire area would be inundated. The results of the rolling easement scenario in Pinellas, Table 2-6, shows only limited conservation easement payments and demolition of houses until 1.05 m, where inundation levels would begin to quickly rise. This is the same tipping point as in Table 2-2 of the armoring prohibition scenario. Soon after, the trend of easement payments declined, but the cost of home removal continued until 1.50 m in the final scenario.

**Discussion**

The “best” policy for a community depends on many factors, including the value that the citizens place on things like their real estate, natural resources, and sandy beaches, among others. While armoring and armoring prohibition may be the best choice for some communities, the rolling easement scenario shows the most promise in terms of further research because governments are interested in trying more progressive strategies to better prepare for SLR, but the county planners have no way to decide if rolling easements would really “work” in their community. The communities are uncertain about rolling easements because there is no long-term record of this policy being implemented in the first place, or the long term consequences. Therefore, the local policymakers cannot presently base their decisions on past trends.

This model, was created to help the communities visualize how each policy would affect their own community; they can choose the DEM, use their own parcel layer, and decide just how high sea level will potentially rise (from 0.01 to infinity, in any increment). Decision makers may also use the tool to simulate SLR’s effects on their community under different policy scenarios including infrastructure relocation, increased flood plain and zoning regulations, building codes or even private property buyouts. New policies can be added easily and compared with other models at different SLR scenarios, which enables decision makers to use their limited resources more effectively and take action in the most vulnerable areas of the community. This is a
contrast to the typical “do-nothing” SLR scenarios that only visualize SLR in a static policy environment.

Policy choices for coastal areas are highly dependent on criteria such as: the elevation of the study area and lot sizes. In areas such as Key West, rolling easements may not be a viable option because the parcels would be inundated quickly, and armoring prohibition would be opposed by property owners since the people would have nowhere to move inland to. On the other hand, the higher elevations of coastal areas around Pinellas County would permit the water to “roll in” gradually, allowing the government and citizen’s ample time to implement progressive policies in order to lower the impact of SLR on their community.

With no direct evidence of possible property losses, tightening budgets and opposition from climate skeptics, planning agencies of many local governments are hesitant to begin planning for SLR. Before the planning offices begin to understand the risks to their community, they need the tools to simulate and map SLR. This model was developed to move beyond the “do nothing” policy scenario adopted by many authors (Snow & Snow, 2009; Zhang et al., 2011). The flexibility of this model allows any community to use their own inputs, such as digital elevation model and SLR estimates, to simulate the relative differences between the three major policy options. Additionally, researchers and/or stakeholders may add different assumptions and variables to model each policy scenario, modify existing assumptions, or simulate entirely new policies. This model also could be applied to study areas of almost any size, whether for a single community or an entire state.

The results in this model were confirmed by comparing the prior Zhang SLR inundation model of Key West to the results in the current model. Both models indicated a linear inundation trend and the only substantial difference is that the current model showed a “tipping point” at the
0.45 m scenario, which can be attributed to the relatively limited study site used in this research, although more than 1000 parcels were modeled. There were no comparable models for the Pinellas region. Uncertainty is a concern. While SLR projection estimates continue to improve, it is difficult to accurately estimate the cost of SLR in a community. This is especially true when the lowest scenario is 0.15 m but the accuracy of the DEM varies between 0.18 m and 0.36 m. By adopting Zhang’s 0.15 m-step methodology to cope with the difficulties of estimating SLR, stakeholders may better understand how different SLR projections affect their communities in different ways, despite the DEM accuracy.

Despite our best efforts, the present study cannot predict all variables therefore remaining limited in scope. There is no way to simulate every variable for a given policy or to fully understand how secondary variables interact with each other (e.g. if real estate prices change, will people abandon their homes before ten percent of the property is inundated?). Also, some costs are community-specific and require substantial site analysis before the costs can be determined. As an example, the cost of armoring a beach can be estimated through the literature, but performing additional coastal engineering studies becomes a necessity in order to accurately estimate the cost. As the coastal policy literature expands and more authors address policy options, new variables may be added to this model and the existing ones be tweaked. Another limitation of this model is that it only accounts for direct losses to real property owners. Non-marking factors such as loss of tourism, loss of public beach use, destruction of public infrastructure, and reduced business output are not within the scope of this study. Finally, many communities are already experiencing substantial flooding in coastal areas during high tides or weather events.
Several ideas are being explored to further improve this model. First, an entire county could be modeled to compensate for the edge problems associated with a small subset as well as the small study area not necessarily representing the county as a whole. Second, storm surge, as well as flooding and drainage, are two problems that will begin affecting counties well before SLR. Third, a Monte Carlo simulation could be used to determine the costs of conservation easements associated with rolling easements; since the easements are voluntary, we cannot assume that 100% of property owners would choose to accept the one-time payment in exchange for a conservation easement attached to their property.

SLR will present a serious threat to coastal lands in the coming decades. While several authors have completed GIS models of extended coastal regions, researchers and policymakers have not yet estimated the costs, benefits and drawbacks of different policy choices using GIS.

This study provides GIS-based models to estimate of the costs to real property under different SLR policy scenarios. The models were created to aid policymakers in determining the best policy choice for each community. These models measured relative changes to parcels, for multiple SLR scenarios ranging from 0 m to 1.5 m, using criteria such as land area loss, land value loss, and other policy-specific factors.

The results indicated that a vulnerable community such as Key West may not benefit from long-term policies such as rolling easements because its low elevations and small lot sizes present the increased risk of rapid SLR inundation. By contrast, communities that would have more time before the most substantial effects of SLR begin will benefit much more from rolling easements because they have time to take actions such as purchasing conservation easements.
Conclusion

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Table 2-1. Results of aroming prohibition scenario in Key West

<table>
<thead>
<tr>
<th>Scenario # (N)</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<th>5</th>
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<tbody>
<tr>
<td>Inundation Level (m)</td>
<td>0.15</td>
<td>0.3</td>
<td>0.45</td>
<td>0.6</td>
<td>0.75</td>
<td>0.9</td>
<td>1.05</td>
<td>1.2</td>
<td>1.35</td>
<td>1.5</td>
</tr>
<tr>
<td>Parcel Inundation (%)</td>
<td>0.00</td>
<td>0.04</td>
<td>2.29</td>
<td>14.18</td>
<td>34.58</td>
<td>59.04</td>
<td>79.577</td>
<td>90.39</td>
<td>96.61</td>
<td>100.00</td>
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<td>231,892</td>
<td>207,041</td>
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<td>29,425</td>
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Table 2-2. Results of the aroming prohibition scenario in Pinellas, FL

<table>
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<tbody>
<tr>
<td>Inundation Level (m)</td>
<td>0.15</td>
<td>0.3</td>
<td>0.45</td>
<td>0.6</td>
<td>0.75</td>
<td>0.9</td>
<td>1.05</td>
<td>1.2</td>
<td>1.35</td>
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<tr>
<td>Parcel Inundation (%)</td>
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<td>0.58</td>
<td>0.62</td>
<td>0.65</td>
<td>0.70</td>
<td>0.98</td>
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<td>65,311,72</td>
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Table 2-3. Results of aroming scenario in Key West, FL

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<tr>
<td>Inundation Level (m) =</td>
<td>0.15</td>
<td>0.3</td>
<td>0.45</td>
<td>0.6</td>
<td>0.75</td>
<td>0.9</td>
<td>1.05</td>
<td>1.2</td>
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<tr>
<td>Parcel Inundation (%) =</td>
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<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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</tr>
<tr>
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Table 2-4. Results of aroming scenario in Pinellas, FL

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<tr>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.5</td>
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<tr>
<td>Parcel Inundation (%) =</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<td>3.94%</td>
</tr>
<tr>
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<td>71,663</td>
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<td>71,663</td>
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Table 2-5. Results of rolling easements Scenario in Key West, FL

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</tr>
</thead>
<tbody>
<tr>
<td>Inundation Level (m)</td>
<td>0.15</td>
<td>0.3</td>
<td>0.45</td>
<td>0.6</td>
<td>0.75</td>
<td>0.9</td>
<td>1.05</td>
<td>1.2</td>
<td>1.35</td>
<td>1.5</td>
</tr>
<tr>
<td>Parcel Inundation (%)</td>
<td>0.00</td>
<td>0.04</td>
<td>2.32</td>
<td>14.36</td>
<td>35.02</td>
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<td>79.83</td>
<td>90.35</td>
<td>96.57</td>
<td>99.05</td>
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<td>New Parcel Value ($1000s)</td>
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<td>229,736</td>
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<td>62,702</td>
<td>29,072</td>
<td>8,695</td>
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<tr>
<td>Home Removal ($1000s)</td>
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<td>14</td>
<td>364</td>
<td>1,988</td>
<td>3,682</td>
<td>5,180</td>
<td>6,132</td>
<td>6,482</td>
<td>6,650</td>
<td>6,664</td>
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<tr>
<td>Compensation ($1000s)</td>
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<td>2,193</td>
<td>1,331</td>
<td>933</td>
<td>612</td>
<td>285</td>
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<td>4,974</td>
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<tr>
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<td>16,490</td>
<td>18,384</td>
<td>23,298</td>
<td>33,186</td>
<td>38,988</td>
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Table 2-6. Results of rolling easements scenario in Pinellas, FL

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<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inundation Level (m)</td>
<td>0.15</td>
<td>0.3</td>
<td>0.45</td>
<td>0.6</td>
<td>0.75</td>
<td>0.9</td>
<td>1.05</td>
<td>1.2</td>
<td>1.35</td>
<td>1.5</td>
</tr>
<tr>
<td>Parcel Inundation (%)</td>
<td>0.548%</td>
<td>0.58%</td>
<td>0.62%</td>
<td>0.65%</td>
<td>0.70%</td>
<td>0.98%</td>
<td>1.67%</td>
<td>2.36%</td>
<td>2.99%</td>
<td>3.94%</td>
</tr>
<tr>
<td>New Parcel Value ($1000s)</td>
<td>70,730</td>
<td>70,678</td>
<td>70,622</td>
<td>70,563</td>
<td>70,490</td>
<td>69,302</td>
<td>65,272</td>
<td>45,417</td>
<td>44,396</td>
<td>42,143</td>
</tr>
<tr>
<td>Home Removal ($1000s)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14</td>
<td>42</td>
<td>126</td>
<td>140</td>
<td>168</td>
</tr>
<tr>
<td>Compensation ($1000s)</td>
<td>0</td>
<td>3,477</td>
<td>1,738</td>
<td>1,159</td>
<td>869</td>
<td>675</td>
<td>504</td>
<td>126</td>
<td>97</td>
<td>61</td>
</tr>
<tr>
<td>Waterfront Gain ($1000s)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>737</td>
<td>3,292</td>
<td>18,993</td>
<td>19,757</td>
<td>21,422</td>
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Figure 2-1. Study areas: (a) Key West (top); (b) in Pinellas (bottom)
Figure 2-2. Process map of armoring prohibition scenario

Figure 2-3. Process map of armoring scenario
Figure 2-4. Process map of rolling easements scenario
Figure 2-5. Property values and inundation percentages in Key West study site under the armoring prohibition scenario

Figure 2-6. Property values ($) and beach loss percentages under the armoring scenario in Key West
Figure 2-7. Rolling easements scenario at 0.30 m, 0.60 m, and 1.20 m for Pinellas

Figure 2-8. Rolling easements scenario at 0.30 m, 0.60 m, and 1.20 m for Key West

Figure 2-9. Results of rolling easement model in Key West study site in $: (a) added value due to new waterfront property, (b) compensation paid to property owners for rolling easements, and (c) cost to remove homes from inundated properties
CHAPTER 3
A GIS MODEL OF ROLLING EASEMENT POLICIES
IN PINELLAS AND SARASOTA FLORIDA

Global mean sea levels are predicted to rise for the foreseeable future, affecting the environment and our way of life. A growing consensus of environmental scientists worldwide fears that the projected rates of global mean sea-level rise (SLR) over the next century will far exceed any previously observed SLR rates. The rising SLR could have unprecedented impacts on the natural and built infrastructure along coastlines: beautiful and expensive real estate might disappear, critical infrastructure built to provide services to coastal citizens will have to be relocated, and natural habitats that have existed for hundreds or even thousands of years will vanish. Even though these effects will occur over time and at different rates and intervals, coastal environments are dynamic and complex environments. However, with careful planning, local governments can act in advance to lower the vulnerability of their communities in the decades to come.

Scientists still do not agree on the magnitude of SLR in the coming century, but plausible scenarios estimate a 0.52 m to 0.98 m rise in sea levels by 2100 (Intergovernmental Panel on Climate Change, 2013). SLR, combined with the relatively common occurrence of tropical storm surges, porous bedrock, and a large population coastal residents, will put substantial amounts of population and real property at risk for property damage, dislocation, personal injury, and death. A rise of less than four feet could translate into the displacement of 5 million people and 2.6 million homes (Strauss, 2012). In addition to its direct effects, SLR will substantially increase the potency of coastal storm surge caused by weather events (Zhang et al., 2011). Despite

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1 Study written by C. A. “Tony” Nettleman III, Dr. Amr Abd-Elraham, Dr. Damian Adams, Dr. Timothy Fik, Thomas Ruppert, Dr. Grenville Barnes, and Dr. Bon Dewitt.
leading scientists and politicians sounding the alarm, local communities are not moving quickly enough to forestall SLR’s effects on their communities (Petz, 2012).

An overview of policy options along Florida’s coastline reveals that—although no one policy fits all contingencies—several categories of policies can be adopted to meet the needs of individual communities, including protection, accommodation, and relocation. Protection policies typically include either hard or soft armoring. Hard armoring includes seawalls, jetties, or rip-rap. Soft armoring techniques include beach nourishment and dune stabilization. Accommodation policies vary but may include revised building codes, zoning ordinances, flood plain regulations, and comprehensive plans for future growth. Finally, relocation policies do not attempt to restrict the sea’s natural advancement. Instead, they move development to less-vulnerable areas while removing as many armoring structures as practicable.

Although these policies are available to local governments, few strategically enact them. Many communities are unprepared to address the fundamental changes that SLR and storm surge will bring to their coastal areas; these communities only assess current risk while ignoring the future risks caused by SLR, storm surge, and other climate-related threats (Batten et al., 2008). Local governments are responsible for the majority of coastal planning, but they often fail to consider future events like SLR for several reasons, including lack of resources; unwillingness to act because of increased liability if they acknowledge SLR; widespread disagreement by different groups of stakeholders about the validity of climate change, let alone how to address it; and most important, a lack of tools to help them understand how SLR could affect their own community. If they do not start acting now, “today’s ‘storm of the century’ may become [tomorrow’s] ‘storm of the decade’” (Tebaldi et al., 2012).
Local governments are also not preparing for SLR because they do not know how coastal policies will affect their own communities. Why would county planners enact a policy against the wishes of property owners and developers when they are unsure whether the policy will work? Analysts have used GIS models to explore how SLR will affect different communities. Examples include a series of papers published by Dr. Zhang and his colleagues (Zhang, 2011; Zhang et al., 2011; Zhang et al., 2013), as well as work by others, such as Frazier (Tate & Frazier, 2013; Thompson & Frazier, 2014). Unfortunately, none of these models has explored how different policy options could lead to different outcomes.

One reason counties fail to plan for SLR is the uncertainty associated with how coastal residents will react to SLR and climate change in general (Frank, 2012; Liechty, 2013). As an example, the mean home prices in Florida counties hit by a hurricane during the 2004–2005 season temporarily dipped followed by a pricing overcorrection (Beracha & Prati, 2008). In other words, the hurricane had no lingering effects on real property values. History tells us that, as coastal property is impacted by SLR, the value of real property will decrease. But hedonic price models indicate the opposite: when landlocked properties become waterfront properties, their value actually rises by about 70% (Landry & Hindsley, 2011). Similarly, since many people do not believe in climate change, they will not perceive a decreased value until SLR begins inundating properties. In sum, the value of real property is highly dependent on the choices people make. But few, if any, scientists and economists understand the human dynamics at play (Fantino, Stolarz-Fantino, & Navarro, 2003).

GIS modeling techniques have been applied to determine how SLR and storm surge could affect coastal areas for several decades. First-generation GIS models were developed in the 1990s and early 2000s and tested a few scenarios (1 m, 2 m, 5 m, etc.) on large areas of land,
such as the Eastern US (El-Raey, 1997; Gornitz, 1991). Shortly thereafter, a second generation of models continued to map large areas but began linking SLR scenarios with SLR predictions made by Intergovernmental Panel on Climate Change and other leading researchers. The accuracy of data, such as digital elevation models, also increased (Rao et al., 2008; Sallenger et al., 2012). Both of these changes significantly enhanced the reliability of the results. Authors also began modeling how rising seas affected other processes, such as storm surge (Frazier et al., 2010b; Hallegatte et al., 2011; McInnes et al., 2003). Today, state-of-the-art GIS models of SLR account for the uncertainties that accompany SLR; for instance, authors use dozens of SLR scenarios, otherwise known as “steps,” in a single model; create hedonic price models that better estimate the changing real property values (Zhang et al., 2011; Landry & Hindsley, 2011); and analyze model results against previous studies to help create more effective and practical policies (Frazier et al., 2010a; Zhang, 2011).

A GIS model to analyze policy options does not exist. Despite the advances in GIS modeling techniques of coastal areas, the policy scenarios that other authors have simulated have changed very little. GIS models consistently simulate the “do nothing” scenarios that do not account for policy choices, but in reality, there is no such scenario. Instead, a complex web of local, state, and federal coastal policies translate into real-world changes that GIS models cannot ignore.

The rolling easement model implemented in this study addresses the deficiencies in current GIS models by moving beyond the do-nothing scenarios and modeling rolling easements, a realistic policy, to determine its feasibility in two Florida counties. The rolling easement policy option is simulated in a GIS environment by determining the most important criteria and simulating those criteria using Python scripts.
The GIS model discussed in this paper is a framework built to model the most important criteria for the rolling easement policy. The modular structure of this model allows the user to add, delete, or modify other processes. The ability to modify any component of the model substantially expands the utility of the model. A few examples include a statistician adding long-term real property price trends, a hydrographic engineer building a process to better understand how storm and sewer systems affect flooding, or a spatial analyst adding population data to understand the demographics at risk of SLR. In fact, entirely new policies can be modeled by modifying existing components or adding new ones using existing tools. The model also allows users to define important criteria, such as the rate of SLR, how SLR inundation affects real property values, or how much the government would pay a property owner for a conservation easement. User inputs are important because leading scientists and GIS modelers do not agree on how these criteria will affect outputs such as real property values. Therefore, creating a model where users can make their own decisions and see the outcomes is a major concern. To decrease the uncertainties associated with human behavior related to a rolling easement compensation program, participation was simulated through a Monte Carlo approach.

In this study, we emphasized the use of a rolling easements model. This model balances the need to protect coastal land for the general public while respecting the property rights that the United States holds so dear. Rolling easements minimize activities that could enhance erosion problems, such as building sea walls, altering beach landscapes, and dumping rip-rap, without prohibiting development altogether. Often, property owners not only receive a cash payment from the government but also can be eligible to receive tax benefits for placing a conservation easement on their property. Furthermore, rolling easements combined with a cash payment
minimizes the likelihood of property “takings” compared to setbacks or outright prohibition on armoring (Grannis, 2011).

This paper consists of five sections. First, the Introduction section provides a general overview of the problem of coastal planning and the proposed solution, as well as an overview of the rolling easement GIS model. Second, the Background section includes a discussion of projections and physical effects of SLR in Florida, policy options available to reduce the vulnerability of coastal counties, and a brief literature review of SLR GIS simulations. Third, the Methods section describes the authors’ GIS simulation of the rolling easement policy in terms of the study areas, the data sources, and the simulated rolling easements criteria and model. The fourth section presents the results of the rolling easements policy simulation. Fifth, the Discussion section explains how the authors chose several variables and discusses larger trends. Finally, the conclusion is presented.

**Background**

**SLR Projections and Threats**

It is difficult to predict how much sea level could rise in the 21st century, but several approaches allow scientists to approximate it. The Intergovernmental Panel on Climate Change (2013) estimated SLR of 0.28 m to 0.62 m. Other authors have calculated more substantial rises, ranging from 0.90 m to 2.00 m (Jevrejeva et al., 2008; Vermeer & Rahmstorf, 2009). For the state of Florida, Florida Atlantic University estimated SLR of 0.61 m to 1.22 m by 2100 (Heimlich et al., 2009), the U.S. Army Corps of Engineers estimated SLR of 0.5 m to 1.50 m by

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2 Under the Fourth Amendment of the Constitution, when a government actually or constructively takes private property for public use, that government must pay “just compensation” to the property's former owners.
2100 (U.S. Army Corps of Engineers, 2013), and four South Florida counties estimated SLR of 0.23 m to 0.61 m by 2060 (Broward, 2010).

The projections outlined in the previous paragraphs will likely have a profound impact on coastal areas in the US as well as Florida. The US has 12,400 miles of coastline and 5.2 million acres of estuarine wetlands (Titus, 1998). Rising waters and the increasing intensity of weather patterns put much of this land in danger due to eroding beaches, destruction of wetlands, and an increase in coastal flooding. A 4 ft rise in the next century is possible and could result in the loss of 7000 square miles of once dry land (Titus et al., 1991). A rise of 2 ft could result in the loss of between 17 and 43% of U.S. wetlands (Smith & Tirpak, 1989). Florida, with its high level of development and dense population, is particularly vulnerable to SLR. In fact, Florida is one of the four most vulnerable states along the Atlantic and Gulf coasts (Titus & Richman, 2001).

Approximately 4,500 square miles (of the total 66,000 square miles) in Florida are within 4.5 ft of sea level (Harrington & Walton, 2008). With a rise of less than 3 ft, $156 billion worth of property, 840,000 people, and 300,000 homes on 2,120 square miles of land could be lost in the US (Strauss, 2012). The EPA (2002) expects that, with a one foot rise, most of Florida’s beaches would vanish (EPA, 2002).

**Policy Options**

The policy choices that local communities adopt today will affect the vulnerability of those communities for decades to come. In general, policy makers can choose between three options: protection, accommodation, or relocation. *Protection* includes hard armoring using seawalls, rip-rap, groins, or other similar manmade structures, as well as soft armoring methods such as beach nourishment and dune stabilization. *Accommodation* involves a variety of policies, including zoning; build code modification; comprehensive community plans; and existing regulations, such as in floodplains, to reduce the vulnerability of the community. *Relocation* is a
set of policy choices that do not attempt to limit the advancement of the sea. Instead, relocation acknowledges the inevitable and seeks to make the transition as easy as possible. This set of policies includes land purchases, eminent domain, and static or rolling easements.

Coastal policy choices, under the umbrella of relocation, allow natural habitats, such as beaches, marshes, and wetlands, to naturally migrate landward as the sea slowly inundates the once dry land (Grannis, 2011). Relocation is a viable option when it is coupled with policies such as limiting development in the most vulnerable areas and removing hard-armoring structures (Grannis, 2011). But relocation becomes more difficult when areas are densely built, such as coastal downtown areas, or when relocation space is unavailable, such as on barrier islands (Titus, 2011). Relocation policies may be phased in alongside accommodation and armoring policies by the local communities through local regulations, such as zoning and land use, requiring property owners to cede a property interest in exchange for permission to armor or rebuild their structures or by purchasing conservation easements (Titus, 2011).

The purpose of relocation is to protect properties along the shoreline by reducing their vulnerability to coastal hazards, such as SLR and storm surge (Siders, 2013). The result of a successful relocation policy is a community that avoids repetitive coastal losses during major weather events (Siders, 2013), unlike the 12,000 homes that FEMA has rebuilt at least four times in the past years (Daley, 2014). Some policymakers argue that relocation places overly restrictive limits on their property, the result is quite the opposite. Relocation often allows property owners unrestricted use of their property, except for building hard-armoring structures to hold back the sea.

Relocation is not a single policy; it is a combination of policies that may include limiting or prohibiting armoring, rebuilding restrictions, land use restrictions, acquisitions, and different
types of easements (Grannis, 2011). Armoring prohibition is essentially a relocation policy; either the state or local government may severely restrict or prohibit the construction or rebuilding of hard-armoring structures rebuilt that allow the sea to naturally relocate landward (Grannis, 2011). Courts in Oregon, North Carolina, and Florida, three states with strict statewide prohibition regulations, have found the policy to be constitutional (McLaughlin, 2010; Richardson, 2010). Limiting the ability of coastal owners to armor is an important component of relocation. Rebuilding restrictions are a viable option for limiting coastal vulnerability because often the most vulnerable structures need frequent rebuilding. Limited resilient rebuilding policies require that damaged structures be replaced by more resilient structures, be built at higher elevations, or be moved further from the coast. Conditional rebuilding allows the owners to rebuild only if they agree to certain land use–related caveats, such as removing their seawall or limiting the number of times they may rebuild. One such caveat could be agreeing to a conservation easement where owners are allowed to use their property any way they see fit, with the exception being that they may not hold back the sea in any way. Conservation easements may also be acquired through state purchases from property owners. Finally, acquisitions, eminent domain, and buyouts can be viable options for the most vulnerable properties, but their prohibitive costs justify them in only the most extreme situations (Grannis, 2011).

Conservation easements are an important component of rolling easements. They prevent landowners from erecting shore-protection structures or elevating the grades of their land (Titus, 2011). Typically, a conservation easement is nothing more than a real property covenant or equitable servitude that prevents the landowner from armoring (Hollingshead, 1996). Depending on the state, conservation easements may be obtained from property owners as a condition for a building permit, through eminent domain or voluntary purchase (Titus, 2011). The mechanisms
available to the government also depend on legislation or court decisions interpreting the public trust doctrine, the state’s fiduciary duties to its citizens, and what constitutes a taking (Kramer, 2011). Rolling easements would be implemented by local governments offering landowners cash payments now in exchange for a perpetual conservation easement. The primary benefit of obtaining a conservation easement is the reduction of legal uncertainties concerning whether a landowner has the right to build shore protection now or in the future, when that right may negatively impact a coastal policy (Titus, 2011). Local governments do not agree on how rolling easement payments should be computed. One study found that “cash payments amounting to less than 5 percent of the land’s value may be adequate for farms whose owners have no intention of developing the land” (Titus, 2011). But given Florida’s boom and bust economy, it is unclear how the intentions of rural property owners might be affected. Other studies have suggested payments for a fixed-term easement (30 years), a terminable easement (owner pays the money back with interest and the restriction is removed), or eminent domain (Richardson, 2010). But none of the studies suggest a formula or methodology for calculating payments to property owners. Furthermore, the studies rarely provided any methodology associated with their findings. Some property owners can benefit even without a one-time payment due to tax reductions from a conservation easement donation (Hilborn v. Commissioner, 1985; IRC). The question of valuing rolling easement would become even more significant if a government decided to take a conservation easement by eminent domain because the Fourth Amendment requires “just compensation” to be paid by the government to avoid a taking (Nollan v. California Coastal Commission, 1987).

Rolling easement policies are attractive to local governments because they allow the communities to accept the inevitable fact that the sea cannot be held back indefinitely. Similarly,
rolling easements do not require a sudden shift from armoring to relocation; the policy allows relocation-related choices to be gradually phased-in. GIS policy models that allow policy makers to understand and visualize potential coastal changes due to SLR will significantly help local communities decide how quickly to adopt rolling easement policies.

Methods

Study Area

This study focused on two counties in southwest Florida: Pinellas County and Sarasota County (Figure 3-1). Both counties are located along the Gulf Coast. Pinellas County is densely populated on the mainland and its barrier islands. Sarasota County is much less populated. In fact, Pinellas County has a population density 5 times larger than Sarasota County. In terms of physical features, Sarasota and Pinellas both include barrier islands and beaches that attract a great deal tourism.

Pinellas County totals 726 sq. km of land (U.S. Census Bureau, 2014a) and is the sixth most populated county in Florida. It is home to a little over 920,000 citizens, with an average population density of 8480 people/sq. km (U.S. Census Bureau, 2014a). Pinellas includes 35 beaches and 11 barrier islands; the majority of these islands are densely built (FL Property Appraiser Pinellas County). As seen in Figure 3-2(a), elevation ranges from mean sea level to 34 m (“Facts about Pinellas,” n.d.).

Sarasota County is also located along the Florida Gulf Coast. It lies to the south of Pinellas County, separated by Manatee County. Its total land area is 1478 sq. km (U.S. Census Bureau, 2014b) and is the 14th most populous county in Florida, with a population of 380,000 people and an average population density of 1720 people/sq. km (U.S. Census Bureau, 2014b). Sarasota County includes six major beaches. Two of the beaches, Lido and Siesta, form a major
barrier between the mainland and the Gulf of Mexico. Elevations in the coastal areas of the county, depicted in Figure 3-2(b), range from mean sea level to 17 m ("Sarasota County," 2014).

Data

A high-quality Digital Elevation Model (DEM) is extremely important when modeling small incremental changes in SLR. The DEMs for both Pinellas and Sarasota counties were obtained from the NOAA Coastal Services Center (2014). The Sarasota DEM, which is derived from LiDAR data, is limited to the coastal areas flown using LiDAR to about 600 sq. km. The Coastal Services Center DEM was created by NOAA’s Center for Sea Level Rise and Coastal Flooding Impacts for the purpose of modeling SLR along the Florida coast. The LiDAR’s horizontal accuracy is +/- 3.8 feet at the 95% confidence level, and vertical accuracy is +/- 0.6 feet at the 95% confidence level.

County parcel data are complex and include property boundary polygons as well as valuable information about each property, including current market value, current and future land use, and 2013 tax value. Parcel data were downloaded from the county assessor’s office in Pinellas and Sarasota. In Pinellas County, the parcel data are available in two separate files (FL Property Appraiser Pinellas County). The Pinellas shapefile contains parcel boundaries as polygons with other basic information, whereas detailed parcel value data are available in a comma-separated value (CSV) format. The CSV file contains detailed parcel value information, including current land-use type, future land-use type, building value, land value, and total parcel value. The two files for Pinellas County, the parcel shapefile and CSV attribute file, were combined then imported into a Geodatabase file (GDB) format. In Sarasota County, the data was obtained as a single GDB file (Sarasota).

SLR inundation masks were created to map the area covered by water during each 0.30 m SLR step from 0.30 m to 2.10 m. First, a raster attribute table, with a resolution of 1 m², was
built for each county’s parcel layer. The result is an attribute table with the parcel ID and total number of pixels (1 m² each) for each parcel. If parcel 7640705 has a land area of 8641 m², then the attribute table would show a GID of 7640705 and a count of 8641. Second, SLR inundation masks were generated in ArcGIS using the raster calculator function by using the DEM as an input and selecting the desired sea rise level (e.g., 0.30 m, 0.60 m, etc.). Third, the tabulate area function is used to overlay the SLR inundation mask with the parcel file (and its associated raster attribute table). The results of the tabulate area function, as shown in Table 3-1, determines whether each 1 m² pixel in each parcel is either wet (1) or dry (0) and sums the binary value associated with each parcel. This gives the total area for each parcel inundated by SLR as well as the percentage of inundation.

**Rolling Easement Model**

The relocation policy was modeled by individually modeling relevant parameters using a combination of built-in ArcGIS tools and user-created Python scripts. The criteria were determined through a literature review of coastal policies and personal correspondence from coastal researchers.

A rolling easement policy is not a single policy that each community would either accept or reject. Instead, a rolling easement policy can be tailored to fit the needs of each county. For this study, Pinellas and Sarasota counties were assumed to have adopted a local ordinance or regulation that prohibits homeowners from repairing existing sea walls or building new ones. After the adoption, the county would most likely send a brochure or pamphlet to each property owner on the tax rolls to explain what a rolling easement is, to explain how rolling easements would affect the community that the people live in, and to offer to purchase a conservation easement on a person’s property. This would include a dollar amount that the owner could either accept or decline. The people who accept would receive a one-time cash payment in exchange
for a perpetual easement. Existing hard protection such as sea walls were not considered in this study because DEMs do not account for the structures. In order to account for hard protection devices, in-situ observations are typically required. These studies are not feasible when modeling an entire county.

A one-time rolling easement compensation scheme based on the vulnerability of the property was adopted from Titus (Titus et al., 1991). Under this type of compensation system, landowners would be offered a one-time cash payment in exchange for a perpetual conservation easement. The owners would be allowed free use of their property except for structures that hold back the sea. The amount of the one-time payment is based on the property’s vulnerability to SLR; the sooner the property is inundated, the more compensation the property owner receives.

The conservation easement program is voluntary, and not every property owner would choose to accept the county’s one-time offer. Therefore, determining who would or would not accept the easement is an integral step in estimating the costs of this program. Unfortunately, the literature concerning property owners’ responses to a rolling easement compensation program is limited because few, if any, local governments have tried the scheme.

Figure 3-3 shows a flowchart of the model processes depicting how the built-in ArcGIS functions with custom Python scripts were combined in in ArcGIS ModelBuilder. The creation of the model in ModelBuilder allows the user to quickly add, remove, or modify policy criteria, assumptions, and formulas. Functions from other computer programs or ArcGIS add-ins can also be added to the model. Four variables have been considered in the model to estimate the rolling easements compensation payments: (a) parcel inundation risk factor based on SLR steps, (b) a dampening coefficient (Beta) that control how quick the compensation will decrease with the reduction in parcel inundation risk, (c) a coefficient to control the overall compensation as a
portion of property value, and (d) and the percentage of property owners participating in the rolling easement compensation program. These parameters were based on a review of coastal policy literature, including journal articles and white papers (Grannis, 2011; Landry & Hindsley, 2011; Nettleman & Abd-Elrahman, 2011; Nettleman et al., 2012; Titus, 2011).

The GIS model used in this study employs a series of tabulate, join, and intersect functions on two GIS data sets: a digital elevation model and land-parcels geodatabase in each county. Once the model has estimated which parcels are affected by SLR and parcel inundation risk, it calculates the rolling easement compensation payments for the properties. A Monte Carlo simulation was conducted by running the model 100 times for each scenario (SLR step) to account for the uncertainties in the properties electing to participate in the rolling easement compensation policy.

Rolling Easement compensation payment for each property electing to participate in the program is computed using Equation (3-1):

\[
RE = K \times [PV \times e^{-Beta \times rf}] .
\]

The equation is based on the risk of the property due to SLR, the value of the property (PV), a friction coefficient (Beta), and a constant (K) to adjust for the present monetary value of the property. The risk factor (RF) was calculated for every parcel based on its vulnerability (potential to be inundated). The risk factor for each parcel was found by creating very small SLR Steps in ArcGIS (0.05 m increments). The risk factor was determined using the SLR step, where the parcel is first touched by water (e.g., more than 1% inundation). This means that a property inundated at the 10th step (e.g., 0.5 m SLR) will have lower risk (higher risk factor RF value) than the one inundated at the 5th step (e.g., 0.25 m SLR). The friction coefficient, Beta, was calculated by setting 10% threshold equal to \( e^{-(Beta \times 40)} \) because 40 is the total number of risk
steps in the model. The Beta value was computed to be 0.05756. A constant (K) of 0.25 was
determined through a sensitivity analysis based on two rolling easement research articles
(Caldwell & Segall, 2007; Kriesel & Friedman, 2013). Both Beta and K were chosen according
to valuations of other types of conservation easements, studies measuring the sensitivity of
rolling easements policies, and the time value of money. Typical conservation easements pay
about 10% to 15% of property values but rolling conservation easements are more intrusive
because they significantly limit the ability of the coastal property to protect the property (Byers,
2005; McLaughlin, 2004).

A Monte Carlo model was used to better simulate the choices of property owners. This
model runs the same simulation a specified number of times to obtain the distribution of an
unknown probabilistic value. This type of stochastic model is well-suited to determining the cost
of conservation easement payments because the literature suggests that a percentage of property
owners would accept the easement but provides little guidance in determining who these people
would be.

A Python script was created to perform the Monte Carlo analysis within the ArcGIS
environment. The Monte Carlo routine works in four steps: (a) reads user inputs, including
percentage of parcels to be selected (n) and number of times the simulation should be run (m);
(b) selects all parcels that will ever be inundated above 0.01% (selection population); (c)
randomly selects a given number of parcels (selected samples); and (d) calculates a
compensation payment for each parcel based on the rolling easement compensation formula.
Once the Monte Carlo simulation was run the specified number of times, statistics (e.g., mean,
median, and range) were calculated for each iteration. In this study, the rolling easement
compensation calculations were run a total of 100 times for every SLR step.
Results

Inundation results (Figures 3-4 and 3-5) were generated for 7 equal SLR steps ranging from 0.30 m to 2.10 m in two counties for a total of 14 inundation raster overlays (e.g. Figures 3-4 and 3-5). Figures 3-6 through 3-13 list the results for Pinellas County and Sarasota County for percentage of area inundated, and rolling easement compensation payments. The results for rolling easement compensation payments generally follow SLR inundation levels. In general, Pinellas County is substantially more affected by SLR than Sarasota County because of lower elevations as well as Tampa Bay area creating a larger coastline.

Figures 3-6 and 3-7 depict the effects of SLR steps between 0.30 m and 2.10 m on Pinellas County. Percentages of inundated land area (Figure 3-6) ranged from 2.76% for the 0.30 m scenario to about 18% for the 2.10 m scenario. During the first few scenarios, barrier islands slowly disappeared. Once SLR reached 1.20 m, mainland areas quickly became inundated. The rolling easement compensation payments (Figure 3-7) began with a small $8.93 million average payout during the 0.30 m step. Payments substantially increased from 0.60 m to 2.10 m, ranging from $140 million at 0.60 m to $243 million at 2.10 m.

In Sarasota County, the area losses and associated costs were lower than Pinellas. Land area inundation percentages (Figure 3-8) ranged from 0.24% during the 0.30 m scenario to a little more than 5% during the 2.10 m scenario. Similar to Pinellas, Sarasota’s inundation levels were flat during the first two scenarios (0.24% and 0.78%) but began an upward trend at the third scenario. From 0.90 m to 2.10 m, inundation levels rose about 1% for every 0.30 m. These percentages were still substantially lower than Pinellas. Rolling easement compensation payments (Figure 3-9) began with a substantial $7.44 million payment at 0.30 m. After the first large payment, payments increased to $8.31 million at 0.60 m and $19.55 million at 2.10 m.
Discussion

There is no debate, either in the scientific or political communities, that the Florida coast is vulnerable to climate impacts such as SLR and storm surge (Gornitz, 1991; Gornitz et al., 1994; Titus & Richman, 2001). In fact, over 75% of Florida’s population lives in coastal areas, the fourth highest percentage in the nation.

Rolling easements allow the community to maintain the status quo for years or decades because nothing changes immediately other than a prohibition on armoring. But the policy’s largest shortcoming is the lack of data supporting its adoption, either in the real world by tracking a community that has already adopted it or through scientific literature. Despite the scant research, the authors simulated the rolling easements coastal policy option through a GIS based computer model. Because each component of the policy model is highly dependent on the choices of policy makers (i.e., amount of compensation for a conservation easement) and the responses from coastal citizens (i.e., choice to opt-in to conservation easements), the value of each model criteria can be modified by the users. Furthermore, a Monte Carlo simulation was created because the literature suggested that about 30% of citizens would accept the payments, but it is difficult to predict which 30% would choose to do so.

A conservation easement is not a novel idea. In general, an easement is a non-possessory right for one person to use the land of another. Conservation easements have been widely used in the U.S. and other countries to protect habitats ranging from plants and engendered animals, to environmentally significant sites by placing restrictions on what a property owner can do with his own land. Conservation easements are a conservation tool that enables users to achieve specific conservation objectives on the land while not transferring ownership to another party (as long as the owner’s uses are consistent with the conservation easement’s objectives). The specific restrictions are listed on the document creating the easement. Payment amounts to
property owners vary greatly based on factors such as the extent of restrictions placed on the land, the value of the property before and after the restrictions, federal income tax reductions, and whether the land owner supports the cause of the easement.

In general, the results show that two counties that are close to each other can have substantially different levels of risk and vulnerability. Pinellas may suffer much greater losses and be required to pay more substantial sums to property owners in exchange for a rolling easement because it is much more densely populated and built. Considering how the physical features of the two counties causing, such large differences in land area losses and rolling easement payments should emphasize how natural vulnerability in terms of topography and demography affect how SLR will affect the communities. Pinellas County compensation payments can be offset by existing hard protection for some of the regions. However, such protection will not serve its intended purpose as SLR increases. Studying the effects of hard protection is a complicated topic that is outside the scope of this research but is suggested as an extension of this research.

Although the percentage of inundated properties increased very quickly as SLR increases, rolling easement compensation did not increase at the same rate. In fact, the increase in rolling easement compensation in Pinellas County started to slow at the 1.5 m SLR step. This can be attributed mainly to the exponential curve used to compute rolling easement compensation payments, which reduces the payment rapidly for inland properties. Variations in rolling easement payments might also be due to varying numbers of properties being inundated at different SLR steps or because the value of properties being selected varies from as little as $20,000 to several million dollars. How average rolling easement payments are affected by
current property value and the processes that select the percentage of properties most likely requires further investigation.

Typically, the costs of SLR in terms of land value loss largely mirror SLR inundation percentages. Minor losses are expected in Pinellas and Sarasota with a 0.30 m rise and projected to increase from 0.60 m to 2.10 m. In Pinellas, the effects of SLR were largely felt along the highly valued barrier islands until the 1.20 m scenario. After 1.20 m, substantial portions of the coastal mainland also began to disappear. These areas typically contain the most expensive homes and high numbers of public parks and beach related activities and substantial amounts of infrastructure, such as emergency stations, water treatment facilities, and other important buildings. Tampa Bay also made Pinellas substantially more vulnerable than Sarasota because the bay exacerbates Pinellas County’s coastal vulnerability. Sarasota suffers from similar coastal barrier island inundation as Pinellas during the first few scenarios, albeit more slowly. Both the mainland and coastal barrier islands sit at higher elevations than Pinellas, which reduces SLR inundation. But after the 0.90 m SLR step, Sarasota begins suffering from the same issues of mainland inundation. The risk to emergency services and water treatment plants can be reduced, but Sarasota will likely suffer similar beach losses, especially during abnormally high tides.

The model’s usefulness is enhanced by two important qualities: the simplicity of the model and the ability of others to easily modify the inputs and variables. First, the model only requires data sets that are publicly available and easily obtained from local government sources. Specifically, the model only required two data sets: LiDAR elevation data and land parcel data. Census data, storm-surge data, or other data sets can be incorporated for model improvement.

Indeed, scaling the model up to the state or even national level only requires the parcel data set to be preprocessed. Second, given that these questions about rolling easements have yet to be
answered, this model was designed to be modular. Users can decide how inundation affects property values, the rolling easement compensation method, and the percentage of people willing to accept the conservation easement.

Whereas the results of the total land inundation percentage were linear, the rolling easement compensation payments presented more interesting findings. The increasing cost of RE payments as the SLR steps progressed was expected because more properties were added to the population as SLR steps increased. But the large payments in Sarasota during the first scenario compared too much smaller payments in Pinellas was not expected. This was most likely due to a large number of parcels at risk in Sarasota at 0.30 m as compared to Pinellas. As mentioned previously, the elevation and topography of the counties greatly affected their vulnerability in terms of real property inundation and rolling easement payments. Pinellas experienced much greater losses due to its densely built environment and low elevations.

State, county, and other levels of government would benefit from adopting the model created in this study because it would allow them to easily understand the costs and benefits of adopting a voluntary rolling easement program and how different SLR projections could affect their own communities in terms of land loss and property-value loss. The community could either rely on all the SLR steps or first choose a SLR projection (i.e., 1 m) and then analyze the results. The community could also modify the model assumptions, such as the real property monetary value, before performing the analysis if they believe other assumptions are more realistic, based on local conditions.

Determining the correct rolling easements payout for each property was difficult because little, if any, literature existed to guide our analysis. Initially, we used a single formula based on the value of the property and the SLR scenario number to determine payouts. After considering
many alternatives, an exponential curve was adopted. The curve is primarily affected by Beta (a friction coefficient) and K (a monetary value constant). Before adopting Beta and K values, a battery of hypotheticals were tested to determine the appropriate values. In the end, a Beta of 0.0576 and K of 25% were chosen because of the relatively low conservation easement payments in other fields as well as the fact that people would receive money today or an event that may happen in 50 or 100 years, if at all. As counties gain a better understanding of resident’s willingness to accept payments, the K variable may be altered. It is suggested that a sensitivity analysis be performed for Beta and K values.

There are still many questions about rolling easements that need to be answered. A limitation of this study, and the field as a whole, is the lack of information concerning how property owners will respond to SLR and other climate impacts. These questions are not only important when valuing rolling easement payments, but also understanding how to value the property itself. Once the first “tier” of coastal properties is inundated, will people realize that the second tier of properties is worth much less than they initially suspected? Or will the value of the second-tier homes rise once they become waterfront properties? Similarly, at what point of inundation will a property lose all its value? The literature suggests that once 10% of a small residential property is inundated, it becomes worthless. But will a million dollar coastal lot be worth zero dollars if 90% of it is still dry? A total-loss threshold based on land use addressed some of these questions, but just when a property loses all its usefulness is a question that will greatly impact this model. No matter how much we know about people’s choices, there will always be some degree of uncertainty. A Monte Carlo simulation was created to randomly select a given percentage of parcels (30% in this case) and calculate the easement compensation.
payments for that scenario to partially remedy some of these uncertainties. More Monte Carlo analysis may still be needed on other parameters.

Many policy makers fear that rolling easements may be too expensive or politically sensitive to be seriously considered in many communities. As an example, a Houston suburb adopted a relocation approach after a 500-home community sank 10 feet due to oil-related subsidence. After incurring substantial losses due to even a minor storm, the local government decided to buy out the homeowners. Despite the small number of homes and their substantial risk, the citizens rejected a referendum funding a buyout multiple times. In contrast, the New York Rising Community Reconstruction Program was created to buy out “those who live in areas that regularly put homes, residents and emergency responders at high risk due to repeated flooding” in Staten Island and Long Island after hurricane Sandy.

Despite upfront costs, rolling easements might have large benefits. Some stakeholders might ask why the county would pay property owners today in exchange for alleviating problems that will not arise for decades. If a county chooses not to address its problems now, several things could happen as SLR continues to accelerate: fighting with property owners over sea wall permits, having contentious debates in public county planning meetings for years, and fighting lawsuits concerning the taking of properties. On the contrary, many of the mechanisms for property owners to fight SLR described above would not be available to them if they already agreed to let the sea “roll” landward in the form of a perpetual conservation easement.

The modular design of this model greatly expands the accessibility for other researchers to make future improvements. Using the existing model components, future improvements include comparing different methods to calculate the property value losses due to SLR
inundation, using Monte Carlo simulations on multiple variables instead of only the easement compensation calculations, and expanding the model from the county level to the entire state.

The current model serves as a framework for analyzing the rolling easements scenario by simulating important criteria. The ArcGIS ModelBuilder was chosen because routines, scripts, and functions are easily added, deleted, or modified. The ability to run scripts of Python code also greatly expands the flexibility of the model. The possible changes to this model are almost endless. Additions to the model include using hedonic price models to estimate the long-term trends in real property prices (given Florida’s boom and bust economic cycles), which would allow for a better understanding of (a) the infrastructure support costs associated with relocating emergency services, utilities, and other services offered by local governments; (b) the population demographics affected by SLR; and (c) the effect of SLR on major weather events, such as storm surge. In addition to these new fields that can be integrated into the existing model framework, coastal policies may be more comprehensively analyzed by integrating other policy criteria to produce more robust results.

**Conclusion**

This study described a method to model the rolling easements coastal policy option to address SLR. The rolling easements policy was modeled using tax assessed property value, monetary value reduction constant, and exponential function employing property inundation risk and a dampening coefficient to calculate the rolling easement compensation payment for property owners. The model was tested on about 500,000 parcels in Pinellas County and Sarasota County, FL using seven equal SLR scenarios ranging from 0.30 m to 2.10 m. The results show that rolling easements is a viable option. Rolling easement payments ranged from few millions to almost $250 million in Pinellas while rolling easement payments in Sarasota ranged from $5 million to about $20 million. The parameters chosen to compute the
compensation are based on literature review and expert opinion. However, more research is needed to achieve better estimates of these parameters and understanding of the practical aspects of a viable rolling easement policy. In this context, more research is needed in two fields: social behavior studies and the estimation of rolling easement payments. In the technical fields, data regarding counties or other local governments adopting rolling easement payments will allow researchers to better understand how rolling easement payments are computed. In the field of social behavior studies, a better understanding how people value conservation easements that restrict their ability to build armoring will help researchers adjust model parameters and to maximize the benefits to property owners while minimizing the costs to government.
Table 3-1. Attribute table showing the percentage of inundation of each parcel

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<th>WET</th>
<th>% Ind</th>
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Figure 3-1. Locations of Pinellas County and Sarasota County
Figure 3-2. Elevation maps of (a) Pinellas and (b) Sarasota. Elevations are in meters.

Figure 3-3. Overview of GIS model workflow
Figure 3-4. Three SLR inundation steps in Pinellas

Figure 3-5. Three SLR inundation steps in Sarasota
Figure 3-6. SLR-related property inundation in Pinellas County

Figure 3-7. Mean rolling easement compensation payments in Pinellas County
Figure 3-8. SLR-related property inundation in Sarasota County

Figure 3-9. Mean rolling easement compensation payments in Sarasota County
As sea level rises and shorelines slowly move inland, Florida’s coasts are steadily losing land area. Governments at the federal, state, and local levels are beginning to prepare for SLR. But before they can create sustainable coastal policies, they must understand how each policy could affect their community. Rolling easements, a coastal policy that allows the water to “roll” landward as seas rise, is considered one of the best policies in low- and medium-density areas (McLaughlin, 2010, p. 369; Titus et al., 1991). Despite the large body of literature on this approach, few articles have estimated the cost of the policy in terms of land area loss and compensation payments to property owners.

Scientists estimate an SLR of 0.50 m to 2 m by 2100 (Pfeffer et al., 2008). In Florida, four South Florida counties estimated SLR between 0.23 m and 0.61 m by 2060 (Broward, 2010; Liechty, 2013). These projections are expected to translate into substantial changes in Florida. Another author projected that 4,500 of Florida’s 171,000 square kilometers are within 1.4 m of sea level (Harrington, 2008). Even with a rise of less than 1 m, $156 billion worth of property, 840,000 people, and 300,000 homes could be lost (Central, 2013).

Many coastal policies are available to local governments to counteract the effects of SLR. These policies are typically grouped by the community’s goal: protection, accommodation, or relocation. Protection policies include hard armoring techniques, such as seawalls, jetties, or rip-rap, or soft armoring methods, such as beach nourishment and dune stabilization. Accommodation policies include revised building codes, zoning ordinances, flood plain

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1 Study written by By C.A. Nettleman III, A. Abd-Elrahman, T. Ruppert, D. Adams, and G. Barnes.
regulations, and comprehensive plans for future growth. Relocation techniques include moving development to less vulnerable areas by removing armoring structures and allowing the sea to naturally move landward.

A gap in the literature exists because policymakers cannot choose between the three policy options unless they understand how each policy could affect their own community. When measuring this effect, losses in coastal real estate values and the upfront cost to purchase rolling easements are two important criteria. Unfortunately, little research has been conducted to determine these criteria. Once policy makers are able to understand how these thresholds affect their own communities, they will be much more able to choose good coastal policies. Before policy makers can make informed decisions, they will likely need to compare the same variables across multiple policies. Real property valuation models are especially important to Florida because the state is subject to boom and bust economic cycles that cause its real estate values to fluctuate—sometimes quite rapidly.

Rolling easements is a collection of policy choices that each community will have to make on its own. As an example, conservation easements are seen by many authors as a requirement for a successful rolling easement policy set because they provide an incentive for property owners to adopt them (Titus, 2011; Caldwell, 2007). But other authors suggest a rolling conservation easement may be created by law without property owners giving up the right to their property (McLaughlin, 2010).

This study explores how uncertainties in three rolling easement parameters affect the costs of implementing the policy in two Florida Gulf Coast counties: Pinellas County and Sarasota County. The first parameter, buy-in percentage, represents the number of property owners willing to accept a conservation easement payment from the government in exchange for
giving up their right to armor their property. The second parameter, a friction coefficient, which determines how quickly a negative exponential curve representing rolling easement payment decreases with a reduction in property risk of SLR inundation. The third parameter controls the overall rolling easement payments as a fraction of property value. Understanding how each of these variables alters the rolling easement compensation payments is important due to the lack of standard procedure or method to compute rolling easement payments. In a previous study, we proposed a method to calculate rolling easement payments based on a negative exponential curve but the results highlighted the need to better understand the interactions between buy-in percentage, friction coefficient, and overall property value constant. The need for a standard easement calculation method is exacerbated by the fact that counties are hesitant to adopt a policy such as rolling easements when a central component, compensation payments, are so uncertain.

**Background**

**Sea Level Rise**

SLR is expected to have a profound impact on our nation’s coasts (Ackerman & Stanton, 2007; Frazier, Wood, Yarnal, & Bauer, 2010; Robertson, Zhang, & Whitman, 2007). If the current projections of SLR between 0.50 and 2 m by 2100 become a reality, we can expect a loss of over 7000 sq. mi. of coastline and 5.2 million acres of estuarine wetlands nationwide (Titus, 1998). In Florida, the lowest Intergovernmental Panel on Climate Change projection will cause a loss of erosion of up to 200 ft on many Florida beaches (EPA, 2002).

Real property values are also expected to sustain major losses due to SLR (Hennecke, Greve, Cowell, & Thom, 2004; Nettleman et al., 2012). For instance, Stanton and Ackerman (2007) found that the percentage of Florida’s residential property at risk is proportional to SLR. Similarly, Ackerman and Stanton (2007) estimated a loss of $360 billion dollars in real property
by 2100 along the Atlantic and Gulf coasts. Real property losses in highly built areas are especially devastating. Ayyub et al. (2012) estimated a loss of over one thousand structures in Washington DC alone by 2100.

In Florida, the effects of SLR on real property are even more substantial. Many barrier islands along Florida’s coasts are expected to disappear with a 1 m rise in SLR (Nettleman, 2014; Zhang et al., 2011). Zhang (2011) estimated that almost 20,000 properties would be inundated in Miami-Dade County alone, while 55,000 properties would be lost in the greater South Florida area. In a follow-up study in the Florida Keys, Zhang et al. (2011) found that, with a 1.5 m rise, only a “narrow ridge” of land would exist; additionally, 58% of the population and 66% of the real property would disappear under the water. Other studies have produced similar findings. In research on Sarasota, FL, Frazier et al. (2010a, 2010b) found that a 1.2 m SLR rise coupled with a category two hurricane would affect over 100,000 residents and that a 1.2 m rise coupled with a category three hurricane would affect almost 200,000 residents.

Coastal Policies

Evaluating each coastal policy in terms of land area and dollar value is an integral part of coastal planning because policies are chosen through a cost–benefit analysis. Relocation policies such as rolling easements allow the sea to naturally “roll in” and to inundate once-dry coastal areas. Local ordinances and regulations often prohibit hard armoring like sea walls but government by totally prohibiting new structures and not allowing property owners to fix their existing sea walls. Although some local governments, such as Sarasota, FL, have adopted this policy, the city might be required to overcome significant legal challenges. The government could also simply purchase the most vulnerable lands for a fee from property owners; the properties could be purchased before or after a major storm damages them. Another option is that the government could purchase a conservation easement from property owners today (year zero)
in exchange for a covenant that prohibits the owners from building any structure to hold back the ocean; this is the most viable relocation option because it is cost efficient (payments substantially lower than the parcel’s fair market value) while eliminating the threat of litigation due to a taking.

Many scholars consider rolling easements to be the best option to address SLR because they avoid the constitutional issue of a taking for several decades and also provide a type of forewarning to property owners, in contrast to new laws that take effect immediately and impede the use of private property (a “takings” occurs when the government takes land from a private property owner without compensation). Several governments have implemented relocation policies over the past few decades. The first examples were in the UK, where an 8000 m² area at Northey Island, Essex, in 1991, was a success (Dagley and Nature 1995), followed by Tollesbury and Orplands in 1995 (Lowe, Gregory et al. 2001). Similar policies have been adopted by a few local governments in the US. In the northeast, New Jersey and New York began purchasing vulnerable property from “those who live in areas that regularly put homes, residents and emergency responders at high risk due to repeated flooding” after hurricane Sandy in 2012 (NY Rising, Governor’s Office of Storm Recovery, n.d.). Similarly, a Houston suburb attempted to buy out a small community of homeowners who had been repeatedly flooded for several decades but a referendum on the ordinance failed (Houston, 2011).

Each coastal policy relies on accurately valuing coastal real estate as it is inundated by SLR. The primary advantage of armoring is that it protects valuable real property. On the contrary, the challenge to armoring prohibitions comes from Amendments 4 and 5 of the Constitution, which deprive real property owners of the economic value of their coastal parcels. Several authors have found that the large costs associated with rolling easements may be offset
by the gain in property values associated with “new” waterfront properties (Landry, 2003). However, one can argue that this gain is not guaranteed once SLR becomes more evidenced, leading a spiral drop of waterfront property values.

Accurately estimating rolling easement compensation payments to property owners is integral in determining if rolling easements is a potentially viable option for a community. Estimating these costs is difficult because conservation easements are voluntary with varying payments; each property owner decides whether to accept the county’s offer of a one-time payment in exchange for a perpetual restriction on their property. This study addressed some of these concerns by assigning a risk factor to each parcel in the county and creating a Monte Carlo simulation to run the same easement compensation formula on a random selection of parcels to gather statistics about those payments, which will be discussed in more detail in the methodology section of this paper. The study provides a framework for modeling and studying the interaction among different parameters affecting rolling compensation cost incurred by local government and highlighting the interaction between the social and monetary aspects of the rolling easement policy.

**Human Responses to Real Property Valuations Caused by Sea Level Rise**

Real property values are expected to be substantially affected by SLR over the next century (Landry and Hindsley, 2011; Zhang et al., 2011). How people value coastal property as seas rise is uncertain (Bin et al., 2011; Landry & Hindsley, 2011). The primary cause of the uncertainty in coastal property values is the lack of literature analyzing how people would respond to disappearing property. In fact, only a few articles have examined how coastal owners would react to different coastal policies (Alexander et al., 2012; Frazier et al., 2010a; Niven and Bardsley, 2013). Therefore, the authors looked to the field of behavioral economics and various public opinion polls describing how people perceived climate change to estimate the percentage
of people who would accept compensation from the county in exchange for a “rolling” conservation easement on their property.

The analysis of real property values affected by coastal policy options utilizes the idea of “perfect foresight” to represent how coastal real estate could respond to SLR threats (Yohe and Neumann, 1997). Perfect foresight assumes that coastal property owners will fully consider all of the potential risks that SLR presents and respond to them in the most efficient manner possible, thus “minimizing potential damages to coastal property” (Yohe and Neumann, 1997). This idea is similar to the rational choice theory, which postulates that “man is a reasoning actor who weighs means and ends, costs and benefits, and makes a rational choice” (Scott, 2000).

Unfortunately, human psychology causes people to make less than efficient choices on a daily basis because of misconceptions, emotions, and natural human behavior (Friedman, 1998; Levine and Perlovsky, 2008). It is logical to assume that people would be reluctant to accept conservation easements only because the scientific community agrees that SLR is occurring and coastal areas are already being affected by it. But if climate change deniers believe there is no such thing as SLR, then they would essentially be receiving a government payment at no risk to their property. Coastal researchers have rarely studied how people would react to rolling easement compensation offers so many of the hypotheticals raised above have not yet been closely studied.

A recent study analyzed how local homeowners would react to managed retreat (i.e., rolling easements) due to rising waters (Alexander et al., 2012). The authors surveyed over 500 coastal property owners and categorized each person into four groups—scientists, theologians, economists, and politicians—based on the respondent’s attitude to managed retreat as a solution to SLR (Alexander et al., 2012). The survey results indicated that one person examined managed
retreat from multiple viewpoints, but the authors indicated that the survey results were flawed because the majority of survey respondents were “climate rejectionist” (Alexander et al., 2012).

The literature above provides little help to understand how many property owners might accept a rolling conservation easement so we also looked to other sources such as a series of Gallup polls conducted between 2012 and 2014 on various subjects such as climate change, global warming, and SLR. The first poll, conducted in March 2014, categorized people into three groups: concerned believers (39%), the mixed middle (36%), and cool skeptics (25%) (EPA, 2002). The major differences between the groups were politics (Democrats were more likely to be believers) and education level (nearly half of the mixed middle did not have more than a high school diploma [EPA, 2002]). Another poll, conducted in 2014 shortly after the Intergovernmental Panel on Climate Change released its latest SLR projections, asked Americans to rank eight environmental problems ranging from pollution in drinking water to climate change and global warming (Hazell). Both climate change and global warming ranked last. This was not surprising to the pollsters because “Americans’ generally low level of concern about global warming compared with other environmental issues is not new; global warming has generally ranked last among Americans’ environmental worries each time Gallup has measured them” (Hazell). In this study, we exterminated a broad range of buy-in rates (15%, 30%, and 45%) to account for the indirect connections between climate changes, SLR perceptions, and rolling easement compensation. Overall, the literature shows that Americans appreciate that SLR is occurring but it is not a current threat to them which adds uncertainty to the voluntarily buy-in rates.

GIS Evaluation of SLR and Coastal Policies

The majority of GIS models estimating the effects of SLR on coastal regions only identify and tally the number of structures lost. Some GIS models have estimated real property
value losses, but only using basic GIS techniques, such as centroid analysis without incorporating their inundation risk. A few studies have used hedonic price models to estimate real property losses, but the results cannot be integrated into a GIS for further analysis, such as the comparisons with population and other data.

To simplify calculations of real property losses, some authors have foregone trying to estimate dollar value. Instead, they have used the total structure method to tally the number of residential structures lost due to SLR. Although this method allows losses in large areas to be estimated quickly, the results are not reliable enough to use in choosing coastal policies because the value losses associated with the structure losses are indeterminable.

In a previous study, a modular GIS computer model was created to estimate the costs and benefits of three coastal policies: armoring, armoring prohibition, and rolling easements (Nettleman and Abd-Elraman, 2012). Each policy was simulated by choosing the most significant criteria for each policy, then combining the simulated criteria in ArcGIS Model Builder using a series of Python scripts. The results indicated that rolling easements were a viable policy option for Pinellas County but would be far less effective in Key West because the island has limited relocation space.

The rolling easement scenario was later refined by the authors in a subsequent study (Nettleman et al., 2015) (Chapetr 3) to use negative exponential function to compute the rolling easement compensation as will be discussed below in the Methods Section. Model parameter selection was based on a review of coastal policy literature, including journal articles and white papers (Grannis, 2011; Landry & Hindsley, 2011; Titus, 2011).
Methods

Study Area

This study involved two counties along the Florida Gulf Coast: Pinellas County and Sarasota County. Both counties are relatively flat, with an elevation that peaks at around 30 m but is much lower in many areas. Pinellas County has five times as many residents per square mile as Sarasota County. Both counties have several large barrier islands as well as several major beaches that attract significant number of tourists each year. Figure 4-1 shows the general layout of the Pinellas and Sarasota counties, the two study sites used in this research.

Pinellas County, the sixth most populated county in Florida is home to a little over 920,000 citizens with an average population density of 8480 people/sq. km. (“US Census Quick Facts for Pinellas, FL,” 2014). The county has over a dozen barrier islands are densely built and mainly zoned for residential or tourism purposes (Pinellas County, 2014a). As seen in Figure 4-2(a), elevation ranges from mean sea level to 34 m (Pinellas County, 2014).

Sarasota County, lying south of Pinellas, is also located along the Florida Gulf Coast. Its total land area is 1478 sq. km (“US Census Quick Facts for Sarasota, FL,” 2014) and it is the 14th most populous county in Florida with a population of 380,000 people and an average population density of 1720 people per sq. km (“US Census Quick Facts for Sarasota, FL,” 2014). Sarasota County includes six major beaches, two of which, Lido and Siesta, form a major barrier between the mainland and the Gulf of Mexico. Elevations in the county, depicted in Figure 4-2(b), range from mean sea level to 30 m (“Sarasota County high point,” 2014).

Data

Data sets for this model included a high-resolution digital elevation model (DEM) of both counties and parcel data from the county property appraiser offices. SLR was modeled by creating inundation masks for seven SLR scenarios in each county from the DEM, joining the
SLR DEM to the county parcel databases, and then tabulating the number of wet and dry pixels for each parcel using the tabulate area function.

The DEMs for both Pinellas County and Sarasota County were obtained from NOAA’s Center for Sea Level Rise and Coastal Flooding Impacts Center to model SLR along the Florida coast. The LiDAR’s horizontal accuracy is +/- 3.8 ft at the 95% confidence level, and vertical accuracy is +/- 0.6 ft at the 95% confidence level (CSC).

County parcel data was downloaded from the tax assessor’s office in either county. Both datasets contained boundary shapefiles for each parcel as well as associated information including current market value, current and future land use, and 2013 tax value. These two files were used in the current model using ArcGIS software. The two files for Pinellas County, the parcel shapefile and CSV attribute file, were combined then imported into a Geodatabase file (GDB) format. In Sarasota County, the data was obtained as a single GDB file.

**Rolling Easement Compensation Model**

A rolling easement compensation model calculating one-time payments to property owners at year zero in exchange for a perpetual conservation easement was adopted from a previous study (Nettleman, 2015). The model computes compensation payments based on a negative exponential curve that is a function of parcel SLR risk and property value. Three parameters are employed in this model: dampening (friction) coefficient, overall compensation coefficient, and voluntarily buy-in percentage of parcel owners. Equation 5-1 is used to compute rolling easement compensation payments (RE):

\[ RE = K \times [PV \times e^{-Beta \times RF}] \]  

The equation utilizes the risk of the property due to SLR (RF), the value of the property (PV), a friction coefficient (Beta), and a constant to adjust for the present monetary value and to
control the overall value level of rolling easement compensation curve (K). The PV used in this equation is the property tax value acquired from the county appraisal records.

The risk factor (RF) was calculated for every parcel based on its vulnerability, which was determined by its potential to be inundated. The risk factor for each parcel was found by assuming that parcels inundated at higher SLR steps have a lower inundation risk, represented by the SLR increment at which 1% of each property is inundated. To identify the SLR increment, small increments (0.05 m) from 0 m to 2.1 m were used. When a first SLR step inundated a parcel by 1%, that increment number was recorded as the property risk factor (e.g., parcel 4842 is first inundated at the 0.15 m, which is the second SLR increment, so a risk factor value of 2 is recorded; numbering in Python begins with zero). It should be mentioned here that a higher risk factor value (higher SLR step for property inundation) indicates lower risk of inundation.

The friction coefficient, Beta, was calculated by setting the $e^{-(beta \times \text{max_increments})}$ term, where max_increment is the total number of risk steps in the model (40 increments are used in this study) equal to 10%, 20%, and 30%. These values were chosen so that the RE compensation of a property with lowest inundation risk (max increment equals to 40) is 10%, 20%, and 30%, respectively of the properties at the highest inundation risk (RF = 0). The Beta values were computed to be 0.085, 0.075, and 0.058, respectively. Constants (K) of 0.25, 0.50, 0.75, and 1.00 were also tested.

This model explores the uncertainties associated with three parameters in the rolling easements policy simulation: the K and Beta values used to compute the rolling easement compensation (Equation 4-1) and the percentage of property owners who accept a rolling easement from the local government. The model was created in three steps: preprocessing the DEM and parcel data, computing the risk factor of each parcel, and randomly selecting a
percentage of owners who elect to purchase a rolling easement. The model framework allows the user to modify all of the variables that underlie the rolling easement compensation model.

The first phase of the GIS model entailed preprocessing the DEM and parcel data. Each parcel was broken into 1 m² pixels. Next, SLR inundation masks were created for seven SLR scenarios in each county (a raster calculator was used to read an Excel file with a list of SLR inundation values; e.g., 0.30 m, 0.60 m, 0.90 m). At each iteration, the DEM was classified into two categories: wet (1) and dry (0). Then, the county parcel data set was joined and overlaid with the DEM from each SLR. The number of “wet” pixels was divided by the total number of pixels to calculate the percentage of total inundation for each property. Other preprocessing steps included deleting any parcels with dollar values of zero. The second phase of the model computed the risk factor using small SLR increments as indicated earlier. The third phase of the model used a Monte Carlo simulation to randomly select a given percentage of real property owners and then computed the rolling easement compensation payment. The Monte Carlo method runs the same simulation 100 times to obtain a distribution of an unknown probabilistic entity (in this case, payments for rolling easements). We used a Monte Carlo approach because the literature suggested that certain percentage of property owners would elect to purchase rolling easements from the county, but there was little evidence explaining the demographics or other factors involved in determining who would elect to participate on the rolling easement compensation program. In this context, we applied the Monte Carlo analysis 100 times for 3 different buy-in percentages (15%, 30%, and 45%).

Results

A sensitivity analysis was performed on the three parameters used in equation 4-1: K (monetary constant), Beta (friction coefficient) and easement buy-in (percentage of real property owners who accept a rolling easement from the local government). Figures 4-3 and 4-4 show the
model results for Pinellas and Sarasota counties with different K, Beta, and buy-in variations. Each chart in Figure 4-3 and 4-4 represent how the change in buy-in percentage affects the rolling easement payment at different SLR increments, with certain K and Beta values. Figures 4-5 and 4-6 show how Beta values change on the rolling easement payment in Pinellas and Sarasota counties with fixed K and buy-in percentage.

Overall, Figures 4-3 and 4-4 show that when the Beta and K values were fixed, changing the buy-in percentages significantly affected the rolling easement payments by tens or hundreds of millions of dollars in some cases (in Pinellas), while Figures 5-5 and 5-6 show that changing the Beta values tested in this study only led to compensation payment differences of tens of millions of dollars in either county when the K and buy-in percentage were held constant. As expected, the RE payments were directly proportional to the four hypothetical K values used in the study. These trends were seen throughout all SLR scenarios in both counties.

Figure 4-3(d) shows with a K of 1.00, 30% buy-in, and Beta of 0.058, average compensation payments ranged from $39.55 million at 0.30 m to $1.01 billion at 2.10 m. Comparing the compensation for different Beta values in the same scenario, at 0.30 m, average payments ranged from $39.55 million with Beta of 0.085, to $41.83 with a Beta of 0.075, and finally $43.18 million with a Beta of 0.058. At 1.50 m, average payments ranged from $867.26 million with Beta of 0.0850, to $917.13 with a Beta of 0.075 and finally $949.71 million with a Beta of 0.058. Changing the Beta values from 0.058 to 0.085, while fixing K, affected rolling easement payments by an average of 12% but the ranges between payment amounts increased as SLR steps increased and average payments became larger.

In Sarasota, with a K of 1.00 and 30% buy-in, and Beta of 0.058, average compensation payments ranged from $31.44 million at 0.30 m to $84.43 million at 2.10 m as shown in Figure
Figure 4-6 compares the compensation with different Beta values in the same scenario (K = 1, buy-in = 30%), at 0.30 m and shows an average payments ranging from $31.55 million with Beta of 0.085, to $33.45 with a Beta of 0.075, and finally $34.99 million with a Beta of 0.058. The Beta values affected the payments a few million dollars between Beta steps. At 1.50 m, average payments ranged from $54.71 million with Beta of 0.085, to $59.80 with a Beta of 0.075, and finally $62.20 million with a Beta of 0.058. Here, the Beta values has larger effect at higher SLR compared to lower SLR steps, which is a trend evidenced in all the Pinellas and Sarasota datasets when K and buy-in percentages were held. This suggests using lower Beta value that increases the compensation for properties with lower risk value will not add significant compensation burden, which will eventually lead to greater management benefits (more properties with rolling easement). However, such practice is expected to encourage more property owners to participate in the program leading to potential higher costs.

Generally, the changes in the tested buy-in percentages (Figure 4-3) affected compensation payments much more than tested Beta values. Comparing the rolling easement payments for different buy-in percentages and fixed K and Beta (K = 1, Beta = 0.085) at 0.30 m in Pinellas County, average payments ranged from $24.95 million with 15% buy-in, to $39.55 million with a 30% buy-in, and finally $58.55 million with 45% buy-in. At 1.50 m, with the same K and Beta values, average payments ranged from $733.88 million with 15% buy-in, to $867.26 with a 30% buy-in, and finally $1.03 billion with 45% buy-in.

The buy-in percentage in Sarasota (Figure 5-4) also significantly affected the compensation payments. Holding a K of 1.00 and Beta of 0.085, at 0.30 m, average payments ranged from $18.57 million with 15% buy-in, to $31.43 with a 30% buy-in, and finally $44.24 million with 45% buy-in. The buy-in values affected the payments by about 30% between each
two successive buy-in values. At 1.50 m, average payments ranged from $37.13 million with 15% buy-in, to $54.72 with a 30% buy-in, and almost doubled with a $72.80 million at 45% buy-in percentage.

In Pinellas County, successive changes between SLR steps were generally linear after the large increase from 0.30 m to 0.60 m. Unlike Pinellas, this trend is not observed in Sarasota for all SLR steps (including the 0.30 m SLR) with smaller K values. This is probably due to the differences in the counties topography, where fewer properties are inundated in Pinellas at 0.3 m, while the coastal terrain in Sarasota adds a significantly large number of properties with each SLR step. The effect of this increase is magnified when the buy-in rate changes leading to slightly larger differences between the rolling easement compensation for different buy-in ratios for larger SLR.

**Discussion**

Coastal damage due to SLR in terms of real property, government infrastructure, and ecological habitat will only increase over the next century (Alexander et al., 2012; Ayyub, Braileanu, & Qureshi, 2012; Yohe & Neumann, 1997). Implementing good coastal policies is the only way for communities to protect themselves against climate impacts such as SLR and storm surge. Despite this fact, few local policymakers have begun to act because they are unsure about how coastal policies will affect their own communities. This is especially true for newer policies such as rolling easements because there are few case studies explaining policies’ costs and benefits.

In this study, we focused exclusively testing the sensitivity of rolling easement variables using a negative exponential curve function devised in the previous study. One question that is still highly debated among authors is how to calculate rolling easement compensation payments. Governments have several incentives to pay property owners for purchasing conservation
easements from property owners. The largest benefit to counties purchasing these easements is the ability for the counties to “rest peacefully” without the threat of armoring permit battles or Constitutional Takings. Conceivably, property owners would become more vocal when they realized how SLR was increasingly threatening their properties and seek to relax armoring permitting processes, protect the land that was once above the public/private boundary but could not considered public property, and need to rebuild after more powerful storms damage their homes. But at the same time, it is still unclear how many property owners would choose to purchase a conservation easement (buy-in percentage) or how much owners would be willing to accept as compensation.

In this study, a sensitivity analysis was performed on three variables (Beta, K, and property owner buy-in rate) of the rolling easement compensation payment formula devised in a previous study. We performed the sensitivity analysis because compensation payments are a central component of rolling easements but no standard method has been devised by other authors. Furthermore, accurate calculation of compensation payments is a significant factor in choosing whether to adopt rolling easements because governments may not be able to afford the program. In fact, some authors have suggested that compensation payments demanded by property owners may cost more than the fair market value of property (Alexander et al., 2012; Niven & Bardsley, 2013).

The results showed that all three variables affected the rolling easement compensation with K simply reducing the payment linearly proportional to its value while the Beta and buy-in variables had varying effects with different SLR. The tested buy-in rates had a greater effect than tested Beta values, which makes sense due to the expected linear increase in rolling easement compensation with the increase in the number of participants. Buy-in percentages are tied to real-
world acceptance of a rolling easement; the more people who voluntarily purchase an easement, the more money a government entity would need to spend in order to purchase the easements. The Beta coefficient, however, is a friction coefficient that alters how quick the rolling easement will decrease with the involving lower inundation risk properties.

Analyzing both buy-in percentages and Beta values presented interesting results. Buy-in percentages were estimated at 15%, 30%, and 45% because the literature does not suggest a typical acceptance rate. Instead, the literature suggests that the range of acceptable rates may vary greatly from community to community. We expected the compensation amounts to double or triple as the buy-in values increased from 15%, to 30%, to 45%. Instead, they increased substantially, but not as much as we expected. This is most likely due to the large fluctuations in property values. Beta, the friction coefficient, caused the rolling easement payment curve to more rapidly decrease as Beta was increased. The practical effect of increasing Beta was that properties closer to the water (more at risk) were paid more relative to inland properties. Increasing Beta increases the buy-in payments of the most vulnerable properties but more inland owners, who are also at risk, may be more inclined to wait and see if the county increases their offer if they do not feel like they are being adequately compensated. As more local governments adopt rolling easements, researchers will have more data to better understand buy-in rates. At that point, the new data can be processed through this (or similar) model again with very little effort.

The general trend of increased rolling easement compensation with increased SLR may suggest planning for smaller SLR levels. However, using small SLR will reduce the number of participating properties undermining the expected increase in SLR and the uncertainties inherent in SLR estimation models. There are no county budgets to better understand how much a local
government could spend on rolling easement payments but the SLR compensation values appear to be reasonable in the case of 30% participation rate based on comparing the RE payments amounts against parcel valuations. Also, a 1.2 or 1.5 m SLR plan shows the starting point of a sharper increase in SLR in most scenarios in Sarasota making it a potential planning target. Planning for a 30% buy in and using a relatively small Beta value (e.g. 0.058) to allow for larger compensation for inland properties without increasing the rolling easement payments is also suggested. This leaves the k as the main variable that can be adjusted to suit the balance between the affordability level of the local government and the reasonable incentive for property owners to participate.

The most accurate method to compute rolling easement conservation payments is still not settled by coastal policy planners or the research community. Some authors suggest payments based exclusively on real property values (Titus, 2011) while others suggest other variables such as land use and risk to SLR (Niven & Bardsley, 2013). Finally, in this study, we propose using a logarithmic curve using SLR risk, property value, and friction coefficients. These questions are unlikely to be answered until communities begin adopting the policies and testing how many owners will voluntarily purchase a rolling easement. Future research includes surveying coastal property owners to better understand their decision making process, testing other K, Beta, and buy-in percentages, and integrating real-world rolling easement policy results into our existing rolling easement compensation model. This is specifically true when examining the rolling easement compensation values obtained in this study, where the compensation values are expected to change not only based on property owner perception but also based on the physical and demographic properties, coastal property distribution and value, land use, etc. For example, we believe that the differences in property value and distribution in addition to the topography
played a role in the changes in the compensation values computed using different model parameters.

Estimating rolling easement compensation payments was further hindered by the lack of counties adopting rolling easement policies with an easement payment component. Similar coastal programs that may benefit rolling easement implementation include buy-outs to high-risk real property after major events like hurricanes. One example is NY Rising, a joint program between the federal government and the states of New Jersey and New York. NY Rising purchases the risk-prone parcels at 100% of pre-storm fair market value in exchange for fee simple title and then uses the properties as coastal buffers. Unfortunately, the funding limitations only allow for a small number of properties to be purchased. Therefore, this type of program would be not sustainable at a county or city level. However, having a parameter similar to the K used in this study model can easily accommodate this change in compensation value as a function in property value. It is also suggested to model the K to be variant to temporal changes in property values and account for varying property owner perception of SLR as it becomes more evidenced.

There are several limitations to this study. The largest limitation is the lack of data explaining buy-in percentages. Given people’s inability to consider the long-term future and the views of climate change deniers, it is unclear just how many property owners would be willing to give-up property rights in exchange for a one-time payment. As communities adopt rolling easements, more data is expected to become available. Similarly, this study did not consider physical (proximity to water) or demographic (political party, age, sex) when selecting parcels that were willing to accept an easement. Another limitation is the lack of consensus among authors regarding how to compute rolling easement payments. We adopted an exponential curve
on parcel risk and property value but deciding on the best variable values was based on a limited number of research studies and past articles. Finally, the choice to adopt a rolling easement and pay property owners is dependent on many political issues with a given community. These questions are very difficult to quantify and were not addressed in the current study.

**Conclusion**

A sensitivity analysis was performed on three rolling easement policy parameters: K (monetary constant), Beta (friction coefficient) and easement buy-in (percentage of real property owners that accept a rolling easement from the local government) in Pinellas, FL and Sarasota, FL to better understand how each parameter affected the estimation of rolling easement compensation payments. Since the literature provided little guidance for the parameter values, a broad range of values were tested for each variable.

The results indicated that tested Beta values affected payments by as much as tens of millions of dollars and controlled the amount of compensation received by coastal property owners relative to inland owners because Beta controlled the slope of the risk compensation curve with respect to inundation risk. Tested buy-in ratios were much more significant; it affected payments by hundreds of millions of dollars in some cases. Buy-in was also important because its values will be determined by how many citizens actually decide to accept a rolling easement; it will be determined by real-world decisions. Overall, compensation payments will be affected by topography because the more vulnerable properties, the more money a county will have to pay, as well as parameter values such as K, Beta, and buy-in percentage.
Table 4-1. Sea level rise estimates at 2.1 m

<table>
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<th>Author</th>
<th>Min (m) @ 2100</th>
<th>Max (m) @ 2100</th>
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<tr>
<td>Jevrejeva et al 2010</td>
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</tr>
<tr>
<td>Grinsted et al 2009</td>
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<td>1.30</td>
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<td>Horton et al 2008</td>
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Figure 4-1. Overview of study area
Figure 4-2. Elevation map of (a) Sarasota and (b) Pinellas
Figure 4-3. Comparison of rolling easement compensation payments with varying buy-in percentages in Pinellas
Figure 4-4. Comparison of rolling easement compensation payments with varying buy-in percentages in Sarasota
Figure 4-5. Comparison of beta values in Pinellas. $K = 1$; Buy-in = 30%.

Figure 4-6. Comparison of beta values in Sarasota. $K = 1$; Buy-in = 30%.
Sea level rise (SLR) is expected to cause losses of over $250 billion dollars in GDP by 2050 in the US and affect every coastal state in the nation. These losses are expected to occur throughout Florida, the US, and the world. According to the Intergovernmental Panel on Climate Change, a substantial portion of the world’s population lives in coastal areas, and the rate of population growth is only increasing. Many major cities, such as New York, New Orleans, Shanghai, and Bombay, rely on the sea to provide “economic, social, and cultural benefits” to tens of millions of people. Many of these cities are expected to see rapid coastal erosion, saltwater intrusion into the drinking-water aquifers, substantial storm damage exacerbated by SLR, and major losses in the barrier systems that protect the population.

Florida is especially vulnerable to SLR. Studies predict a 1.5 m rise will translate into property losses of $156 billion, displace almost a million people, and destroy several hundred thousand homes. The only solution to SLR is sound coastal policies. This study is one of the first efforts to simulate coastal policies. It began by exploring several criteria relevant to SLR coastal policies through case studies in Key West, FL, and Pinellas County, FL. Then, the study focused on a GIS analysis of the rolling easement policy in the entire coastal area of two Florida counties (Pinellas and Sarasota). Finally, a sensitivity analysis was performed on three of the rolling easement policy parameters.

This study bridged the gap between GIS modeling and coastal policy research by simulating a series of coastal policy options using ArcGIS and Python programming scripts.

A prototype model was created to analyze the effects of SLR on two study areas in South Florida (Monroe County and Pinellas County) under three policy scenarios: armoring prohibition, armoring, and relocation (rolling easements). The simulations employed Model
Builder and Python, as well as data such as high-resolution digital elevation models (DEM) derived from airborne light detection and ranging (LiDAR) measurements, parcel data, and beach transects. SLR was simulated in 0.15 m steps between 0.15 m and 1.35 m. The study showed that it was feasible to model coastal policies, not just the “do nothing” scenario, utilizing GIS functionalities using standard tools in ArcGIS (e.g. buffer, intersect, tabulate) combined with custom Python scripts to simulate the major components of a coastal policy such as increasing the value of a property because it was “waterfront” due to SLR rise or holding back the water to simulate hard armoring structures. Furthermore, the study found that some policies that work well in a community would not provide the same beneficial results in others. As an example, the study concluded that Key West would be rapidly inundated by rising waters, leaving little room for “relocation” but the mainland of Pinellas would be inundated much more slowly, allowing for the possibility that many more policy choices such as rolling easements. While this may sound self-evident, modeling the changes in each 0.15 m SLR step, as previously described in Zhang (2010), provided a tool for county governments to plan for SLR by first linking SLR steps to dates (e.g. 0.50 m will happen by 2075) and then allowing counties to make coastal policy choices based on their own assumptions.

After the prototype model was built, the study focused on one policy option (rolling easements), integrated a Monte Carlo simulation to account for property owner participation in the rolling easement program uncertainties, and finally, adopted a negative exponential function to simulate payments to parcel owners based on the parcels inundation risk. The rolling easement compensation payments were modeled through four variables: (a) parcel inundation risk factor, (b) a dampening coefficient (Beta) that control how quick the compensation will decrease with the reduction in parcel inundation risk, (c) a coefficient to control the overall compensation as a
portion of property value, and (d) and the percentage of property owners participating in the rolling easement compensation program. A Monte Carlo simulation was created to better account for the fact that the uncertainties in determining which parcel owners would accept an easement. The Monte Carlo function calculated the average payments for a given percentage of owners that accept the easement payments. The results of the study were particularly illustrative because one policy was being compared in two counties that were geographically close but very different in terms of topography, land value, land use, and population density; Pinellas had lower elevations as well as substantially more expensive real estate and five times as many residents per km as Sarasota (especially along the coastal regions). In terms of losses, Pinellas suffered substantially more land area and land value losses than Sarasota. Similarly, rolling easement payments were substantially more in every SLR scenario than Sarasota because more payments were made in counties where SLR will lead to much more land area inundation, especially that Pinellas is more densely populated along its coastal extension. Pinellas could try armoring, a hypothetical outside the scope of the study, but the literature has concluded that armoring is only a temporary solution.

A sensitivity analysis was performed on three rolling easement compensation model parameters. The first parameter, buy-in percentage, simulated the percentage of property owners that would voluntarily purchase a rolling conservation easement from the county. The second parameter, a friction coefficient (Beta), controlled how much riskier properties would be paid relative to properties with less inundation potential. The third variable, a constant (K), reduced the overall rolling easement payments. The sensitivity analysis was performed by holding two variables and then calculating rolling easement payments as the third variable changes. The last parameter, K, considered an overall discount that caused linear decline in the payments when k
changes from 0 to 0.75. The dampening constant, (Beta), caused compensation amounts to fluctuate by millions or tens of millions of dollars, with the range of values growing as the number of properties being paid increased with each SLR step. Buy-in percentage presented the most interesting results. Buy-in rates (15%, 30%, and 45%) greatly affected the average rolling easement compensation payments because of the wide range of property owner participation between the scenarios. Understanding how buy-in affected payments was also very important because many counties would likely not have a large budget when paying owners so knowing the costs based on hypotheticals has many real-world applications. In the end, the three variable values will be chosen based on the needs and budget of individual communities. If the government has limited available funds or the home owners believe SLR is a major threat, the government may choose to adopt small K values to reduce the overall payout to home owners. If the county believes that coastal owners should not be rewarded for building in risky areas, the government could decrease the friction coefficient (Beta) to pay more money to inland owners relative to coastal owners. Overall, this study demonstrated a framework for rolling easement compensation modeling and each agency tasked with administering a rolling easement policy should conduct its own polls or surveys to estimate the buy-in percentage before adopting this policy to better understand the real-world variables behind rolling easements and how these variables interact with each other. Given the modular design of this model, the study expects to yield significant future research. Major revisions of the model include the addition of storm surge simulations, census population and demographic data, and more coastal policy options. SLR is seen as a “silent threat” because of how slow the waters continue to rise. On the other hand, damages caused by storm surge cause a huge amount of damage to coastal policy, even
today. Given the results of Frazier’s studies of how SLR significantly increases the potency of
storm surge, modeling the combined effects of the two phenomena is a logical next step.
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117


119


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BIOGRAPHICAL SKETCH

Tony Nettleman is a Land Surveying Engineer who holds the distinguished position of assistant professor at Texas A&M Corpus Christi, teaches continuing education courses for attorneys and land surveyors, and serves as an expert witness in boundary, easement, and title disputes. After working at his family’s law firm in Atlanta before college, Tony went on to graduate with Honors at New Mexico State University with a Bachelor of Science in Land Surveying Engineering, a Master of Science in Geospatial Engineering from Texas A&M Corpus Christi with honors, a Phd in Geomatics at University of Florida, and a Juris Doctor at Florida International University. While attending various universities, Tony has worked with several multi-national engineering firms, taught classes at Troy University, Florida Atlantic University, and University of Florida. Currently, Tony serves as an assistant professor of Geomatics at Texas A&M Corpus Christi while lecturing for various profession groups and serving as an expert witness. He is licensed as a professional surveyor in the state of Florida. Tony can be contacted through www.CNettleman.net.