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A GIS based model of rolling easement policies in Pinellas County and Sarasota County, Florida

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A B S T R A C T

Florida is the fourth most vulnerable coastal state in the USA to sea level rise (SLR). Studies predict that a 1.20 m rise translates into the displacement of almost five million people and destroys about 2.6 million homes. The only solution to reducing the vulnerability of Florida's coastline is the creation and implementation of coastal policies, including a reduction in armoring and the adoption of policies such as rolling easements. This paper advances a SLR inundation computer model that estimates the costs of applying rolling easement policy through three outcomes: property value loss, property area loss and conservation easement payments to home owners. The GIS computer model is modular which allows new policy components, datasets, or ArcGIS tools to easily be added to the model. The results show that property land inundation and real property losses are primarily linear while rolling easement compensation payments are substantial during the first three scenarios then are largely stable for the remaining SLR steps.

1. Introduction

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 fear that the projected rates of global mean sea-level rise (SLR) over the next century will far exceed any previously observed SLR rates. Rising seas may 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 might have to be relocated, and natural habitats that have existed for hundreds or even thousands of years could vanish. Even though these effects will occur over time and at different rates, coastal environments are dynamic and complex. However, with careful planning, local governments can act in advance to lower the vulnerability of their communities in the decades to come.

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Scientists still do not agree on the magnitude of SLR in the coming century but plausible scenarios estimate a 0.52 m–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 1.20 m could translate into the displacement of 5 million people and 2.6 million homes in Florida alone (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 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, relocation policies move development to less-vulnerable areas while removing as many armoring structures as practicable.

Although a wide variety of coastal policies are available to local governments, few city or county governments 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 et al. and his colleagues (Zhang, 2011; Zhang et al., 2011, 2013), as well as work by others, such as Frazier (Tate and Frazier, 2013; Thompson and Frazier, 2014). Unfortunately, none of these models has explored how different policy options could translate into 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 and 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 due to rising seas, their value actually rises by about 70% (Landry and 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 et al., 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; Vivien 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 and 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 and compare 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 framework models the most important criteria for the rolling easement policy. Its modular structure allows the user to add, delete, or modify individual sub-routines within the model. This ability to modify any component of the model substantially expands its utility. 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 benefit. 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 with 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[1]” compared to setbacks or outright prohibition on armoring (Grannis, 2011).

2. Background

2.1. 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 0.52 m–0.98 m. Other authors have calculated more substantial rises, ranging from 0.90 m to 2.00 m (Jevrejeva et al., 2008; Vermeer and Rahmstorf, 2009). For the state of Florida, Florida Atlantic University estimated SLR of 0.61 m–1.22 m by 2100 (Heimlich et al., 2009), the U.S. Army Corps of Engineers estimated SLR of 0.5 m–1.50 m by 2100 (U.S. Army Corps of Engineers (2013)), and four South Florida counties estimated SLR of 0.23 m–0.61 m by 2060 (Liechty, 2013).

The projections outlined in the previous paragraph 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 1.20 m 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 0.60 m could result in the loss of between 17 and 43% of U.S. wetlands (Smith and 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 and Richman, 2001). Approximately 4500 square miles (of the total 66,000 square miles) in Florida are within 1.5 m of sea level (Harrington and Walton, 2008). With a rise of less than 1 m, $156 billion worth of property, 840,000 people, and 300,000 homes on 2120 square miles of land could be lost in the US (Strauss, 2012). The EPA (2002) expects that, with a 0.30 m rise, most of Florida's beaches would vanish (EPA, 2002).

2.2. 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). This paper only analyzing the rolling easement policy that falls under the relocation policy umbrella.

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 but 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 relocation policies 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, p.

[1] 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.

7). 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 by voluntary purchase (Titus, 2011, p. 7). 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, 2010). 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, p. 7). 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, p. 8). 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. 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*, 483 U.S. 825, 828–829 [1987]).

Rolling easement policies are attractive to local governments because they allow the communities to accept the fact that the sea cannot be held back indefinitely. Similarly, rolling easements do not require a sudden shift from armoring to relocation; the policies allow 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.

3. Methods: case study and data collection

3.1. Study area

This study focused on two counties in southwest Florida: Pinellas County and Sarasota County (Fig. 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 Fig. 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 Fig. 2(b), range from mean sea level to 17 m (Sarasota County, 2014).

3.2. 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 coastal areas. 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 $\pm$ 3.8 feet at the 95% confidence level, and vertical accuracy is $\pm$ 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 m^2, was built for each county's parcel layer. The result is an attribute table with the parcel ID and total number of pixels (1 m^2 each) for each parcel. If parcel 7,640,705 has a land area of 8641 m^2, then the attribute table would show a GID of 7,640,705 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 was 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 1, determined whether each 1 m^2 pixel in each parcel was 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.

3.3. Rolling easement compensation 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,

Fig. 1. Locations of Pinellas County and Sarasota County in the state of Florida.

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

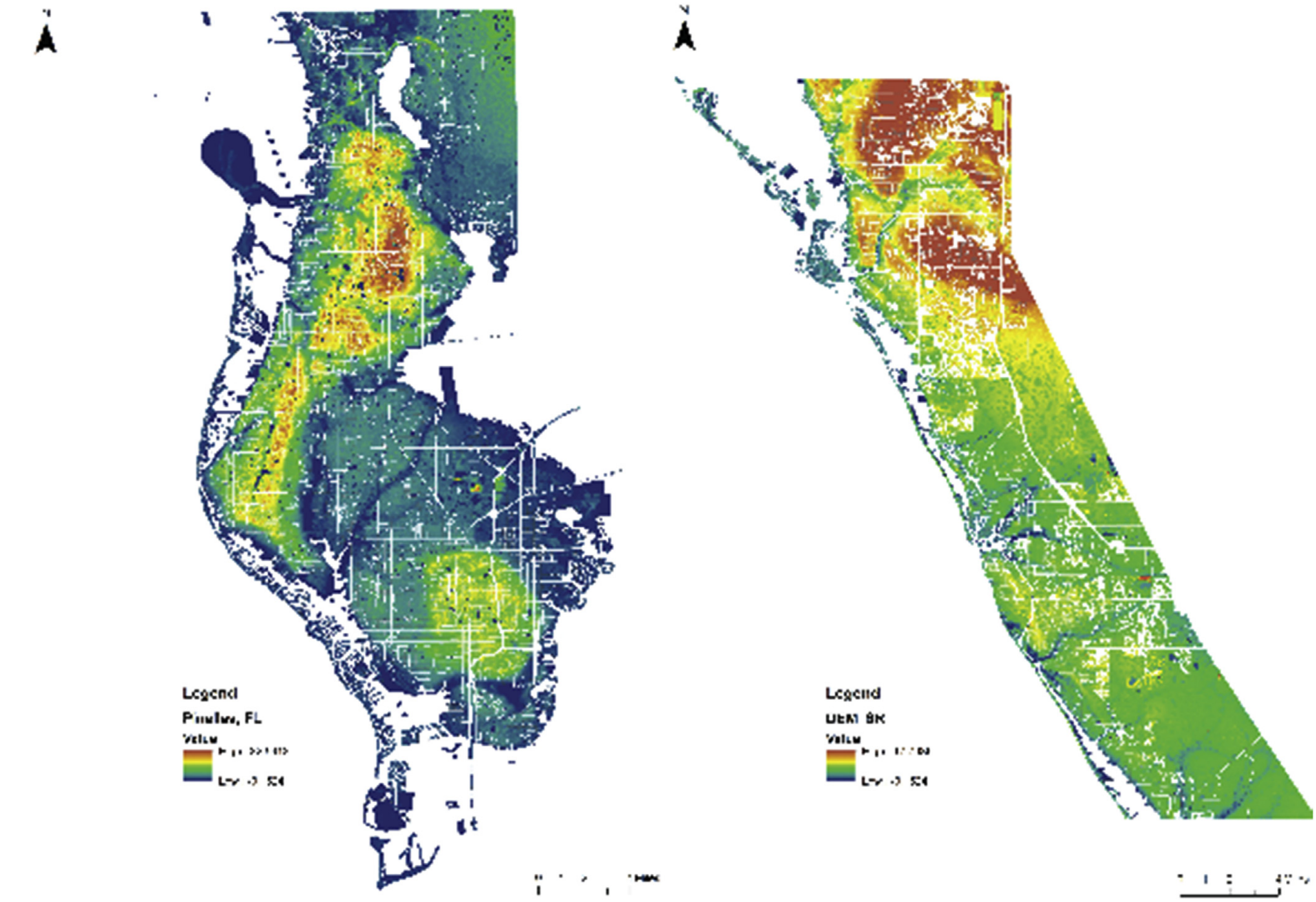

Fig. 2. Elevation Maps of Pinellas (a) and Sarasota (b). Elevations are in meters.

Table 1
Attribute table showing the percentage of inundation of each parcel.

GID	DRY	WET	%Ind
117	6674	0	0
118	2919	3409	0.538717
119	3143	3536	0.529421
120	7334	2104	0.222929
121	6829	0	0
122	7378	0	0
123	6194	0	0
124	6409	0	0
125	6652	0	0
126	6593	0	0
127	6144	0	0
128	6000	0	0
129	6590	0	0
130	7407	280	0.036425
131	8346	788	0.086271
132	6042	0	0

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 observations 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; 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 local governments, if any, have tried the scheme.

Fig. 3 shows a flowchart of the model processes depicting how the built-in ArcGIS functions with custom Python scripts were combined 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

Fig. 3. Overview of GIS model workflow.

based on a review of coastal policy literature including journal articles and white papers (Grannis, 2011; Landry and Hindsley, 2011; Nettleman and Abd-Elraman, 2011; Nettleman et al., 2014; 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 parcel geodatabase in each county. Once the model has estimated which parcels are affected by SLR and calculates parcel inundation risk, the model 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 payments for each property electing to participate in the program is computed using the equation below:

$$RE = K* \left[PV* e^{-\beta*RF} \right] \quad (1)$$

Equation (1): Rolling Easement Compensation Payment.

The rolling easement compensation equation (Eq. (1)) was created by the authors because there were no rolling easement compensation formulas or equations currently in the literature to predict real property prices. 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 (its 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 $e^{-(Beta*40)}$ 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 and Segall, 2007). Both beta and K were chosen based on 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%–15% of property values but rolling conservation easements are more intrusive because they significantly limit the ability of the coastal property to protect his property (Byers and Ponte, 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. The result is not a single value but a range of possible outcomes. 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. Furthermore, the Monte Carlo analysis is quite important because the parameters used to calculate rolling easement compensation, based on property values, loss of value as the sea level rises, and the number of people who would accept such a payment, are still in flux and unknown. Therefore, a deterministic model with set variable and inputs would simply lead to guesses based on input estimates.

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.

4. Results

Inundation results (Figs. 4 and 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. Figs. 4 and 5). Fig. 6 through 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, higher population densities, and because Tampa Bay creates a larger coastline.

Figs. 6 and 7 depict the effects of SLR steps between 0.30 m and 2.10 m on Pinellas County. Percentages of inundated land area (Fig. 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 (Fig. 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 (Fig. 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

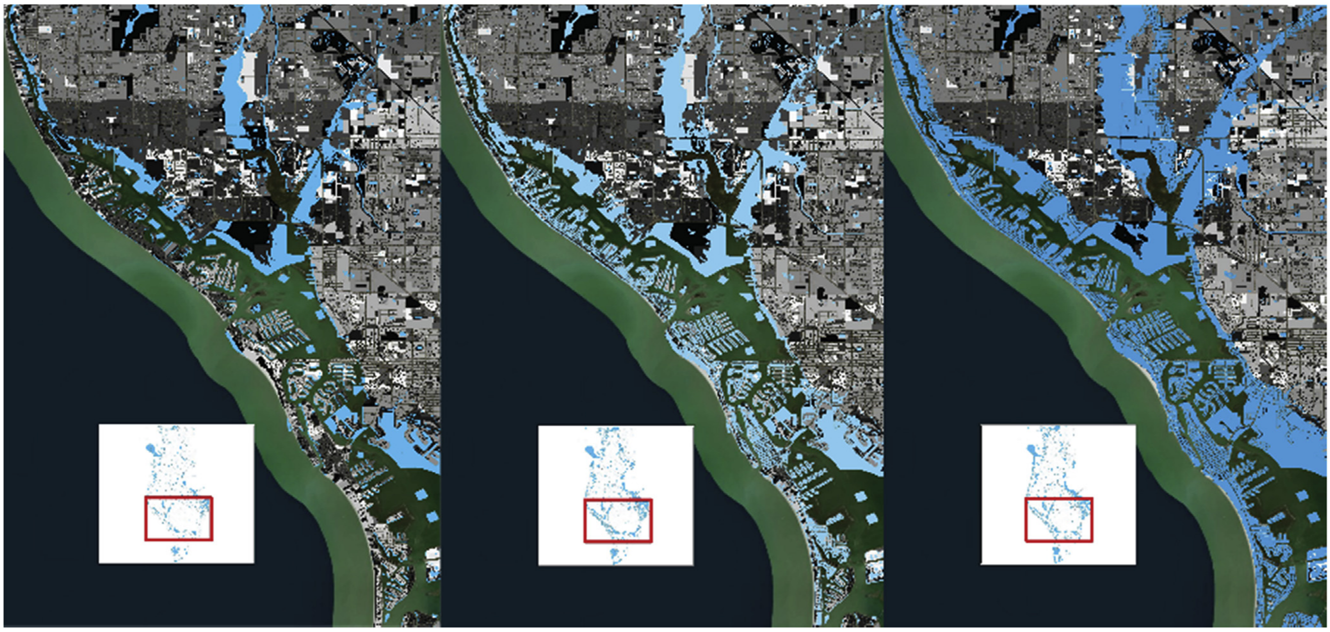

Fig. 4. Three SLR inundation steps in Pinellas.

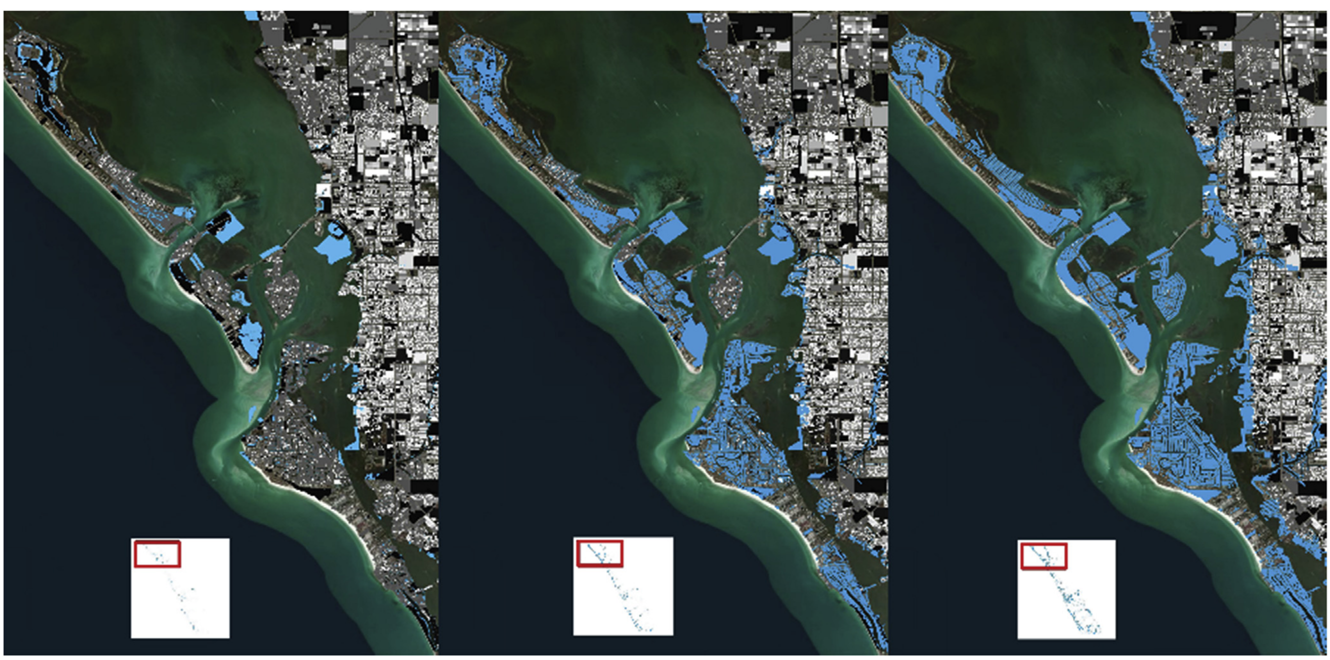

Fig. 5. Three SLR inundation steps in Sarasota.

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 (Fig. 9) began with a substantial $7.44 million payment at 0.30 m. After the first payment, payouts increased from $8.31 million at 0.60 m to $19.55 million at 2.10 m.

5. 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 (Vivien Gornitz, 1991; Vivien M Gornitz et al., 1994; Titus and 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

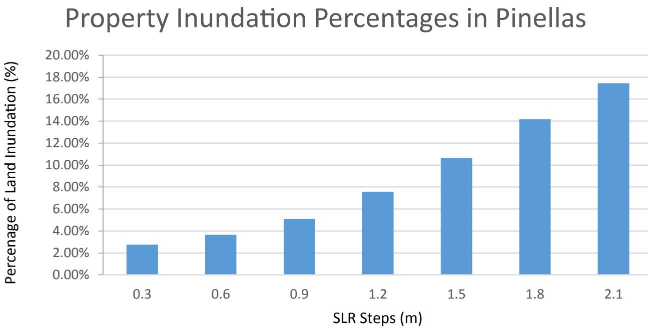

Fig. 6. SLR inundation in Pinellas County.

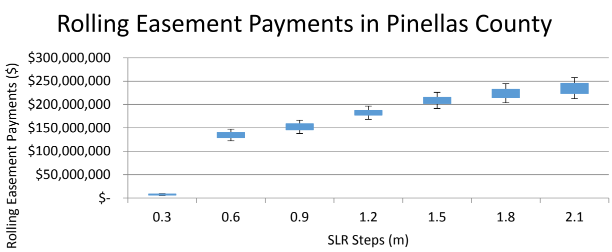

Fig. 7. Mean rolling easement compensation payments in Pinellas County.

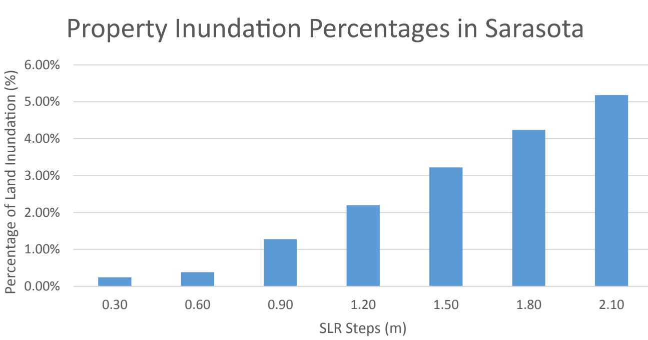

Fig. 8. SLR inundation in Sarasota County.

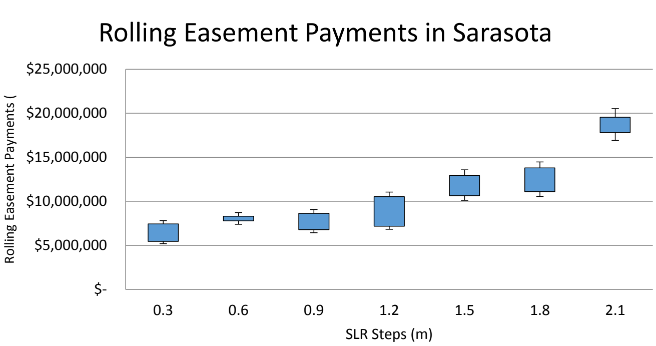

Fig. 9. Mean rolling easement compensation payments in Sarasota County.

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. Common sense dictates that we build a rolling easement policy using pieces of existing relocation policies.

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 greatly vary 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. The results from specific situations will dictate the extent of the benefits and restrictions placed on a coastal rolling easement compensation scheme.

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 but also because greater percentages of land are inundated by water at every SLR step. Considering how the physical features of the two counties caused such as large difference in land area losses and rolling easement payments, other counties should not underestimate how their natural vulnerability in terms of elevation and topography affects how SLR will affect their community. 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 inundated areas, rolling easement compensation did not increase at a proportional 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 mainly attributed 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. Again, further research is suggested to more accurately more the physical changes to the county and the payments made to property owners.

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 in this study only required two data sets: LiDAR elevation data and land parcel data. Census data, storm-surge data, or other data sets may be used but are not required. The model was created to use only a minimal number of data sets because it enhances the usefulness of the model. Indeed, scaling the model up to the state or even national level only requires the parcel data set to be preprocessed into a common format. 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, at what point the parcel loses all of its value, 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 to 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. As we already know, rolling easements will be a wise choice in some counties and not in others. Models to help us make those decisions will have to include all relevant criteria if they are to relied upon to make “real world” decisions.

Another question was raised when the RE payment graphs appeared to show Sarasota payments increasing until the 2.10 m step while Pinellas payments increased much slower from 1.80 m to 2.10 m. But after examining the tables, Pinellas gained almost three times as much than Sarasota in the last step ($12.39 million vs. $5.76 million). The small payment in Pinellas at 0.30 m skewed the chart.

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 an SLR projection (i.e., 1 m) and then analyze the results. The community could also modify assumptions, such as the real property monetary value, before performing the analysis if they believe those assumptions are more realistic based on local knowledge.

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. Whereas both K and beta affected the rolling easements payments, K altered the payments by magnitudes, and a large change in beta only affected the model by about $10 million (beta of 10% vs beta of 30% in Pinellas). 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. Therefore, 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.

Many policy makers fear that rolling easements may be too expensive or too 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 quickly 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 fielding 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.

6. Conclusion

This study described a GIS model of 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 parameters chosen to compute the compensation are based on literature and expert opinions. However, more research is needed to achieve better estimates of these parameters to better understanding 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.

References

Batten, B.K., Weberg, P., Mampara, M., Xu, L., 2008. Evaluation of sea level rise for FEMA flood insurance studies: magnitude and time-frames of relevance. In: American Society of Civil Engineers Conference Proceedings for Solutions to Coastal Disasters Congress, Apr. 13–16, Turtle Bay, HI. http://dx.doi.org/10.1061/40968(312)6.

Beracha, E., Prati, R.S., 2008. How major hurricanes impact housing prices and transaction volume. Real Estate Issues 33 (1), 45–57. http://www.cre.org/memberdata/pdfs/hurricanes.pdf.

Byers, E., Ponte, K.M., 2005. The Conservation Easement Handbook. Land Trust Alliance, Washington, DC.

Caldwell, M., Segall, C.H., 2007. No day at the beach: sea level rise, ecosystem loss, and public access along the California coast. Ecol. Law. Quart. 34, 533–578.

Daley, B., 2014, Mar. 9. Houses Wrecked Repeatedly by Sea Rebuilt with Taxes: Multiple Damage Claims for Coastal Homes Raise Flood Insurance Questions. Boston Globe. http://www.bostonglobe.com/lifestyle/health-wellness/2014/03/09/sea-level-rose-government-paid-nine-flood-claims-scituate-home/P9PvgncnRm3pjdQYt8mxuK/story.html.

El-Raey, M., 1997. Vulnerability assessment of the coastal zone of the Nile Delta of Egypt, to the impacts of sea level rise. Ocean. Coast. Manage 37 (1), 29–40. http://dx.doi.org/10.1016/S0964-5691(97)00056-2.

Environmental Protection Agency, 2002. Saving Florida's Vanishing Shores. EPA-430-F-02–007. http://www.epa.gov/climatechange/Downloads/impacts-adaptation/saving_FL.pdf.

Facts about Pinellas, n.d. Retrieved June 25, 2014, from http://www.pinellascounty.org/facts.htm.

Fantino, E., Stolarz-Fantino, S., Navarro, A., 2003. Logical fallacies: a behavioral approach to reasoning. Behav. Anal. Today 4 (1), 109–117.

Frank, K., 2012. Planning for Sea Level Rise in Florida: a Pilot Study to Evaluate and Improve the Development and Delivery of Habitat Vulnerability Assessments and Adaptive Conservation Designs to Coastal Decision Makers. National Estuarine Research Reserve System Science Collaborative. http://www.PlanningMatanzas.org.

Frazier, T.G., Wood, N., Yarnal, B., 2010a. Stakeholder perspectives on land-use strategies for adapting to climate-change-enhanced coastal hazards: Sarasota, Florida. Appl. Geogr. 30 (4), 506–517. http://dx.doi.org/10.1016/j.apgeog.2010.05.007.

Frazier, T.G., Wood, N., Yarnal, B., Bauer, D.H., 2010b. Influence of potential sea level rise on societal vulnerability to hurricane storm-surge hazards, Sarasota County, Florida. Appl. Geogr. 30 (4), 490–505. http://dx.doi.org/10.1016/j.apgeog.2010.05.005.

Gornitz, V., 1991. Global coastal hazards from future sea level rise. Palaeogeogr. Palaeocl 89 (4), 379–398. http://dx.doi.org/10.1016/0031-0182(91)90173-O.

Gornitz, V.M., Daniels, R.C., White, T.W., Birdwell, K.R., 1994. The development of a coastal risk assessment database: vulnerability to sea-level rise in the U.S. Southeast. J. Coast. Res. Spec. Iss. 12, 327–338.

Grannis, J., 2011. Adaptation Tool Kit: Sea Level Rise and Coastal Land Use. How Governments Can Use Land-use Practices to Adapt to Sea-level Rise. http://www.georgetownclimate.org/resources/adaptation-tool-kit-sea-level-rise-and-coastal-land-use.

Hallegatte, S., Ranger, N., Mestre, O., Dumas, P., Corfee-Morlot, J., Herweijer, C., Wood, R.M., 2011. Assessing climate change impacts, sea level rise and storm surge risk in port cities: a case study on Copenhagen. Clim. Change 104 (1), 113–137. http://dx.doi.org/10.1007/s10584-010-9978-3.

Harrington, J., Walton, T.L., 2008. Climate Change in Coastal Areas in Florida: Sea Level Rise Estimation and Economic Analysis to Year 2080. http://www.cefa.fsu.edu/content/download/47234/327898.

Heimlich, B.N., Bloetscher, F., Meeroff, D.E., Murley, J., 2009. Southeast Florida's Resilient Water Resources: Adaptation to Sea Level Rise and Other Impacts of Climate Change. http://www.ces.fau.edu/files/projects/climate_change/SE_Florida_Resilient_Water_Resources.pdf.

Hollingshead, J.L., 1996. Conservation easements: a flexible tool for land preservation. Envtl. Law 3, 319–324.

Intergovernmental Panel on Climate Change, 2013. The Physical Science Basis. IPCC Working Group I Contribution to AR5. Available at: http://www.ipcc.ch/report/ar5/wg1/#.UlvpNH_Ix8E.

Jevrejeva, S., Moore, J., Grinsted, A., Woodworth, P., 2008. Recent global sea level acceleration started over 200 years ago? Geophys. Res. Lett. 35 (8), L08715. http://dx.doi.org/10.1029/2008GL033611.

Kramer, K., 2010. Coastal Preservation and Transferred Development Rights. Available at: http://law.rwu.edu/sites/law/files/rwu/MarineAffairs/pdf/Kramer-MACZM%20TDR%20Memo%20Final%2001%2011.pdf.

Landry, C.E., Hindsley, P., 2011. Valuing beach quality with hedonic property models. Land Econ. 87 (1), 92–108. http://dx.doi.org/10.1353/lde.2011.0026.

Liechty, J., 2013. Compact policy and legislative coordination. In: Broward County Natural Resources Planning and Management Division PowerPoint Presentation. http://www.nlc.org/Documents/Influence%20Federal%20Policy/Policy%20Committees/EENR/2013_Fall_Jason%20Liechty%20presentation.ppt.

Mcinnes, K., Walsh, K., Hubbert, G., Beer, T., 2003. Impact of sea-level rise and storm surges on a coastal community. Nat. Hazards 30 (2), 187–207. http://dx.doi.org/10.1023/A:1026118417752.

McLaughlin, N.A., 2004. Increasing the tax incentives for conservation easement donations-A responsible approach. Ecol. LQ 31, 1.

Mclaughlin, R.J., 2010. Rolling easements as a response to sea level rise in coastal Texas: current status of the law after Severance v. Patterson. J. Land Use Env. Law 26 (2), 365–394.

Nettleman, C.A., Abd-Elraman, A., 2011. A contemporary review of deficiencies associated with calculated tidal datums and property ownership law. Surv. Land Info. Sci. 71 (2), 69–77.

Nettleman, C.A., Abd-Elraman, A., Adams, D., Fik, T., Ruppert, T., Barnes, G., Dewitt, B., 2014. GIS-based modeling of sea level rise's effects on coastal property management policies. Surv. Land Info. Sci. (in press) https://www.researchgate.net/publication/273402393_GIS-Based_Modeling_of_Sea_Level_Rise_Effect_on_Coastal_Property_Management_Policies.

NOAA Coastal Services Center, 2014. Personal Correspondence with CSC Staff.

Petz, B., 2012, Jul 3. North Carolina legislature Bans Sea Level Rise Due to Global Warming. Ecology Today. http://www.ecology.com/2012/07/03/north-carolina-ignores-sea-level-rise/.

Rao, K.N., Subraelu, P., Rao, T.V., Malini, B.H., Ratheesh, R., Bhattacharya, S., Rajawat, A., 2008. Sea-level rise and coastal vulnerability: an assessment of Andhra Pradesh Coast, India through remote sensing and GIS. J. Coast. Conserv. 12 (4), 195–207. http://dx.doi.org/10.1007/s11852-009-0042-2.

Richardson, J.J., 2010. Conservation easements and adaptive management. Sea Grant Law Policy J. 3 (1), 31–58.

Sallenger, A.H., Doran, K.S., Howd, P.A., 2012. Hotspot of accelerated sea-level rise on the atlantic coast of North America. Nat. Clim. Change 2 (12), 884–888. http://dx.doi.org/10.1038/nclimate1597.

Sarasota County high point, Florida. 2014. Retrieved June 25, 2014, from http://www.peakbagger.com/peak.aspx?pid=22829.

Siders, A., 2013. Managed Coastal Retreat: a Legal Handbook on Shifting Development Away from Vulnerable Areas. https://web.law.columbia.edu/sites/default/files/microsites/climate-change/files/Publications/ManagedCoastalRetreat_FINAL_Oct%2030.pdf.

Smith, J.B., Tirpak, D.A., 1989. The Potential Effects of Global Climate Change on the United States: Report to Congress. EPA-230-05-89-050. http://www.co.berks.pa.us/dept/bcaeac/documents/environmental_library/20_earth/20.21_earth_global_warming/20.21.90.01_potential_effects_of_global_climate_change.pdf.

Strauss, B., 2012. Surging Seas: Sea Level Rise, Storms and Global Warming's Threat to the US Coast: a Climate Central Report. http://sealevel.climatecentral.org/research/reports/surging-seas.

Tate, C., Frazier, T., 2013. A GIS methodology to assess exposure of coastal infrastructure to storm surge & sea-level rise: a case study of Sarasota County, Florida. J. Geogr. Nat. Disast. Suppl. 1, 1–12. http://dx.doi.org/10.4172/2167-0587.S1-001.

Tebaldi, C., Strauss, B.H., Zervas, C.E., 2012. Modelling sea level rise impacts on storm surges along US coasts. Environ. Res. Lett. 7 (1), 014032. http://dx.doi.org/10.1088/1748-9326/7/1/014032.

Thompson, C.M., Frazier, T.G., 2014. Deterministic and probabilistic flood modeling for contemporary and future coastal and inland precipitation inundation. Appl. Geogr. 50, 1–14. http://dx.doi.org/10.1016/j.apgeog.2014.01.013.

Titus, J.G., 1998. Rising seas, coastal erosion, and the takings clause: how to save wetlands and beaches without hurting property owners. Md. L. Rev. 57 (4), 1279–1399. http://papers.risingsea.net/downloads/takings.pdf.

Titus, J.G., 2011. Rolling Easements. Climate Ready Estuaries Program. United States Environmental Protection Agency. http://water.epa.gov/type/oceb/cre/upload/rollingeasementsprimer.pdf.

Titus, J.G., Richman, C., 2001. Maps of lands vulnerable to sea level rise: modeled elevations along the US Atlantic and Gulf Coasts. Clim. Res. 18 (3), 205–228. http://dx.doi.org/10.3354/cr018205.

Titus, J.G., Park, R.A., Leatherman, S.P., Weggel, J.R., Greene, M.S., Mausel, P.W., Brown, S., Gaunt, C., Trehan, M., Yohe, G., 1991. Greenhouse effect and sea level rise: the cost of holding back the sea. Coast. Manage 19 (2), 171–204. http://dx.doi.org/10.1080/08920759109362138.

U.S. Army Corps, 2013. Incorporating Sea Level Change in Civil Works Programs. ER 1100-2-8162. Available at: https://www.flseagrant.org/wp-content/uploads/USACE_SLR_guidance_ER_1100-2-8162.pdf.

U.S. Census Bureau, 2014a. US Census Quick Facts for Pinellas, FL. Retrieved June 25, 2014, from. http://quickfacts.census.gov/qfd/states/12/12103.html.

U.S. Census Bureau, 2014b. US Census Quick Facts for Sarasota, FL. Retrieved June 25, 2014, from. http://quickfacts.census.gov/qfd/states/12/12115.html.

Vermeer, M., Rahmstorf, S., 2009. Global sea level linked to global temperature. P. Natl. A. Sci. 106 (51), 21527–21532. http://dx.doi.org/10.1073/pnas.0907765106.

Zhang, K., 2011. Analysis of non-linear inundation from sea-level rise using LIDAR data: a case study for south Florida. Clim. Change 106 (4), 537–565. http://dx.doi.org/10.1007/s10584-010-9987-2.

Zhang, K., Dittmar, J., Ross, M., Bergh, C., 2011. Assessment of sea level rise impacts on human population and real property in the Florida Keys. Clim. Change 107 (1–2), 129–146. http://dx.doi.org/10.1007/s10584-011-0080-2.

Zhang, K., Li, Y., Liu, H., Rhome, J., Forbes, C., 2013. Transition of the coastal and estuarine storm tide model to an operational storm surge forecast model: a case study of the Florida coast. Weather Forecast 28 (4), 1019–1037. http://dx.doi.org/10.1175/WAF-D-12-00076.1.