USING THE LANDSCAPE TO IDENTIFY TIPPING POINTS AND THRESHOLDS TO ASSESS VULNERABILITY TO SEA LEVEL RISE FOR INFORMING ADAPTATION PLANNING IN LEVY COUNTY, FLORIDA

By

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To my family, friends, Maria, and Anastasia

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TABLE OF CONTENTS

CHAPTERS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DEM	Digital Elevation Model
FDOT	Florida Department of Transportation
FGDL	Florida Geographic Database Library
FWC	Florida Fish and Wildlife Commission
GCM	General Circulation Model
GIS	Geographic Information Systems
LiDAR	Light Detection and Ranging
MHHW	Mean Higher High Water (MHHW
NWFWMD	North West Florida Water Management District
NOAA	National Oceanic and Atmospheric Administration
SEFRCCC	Southeast Florida Regional Climate Change Compact
SLR	Sea level rise
UF GeoPlan	University of Florida GeoPlan Center
USB	Urban Service Boundary

Abstract of Thesis Presented to the Graduate School
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Sea level rise (SLR) is a threat to coastal assets across the world. The state of Florida is particularly vulnerable to SLR impacts. Adaptation will be necessary for communities to adjust to future change. Uncertainty surrounding SLR and climate change acts as a barrier to communities trying to both assess future vulnerability and begin the process of adaptation. Using the landscape to identify tipping points and thresholds to assess vulnerability and cope with uncertainty has been an emerging trend in planning. A bathtub inundation model containing hydrologically connected areas to the coast was used to determine vulnerability in low-lying coastal areas in Levy County and Cedar Key, Florida. The undeveloped areas and conservation lands of Levy County and Cedar Key were the most vulnerable areas, likely to be negatively affected by a 21 inch or greater increase in sea level. Developed areas and taxable property were most vulnerable to increases in SLR greater than 43 inches.

CHAPTER 1
INTRODUCTION

Climate change stands to have significant global impacts on communities (IPCC, 2007). Sea level rise (SLR) is believed to be a huge threat to coastal areas, particularly places with large amount of low-lying coastal land areas and high levels of human settlement along the coast. There is growing concern with identifying the vulnerability of these coastal areas and beginning the process of adaptation to future change to alleviate negative impacts to important assets. In this thesis, vulnerability is defined as the propensity or predisposition to be adversely affected (IPCC, 2012), and adaptation is defined as the process of adjustment to actual or expected climate and its effects in human and natural systems (IPCC, 2012).

Coastal areas are dynamic places constantly experiencing changes in coastal habitat and shifting patterns in the landscape, coastal erosion, corrosion of infrastructure, storm surge and flooding, and changes in the saltwater/freshwater interface. The growing concern is that changes to the coast will likely be magnified and intensified by SLR, thus increasing the vulnerability in existing vulnerable areas. SLR impacts stand to increase the rate of change in the coastal landscape, cause flooding to become more frequent at high tides, increase the magnitude of coastal erosion, increase the exposure of infrastructure to hazards and coastal elements, lead to the release of pollutants during flooding or changes in the water table, increase the likelihood of saltwater intrusion in aquifers and drinking water supplies, and cause storm surge to stretch further inland (IPCC, 2007; Ruppert et al., 2008; Frazier et al., 2010; Geselbracht et al., 2011; Moser et al., 2012). As a result, it is important for coastal communities to understand where they may be vulnerable so they can begin the process of identifying appropriate strategies for adaptation.

In the United States, Florida is particularly vulnerable to SLR impacts due to its large coastal land area and estimated population of nearly 1.5 million residents living less than three feet above the high tide line (Strauss et al., 2012). Furthermore, coastal areas are instrumental to Florida's economy and development, generating over $39 billion in revenues for both local communities and the state (Cantanese Center Florida Atlantic University, 2005, cited in Marshall et al., 2011). As a result, SLR could seriously impact Florida's economic, cultural, social, and natural assets along the coast (Florida Oceans and Coastal Council, 2011). Adaptation to SLR is a challenging reality facing numerous coastal communities in Florida.

Measureable SLR has been observed over the past century and researchers expect an increase from the historic trend of 8 inches a century to a higher rate that could result in SLR increases of greater than 3 feet by the end of this century (Parris et al., 2012). But a great deal of uncertainty remains and acts as a barrier to adaptation, such as uncertainty in SLR projections and climate science and uncertainty in modeling of impacts (Kettle, 2012; Kiem & Austin, 2013). Uncertainty is defined here as a lack of sureness (Kettle, 2012). Using tipping points and thresholds to cope with uncertainty is an emerging trend in adaptation planning and vulnerability assessments (Russil and Nyssa, 2009; Kwadjik et al., 2010; Zhang et al., 2011; Werners et al., 2013). Tipping points and thresholds are being used to identify the points at which current policies and settlement patterns fail to remain viable in light of future change.

This thesis will focus on using the landscape to identify tipping points and thresholds to assess vulnerability to SLR in Levy County, Florida by identifying the levels of SLR the area and its assets may be vulnerable to. The purpose of this thesis is to apply this approach to SLR adaptation planning and vulnerability assessments as a preliminary step towards initiating adaptation planning in coastal communities, thus providing a basic operating framework in which planners, decision-makers, and stakeholders can begin to contextualize vulnerability within their respective community. Growing interest in planning with uncertainty and using thresholds and tipping points to cope with uncertainty prompted the foundational research question for this study: can low-lying elevation areas along the coast be used to identify tipping points and thresholds in the landscape that can act as a baseline for understanding coastal vulnerability to initiate the adaptation planning process? A bathtub inundation model containing hydrologically connected areas to the coast was applied to assess the incremental changes in vulnerability of low-lying coastal areas in Levy County to SLR using a wide range of elevation data increments between 20-77 inches in elevation.

Following this introduction chapter, Chapter 2 provides an overview of the literature regarding SLR projections and climate science, modeling SLR with the bathtub inundation model, and how tipping points, thresholds, and a wide range of planning scenarios are used to cope with uncertainty in adaptation planning and vulnerability analyses. Chapter 3 provides an overview of the tipping point and threshold methodology for assessing vulnerability. Chapter 4 discusses the result of this analysis and Chapter 5 provides concluding statements.

CHAPTER 2
LITERATURE REVIEW

Uncertainty in SLR Projections and Estimates

SLR poses a great threat to coastal areas and communities. Action is needed to both mitigate and adapt to future impacts. Although some communities have begun to address the issue, many have not. There is a great deal of uncertainty surrounding both climate change and SLR projections, which can be troubling for stakeholders and decision-makers and is the likely impetus for inaction for many places (Moser, 2005; Wilby & Dessai, 2010; Kettle, 2012; Moser et al., 2012; Sapuan, 2012; Deyle & Butler, 2013). Managing and overcoming uncertainty is crucial to the advancement of SLR adaptation planning. The literature has reviewed the wide range of SLR projections and the uncertainty surrounding those projections, thus providing a fairly comprehensive look at the latest science and the uncertainty that accompanies it.

As part of the United States of America's National Climate Assessment, Parris et al. (2012) reviewed the body of global SLR projections and models to determine a range of scenarios for which SLR can be expected to occur by 2100 (see Figure 2-1). In reviewing the different projections and models, Parris et al. (2012) found that "global mean SLR can be estimated from physical evidence (e.g. observations of sea level and land ice variability) (Pfeffer et al., 2008; Katsman et al., 2011; Jevrejeva et al., 2012), expert judgment (NRC, 1987; NRC, 2011; NRC, 2012), general circulation models (GCMs) (IPCC, 2007; Yin, 2012), and from semi-empirical methods that utilize both observations and GCMs (Grinsted et al., 2009; Jevrejeva et al., 2010; Vermeer and Rahmstorf, 2009; Horton et al., 2008; Rahmstorf et al., 2012)" (p. 10-11). Additionally, Parris et al. (2012) concluded that there is a greater than 9 in 10 chance "that global mean sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100" (p.10). This is a very large range to consider for decision-makers. Parris et al. (2012) categorized the range into four scenarios: lowest, intermediate-low, intermediate-high, and highest.

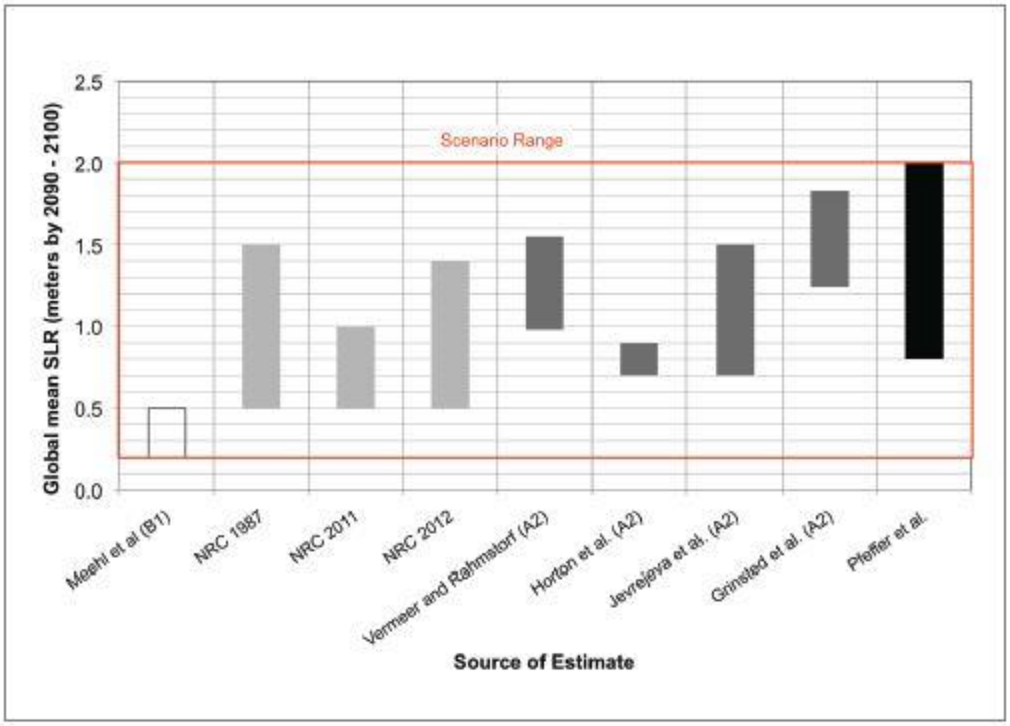


Figure 2-1. The review of global SLR estimates in meters produced by Parris et al. (2012).

In a similar review, Cooper et al. (2013) concluded "that research on SLR projections is converging on a short-term planning target of 32 cm global SLR by 2050 and a long-term planning target of 1 m global SLR by 2100" (p. 762). Cooper et al. (2013) acknowledged that a great deal of uncertainty remains regarding SLR projections and that there is a need to advance the understanding of the effects thermal expansion of ocean waters and land based ice melt into the ocean have on global sea level.

At present, researchers are limited by a lack of knowledge and ability to adequately understand, model, and acquire data for complex earth and climate systems, which the United States Army Corps of Engineers (USACE, 2011) refer to as ‘knowledge uncertainty’. Such limitations include: the ability to downscale global SLR projections and climate models to the regional and local scales (Wilby & Dessai, 2010; Mitchum, 2011; Parris et al., 2012; Sapuan; 2012; Deyle & Butler, 2013); ability to measure and monitor historic and current sea level data and determine relative sea level trends (Mitchum, 2011; Kettle, 2012); and the ability to model and understand glacial and ice sheet dynamics in Greenland and Antarctica, which have a huge effect on SLR rates (Kettle, 2012, Sapuan, 2012; Deyle & Butler, 2013). Although researchers may feel confident in their models and projections, the associated uncertainty can be troubling to decision-makers and lay people that lack their level of knowledge science, thus creating a gap between scientists and stakeholders that results in a lack of action in the realm of SLR adaptation planning (Moser, 2005; Moser & Ekstrom, 2010; Kiem & Austin, 2013; Kirchoff et al., 2013).

Modeling SLR with the Bathtub Inundation Model

Mapping potential inundation from SLR using elevation data is one of the most commonly used techniques in SLR vulnerability assessments (Gesch, 2009; Mcleod et al., 2010; Strauss et al., 2011; Weiss et al., 2011; Kettle, 2012; Cooper et al., 2013; Murdukhayeva et al., 2013). This method is commonly referred to as the bathtub inundation model, bathtub model, or the inundation model – it will be referred to as the bathtub inundation model in this paper. The bathtub inundation model typically uses elevation and tidal data to identify land areas and assets that may be vulnerable to future SLR. The scale at which the model is applied can range from global, national, state, regional, to local scales depending on the available data used in the model, although analysis of SLR less than 1 meter require high quality data such as high-resolution light detection and ranging (LiDAR) data (Gesch, 2009; Cooper et al., 2013).

Generally, the bathtub inundation model is used to develop SLR vulnerability maps and data that assess potential vulnerability by providing a spatial component to SLR impacts. As Cooper and colleagues (2013) noted, “[g]enerating reliable maps of low-lying, low-slope coastal systems vulnerable to the potential effects of future SLR primarily depends on the resolution and accuracy of the elevation data used to identify sensitive areas” (p.746). Digital elevation models (DEMs) are used to represent the topography of the land area for analysis, and areas below the determined elevation corresponding with projected SLR are assumed to be inundated. These inundation areas can be used to quantify or identify impacts to people, property, and lands (Zhang et al., 2011).

All DEMs have errors though (Kettle, 2012), so the level of analysis is highly dependent on the resolution of the data, i.e., the coarser the horizontal resolution the more likelihood for map errors (Cooper et al., 2013). Thus finer grained analysis requires high-resolution data. Cooper and colleagues (2013) noted “Strauss et al. (2012) mention that the application of 10 m horizontal resolution DEMs was beneficial for demonstrating the general impacts of SLR, but not for generating detailed vulnerability maps” (p. 746). The increasing availability of LiDAR data has made finer grained analysis of SLR more possible, particularly for analyzing low-lying elevations below 1 meter (Zhang et al., 2011; Cooper et al., 2013; Gesch, 2013; Schmid et al., 2014), but mapping uncertainty continues to exist despite access to higher quality

LiDAR data (NOAA, 2010a; NOAA, 2010b; Kettle, 2012; SEFRCCC, 2012; Cooper et al., 2013; Schmid et al., 2014).

LiDAR data has vertical resolution errors that can prove problematic in mapping SLR vulnerability (Gesch et al., 2009; Gesch, 2013) and some have called for a comprehensive standard for addressing vertical mapping uncertainty (Copper et al., 2013). Techniques have been developed to address mapping uncertainty and vertical error by analyzing areas of inundation based on the 95% confidence level of the data (Gesch, 2009; Gesch et al., 2009; NOAA, 2010a; Schmid et al., 2014). To help communicate these results, confidence level can be represented on vulnerability maps as ‘more likely’ or ‘possibly’ inundated based on the confidence interval, which is how the Southeast Florida Regional Climate Change Compact (SEFRCCC) (2012) represented their results in their vulnerability analysis. Cooper et al. (2013) raised concerns about this method because it assumes that the vertical errors follow a normal distribution with zero bias, which may not be the case because of operator bias and lack of a set standard in processing raw LiDAR data. Additionally, Cooper et al. (2013) added that “mapping a minimum statistically significant [low end] SLR planning target of 32 cm is difficult to achieve based on current LiDAR and VDatum data sets” (p.762). Regardless of controversy regarding mapping uncertainty, researchers are getting better at analyzing low-lying elevations using the bathtub inundation model at a finer grained detail of analysis and this will likely improve into the future and aid decision makers in the decision making process as more detailed analyses become available.

The bathtub inundation model is also limited in that it is a simple model that does not reflect complex, dynamic coastal processes, such as coastal erosion or other land responses to changing coastal conditions, thus it does not assume changes to the shoreline as a result of SLR (Kettle, 2012; Schmid et al., 2014). It can also include low-lying areas that are not hydrologically connected to the coast, leading to overestimations of impacted areas (Poulter and Halpin, 2008). To avoid this pitfall, studies have updated inundation areas to reflect hydrological connectivity and removed non-hydrologically connected areas (Gesch, 2009; Zhang et al., 2011; Gesch, 2013). Additionally, bathtub inundation models are relatively inexpensive to run and can be routinely and quickly updated as new data becomes available (Mcleod et al., 2010). They can be run through Geographic Information System (GIS) based software by more advanced users or through interactive web-based tools, such as the National Oceanic and Atmospheric Association's (NOAA) SLR and Coastal Flooding Impacts Viewer tool and the University of Florida GeoPlan Center's (UF GeoPlan) Sea Level Scenario Sketch Planning Tool, making the model highly accessible to users and decision-makers.

Although the bathtub inundation model has issues with accuracy and representing complex coastal processes, the model provides a solid baseline for understanding vulnerability in low-lying coastal areas. It may not accurately reflect how these areas may be impacted, but it does identify areas that are likely to be vulnerable to SLR, which establishes a solid baseline for vulnerability given the available data and models. The bathtub inundation model allows users to analyze a wide range of scenarios, providing a robust framework of analysis that can help decision-makers and stakeholders cope with the uncertainty surrounding SLR projections. As higher quality data becomes available, users and researchers can easily update their bathtub inundation models to reflect new information and provide more detailed levels of analysis until better technologies and models can replace it. Until that time comes, the model will continue to be used to assess the vulnerability of coastal areas to SLR and provide context to decision-makers and stakeholders so that they can begin the process of adaptation planning.

Using Tipping Points and a Range of Scenarios to Cope with Uncertainty in Adaptation Planning and Vulnerability Analyses

Much of the focus for SLR planning has been on SLR projections and time horizons for impacts when formulating planning scenarios. Uncertainty regarding these projections, time horizons, and the models used to analyze impacts has crept into the planning and public discourse and has acted as a barrier to adaptation planning efforts (Moser, 2005; Mastrandrea et al., 2010; Moser & Ekstrom, 2010; Kettle, 2012; Kiem & Austin, 2013). This uncertainty, coupled with peoples’ struggle to comprehend SLR impacts and climate science data (Norgaard, 2011, Kettle, 2012), has led to little action and implementation of adaptation efforts (Moser and Ekstrom, 2010; Kiem and Austin, 2013; Kirchoff et al., 2013).

The discourse surrounding climate change and SLR can be a highly contested and politicized issue (Russil & Nyssa, 2009; Norgaard, 2011; Leiserowitz et al., 2013). The contested nature of this issue can bog down the adaptation planning process and derail it with debates over the merits of climate science, climate models, or planning for climate change or SLR in general. Such discourse can become toxic and act as a barrier to planning for SLR (Kiem & Austin, 2013). One such example is North Carolina, where debate in the state legislature focused on whether SLR rates used by state agencies could deviate from linear historic trends. The legislature passed a law (HB

819) that updated North Carolina state law to require a state determined rate of SLR, effectively putting a moratorium on state agencies considering SLR until the North Carolina Coastal Resource Commission reached an agreed upon rate of sea level change in their 2015 assessment (Lee, 2012). Such controversy should be avoided at all costs.

An emerging trend within the planning and climate change communication communities is the use of tipping points and thresholds to both contextualize vulnerability and cope with the uncertainty surrounding future SLR and climate change science (Russil & Nyssa, 2009; Kwadjik et al., 2010; Haasnoot et al., 2013; Werners et al., 2013). Kwadjik et al. (2010) defined ‘adaptation tipping points’ as points where the magnitude of change due to climate change or SLR is such that the current strategy will no longer be able to meet the objectives” (p. 3). The basic idea is to use tipping points and thresholds to express uncertainty in terms of how long, or up to what point, the existing strategy or development pattern is effective, thus making it more understandable for stakeholders and decision makers (Kwadjik et al., 2010). Such an approach is uncoupling uncertainty from the climate change and SLR scenarios that define the process presently, and placing it within the context of the place that is being analyzed, hopefully minimizing it. For example, establishing that the amount of low-lying lands in a community doubles from the 21 to 31 inch elevation zones is a tangible effect of SLR that provides a sense of magnitude that stakeholders can comprehend and begin to set planning targets for and adaptation strategies to address. It is not uncertain that a certain amount of land is likely vulnerable to a 31 inch rise in sea level.

Additionally, the tipping point and threshold approach embraces the ideas of robust planning and anticipatory governance that seek to examine a wide range of scenarios for the purposes of analysis (Quay, 2010; Chakraborty et al., 2011). Using a wide range of SLR scenarios helps overcome issues of uncertainty and complexity by considering a variety of possible futures and identifying a wide range of impacts, thus providing robustness to the planning process (Chakraborty et al., 2011). Given SLR projection's high level of uncertainty, using a wide range of scenarios acknowledges this inherent uncertainty and accepts knowledge limitations regarding the future and accounts for this during the vulnerability analysis, thus adding a level of robustness that compensates for our lack of knowledge or certainty. This range can even exceed the projected range of SLR (Zhang et al., 2011). Using one SLR projection or scenario for analysis may not cover the range of future possibilities, thus inadequately addressing the issue. Furthermore, it does little to address uncertainty that stakeholders may find troubling. Additionally, based on local topography and the distribution of low-lying areas, the inundation process and SLR inundation dynamics may be non-linear, thus affecting large areas in small increments, so it is essential to assess multiple scenarios to identify tipping points and elevation thresholds that indicate non-linear impacts (Zhang et al., 2011). As a result, a solid understanding of the local landscape helps researchers and stakeholders understand the distribution of low-lying lands in a community and how their vulnerability changes under various SLR scenarios, thus building their capacity to understand vulnerability and inundation dynamics within the local context.

Kwadjik et al. (2010) developed their approach to examine water management policies in the Netherlands and Gersonius et al. (2012) applied it to examine adaptation of stormwater systems to climate change, but the approach can be similarly applied to examine SLR vulnerability. Zhang et al. (2011) employed a similar method to the adaptation tipping point approach in their analysis of SLR vulnerability in the Florida Keys using low-lying areas (i.e., the landscape) to determine tipping points and examine inundation dynamics. Zhang and colleagues (2011) examined a wide range of low-elevation areas in the Florida Keys using a tidally adjusted, LiDAR based bathtub inundation model to identify tipping points based on population, property values, and land area within the determined range of elevations (0.15 to 5.1 meters).

Zhang et al. (2011) found that multiple tipping points existed based on the area (Upper, Middle, and Lower Keys), population, and properties within an elevation range. In this regard, context is very important when considering tipping points. For example, some areas had lower tipping points than others based on affected land areas and although a large percentage of land may be below a certain elevation threshold, the population base may be concentrated in a higher elevation zone, thus having a different tipping point. As a result, an area may have a wide range of tipping points based on specific assets, so when making decisions to address vulnerability for planning purposes, decision-makers and stakeholders need to determine which tipping points are priorities for planning and policy (Zhang et al., 2011). Additionally, Zhang and colleagues (2011) found that prior to the tipping point there is a lack of direct or dramatic evidence of impacts or vulnerability, which both lends support to the need for a wide range of scenarios when assessing vulnerability and for beginning the process of capacity building now since it may be too late to plan for adaptation effectively by the time SLR impacts are easily observable to stakeholders.

When applied to the assessment of SLR vulnerability in preliminary stages of planning, the process is predicated on increasing knowledge and understanding of the coastal landscape by identifying tipping points and thresholds in the low-lying coastal lands. This can be accomplished by identifying low-lying lands that are located within the range of SLR projections, then identifying the pre-determined assets located within this vulnerable area, and then examining the landscape to determine how much SLR makes those areas vulnerable and at what point the current pattern of development is no longer tenable (Zhang et al., 2011). A more traditional top-down approach, that predicts and plans (Quay, 2010), would seek to find an agreed upon SLR scenario (that is both socially and politically agreeable) and subsequently analyze the cause and effect chain implied by that scenario and consider adaptation strategies and responses to particular impacts based on the scenario, which may not be robust enough to address inherent risk within the community (Kwadjik et al., 2010). By applying a wide range of scenarios and identifying tipping points within this range, a community can develop robust plans that support choices that address their vulnerability and benefit them across a wide range of scenarios and outcomes (Chakraborty et al., 2011). This approach also avoids the social and political pitfalls that can derail the initial dialogue regarding adaptation planning processes.

At present, there is a major issue with how the problem of SLR vulnerability is initially framed. It is typical of planners and stakeholders to want to know how much SLR can they expect and when it can be expected (Deyle & Butler, 2013). The current orientation of practice is misguided and misses the underlying issue of exposure and vulnerability based on the existing assets and development within the community.

Initiating the SLR adaptation planning process by using an effect-based approach that focuses on the implicit vulnerability of a community based on its landscape (i.e., the distribution of low-lying lands and assets within the landscape) can help frame the issue for stakeholders in terms of what levels of SLR put their community at risk. Examining the landscape to identify tipping points and thresholds considers exposed and vulnerable areas first, thus establishing a baseline of risk for stakeholders to begin to understand. Once these factors are better understood, then it would be apt to introduce vulnerability in relation to time horizons and SLR curves to understand how vulnerability changes over time.

A landscape based approach that identifies tipping points and thresholds in low-lying areas is only an introductory look at SLR vulnerability for a community. Time horizons and SLR rates are critical for time-sensitive projects (such as the expected life cycle of a water treatment plant) and ecologically sensitive areas and habitats (as the rates of SLR affect how natural areas respond to changes in sea level). This approach should be used to begin conversations regarding vulnerability and future adaptation, to cope with issues of uncertainty, and to move the SLR adaptation planning process forward as a means to build stakeholders’ capacity to engage themselves in SLR adaptation processes.

CHAPTER 3
METHODOLOGY

Growing interest in planning with uncertainty and using tipping points and thresholds to cope with uncertainty prompted the foundational research question for this study: can low-lying elevation areas along the coast be used to identify tipping points and thresholds in the landscape that can act as a baseline for understanding coastal vulnerability to initiate the adaptation planning process? The purpose of this research is to examine the local landscape to identify critical tipping points and thresholds for SLR adaptation planning. This method is predicated on the use of elevation data to identify low-lying areas that are likely to be vulnerable to future changes in sea level and coastal hazards in general (Gesch, 2009; Gesch et al., 2009; Strauss et al., 2011; Weiss et al., 2011). GIS will be used to analyze the low-lying areas in Levy County and Cedar Key that fall within the projected rates of SLR by the year 2100, which range from less than 21 inches to 77 inches (Parris et al., 2012). The adapted GIS-based analysis will be related to planning and policy to further inform SLR adaptation planning efforts and provide context for future analyses and planning processes.

Study Area

Levy County is located in the southern Big Bend region along the Gulf Coast of Florida (Figure 3-1). Levy County has extensive, low-lying coastal areas with gradually sloping topography. This area is mostly undeveloped and contains saltmarsh and coastal forests. The large amount of low-lying land and gradually sloping coastline put the coastal landscape and small waterfront communities in the area at risk to SLR impacts.

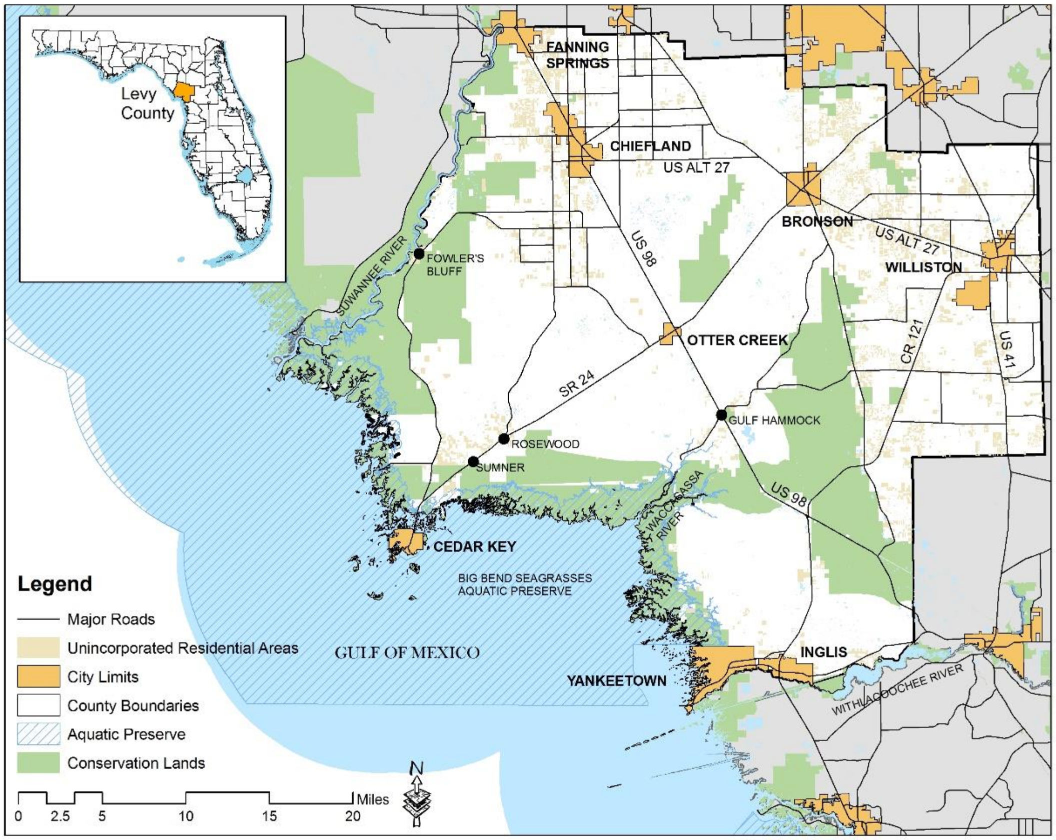


Figure 3-1. Map of the Levy County and Cedar Key study area.

Levy County contains significant ecologically sensitive areas and conservation lands, including the Big Bend Seagrasses Aquatic Preserve, the Waccasassa Bay Preserve State Park, the Goethe State Forest, the Cedar Keys and Lower Suwannee National Wildlife Refuges, the Cedar Key Scrub State Reserve, and the Cross Florida Greenway. It also contains the small coastal communities of Cedar Key, Yankeetown, and Inglis. To provide an additional detailed level of analysis, particularly to look at vulnerability to the built environment, Cedar Key will be used as a sub-study area for this thesis. Cedar Key's local economy mostly relies upon tourism, fishing, and aquaculture. As a result, the surrounding natural areas are a significant resource to the community. Additionally, the town’s character, history, and culture provide a strong sense of identity that could be threatened by SLR impacts that affect the built environment or displace residents.

SLR stands to affect natural and developed areas in Levy County. SLR impacts in the area have already been documented through studies of habitat migration and coastal forest retreat (Raabe et al., 2004; Castaneda & Putz, 2007; DeSantis et al., 2007). Researchers analyzed historic changes in the tidal marshes in the region and found that saltwater marshes have migrated inland to displace coastal forest as a response to changes in sea level. Furthermore, researchers have modeled future SLR impacts to coastal habitats in the region, concluding that coastal forests are particularly vulnerable to rises in sea level (Geselbracht et al., 2012).

Levy County was selected as the study area for this thesis due to its perceived vulnerability to SLR, the availability of data for the region, the scale of the region, and the author’s familiarity with the region.

Low-lying Areas Method for Analyzing SLR Tipping Points and Thresholds

The methodology used in this thesis is an adapted version of the adaptation tipping points approach proposed by Kwadjik et al. (2010) and similar to Zhang and colleagues’ (2011) analysis of tipping points in the Florida Keys. The adaptation tipping points approach was developed as a means to cope with uncertainty in efforts to plan for SLR adaptation. Kwadjik et al. (2010) used the adaptation tipping points approach to evaluate water management policies in the Netherlands using different SLR scenarios to identify what the first impacts may be and when existing policy failed to meet current objectives, thus requiring an adaptive strategy to compensate for new conditions. The method employed in this thesis will be different from Kwadjik and colleagues’ (2010) method in that it will be used as a preliminary assessment of vulnerability to analyze impacts and potential thresholds to the physical environment and the assets within those areas rather than an analysis of current policies. Additionally, the “when can we expect this” approach will focus on the level of SLR rather than a time element. However, the fundamental question of analysis from Kwadjik et al. (2010) – “How much SLR can the current strategy [in this case, low-lying coastal areas] cope with?” – remains the same. This will be accomplished by analyzing the low-lying coastal lands that fall within the range of SLR projections and analyzing impacts to basic assets (e.g., land area, development, and land use) within this range to identify potential tipping points and thresholds to determine the levels of SLR the study area may be vulnerable to.

Given the uncertainty regarding how much, how fast, and when sea levels will rise, it is recommended that scenarios use a range of projections rather than a single rate to analyze potential impacts when planning for SLR (NOAA, 2012a). This thesis will employ the bathtub inundation model to identify low-lying areas vulnerable to SLR. The bathtub inundation model is a static model that does not operate on a timescale that depicts a rate at which dry land converts to wet land over time, but rather it depicts all lands below the determined tidally adjusted elevation to be inundated all at once. As a result, SLR projections are not entirely necessary for the formulation of SLR scenarios using the bathtub inundation model, although they can be used as guidance for selecting the elevations used for the analysis. Elevation is the predominant operating framework of the model, not SLR projections (Gesch et al., 2009; NOAA, 2012b). This study will not use time horizons or SLR projections for its vulnerability scenarios.

Instead, scenarios will be framed within the context of elevation as elevation zones in low-lying areas.

A tidally adjusted bathtub inundation model of hydrologically connected low-lying areas will be the basis for this analysis. The model in this study used Mean Higher High Water (MHHW) for its tidal datum, which is the average highest high tide event for each day, thus more accurately reflecting the high water mark of an area and including the largest wet land area possible for the purpose of analyses, i.e., the worst case scenario for inundation. This method was employed in a similar fashion in the SEFRCCC *Inundation Mapping and Vulnerability Assessment* (2012), which used 1 foot, 2 foot, and 3 foot scenarios to analyze potential vulnerability to SLR, as well as Zhang et al. (2011) in their analysis of SLR impacts in the Florida Keys.

In a similar fashion to Zhang et al. (2011), this study will expand the scope of the analysis used by the SEFRCCC and include elevations up to 77 inches – based on the National Climate Assessment's analysis of the high range of global SLR scenarios (Parris et al., 2012) – to identify tipping points, thresholds, and levels of SLR the study area is vulnerable to. Based on the available data, low-lying areas below 21, 25, 31, 37, 43, 50, 58, 67, and 77 inches will be analyzed to determine potential vulnerability to SLR. This thesis will describe thresholds and tipping points as a *clear tipping point* or a *cumulative threshold*. This thesis defines a clear tipping point as the point preceding an easily observed increase in the amount of exposed assets (land area, structures, and economically/socially significant areas) following an increment of measurement. There is no standard for how much is considered a significant increase, but if the amount of exposed assets doubles or triples in the order of one magnitude of measurement, that would likely be considered significant. This thesis defines a cumulative threshold as a threshold that occurs when a large amount of aggregated assets are below a particular elevation zone. For example, if 60% of the land area below 77 inches lies below the 31 inch elevation zone, then 31 inches of SLR may be considered a cumulative threshold and an indicator of vulnerability to that amount of SLR. A cumulative threshold would warrant further attention for planning. Thresholds can be proportional to both the assets within the low-lying elevation range (below 77 inches) and all the assets within the study area based on the context of the analysis.

Depending on the scale and scope of planning, as well as the planning goals and objectives, there may be different SLR tipping points and thresholds at which an area is vulnerable or decision-makers and planners would like to plan for. For example, natural areas and habitats may have a different tipping point or threshold than the built environment. If decision makers decided to plan for 37 inch rise in sea level (because that may have been what their constituents or themselves felt comfortable with) but a significant portion of their building stock lay between 37 and 50 inches in elevation, they may be inadequately addressing, or reducing, their community’s vulnerability. Having a wide range of low-lying elevations provides a robust framework that helps users identify thresholds that may have been otherwise overlooked if a more narrow scope was used.

This study will use two levels of analysis of examine impacts to its study area: the county level (Levy County, Florida) and the municipal level (Cedar Key, Florida). The county level analysis will look at potential impacts to land area, land use, and taxable property. The municipal level will focus on potential impacts to land area, land-use, building stock, and taxable property. Thresholds and tipping points will be identified at both levels, as well as the SLR scenarios the assets are vulnerable to.

Data Sources

The basis for this paper's low-lying areas analysis is UF GeoPlan's SLR inundation model layers developed through their *Development of a Methodology for the Assessment of Sea Level Rise Impacts on Florida's Transportation Modes and Infrastructure* Project with the Florida Department of Transportation (FDOT). UF Geoplan developed a statewide DEM and eight regional inundation data layers based on FDOT districts. FDOT District 2 was divided into Gulf (West) and Atlantic (East) regions. This study used the FDOT District 2 West region inundation layers for its analysis.

UF GeoPlan created a 5-meter cell size DEM "by mosaicking data from four different sources, with the following order of priority: 1) North West Florida Water Management District (NWFWMD) DEM; 2) Florida LIDAR (FLIDAR) Coastal DEM; 3) Statewide Florida Fish and Wildlife Commission (FWC) 5-Meter DEM; and 4) LIDAR Contour Derived DEM from the Florida Department of Emergency Management" (UF GeoPlan, 2013, pg. 14). The data conforms to Gesch's (2009; 2013) recommendation of mapping SLR inundation zones at the 95% confidence level. This data has a 10 inch minimum vertical mapping resolution, thus "any projected sea level change that yields inundation levels equal to or greater than 10 inches have a 95% chance of being accurately mapped on the DEM" (UF GeoPlan, 2013, pg., 15).

As previously mentioned, for finer tuned SLR analysis, UF GeoPlan created regional inundation layers based on FDOT Districts. The regional inundation layers used local tide gauges to account for variations in local tide and sea level trends (UF

GeoPlan, 2013). UF GeoPlan calculated area-weighted means for each district to produce regional values proportional to their area in the FDOT District (UF GeoPlan, 2013). SLR scenarios were then created using the bathtub inundation model based on the United States Army Corps of Engineers' SLR projection curves, time frames at decadal intervals, tidal datums, and geographic area (statewide and FDOT regional District) (UF GeoPlan, 2013). This thesis used MHHW for its tidal datum and opted to not define its scenarios with time frames, but rather the elevation increment associated with the time frame (i.e., classifying the scenario as a 21 inch elevation zone rather than UF GeoPlan's classification of 2040 low projection). FDOT District 2 West's tidal station is the National Oceanic and Atmospheric Administration's (NOAA) Cedar Key Tidal Station, which is located in the study area of this thesis. Within the FDOT District 2 West region is a small data gap in southern Levy County just west of Yankeetown, Florida.

UF GeoPlan applied a hydrologic connectivity rule to refine their bathtub inundation model (UF GeoPlan, 2013). Since the basic bathtub model only accounts for elevation, UF GeoPlan refined its model by accounting for hydrologic connections to "include rivers, canals, estuaries, bays, and other water bodies that have direct connection to open water" (UF GeoPlan, 2013, pg. 27), unconnected, inland low-lying areas that are not likely to be inundated were removed from the layer. It must be noted that the hydroconnectivity rule only accounts for surficial water flows and does not account for SLR effects on groundwater flows (UF GeoPlan, 2013).

This thesis utilized Florida property parcel data for Levy County for the year 2010 for the vulnerability analysis. The property parcel data includes property boundaries, land area, the just value of a property, property owner information, land-use, and similarly associated property data. This data was accessed through the Florida Geographic Database Library (FGDL) and was the most recent data available for Levy County. Like Zhang and colleagues' (2011) method, the just value of a property was used to estimate potential property vulnerability of taxable property to SLR. Additionally, a building footprint layer for structures in Cedar Key was created using ESRI's aerial image base maps. Visible building footprints were traced and made into individual polygons. Due to the coarse resolution and tree cover in the aerial imagery, buildings may not accurately reflect the exact building footprint or number of structures on a parcel, thus counts on structures may not be exact with regards to what exists on the ground. Regardless of these potential limitations in the data, the building footprints are a good indicator of vulnerability to the built environment since they approximate existing built structures. Therefore, their inclusion in an elevation zone will be assumed as an indicator of vulnerability within the built environment. Additionally, the building footprints did not take into account the elevation of the structures, thus building footprints within the inundation layers may be elevated and outside the inundation zone. Even if the structure is elevated, its proximity to the inundation layer classifies it as vulnerable for the purpose of this study because the structure is assumed to be inaccessible by land.

Calculating Vulnerability within the Low-lying Elevation Zones

This study used a combination of UF GeoPlan's inundation layers (elevation zones) and property parcel data as the basis for evaluating inundation and vulnerability to SLR. Following Zhang and colleagues' (2011) method, property parcel data was converted to centroid point features, meaning the geometric center of each parcel. Parcel points within each elevation zone were selected. The total taxable amount of property in the elevation zones was found by summing up the just value of the selected properties.

This method is rather coarse in that it does not account for the level of inundation on a property parcel, or determine if a parcel is fully or partially inundated. Additionally, some parcels extend far into the tidal zone, so parcel centroids were located outside of the elevation zones and not counted, thus undercounting the amount of taxable property. The purpose of this study is to identify sources of vulnerability rather than to assess dollar values to SLR impacts, which Zhang et al. (2011) calculated. Rather than assume that taxable property within the elevation zones are a receive a proportional loss of revenue to the area inundated, taxable property within the low-lying elevation are assumed to be an indicator of vulnerability to revenue sources for municipalities and revenue collecting entities. Furthermore, the amount of taxable property in elevation zones can also be viewed as an indicator of vulnerability to developed areas since those areas hold more value. Methods exist to calculate potential loss of revenue by multiplying the just value with the ratio of the inundated parcel area to the total parcel area (Zhang et al., 2011), but such an analysis may not accurately reflect SLR impacts to property because they do not consider the location of physical structures that add significant value to a property. For example, if 65% of a parcel is inundated, but the structure that provides the majority of the value to the property is outside that inundated zone then this method may over count impacts to property values. This thesis elected to forego Zhang and colleagues’ (2011) loss of taxable property method given that it does little to consider the distribution of structures on a parcel and that the intent of this thesis was to provide a baseline for understanding community vulnerability (meaning it is a coarse understanding that is flexible and open for interpretation) rather than an detailed analysis that estimated loss of revenue due to SLR impacts.

To assess impacts to land use, all parcels that intersected with the elevation zones were selected, geoprocessed using Esri's clip tool to include inundated areas within the parcel features, and the low-lying area within the parcel data was recalculated to determine the amount of land use acreage within the low-lying elevation zone. The total area of impacted land use was calculated by summing up the total area within the parcel's low-lying elevation zone. Within the Cedar Key study area, building footprints were used to further qualify impacts on the built environment. Structure counts should not be considered an exact amount of structures to be impacted by future SLR, but should rather be considered an indicator of vulnerability to developed areas and the built environment. Building footprints within the elevation zones were selected and the total amount of structures was found by summing up the selected amount within each elevation zone.

CHAPTER 4
RESULTS

Levy County

Levy County has a total land area of approximately 728,000 acres (Table 4-1). 105,874 acres, or roughly 15% of the land area, is within low-lying coastal areas below 77 inches in elevation. The 0-21, 21-25, and 25-31 inch zones have substantially larger increases in land area compared to other elevation zones (Figures 4-1, 4-2, and 4-3). The largest net increase in land area was the 0-21 inch elevation zone. Although the large range of elevations included in this zone (data was not available for lower elevation increments) may inflate the amount of land in this zone, a large amount of low-lying land remains in this elevation zone regardless of the distribution of elevation zones. The 0-21 inch elevation zone accounts for 23% of the exposed low-lying land area in Levy County, amounting to 24,813 acres.

A significant amount of low-lying land is also located in the 21-25 inch and 25-31 inch elevation zones. 28,943 acres are located in this 10-inch elevation area, accounting for 27% of the low-lying land area in Levy County. The 31-37 inch elevation zone also includes a large amount of land area, including an additional 10,195 acres (10% of the low-lying areas). The amount of land up to the 37 inch elevation zone accounts for 60% of the low-lying coastal lands in Levy County. It is difficult to define a clear tipping point for the lower elevation zones due to the wide range of elevations within the 21 inch elevation zone, but the large increase in lands in the 25-37 inch elevation zones indicates that a tipping point exists at or below the 21 inch elevation zone. The large amount of low-lying lands within this area indicates a cumulative threshold at the 37 inch elevation zone. SLR scenarios greater than 21 inches would lead to significant impacts to the coastal land area in Levy County due to this threshold.

SLR Scenarios – Levy County			**Top three impacted land uses (acres)**		
Elevation (MHHW)	Land area (acres)	Taxable Property ($)	Public and Conservation Lands	Timberland	Vacant Residential
21 in.	24,813	39,149,468	20,524	2,483	569
25 in.	37,326	56,765,250	30,312	4,153	1,005
31 in.	53,666	80,722,074	41,985	7,500	1,528
37 in.	63,861	104,796,728	47,699	11,307	1,840
43 in.	70,969	127,116,322	50,298	15,296	2,102
50 in.	78,802	169,638,507	52,117	20,716	2,409
58 in.	86,745	225,872,012	53,428	26,704	2,731
67 in.	95,999	277,686,178	54,721	33,759	3,192
77 in.	105,874	336,536,762	55,611	41,769	3,680
Baseline	728,454	4,420,624,432	135,179	341,131	45,059

Table 4-1. Levy County land area, taxable property, and top three impacted land uses in the elevation zones.

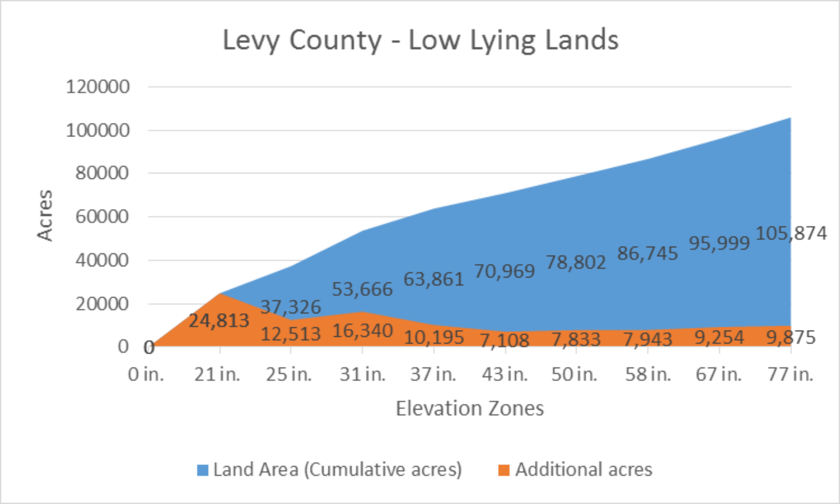


Figure 4-1. Levy County low-lying lands area chart depicting the land area in the elevation zones plus each set of additional acres per elevation zone.

Following the 37 inch elevation zone, the rate of additional low-lying coastal lands decreases. For example, the 37-43 inch elevation zone adds an additional 7,108 acres (7% of the low-lying areas). There is a minor increase in the 58-67 inch and 67-77 inch elevation zones as each zone adds over 9,000 additional acres, amounting to 18% of the total low-lying coastal lands in Levy County. It is difficult to state that the increase from the 58-67 inch elevation zone constitutes a tipping point, but the increase in the amount of land can be considered a cumulative threshold, but this threshold is much less substantial than the threshold at the 37 inch elevation zone.

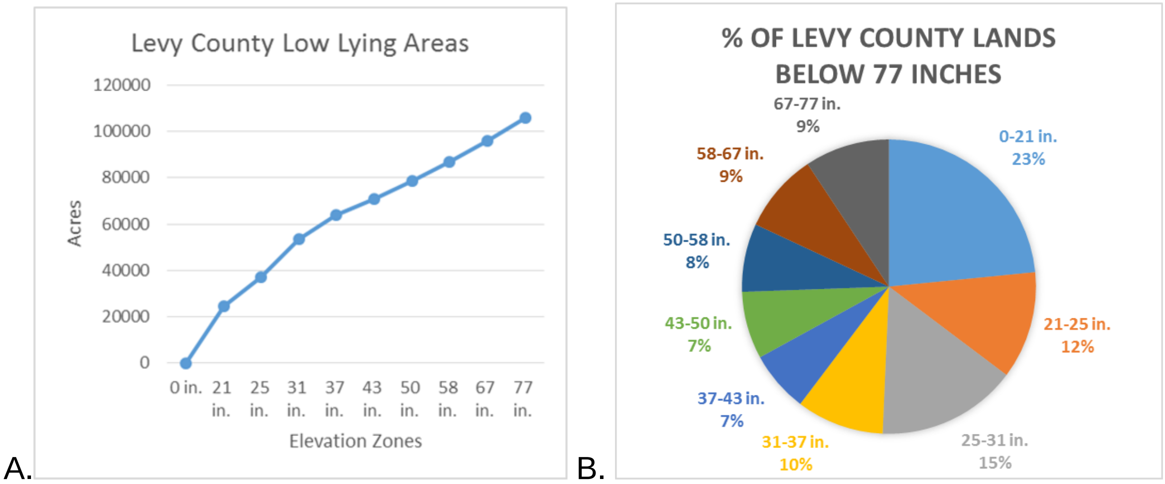


Figure 4-2. Levy County low-lying area line and pie chart. A. Line chart depicting the increase in Levy County acreage per elevation zone. B. Pie chart depicting the proportion of Levy County land per elevation zone in relation to the total land area below 77 inches.

Levy County has a total taxable property amount of $4,420,624,432 (Table 4-1). Within the 77 inch low-lying coastal area elevation zone remains $336,536,762 of taxable property, accounting for 8% of the taxable land in Levy County. The amount of taxable assets in coastal Levy County is small compared to the rest of the county. The amount of taxable property in Levy County's low-lying coastal areas increases dramatically after the 43 inch elevation zone (Figure 4-4). The land area up to the 43 inch elevation zones account for approximately 38% of the taxable property in Levy County's low-lying coastal areas at a total taxable property value of $127,116,322.

Whereas the 50-77 inch elevation zones account for 62% of the taxable property in Levy County's low-lying coastal areas at a total taxable property value of $209,420,440. The 43 inch elevation zone is a clear tipping point due to the rapid increase in exposed assets after this elevation zone. Although there is a substantial portion of taxable property below the 43 inch elevation zone, SLR scenarios greater than 43 inches stand to significantly impact taxable property in Levy County. SLR scenarios higher than 43 inches could significantly affect revenue sources and property values based on the current state of development in the coastal area, thus indicating vulnerability to a 43 inch or more SLR scenario.

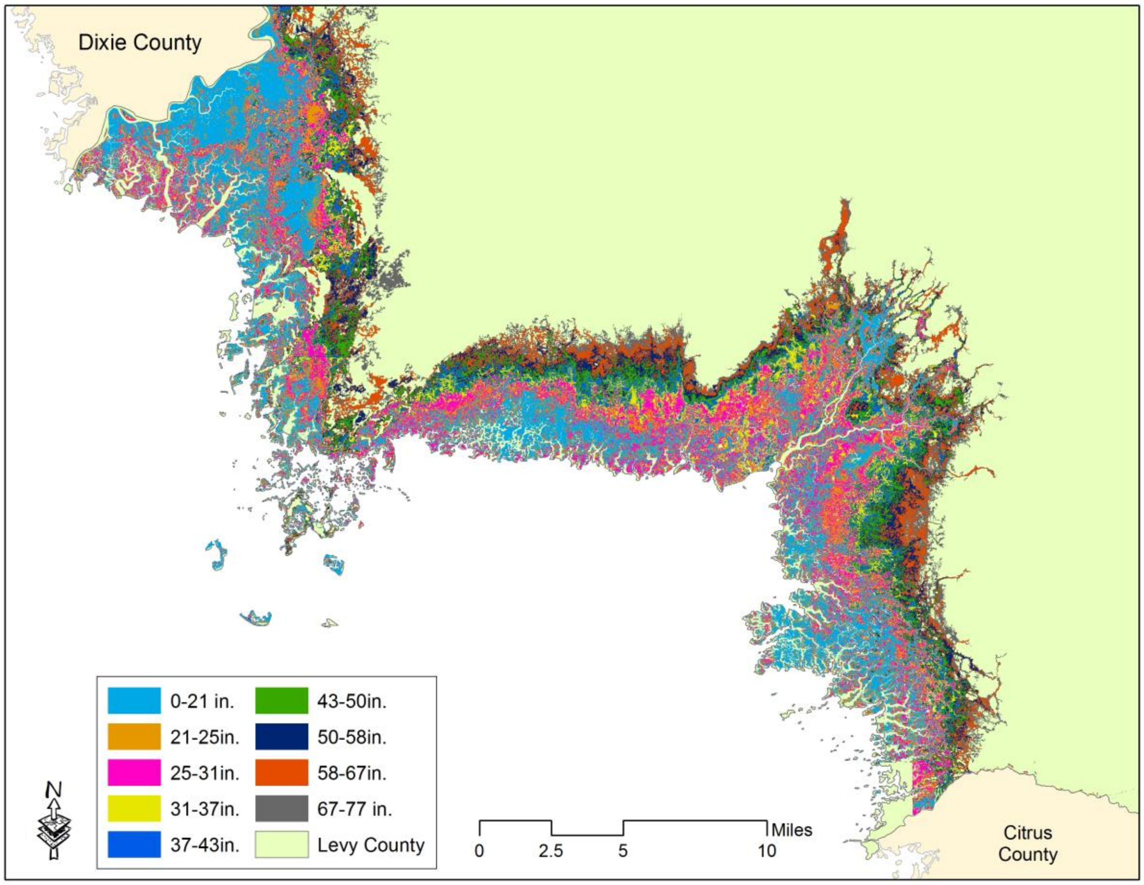


Figure 4-3. Levy County low-lying areas map.

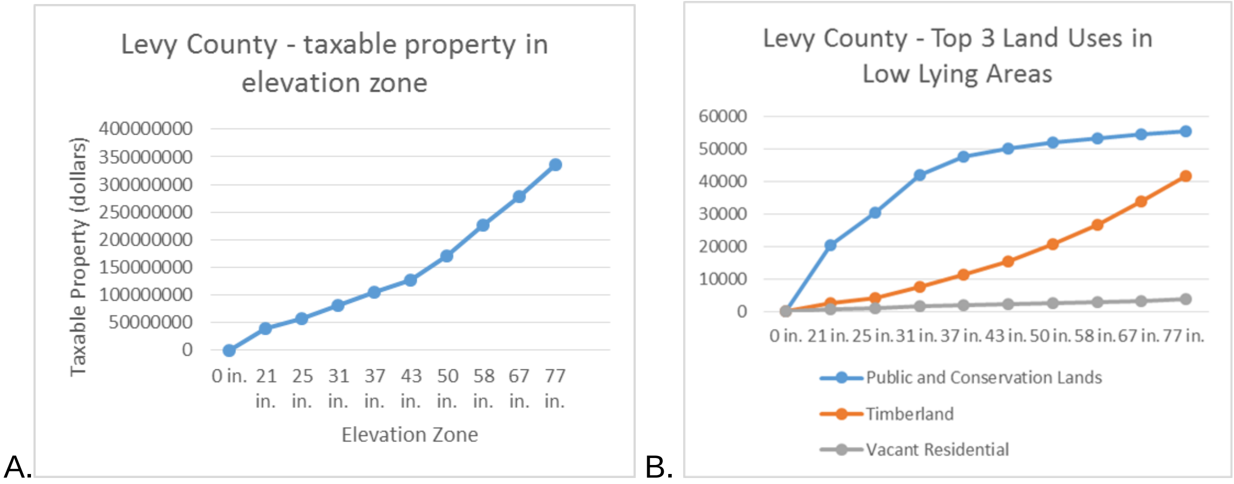


Figure 4-4. Levy County taxable property and top three impacted land uses chart. A. Line chart depicting the increase in the amount of Levy County's taxable property per elevation zones. B. Line chart depicting the top 3 land uses in Levy County's low-lying areas.

The top three land uses by acreage in Levy County are timberland, public and conservation lands, and grazing lands. The majority of land uses in coastal Levy County are undeveloped/working lands or natural areas that are publicly owned or in conservation. Timberland, public and conservation lands, and vacant residential land uses are among the top 3 impacted land uses in low-lying elevation zones in Levy County (Table 4-1, Figure 4-4). Public and conservation lands are the most impacted land use in Levy County. 55,611 acres of Levy County's 135,179 acres of public and conservation lands are located within the 77 inch low-lying coastal elevation zone, amounting to 41% of the total public and conservation land in the county. Most of Levy County's coastal conservation lands and natural areas are located in the lowest elevation zones, thus making them highly vulnerable to SLR. 86% of the public and conservation lands in coastal areas are within the 37 inch elevation zone. 16% of the public and conservation lands in Levy County are located within the 21 inch elevation zone (21% within the coastal areas), amounting to 20,524 acres. This increase to 22%

within the 25 inch elevation zone, and jumps to 31% within the 31 inch elevation zone. By 37 inch elevation zone, 47,699 acres are located in low-lying areas amounting to 35% of the county's conservation lands and 86% of the coastal conservation lands. The rate of additional public and conservation lands decreases substantially following the 37 inch elevation zone, indicating that most of the lands in the coastal area fall below the 37 inch elevation zone.

Due to the wide range in elevations below the 21 inch elevation zone it is difficult to determine a clear tipping point, as the tipping point may be below 21 inches. It is clear that SLR scenarios of 21 inches or greater can lead to significant impacts to coastal public and conservation lands in Levy County. Such scenarios fall within the low to medium range SLR projections. A 37 inch or greater rise in sea level could prove disastrous to Levy County's coastal public and conservation lands, impacting most of the lands. It is clear that a cumulative threshold exists at the 37 inch elevation zone and that Levy County public and conservation lands are extremely vulnerable to rises in sea level 21 inches or greater.

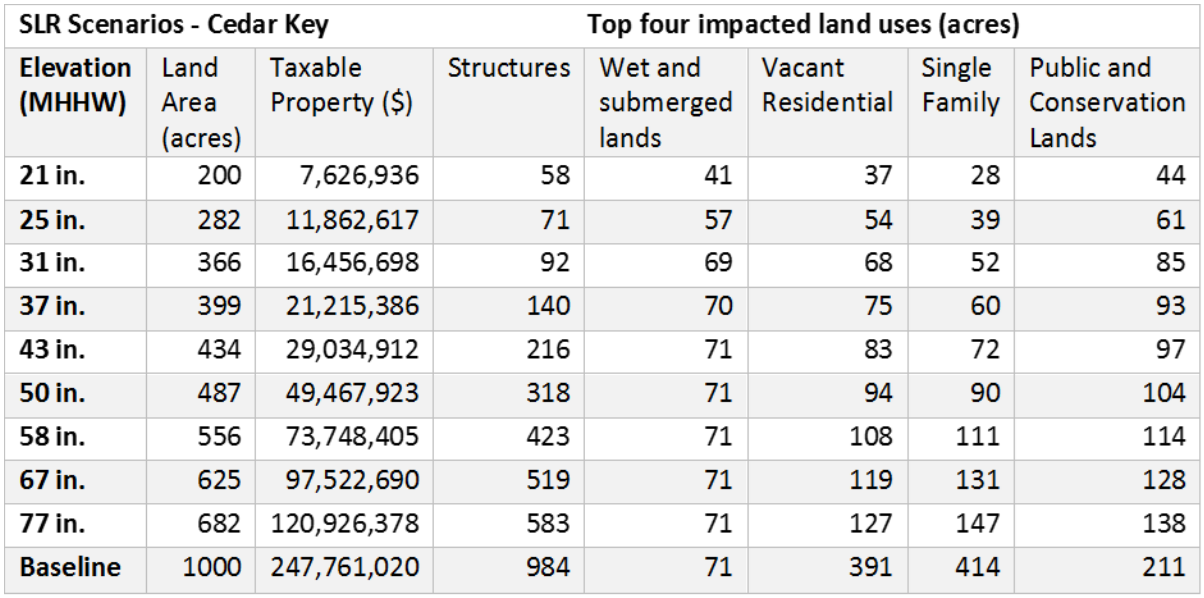
Timberland is the next most impacted land use in Levy County. 41,769 acres out of Levy County's 341,131 acres of timberland are located within the 77 inch coastal elevation zone. This only amounts to 12% of Levy County's timberland. For the timberland in the coastal elevation zones, the amount of acreage increases substantially after the 50 inch elevation zone, amounting to 63% of the acreage within the 50-77 inch elevation zones. This indicates that a SLR scenario of 43 inches or greater could begin to have serious impacts on the timberlands in the coastal elevation zones, thus indicating vulnerability to medium to higher range SLR projections. The amount of vacant residential property in the 77 inch coastal elevation zone is far less than the other two land uses (3,680 acres and 8% of Levy County's total vacant residential land use) and does not appear to have any tipping points or thresholds.

Cedar Key

The study area for Cedar Key included approximately 1000 acres of land. Within this area, 682 acres were located below 77 inches (Table 4-2), amounting to 68% of the existing land area in Cedar Key. The 0-21, 21-25, and 25-31 inch zones have substantially larger increases in land area compared to other elevation zones (Figures 4-5, 4-6, and 4-7). The largest net increase in land area was the 0-21 inch elevation zone, which makes sense given that it includes the largest range of elevations. The 21 inch elevation zone includes 200 acres, or 20% of Cedar Key's land area, which is more than double any other elevation zones. In proportion to the other elevation zones, the 21 inch elevation zone accounts for 29% of the low-lying land area. Regardless of the wider range of elevations included in the 21 inch elevation zone, a large amount of land is located in this zone. A significant amount of low-lying land is also located in 21-25 and 25-31 inch zones. 166 acres are located in the 10 inches between the 21 and 31 inch zone, accounting for an additional 16% of Cedar Key's land area and 24% of the low-lying land area.

Between the 21-31 inch elevation zones approximately 366 acres are vulnerable to a SLR scenario of 31 inches or more. 36% of Cedar Key's total land area and 53% of the low-lying land area is located below the 31 inch elevation zone. The amount of land area below the 31 elevation in relation to the rest of the low-lying land area indicates a cumulative threshold. Although the wide range of elevations within the 21 inch elevation zone inflates its numbers, it can still be viewed as a clear tipping point given the continued increase in low-lying land area in the 25 and 31 inch elevation zones. The elevations in these zones fall squarely within the low to mid-range SLR projections by 2100 and warrant further attention and study.

The rate of exposed land area decreases in the 31-37 and 37-43 inch elevation zones. These elevation zones account for 10% of the low-lying land area. The 43 inch elevation zone appears to be another clear tipping point based on the increases in low-lying land area in the 50-77 inch elevation zones, given that 27% of the total low-lying land area falls within the 50-77 inch elevation zones. The 50 inch elevation zone accounts for 487 acres of low-lying land (48% of the total land area) and increases an additional 53 acres from the previous 35 acre increase in the 43 inch elevation zone.



SLR Scenarios - Cedar Key				**Top four impacted land uses (acres)**			
Elevation (MHHW)	Land Area (acres)	Taxable Property ($)	Structures	Wet and submerged lands	Vacant Residential	Single Family	Public and Conservation Lands
21 in.	200	7,626,936	58	41	37	28	44
25 in.	282	11,862,617	71	57	54	39	61
31 in.	366	16,456,698	92	69	68	52	85
37 in.	399	21,215,386	140	70	75	60	93
43 in.	434	29,034,912	216	71	83	72	97
50 in.	487	49,467,923	318	71	94	90	104
58 in.	556	73,748,405	423	71	108	111	114
67 in.	625	97,522,690	519	71	119	131	128
77 in.	682	120,926,378	583	71	127	147	138
Baseline	1000	247,761,020	984	71	391	414	211

Table 4-2.Cedar Key land area, taxable property, structures, and top four impacted land uses in the elevation zones.

The 51-58 and 58-67 inch elevation zones add an additional 69 acres each (138 acres total and 13% of Cedar Key's total land area) of low-lying lands, accounting for 20% of the low-lying land area, while the 67-77 inch elevation zone decreases to 57 additional acres and accounts for 9% of the low-lying land area. The increases in low-lying land area in the 51-58 and 58-67 inch elevation zones indicates that both can be considered cumulative thresholds, but these thresholds are less substantial than those in the lower elevation zones. SLR scenarios above 43 inches stand to impact a significant amount of land area in Cedar Key. Such SLR scenarios fall within the higher range of SLR projections.

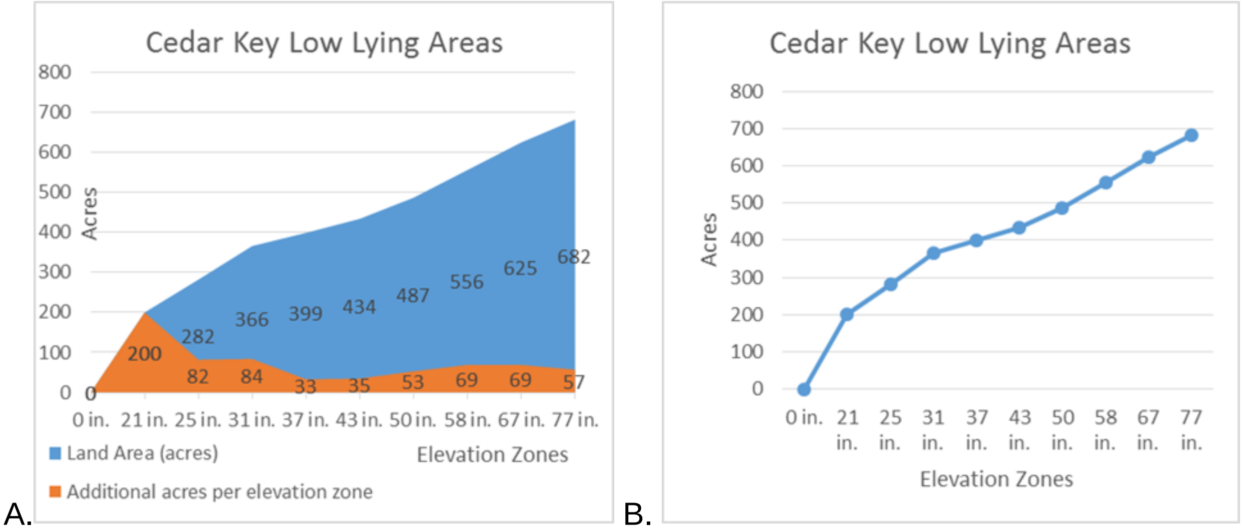


Figure 4-5. Cedar Key low-lying areas charts. A. Cedar Key low-lying lands area chart depicting the land area in the elevation zones plus each set of additional acres per elevation zone. B. Line chart depicting the increase in Cedar Key acreage per elevation zone.

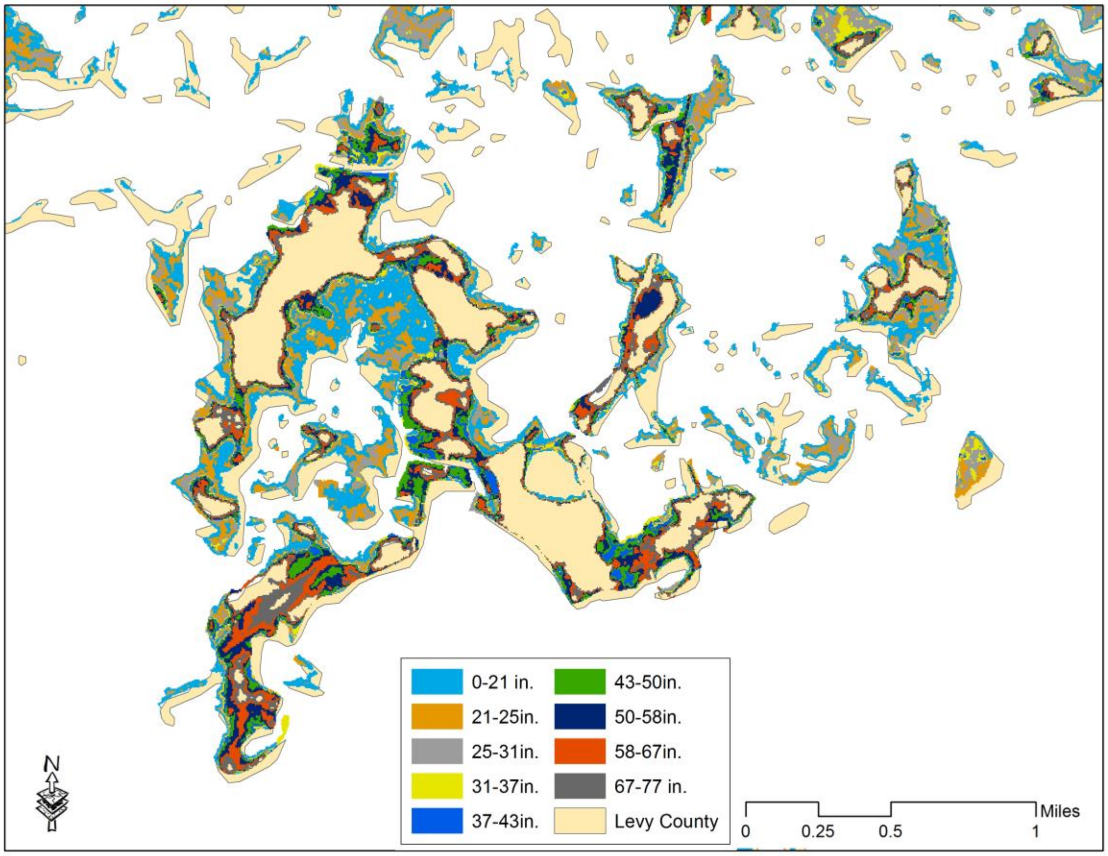


Figure 4-6. Map of Cedar Key low-lying areas.

The Cedar Key area has a total taxable property amount of $247,761,020 (Table 4-2). Within the 77 inch low-lying area elevation zone remains $120,926,378 of taxable property. Cedar Key has substantial assets within its low-lying areas, accounting for approximately 49% of the taxable property in the area. The amount of taxable property in Cedar Key's low-lying areas increases dramatically after the 43 inch elevation zone (Figure 4-5). The 21-43 inch elevation zones account for approximately 24% of the taxable property in Cedar Key's low-lying areas at a total taxable property value of $ 29,034,912, or 12% of the total taxable property in Cedar Key. Whereas the 50-77 inch elevation zones account for 76% of the taxable property in Cedar Key's low-lying areas and 37% of Cedar Key's total taxable property at value of $ 91,891,466. The 43 inch elevation zone is a clear tipping point due to the rapid increase in exposed assets after this elevation zone. Although there is a substantial portion of taxable property below the 43 inch elevation zone, SLR scenarios greater than 43 inches stand to significantly impact taxable property in Cedar Key. SLR scenarios higher than 43 inches could prove catastrophic based on the current state of development.

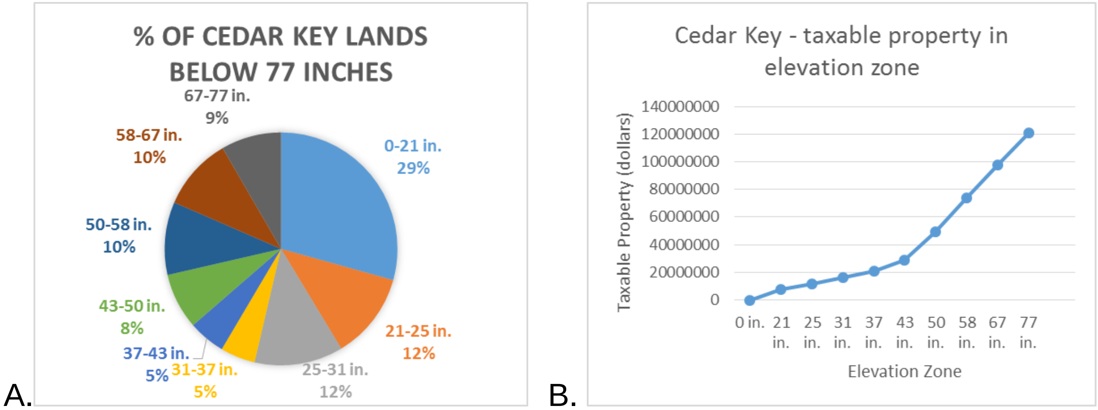


Figure 4-7. Cedar Key low-lying areas and taxable property charts. A. Pie chart depicting the proportion of Cedar Key land per elevation zone in relation to the total land area below 77 inches B. Line chart depicting the increase in the amount of Cedar Key's taxable property per elevation zones.

The top four land uses within Cedar Key's low-lying areas were single family, public and conservation lands, vacant residential, and wetlands (Table 4-2). These four land uses are also the top four total land uses in the Cedar Key area. In the lower elevation zones, up to 31inches, there is a sharp increase in the amount of wetlands, public and conservation lands, and vacant residential uses (Figure 4-8). These areas mostly constitute undeveloped areas of the saltwater marsh and wetlands. The amount of wetlands peaks at the 31 inch elevation zone, amounting to 69 acres with an additional 2 acres within the rest of the elevation zones (nearly 100% of the wetlands in the elevation zones). The rate of additional public and conservation lands also decreases at this zone too, amounting to 62% of the total lands in the elevation zones. It is likely that the 31 inch elevation zone is a cumulative threshold for undeveloped and natural areas in Cedar Key, leading to significant impacts if there was 31inches or greater of SLR.

36% of the single family land use acreage in Cedar Key is within the 77 inch elevation zone, amounting to 147 acres. There is a clear tipping point for singe family uses at the 43 inch elevation zone. 40% of the low-lying single family acreage is below this zone. The 43-77 inch elevation zones contain the remaining 60% of the single family acreage. The amount of single family uses in low-lying areas increases rapidly past this point, indicating that a SLR scenario of 43 inches or higher would begin to have serious impacts on single family land uses. Such scenarios fall within the medium to high range SLR projections. The amount of vacant residential and public and conservation lands begin to increase after 50 inch elevation threshold. The 50-77inch elevation zones amount to 26% of the low-lying vacant residential lands and 25% of the low-lying public and conservation lands. The increase in additional lands past the 43 inch elevation zone could constant an additional tipping point for each land use.

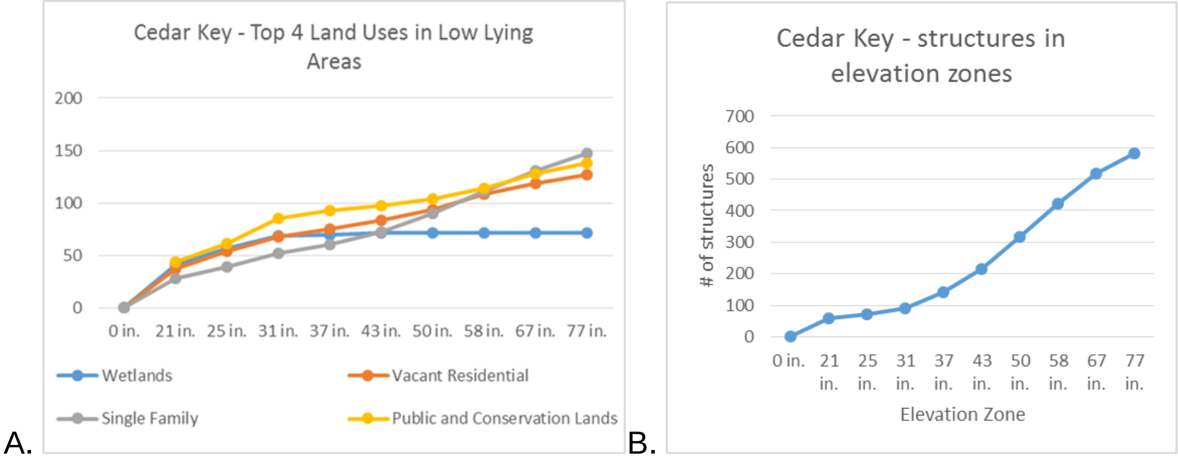


Figure 4-8. Cedar Key's top four impacted land use and structures chart. A. Line chart depicting the top four land uses in Cedar Key's low-lying areas. B. Line chart depicting the increase in the number of Cedar Key structures per elevation zone.

Based on the building footprint data, there are 984 structures within the Cedar Key area and 583 of these structures are located in low-lying elevation zones (Table 4-2), thus accounting for 59% of Cedar Key's building stocks in low-lying areas and 59% of the total building stock. The amount of structures in low-lying areas increase rapidly following the 37 inch elevation zone, indicating a clear tipping point. Only 16% of the structures in the Cedar Key low areas are below the 31 inch elevation zone, whereas 84% remain in the 37-77 inch elevation zones. The 50 and 58 inch elevation zones account for the largest increase in structures, amounting to 36% of the low-lying structures. SLR scenarios greater than 37 inches will stand to seriously begin to affect the developed areas in Cedar Key. SLR scenarios greater than 50 inches could be catastrophic to Cedar Key in its current state. A 37 inch SLR scenario is within the medium range of SLR projections, whereas a 50 inch SLR scenario is towards the higher end of the range. Any type of SLR scenario above 37 inches would likely lead to serious impacts to structures and the built environment as it is currently constituted. This indicate that Cedar Key's built environment is vulnerable to SLR scenarios greater than 37 inches.

Comparison of Levy County and Cedar Key

Although the scale between the two areas are very different, Levy County and Cedar Key both have thresholds within their lower elevation zones based on the amount of land area below 37 inches. Both places have substantial amounts of undeveloped and natural land areas below 37 inches in their coastal lands, most of which is in conservation. These will be the first areas impacted by SLR. These lands are extremely vulnerable to SLR scenarios between 21-37 inches (Figure 4-9, Figure 4-10). A 37 inch SLR scenario could potentially impact 86% of the coastal conservation lands in Levy

County. This means that coastal public and conservation lands are the most vulnerable areas in Levy County and Cedar Key. These areas could be mostly lost in the event of a 37 inch rise in sea level.

With regards to taxable properties impacted by SLR, both areas have a clear tipping point of 43 inches, but Cedar Key is more vulnerable to impacts to taxable property than Levy County in relation to relative total impacts to taxable property. SLR scenarios of 43 inches or higher could considerably impact the revenues generated by property values. 62% of Levy County's low-lying taxable property lies within the 50-77 inch elevation range (6% of all taxable property in Levy County) whereas 76% of the taxable property is in Cedar Key's low-lying areas in the same elevation zones (37% of all taxable property in Cedar Key). Most of Cedar Key and Levy County's valuable assets within the coastal elevation zone are located at the higher end of the elevation range, thus making them vulnerable to higher rates of SLR. For example, 25 inches of SLR would have significantly less of an impact on taxable property compared to a 50 inch rises in sea level. A 25 in SLR scenario would affect $11,862,617 worth of property in Cedar Key and $56,765,250 in Levy County compared to $49,467,923 in Cedar Key and $169,638,507 in Levy County in a 50 inch SLR scenario.

The biggest difference between the two areas is that future SLR in Cedar Key stands to have more of an impact on development and the built environment than in Levy County. The most impacted land uses in Levy County are conservation and working lands that are in a mostly natural state, whereas Cedar Key has significant amounts of land uses and developed areas related to human habitation and activities that are within the low-lying elevation zones. The majority of the developed areas in

Cedar Key are located outside the lower range elevation areas, making them less vulnerable to lower levels of SLR. 37 inches of SLR can be seen as a tipping point for the built environment in Cedar Key (Figure 4-11). SLR scenarios greater than 37 inches are likely to increase the impacts to developed areas and infrastructure in Cedar Key. SLR scenarios greater than 37 inches would likely impact residential areas in Cedar Key, as well as the downtown area. Such scenarios also stand to impact more people. Although Cedar Key's developed areas may be less vulnerable to lower end SLR projections, rises in sea level above 37 inches are likely to impact significant assets within the developed area in Cedar Key and require adaptation strategies to deal with impacts.

Cedar Key and Levy County both have areas that are likely to be affected by SLR. Conservation lands and natural areas below 37 inches are the most vulnerable areas to SLR impacts in both places. The quantity of conservation lands in Levy County within this elevation zone are a clear indicator of vulnerability and will require the implementation of adaptation strategies to deal with future impacts. Due to the amount of development on Cedar Key, there is an additional layer of vulnerability to consider. Relative to Levy County, larger rises in sea level exceeding 37 inches pose a severe risk to Cedar Key and its developed areas. Whereas the natural areas are vulnerable to smaller increases in sea level, the developed areas will likely be severely impacted by higher increases in sea level above 37 inches. Increases in sea level above 37 inches in Cedar will likely require adaptation of the built environment to deal with potential impacts, whereas, in the county, such increases would likely only require adaptation in natural areas.

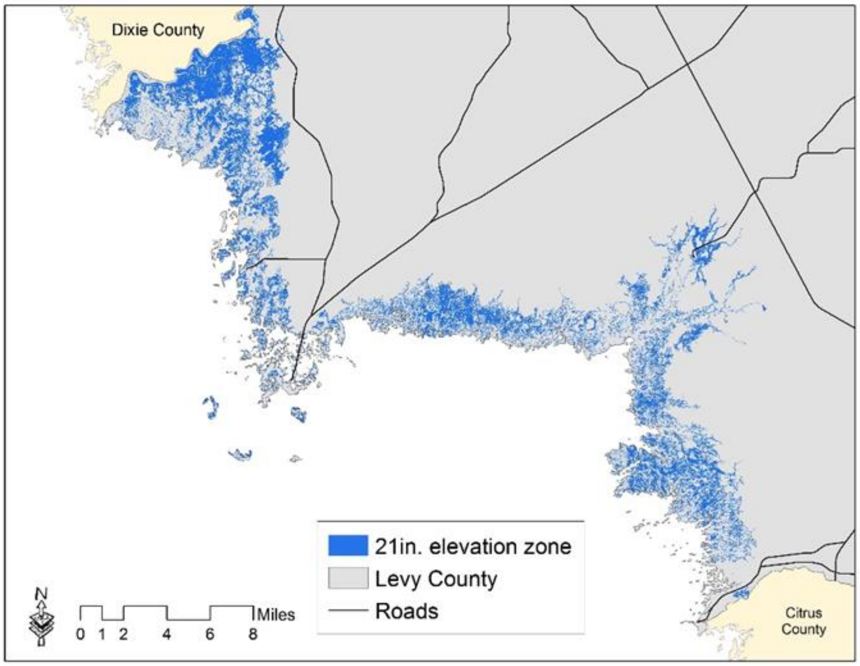


Figure 4-9. Map depicting low-lying lands in Levy County’s 21 inch elevation zone.

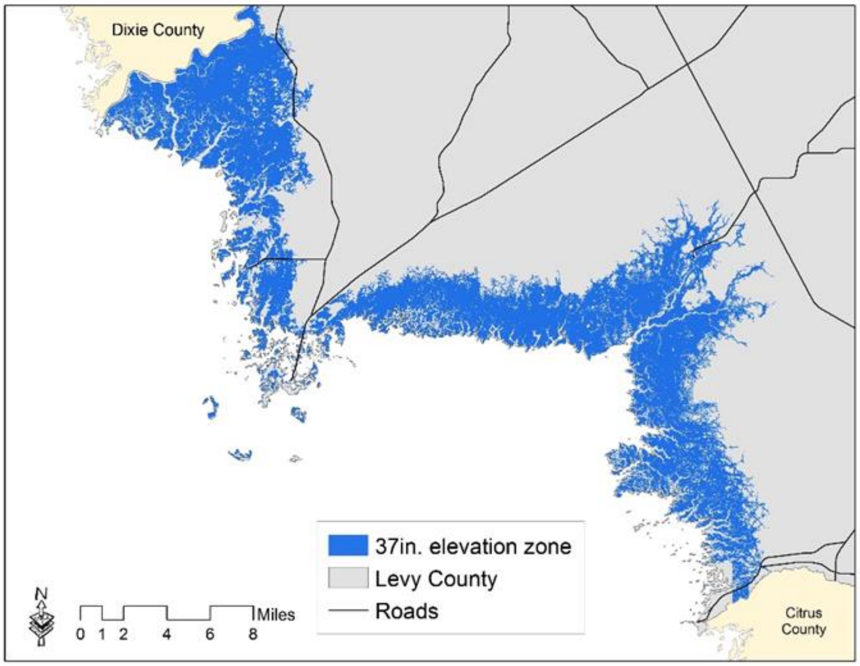


Figure 4-10. Map depicting low-lying lands in Levy County’s 37 inch elevation zone.

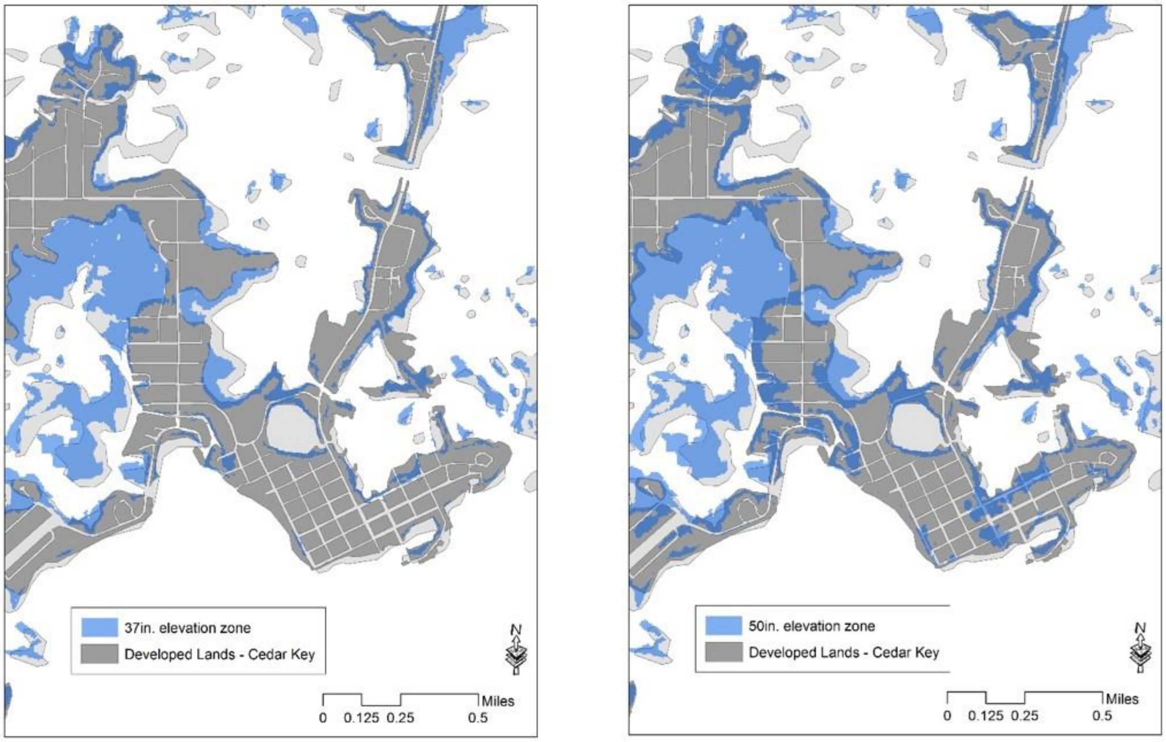


Figure 4-11. Map depicting Cedar Key 37 and 50 inch elevation zones.

CHAPTER 4
DISCUSSION

Dealing with Uncertainty in SLR Adaptation

The current practice of SLR vulnerability assessment is tied to SLR curves and projections (e.g., SEFRCCC, 2012; Deyle and Butler, 2013; UF GeoPlan, 2013), which are mired in uncertainty. Practice needs to reorient itself to build capacity to understand vulnerability in more familiar ways for stakeholders as a means to cope with uncertainty and to build capacity to plan for SLR. Understanding the landscape, and the assets within it, can serve as that initial point to begin the capacity building and learning process to both assess vulnerability and initiate the adaptation planning process. Identifying tipping points and thresholds based on local topography may be one way to manage uncertainty on the front-end of the vulnerability analysis and adaptation planning process, thus enabling a community to better build its capacity for understanding threats to its current system. A better working knowledge of the landscape can help stakeholders begin to contextualize impacts and vulnerability by helping them understand the distribution of low-lying lands in the coastal landscape, the assets located in these areas, and the incremental changes in vulnerability as elevations increase or decrease (which provides a better understanding of inundation dynamics).

Once tipping points and thresholds in the landscape are identified, these factors can be related to SLR scenarios and serve as a baseline understanding of SLR vulnerability. Relating vulnerability to low-lying areas and linking those areas to thresholds that require action, rather than to time sensitive SLR projections that are couched in uncertainty, may help vulnerability analyses be more useful to end-users during preliminary stages of analysis where users may not have the requisite understanding of SLR adaptation planning to comprehend the highly nuanced and complex nature of climate change science and modeling. Visual and graphic representations of data – such as illustrating tipping points and thresholds in maps, graphs, and charts – can serve as reference points that provide context to vulnerability and potential impacts. Once these factors are better understood, then planning can proceed to deal with the more uncertain aspects of SLR adaptation and vulnerability, such as SLR curves and time horizons, to better understand how vulnerability changes over time.

Using local topography to identify thresholds and tipping points gives decision-makers and researchers information that is derived from the local area, and based on local conditions, thus establishing a familiar baseline of vulnerability that gives stakeholders a foundation to build upon. Communities beginning the SLR adaptation planning or vulnerability assessment process by applying a wide range of scenarios based on local topography can avoid potentially contested discussions about which SLR projections to employ – which must overcome social, institutional, economic, informational, and cultural constraints (Moser et al., 2012) – and focus on the vulnerabilities that are inherent in their community. If the community understands what levels of SLR it is vulnerable to in a general sense, it can begin to address more specific or detailed issues that are couched in more uncertainty and it can begin to establish planning and policy priorities based on their exiting knowledge of vulnerability.

Based on the results of the tipping point and thresholds analysis in Levy County and Cedar Key, it is clear the two areas are vulnerable to several different levels of SLR based on potentially affected assets. The undeveloped coastal areas, mostly in conservation, are highly vulnerable to rises in sea level greater than 21 inches. The large concentration of lands between 21 and 37 inches of elevation provide a solid basis of certainty for stakeholders to understand the levels of SLR these areas are vulnerable to and require adaptation. By establishing a baseline for vulnerability, the institutions governing vulnerable areas can begin the process of further examination to deal with vulnerability and assess adaptation options, such as analyzing how policy is affected or where policy needs to be updated to reflect vulnerability and facilitate adaptation. This notion of establishing a baseline for vulnerability can be similarly applied to the developed areas in Cedar Key, which begin to be significantly affected by changes in sea level exceeding 37 inches, or to taxable property in both Levy County and Cedar Key, which have clear tipping points at 43 inches of SLR. Establishing what levels of SLR a community is at risk to and how assets may be impacted helps contextualize community vulnerability.

Additionally, once this baseline of vulnerability is established, further analyses can be employed that examine finer scales of analysis and time sensitivity to SLR impacts, such as impacts to infrastructure and existing capital investments, the costs of adaptation, or when SLR impacts can be expected to happen. To help cope with uncertainty and vulnerability, communities need to begin a new way of thinking that reframes decisions within the context of future change, so that hazard vulnerability and SLR adaptation are a regular consideration during decision-making and planning, such an approach can help ensure that wise decisions for future investments are made. Having a baseline understanding of vulnerability can facilitate this process. Although

SLR is a slow process relative to other processes that affect community planning and decision-making, initiating dialogue as soon as possible and examining existing and potential vulnerabilities can help places like Levy County, Cedar Key, and other coastal communities build their capacity to deal with the issue, perpetuating a path that initiates actions and adaptive responses that bolster the future health and prosperity of coastal communities.

CHAPTER 6
CONCLUSION

This thesis was able to use the landscape and low-lying elevation areas hydrologically connected to the coast to identify tipping points and thresholds in Levy County and Cedar Key. A wide range of elevation areas (scenarios) were used to accommodate the uncertainty surrounding SLR projections, ranging from 21 to 77 inches. Within Levy County, 15 % of the land area and 8% of the taxable property is coastal land below 77 inches in elevation. Of the total low lying land area, 52% is public and conservation lands (accounting for 40% of the total public and conservation lands in Levy County). Public and conservation lands are the most impacted land use in Levy County. 55,611 acres of Levy County’s 135,179 acres of public and conservation lands are located within the 77 inch low-lying coastal elevation zone, amounting to 41% of the total public and conservation land in the county. 35% of the county’s conservation lands are within the 37 inch elevation zone, amounting to 47,699 acres and 86% of the Levy County’s coastal conservation lands. A 21 inch or greater increase in sea level can lead to significant impacts to coastal public and conservation lands in Levy County, while a 37 inch rise could prove devastating. Low-lying taxable property in coastal Levy County reached a tipping point at the 43 inch elevation zone. 62% of the low-lying taxable property (8% total Levy County taxable property) lies within the 50-77 inch elevation range. Increases in sea level above 43 inches would begin to negatively impact properties in the low-lying elevation zone.

Within the Cedar Key study area, 68% of the land area is below 77 inches in elevation. Additionally, 49% of the taxable property and 59% of the structures in Cedar

Key are below 77 inches in elevation, but a majority of this is located above the 37 inch elevation zone. 100% of the wetlands acreage, 65% of the public and conservation lands acreage, 36% of the single family acreage, and 33% of the vacant residential acreage are below the 77 inch elevation zone in Cedar Key. The undeveloped and natural areas (wetlands and conservation lands) have a tipping point at 21 inches. SLR exceeding 21 inches would begin to dramatically affect these areas. A second tipping point for land area exists at the 43 inch elevation zone. 27% of the total low-lying land area falls within the 50-77 inch elevation zones. This is the area where most of the development in Cedar Key is located. The developed area’s tipping point is at 37 inches. SLR exceeding 43 inches would likely have dramatic impacts on the built environment and require adaptation in the built environment. 76% of the taxable property in the low-lying areas in Cedar Key are located between the 50 and 77 inch elevation zones (37% of all taxable property in Cedar Key). A 58 inch rise of sea level would affect 30% of the taxable property in Cedar Key and 43% of the structures in Cedar Key. Based on the nature of vulnerability in Cedar Key, planning for future SLR should account for impacts to both the developed and undeveloped areas and not focus on one tipping point.

Understanding how incremental changes in elevation can affect vulnerability to SLR may be a useful approach for communities beginning the process of assessing vulnerability to SLR and adaptation planning. Such an approach provides users the opportunity to relate vulnerability to the local landscape and contextualize how the low-lying areas and assets vulnerable to SLR are distributed throughout a community. An approach that builds community understanding of their vulnerabilities to SLR can be leveraged by planners and researchers to build community capacity to plan for and adapt to future SLR.

To respond to an uncertain future and the challenges associated with planning for SLR, the field of planning must adapt itself. Current planning and decision-making paradigms need to become more flexible and robust to respond to growing uncertainty. Planners need to become more assertive in changing current perspectives to reflect this and they must facilitate communication and education that build capacity to plan for SLR and climate change. Climate change and SLR are a true test of society's ability to plan for its future. Climate change and SLR simply further intensify existing pressures and planning problems. It is not only important to make planning for SLR adaptation (and climate change) a priority for the sake of vulnerable communities, but it also important because it genuinely tests our ability to plan for and manage our future, which are the ultimate goals of planning. Highlighting the multi-faceted, complex, and highly nuanced nature of SLR adaptation planning and making such issues pervasive through the field of planning, may provide a nexus for which the field of planning can improve its ability to plan for systems as a whole (e.g., integrated social-ecological systems) and, ultimately, produce results that truly foster the long term health and prosperity of communities. It is not a challenge for the faint of heart, but the reality is that someone has to do something help communities cope with future change, and the field of planning is certainly equipped to meet the challenge and rise to the occasion.

LIST OF REFERENCES

Cantanese Center. (2005). Cantanese Center Florida Atlantic University prepared for the Florida Department of Environmental Protection: economics of beach tourism in Florida. Retrieved 2009 http://www.dep.state.fl.us/beaches/publications/pdf/phase2.pdf99–106.

Castaneda, H., & Putz, F.E. (2007). Predicting sea-level rise effects on a coastal nature preserve on the Gulf coast: a landscape perspective. *Florida Science*, 70,166–175.

Chakraborty, A., Kaza, N., Knaap, G.J., & Deal, B. (2011). Robust Plans and Contingent Plans: Scenario Planning for an Uncertain World. *Journal of the American Planning Association, 77(3), 251-266.*

Cooper, H.M., Fletcher, C.H., Chen, Q., & Barbee, M.M. (2013). Sea-level rise vulnerability mapping for adaptation decisions using LiDAR DEMs. *Progress in Physical Geography,* 37(6), 745–766.

DeSantis, L.R.G., Bhotik, S., Williams, K., Putz, F.E. (2007). Sea-level rise and drought interactions acceler- ate declines of coastal forests on the Gulf Coast of Florida, USA. *Global Change Biology*, 13, 2349–2360.

Deyle, R., & Butler, W.H. (2013). Resilience Planning in the Face of Uncertainty: Adapting to Climate Change Effects on Coastal Hazards. Chapter in Disaster Resiliency: Interdisciplinary Perspectives.

Florida Oceans and Coastal Council. (2010). Climate change and sea-level rise in Florida: an update of "The effects of climate change on Florida's ocean and coastal resources." [2009 Report]. Tallahassee, Florida. http://www.floridaoceanscouncil.org/reports/Climate_Change_and_Sea_Level_Rise.pdf

Frazier, T., Wood, N., & Yarnal, B. (2010). Influence of Future Sea Level Rise on Societal Vulnerability to Hurricane Storm-Surge Hazards, Sarasota County, Florida. *Applied Geography,* 30, 490-505.

Gersonius, B., Ashley, R., Pathirana, A., & Zevenbergen, C. (2013). Climate change uncertainty: building flexibility into water and flood risk infrastructure. *Climatic Change*, 116, 411–423.

Gesch, D.B. (2009). Analysis of lidar elevation data for improved identification and delineation of lands vulnerable to sea-level rise. *Journal of Coastal Research*, SI53, 49–58.

Gesch, D.B. (2013). Consideration of Vertical Uncertainty in Elevation-Based Sea-Level Rise Assessments: Mobile Bay, Alabama Case Study. *Journal of Coastal Research,* 63, 197–210.

Gesch, D.B., Gutierrez, B.T., & Gill, S.K. (2009). Coastal elevations. In: Titus, J.G. (ed) *Coastal sensitivity to sea-level rise: a focus on the Mid-Atlantic Region. A report by the U.S. climate change science program and the subcommittee on global change research*, U.S. Environmental Protection Agency, Washington, 25–42.

Geselbracht, L., Freeman, K., Kelly, E., Gordon, D.R., & Putz, F.E. (2011). Retrospective and prospective model simulations of sea level rise impacts on Gulf of Mexico coastal marshes and forests in Waccasassa Bay, Florida. *Climate Change*, 107(1–2), 35–57.

Grinsted, A., Moore, J. C., & Jevrejeva, S. (2009). Reconstructing sea level from paleo and projected temperatures 200 to 2100AD, *Climate Dynamics*, doi:10.1007/s00382-008-0507-2.

Haasnoot, M., Kwakkel, J.H., Walker, W.E., Maat, J.T. (2013). Dynamic adaptive policy pathways: a method for crafting robust decisions for a deeply uncertain world. *Global Environmental Change*, 23, 485–498.

Horton, R., Herweijer, C., Rosenzweig, C., Liu, J., Gornitz, V., & Ruane, A.C. (2008). Sea level rise projections for current generation CGCMs based on the semi-empirical method, *Geophysical Research Letters*, 35 (L02715), doi: 10.1029/2007GL032486, 2008.

IPCC (2007a) Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

IPCC, (2012). Summary for Policymakers. In: *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation* [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, and New York, NY, USA, pp. 1-19.

Jevrejeva, S., Moore, J.C., Grinsted, A. (2010). How will sea level respond to changes in natural and anthropogenic forcings by 2100? *Geophysical Research Letters,* 37.

Jevejeva, S., Moore, J.C., Grinsted, A. (2012) Sea Projections to AD2500 with a new generation of climate change scenarios, *Global and Planetary Change*, 80-81, 14-20.

Katsman, C.A., Sterl, A., Beersma, J.J., van den Brink, H.W., Church, J.A., Hazeleger, W., Kopp, R.E., Kroon, D., Kwadijk, J., Lammersen, R., Lowe, J., Oppenheimer, M., Plag, H-P., Ridley, J., von Storch, H., Vaughan, D.G., Vellinga, P., Vermeersen, L.L.A., van de Wal, R.S.W., & Weisse, R. (2011). ‘Exploring high-end scenarios for local sea level rise to develop flood protection strategies for a low-lying delta-the Netherlands as an example'. *Climatic Change*, 109(3-4), 617-645.

Kettle, N.P. (2012). Exposing Compounding Uncertainties in Sea Level Rise Assessments. *Journal of Coastal Research*, 28(1), 161–173.

Kiem, S.A., & Austin, E.K. (2013). Disconnect between science and end-users as a barrier to climate change. *Climate Research*, 58, 29-41.

Kirchhoff, C.J., Lemos, M.C., & Dessai, S. (2013). Actionable Knowledge for Environmental Decision Making: Broadening the Usability of Climate Science. *Annual Reviews of Environment and Resources*, 38, 393-414.

Kwadijk, J.C., Haasnoot, M., Mulder, J.P., Hoogvliet, M. M., Jeuken, A. B., van der Krogt, R. A., van Oostrom, N.G.C., Schelfhout, H.A., van Velzen, E.H., van Waveren, H., & de Wit, M.J.M. (2010). Using adaptation tipping points to prepare for climate change and sea level rise: a case study in the Netherlands. *Climate Change,* I, 729-740. Retrieved from http://www.deltares.nl/xmlpages/tan/files?p_file_id=14123.

Lee, J.J. (2012, July 3). Update: Revised North Carolina Sea Level Rise Bill Goes to Governor*. Science Magazine*. Retrieved from http://news.sciencemag.org/climate/2012/07/update-revised-north-carolina-sea-level-rise-bill-goes-governor

Leiserowitz, A., Maibach, E., Roser-Renouf, C., Feinberg, G., & Howe, P. (2013). Global Warming's Six Americas in September 2012. Yale University and George Mason University. New Haven, CT: Yale Project on Climate Change. http://environment.yale.edu/climate/files/Six-Americas-September-2013.pdf

Marshall, A., Robinson, L., & Owens, M.A. (2011) Coastal construction trends in response to coastal erosion: an opportunity for adaptation. *Journal of Coastal Conservation,* 15(1), 61-72.

Mastrandrea, M.D., Heller, N.E., Root, T.L., Schneider, S.H. (2010) Bridging the gap: linking climate-impacts research with adaptation planning and management. *Climatic Change*, 100, 87–101.

McLeod, E., Poulter, B., Hinkel, J., Reyes, E., & Salm, R. (2010). Sea-level rise impact models and environmental conservation: a review of models and their applications. *Ocean & Coastal Management*, 53, 507–517.

Meehl, G.A., Stocker, T.F., Collins, W.D., Friedlingstein, P., Gaye, A.T., Gregory, J.M., Kitoh, A., Knutti, R., Murphy, J.M., Noda, A., Raper, S.C.B., Watterson, I.G., Weaver, A.J., & Zhao, Z.-C. (2007). Global climate projections. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, & H. L. Miller (Eds.), *Climate change 2007: The physical science basis. Contribution of*

Working Group I to the fourth assessment report of the Intergovernmental Panel on Climate Change, New York: Cambridge University Press, 747-845.

Mitchum, G. (2011). Sea Level Changes in the Southeastern United States: Past, Present, and Future. Florida Climate Institute and Southeast Climate Consortium. http://www.seclimate.org/pdfpubs/201108mitchum_sealevel.pdf

Moser, S.C. (2005). Impact assessments and policy responses to sea-level rise in three US states: An exploration of human-dimension uncertainties. *Global Environmental Change*, 15(4), 353-369.

Moser, S.C., & Ekstrom, J.A. (2010). A framework to diagnose barriers to climate change adaptation. *Proceedings of the National Academy of Science of the United States of America*, 107(51), 22026−22031.

Moser, S.C, Williams, S.J., & Boesch, D.F. (2012). Wicked Challenges at Lane's End: Managing Coastal Vulnerability Under Climate Change. *Annual Review of Environment and Resources* (37): 51-78.

Murdukhayeva, A., August, P., Bradley, M., LaBash, C., & Shaw, N. (2013). Assessment of inundation risk from sea level rise and storm surge in northeastern coastal national parks. *Journal of Coastal Research*, 29 (6a), 1 – 16.

National Oceanic and Atmospheric Administration (NOAA) Coastal Services Center. (2010a). "Mapping Inundation Uncertainty." Charleston, SC: NOAA Coastal Services Center.

NOAA Coastal Services Center. (2010b). New Mapping Tool and Techniques for Visualizing Sea Level Rise and Coastal Flooding Impacts. NOAA Technical Report. Silver Springs, MD.

NOAA Coastal Services Center. (2012a). "Lidar 101: An Introduction to Lidar Technology, Data, and Applications." Revised. Charleston, SC: NOAA Coastal Services Center.

NOAA Coastal Services Center. (2012b). Mapping Coastal Inundation Primer. NOAA Technical Report. Charleston, SC.

National Research Council (NRC). (1987). Responding to Changes in Sea Level: Engineering Implications. National Academy Press: Washington, D.C.

NRC. (2011). Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia. National Academy Press: Washington, D.C.

NRC. (2012). Sea-Level Rise for the Coasts of California, Oregon, and Washington: Past, Present, and Future. Washington, DC: The National Academies Press.

Norgaard, K.M. (2011). Climate change as background noise in the United States in *Living in Denial: Climate Change, Emotions, and Everyday Life*. Cambridge, MA: MIT Press. 177-205.

Pfeffer, W.T., Harper, J.T., & O'Neel, S. (2008). Kinematic constraints on glacier contributions to 21st century sea-level rise*. Science,* 321, 1340–1343.

Poulter, B. & Halpin, P.N. (2008). Raster modeling of coastal flooding from sea level rise. *International Journal of Geographical Information Science*, 22(2), 167–182.

Quay, R. (2010). Anticipatory governance: A tool for climate change adaptation*. Journal of American Planning Association*, 76(4), 497–511.

Raabe, E., Streck, A.E., & Stumpf, R.P. (2004). Historic Topographic Sheets to Satellite Imagery: A Methodology for Evaluating Coastal Change in Florida's Big Bend Tidal Marsh. U.S. Geological Survey Open-File Report, 02–211 (as revised in 2012). Retrieved from http://pubs.usgs.gov/of/2002/of02-211/

Rahmstorf, S., Perrette, M., & Vermeer, M. (2012). Testing the robustness of semi-empirical sea level projections. *Climate Dynamics*. 39(3-4), 861-875.

Ruppert, T., Ankersen, T., Covington, C., Feinberg, R., Huang, T., & Miller, A. (2008). Eroding long-term prospects for Florida's beaches: Florida's Coastal Management Policy. University of Florida College of Law and UF Institute for Food and Agricultural Sciences.

Russil, C., & Nyssa, Z. (2009). The tipping point trend in climate change communication. *Global Environmental Change*, 19(3), 336-344.

Sapuan, M. (2012) Using uncertain sea level rise projections: adaptation in Rotterdam and New York. (Master's thesis, Massachusetts Institute of Technology). Retrieved from http://dspace.mit.edu/handle/1721.1/73800.

Schmid, K., Hadley, B., & Waters, K. (2014). Mapping and Portraying Inundation Uncertainty of Bathtub-Type Models. *Journal of Coastal Research,* 30(3), 548 – 561.

Sea Level Rise and Coastal Flooding Impacts Viewer. National Oceanic and Atmospheric Administration, n.d. Web. 05 June 2014. http://www.csc.noaa.gov/digitalcoast/tools/slrviewer

Sea Level Scenario Sketch Planning Tool. University of Florida GeoPlan Center, n.d. Web. 05 June 2014. http://sls.geoplan.ufl.edu/

Southeast Florida Regional Climate Change Compact (SEFRCCC) Inundation Mapping and Vulnerability Assessment Work Group. (2012). Analysis of the Vulnerability of Southeast Florida to Sea Level Rise.

Strauss, B., Ziemlinski, R., Weiss, J., & Overpeck, J.T. (2011). Tidally-adjusted estimates of topographic vulnerability to sea level rise and flooding for the contiguous United States. *Environmental Research Letters*, 7 014033.

United States Army Corps of Engineers (USACE). (2011). *Coastal storm risk management national economic development manual.* http://www.corpsnedmanuals.us/Includes/PDFs/2011-R-09.pdf

UF GeoPlan. (2013). Development of a Geographic Information System Tool for the Preliminary Assessment of the Effects of Predicted Sea Level and Tidal Change in Transportation Infrastructure. Final Report. Florida Department of Transportation. Retrieved from ftp://ftp.sls.geoplan.ufl.edu/pub/sls/docs/FDOT_BDK75_977-63_Final_Technical_Report.pdf

Vermeer, M., & Rahmstorf, S. (2009). Global sea level linked to global temperature. *Proceedings of the National Academy of Science of the United States of America*, 106, 21527–21532.

Weiss, J.L., Overpeck, J.T., Strauss, B. (2011). Implications of recent sea level rise science for low-elevation areas in coastal cities of the conterminous U.S.A. *Environmental Research Letters*. 7 014033.

Werners, S.E., Pfenninger, S., van Slobbe, E., Haasnoot, M., Kwakkel, J.H., & Swart, R.J. (2013). Thresholds, tipping and turning points for sustainability under climate change. *Environmental Sustainability*, 5, 334-340.

Wilby, R. L., & Dessai, S. (2010, July). Robust adaptation to climate change. *Weather*, 65 (7), 180-185.

Yin, J. (2012) Century to multi-century sea level rise projections from CMIP5 models, *Geophysical Research Letters*, 39.

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. *Climatic Change,* 107(1–2): 129–146.

BIOGRAPHICAL SKETCH

Sean Reiss was born and raised in Ocala, Florida. Growing up in horse country instilled in Sean a great respect and appreciation for the landscape and its interactions with people. He received a bachelor’s degree in history from the University of Florida in 2009, focusing on Florida environmental history. His interest in Florida’s legacy of despoliation and rapid suburbanization of paradise led him to continue his education by pursuing a master’s degree in urban and regional planning from the University of Florida. In his time at the Department of Urban and Regional Planning, Sean has had the opportunity to explore topics and research interests such as innovative approaches to planning, planning for linked-ecological systems, capacity building for planning and community resilience, rural planning, and sea level rise adaptation planning. He hopes to build off of his work at the University of Florida and carry it forward into a professional career that improves community health and prosperity today, tomorrow, and well into the future.