Climate Change in Coastal Areas in Florida: Sea Level Rise Estimation and Economic Analysis to Year 2080

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Table of Contents

List of Tables

List of Figures

Executive Summary

Florida's coastal resources provide many services, which contribute to the livelihood of Florida's economy and its residents. Climate change and rising sea levels threaten the sustainability of these resources by increasing the likelihood of flooding, saltwater intrusion, inundation of low-lying lands, and erosion of beaches and barrier islands. Previous studies have emphasized global trends in sea level rise[1] (SLR) and the impacts of these trends on coastal resources. This study, however, estimates regional SLR trends and increases in the risks of inundation and storm surge associated with increasing sea level in six Florida counties: Dade, Dixie, Duval, Escambia, Monroe, and Wakulla. The counties were selected as they represented diverse geographic locations around the state, including urban and rural counties, and because of the availability of data on storm surge.

This study uses current estimates of SLR from Florida State University's (FSU's) Beaches and Shores Resource Center (BSRC) and 2001 estimates from the Intergovernmental Panel on Climate Change (IPCC)[2] to evaluate the effect of SLR on the six coastal counties. The results show projected trends in storm surge flood return periods associated with hurricanes (probable change in the frequency of 100-year hurricane-induced storm surge), damage costs associated with flooding from major storm events, and the value and area of land at risk. While these findings do not account for adaptive strategies, they still provide valuable information about potential impacts and resources that are put at risk from SLR. The following section provides a summary of FSU's projection of SLR in Florida and its analyses of hurricane return period, damage costs, and property values at risk.

Projected Sea Level Rise in Florida. SLR estimates from the IPCC represent global estimates, which do not account for regional variations in SLR. These regional estimates take into account the relative rise in sea level at a site, i.e., relative to the site ground elevations (e.g., accounting for ground subsidence or rise). In order to understand the regional impacts of climate change around Florida, FSU developed regional estimates of SLR in the six coastal counties. The FSU BSRC used historical tidal gauge data from six gauge stations to estimate SLR in the years from 2006 to 2030 and 2080. Although there was a wide distribution of gauge sites across the Florida

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[1] Sea level rise: An increase in the mean level of the ocean. Eustatic sea level rise is a change in global average sea level brought about by an increase in the volume of the world ocean. Relative sea level rise occurs where there is a local increase in the level of the ocean relative to the land, which might be due to ocean rise and/or land level subsidence. Available: http://www.ipcc.ch/pdf/glossary/ar4-wg2.pdf.

[2] In 2007, the IPCC slightly lowered SLR estimates but concluded that because of uncertainties about the melting of major ice sheets such as those in Greenland, it is difficult to project the upper limit of SLR.

Peninsula, the projected SLR in years 2030 and 2080 did not vary substantially from site to site. FSU's 2030 estimates ranged from 0.23 feet (ft) [0.07 meters (m)] in Dixie to 0.29 ft (0.09 m) in Escambia, and its 2080 estimates ranged from 0.83 ft (0.25 m) in Duval to 1.13 ft (0.34 m) in Escambia. These estimates represent a lower-end estimate of SLR in Florida. The IPCC's estimates, which range from 0.33 to 2.13 ft (0.1 to 0.65 m) in 2080, represent a higher-end estimate of SLR.[3] FSU uses both the low-end and high-end estimates in its calculation of hurricane return period and damage costs.

In addition to estimating regional SLR in six Florida counties, FSU explored SLR forecasting methods beyond the traditional polynomial linear estimation methods. FSU tested three forecasting methods: linear first order, linear second order, and nonlinear exponential. The FSU BSRC used a second order linear approach for the final analysis to estimate potential damage costs due to SLR. This approach includes a higher-order term that accounts for acceleration in SLR, which is in accord with climate modeling scenarios that project an exponential rise in sea levels due to greenhouse gas (GHG) effects.

Hurricane return period. FSU's Center for Economic Forecasting and Analysis (CEFA) used storm return period and storm surge data from the Federal Emergency Management Agency's (FEMA's) Flood Insurance Studies as a baseline for hurricane return period (i.e., the average number of years between events) analysis. In this context, hurricane return period relates only to extreme water levels and does not consider changes in other important damage parameters, such as wind and precipitation. These data were used to predict storm surge associated with projected changes in future hurricane return periods for the years 2030 and 2080 assuming rising sea levels. FSU BSRC used its county-specific SLR estimates and IPCC's high estimates for the years 2030 and 2080. All SLR scenarios used here show a dramatic decreasing trend in hurricane return period. For instance, Hurricane Wilma resulted in a 7-foot high surge in Dade County and, according to FEMA's study, has a 76-year return period. Given an SLR of 1.02 ft (0.31 m), the return period for the same 7-foot (2.13 m) storm surge would be reduced from 76 years to 21 years (i.e., a similar storm surge could be expected, on average, to occur every 21 years instead of every 76 years). Given an SLR of 2.13 ft (0.65 m), the return period for the same 7-foot (2.13 m) storm surge would be reduced from 76 years to 5 years (e.g., a similar storm surge could be expected to occur, on average, every 5 years instead of every 76 years). This means that a storm surge similar to Hurricane Wilma would happen with about 15 times the frequency experienced in the past. The implications of these findings could be important for decisions of businesses and residents in these counties.

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3. Note: the IPCC estimates given are eustatic and are being compared to relative values estimated by the authors.

Damage Cost Assessment. Using data from the Florida Office of Insurance Regulation and from the Hurricane Summary Data Reports, FSU CEFA located storm surge data and historical damage costs for eight hurricanes between 2004 and 2005. The damage costs for these hurricanes ranged from $661 in Dixie County (Hurricane Rita) to $2.21 billion in Dade County (Hurricane Wilma). FSU CEFA used a simple extrapolation from these historical damage cost data to estimate future damage costs in each of the counties using FSU BSRC and IPCC's high SLR estimates for the year 2080. For each county, FSU CEFA selected a representative hurricane to estimate future damage costs.

The results show that damages in each of the counties could be much higher as sea levels rise in the future. For example, when Hurricane Wilma hit Dade County in 2005, the damage costs were approximately $2.21 billion. If a hurricane with a similar storm surge hit in 2080, assuming a SLR of 2.13 ft (0.65 m), the damage costs could be as high as $2.9 billion. These results do not account for changes in population or the built environment, nor do they reflect any adaptive behaviors people could take in response to the rising sea levels. On the other hand, the estimate does not account for potential increases in the strength of hurricanes because of climate change and the associated height of storm surge.

Property Value Assessment. Using IPCC's SLR estimates and current property value data, Industrial Economics, Inc (IEc). and FSU developed a geographic information system (GIS) elevation model to identify the area, value, and per-acre value of land at risk under different IPCC SLR scenarios for three of the six counties (Dade, Duval, and Escambia counties). IEc also ran the model using FSU's county-specific SLR estimates.

As the IPCC SLR scenarios increase from 0.16 ft (0.05 m) to 2.13 ft (0.65 m), the value of land at risk and acreage of land at risk also increase in all three counties. In Dade County, for example, the value of land at risk under the 0.16-foot (0.05 m) scenario is $1.05 billion; in the 2.13-foot (0.65 m) scenario, the value increased to $12.3 billion (using current property values).

These results do not include any escalation of property values as coastal population and incomes increase and do not incorporate any adaptive responses to climate change and SLR (e.g., relocation of homes). Even so, this property value assessment helps describe the extent and value of land at greatest risk due to SLR, and how resources at risk vary with different rates of SLR over time.

Introduction

Florida's economy and way of life depend on the long-term sustainability of its coastal resources. Eighty percent of Floridians live or work in one of the state's 35 coastal counties (Hauserman, 2006). In 2005, nearly 86 million tourists visited Florida, generating more than $63 billion in revenue (roughly 10% of Florida's economic output) and creating more than 944,000 jobs (Hauserman, 2006).

The state's low-lying lands and predominantly coastal population make it particularly vulnerable to climate change and sea level rise (SLR). Titus and Richman (2001) found that Florida was one of the four most vulnerable states along the Atlantic and Gulf coasts.[4] Florida is the fourth most populated state (17.5 million people in 2005), and its population is projected to grow 47% by the year 2025 (U.S. Census Bureau, 2005). Approximately 4,500 square miles (of the total 66,000 square miles) in Florida are within 4.5 feet (ft) [(1.37 meters (m)] of sea level. In 2005, 17.3 million people lived in Florida's coastal communities, accounting for half of the coastal population of states stretching from North Carolina to Texas (U.S. Census Bureau, 2006). As the climate continues to change and sea levels continue to rise, more and more people will be at risk of increased coastal flooding, saltwater intrusion, and storm events.

From 1961 to 2003, global average sea levels rose at an average rate of 0.07 inches (in) [0.18 centimeters (cm)] per year (IPCC, 2007c). From 1993 to 2003, the average rate increased to 0.12 in [3.1 millimeters (mm)] per year (IPCC, 2007c). These findings suggest global sea level is not only rising but also accelerating due to increasing greenhouse gas (GHG) levels in our environment. Coastal communities will most likely feel the impact of SLR as the intensity of tropical storms rises, with vulnerability increasing as property values rise and population grows (IPCC, 2007b).

This study estimates the future changes in hurricane return period, or the average number of years between events, under different SLR scenarios. In this context, hurricane return period relates only to extreme water levels and does not consider changes in other important damage parameters, such as wind and precipitation. Several studies to date have analyzed the effect of SLR on the occurrence of hourly sea level extremes (Cayan et al., 2006) and on the frequency of 100-year floods[5] (Frumhoff et al., 2007). Additionally, this study estimates the economic impact

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[4] Titus and Richman (2001) estimated that 58,000 km^2 of land along the Atlantic and Gulf coasts lie below the 1.5-m contour. Louisiana, Florida, Texas, and North Carolina account for more than 80% of the low-lying land.

[5] Researchers typically use a "100-year flood" as a benchmark to determine how frequently a flood of similar magnitude may occur with future SLR (Frumhoff et al., 2007).

of SLR in Florida, which has not previously been studied. More specifically, this study estimates damage costs associated with large hurricane events and changes in property values at risk due to SLR.[6]

Impacts of Sea Level Rise in Florida

Rising sea levels could inundate low coastal areas of Florida and cause saltwater intrusion into coastal estuaries and fresh, groundwater aquifers, affecting the availability of drinking water. Additionally, the loss of sediment in the offshore area could lead to beach and dune recession.[7] Rising sea levels could also increase storm surge height and the occurrence of flooding; erode beaches, barrier islands, and other coastal ecosystems; and inundate the lower Everglades (Fiedler et al., 2001). The loss of coastal estuaries and associated fisheries because of SLR would also negatively impact Florida's economy.

Currently, few studies have examined the economic impacts of SLR on property values or property damages in Florida.[8] Several studies have addressed the ecological and geological impacts of climate change and SLR in Florida (Trimble et al., 1998; Williams et al., 1999; Fiedler et al., 2001; Rodriguez, 2002; U.S. EPA, 2002; Florida Department of Community Affairs, 2006; National Wildlife Federation, 2006; Walton, 2007).

According to a recent U.S. Environmental Protection Agency (EPA) study (U.S. EPA, 2002), a 1-foot (0.3 m) rise in sea level would erode most of Florida's beaches by at least 100-200 ft (30.5-61 m) unless mitigation measures are used. The Florida South Water Management District studied the impact of SLR on the water resources of the region and found that a 0.49-foot (0.15 m) SLR would result in southeastern coastal Florida flooding and a greater need for water use cutbacks (Trimble et al., 1998). They also found that certain areas throughout the district would need additional freshwater deliveries to offset the intruding saltwater.

The National Wildlife Federation and the Florida Wildlife Federation analyzed the effects of SLR (using a scenario of 15 in by 2100) in nine coastal areas in Florida. They found that about 50% of saltmarsh (23,000 acres) and 84% of tidal flats (167,000 acres) at these sites would be lost (National Wildlife Federation, 2006). Additionally, the area of dry land is projected to

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[6] This study addresses SLR only throughout the analysis, but maintains that it is important to examine other drivers of risk in addition to SLR.

[7] This recession is a function of the SLR rate, the active beach profile width, and the depth of closure as first postulated by Bruun (1962). See, for example, Dean and Dalrymple (2002).

[8] For example, Stanton and Ackerman (2007) conducted a study of the costs of inaction with respect to climate change in Florida.

decrease by 14% (175,000 acres), and about 30% of ocean beaches (1,000 acres) and two-thirds of estuarine beaches (5,880 acres) would disappear.

The purpose of this study is to examine the effects of projected SLR (due to climate change) in six coastal counties in Florida: Dade, Dixie, Duval, Escambia, Monroe and Wakulla (see Figure 1). For each county, Florida State University (FSU) used projected SLR values [from historical tidal gauge data and the Intergovernmental Panel on Climate Change (IPCC) 2001 report (IPCC, 2001)] to estimate:

- Hurricane return period
- Damage costs
- Value, area, and per-acre value of lands at risk.[9]

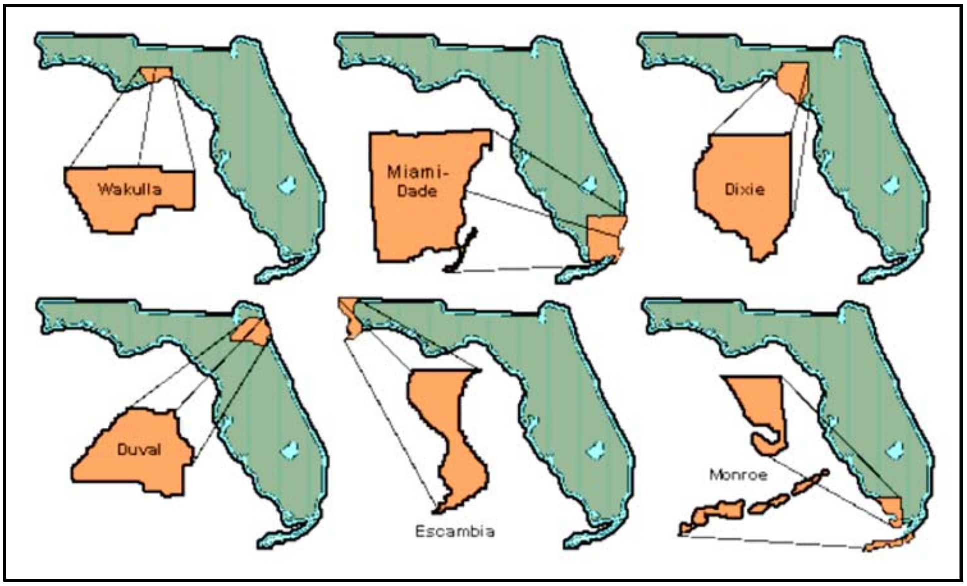

Figure 1. Map of six Florida counties.

The following section describes the current IPCC estimates of SLR and the methods FSU used to develop regional estimates of SLR in Florida. It also shows how the IPCC and FSU SLR scenarios were used to estimate hurricane return period.

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9. For this portion of the study, we looked only at Dade, Duval, and Escambia data.

Projected Sea Level Rise in Florida

IPCC Projections

Projections of SLR have changed over the years as more information has become available (e.g., more advanced climate change models and more accurate data). The 1990 IPCC report reported a scenario of global warming and consequent global SLR of 0.6 ft (0.18 m) by 2030 and between 0.69 to 2.33 ft (0.21-0.71 m) by 2070 (IPCC, 1990). In 2001, the IPCC projected that SLR would increase by 0.3 to 2.9 ft (0.09-0.88 m) by 2100 over 1990 sea levels (IPCC, 2001). Uncertainties about GHG emissions scenarios, temperature sensitivity of the climate system, contributions from the Antarctic, and glacial melt can explain the large range of SLR predictions.

In 2007, the IPCC slightly lowered its estimate of SLR to between 0.59 and 1.94 ft (0.18-0.59 m) by 2100 over 1990 sea levels because new information became available about the contribution of thermal expansion to SLR. However, the new range does not incorporate the potential acceleration of melting of Greenland or the West Antarctic Ice Sheet. Although recent studies show that net melting from Greenland and the West Antarctic Ice Sheet may be occurring (e.g., Thomas et al., 2004; Cook et al., 2005; Chen et al., 2006; Luthcke et al., 2006; Velicogna and Wahr, 2006; Shepherd and Wingham, 2007), the IPCC admitted its challenge in incorporating contributions from melting ice sheets into the SLR models and that the published range may be too low (IPCC, 2007a).

Table 1 summarizes the range of SLR scenarios developed by the IPCC in 2001 for years 2030 and 2080.

Table 1. Eustatic sea level rise scenarios[a]

Year	Low	Middle	High
2030	0.16	0.33	0.49
2080	0.33	0.98[b]	2.13

a. Units: feet.

b. Mid-range year 2080 estimate corresponds to a 70% probability of SLR for the Treasure Coast Region in Florida based on a Treasure Coast Regional Planning Council study.

Source: IPCC (2001).

Using an empirical approach to compare observed SLR and temperatures changes, Rahmstorf (2007) projected that sea level will rise 1.64 to 5.93 ft (0.5 to 1.4 m) by 2100. He found that the IPCC may have underestimated the SLR projections. The rate of SLR for the last 20 years is 25% higher than any other 20-year period in the preceding 115 years (Rahmstorf, 2007).

Although the time interval is relatively short and could be attributed to internal decadal climate variability, Rahmstorf (2007) stresses that the largest contribution to the rapid SLR comes from ocean thermal expansion and the melting from non-polar glaciers. Additionally, he provides evidence that the contribution to SLR by the melting of ice sheets is rapidly increasing. This study suggests that the IPCC estimates do not capture the upper bound of global SLR projections. Indeed, the IPCC admits that their projections do not include uncertainties in climate-carbon cycle feedbacks and the full effects of changes in ice sheet flow; therefore, the upper values of the ranges are not to be considered upper bounds for global SLR (IPCC, 2007a).

Florida State University Projections

Just how these global sea level projections translate to Florida is vitally important to economic projections for both Florida coastal development decisions as well as population growth decisions.

FSU's Beaches and Shores Resource Center (BSRC) and Center for Economic Forecasting and Analysis (CEFA) developed regional estimates of future SLR using historical tidal gauge data (via a data-based approach) in six coastal counties: Monroe, Dade, Duval, Escambia, Dixie, and Wakulla. FSU tested three different approaches to estimate future SLR: linear first order, linear second order, and nonlinear least squares to determine the best approach to use in the final analysis for projecting economic scenarios of future costs due to SLR. These three approaches were used under the assumption that sea levels are rising *and* accelerating. FSU also looked at another approach to estimate regional SLR assuming no acceleration in SLR: standard linear least squares estimation.

FSU BSRC collected historical tidal station gauge data to estimate changes in sea level. Using the IPCC's 2001 SLR estimates (IPCC, 2001), FSU BSRC analyzed projected changes in eustatic SLR for years 2030 and 2080. In addition, they examined the effects of accelerated SLR and subsidence. The following sections describe the data sources and methods used by FSU BSRC to develop the SLR estimates and present the results.

Data Sources

The projected SLR scenario data come from the National Oceanic and Atmospheric Administration's (NOAA's) primary tidal gauge station network in Florida. Although numerous coastal tide stations exist in Florida, most have operational data only for short record periods, and these data are not suitable for the analysis provided here. The length of data record is an important consideration in choosing which stations to use in SLR analyses. If the data record is too short, it will not reflect a proper trend. If the data record is too long, it will allow for non-stationarity in the data series and hide important, shorter-term fluctuations that may govern the forecast period.

Several studies have analyzed the effect of data record length. For example, Pugh (1987) demonstrated that 10-year trends at a site could show increases or decreases in sea level depending on the time interval. Using the San Francisco tide gauge data,[10] Douglas (1991) found that 30-year trends computed anywhere in the entire series varied from -0.08 to 0.2 in (-2 to 5 mm) per year. These findings suggest that a 30-year record would be too short for analysis (and consequent forecasting/extrapolation). In a later study, Douglas (1992) supported a 50-year period. In another finding, Emery and Aubrey (1991) noted strong coherence of results for sea level records longer than 40-50 years, which might be suggestive that such a period is reasonable for forecasting future sea levels. Roemmich (1990) investigated sea level records at Bermuda and Charleston, South Carolina, and found that coastal and nearby mid-ocean sea level trends differ markedly over several decades. His conclusions suggest that 50-year records of sea level are necessary to understand the fluctuations at a given coastal location.

As suggested in previous studies, the tide stations used in this study all have at least 50 years of data recorded. Table 2 lists the stations and station numbers used in this analysis.

Table 2. Florida tide stations with at least 50 years of historical data

Station name	Station number
Fernandina, FL	8720030
Key West, FL	8724580
St. Petersburg, FL	8726520
Cedar Key, FL	8727520
Pensacola, FL	8729840

All of these tide station gauges are located in somewhat protected waters, which explains the availability of complete analysis records. Some open-coast tidal stations might have a higher sea level due to the effects of wave setup. This reduced sensitivity to wave setup in the stations used is a benefit for the present analysis, which aims at projecting the low-frequency water level rise over an approximately 75-year period. Monthly data rather than annual data were used to minimize the Nyquist effect. The monthly mean sea level series was used from each of the above gauges for this analysis.

An additional gauge with a long historical record period is Mayport, Florida (Station number 8720220); however, data were not available for the period 1999 through 2005. The Fernandina gauge also had an extended period of missing data (1960-1969). The two gauges had a strong linear correlation between the data sets, which shows that either of the gauges could be a proxy for the other. For Fernandina, the data were missing from the middle portion of the historical

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[10] These data represent the longest continuous record (140 years) in the United States.

series rather than at the end of the series. For this reason, the Fernandina record would provide a more meaningful analysis period than the Mayport historical series.

Methodology

To keep the SLR scenario projections on the same timeline, a starting date of January 1941 provided the historical parameter fitting (except for the St. Petersburg series for which available data started in 1947). This was the earliest monthly mean data available for the Key West tide gauge station. Hence, the other series records were shortened accordingly (except for St. Petersburg) for this analysis.

The fit historical series record period extended from January 1941 (January 1947 for the St. Petersburg series) through December 2005, while the forecast record period continued from 2006 to 2080 (with the projected estimates at year-end 2080 provided). Since the fit historical record period spanned approximately 69 years (63 years for the St. Petersburg series), it is reasonable to project (extrapolate) to a 75 year forecast period (i.e., time spans of historical fit and future forecast are roughly equal).

Although a complete data set exists for most of the station series, there are missing values in station records for some months (as shown in later graphics). These missing values do not allow for analysis techniques such as linear or nonlinear filtering, which typically require complete data series. Rather than attempt to provide estimates of unmeasured data to fill in the incomplete series,[11] the analyses were limited to both linear and nonlinear least squares analyses, as well as seasonal mean estimation (which can be applied to incomplete series data).

As noted previously, the model fitting assumes that global sea level (and consequently Florida relative sea level) is not only rising, but also accelerating due to the climatic influence of GHGs. This assumption will later be compared (using the same approach and data) to a standard linear least squares estimation, which assumes SLR is not accelerating.

Climatic modelers have demonstrated that global sea level is rising exponentially, which would suggest a similar trend for relative SLR in Florida. This exponential relationship is described by the following equation:

$$y(t) = p_1 + p_2 e^{p_3 t} \qquad (1)$$

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[11] See Walton (1996).

This formula can be expanded in series form to:

$$y(t) = p_1 + p_2\left(1 + p_3 t + \frac{1}{2} p_3{}^2 t^2 + \frac{1}{3} p_3{}^3 t^3 + \dots\right) \tag{2}$$

where t represents the time component (i.e., the monthly-mean sea level index) and where the modeled *y* is a seasonally filtered water level developed by removing the seasonal (monthly) means of the monthly mean sea level series. The p_1, p_2, etc., represent the coefficients of the statistical model. It should be noted that the *y(t)* series being fit is not the raw data but rather the deseasonalized data residual [e.g., where the actual fit or forecast data would be the modeled or forecasted *y(t)* with the seasonal (monthly) average added].

The seasonal averaging filter reduces the noise of the fit and therefore provides more parameter stability. Also, missing data in the raw data series did not allow for typical linear or nonlinear filtering approaches without making estimates about the missing data. No a priori assumptions regarding missing (unavailable) data were used. Although the model to be fit is assumed to be of a nonstationary, exponential form in this expansion approach, a series expansion of a stationary harmonic model approach can also lead to a higher order polynomial model with dependent coefficients.

Approaches for Model Fitting

FSU BSRC used three approaches to estimate SLR: first order linear, second order linear, and nonlinear least squares. FSU BSRC also used a seasonal mean estimation to model parameter estimation. These approaches were chosen because there were some missing values in station records for some months, which would not allow for linear or nonlinear filtering (the linear and nonlinear approaches require complete data sets). Because nonlinear estimation techniques require information on the starting parameter values, a linear estimation technique was used to formulate the estimated starting values in the nonlinear estimation approach.

FSU BSRC made several assumptions for model fitting. First, they assumed that global sea level (and Florida relative sea level) is accelerating because of climate change impacts (e.g., thermal expansion, melting of glaciers, and melting of ice sheets). They also assumed that the model is a nonstationary exponential form. Based on these assumptions, FSU BSRC deseasonalized the data by removing monthly means.

A harmonic cycle approach was performed using the raw Key West data series. The harmonic cycle approach provided an additional check on the aforementioned model (nonstationary exponential form). The harmonic cycle approach is another widely accepted approach to perform forecasting, and provided reinforcement regarding the nonstationary exponential form model.

In this harmonic cycle approach, the data series was not deseasonalized (i.e., monthly means were not removed). The entire dataset was fit using two additional parameters (phase and amplitude) to represent the monthly series as a harmonic. This approach represents the modeled series as shown in Equation 3.

$$y(t) = A_{mp}\left(cos\left(\frac{2\pi t}{T} - phase\right)\right) + p_{1m} + p_{2m}t + p_{3m}t^2 \qquad (3)$$

This approach considered a monthly cycle of the form with T = 12 (months) for the yearly cycle and the two unknowns being A_{mp} = Amplitude (*m*), and Phase = Phase of cycle (radians). For the Key West series, a forecast of the year 2080 produced the exact same SLR forecast result (to two decimal places) as the previous deseasonalized approach (nonstationary exponential form) and additionally produced similar Gaussian residual magnitudes. Note that in the harmonic cycle approach, the $y(t)$ series is the full mean sea level series rather than the deseasonalized series. This check confirmed the simpler deseasonalized data forecast model approach (nonstationary exponential form model) provided similar (to two decimal places) results as the harmonic cycle approach.

Results

The fit deaseasonalized, monthly mean SLR data $y(t)$ series are shown as the ordinate values in Figures 2 through 6 where the abscissa is the monthly time index (i.e., 1 = January 1941, except for St. Petersburg, where 1 = January 1947). The deseasonalized, monthly mean sea level data during the historical period are shown as points on the graphs. The solid line represents the deseasonalized historical sea level data fit during the span of the historical data and the deseasonalized sea level forecast curve during the forecast period. The estimate of SLR from years 2006 to 2080 is the difference in the solid line between the final forecast time (2080) and the final historical time (2006) and is summarized in Table 3 based on the linear second order SLR forecast results. For informational purposes, a second set of forecast SLR values is also provided in Table 3 for the shorter time forecast horizon from 2006 to year 2030.

Nonlinear estimation techniques do not always provide stable fit parameter values. However, the nonlinear forecast of SLR was very close to the linear second order forecast of SLR, confirming the validity of both approaches. Due to the fact that most of the gauge fits provided comparable values based on the two approaches, the linear second order forecast of SLR was chosen for projecting final SLR scenarios in the year 2080 due to the allowance of an acceleration component and the fact that the second order term was significant in all but one of the gauge fits. The linear first order forecast of SLR is also provided for comparison purposes.

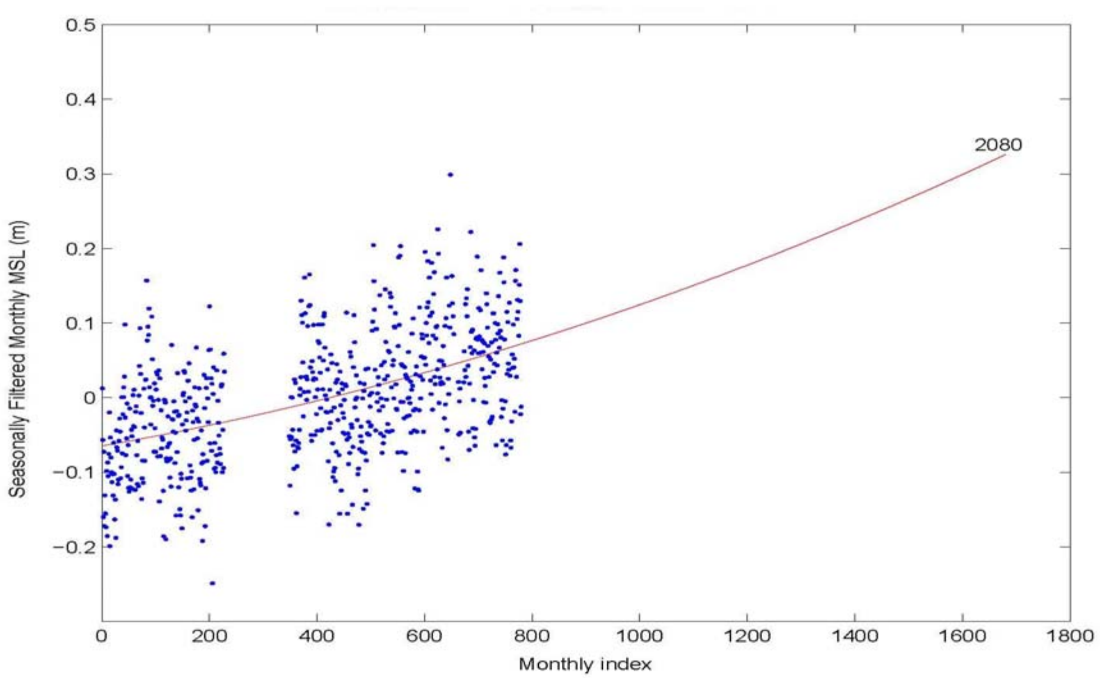

Figure 2. Fernandina gauge station forecast filtered sea level rise.

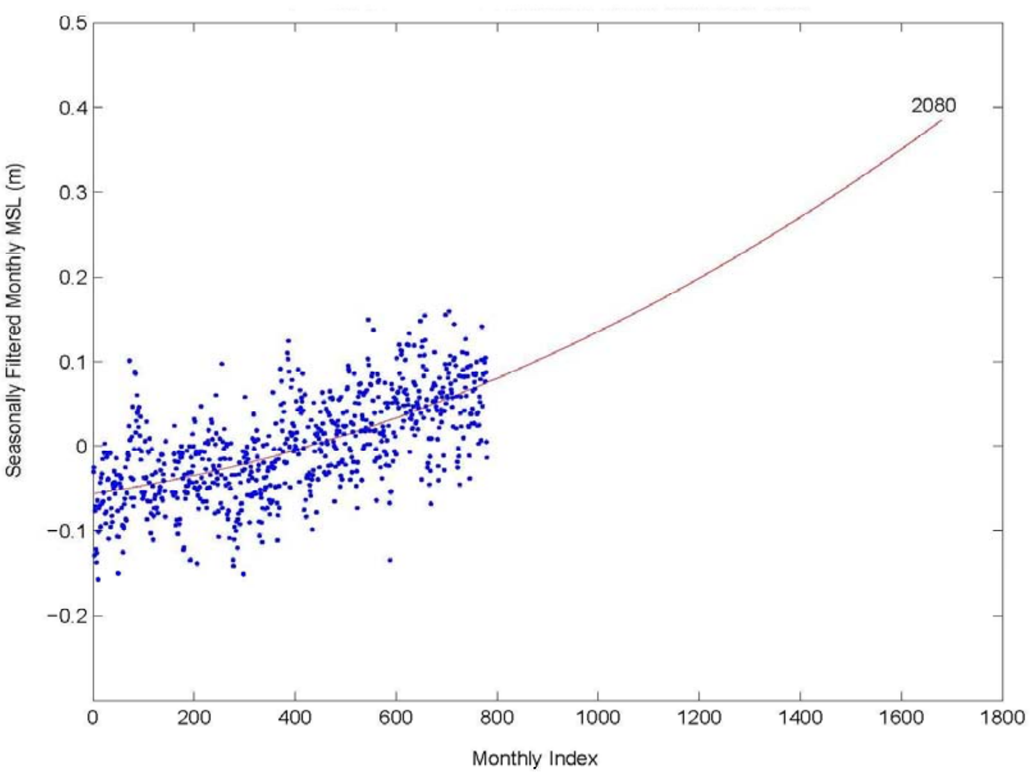

Figure 3. Key West gauge station forecast filtered sea level rise.

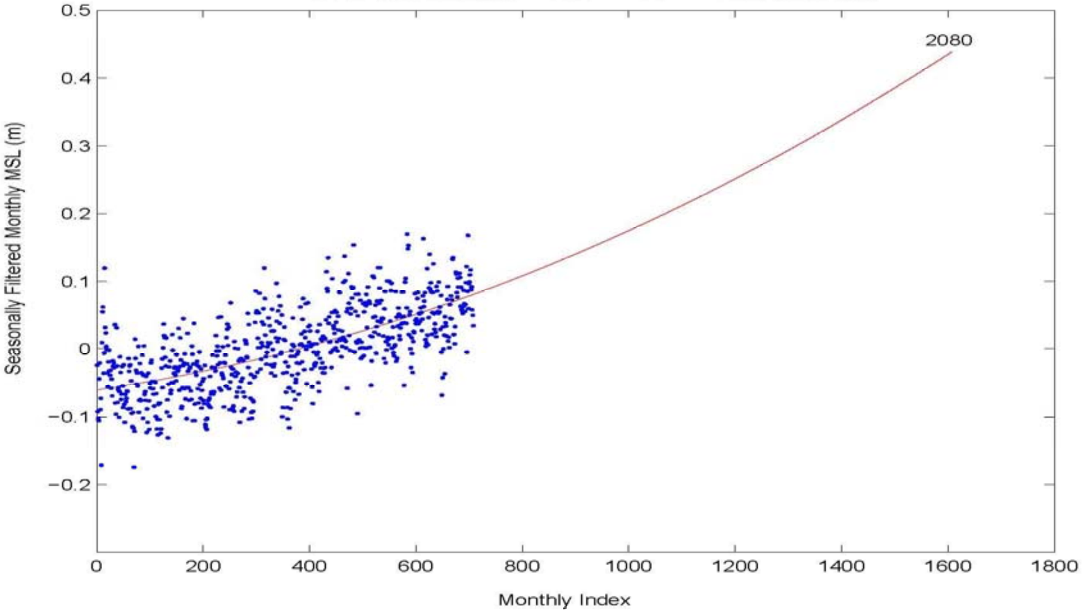

Figure 4. St. Petersburg gauge station forecast filtered sea level rise.

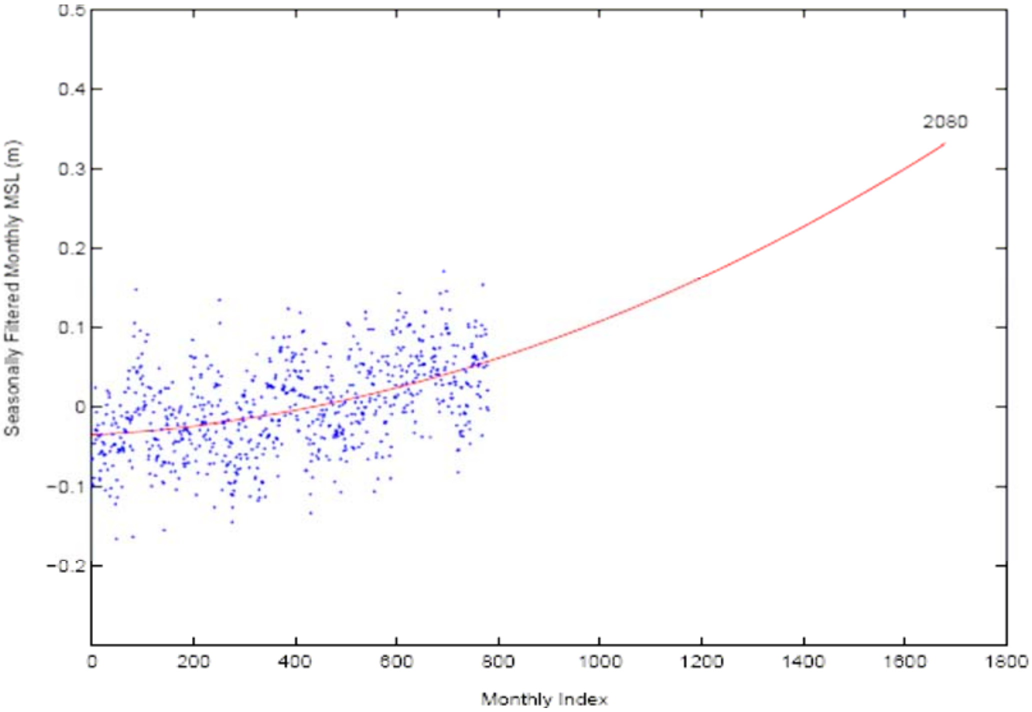

Figure 5. Cedar Key gauge station forecast filtered sea level rise.

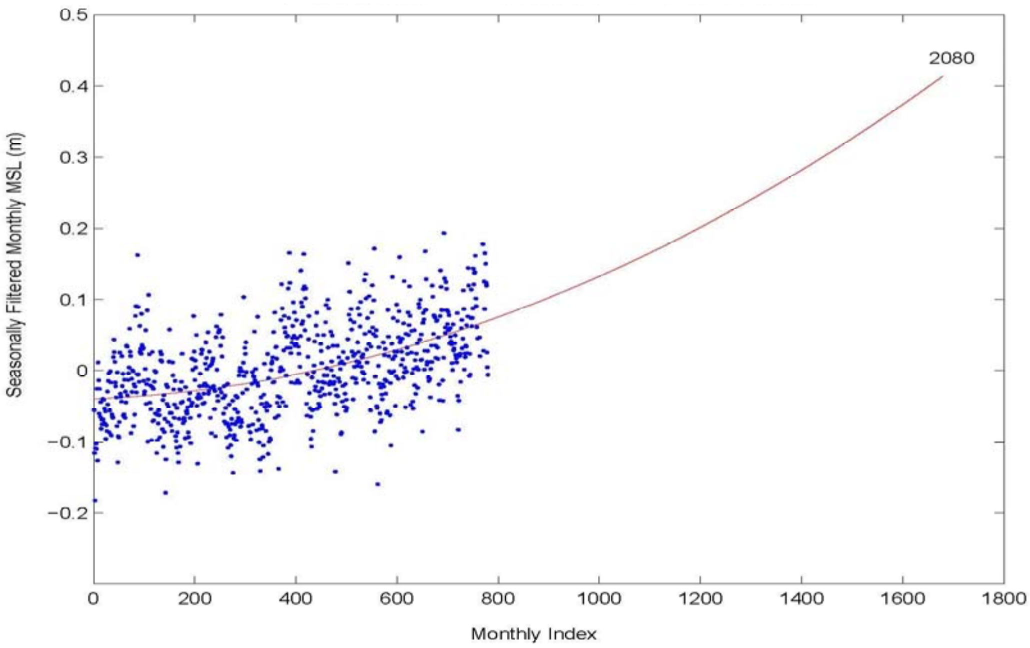

Figure 6. Pensacola gauge station forecast filtered sea level rise.

Table 3. Forecast relative sea level rise for years 2030 and 2080[a]

County	2030	2080
Dade	0.28	1.02
Dixie	0.23	0.90
Duval	0.24	0.83
Escambia	0.29	1.13
Monroe	0.28	1.02
Wakulla	0.27	1.05

a. Units: feet.

An interesting result from FSU's SLR forecast is that for the different gauge sites (which are widely spaced over the Florida Peninsula), the projected SLR in year 2080 does not vary by much; the largest value is 1.15 ft (0.35 m) in St. Petersburg, Florida, and the smallest value is 0.82 ft (0.25 m) in Fernandina, Florida. Additionally, in all but the Fernandina gauge data, the second order nonlinear term has a parameter that is statistically different from zero (and positive) at a 95% confidence interval. The Fernandina series may have provided a less than significant second order term because of the large gap in the data and the higher tidal range, which may be responsible for the magnification of error in the residual model.

Table 4 compares the three modeling approaches (i.e., the linear first order, the linear second order, and the nonlinear exponential) used to forecast SLR. Table 4 suggests that for gauges where nonlinear estimation convergence was obtained, both the second order linear model and the exponential model were comparable. Table 4 also shows that the linear first order SLR estimates were on the order of one-half of the linear second order SLR estimates.

Table 4. Forecast relative sea level rise using three approaches from 2006 to 2080[a]

Station	Relative SLR first order	Relative SLR second order	Relative SLR exponential
Fernandina, FL	0.53	0.82	0.89
Key West, FL	0.49	1.02	0.92
St. Petersburg, FL	0.59	1.15	1.18
Cedar Key, FL	0.36	0.89	1.53[b]
Pensacola, FL	0.43	1.12	0.69[b]

a. Units: feet.
b. Parameter estimation suspect due to convergence problems.

Similar linear first order estimates can be projected from SLR rates provided in Zervas (2001). The fact that the second order forecasts provided greater SLR than the linear “standard” approach suggests that the scenario of acceleration in SLR rather than deceleration is a more likely scenario on the basis of the actual data available.

Residuals from the data fitting procedure for the Florida gauges are provided in Figures 2 through 5. These figures show that the data residuals provide reasonable Gaussian bell shaped curves, which suggests that the higher order fitting is appropriate.

A forecast for the year 2080 produced, using harmonic cycle analysis, the exact SLR forecast (up to 2 decimal places) as the deseasonalized approaches (i.e., the first and second order linear and non-linear least square approaches).[12]

Summary

The 2001 IPCC estimates represent the high-end SLR scenario, while FSU BSRC’s estimates represent the lower-end SLR scenario. FSU BSRC used historical tidal gauge data to forecast relative SLR from 2006 to 2080 using three different methods: first order linear, second order

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[12] Additionally, the standard linear least squares estimation produced similar Gaussian residual magnitudes.

linear, and nonlinear least squares. The FSU BSRC recommends the second order linear approach for the final analysis to project economic scenarios of future costs due to SLR. FSU BSRC proposes the second order linear approach because it includes a higher order term that allows for acceleration in SLR, which is in accord with climate modeling scenarios that project an exponential SLR due to GHG effects. A pragmatic approach to future economic planning should be in tune with climatic model scenarios that suggest the strong possibility of an accelerating SLR in Florida and future values of SLR on the order of the magnitude herein.

The next section will discuss the economic impact of SLR in Florida in terms of damage costs and changes in property values.

Economic Analysis of Sea Level Rise

FSU conducted economic analyses in order to (1) link damage cost and hurricane return period (based on storm surge), and (2) determine the value of land that could be affected by SLR over time for three of the six Florida coastal counties, based on the IPCC’s 2001 SLR scenarios and the FSU BSRC’s SLR forecasts.

Property owners, visitors, and coastal planners along hurricane-prone coastal areas should be aware of hurricane information, including path, intensity, and potential damage, in order to prepare for property protection and survival. While precise hurricane forecast information from the National Hurricane Center is easily obtained, information about potential damage costs associated with hurricanes is less readily available. Insurance and reinsurance companies often estimate damages; however, these results are not typically released to the public.

The science has not resolved whether Atlantic hurricane intensity has increased (e.g., Emanuel, 2005; Landsea, 2005; Webster et al., 2005). However, the IPCC concluded that the intensity of tropical storms has likely increased in some regions and that future hurricane intensities are likely to increase.

The estimation of damage cost is variable, depending on the methodology used. Wind speed along the hurricane path is generally used to predict damage costs. Since storm surge is positively correlated with wind speed (CNMOC, 2005), one can predict a positive relationship between flood damage and wind damage. This study, however, did not estimate changes in storm surge resulting from higher wind speeds. Rather, it focused only on changes in storm surge due to higher sea levels.

For this analysis, storm surge data based on the return period was linked to historical damage cost data to yield a potential future total damage cost for various sized hurricanes[13] for each of the six counties. Two different methods were used to measure damage cost associated with SLR: hurricane return period[14] and damage cost. In addition to estimating damage costs, FSU [and Industrial Economics, Inc. (IEc)] measured property values at risk because of SLR. The following sections explain how FSU calculated hurricane return period and associated damage costs in each of the six coastal counties in Florida, as well as how FSU and IEc estimated property at risk.

Hurricane Return Period Assessment

FSU CEFA assessed how the hurricane return period for past hurricane events could change, on average, using IPCC and FSU BSRC's SLR scenarios for the years 2030 and 2080. FSU CEFA used data from Federal Emergency Management Agency's (FEMA's) Flood Insurance Studies (conducted since the 1980s) to complete the analysis. FEMA conducted these studies in each county to investigate the existence and severity of flood hazards in Florida counties and to help administer the National Flood Insurance Act of 1968 (NFIA) and the Flood Disaster Protection Act of 1973 (FDPA). In each study, FEMA estimated stillwater elevations and storm return year(s) for Florida counties and storm surge elevations for several storm return year floods: 10-, 50-, 100-, and 500-year floods.

FSU CEFA expressed the relationship between storm surge and return period using the following equation:

$$ss = \alpha_0 + \alpha_1 \log rp \quad \text{or} \quad rp = \beta_0 + \beta_1 e^{s} s \tag{4}$$

where ss = surge (ft), rp = estimated return period

The regression summary results for regression Equation 4 (return period for flood elevation) are presented in Table 5.

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[13] Hurricane strength in terms of Category 1-5.

[14] Johnson and Watson (1998) detailed the statistical methodology to estimate hurricane return periods and attendant confidence and prediction limits.

Table 5. Regression results for return period for flood elevation by county

County	Intercept (t-value)	X-variable (t-value)	F Statistic
Dade	3.9068	1.5914	
	(17.26)	(13.69)	187.43
Dixie	3.3128	5.1837	
	(4.89)	(14.89)	221.72
Duval	0.6504	2.6932	
	(2.30)	(19.30)	372.30
Escambia	(0.1626)	4.1161	
	(-1.39)	(68.38)	4,675.94
Monroe	1.1295	2.4712	
	(1.02)	(4.33)	18.75
Wakulla	0.2714	5.9090	
	(0.56)	(23.69)	561.17

All X-variable coefficients are statistically significant at the 95% confidence level. Regarding the intercept, Dade and Dixie are the only statistically significant counties. The number of observations is few; this will have an effect on R-squared and F statistics.

FSU CEFA selected recent hurricane events representative of each county and in accordance with damage cost data and storm surge elevations. Table 6 shows current and estimated future hurricane return periods for each county under different SLR scenarios (FSU BSRC and IPCC scenarios) for the years 2030 and 2080. In Duval, for example, a hurricane like Dennis would occur every 64 years under IPCC’s high SLR scenario for 2030 instead of every 100 years.

In all counties, the predicted hurricane return period decreases substantially as the SLR scenario increases.[15] In Wakulla, for example, a future hurricane event with similar storm surge as Frances would occur more frequently with SLR. For a more thorough discussion of the future hurricane return period for each county, refer to Appendix A.

Damage Cost Assessment

The damage cost analysis is based on insurance claims data that the Florida Office of Insurance Regulation (FLOIR) provided (in 2006 dollars). Although FLOIR analyzed the insurance claimant data for completeness and reasonability, they did not formally audit or verify the data.

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15. Note that in this context, the term hurricane return period relates only to extreme water levels and does not consider changes in other important damage parameters, such as wind and precipitation.

Table 6. Estimated hurricane return period under FSU and the IPCC SLR scenarios

County	Hurricane	Storm surge[a]	Current return period[b]	Source	Year	SLR[a]	Estimated return period[b]
Dade	Wilma	7.00	75.8	FSU	2030	0.28	51.3
					2080	1.02	20.6
				IPCC	2030	0.49	39.5
					2080	2.13	5.2
Dixie	Dennis	9.00	13.6	FSU	2030	0.23	13.3
					2080	0.92	9.6
				IPCC	2030	0.49	11.3
					2080	2.13	6.0
Duval	Frances	5.90	100	FSU	2030	0.24	80.2
					2080	0.83	47.0
				IPCC	2030	0.49	63.7
					2080	2.13	14.0
Escambia	Dennis	12.00	846	FSU	2030	0.29	732
					2080	1.13	470
				IPCC	2030	0.49	657
					2080	2.13	272
Monroe	Wilma	2.76	7.35	FSU	2030	0.28	6.04
					2080	1.02	3.61
				IPCC	2030	0.49	5.22
					2080	2.13	1.65
Wakulla	Dennis	9.00	30.0	FSU	2030	0.27	27.1
					2080	1.05	20.4
				IPCC	2030	0.49	25.1
					2080	2.13	13.7

a. Unit: feet.
b. Unit: years.

FSU CEFA compiled data from FLOIR’s Hurricane Summary Data Reports to present historical damage costs for eight hurricanes that occurred between 2004 and 2005: Charley, Frances, Ivan, Jeanne, Dennis, Katrina, Rita, and Wilma (see Table 7). Although the hurricane events listed in Table 7 have high category ratings, the level of corresponding cost damages is highly variable across the counties. The cost damages are a function of storm intensity and proximity of each county to the associated hurricane. Overall, the damage cost estimates for recent hurricanes range from hundreds to billions for the six counties.[16]

FSU CEFA used historical damage cost estimates and estimated storm surge data to estimate the potential damage costs under the county-specific SLR scenario for FSU BSRC and the high SLR scenario for IPCC in the year 2080. FSU CEFA applied the SLR scenarios to the initial storm surge level to express new damage cost estimates. This simple extrapolation from historical data assumes that damage costs are a function of storm surge.[17] Table 8 shows how past hurricanes (or hurricanes of a similar strength) could affect damage costs in the six counties if they struck in 2080 using the FSU BSRC's county-specific estimate of SLR and IPCC's high estimate of SLR (2.13 ft or 0.65 m).

Figures 7 through 12 show the county-specific damage costs and storm surge elevation at each SLR scenario for the year 2080. Using IPCC's SLR estimates for the year 2080, a storm similar in size and intensity to Hurricane Dennis in Dixie, Escambia, and Wakulla counties could increase damage costs by 33%, 34%, and 56%, respectively (see Figures 8, 10, and 12). Dade and Monroe counties could see an increase in damage costs of 31% and 72%, respectively, if Hurricane Wilma (or a similar storm) hits the coast (see Figures 7 and 11). Finally, if Duval County is hit by a hurricane similar in intensity to Frances, it could see a 36% increase in damage costs (Figure 9).

It should be noted that the following results are location-specific for the six Florida counties, on an individual hurricane basis, and not representative in application to all storm events in all Florida counties.

Appendix B contains figures to depict the joint representation of hurricane return period and associated damage costs based on these SLR estimates for each of the six counties. Each figure can be thought of as two separate figures. The right part links the hurricane return period and associated storm surge values. The left part links damage cost data and associated storm surge values. The benefit of illustrating both return period and cost damages in one figure provides clarity to the interpretation of temporal results of SLR. These merged figures could be used by policy decision-makers and insurance companies, among others.

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16. It should be noted that damage costs did not include emergency management and damages to natural resources (e.g., direct economic value of fisheries) among others. The damage costs for this study are certainly underestimated.

17. Damage costs are a function of storm surge in addition to other factors or variables such as wind speed, precipitation, etc. In addition, there are limitations to the assumption that damage costs are linearly related to storm surge height. Damage costs also depend on land slope, land use, etc.

Table 7. Historical damage costs by county for eight hurricane events in 2004 and 2005 (in $2006)[a]

	Damage cost							
County	**Charley (Category 4)**	**Frances (Category 2)**	**Ivan (Category 3)**	**Jeanne (Category 3)**	**Dennis (Category 4)**	**Katrina (Category 5)**	**Rita (Category 4)**	**Wilma (Category 5)**
Dade	$3.01 M	$70.5 M	$2.87 M	$16.2 M	$5.98 M	$584.2 M	$4.40 M	$2.21 B
Dixie	$0.04 M	$4.95 M	$0.06 M	$0.97 M	$0.06 M	b	b	$0.03 M
Duval	$5.91 M	$72.3 M	$1.65 M	$22.4 M	$0.36 M	$0.83 M	$0.15 M	$1.06 M
Escambia	$1.00 M	$13.0 M	$2.01 B	$19.1 M	$70.7 M	$11.3 M	$0.15 M	$0.28 M
Monroe	$0.66 M	$4.95 M	$0.36 M	$0.13 M	$4.40 M	$27.9 M	$11.3 M	$215.3 M
Wakulla	$0.01 M	$1.85 M	$0.21 M	$0.19 M	$4.42 M	$0.59 M	b	$0.03 M

a. Hurricane Summary Data (FLOIR, 2006).
b. The damage cost value is less than $10,000.

Table 8. Effect of storm surge and sea level rise on future damage costs

County	Hurricane	Storm surge[a]	Historical damage cost	Storm surge based on FSU BSRC SLR estimates[a,b]	Damage cost	Storm surge based on IPCC SLR estimate[a,b]	Damage cost
Dade	Wilma	7.00	$2.21 B	8.02	$2.48 B	9.13	$2.90 B
Dixie	Dennis	9.00	$0.06 M	9.90	$0.07 M	11.13	$0.08 M
Duval	Frances	5.90	$72.3 M	6.73	$80.2 M	8.03	$98.00 M
Escambia	Dennis	12.00	$70.7 M	13.13	$84.5 M	14.13	$95.00 M
Monroe	Wilma	2.76	$215.3 M	3.78	$298 M	4.89	$370.00 M
Wakulla	Dennis	9.00	$4.42 M	10.05	$5.73 M	11.13	$6.90 M

a. Unit: feet.
b. SLR estimates are for the year 2080.

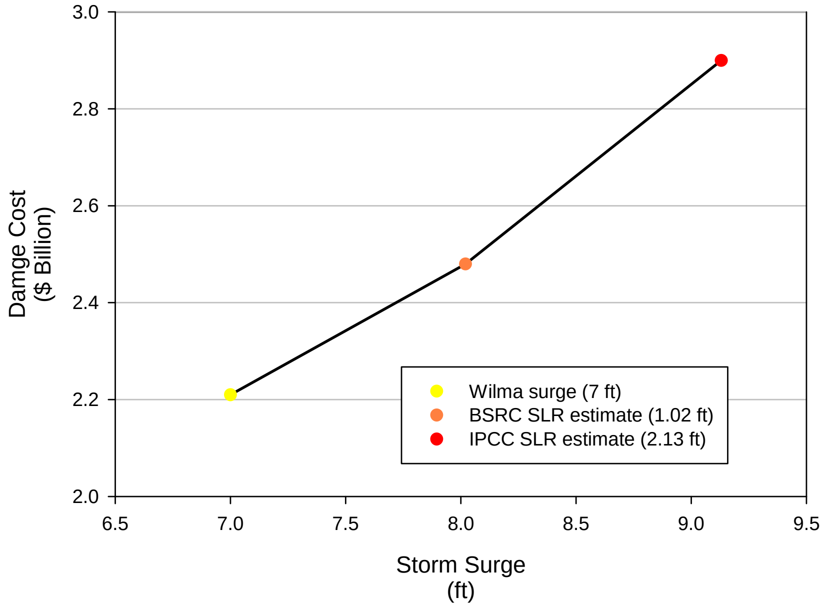

Figure 7. Damage cost and storm surge estimates in Dade County.

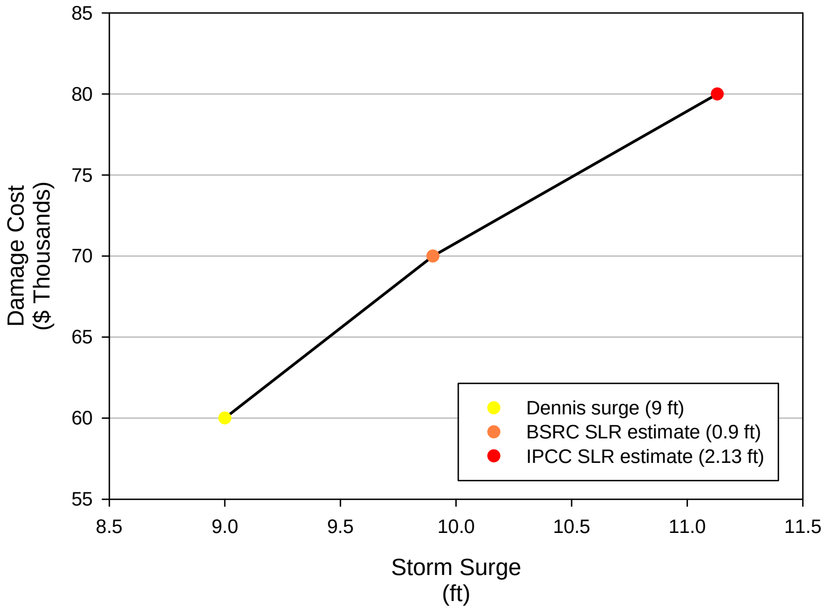

Figure 8. Damage cost and storm surge estimates in Dixie County.

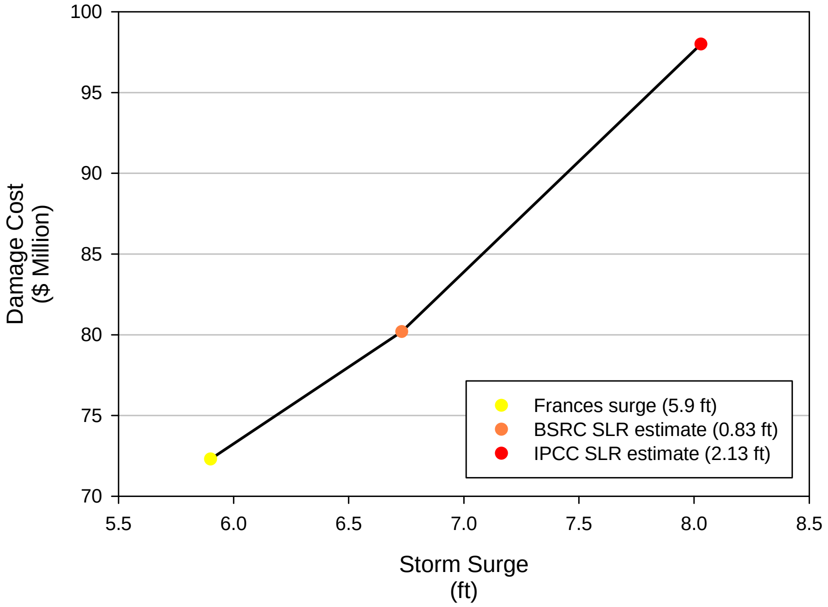

Figure 9. Damage cost and storm surge estimates in Duval County.

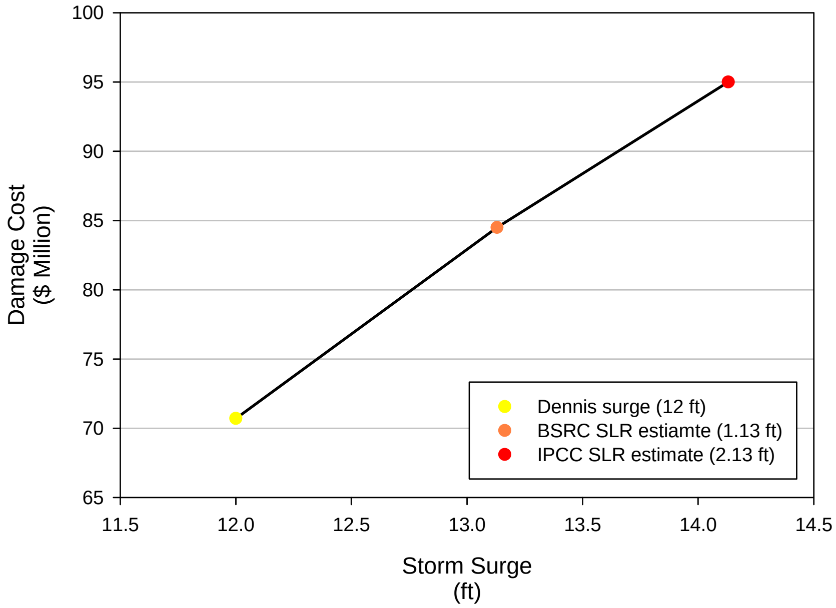

Figure 10. Damage cost and storm surge estimates in Escambia County.

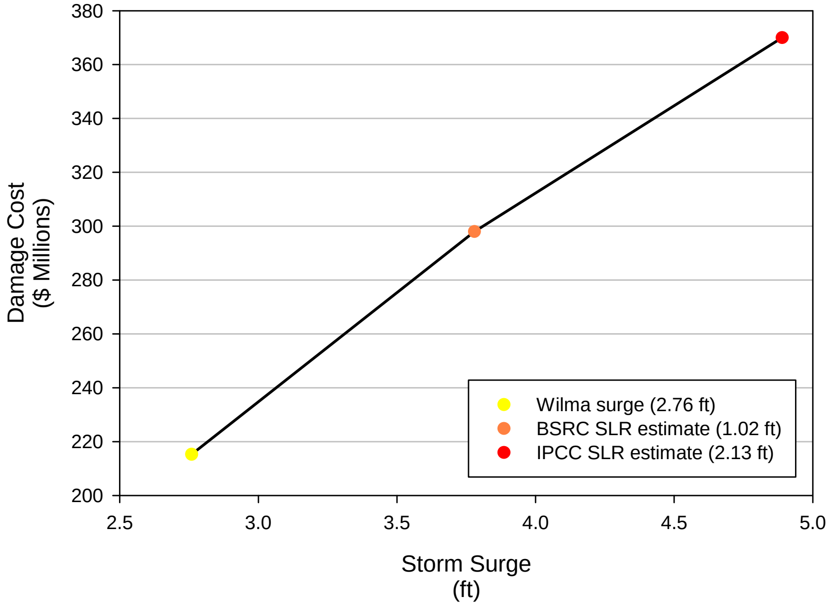

Figure 11. Damage cost and storm surge estimates in Monroe County.

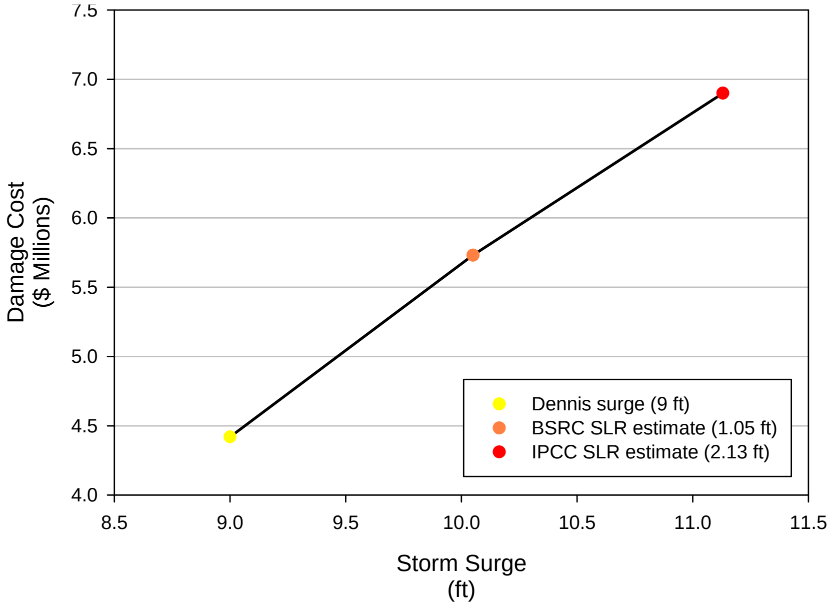

Figure 12. Damage cost and storm surge estimates in Wakulla County.

Property Value Assessment

The objective of this phase of the project was to determine the value and acreage of property that could be affected by SLR (from permanent inundation)[18] over time for three of the six Florida coastal counties – Dade, Duval, and Escambia – using IPCC's SLR scenarios for 2030 and 2080 (see Table 2). FSU CEFA and IEc, under the guidance of James Neumann, created a geographic information system (GIS) elevation model to process Florida parcel data[19] and combine it with Digital Elevation Model (DEM)[20] elevation data.

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18. The elevation data were reconciled to mean spring high water. This means that the zero elevation contour defines inundation. So, inundation is defined as a parcel centroid below the projected mean spring high water.

19. Florida Department of Revenue (FDOR) DR-590 (12D.8) parcel data. FSU CEFA did not verify or validate the FDOR data, thus, the results of this study are based on the quality and correct topology of the FDOR parcel data. FSU CEFA used the variable "just value" to best reflect property values. FDOR uses just value for property tax assessment and recommended its use (Dr. Ke-tsai Wu, FDOR Statistician, personnel communication, February 2007).

20. A DEM is a digital representation of ground surface topography or terrain, expressed in grid of specified resolution. In this case, the DEM data used have a grid size of 32.8 ft (10 m) in Dade County, and 98.4 ft (30 m) in Duval and Escambia counties. Note that DEM values were recalibrated to mean spring high water in the year 1992.

DEM values are presented in a grid format, while property values are available for specific parcels, each associated with a polygon that represents the parcel border. To attribute elevation to each parcel, the GIS model first locates the centroid of each parcel in the county.[21] The model then attributes elevation based on the location of the centroid in the DEM grid. Based on these results, the model generates a shapefile of parcels at risk, and the value of those parcels, for any user-defined SLR estimate. See Appendix C for a thorough discussion about the project data sources for the GIS mapping portion of this study.

Table 9 presents the value of land at risk, the area of land at risk, and the per-acre value of land at risk for Dade, Duval, and Escambia counties under five IPCC SLR scenarios. These values reflect changes in SLR overlaid on current parcels and their values – it does not reflect changes in the value of property or the location of possible new development. Because we did not consider changes in property values over time or possible new development, these values almost certainly underestimate the values of property that may ultimately be at risk from SLR. These data also do not account for any adaptation measures by property owners, such as beach nourishment or relocation of homes, both of which would ultimately reduce damages attributable to SLR.

Table 9. Value of land at risk in Dade, Duval, and Escambia counties using IPCC's SLR scenarios (in 2005$)

County	Variable	SLR scenarios[a]				
		0.16 feet	**0.33 feet**	**0.49 feet**	**0.98 feet**	**2.13 feet**
Dade	Value of land at risk	$1.05 B	$1.4 B	$2.33 B	$4.81 B	$12.3 B
	Area at risk[b]	5,486	5,861	7,903	11,627	26,467
	Per-acre value	$0.19 M	$0.24 M	$0.29 M	$0.41 M	$0.47 M
Duval	Value of land at risk	$10.4 M	$13.7 M	$19.6 M	$344 M	$572 M
	Area at risk[b]	1,855	1,868	1,878	10,625	18,743
	Per-acre value	$5,624	$7,354	$10,462	$32,384	$30,508
Escambia	Value of land at risk	$126 M	$136 M	$148 M	$194 M	$499 M
	Area at risk[b]	798	899	962	1,863	5,209
	Per-acre value	$0.16 M	$0.15 M	$0.15 M	$0.10 M	$95,760

a. Values calculated for years 2030 and 2080. However, the overlap between the mid-2030 scenario and the low 2080 scenario (both 0.33 ft, or 0.1 m) is redundant, and since property value changes over time are not considered, the years are not shown here.
b. Unit: acres.

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[21] The GIS model derives centroid elevation values from a spatial analyst function using DEM data (parcels that are not within the shoreline range of the DEM are deleted).

All three counties show an increasing trend in the value of land at risk and area of land at risk. Dade has the largest values of land at risk (as well as the largest acres of land at risk and per-acre value of land) starting with $1.05 billion at a 0.16 ft (5 cm) SLR and $12.3 billion at 2.13 ft (0.65 m). The value of land at risk in Duval makes a large jump between 0.49 and 0.98 ft (0.15 to 0.3 m) SLR scenarios. The jump is attributable to two areas that we estimate could be inundated at SLR just less than 0.98 ft (0.30 m): (1) the Baptist Medical Center (valued at roughly $110 million) and (2) a large part of the Jackson Port Authority (property valued at $140 million). At any given SLR scenario, Escambia has less land at risk and less value at risk However, Escambia's per-acre value of land shows a decreasing trend, which reflects that nearshore parcels in Escambia, which are inundated first, are of much higher value than the properties directly behind the nearshore parcels. Escambia County, in particular, is characterized in many areas by condominium towers on the shorefront and much lighter development as one moves inland.

Table 10 shows the value of land at risk, the area of land at risk, and the per-acre value of land at risk for Dade, Duval, and Escambia counties using FSU's county-specific estimates of SLR for 2080.

Table 10. Value of land at risk in Dade, Duval, and Escambia counties using FSU's county-specific SLR estimates for 2080 (in 2005$)

County	FSU relative SLR estimate[a]	Value of lands at risk	Area at risk[b]	Per-acre value
Dade	1.02	$6.7 B	15,330	$0.44 M
Duval	0.83	$29.5 M	1,992	$0.01 M
Escambia	1.13	$203 M	1,913	$0.11 M

a. Unit: feet.
b. Unit: acres.

The values in Tables 9 and 10 were derived by calculating the elevation[22] at the center of each land parcel and attributing that elevation to the entire parcel. This method could misrepresent the area of lands at risk, depending on the size of the parcel, the individual cell size, and the topography of the area. For example, there is a large difference between the value and area of land at risk in Dade County when comparing the 0.98-foot (0.3 m) IPCC scenario to FSU's relative estimate (1.02 ft or 0.31 m) even though the SLR estimates do not vary much. This large difference in the value and area of lands at risk between 0.98 and 1.02 ft (0.3 and 0.31 m) is likely due to the methods used (e.g., attributing one elevation to each parcel when in fact most parcels, particularly larger areas, exhibit some slope).

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[22] The elevation data came from the DEM.

Figures 13-15 show the relationship between incremental increase in SLR and the value and area of property at risk. The blue line (value of property at risk) incorporates the current value of property and does not consider changes in the future. The red line (area inundated) generally tracks the topography of the area. However, the methods used to attribute an elevation to each parcel create some "lumpiness" to the trajectory of potentially inundated land. This is particularly apparent in Duval County. In Figure 14, for example, there is a gradual increase in the value and area of land at risk from 0 ft until about 0.82 ft (0.25 m) SLR scenario. However, once the SLR scenario increases past 0.82 ft (0.25 m), there is a large jump in the value and area of land at risk. Results from Dade and Escambia Counties also show some "lumpiness" (Figures 14 and 15, respectively), though it is not as apparent as it is in Duval County.

Figures 16-18 show a larger view of the area of land at risk in Dade, Duval, and Escambia counties, respectively. Each figure shows the area of lands at risk to due SLR using IPCC's high estimate of 2.13 ft (0.65 m) and FSU's county-specific estimate for the year 2080.

Summary and Conclusions

Rising sea levels pose a large threat to Florida's coastal resources, economy, and residents' property and livelihoods. Deepening our understanding about the future impacts of SLR will help Floridians prepare for the advancing seas and find ways to adapt. FSU used its regional SLR estimates and IPCC's 2001 global SLR estimates to estimate the impacts of SLR in the future. This study explores the impact of global and regional SLR on the return frequency of extreme storm events, on the costs associated with extreme storm events, and on the value of land at risk. Although FSU did not consider adaptive behaviors in response to SLR, the findings still contribute to a stronger understanding of the potential impacts of SLR for Floridians.

Limitations to the study include:

- Socioeconomic variables and analysis were not included in the scenarios. The inundation estimates are limited to assessing vulnerability of property, at current prices, to inundation, and that other effects on economic production, incomes, or other socioeconomic impacts that might be associated with inundation or increased storm damage were not assessed.

- Adaptive behaviors or strategies were not examined in response to SLR. These findings are an initial vulnerability/impact assessment, which does not incorporate the effects of either existing or potentially enhanced adaptive capacity.

- Escalating property values (as coastal population and incomes increase) were not included in the analysis. In other words, this study used property at current prices.

- Elevation data available at the time of study for all counties were limited to 10 and 30-m grid resolution.

- While the FSU scenarios implicitly incorporate land subsidence, and therefore estimate relative SLR, the IPCC-based scenarios are based on eustatic sea level changes and do not reflect subsidence. The effect of this omission varies by location, but prior work (Yohe et al., 1999) suggests that land subsidence rates could be in the 0.7 to 1.8 mm per year range (with Dade County at 1.1 mm per year), adding 7 to 18 cm to estimates of relative SLR.

These limitations to the study point to the need for further research to examine the complexities of SLR and its associated economic implications in Florida.

Four major findings come out of this report. First, regional SLR scenarios projected from historical data do not vary much from station to station in each given year (2030 and 2080), but are lower than the simulated global SLR estimates generated by IPCC. Second, storm surge events of a particular frequency today could occur much more often because of the higher base elevation of the ocean due to SLR. Third, as SLR increases over the years, damage costs associated with extreme storm events could increase significantly in the six coastal counties. And fourth, the value of land at risk of inundation from SLR increases as the trend of SLR increases across different scenarios. The value of land at risk for the year 2080 represents a significant portion of the area's property wealth, more than $10 billion in Dade County alone.

The study finds significant property value at risk of inundation, as well as the potential for much increased storm damage from storm surge. The obvious next steps include: (1) a more in-depth analysis of inundation effects, incorporating the effect of a dynamic assessment of future property value; (2) an assessment of multiple modes of adaptive capacity; and recommendations for efficient adaptation responses; and (3) a more in-depth analysis of the potential for more far-reaching and elevated, and therefore more damaging, storm surge associated with current storm frequency and intensity, as well as an analysis of the effects of potentially more frequent and intense storms that might result from climate change.

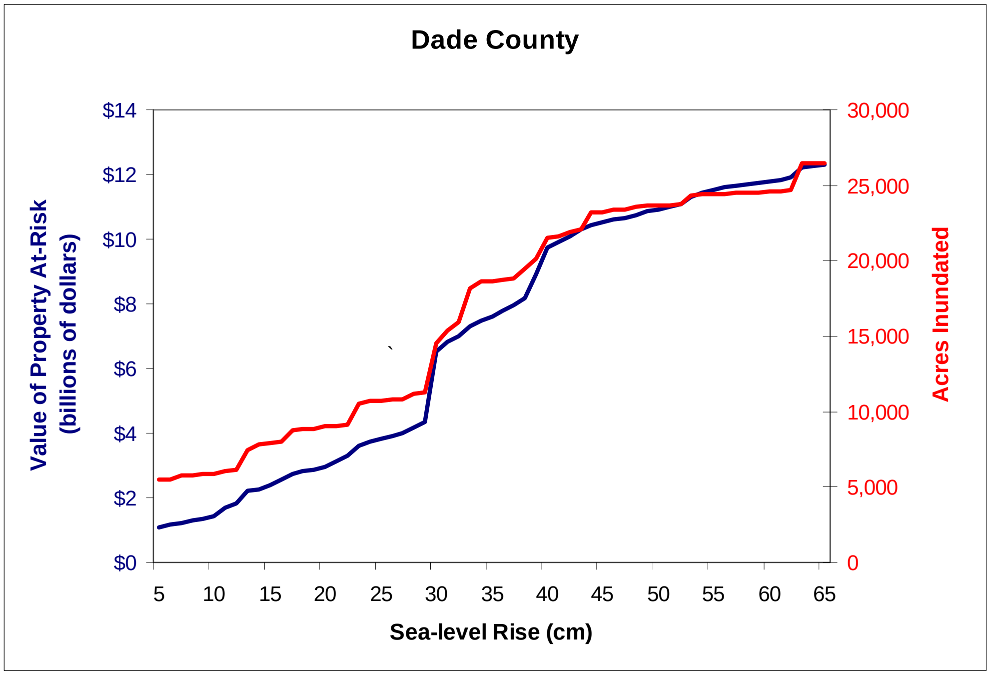

Figure 13. Trend in the area and value of property at risk of sea level rise in Dade County.

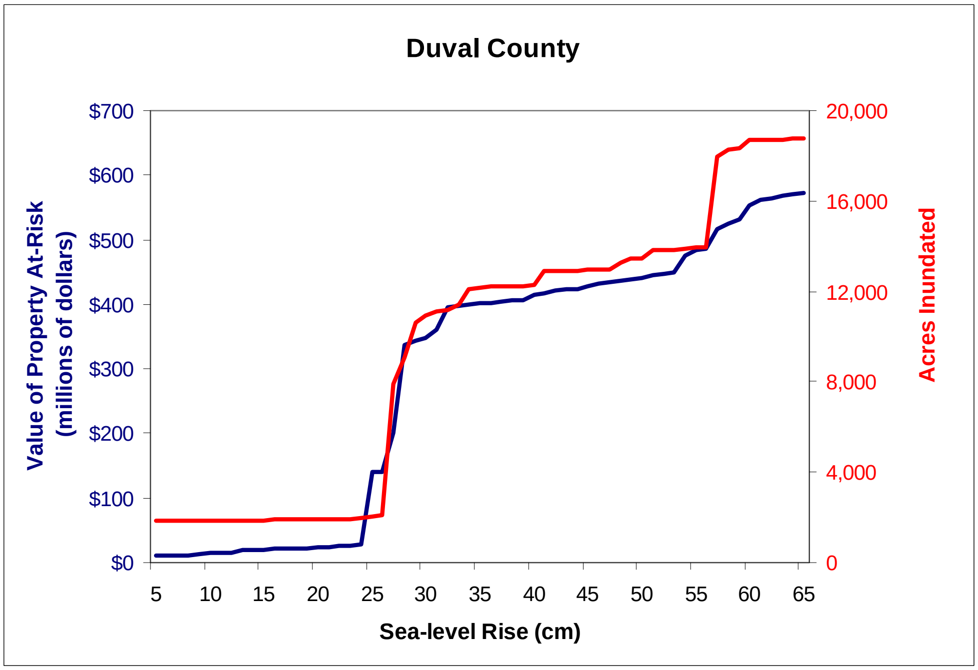

Figure 14. Trend in the area and value of property at risk of sea level rise in Duval County.

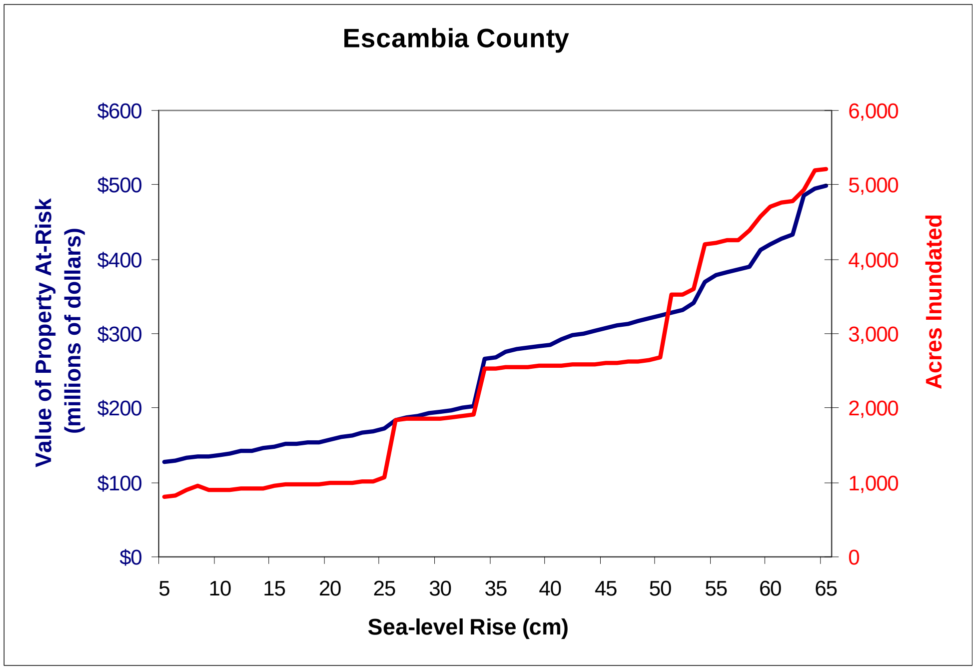

Figure 15. Trend in the area and value of property at risk of sea level rise in Escambia County.

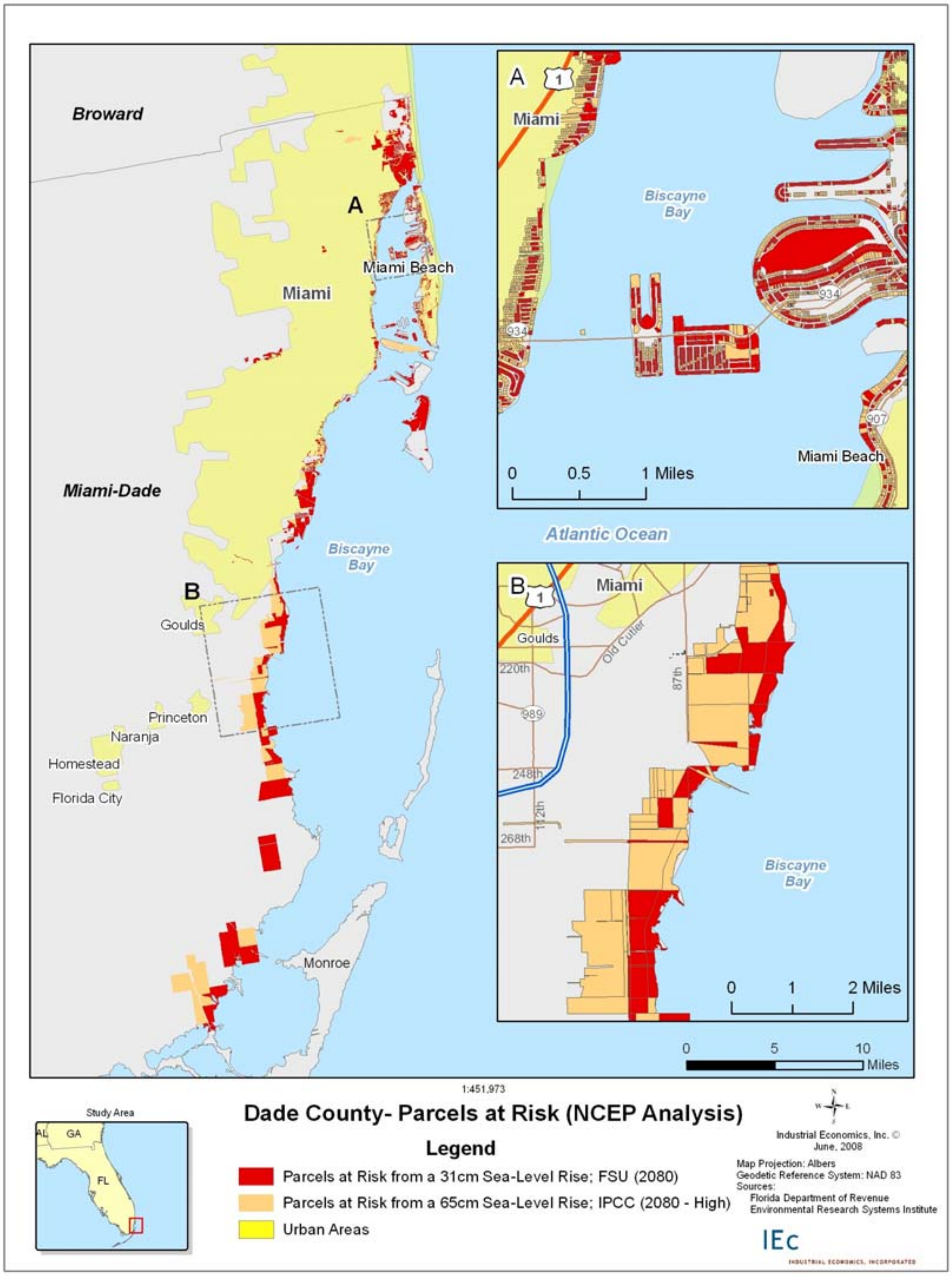

Figure 16. Land parcels at risk in Dade County.

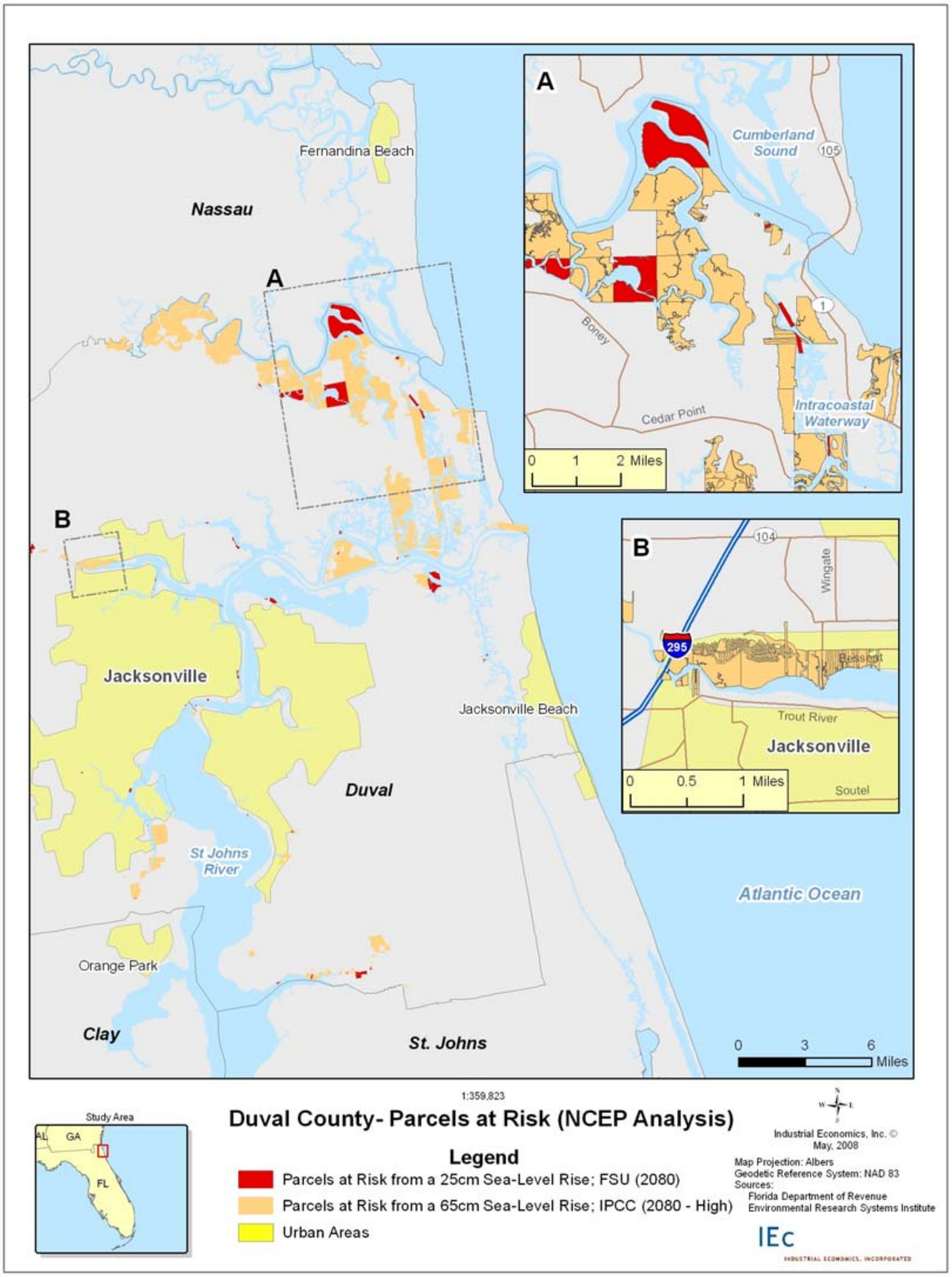

Figure 17. Land parcels at risk in Duval County.

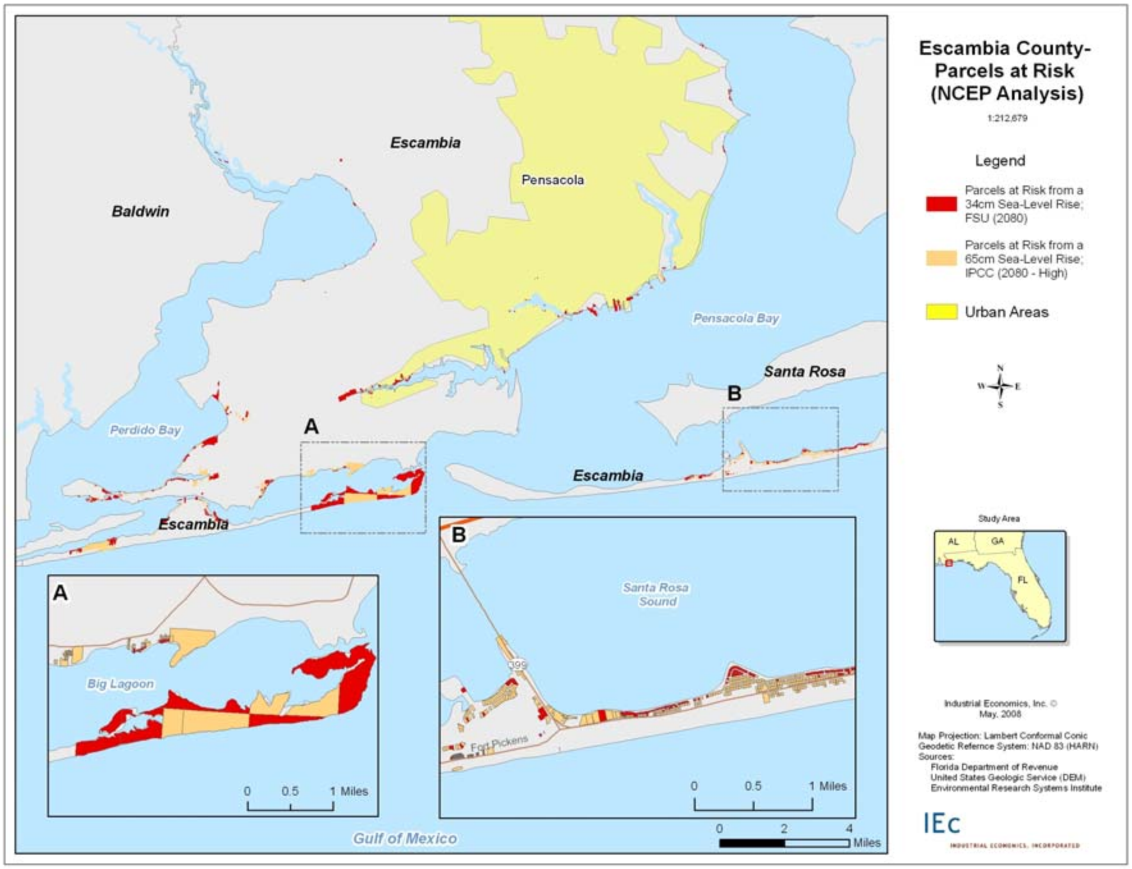

Figure 18. Land parcels at risk in Escambia County.

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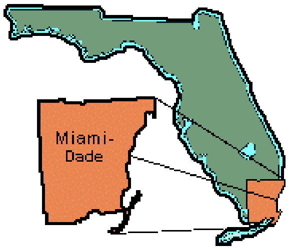
Appendix A: Hurricane Return Period Assessment

Dade County



Purpose of Flood Insurance Study (FIS). The purpose of the Dade County FIS was to allow local and regional planners to develop actuarial flood insurance rates, update existing floodplain regulations, and further promote sound land use and floodplain development (FEMA, 1994). The study encompassed all of Dade County, with the exception of Everglades National Park (about one-third of the county).

Dade County Background Information. Dade County is flat and low with elevations generally below 10 ft (3.05 m). The western and southern areas are marshy with a mean elevation of around 5 ft (1.52 m) mean sea level (MSL).

Hurricane Return Period Results. Hurricane Wilma resulted in a 7-foot (2.13 m) high storm surge in Dade County. Based on FEMA’s study, it was classified approximately as a 75.8-year event hurricane. For a 0.28-foot (8.53 cm) and a 1.02-foot (0.3 m) SLR scenario (FSU BSRC SLR estimate for year 2030 and 2080), the same density hurricane as Wilma would be reduced from a 75.8-year to a 51.3-year and 20.6-year event, respectively. For a 0.49-foot (14.9 cm) and a 2.13 ft (0.65 m) SLR scenario (IPCC estimates for years 2030 and 2080, it would be reduced to 39.5 years and 5.2 years, respectively. Figure A-1 indicates the scenario of reduction of hurricane return period in Dade County, according to the IPCC and FSU BSRC SLR estimates for year 2080.

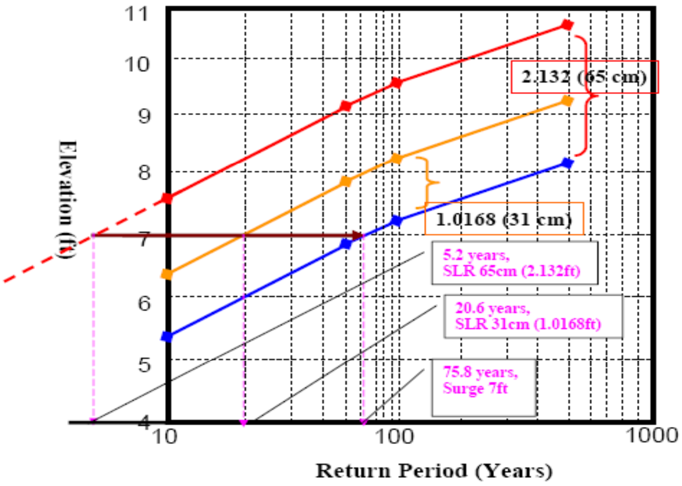
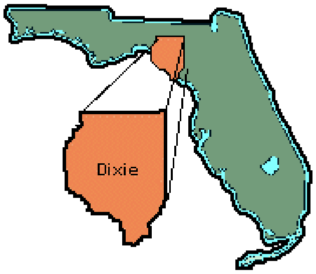


Figure A-1. Reduction of hurricane return period^{a} **in Dade County by elevation based on IPCC and FSU sea level rise estimates.**

a. Hurricane return periods capture the essence of uncertainty in extreme meteorological phenomena (storm surge, wave, and wind) associated with hurricanes.

Dixie County



Purpose of FIS. The purpose of the Dixie County FIS was to (1) investigate the existence and severity of flood hazards in Dixie County, and (2) aid in the administration of the NFIA and the FDPA (FEMA, 1983). The study was also used to convert Dixie County to the regular program of flood insurance by FEMA. Local and regional planners use this study to promote sound floodplain management. The study covered all the unincorporated areas of Dixie County.

Dixie County Background Information. Dixie County is on the North Florida Gulf Coast, about 90 miles south of Tallahassee and about 100 miles north of Tampa. Dixie County is low in elevation, with gently sloping and poorly drained marshy areas. The elevations range from 10 ft (3.05 m) NGVD29 to higher areas in the northern portion of the county, extending to 60 ft (18.23 m) NGVD29.

Hurricane Return Period Results. Hurricane Dennis resulted in a 9-foot (2.74 m) high surge in Dixie County, which FEMA classified as a 13.6-year event hurricane (FEMA, 1983). For a 0.92-foot (0.28 m) SLR scenario (IPCC estimate for 2080), it would be reduced to 9.6 years. For a SLR scenario of 0.23 ft (0.07 m) (FSU BSRC estimate for year 2030), the same hurricane storm surge as Dennis would be reduced from 13.6 years to 13.3 years. For IPCC's SLR scenarios of 0.49 ft (14.9 cm) and 2.13 ft (0.65 meters) for years 2030 and 2080, the same hurricane storm surge would be reduced to 11.3 years and 6 years, respectively. Figure A-2 indicates the scenario of reduction of hurricane return period in Dixie County, according to the IPCC and FSU BSRC SLR estimates for year 2080.

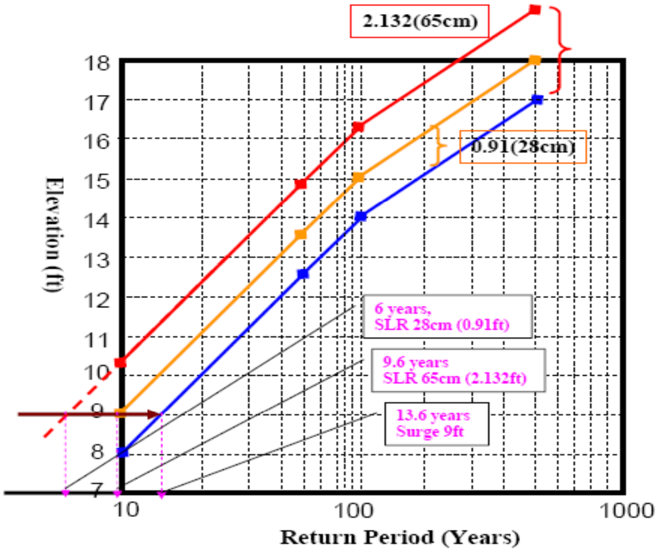
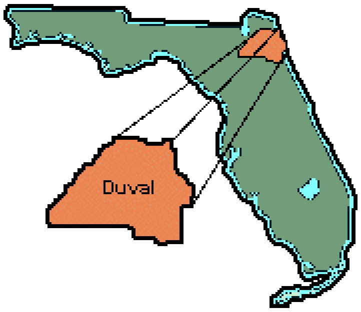


Figure A-2. Reduction of hurricane return period in Dixie County by elevation based on IPCC and FSU sea level rise estimates.

Duval County



Purpose of FIS. The FIS for Duval County was used by the community to update existing floodplain regulations as part of the regular phase of the National Flood Insurance Program (NFIP) (FEMA, 1989). Local and regional planners used this information to promote sound land use and floodplain development.

Duval County Background Information. Because of its flat terrain, many inland areas experience shallow flooding after a heavy rainfall. The City of Neptune Beach is partially protected from the Atlantic Ocean by a seawall.

Hurricane Return Period Result. Hurricane Frances resulted in a 5.9-foot (1.8 m) high surge in Duval County. Based on FEMA's study (FEMA, 1989), it was classified as a 100-year event hurricane. For SLR scenarios of 0.24 ft (7.3 cm) and 0.83 ft (0.25 m) (FSU BSRC's estimates for years 2030 and 2080), the same hurricane storm surge as Frances would be reduced to 80.2 years and 47 years, respectively. For a 0.49-foot (14.9 cm) and 2.13-foot (0.65 m) scenario (IPCC's estimates for years 2030 and 2080), the same hurricane storm surge would be reduced to 63.7 years and 14 years, respectively. Figure A-3 indicates the scenario of reduction of hurricane return period in Duval County, according to the IPCC and FSU BSRC SLR estimates for year 2080.

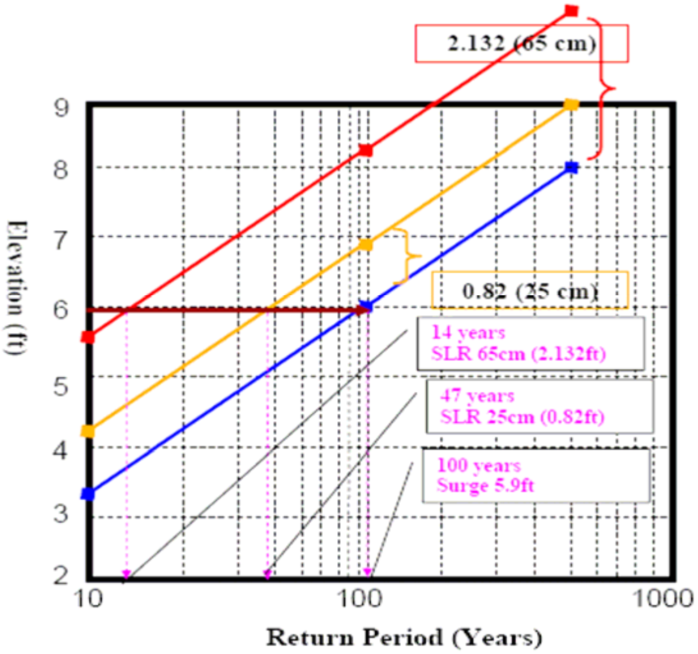
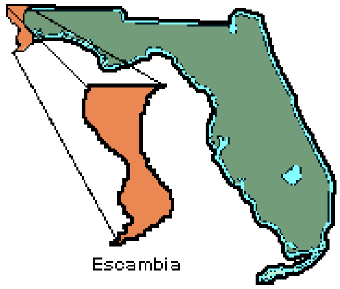


Figure A-3. Reduction of hurricane return period in Duval County by elevation based on IPCC and FSU sea level rise estimates.

Escambia County



Purpose of FIS. The goal of the Escambia County FIS was to develop actuarial flood insurance rates, update existing floodplain regulations, further promote sound land use and floodplain development by local and regional planners, and aid in the administration of NFIA and the FDPA (FEMA, 2000). The study covered the entire geographic area of Escambia County.

Escambia County Background Information. The terrain in Escambia County is highly variable. Level to moderately sloping terrain is indicative of the southwest portion of the county (west of Pensacola). The soils here are somewhat impermeable and poorly drained. The southwestern area comprises flat, low, and marshy areas. In the central and northern portions of the county, there are rolling, forested hills and moderately steep slopes. Elevations in these areas may reach up to 300 ft (91.44 m). Flooding in Escambia County is normally a result of tidal surge and overflow of streams and swamps associated with rainfall runoff.

Hurricane Return Period Results. Hurricane Dennis resulted in a 12-foot (3.66 m) high surge in Escambia County. Based on FEMA's study, it was classified as an 846-year hurricane event. For SLR scenarios of 0.29 ft (8.8 cm) and 1.12 ft (0.34 m) (FSU BSRC estimates for years 2030 and 2080), the same hurricane storm surge as Dennis would be reduced from 846 years to 732 years and 470 years, respectively. For a 0.49-foot (0.15 m) and 2.13-foot (0.65 m) scenario (IPCC estimates for years 2030 and 2080), the same hurricane storm surge would be reduced to 657 years and 272 years, respectively. Figure A-4 indicates the scenario of reduced hurricane return period in Escambia County, according to IPCC and FSU BSRC SLR estimates for year 2080.

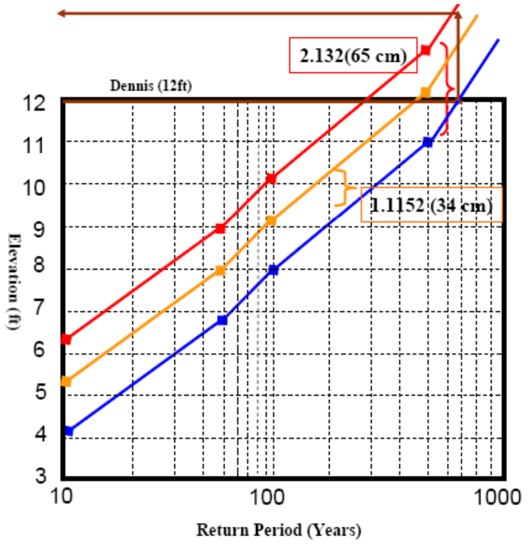
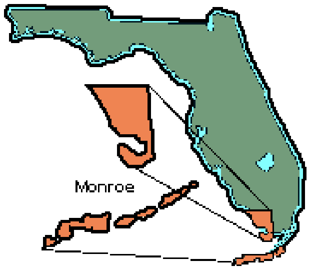


Figure A-4. Reduction of hurricane period in Escambia County by elevation based on IPCC and FSU sea level rise estimates.

Monroe County



Purpose of FIS. The purpose of the Monroe County FIS was to aid in the administration of the NFIA and the FDPA, develop flood risk data for various areas of the county to establish actuarial flood insurance rates, and assist the county in promoting sound floodplain management. The FIS covers the entire geographic area of Monroe County (FEMA, 2005).

Monroe County Background Information. Residential, commercial, and industrial development in Monroe County occurs mainly along the Florida Keys. The mainland remains largely undeveloped and includes the Big Cypress National Preserve and Everglades National Park. Coastal areas bordering the Atlantic Ocean and the Gulf of Mexico are subject to storm surge flooding due to hurricanes and tropical storms. Flood protection measures are not known to exist in Monroe County.

Hurricane Return Period Results: Hurricane Wilma resulted in a 2.76-foot (0.84 m) high surge in Monroe County. Based on FEMA's study, it was classified as a 7.35-year hurricane event. For SLR scenarios of 0.28 ft (8.53 cm) and 1.02 ft (0.31 m) (FSU BSRC estimates for years 2030 and 2080), the same hurricane storm surge as Wilma would be reduced from 7.35 years to 6.04 years and 3.61 years, respectively. For a 0.49-foot (14.9 cm) and 2.13-foot (0.65 m) scenario (IPCC estimates for years 2030 and 2080), the same hurricane storm surge would be reduced to 5.22 years and 1.65 years, respectively. Figure A-5 indicates the scenario of reduction of hurricane return period in Monroe County, according to the IPCC and FSU SLR estimates for year 2080.

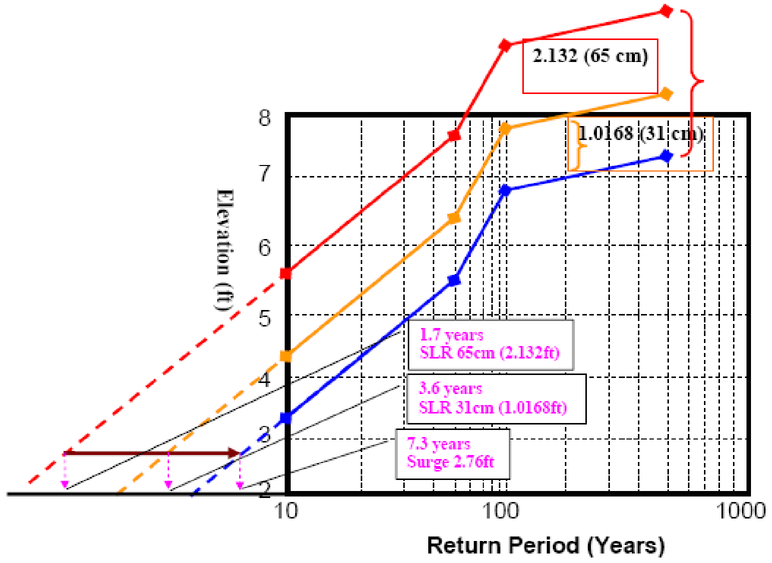
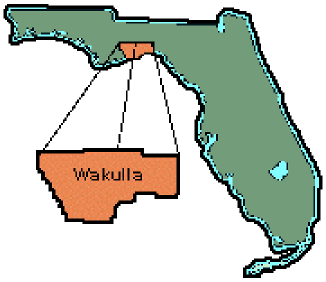


Figure A-5. Reduction of hurricane return period in Monroe County by elevation based on IPCC and FSU sea level rise estimates.

Wakulla County



Purpose of FIS. The purpose of the Wakulla County FIS was to investigate the existence and severity of flood hazards in the unincorporated areas of Wakulla County, Florida, and to aid in the administration of the NFIA and the FDPA. Wakulla County had converted to the regular program of flood insurance by FEMA in January 1981.

Wakulla County Background Information. Wakulla County's ground elevations are typically very low throughout the county, ranging from sea level to 10 ft (3.05 m) near the coast to greater than 25 ft (7.62 m) near the northern part of the county. As mentioned in the FEMA (1986) study, the main flood hazard in terms of damage to Wakulla County is the inundation of low-lying coastal areas during the passage of a severe hurricane or tropical storm. The coastal area is very prone to extreme storm tides. The storm surge elevations are higher in certain areas (west and south of Apalachee Bay) for two reasons. First, shallow water depths extend a great distance offshore, thereby increasing the effect of bottom and wind friction, which results in higher storm surge elevations. Second, storm-generated winds out of the south-southeast create a flow of water in a northwest direction along Florida's west coast into Apalachee Bay.

Hurricane Return Period Results. Hurricane Dennis resulted in a 9-foot (2.74 m) high surge in Wakulla County. Based on FEMA's study, it was classified as a 30-year event hurricane. For SLR scenarios of 0.27-foot (8.23 cm) and 1.05-foot (0.32 m) (FSU BSRC's estimates for years 2030 and 2080), the same hurricane storm surge as Dennis would be reduced from 30 years to 27.1 years and 20.4 years, respectively. For 0.49-foot (14.9 cm) and 2.13-foot (0.65 m) SLR scenarios (IPCC's estimates for years 2030 and 2080), the same hurricane storm surge would be reduced to 25.1 years and 13.7 years, respectively. Figure A-6 indicates the scenario of reduced hurricane return period in Wakulla County according to the IPCC and FSU's SLR estimates for year 2080.

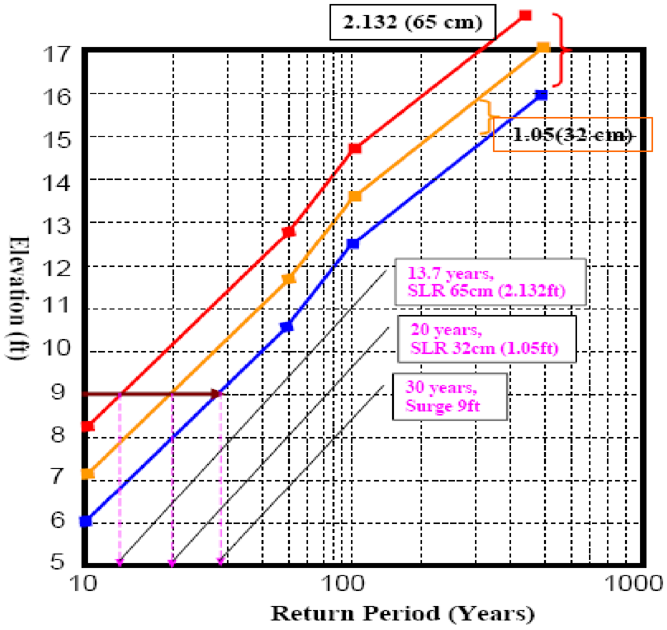


Figure A-6. Reduction of hurricane return period in Wakulla County by elevation based on IPCC and FSU sea level rise estimates.

Appendix B: Figures of Hurricane Return Period and Damage Cost Assessments in the Six Florida Counties

Figures B-1 through B-6 depict the joint representation of hurricane return period and associated damages costs based on SLR estimates.[23] For example, in Figure B-6, Hurricane Dennis resulted in a 9-foot high surge (2.74 m) in Wakulla County and according to FEMA's study, was classified as a 30-year event hurricane. For an SLR of a 2.13-foot scenario (0.65 m) (IPCC's estimate to year 2080), the same hurricane storm surge as Dennis will be reduced from a 30-year to a 13.7-year event. There will be an increasing return period frequency with an associated SLR. Damage costs associated with storm events can also be expected to increase with respect to sea level rise. The benefit of viewing both return period and damage costs in one figure provides clarity to the interpretation of temporal results of sea level rise. These merged figures could be used be policy decision-makers and insurance companies, among others.

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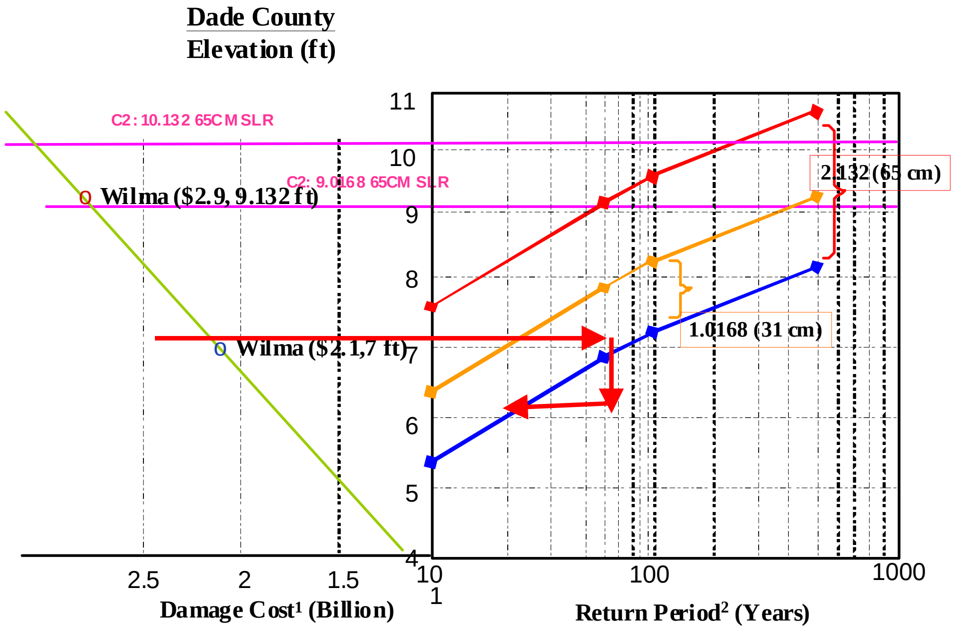
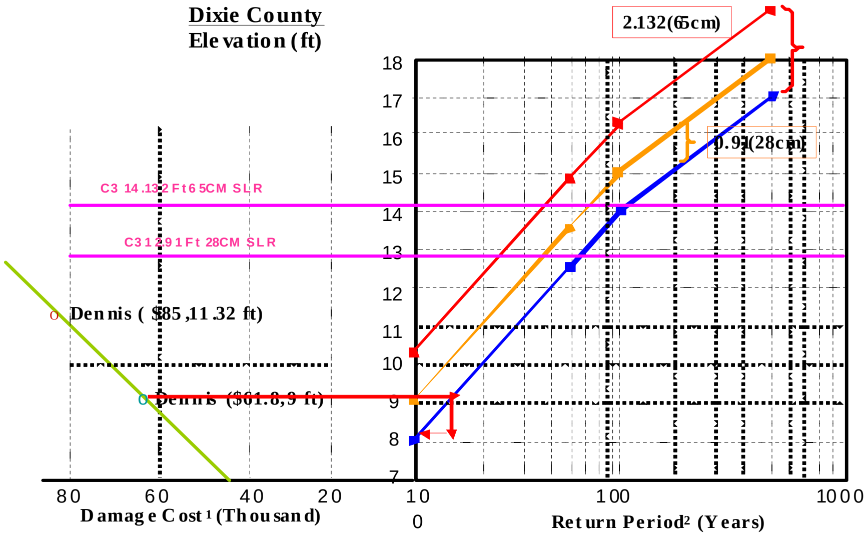
23. In order to fit both graphs into one figure, FSU CEFA selected hurricanes that would fit most appropriately on both the reduction of hurricane return period and hurricane cost damage assessment figures. Hence, in a few counties, figures will extend slightly beyond the slope on one or two figures.



1. Hurricane summary data, Florida Office of Insurance Regulation, 2006.
2. Flood Insurance study, FEMA, 2000.

Figure B-1. Hurricane return period and cost damages in Dade County.

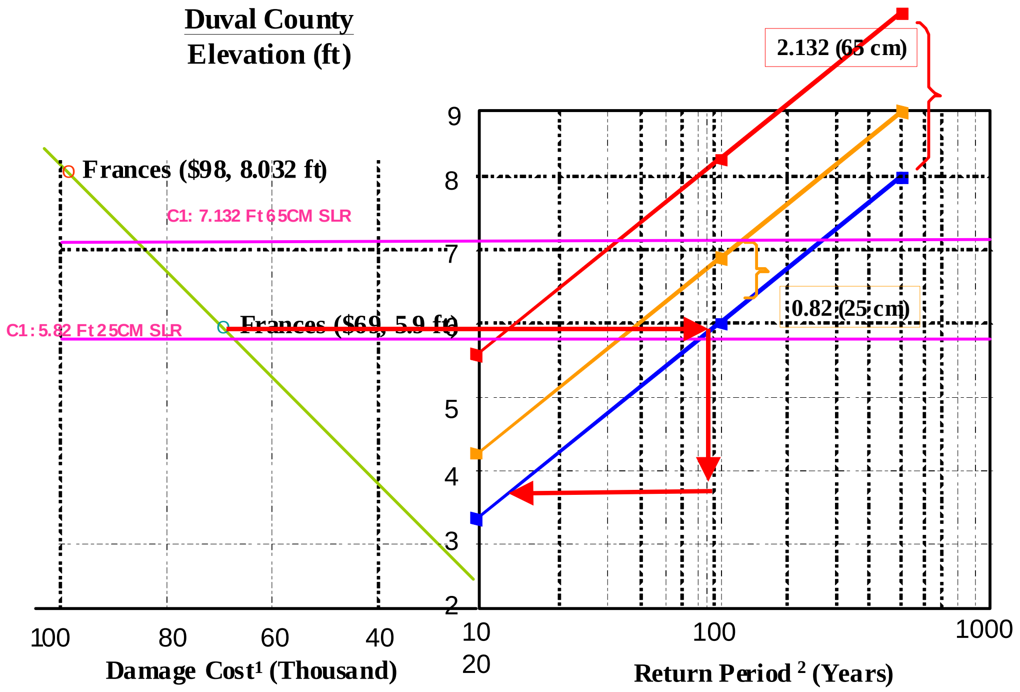
Source: CEFA, Florida State University, 2006.



1. Hurricane summary data, Florida Office of Insurance Regulation, 2006.
2. Flood Insurance study, FEMA, 2000.

Figure B-2. Hurricane return period and cost damage in Dixie County.

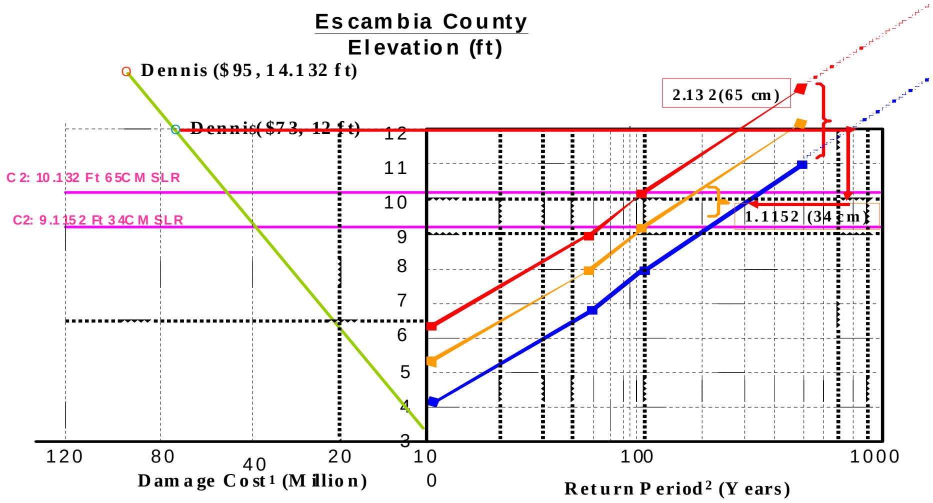
Source: CEFA, Florida State University, 2006.



1. Hurricane summary data, Florida Office of Insurance Regulation, 2006.
2. Flood Insurance study, FEMA, 2000.

Figure B-3. Hurricane return period and cost damages in Duval County.

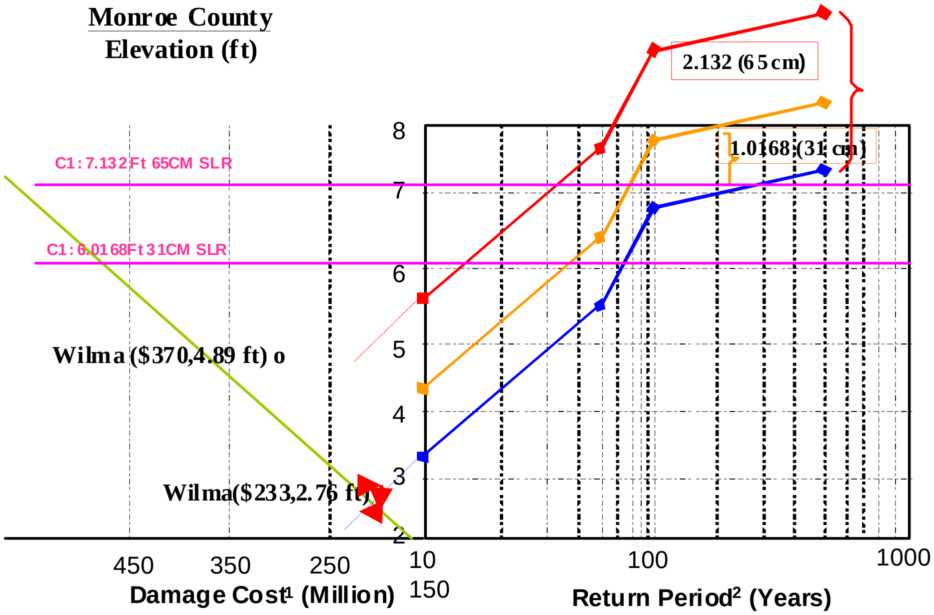
Source: CEFA, Florida State University, 2006.



1. Hurricane summary data, Florida Office of Insurance Regulation, 2006.
2. Flood Insurance study, FEMA, 2000.

Figure B-4. Hurricane return period and cost damages in Escambia County.

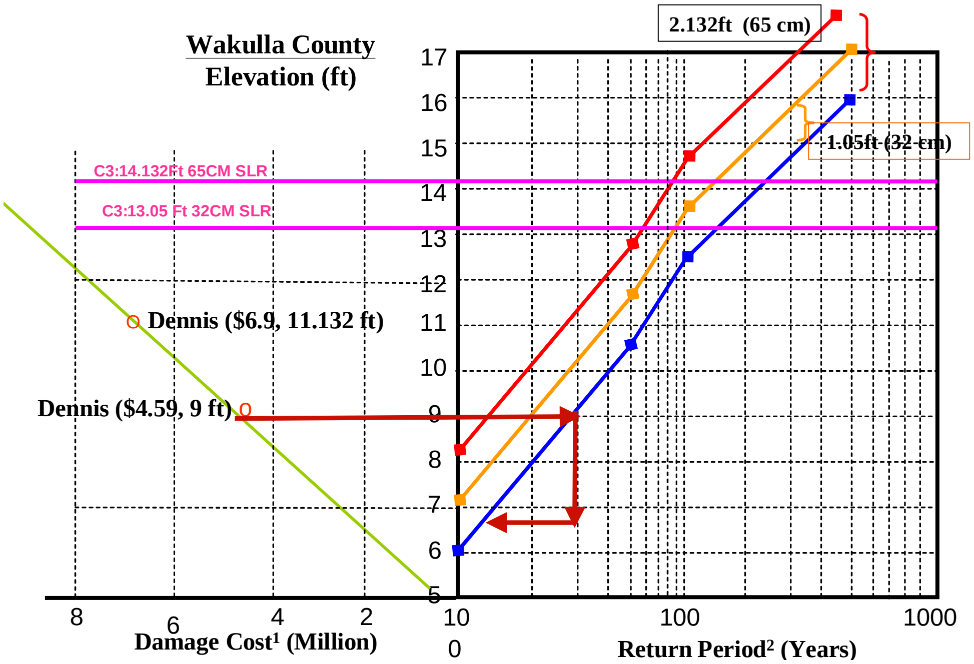
Source: CEFA, Florida State University, 2006.



1. Hurricane summary data, Florida Office of Insurance Regulation, 2006.
2. Flood Insurance study, FEMA, 2000.

Figure B-5. Hurricane return period and cost damages in Monroe County.

Source: CEFA, Florida State University, 2006.



1. Hurricane summary data, Florida Office of Insurance Regulation, 2006.
2. Flood Insurance study, FEMA, 2000.

Figure B-6. Hurricane return period year average(s) and cost damages in Wakulla County.

Appendix C: DEM Data Sources

At the project's onset, it was determined that the U.S. Geological Survey (USGS) DEM data had some reliability issues and did not provide resolution below 32.8 ft (10 m) elevation (pertaining to the counties for this study). Because of these concerns, FSU's CEFA opted to initially work with Light Detection and Ranging (LiDAR) data given its better resolution. LiDAR is an optical remote sensing technology that measures properties of scattered light to find range and/or other information of a target at a distance. FSU CEFA tested one county (Escambia) using LiDAR data, and spent a considerable amount of time error checking and data cleaning, and creating numerous TIN files (in order to overlay the parcel id data). The year 2005 proved to be fraught with errors (based on the Army Corps not providing sufficient quality checks before release to the public). FSU CEFA decided to use 2004 data instead since it proved to be more accurate. FSU's CEFA (and in consultation with the Florida Resources and Environmental Analysis Center at FSU) found that the LiDAR data was raw; i.e., not each value in the file reflected "bare earth" and in some cases, building roof tops, tree lines, etc., were captured. Therefore, manually cleaning these data was not be a reasonable solution given the time and financial constraints of the project. In many cases, along the bay side of the island, LiDAR values started at 5 or 6 ft (1.5 or 1.8 m) (likely due to mangrove or other vegetation along the shoreline). Currently, LiDAR data is used by coastal counties in Florida primarily for beach erosion and beach profile measurements by Florida Department of Environmental Protection's (FDEP's) Bureau of Beaches and Coastal Systems.[24] Hence, FDEP is interested in the mean water level to the edge of the parcel data, and is not very concerned with data further inland. Since we were interested in the data further inland and since the LiDAR would require laborious clean up efforts, a decision was made to use USGS's National Elevation Dataset (NED) data.[25] Although the NED data does not have the resolution that the quality LiDAR has, NED is a proven data source and widely available in 32.8 ft (10 m) and some 98.4 ft (30 m) resolution [where 32.8 ft (10 m) was unavailable]. LiDAR data collection for all of Florida's counties has just been completed as of June 2008 by the Florida Department of Emergency Management. LiDAR data for several coastal counties are available for use, however, the entire Florida coastal county dataset (28,100 square miles) will be data checked and available for use by December 2008.[26]

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[24] The Florida Division of Emergency Management (FDEM), Department of Community Affairs, has issued a contract to perform LiDAR flyover(s) for all coastal counties in Florida. FDEM will catalog all existing LiDAR data and related products (bathymetry and orthophotography) within areas of the state affected by hurricane surge. See http://www.floridadisaster.org/gis/lidar/ for latest updates (FDEM, 2008a).

[25] USGS's NED data sources. Available: http://ned.usgs.gov/.

[26] See: http://www.floridadisaster.org/gis/LiDAR/Documents/scheduled_delivery.pdf (FDEM, 2008b) for scheduled delivery.