A Sea Level Rise Impact Projection Study for Wakulla County, Florida

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ABSTRACT

Sea level rise related to climate change poses problems globally, resulting in frequent flooding, storm surges, economic losses, land inundation, reduced biodiversity, and forced migration. Sea level rise can begin with nuisance flooding and saltwater intrusion and end with permanent land inundation. With its 1,350 miles of coastline, Florida is particularly vulnerable to sea level rise. This study analyzes how a sea level rise scenario can affect property and socially vulnerable populations in Wakulla County, Florida, in 2050. Our study focuses on permanent inundation. Findings reveal that the total just value of affected properties ranges from \$225 million to \$350 million in today's dollars, predominantly impacting residential homes. Social vulnerability analysis shows increased vulnerability for Socioeconomic and Household & Disability themes for residents living within areas at risk of permanent inundation. The analysis indicates minimal variations in the vulnerability themes of Ethnicity & Language and Housing & Transportation. This study can serve as a framework for other Florida counties implementing sea level studies.

Keywords: Sea level rise, social vulnerability, GIS, Florida Statute, property risk.

ACKNOWLEDGMENT

This study began as a 2021 Master's in Geographic Information Systems (MSGIS) Capstone Project with Dr. Julie Harrington of Florida State University's Center for Economic Forecasting and Analysis (CEFA). Dr. Harrington was an influential voice for the bi-partisan Florida Statute 161.551 addressing Florida sea level rise at the heart of this study.

ACRONYMS and ABBREVIATIONS

SLR – Sea Level Rise

GMSL – Global Mean Sea Level

USACE – US Army Corps of Engineers

CDC – U.S. Centers for Disease Control and Prevention

SLIP – Sea Level Impact Projection

FDEP – Florida Department of Environmental Protection

NOAA – National Oceanic and Atmospheric Administration

NAVD88 – North American Vertical Datum of 1988

FEMA – Federal Emergency Management Agency

INTRODUCTION

Sea level rise (SLR) threatens coastal properties and those living and working in these at-risk areas. Over time, it is expected that SLR will not only cause transient flooding and its associated adverse effects in many coastal areas but will also cause permanent inundation of land. Despite this, coastal properties are generally densely populated, and these communities are often major economic producers, providing a disproportionate number of jobs, economic output, and trade entry points. The trend of coastal communities serving as hubs of high population density and significant economic activity is unlikely to change in the foreseeable future, as highlighted by McAlpine and Porter (2018). Understanding the timing, extent, affected populations, and financial repercussions of permanent inundation due to SLR is crucial for future community planning efforts.

Sea level rise can cause many adverse effects, including saltwater intrusion, erosion, and inundation (Chang et al., 2013). However, SLR does not affect all areas equally, instead having the most pronounced effect on low-lying coastal areas. Over the next century, these areas will likely experience flooding, erosion, and submergence (Beck and Lin, 2020).

Florida has around 1,350 miles of coastal shoreline, the second most of any U.S. state, trailing only Alaska. Significant SLR will put substantial numbers of people at risk of having their properties damaged or destroyed. Some coastal residents and workers can weather the threats posed by SLR, but others would have their lives turned upside down with no clear path to recovery.

Florida is a significant tourism draw, with over 140 million tourists visiting in 2023 (VisitFlorida, n.d.). The economic impact of this creates many jobs and billions of dollars of revenue for the state (Harrington et al., 2017). Many visit Florida's beaches, which account for 825 miles of Florida's coastline, and receive more than 810 million visits per year (Houston, 2013). Florida's coastlines are clearly important to its people and economy.

In 2020, the Florida Legislature passed a bipartisan law to address new coastline construction beginning in 2021. Florida Statute 161.551 requires new coastal construction projects using public funds to undergo a sea level impact projection (SLIP) model analysis before construction. The Florida Department of Environmental Protection (FDEP) Florida Resilient Coastlines Program is responsible for approving the models and making them publicly available.

The original intent of this study was to demonstrate the FDEP's methodology to interpret and implement Florida Statute 161.551. However, the FDEP had not completed the rules and methods at the time of this project. Further, the FDEP's methods were designed to protect selected individual infrastructure investments, not a larger geographic area. Since we could not use the FDEP's methodology, we performed a county-wide analysis in hopes that our work could complement the FDEP methods.

For this study, we perform a SLR impact projection for Wakulla County, Florida, for the year 2050 to determine areas of permanent inundation. We use low, intermediate, and high scenarios, as shown by the U.S. Army Corps of Engineers (USACE) Sea-level Change Curve Calculator, to determine SLR. The areas of permanent inundation are used to calculate the value of damage done to property parcels. As calculated by the Centers for Disease Control and Prevention (CDC), social vulnerability characteristics are also used to count who is at risk and compare Wakulla County's population to the portion of the county that will be at risk under the high scenario.

BACKGROUND

Sea levels have undergone major shifts over the past several million years, at times higher and lower than modern levels. These shifts have caused significant changes in shoreline positions around the world. Sea levels have been highly stable for approximately the last 6,000 years, as have shoreline positions. However, recent projections show that this period of sea level stability could end and that future sea level rise (SLR) rates could soon resemble historical deglaciation periods (Donoghue, 2011).

The primary drivers of SLR are melting ice masses and thermal expansion of seawater, both accelerated by global warming (Bilskie et al., 2016). Global mean sea level (GMSL) rise was determined to be 1.7 ± 0.3 mm/year throughout the 20th century. If this increase continues at this rate, then sea level in 2100 would be 310 ± 30 mm higher than the previous century (Church and White, 2006). The rate of SLR has historically exhibited non-linear acceleration. For example, between 1950 and 2000, the 1980s recorded the lowest rates, while the 1990s experienced the highest (Holgate and Woodworth, 2004). Satellite altimetry data was combined with other data to determine a 2.2 ± 0.3 mm/year GMSL rise in 1993, and a 3.3 ± 0.3 mm/year GMSL rise in 2014. Researchers expect that SLR will further accelerate over the next century, eclipsing the fast rates of GMSL rise detected by this satellite altimetry (Chen et al., 2017).

Evaluating Sea Level Rise

There are many ways to analyze SLR. Appendix A is a brief overview of data used in studies for different purposes. The chart is not a comprehensive view of data inputs, but it gives a sufficient perspective of the various types of data inputs used in studies geographically proximal to Florida. The studies incorporate an array of 35 different types of data inputs, with tide gauges standing out as the most frequently used. Tide gauges were predominantly used because they offer long-term, consistent records crucial for robust sea-level rise projections. Local past sea level values and LiDAR data are the second most common inputs, followed by greenhouse emissions, air temperature, subsidence, land elevation, and global sea level values. Hydrography, precipitation, glacier and ice loss, and tropical storms are uncommon inputs. The subject matter of these studies is varied. Several assess past and future SLR values. Others examine coastal forest loss, saltwater intrusion, socially vulnerable populations, real estate losses, mortgage and home price vulnerability, and community exposure to flooding. Appendix A shows a temporal view of data inputs. Tide gauges were used consistently across 30 years. LiDAR data is a recent addition predominantly utilized in contemporary studies. Table A1 in the appendix provides a broad temporal perspective of the subject areas affected by SLR and the different data types used to quantify the results.

Florida Response to SLR

Rule 62S-7 of Florida Statute 161.551 requires planned, state-financed, coastal construction projects to complete sea level impact projection (SLIP) studies. These studies evaluate potential storm or SLR impacts on the construction. Florida Statute 161.551 places the FDEP's Florida Resilient Coastlines Program in charge of developing and adopting implementation rules for the statute. Sea level impact projection studies can be submitted through a web-based application developed by the FDEP or by adhering to the standards specified in Chapter 62S-7.012 of the Florida Administrative Code (F.A.C.).

The SLIP study standards outlined in the statute require analysis of SLR 50 years into the future or for the life of the proposed project, whichever time is less. It is required that analysis of SLR must include the intermediate-high SLR scenario from the National Oceanic and Atmospheric Administration's (NOAA) 2017 report, *Global and Regional Sea Level Rise Scenarios for the United States*. The analysis must also use interpolated local SLR data from the two closest NOAA coastal tide gauges to the project site. Flood depth must be calculated using, at a minimum, the North American Vertical Datum of 1988 (NAVD88) for the Intermediate-High SLR scenario as defined by NOAA. Land subsidence must be included in the study as calculated by NOAA. This interpolation uses local tide gauges and is automatically included in the NOAA SLR projections. The standards also require analysis of flooding, wave action, and inundation 50 years into the future or for the life of the planned project, whichever time is less. The statute outlines three specific methodologies for conducting this analysis. First, NAVD88 must be used to approximate FEMA (Federal Emergency Management Agency) storm surge flood depth for a 100-year flood scenario. Second, this flood depth must be used with the Intermediate-High flood scenario defined by NOAA to assess flood risk using critical elevation points. Third, for vertical construction projects only, the cost of future flood damage must be estimated using Depth-Damage Curves from the USACE's 2015 *North Atlantic Coast Comprehensive Study*. The project must also receive a risk category defined by the 2020 Florida Building Code (Table 1604.5, Risk Category of Buildings and Other Structures). The construction project must provide the windspeed for which it was designed. This designation is determined by the risk category mentioned above. Alternative project designs and site locations must also be submitted. These designs and sites must state how they address issues such as releasing pollution and hazards from flying debris.

Florida Department of Environmental Protection Response

The FDEP began developing the SLIP study requirements in October 2020. During this process, they held roundtable talks with stakeholders, development workshops, and went through multiple refinements of the draft language. On 1 July 2021, they finalized the SLIP study requirement language. For the most recent updates on the process, refer to the official FDEP websites: https://floridadep.gov/rcp/florida-resilient-coastlines-program and https://floridadep.gov/rcp/beaches-funding-program/content/resilience-and-coastal-protection-rules-development.

STUDY AREA

Wakulla County, Florida, was selected as the study area for this project due to its geographical vulnerability to SLR and diverse social demographics, making it an ideal case study for a comprehensive approach. Wakulla County (see Fig. 1) is located fewer than 20 miles south of the state capital, Tallahassee. The county exhibits minimal development and encompasses segments of both the Apalachicola National Forest and the St. Marks National Wildlife Refuge. The shorelines are mostly marsh, only containing four small sand beaches stretching three miles. Wakulla County is renowned for Wakulla Springs State Park and the iconic lighthouse at St. Marks. Many movies have been filmed at Wakulla Springs because of its crystal-clear waters and secluded location. *Tarzan* films were made in 1938, followed by *The Creature from the Black Lagoon* in 1954, as well as numerous other works requiring clear water backgrounds.

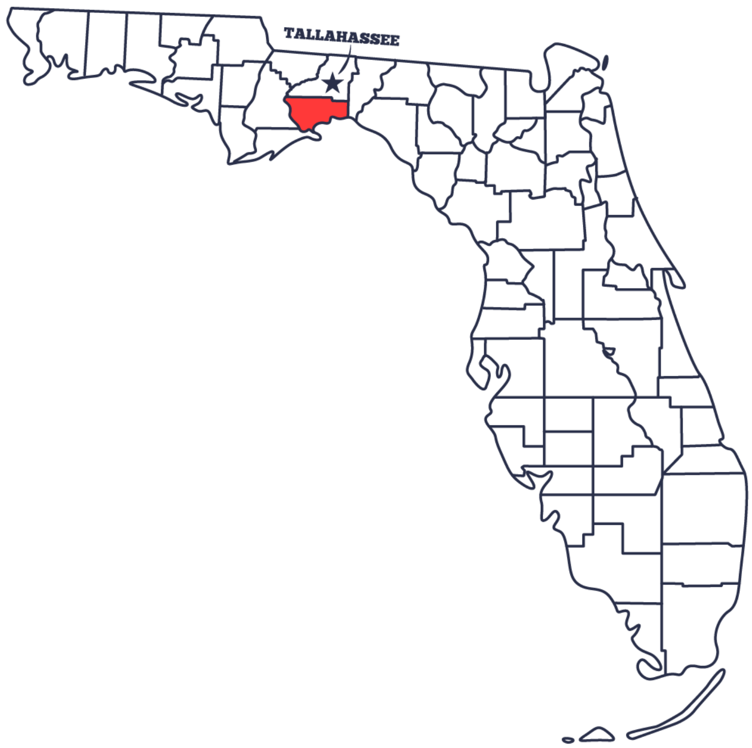

Figure 1. Wakulla County, Florida (in red) is just south of Tallahassee.

Looking to the future, populations are expected to increase. At the time of this writing, the 2010 census was the most recent population data available and shows Wakulla County with a population of 30,766 residents. Table 1 provides population projections from the University of Florida's Bureau of Economic and Business Research (BEBR, 2021) and the Florida Department of Transportation (FDOT). According to FDOT projections, Wakulla County is expected to have 41,800 people by the year 2050, marking a 35.82% increase over a four-decade span.

Census	Projections (BEBR)						Projections (FDOT)				
2010	2020	2025	2030	2035	2040	2045	2050	2055	2060	2065	2070
30,776	33,300	35,400	37,200	38,500	39,600	40,600	41,800	43,000	43,900	44,900	45,600

Table 1. Wakulla County populations from the 2010 census and future projections from two different sources.

DATA PREPARATION and METHODOLOGY

Our study calculates three categories of SLR risk (low, medium, and high) and analyzes each of these categories, as well as the entirety of Wakulla County, to identify social and property risks. Our data is gathered from various sources: some we prepare ourselves, some is publicly available, and a dataset was prepared for this project by request of field experts. Table 2 provides an overview of all data used in the project and its acquisition method and source.

Data Type	**Development and/or Acquisition Method**	**Publisher(s)**	**Data Product(s)**
SLR Risk Categories	Developed by authors	Coastal Services Center Coastal Inundation Digital Elevation Model (DEM) Current Mean Higher High Water Inundation Extent (MHWIE) US Army Corps of Engineers (USACE)	National Oceanic and Atmospheric Administration (NOAA) NOAA Office for Coastal Management Sea-level Rise US Army Corps of Engineers (USACE)
Population Counts	By request	Florida Resource and Environmental Analysis Center (FREAC) / Florida State University (FSU)	Custom intercensal population estimates
Social Vulnerability Index (SVI)	Publicly available	FREAC/FSU	FREAC SVI App. https://arcg.is/0P1Wfe
Property Appraisal	Publicly available	Florida Department of Revenue	Wakulla County Property Records

Table 2. Overview of all data development and/or acquisition methods.

Sea Level Rise Risk Category Data Preparation

For this analysis, we adopted an approach to calculating SLR similar to that used by Tewari et al. (2019), specifically adapting it for Wakulla County, Florida. The data and products used to develop the three scenarios of low, intermediate, and high SLR are shown in Table 3. The projected

SLR and associated risk categories for the year 2050 are as follows: 0.41 feet for the low-risk category, 0.71 feet for the intermediate-risk category, and 1.66 feet for the high-risk category.

Date	Data/Product	Source	Purpose
2012	Coastal Services Center Coastal Inundation Digital Elevation Model (DEM)	National Oceanic and Atmospheric Administration (NOAA)	Used to generate current elevation values
2016	Current Mean Higher High Water Inundation Extent (MHWIE)	NOAA Office for Coastal Management Sea-level Rise	Used to fill missing gaps in the DEM for current elevation values
2021	Sea-level Change Curve Calculator	US Army Corps of Engineers (USACE)	Used to determine inundation classes of low, intermediate, and high

Table 3. Details of the data and products used to prepare the three risk categories.

Appendix B provides the details of the SLR category preparation and may be of interest for those seeking more information on SLR preparation. Figures 2 and 3 show the spatial results of the three SLR scenarios of low, intermediate, and high.

Figure 2. Three resulting SLR scenarios for the county. Blue (low) represents areas inundated by just 0.41 feet of SLR, yellow (medium) represents areas inundated by 0.71 feet of SLR, and red (high) represents areas covered by 1.66 feet.

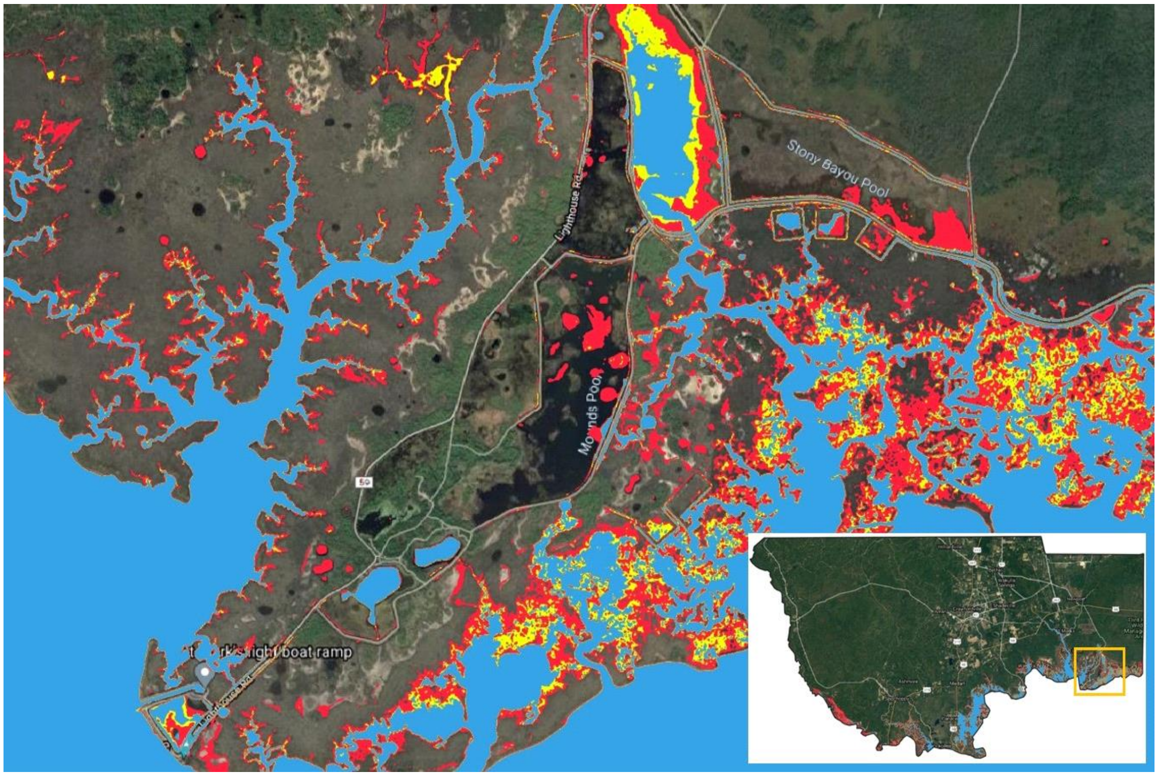

Figure 3. The three resulting SLR scenarios at closer zoom. The categories of low, medium, and high are shown by blue, yellow, and red respectively.

Population Count Data Preparation

Due to the delay of the 2020 census data release, we used an intercensal population estimation method to obtain 2021 population estimates at the property parcel scale. This method is developed by the Florida Resources and Environmental Analysis Center (FREAC) at Florida State University. More information can be found on this unpublished method in Appendix C.

The intercensal methodology combines census group quarter data, city/county population estimates, and property appraiser data. The group quarter data is from the U.S. 2010 Census (group quarter data is updated every ten years in the decennial census). The 2021 city/county population estimates are from the University of Florida's Bureau of Economic and Business Research (BEBR). The Florida Department of Revenue provided the 2021 property appraiser database. The intercensal estimation methodology focuses solely on aggregate population figures and does not extend to detailed demographic categories such as age or race. Figure 4 shows the resulting intercensal population estimates at the property parcel scale where each land parcel has a population estimate.

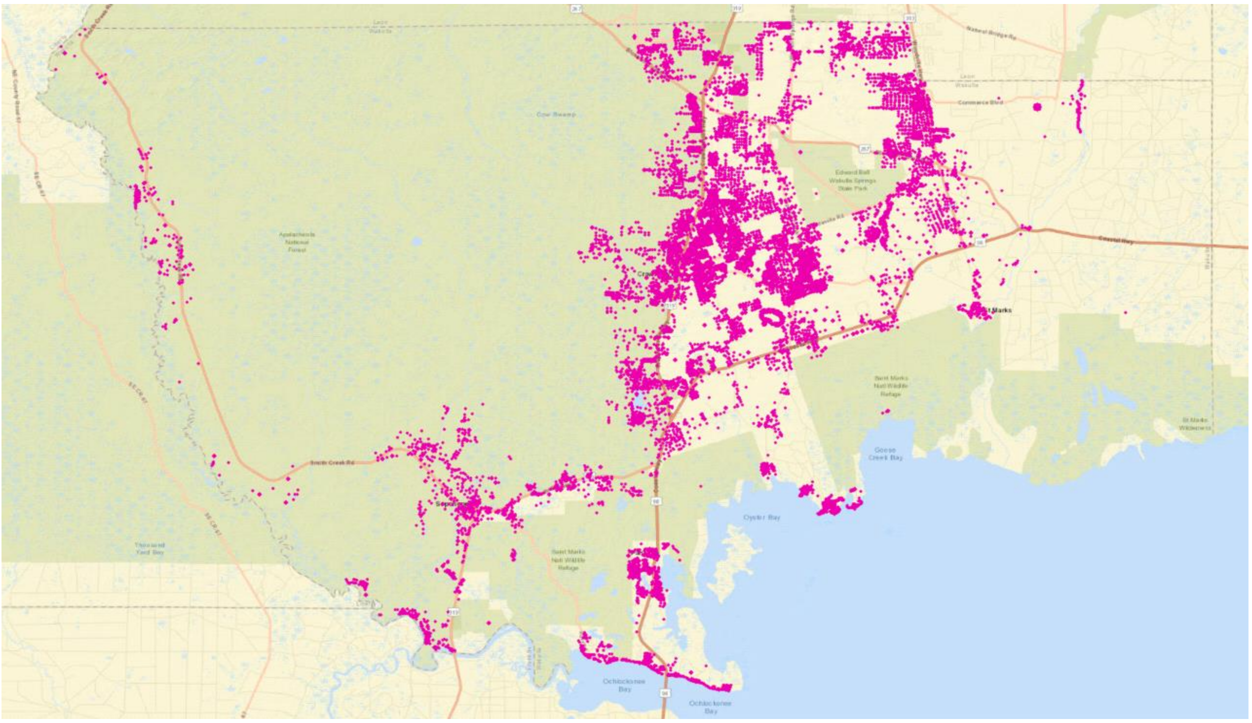

Figure 4. 2021 population estimates using an intercensal parcel estimation method (see Appendix C). Each dot represents an estimated number of people (usually 1+ to 10+ persons) at each property parcel. Larger circles represent higher populations. Note that the population is more logically distributed in towns and on the coast and not in national forests (census tract population distribution would have inaccurately placed population in the national forest).

There are several advantages to the intercensal parcel-based method. First, it can be calculated annually, thus giving regular population updates rather than relying on the decennial census. Second, the scale is more resolute as the results estimate the population for each property parcel. Typically, population estimates are at the census tract scale, which assumes that a population is evenly spread over an area when, in reality, populations tend to cluster. A census tract approach to population mapping could display populations in unpopulated areas such as forests and water bodies.

Social Vulnerability Data Preparation

Social vulnerability index (SVI) data from the U.S. Centers for Disease Control and Prevention (CDC, 2018) is included in this study to assess further the populations affected by SLR. The SVI data is published by the CDC at the census tract level. For improved readability, we chose to use a publicly available tool that reworked the data to tie it to populated areas and visualize the four themes simultaneously instead of using four different maps (FREAC, 2021).

The social vulnerability data are calculated using 15 data variables from the U.S. Census at the census tract scale. Each variable is statistically processed and ranked across all other tracts within Florida on a scale of 1 to 99. Each tract is assigned a score indicating its level of vulnerability. For example, a score of .23 represents a tract more vulnerable than only 23% of the tracts in Florida, indicating low vulnerability. A tract with a vulnerability score of .90 would be more vulnerable than 90% of Florida's census tracts, indicating high vulnerability. The CDC uses a quartile method to distinguish vulnerabilities, with breakpoints at .25, .50, and .75 to determine the four categories.

The social vulnerability dataset comprises five distinct indices as decided by the Center for Disease Control and Prevention. One is an overall index considering all 15 original data variables. Four other theme indices include assessments of census subsets to represent different vulnerability types. Socioeconomic vulnerability includes income and education, which can affect basic household needs, emergency savings, health literacy, and awareness of legal rights and social services. Socioeconomic vulnerability can have intergenerational effects. The Household & Disability theme looks at the ratio of dependent persons in households and their disabilities. Households with a high number of elderly and children face increased need for caregiving, which can strain the working-age population. Those with disabilities often require specialized healthcare while simultaneously facing possible communication or physical barriers. Dependence on support systems increases vulnerability if these systems are weakened or displaced. Ethnicity & Language considers ethnic diversity and English skills. Ethnic differences can contribute to systemic discrimination in employment, education, or housing resulting in unequal opportunities. Limited proficiency in the dominant language can restrict information access, limit resources, and contribute to social isolation. The Housing & Transportation theme includes measures housing quality, safety, and stability, and access to transportation. Quality of housing can affect health, safety, and structural integrity in disasters. Transportation can determine access to healthcare and other resources and allow evacuation from an oncoming disaster. This study employs these four theme-based social vulnerability indices to better delineate various public risk categories. (For researchers interested in replicating the Social Vulnerability Index in the southeastern United States, the Florida State University application provides a convenient tool for this purpose [FREAC, 2021]).

To avoid using four separate maps, we chose a publicly available glyph symbology (FREAC 2021; Strode et al. 2020), where the four vulnerability themes are mapped simultaneously. The glyph design uses a 1-km grid system that omits unpopulated areas to avoid confusion in forests and water bodies. The glyph design incorporates color and spatial arrangement to signify the vulnerability type, and the glyph's size indicates the degree of vulnerability. For example, the Socioeconomic theme is shown in red in the upper left corner. The size of the Socioeconomic symbology indicates the degree of vulnerability. A small Socioeconomic square indicates the lowest vulnerability (<.25), while the largest square represents the highest category of vulnerability (>.75). Compared to other regions in Florida, Wakulla County exhibits a relatively elevated level of vulnerability. The southern side of Crawfordville (Wakulla County's seat) has a somewhat high vulnerability for Household & Disability and low Socioeconomic vulnerability, as evidenced by the green and red of the glyphs. The town of St. Marks has higher Socioeconomic and higher Housing & Transportation vulnerabilities. The county has low Ethnicity & Language vulnerability. Figure 5 maps the four social vulnerability themes for the county.

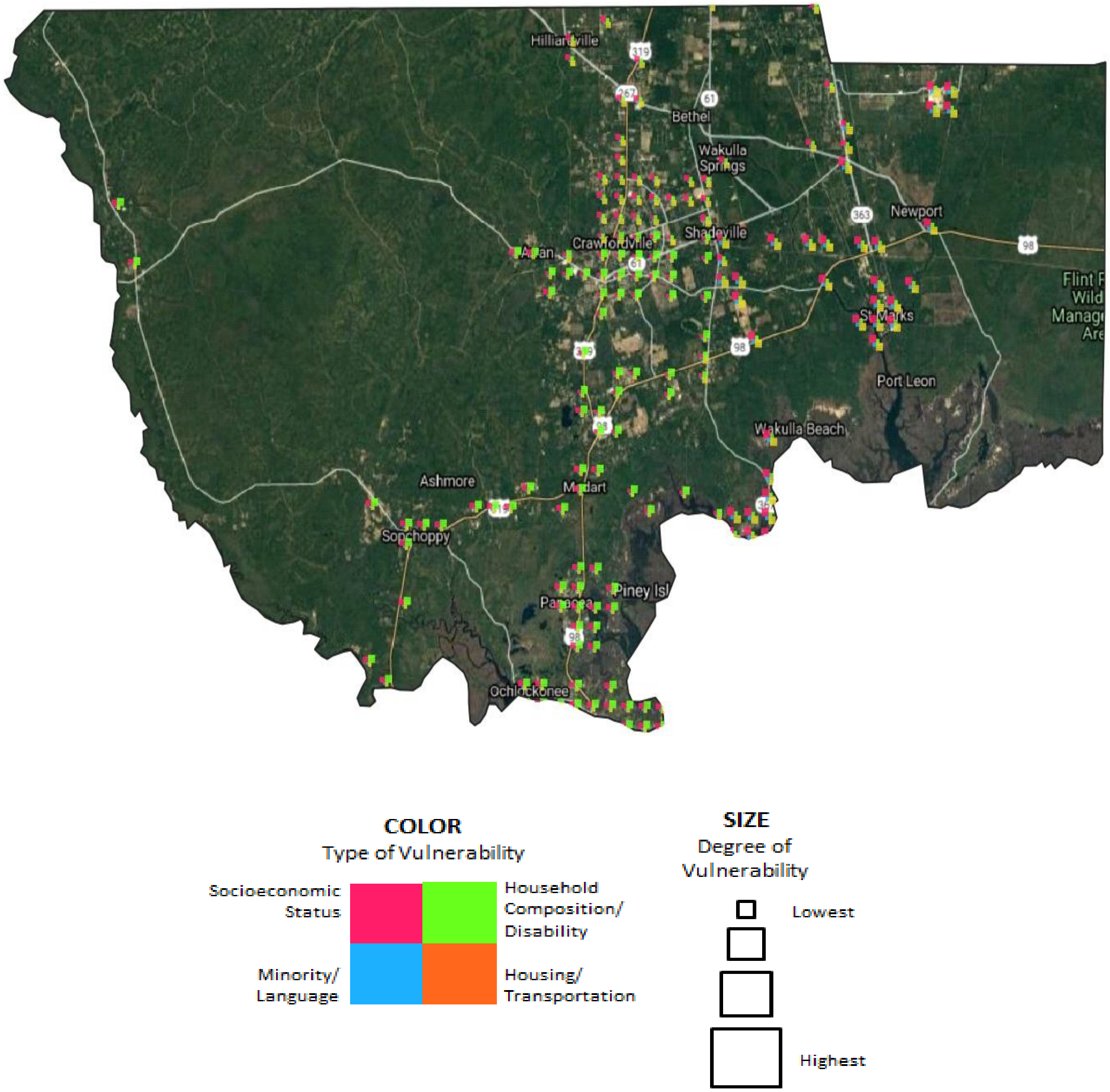

Figure 5. The four social vulnerability themes mapped simultaneously as glyphs for populated areas. Note that there is very little blue showing in the glyph because there is little Ethnicity/Language vulnerability in the county.

The land parcel inundation data and the parcel-based population estimates were used to determine which populations within the county intersected with the social vulnerability data. A detailed population count was conducted, segmented by vulnerability levels, focusing on individuals residing in parcels with a vulnerability index score of 0.50 or higher. The 0.50 measure was chosen as it divides the upper and lower halves of the vulnerability rankings.

Property Appraisal Data Preparation

Identifying land parcels at risk for inundation is vital for community leaders, planners, and property owners. Florida Department of Revenue data includes the geometry for land parcels and other information such as just value and land use classifications. Figure 6 shows the geometries of land parcels.

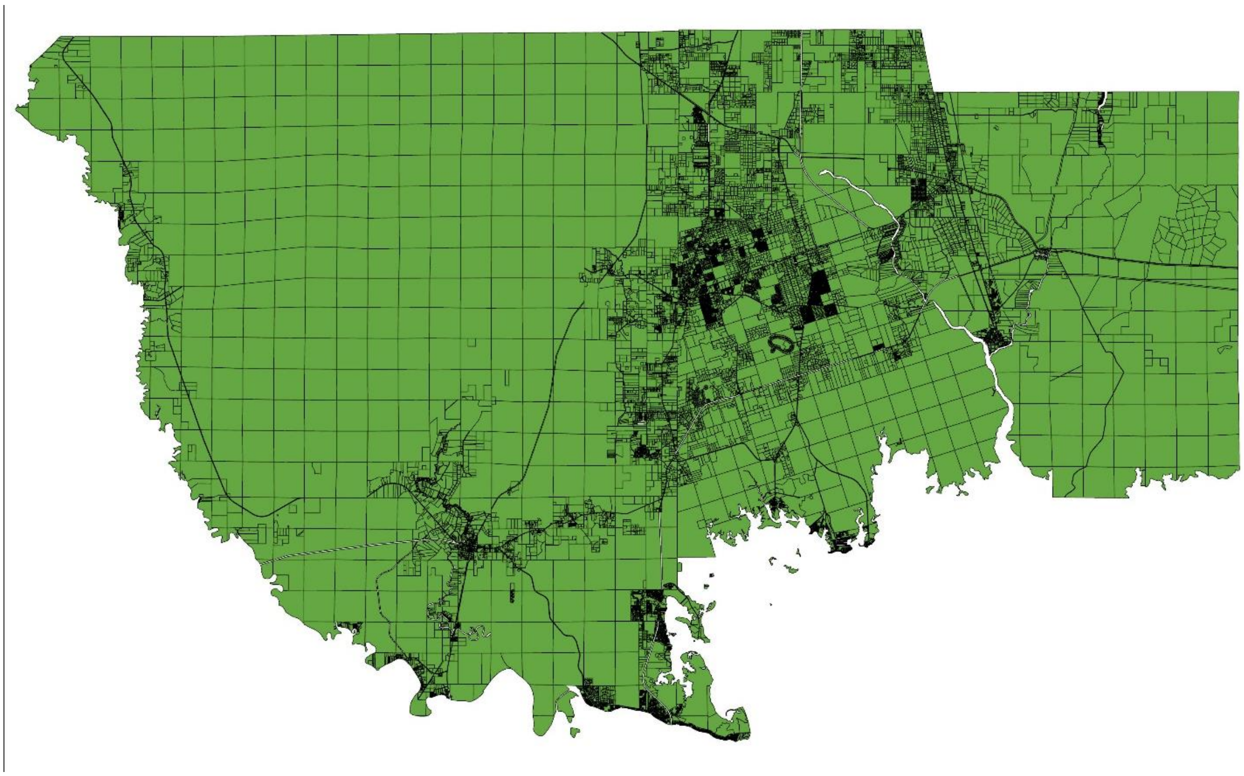

Figure 6. Property appraiser land parcels of Wakulla County. Note that the parcels' size and shape suggest land use (residential/commercial properties tend to be small and congested while agricultural/governmental parcels are larger and more orderly).

The three SLR scenarios—low, intermediate, and high—were employed to identify land parcels susceptible to permanent inundation beginning in 2050. Figure 7 shows which parcels are affected under the low, intermediate, and high scenarios. Affected parcels within the property appraiser database were analyzed for each SLR scenario to calculate the aggregate 'just value,' categorize them based on land use, and sum the 'just values' for each category. The term 'just value' refers to the land parcel's fair market value, determined by various factors, including location, size, and use. The methodology for calculating property loss is straightforward and can be replicated using various geographic information systems, thus facilitating comparative studies. Figures 8 and 9 show the affected parcels and glyphs mapped together.

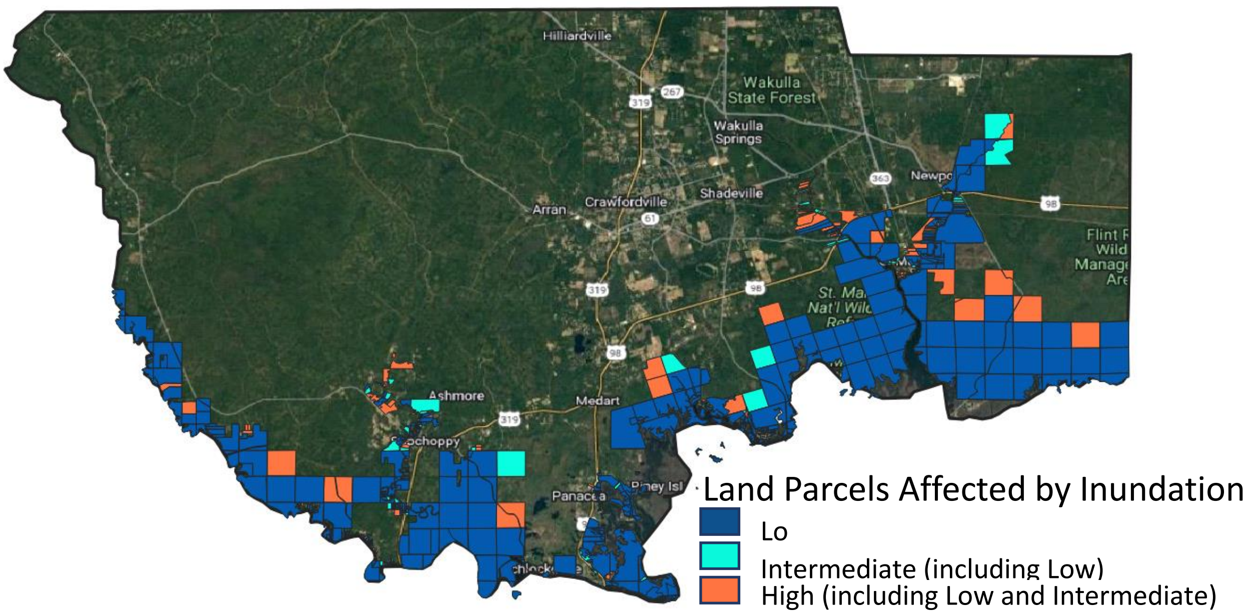

Figure 7. Land parcels experiencing any inundation under all three scenarios.

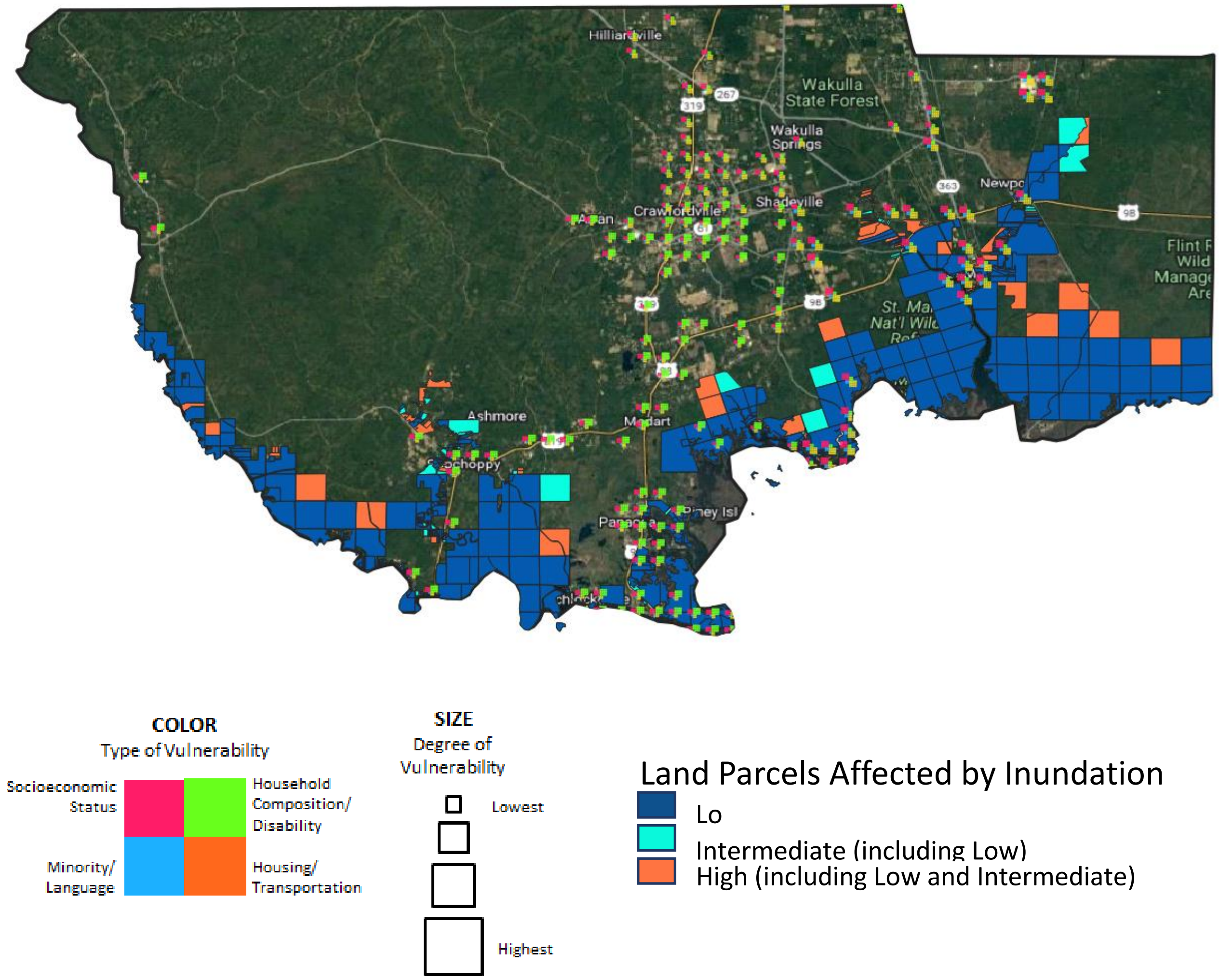

Figure 8. SLR-affected parcels overlain by social vulnerability glyphs. The two legends on the left represent the social vulnerability glyphs, and the legend on the right shows land parcels affected by SLR. Note that many of the SLR areas are unpopulated (recognized as not having glyphs).

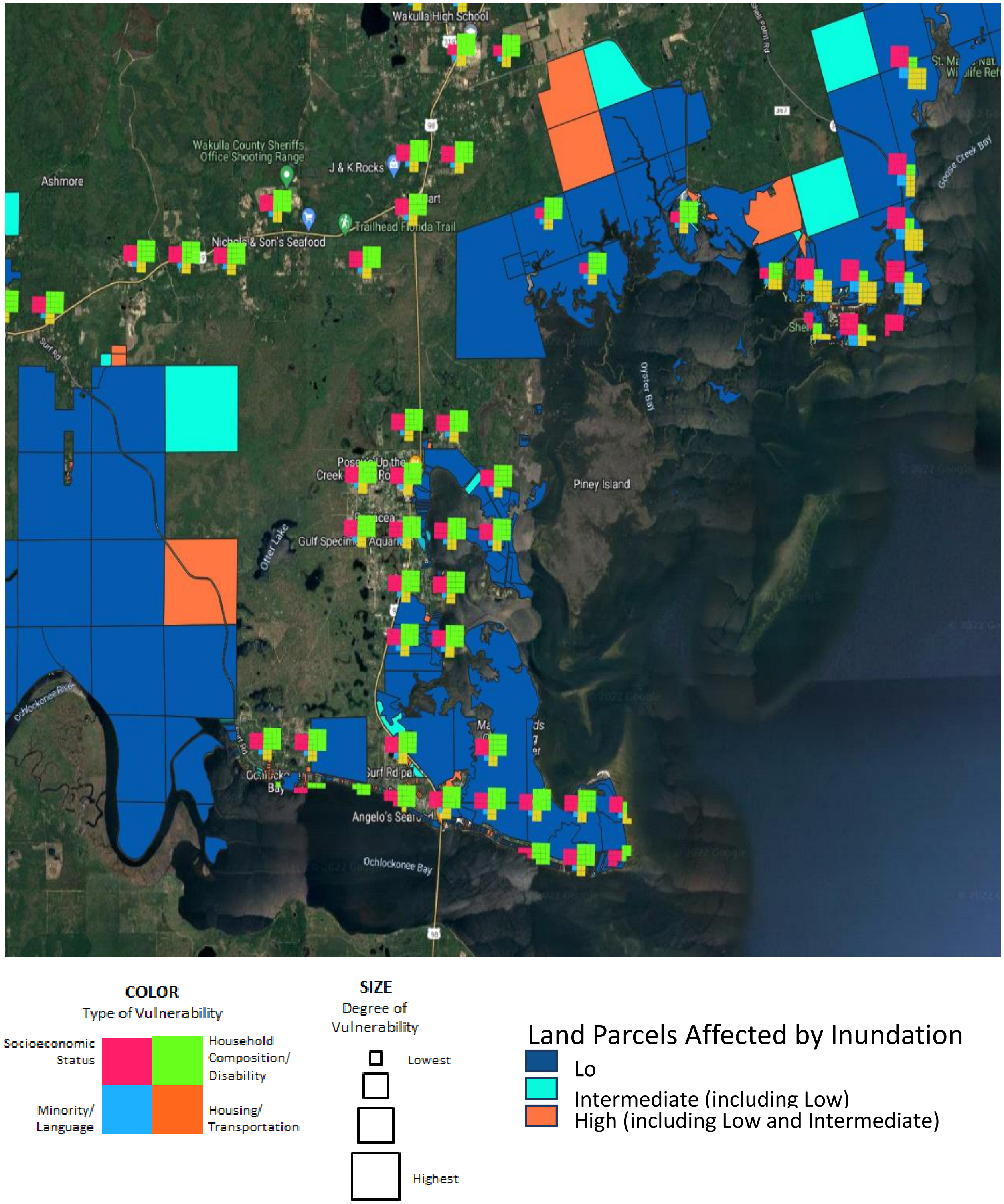

Figure 9. SLR-affected parcels and social vulnerability glyphs zoomed into southern Wakulla County. The two legends on the left represent the social vulnerability glyphs (areas without glyphs are unpopulated), and the legend on the right shows land parcels affected by SLR.

The geographic information system (GIS) software used for this study includes ArcGIS Pro for raster analysis and data visualization. The three SLR risk categories are produced in shapefile format. We used QGIS, an open-source tool, as a cost-effective approach to comprehensive analysis. The three SLR scenarios are superimposed on population, social vulnerability, and property appraisal data to understand the potential impact on society. The GIS tools used are considered basic.

RESULTS

Sea level rise projections for the year 2050 using the US Army Corps of Engineers Sea-level Change Curve Calculator for low, intermediate, and high scenarios have allowed us to create estimates for property value loss due to permanent inundation. Estimations were made for the number of individuals impacted under each scenario, utilizing the CDC's Social Vulnerability Index to assess the demographics of the affected population. While the intercensal dasymetric method was used here for population estimates, researchers may employ alternative methods based on specific needs and contexts.

Population and Social Vulnerability Analysis

This study seeks to determine if SLR affects vulnerable persons equally across the county. The proportion of the vulnerable population at the county level was compared to that within areas designated as high-risk due to SLR. Vulnerable populations are those in the upper 50% of the vulnerability index, with scores of 0.50 or higher, encompassing the two most vulnerable quartiles. To determine if SLR affects vulnerable persons equally, we compared the percentages of vulnerable persons in the county with those within the high SLR scenario. Table 4 shows the vulnerable population comparisons in chart form. Figure 10 shows the same data in graph form.

	All of Wakulla County		High SLR Scenario Only	
	Total Population	Percent of Total	Total Population	Percent of Total
	34,164	**100%**	**1,828**	**100%**
Socioeconomic	15,074	44%	1,200	66%
Household & Disability	11,010	32%	742	41%
Ethnicity & Language	0	0%	0	0%
Housing & Transportation	11,249	33%	561	31%

Table 4. Population counts and percentages for the four social vulnerability themes for the highest 50% of vulnerability scores. Counts were taken for the county and the area of high SLR scenario.

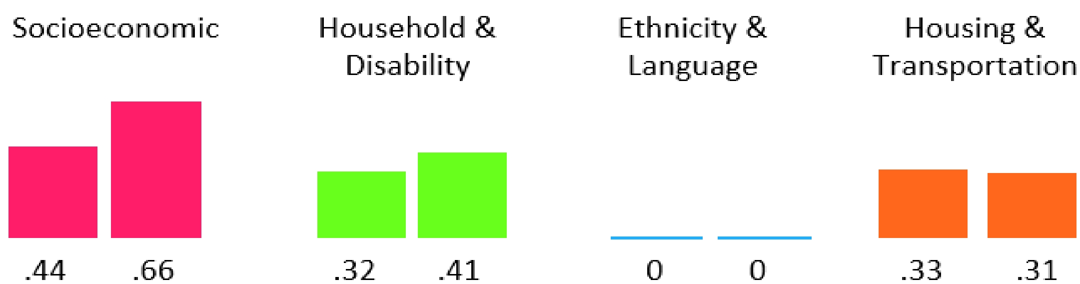

Figure 10. Bar charts showing percentages of vulnerable populations (in the most vulnerable 50%) for the county and the high SLR scenario. The left columns represent the county; the right columns represent the high SLR scenario. The numbers below the bar charts show the percentage of vulnerable populations within each area.

Among the four indices of social vulnerability examined, both Socioeconomic and Household & Disability metrics reveal elevated levels of vulnerability within regions designated as high-risk due to SLR compared to the county-wide data. Contrastingly, the Ethnicity & Language and Housing & Transportation vulnerability metrics show slight variation between populations residing in high-risk inundation zones and the general populace of Wakulla County. This data implies a heightened Socioeconomic and Household & Disability vulnerability for populations residing in coastal regions, which are most susceptible to permanent inundation due to SLR, compared to the broader county population. Although this study employs the intercensal dasymetric method for population estimation, alternative methodologies could be utilized, depending on the specific requirements and geographical context.

Property Analysis

Results from all three projections of sea-level rise indicate that permanent inundation will impact many land parcels. For this study, a land parcel experiencing any permanent inundation is classified as affected when calculating the just value of impacted properties. The methodology for calculating property loss is straightforward and can be replicated using various geographic information systems, thus facilitating comparative studies. Under the low scenario, the total just value of land parcels experiencing permanent inundation is $225 million; under the intermediate scenario, the just value of inundated land is $266 million; and under the high scenario, $350 million of land will be inundated. No matter which scenario is considered, the most valuable category of land parcel is residential, totaling $110 million, $138 million, and $204 million of land in low, medium, and high SLR scenarios, respectively. The second highest valued category of land parcel affected is governmental, with inundated land parcel values totaling $79 million, $83 million, and $95 million in low, medium, and high SLR scenarios, respectively. The third highest valued category of land parcel affected is agricultural, with inundated land parcel values totaling $22 million, $28 million, and $33 million in low, medium, and high SLR scenarios, respectively. All remaining land use categories under all three scenarios total less than $10 million each, with industrial having the highest just value, then decreasing in order are commercial, non-agricultural acreage, institutional, and miscellaneous.

The findings suggest that vulnerable land will incur significant value losses due to inundation over the next three decades across all scenarios. Notably, the high SLR scenario forecasts a value loss exceeding 50% compared to the low scenario. This increase is due to the permanent inundation of more land. Table 5 shows that under the low SLR scenario, 975 parcels are affected; under the intermediate scenario, 1,231 parcels are affected; and under the high scenario, 1,786 parcels are affected. While this study employs specific criteria for assessing property impacts, alternative methodologies may provide different insights depending on contextual needs.

Low Scenario	
Number of Land Parcels Affected and Categorization	**Just Value of Land Parcels ($)**
623 Residential	109,520,906
142 Governmental	79,121,488
95 Agricultural	22,093,754
5 Industrial	8,005,985
24 Commercial	4,982,703
43 Non-Ag Acreage	866,854
2 Institutional	434,887
41 Miscellaneous	161,086
975 total	**225,187,663**

Intermediate Scenario	
Number of Land Parcels Affected and Categorization	**Just Value of Land Parcels ($)**
830 Residential	138,228,002
147 Governmental	82,620,845
121 Agricultural	28,178,763
8 Industrial	8,613,641
30 Commercial	6,265,469
50 Non-Ag Acreage	1,085,135
2 Institutional	434,887
43 Miscellaneous	161,386
1,231 total	**265,588,128**

High Scenario	
Number of Land Parcels Affected and Categorization	**Just Value of Land Parcels ($)**
1309 Residential	203,760,903
172 Governmental	95,131,489
150 Agricultural	33,375,498
11 Industrial	8,801,205
37 Commercial	6,646,804
61 Non-Ag Acreage	1,288,441
2 Institutional	434,887
44 Miscellaneous	179,546
1,786 total	**349,618,773**

Table 5. Land parcel counts subject to permanent inundation and valuations of those parcels under the three SLR scenarios.

STUDY LIMITATIONS

While this study provides valuable insights, it has limitations. For instance, the research focuses solely on permanent inundation, the final phase of SLR, without accounting for preceding chronological stages such as increasingly frequent nuisance flooding, storm frequency, and land subsidence. Likewise, other factors related to SLR were not considered, including forced migration, saltwater intrusion, property devaluation, and job losses. A broader study could include an assessment of infrastructure, including transportation, sewage, stormwater drainage, and pollutant impact. Further, studies into economic impacts such as employment and tourism would be beneficial. The SLR risk categories could be skewed due to disagreements between the DEM and actual relief of the earth's surface. Likewise, a bathtub model was used to estimate SLR that does not account for hydrologic processes.

CONCLUSION

This study analyzes how a SLR scenario can affect property and socially vulnerable populations in north Florida's Wakulla County, in 2050. We applied land parcel, population, and social vulnerability analysis to projected SLR inundation for Wakulla County. We considered low, intermediate, and high SLR projections through 2050.

Population projections show a nearly 36% increase in population between the 2010 census results and 2050. Land parcel analysis shows properties of various land use types threatened by SLR totaling $225 to $350 million in just value in today's dollars. Most social vulnerability themes have even spatial distribution across the county, both inland and within the risk areas, except Housing & Transportation vulnerability, where the residents of the coastal areas have less vulnerability of residents of inland areas, although the reasons are unclear. Possible explanations could be that they have vehicular means to evacuate or housing structural advantages. This finding, observed but unexplained, aligns with other research showing that coastal residents could have more resources available for storm and flood mitigation (Wang and Yarnal, 2012).

The initial objective of the study involved demonstrating the methodology established by the Florida Department of Environmental Protection under Florida Statute 161.551, utilizing Wakulla County as the focal research area. However, during the inception of this research, the guidelines for FDEP's methodology were in the process of revision and development. We learned that the purpose of the FDEP's guidelines was primarily to protect the state's financial investment and only applied to single construction sites. The FDEP's methodology would inform planners of any risks to property during the structure's life or fifty years out, whichever is shorter. This is helpful for analyzing risks to state infrastructure, but almost meaningless in assessing risks to private property owners.

This study assesses risks to more land and people than the FDEP's methodology. It shows SLR for all of Wakulla County using three scenarios. Further, we overlay population, social vulnerability, and land parcels with SLR. Our results are helpful in several ways. The maps can raise awareness of SLR's dangers using visual demonstration. Planners can use the provided information for locating and permitting development projects. The social vulnerability information can assist planners in allocating resources according to vulnerability type and population density.

Our research advances analysis through fine-grained population and social vulnerability mapping. Our parcel-based population estimates improve census tract population mapping by providing a clear view of residential areas. Evaluating multiple social vulnerability themes instead of a singular index allowed the detection of variation in the Housing & Transportation category. We hope this research catalyzes further interest in fine-grained assessments, thereby uncovering data patterns that might otherwise remain obscured. The use of open-source software (no financial cost) for a portion of the analysis demonstrates that the tools needed for this type of research are within the reach of municipalities with limited funding.

We hope that our findings stimulate public discourse on the criticality of integrating climate models with societal impacts. Additionally, this research could help inform policy recommendations including enforcing stricter construction regulations in high-risk areas and allocating resources based on vulnerability type and population density. We hope to educate the public and empower local governments to set policies for addressing SLR.

REPLICATION

This study can be replicated for other counties and the results could be combined for a statewide assessment. The most time-consuming process is the development of the SLR categories of low, medium, and high (see Appendix B). We used Esri software for this step. It may be possible to use alternative methods from other sources to develop these boundaries. We used custom population data because at the time of this project the 2020 U.S. Census data had not been released and our choices were to develop our own method of estimation or use 2010 data. However, now that the 2020 data is released, there are several alternatives for population data that could be substituted. (The intercensal population method is currently submitted for publication.) The SVI data is publicly available from the CDC, however, we recommend using FSU's application as it improves visualization and simplifies analysis. Property appraiser data is readily available for every Florida county.

REFERENCES

Anderson, J.B., D.J. Wallace, A.R. Simms, A.B. Rodriguez, and K.T. Milliken. 2014. Variable Response of Coastal Environments of the Northwestern Gulf of Mexico to Sea-Level Rise and Climate Change: Implications for Future Change. *Marine Geology*. 352: 348-366.

Azevedo de Almeida, B. and A. Mostafavi. 2016. Resilience of Infrastructure Systems to Sea-Level Rise in Coastal Areas: Impacts, Adaptation Measures, and Implementation Challenges. *Sustainability*. 8(11): 1115.

BEBR (Bureau of Economic and Business Research). 2021. Projections of Florida Population by County, 2025–2045, with Estimates for 2020. *Florida Population Studies*, Vol. 54, Bull. 189. Gainesville: University of Florida. https://www.bebr.ufl.edu/sites/default/files/Research%20Reports/projections_2021.pdf

Beck, J. and M. Lin. 2020. The Impact of Sea Level Rise on Real Estate Prices in Coastal Georgia. *Southern Regional Science Association*. 49: 43–52.

Bilskie, M.V., S. C. Hagen, K. Alizad, S. C. Medeiros, D. L. Passeri, H. F. Needham, and A. Cox. 2016. Dynamic Simulation and Numerical Analysis of Hurricane Storm Surge under Sea Level Rise with Geomorphologic Changes along the Northern Gulf of Mexico. *Earth's Future*. 4(5):177–193.

Bloetscher, F., T. Romah, L.Berry, N.H.Hammer, and M.A.Cahill. 2012. Identification of Physical Transportation Infrastructure Vulnerable to Sea Level Rise. *Journal of Sustainable Development*. 5(12): 40–51.

CDC (U.S. Centers for Disease Control and Prevention). 2018. *CDC/ATSDR Social Vulnerability Index Fact Sheet*. Accessed 13 August 2024. https://svi.cdc.gov/factsheet.html

Chang, B., J. Guan, and M.M. Aral. 2013. Modeling Spatial Variations of Sea Level Rise and Corresponding Inundation Impacts: A Case Study for Florida, USA. *Water Quality, Exposure and Health*. 6(1-2): 39–51.

Chen, X., X. Zhang, J.A. Church, C.S. Watson, M.A. King, D. Monselesan, B. Legresy, and C. Harig. 2017. The Increasing Rate of Global Mean Sea-Level Rise during 1993–2014. *Nature Climate Change*. 7(7): 492–495.

Church, J.A. and N.J. White. 2006. A 20th Century Acceleration in Global Sea-Level Rise. *Geophysical Research Letters*. 33(1).

Dahl, K.A., M.F. Fitzpatrick, and E. Spanger-Siegfried. 2017. Sea Level Rise Drives Increased Tidal Flooding Frequency at Tide Gauges along the U.S. East and Gulf Coasts: Projections for 2030 and 2045. *PLoS ONE*. 12(2).

Office for Coastal Management. 2012. 2012 NOAA Office for Coastal Management Coastal Inundation Digital Elevation Model: Mobile/Tallahassee (AL/FL) WFO - Mobile County in Alabama and Escambia, Santa Rosa, and Okaloosa (portion) Counties in Florida from 2010-06-15 to 2010-08-15." *NOAA National Centers for Environmental Information*. www.fisheries.noaa.gov/inport/item/48056.

DOC, NOAA, NOS, and CSC. 2012. 2012 NOAA Coastal Services Center Coastal Inundation Digital Elevation Model: Mobile/Tallahassee (AL/FL) WFO - Mobile County in Alabama and Escambia, Santa Rosa, and Okaloosa (portion) Counties in Florida; 2012 NOAA Coastal Services Center Coastal Inundate. Charleston, South Carolina: CSC. https://coast.noaa.gov/htdata/Inundation/SLR/SLRdata/FL/ALFL_MOB_TLH_dems.zip.

DOC, NOAA, NOS, and OCM. 2016. NOAA Office for Coastal Management Sea Level Rise Data: Current Mean Higher High Water Inundation Extent. Charleston, South Carolina: OCM. https://coast.noaa.gov/htdata/Inundation/SLR/SLRdata/FL/ALFL_MOB_TLH_slr_data_dist.zip.

Donoghue, J.F. 2011. Sea Level History of the Northern Gulf of Mexico Coast and Sea Level Rise Scenarios for the near Future. *Climatic Change*. 107 (1-2): 17–33.

Doyle, T.W., K.W. Krauss, W.H. Conner, and A.S. From. 2010. Predicting the Retreat and Migration of Tidal Forests along the Northern Gulf of Mexico under Sea-Level Rise. *Forest Ecology and Management*. 259(4): 770–777.

Esri. 2016. How to: Convert z-Units in a Mosaic Dataset from Feet to Meters or Vice Versa. support.esri.com/en/technical-article/000012388.

Esri. 2021. ArcGIS Pro: Version 2.8.1. Redlands, California: Environmental Systems Research Institute.

FDOT (Florida Department of Transportation). 2020. Projections of Florida Population by County, 2020-2070.

FREAC (Florida Resources and Environmental Analysis Center). 2021. Florida State University, FREAC SVI App. https://arcg.is/0P1Wfe

Frazier, T.G., N. Wood, B. Yarnal, and D.H. Bauer. 2010. Influence of Potential Sea Level Rise on Societal Vulnerability to Hurricane Storm-Surge Hazards, Sarasota County, Florida. *Applied Geography*. 30(4): 490–505.

Geselbracht, L., K. Freeman, E. Kelly, D.R. Gordon, and F.E. Putz. 2011. Retrospective and Prospective Model Simulations of Sea Level Rise Impacts on Gulf of MEXICO Coastal Marshes and Forests in Waccasassa Bay, Florida. *Climatic Change*. 107: 35–57.

Gutiérrez, E.O.P., et al.2012. *Impacto Del Cambio Climático y Medidas De Adaptación En Cuba. La Segunda Comunicación Nacional De Cuba Al Convenio Marco De Naciones Unidas Sobre Cambio Climático*. www.redciencia.cu/geobiblio/paper/2012_Planos_Impacto%20y%20Adaptacion,%20Libro.pdf.

Hardy, R.D., and M.E. Hauer. 2018. Social Vulnerability Projections Improve Sea-Level Rise Risk Assessments. *Applied Geography*. 91: 10–20.

Harrington, J., H. Chi, and L.P. Gray. 2017. Florida tourism, in E.P. Chassignet, J.W. Jones, V. Misra, and J. Obeysekera (eds.), *Florida's Climate: Changes, Variations, and Impacts*. Gainesville: Florida Climate Institute, 297-309.

Hauer, M., D. Hardy, S. Kulp, V. Mueller, D. Wrathall, P. Clark, and M. Oppenheimer. 2020. A Framework for Classifying and Assessing Sea Level Rise Risk.

Holgate, S. J. and P. L. Woodworth. 2004. Evidence for Enhanced Coastal Sea Level Rise during the 1990s. *Geophysical Research Letters*. 31(7): L07305, 1-4.

Houston, J.R. 2013. The Value of Florida Beaches. *Shore & Beach*. 81(4): 4-11.

Keys, B. and P. Mulder. 2020. Neglected No More: Housing Markets, Mortgage Lending, and Sea Level Rise.

Maul, G.A. and D.M. Martin. 1993. Sea Level Rise at Key West, Florida, 1846-1992: America's Longest Instrument Record? *Geophysical Research Letters*. 20(18): 1955–1958.

McAlpine, S.A. and J.R. Porter. 2018. Estimating Recent Local Impacts of Sea-Level Rise on Current Real-Estate Losses: A Housing Market Case Study in Miami-Dade, Florida. *Population Research and Policy Review*. 37: 871–895.

Méndez-Tejeda, R., G.A.R. Jimenez, D.V. Rivas, and T. Montilla. 2016. Climate Variability and Its Effects on the Increased Level of Lake Enriquillo in the Dominican Republic, 2000-2013. *Applied Ecology and Environmental Sciences*. 4(1): 26–36.

NOAA (National Oceanic and Atmospheric Administration). 2017. *Global and regional sea level rise scenarios for the United States*. U.S. Center for Operational Oceanographic Products and Services, NOAA technical report NOS CO-OPS, 83.

NOAA (National Oceanic and Atmospheric Administration). 2020. Sea Level Rise Data Download. *NOAA Office for Coastal Management*. https://coast.noaa.gov/slrdata

Park, J. and W. Sweet. 2015. Accelerated Sea Level Rise and Florida Current Transport. *Ocean Science*. 11(4): 607–615.

Parris, A.S., P. Bromirski, and V. Burkett. 2012. Global Sea Level Rise Scenarios for the United States National Climate Assessment. *Welcome to the NOAA Institutional Repository*. repository.library.noaa.gov/view/noaa/11124

Passeri, D.L., S.C. Hagen, N.G. Plant, M.V. Bilskie, S.C. Medeiros, and K. Alizad. 2016. Tidal Hydrodynamics under Future Sea Level Rise and Coastal Morphology in the Northern Gulf of Mexico. *Earth's Future*. 4(5): 159–176.

Pendleton, E.A., Barras, J.A., Williams, S.J., and Twichell, D.C. 2010. Coastal Vulnerability Assessment of the Northern Gulf of Mexico to Sea-Level Rise and Coastal Change: U.S. Geological Survey Open-File Report 2010-1146.

Penland, S. and K.E. Ramsey. 1990. Relative Sea-Level Rise in Louisiana and the Gulf of Mexico: 1908-1988. *Journal of Coastal Research*. 6(2): 323–342.

Ramsey, K. E. and S. Penland. 1989. Sea-Level Rise and Subsidence in Louisiana and the Gulf of Mexico. *Gulf Coast Association of Geological Societies Transactions*. 39: 491–500.

Reguero, B.G., I.J. Losada, P. Díaz-Simal, F.J. Méndez, and M.W. Beck. 2015. Effects of Climate Change on Exposure to Coastal Flooding in Latin America and the Caribbean. *PLoS ONE*. 10(7).

Saha, A.K., S. Saha, J. Sadle, J. Jiang, M.S. Ross, R.M. Price, L.S. L.O. Sternberg, and K. Wendelberger. 2011. Sea Level Rise and South Florida Coastal Forests. *Climatic Change*. 107(1): 81–108.

Strode G., Mesev, V., and Maantay, J. 2018. Improving Dasymetric Population Estimates for Land Parcels: Data Pre-Processing Steps. *Southeastern Geographer, 58(3): 300-316.*

Strode, G., V. Mesev, S. Bleisch, K. Ziewitz, F. Reed, and J.D. Morgan. 2020. Exploratory Bivariate and Multivariate Geovisualizations of a social vulnerability index. *Cartographic Perspectives*. 95: 5-23.

Tewari, S., F. Manning, and W. Palmer. 2019. Sea Level Rise and Land Subsidence in Coastal Louisiana: Forecasting, Mapping and Identification of At-Risk Transportation Infrastructure.

Uddameri, V., S. Singaraju, and E.A. Hernandez. 2014. Impacts of Sea-Level Rise and Urbanization on Groundwater Availability and Sustainability of Coastal Communities in Semi-Arid South Texas. *Environmental Earth Sciences*. 71: 2503–2515.

USACE (U.S. Army Corps of Engineers). 2021. Sea-Level Curve Calculator. *NWPL Home v3.4-f9c* https://cwbi-app.sec.usace.army.mil/rccslc/slcc_calc.html

Visit Florida. n.d. https://www.visitflorida.org/resources/research/research-faq/

Wakulla County. *Florida Department of Environmental Protection*. floridadep.gov/rcp/coastal-access-guide/content/wakulla-county.

Wang, C. and B. Yarnal. 2012. The Vulnerability of the Elderly to Hurricane Hazards in Sarasota, Florida. *Natural Hazards*. 63: 349–373.

Wdowinski, S., R. Bray, B.P. Kirtman, and Z. Wu. 2016. Increasing Flooding Hazard in Coastal Communities Due to Rising Sea Level: Case Study of Miami Beach, Florida. *Ocean & Coastal Management*. 126: 1–8.

Zhang, K. 2010. Analysis of Non-Linear Inundation from Sea-Level Rise Using LIDAR Data: A Case Study for South Florida. *Climatic Change*. 106: 537–565.

Zhang, K., J. Dittmar, M. Ross, and C. Bergh. 2011. Assessment of Sea Level Rise Impacts on Human Population and Real Property in the Florida Keys. *Climatic Change*. 107: 129–146.

Appendix A

Author(s)	Year	Project Goal	Study Area	Tide Guage	Coastal Slope	Local SLR	Global SLR	Shoreline	Wave Height	Sea / Lake Water Elevation	Altimetry	MHHW	LiDAR	Precipitation	Hydrography/ Groundwater/ Wetlands	Bathemetry	Elevation	NGS CORS	Greenhouse Emissions	SLOSH Grids	King Tide Value	Acceptable Level of Flooding	Flood Media Reports	Insurance Flood Claims	Flood Photos	Ortho Photos	Glacier & Ice Loss	Ocean Temp	Air Temp	Coastal Forest/ Mangrove	Saltmarsh/ Saltwater Intrusion	Global Temp Change	Diminished Sediment	Subsidence Water/Fluid Withdrawal	Tropical Storms/ El Nino	Evaporation	Max Surge Heights	Depth of Water Table	Ocean Transport
Ramsey & Penland	1989	Determine Rates of SLR and Subsidence	Louisiana and Gulf of Mexico	✓																																			
Penland & Ramsey	1990	Assess SLR 1908-1988	Louisiana and Gulf of Mexico	✓																																			
Pendleton et al	1990	Assess future SLR	Northern Gulf of Mexico Galveston, TX to Panama City, FL	✓	✓	✓		✓	✓																														
Maul & Martin	1993	Trace sea level 1846 to 1992	Key West, Florida	✓																																			
Doyle et al	2010	Predict coastal forest retreat	Southeastern United States	✓																											✓								
Frazier et al	2010	Examine community exposure to hurricane storm-surge hazards	Sarasota County, Florida																	✓																	✓		
Donoghue	2011	Describe Sea Level History and Future Scenarios	Northern Gulf of Mexico				✓												✓								✓		✓			✓							
Saha et al	2011	Estimate salinity risk to 21 rare coastal species	Everglades National Park, South Florida																												✓							✓	
Geselbracht et al	2011	Explore impacts on coastal marshes and forests	Wacassassa Bay, Florida	✓									✓																	✓									
Zhang et al	2011	Project inundation to 100 years	Florida Keys			✓					✓		✓				✓									✓													
Zhang	2011	Project inundation through 2100 using two different DEMS	South Florida, 7 counties and the Everglades National Park										✓				✓																						
Bloetscher et al	2012	Identify populations most vulnerable to sea-level rise	Southeast Florida	✓									✓		✓							✓																	
Parris et al	2012	Calculate Global SLR Projections	Global							✓	✓								✓								✓	✓	✓										✓
Gutiérrez et al	2012	Project SLR 2021 - 2050 and 2071 - 2100	Cuba											✓					✓										✓										
Ezer	2013	Compare results of SLR	U.S. East Coast	✓																																			
Anderson et al	2014	Evaluate historical SLR to understand the future	Northern Gulf of Mexico	✓			✓																										✓	✓	✓				
Chang et al	2014	Conduct SLR projections and inundation assessment	Florida														✓																						
Uddameri et al	2014	Assess Impact of Climate Change and Urbanization and Freshwater-Saltwater Interface	South Texas							✓	✓			✓																				✓					
Park & Sweet	2015	Assess changes in mass transport	Florida Current (Gulf Stream)	✓																																			✓
Reguero et al	2015	Assess Impacts of SLR	Latin America and Caribbean				✓																											✓	✓				
Passeri et al	2016	Examine SLR and future morphology on tidal hydrodynamics	Northern Gulf of Mexico	✓		✓								✓					✓								✓												
Bilskie et al	2016	Examine the effects on tropical cyclone-driven storm surge inundation	Northern Gulf of Mexico	✓						✓	✓								✓								✓	✓	✓										
Méndez-Tejeda et al	2016	Climatological analysis seeking explanation for rising level of Lake Enriquillo.	Dominican Republic							✓				✓	✓														✓			✓			✓	✓			
Wdowinskia et al	2016	Study flooding frequency and causes	City of Miami Beach, FL	✓																			✓	✓	✓														
Dahl et al	2017	Project tidal flooding frequency to 2030 and 2045	Southeast USA			✓	✓																																
Hardy & Hauer	2018	Estimate Social Vulnerability	Georgia, 6 coastal counties	✓		✓	✓	✓				✓	✓		✓				✓																				
MacAlpine	2018	Estimate Real Estate losses due to flooding	Miami-Dade County, FL	✓						✓		✓	✓							✓	✓																		
Tewari et al	2019	Identify transportation infrastructure loss over next 100 years	Southern Louisiana										✓		✓	✓		✓																✓					
Beck & Lin	2020	Study home price vulnerability to inundation	Savannah, Georgia			✓																																	
Keys & Mulder	2020	Explore changes and risk in housing and mortgage markets	Coastal Florida			✓																																	
Hauer et al	2020	Calculate Populations at Risk using 3 SLR scenarios	US Coastal	✓		✓							✓			✓	✓																	✓					
				16	1	8	5	2	1	5	4	2	8	4	4	2	4	1	6	2	1	1	1	1	1	1	4	2	5	1	2	2	1	5	3	1	1	1	2

Table A-1. Overview of data inputs used for previous SLR studies in areas near Florida.

Appendix B

Detailed Instructions for Developing the Three SLR Categories

We began with the National Oceanic and Atmospheric Administration (NOAA) Sea-Level Rise Data Digital Elevation Models (DEM) (NOAA, 2020). The DEMs needed for this project were the 2012 NOAA Coastal Services Center Coastal Inundation Digital Elevation Model: Mobile/Tallahassee (AL/FL) WFO - Mobile County in Alabama and Escambia, Santa Rosa, and Okaloosa (portion) Counties in Florida (ALFL A1); the 2012 NOAA Coastal Services Center Coastal Inundation Digital Elevation Model: Mobile/Tallahassee (AL/FL) WFO - Okaloosa (portion), Walton, Bay, Gulf, Franklin (portion), and Wakulla (portion) Counties (AL/FL A2); and the 2012 NOAA Coastal Services Center Coastal Inundation Digital Elevation Model: Mobile/Tallahassee (AL/FL) WFO - Wakulla (portion), Franklin (portion), Jefferson, Taylor, Dixie, and Levy Counties (AL/FL A3) (DOC, NOAA, NOS, & CSC 2012).

The AL/FL A1, AL/FL A2, and AL/FL A3 DEMs were available via the NOAA Sea-Level Rise Data Download portal (NOAA 2020). The DEMs were in a 5m resolution, referenced vertically to the North American Vertical Datum of 1988 (NAVD88) in meters, and horizontally to the North American Datum of 1983 (NAD83). The DEMs were derived from LiDAR data with an assumed 1m horizontal accuracy. The DEM values were in a 32-bit floating-point raster tiff format. Lastly, the data for the DEMs were collected in 2007 (DOC, NOAA, NOS, & CSC 2012). The DEMs were used to generate the elevation values from which each inundation class was derived (Tewari et al., 2019).

The second data needed were the features from the NOAA Office for Coastal Management Sea-Level Rise Data: Current Mean Higher High Water Inundation Extent (MHWIE) (DOC, NOAA, NOS, and OCM, 2016). The MHWIE data was available for download from the NOAA Sea-Level Rise Data Portal (NOAA, 2020). The MHWIE data was in a geodatabase format with feature classes that represent water inundation in feet. The data ranges from 0 to 10ft. inundation. The feature class data utilized the NAD83, the NAVD88 and was updated in 2016 (DOC, NOAA, NOS, and OCM, 2016). The 0ft. MHWIE feature classes for TLH 1, TLH 2, and TLH 3 were utilized to fill *NoData* gaps and missing 0ft. elevation data in the DEMs.

The last dataset was needed to determine the classes or categories for sea-level rise inundation for 2050. The US Army Corps of Engineers (USACE) Sea-level Change Curve

Calculator: Version 2021.12, Estimated Relative Sea-Level Change Projections (ERSLCP) for Gauge: 8728690, Apalachicola, Florida, for the USACE 2013 Scenario (USACE, 2021), were used to set the inundation classes. The 2050 values were 0.41ft. for the USACE Low category, 0.71ft. for the USACE Int., category and 1.66ft. for the USACE High category for sea-level rise estimates (USACE, 2021). The Low, Int., and High USACE ERSLCP categories were used to classify the value ranges derived from the merged DEM and MHWIE data sets.

The SLR scenarios for the analysis were processed using Esri's ArcGIS Pro: Version 2.8.1 (Esri, 2021). As in Tewari et al. (2019), the DEMs were added to a project document in ArcGIS Pro, inspected visually and via histogram. The AL/FL A1 DEM had large areas classified as *NoData* with elevation data values of -9999. All DEMs had some areas of *NoData*. The *NoData* areas would need to be fixed later utilizing the MHWIE 0ft. elevation values. *NoData* values for the DEMs were set to -9999 in subsequent raster processing to remove these erroneous areas from the analysis (Esri, 2021).

Next, the AL/FL A1, AL/FL A2, AL/FL A3 data sets were processed using the Raster Calculator in the Spatial Analysis Extension (Esri, 2021). The first calculation was to multiply each raster cell by 1000. Then each raster cell was converted to an integer. Afterward, each raster was converted to a polygon using the Raster to Polygon Conversion Tool (Esri, 2021).

In the newly created AL/FL A1, AL/FL A2, and AL/FL A3 polygon feature classes, fields were added to the attribute tables of the layers for calculations using the Calculate Field Data Management Tool (Esri, 2021). The first calculation was to convert the grid code back to its original value by dividing the values by 1000. Next, each value was converted from meters to feet by multiplying by 3.28084 (Esri, 2016). Finally, the last Calculate Field operation was used for classifying the USACE ERSLCP low, int., and high categories/classes from the DEM derived grid code feet values into a text field.

The TLH 1-, TLH 2-, and TLH 3-MHWIE 0ft. feature classes were added to the project document like the DEM data. Afterward, a new text field was added to the MHWIE feature classes for the USACE ERSLCP low classification category to be calculated for each feature in the dataset (Esri, 2021). Once all features in the MHWIE 0ft. feature classes, AL/FL A1 feature class, AL/FL A2 feature class, and AL/FL A3 feature class were classified with a USACE ERSLCP range of low, int., or high, the features were dissolved using the Dissolve Data Management Tool (Esri, 2021), based on the text field with the USACE ERSLCP classes. The last step was to merge the TLH 1-, TLH 2-, TLH 3-MHWIE 0ft., AL/FL A1, AL/FL A2, and AL/FL A3 feature classes into one shapefile using the Merge Data Management Tool (Esri, 2021).

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Appendix C

Summary of Expanding cadastral-based population methods to produce estimates for intercensal years (*This method is under review for publication)*

Accurate population estimation is important in many fields of study, including emergency management, access to healthcare, crime hotspots, and environmental monitoring. The Census Bureau aggregates its collected data for privacy concerns and these data are widely available for planning purposes. Most maps created from census data are in choropleth format, a simple and commonly used mapping technique. Although the mapping style is ubiquitous, questions arise concerning the usefulness and scalability of census data in this original format.

Choropleth mapping has known problems that lie with the structure of the choropleth map itself. The choropleth map gives poor resolution, arbitrary boundaries, and abrupt data shifts at area edges. Population is assumed to be evenly distributed across areas and accuracy is compromised when census areas are divided. Subtle population changes can be masked causing nuanced patterns to be overlooked. As a result, the questions planners and emergency responders are able to ask are limited and the answers they receive are often in coarse resolution.

Cadastral-based population methods can alleviate many of the problems with choropleth mapping because of its fine grain. Figure C-1 shows an example of a population model using census block data, census group quarter data, and county property appraisal data. This high-resolution mapping allows easy estimation of populations with custom polygons. (See https://usng-gis.org/population.html for more information on estimation models for Florida.) FREAC has developed a statewide cadastral estimate using 2010 data using the method by Strode et al. (2018).

Figure C-1. Sample of 2010 cadastral-based population distribution where each land parcel is assigned a population estimate.

For those wanting high-resolution and timely data, we developed an intercensal method that combines a decennial cadastral baseline, newer data from county property appraisers, and city/county population projections.

Here is a simplified overview of our method:

1. Obtain a baseline (historical) cadastral population estimate (we used 2010).
2. Obtain projected population estimates at the city/county scale (we used BEBR).
3. Obtain property parcel layer of the same or previous year as the projected population.
4. Using GIS, compare the baseline parcel layer with the new parcel layer. Pay attention to new and demolished housing.
5. Disaggregate the city/county population projections to the newer property parcel layer to appropriate areas. Add population to new housing, remove population from demolished housing, and retain the baseline population estimates if the housing has not changed.

Be sure to validate that the population totals for the new parcel layer total the city/county population projections. The result is an updated property parcel layer with current population estimates. Figure C-2 shows a map of Leon County with population estimates gained and lost due to housing changes according to property appraisal data.

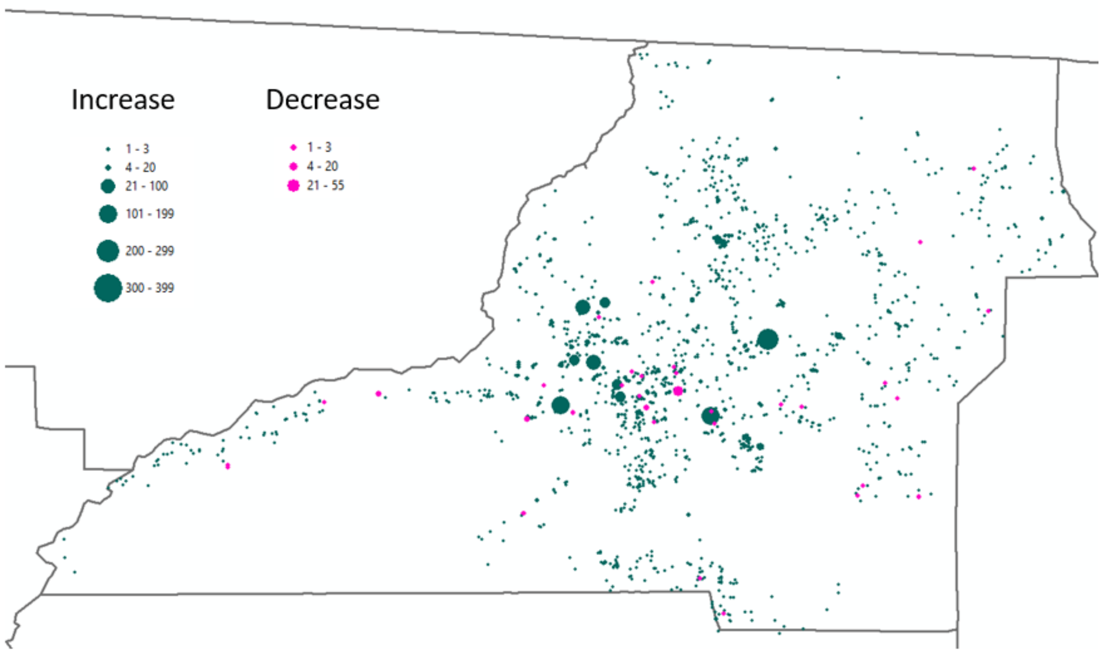

Figure C-2. Leon County, Florida population estimation changes 2010-2013 as determined by changes in housing availability.

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