# Annual Assessment of Flooding and Sea Level Rise

*2022 Edition*

**Volume 4**

# Acknowledgements

EDR wishes to thank staff members of the following organizations for their substantial assistance with this report:

Florida Department of Agriculture and Consumer Services

Florida Department of Environmental Protection

Florida Fish and Wildlife Conservation Commission

Florida Natural Areas Inventory

Florida Public Service Commission

Food and Resource Economics Department, Institute of Food and Agricultural Sciences, University of Florida

Tropical Research & Education Center, University of Florida

Northwest Florida Water Management District

Program for Resource Efficient Communities, Institute of Food and Agricultural Sciences, University of Florida

South Florida Water Management District

Southwest Florida Water Management District

St. Johns River Water Management District

Suwannee River Water Management District

U.S. Department of Agriculture, Office of Rural Development

U.S. Environmental Protection Agency

U.S. Geological Survey

# Table of Contents

# 6. Flooding and Sea Level Rise

Given Florida's flat topography and phenomenal rainfall events, flooding has been an issue throughout its history as a state. During the 2021 Session, the Florida Legislature passed CS/CS/SB 1954, an act relating to Statewide Flooding and Sea Level Rise Resilience. Among other things, the Legislature's Office of Economic and Demographic Research (EDR) was directed to develop an analysis of future expenditures by federal, state, regional, and local governments required to achieve the Legislature's intent of minimizing the adverse economic effects of inland and coastal flooding, thereby decreasing the likelihood of severe dislocations or disruptions in the economy and preserving the value of real and natural assets to the extent economically feasible.[1] Further, to the extent possible, the analysis must evaluate the cost of the resilience efforts necessary to address inland and coastal flooding associated with sea level rise, high tide events, storm surge, flash flooding, stormwater runoff, and increased annual precipitation over a 50-year planning horizon. While EDR recognizes that the impacts of climate change are more wide-ranging than this list alone suggests, the new statute is narrowly focused on the problems associated with excess water of various forms and durations over previously dry land.[2] For this first report, particular emphasis has been placed on identifying the analytical challenges in compiling and evaluating data from across the state that has differing availability, vintages, accuracy, quality and level of detail.

## 6.1. Introduction

To analyze the expenditures associated with minimizing adverse economic impacts and evaluate the costs of conducting resilience efforts, EDR must first apply geospatial technology to identify the precise boundaries of different risk or hazard zones. Ultimately, a new model will be needed to map multiple flooding scenarios and the potential impacts associated with them. A broad overview of EDR's research plan for this element is as follows:

- Step 1: Assessment of Data Availability, Potential Economic Risks, and State of Current Knowledge – August 2021 through June 2022
- Step 2: Identification of Areas Most At-Risk, Initial Testing of the Florida Flooding Assessment Model (FFAM), and Preliminary Static Estimates – July 2022 through July 2023
- Step 3: Expansion of FFAM to the Entire State – August 2023 through July 2024
- Step 4: Full Linkage of FFAM to EDR's Statewide Economic Model[3] to Generate Dynamic Estimates – August 2024 to June 2025

It is important to note that EDR will not directly collect data from the field or make independent measurements of climate or weather phenomena. Instead, its role is to evaluate sea level rise and other flooding events by delving into the most recent academic literature and available models; quantifying the impacts and evolving risks; selecting likely choices for adaptation and hazard mitigation; and estimating the most probable near-term and longer-term costs and consequences.

[1] Ch. 21-28, Laws of Fla. (codified as § 403.928(4), Fla. Stat.)
[2] Examples include drought, heightened conditions for wild fires, and heat waves.
[3] The Statewide Model is a dynamic computable general equilibrium (CGE) model that simulates Florida's economy and government finances. For a more complete description of this model, see various studies and presentations at Return on Investment (state.fl.us). (Accessed May 2022.)

As part of Step 1, EDR compiled the most recent research and data regarding the flood factors impacting Florida. These factors include sea-level rise, high tide events, storm surge, flash flooding, stormwater runoff and changes in annual precipitation. In this Edition, EDR discusses how the literature review and background research flesh out the specific problems facing the state over the next 50 years. In line with the evaluation of overall risks, the study highlights which ones are more immediate or of the greatest threat in terms of impact. Likewise, information gathered from different regions and counties helps pinpoint the most vulnerable areas and cost ramifications. EDR also identifies possible sources for additional information, as well as opportunities for collaboration with various federal, state and local departments and organizations. The overarching goal is to work in partnership with others who are similarly tasked in order to benefit from the scientific and practical research that is already underway.

In addition, federal organizations, such as U.S. Geological Survey (USGS) within the Department of the Interior, are in the process of developing models to project coastal flooding due to climate change-driven sea level rise and storms in different areas of the country. One of USGS' current projects focuses on the East Coast of Florida. It is possible that this work will ultimately replicate the Coastal Storm Modeling System (CoSMoS) already deployed in California. Based on the latest research and technology, CoSMoS and its associated web tools integrate local data, including socio-economic datasets. To the extent the technology is replicated in Florida, it can be used to conduct rough economic analyses that would accelerate full linkage to EDR's Statewide Economic Model. For this reason, EDR is hoping to develop a close collaboration with USGS to explore the best ways to incorporate these tools and their data into EDR's short term and long term studies. In this Edition, we explain how a CoSMoS-based approach can help Florida create a harmonized model for the entire state. Further, EDR discusses some of the efforts that have already been made at the county and regional level to assess the impact of sea level rise and flooding, and how these efforts can both inform and benefit from EDR's analysis.

EDR also attempts to determine the best strategy to categorize and assess the state in the short run, given its differing regional vulnerabilities and the multiplicity of available climate change scenarios. Over time, the study will geospatially identify a range of zones in order to quantify the potential economic impacts within each of them, a necessary step for accurate analysis. These zones will be differentiated by probability and type of adverse events. Going forward, the quality of available data will play a significant role in understanding the precise risks facing the state.

As a first step in this analysis, EDR has begun to identify and assess risk in several economically meaningful impact zones, with the intent to focus on an evolving selection to match the availability of information and data. The initial series of impact zones is primarily defined by proximity to the coastal area and susceptibility to flooding-related issues. The current working categories are discussed below:

- *High Impact Zone* is based on federal data sources and modeling of the coastal areas which currently extends to the head of the tide. These areas are affected by a multiplicity of factors occurring persistently, rather than periodically or as a consequence of one-off events.

- *Intermediate Impact Zone* is the area beyond the High Impact Zone that may still be affected by storm surge, as well as the area along rivers or larger lakes where significant flooding either is recurrent or will likely be recurrent in the future.
- *Dispersed Impact Zone* is the area outside the High and Intermediate Impact Zones that still experiences localized flooding challenges, but where those are primarily caused by factors such as higher levels of precipitation in urban or urbanized areas, the weaker impacts of storms and hurricanes, or nuisance flooding.[4]

This year's assessment concludes with a discussion of the challenges that lie ahead and an explanation of next steps. The findings will be ultimately evaluated in tandem with the other topics addressed by the Annual Assessment of Florida's Water Resources and Conservation Lands in order to blend with those results and address aspects that have overlaps.

In section 6.2, the analysis begins with a summary of existing material on climate trends and flooding factors such as sea-level rise, high tide events, storm surge, flash flooding, stormwater runoff and changes in annual precipitation. This material highlights the most recent data regarding these factors, whether global, regional or Florida-specific. One of the major objectives of this analysis is to select the more plausible scenarios to assess the impact of flooding. In section 6.3, other considerations that the assessment must take into account are identified. While the list is preliminary and not exhaustive, these include saltwater intrusion, the high reliance on septic tanks in Florida, and general impacts on water supply and water quality. A few examples of state and local initiatives are provided in section 6.4. A brief overview of current modeling methods and techniques is presented in section 6.5. The methodology that has been applied by USGS is described in detail in sections 6.6 and 6.7, which also frame the advantages of adopting the same or a similar methodology for this assessment. And finally, section 6.8 provides an overview of the key economic issues that need to be addressed by the assessment. While far from an exhaustive list, these issues have already begun to affect and will continue to affect the state's wellbeing.

## 6.2. Current Climate Trend and Flooding

Studies and research on climate trend have progressed over time with the advent of new technology and methodologies to measure and understand the impact of natural and anthropogenic factors on the environment. In the annual assessment, EDR will rely on published research from respected international, national and local sources to provide background on the factors that cause flooding and the implications for Florida. The primary sources include the Intergovernmental Panel on Climate Change (IPCC), National Oceanic and Atmospheric Administration (NOAA), U.S. Geological Survey (USGS), and the U.S. Army Corps of Engineers (USACE).

Amplification of weather extremes, including many of the factors that cause flooding, is currently emerging as one of the most important and direct results of climate change. Flooding typically results from one of five commonly understood reasons:[5]

---

[4] As used here, nuisance flooding refers to low levels of inundation—regardless of source—that do not pose significant threats to public safety or cause major property damage, but can disrupt routine day-to-day activities, put added strain on infrastructure systems such as roadways and sewers, and cause minor property damage.

[5] *See*, for example, the discussion in Moving to Higher Ground: Rising Sea Level and the Path Forward by John England (2021). This particular list is largely drawn from page 80 of his book.

1. Severe storms and storm surge stemming from hurricanes, typhoons, and other extreme weather events;
2. Heavy rainfall with wet microbursts (rain bombs) and monsoons as extreme forms;
3. Downhill runoff and downstream flooding;
4. Extreme high tides; and
5. Sea level rise.

According to IPCC reports (2007[6]; 2014[7]; 2019[8]; 2021[9]), the global averaged precipitation over land has increased since 1950, with a faster rate of increase since the 1980s. The studies also indicate that globally averaged sea level increased by approximately 6 to 10 inches between 1901 and 2018, with more precise data gathered from satellite radar measurements from 1993 to 2017 showing an accelerating rise of 3 inches.[10] More recently, NOAA indicated that global sea level set a new record high—3.6 inches—above 1993 levels in 2020. Since no place in the state is more than 75 miles from the Gulf of Mexico or the Atlantic Ocean and the topography is essentially flat, sea level rise is of particular concern to Florida. It stands out among the five flooding factors since it both amplifies the other causes of flooding and introduces its own set of problems. In some of the long-term forecasts, sea level rise is predicted to cause a number of world's coastal areas and low-lying islands to become uninhabitable.

### *6.2.1 Sea Level Rise*

Sea level rise is what it sounds like. More than the visible and obvious change caused daily by tides, sea level rise is a permanent increase in the mean (or average) surface level of seas and oceans. Florida is surrounded by the Atlantic Ocean and the Gulf of Mexico. Even a modest increase generates significant impacts, particularly because Florida's mean elevation is just 100 feet above sea level and 18.5 percent of the state is already covered by water.[11] Sea level rise is generally attributed to two factors related to global warming: (1) the added water from melting ice sheets and glaciers, and (2) the expansion of seawater as it warms. In addition, subsidence is an important contributor to changes in relative sea level rise in many of the delta regions of the United States.[12] Subsidence increases the magnitude of the relative sea level rise.

---

[6] IPCC (Intergovernmental Panel on Climate Change). 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge: Cambridge University Press.
[7] IPCC (Intergovernmental Panel on Climate Change). 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
[8] IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press. https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/03_SROCC_SPM_FINAL.pdf (Accessed January 2022.)
[9] IPCC, 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press. In press.
[10] *See* IPCC (2021). "Summary for Policymakers" (PDF). Climate Change 2021: The Physical Science Basis. A.1.7.
[11] *See* https://www.usgs.gov/special-topics/water-science-school/science/how-wet-your-state-water-area-each-state. (Accessed March 2022.)
[12] Ericson, J.P., C.J. Vörösmarty, S.L. Dingman, L.G. Ward, and M. Meybeck, 2006. "Effective Sea-Level Rise and Deltas: Causes of Change and Human Dimension.

The amount of sea level rise is not globally uniform and varies regionally. According to a recent IPCC report, regional differences of as much as ±30% of the global mean sea level rise result from land ice loss and variations in ocean warming and circulation. Differences from the global mean can be even greater in areas of rapid vertical land movement.[13] Currently, the most credible scientific studies suggest that the sea level continues to rise at an increasing rate. The IPCC reports that extreme sea level events that are historically rare (once per century in the recent past) are projected to occur frequently (at least once per year) by as early as 2050—especially in tropical regions (IPCC 2019; IPCC 2013).[14] It is further predicted that these events will occur at least annually at more than half of all tide gauge locations by 2100. As this occurs, there will be concomitant increases in the frequency and severity of coastal flooding in low-lying areas and to incidences of coastal erosion along most sandy coasts.[15] The following table shows several ICPP Global Mean Sea Level (GMSL) rise projections for the years 2081 and 2100 under better and worse case scenarios (Table 6.2.1).

**Table 6.2.1 ICPP Global Mean Sea Level Rise under better and worse case scenarios**

| | 2081 (ft.) \| IPCC 2013 | 2100 (ft.) \| IPCC 2013 | 2100 (ft.) \| IPCC 2019 | 2100 (ft.) \| IPCC 2021 |
|---|---|---|---|---|
| **Better** *(RCP2.6)* | 1.27 (0.95-1.93, likely range) | 1.41 (0.95-1.93, likely range) | 1.00-3.00 | Very low (0.91-1.80) |
| | | | | Low (1.049-2.03) |
| **Worse** *(RCP8.5)* | 2.32 (1.67-3.01, likely range) | 2.75 (2.00-3.60, likely range) | | Intermediate (1.44-2.49) |
| | | | | High (2.06-3.31) |

Note: RCP8.5 is the ICPP scenario where greenhouse gas emissions remain at high rates (business as usual). The RCP2.6 scenario is based on a continuous decline in carbon dioxide ($CO_2$) emissions starting in 2020 and ending at zero by 2100.

The IPCC has developed a number of scenarios for its assessment reports on climate change. The two scenarios that appear to establish the most reasonable brackets for Florida are the intermediate RCP4.5 scenario wherein emissions peak in mid-21st Century and diminish thereafter; and the higher RCP8.5 scenario wherein emissions continue to rise along with population growth throughout the 21st Century.[16] The GMSL projections up to 2050 are believed to have greater certainty, thereby providing a more robust basis for planning adaptation pathways (Table 6.2.2).

[13] IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press. https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/03_SROCC_SPM_FINAL.pdf (Accessed January 2022.)
[14] ICPP (Intergovernmental Panel on Climate Change), 2013. Climate Change 2013: the Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
[15] IPCC, 2021. Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S.L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M.I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T.K. Maycock, T. Waterfield, O. Yelekçi, R. Yu, and B. Zhou (eds.)]. Cambridge University Press.
[16] IPCC, 2019: Summary for Policymakers. In: IPCC Special Report on the Ocean and Cryosphere in a Changing Climate [H.-O. Pörtner, D.C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, K. Mintenbeck, A. Alegría, M. Nicolai, A. Okem, J. Petzold, B. Rama, N.M. Weyer (eds.)]. In press. https://www.ipcc.ch/site/assets/uploads/sites/3/2019/11/03_SROCC_SPM_FINAL.pdf. (Accessed January 2022.)

**Table 6.2.2 ICPP Global Sea Level Rise projections for 2050**

| | 2050 (ft.) |
|---|---|
| **Better...RCP2.6** | 0.71 (0.50-0.92) |
| **Intermediate...RCP4.5** | 0.74 (0.54-0.96) |
| **Worse...RCP8.5** | 0.88 (0.64-1.12) |

While not an operable feature in many global and national climate models, a number of organizations and government entities have attempted to develop sea level projections for smaller-scale or local geographies. As these initiatives are largely undertaken independently with varying levels of expertise, known science and assumptions, it is difficult to piece together the results in a coherent manner that presents a harmonized picture. This is true within Florida as well; however, some specific impacts of sea level rise are already detectable[17], which—at least—enables ongoing data collection and monitoring. These include saltwater intrusion and contamination of freshwater aquifers[18]; flooding at extreme high tide; and an observed diminishment in the effectiveness of the Southeast Florida canal system[19]. Adding to the challenges, an equivalent numeric change in sea level can have differing location-specific ramifications, including greater or lesser beach erosion, greater or lesser alteration of storm surge patterns, and more or less loss of coastal habitats for particular species.

As Southeast Florida is one of the world's areas most prone to the more severe flooding aspects of climate change,[20] several initiatives and studies have already been conducted in the four counties of Broward, Miami-Dade, Monroe, and Palm Beach. Based on recent research and regional observations in Florida, virtually all projections agree that sea level rise has accelerated.[21,22] For example, the Key West tide gauge from 2000 to 2017 has observed 3.9 inches of sea level rise. Even so, it is currently unknown whether the rapidity of this rise will persist into the future.

In 2015, the information provided by the United States Army Corps of Engineers (USACE) for civil works projects was deemed the best available information for local planning. These estimates suggested an approximate local sea level rise of 2.0 to 8.0 inches over a 20-year horizon (2015 to

---

[17] Emrich, C., Morath, D., Bowser, G., and Reeves, R., 2017. Hazards and Vulnerability Research Institute, CLIMATE-SENSITIVE HAZARDS IN FLORIDA Identifying and Prioritizing Threats to Build Resilience against Climate Effects.
[18] Shaw, J., P.G. and Zamorano, M., 2020, Saltwater Interface Monitoring and Mapping Program, Technical Publication WS-58 December 2020, Resource Evaluation Section, Water Supply Bureau1 Compliance Assessment & Reporting, Water Quality Bureau2 Water Resources Division South Florida Water Management District.
[19] Climate Central, 2013. Surging Seas Sea Level Rise Analysis. https://riskfinder.climatecentral.org/search?q=fl (Accessed January 2022.)
[20] *See*, for example, OECD's Ranking of the World's Cities Most Exposed to Coastal Flooding Today and in the Future (2007), which placed Miami #9 in terms of population and #1 in terms of assets exposed to coastal flooding in the 2070s. https://climate-adapt.eea.europa.eu/metadata/publications/ranking-of-the-worlds-cities-to-coastal-flooding/11240357. (Accessed March 2021.) Similarly, a 2021 listing of the world's cities by The Week UK ranked Miami #7.
[21] Sweet, W., Kopp, R., Weaver, C., Obeysekera, J., Horton, R., Thieler, E. and Zervas, C., 2017. GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES, Silver Spring, Maryland. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf (Accessed January 2022.)
[22] Volkov, D. L., Lee, S. K., Domingues, R., Zhang, H., & Goes, M., 2019. Interannual Sea Level Variability along the Southeastern Seaboard of the United States in Relation to the Gyre-Scale Heat Divergence in the North Atlantic. Geophysical Research Letters, 46(13), 7481–7490. doi: 10.1029/2019gl083596.

2035), with an intermediate-level projection of 3.5 inches. Over a 50-year horizon (2015 to 2065), a frequently used lifecycle for infrastructure design, the projected local increase was 5.2 to 26.0 inches, with an intermediate-level projection of 10.3 inches. These estimates were consistent with the contemporaneous methodologies used by NOAA and IPCC.

Conveying a sense of caution, the USACE analysis emphasized that the given ranges were largely dependent on the continuance of the existing level of global emissions and melting rate of land-locked ice. There are even more assumptions embedded in the underlying analysis. The takeaway is that local planners must be fully aware of the various processes, operating over multiple temporal and spatial scales, affecting water levels.[23,24,25] Overall, there is significant uncertainty associated with all of the current projections, and they are subject to substantial change as events unfold and science evolves.

More recent studies have combined results from different models and included more regional tide gauge readings. Notable among these efforts, USACE has developed a Sea Level Change Curve Calculator that provides decadal projections of sea level rise based on NOAA 2012, USACE 2013, Coastal Assessment Regional Scenario Working Group (CARSWG) 2016 and NOAA 2017. [26,27]

There are 16 gauge stations along the coast of Florida.[28] Figures 1 through 3 compare the low, intermediate, intermediate high and highest projections of regional SLR for these stations based on USACE 2013, CARSWG 2016 and NOAA 2017 for 2050. To begin addressing the 50-year forecast horizon required by state law, Figure 4 shows the NOAA 2017 station projections for 2070. An associated table showing the values for the 16 gauge stations can be found in Appendix D.1. The charts below highlight the different locational outcomes expected within Florida, as well as the vintage differences in model projections.

[See figures on following pages]

[23] Kopp, R. E., C.C Hay, C.M Little, & J.X. Mitrovica, 2015. Geographic variability of sea-level change. Current Climate Change Reports, 1(3), 192-204.
[24] NOAA Technical Report, 2017 https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf (Accessed January 2022.)
[25] DeConto, R. M. and Pollard, D., 2016. Contribution of Antarctica to past and future sea-level rise. Nature, 531(7596), 591-7
[26] Hall, J.A., S. Gill, J. Obeysekera, W. Sweet, K. Knuuti, and J. Marburger, 2016. Regional Sea Level Scenarios for Coastal Risk Management: Managing the Uncertainty of Future Sea Level Change and Extreme Water Levels for Department of Defense Coastal Sites Worldwide. U.S. Department of Defense, Strategic Environmental Research and Development Program. 224 pp. https://www.hsdl.org/?abstract&did=792698 (Accessed January 2022.)
[27] Sweet, W., Kopp, R., Weaver, C., Obeysekera, J., Horton, R., Thieler, E. and Zervas, C., 2017. GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES, Silver Spring, Maryland. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf (Accessed January 2022.)
[28] Tide gauges can independently measure sea level rise relative to land; however, they do not take account of subsidence directly.

**Figure 6.2.1 Low, intermediate, and high projections of Regional SLR by 2050 from USACE 2013**

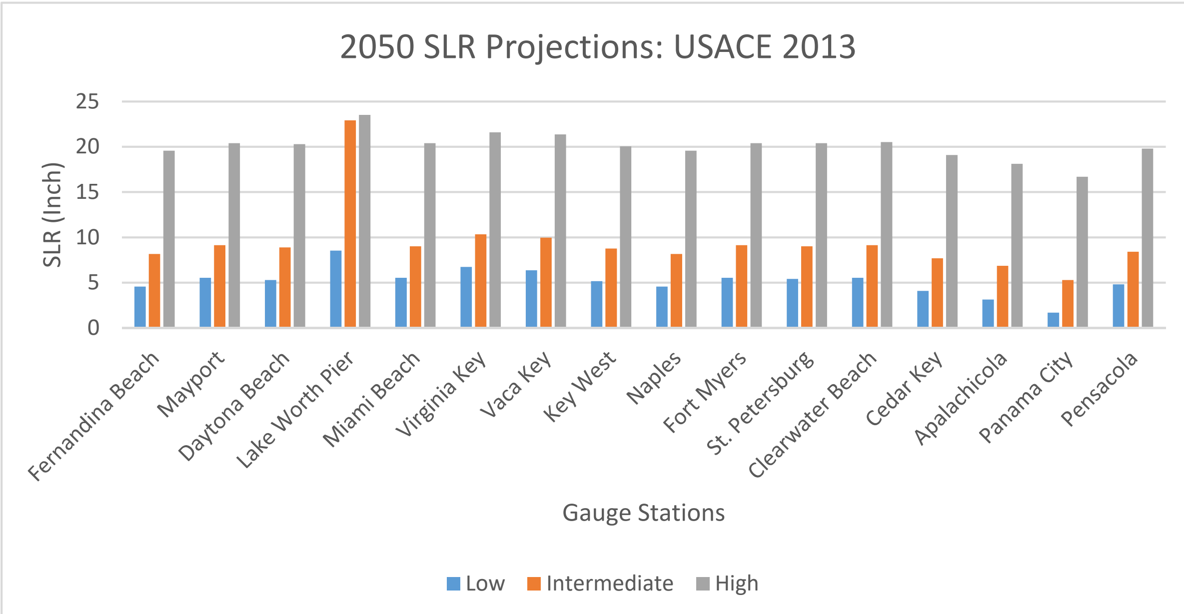



**Figure 6.2.2 Low, intermediate, high and the highest projections of Regional SLR by 2050 from CARSWG 2016**

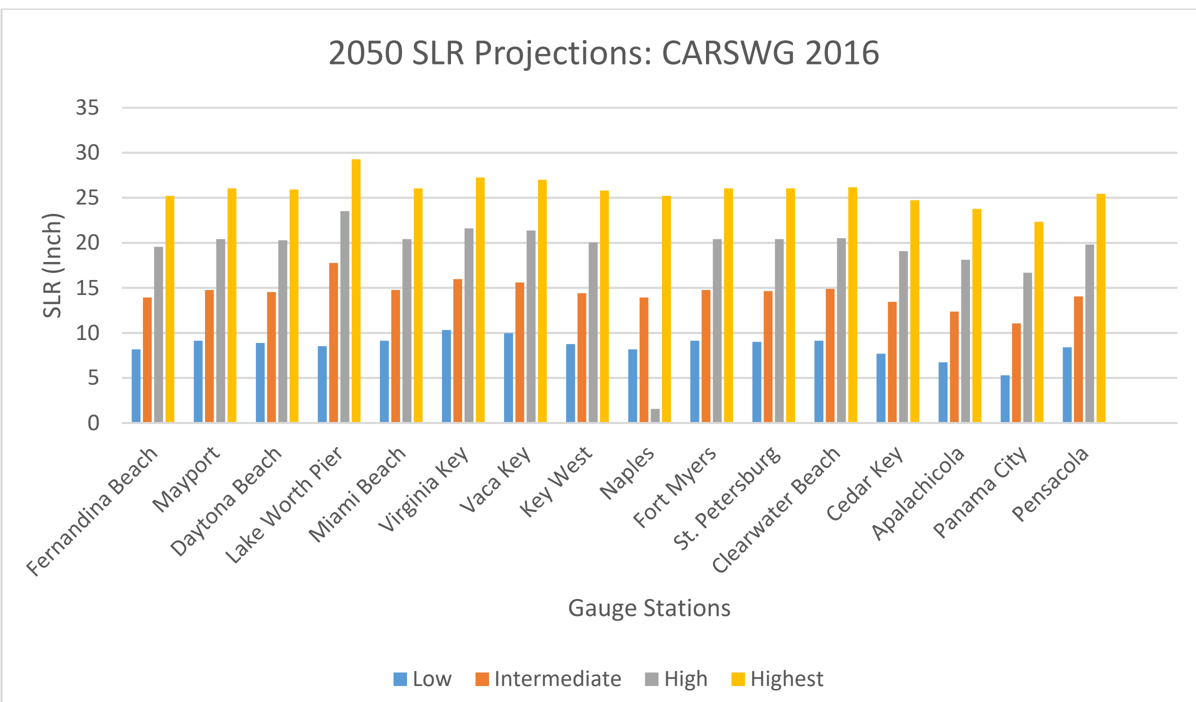


**Figure 6.2.3 Low, intermediate low, intermediate high and the highest projections of Regional SLR by 2050 from NOAA 2017**

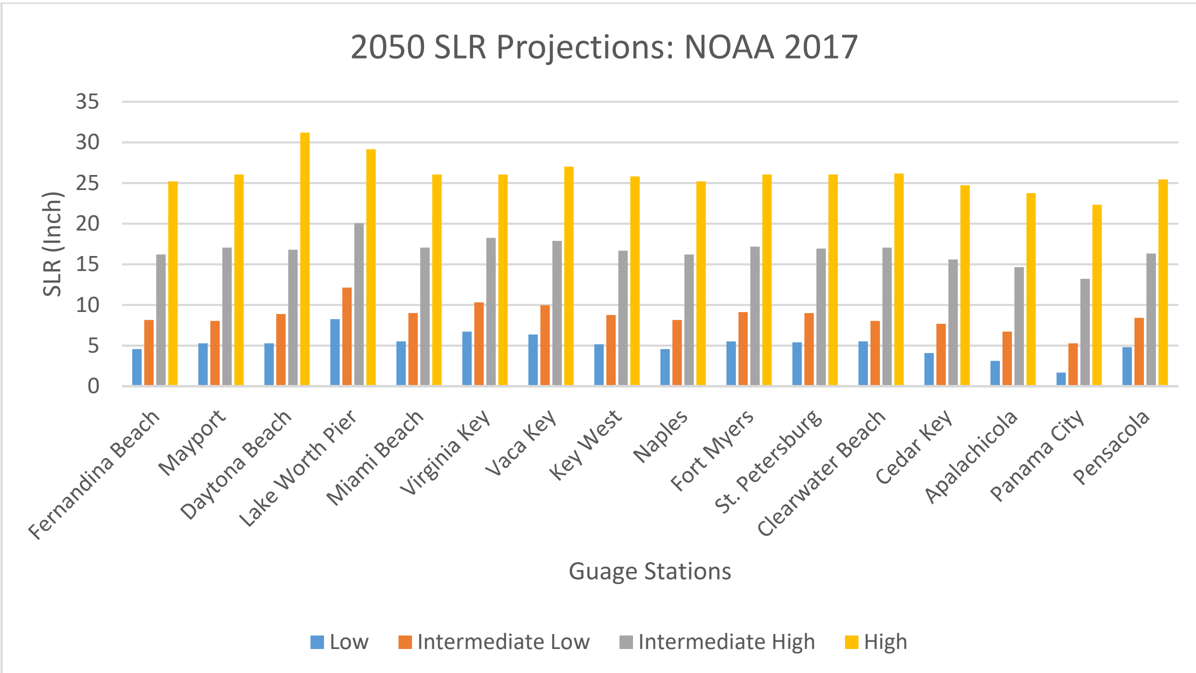
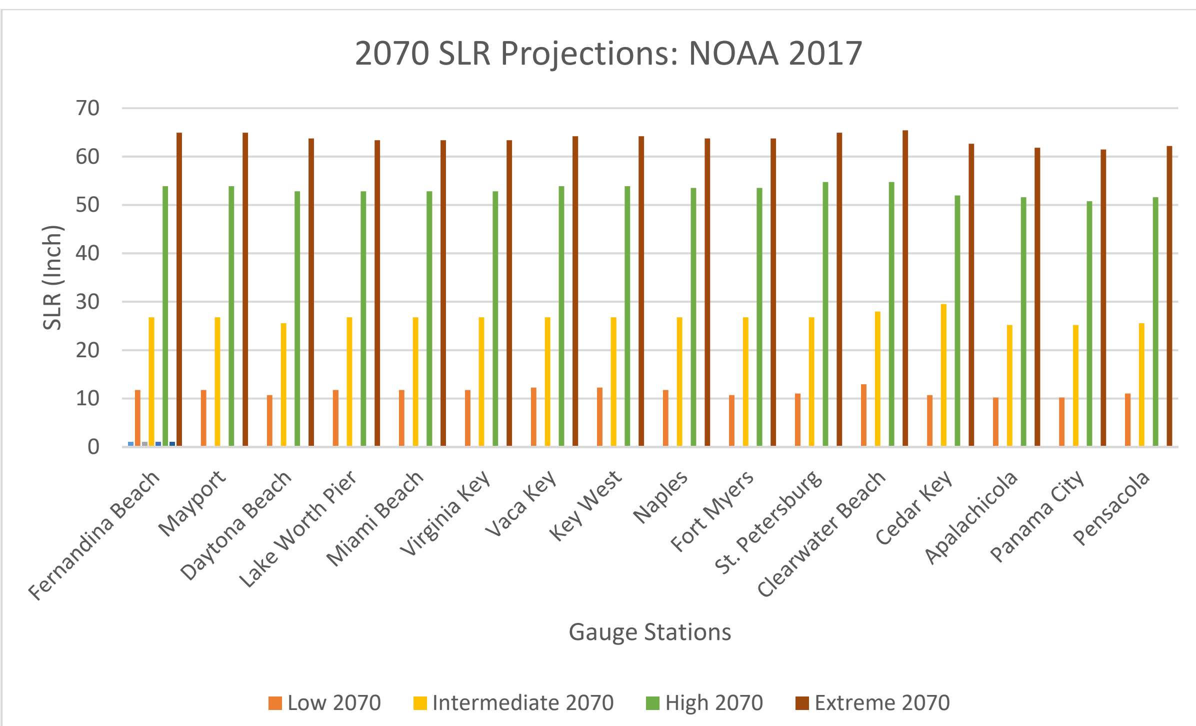



**Figure 6.2.4 Low, Intermediate, intermediate high and the highest projections of Regional SLR by 2070 from NOAA 2017**



Given the three alternatives, the NOAA 2017 study offers the most up-to-date set of projections. Not only is it a more recent study, but the work is anchored in the year 2000 (i.e., the 1991–2009 epoch) instead of 1992 (i.e., the National Tidal Datum Epoch of 1983–2001). Notable elements include the provision of decadal-scale estimates through 2100, a broader and higher range for GMSL rise by 2100 (0.98–8.2 feet), and projections through the year 2200. Further, it uses an algorithm capable of downscaling to a 1-degree gridded basis in order to provide a systematic spatial framework that more broadly supports regional and local decision making.[29,30]

Considering several locational factors impacting sea level rise at the regional level[31], NOAA 2017 found that:

- For almost all future scenarios, relative sea level rise is projected to be greater than the global average along the coasts of the U.S. Northeast and the western Gulf of Mexico.
- Under the Intermediate and Low scenarios, relative sea level rise is projected to be less than the global average along much of the Pacific Northwest and Alaska coasts.
- Under the Intermediate-High, High and Extreme scenarios, relative sea level rise is projected to be higher than the global average along almost all U.S. coasts outside Alaska.

As seen in the preceding figures, most studies focus on key milestone scenarios (e.g., 2050, 2070 or 2100); however, sea level rise is accelerating (Nerem et al., 2018)[32], consequential (Cazenave et al., 2018)[33], and causing a continual shift in coastal flooding patterns. This means extreme water levels[34] at coastal locations will actually be exceeded annually sometime before 2050.[35,36] Also, the frequency of 50-year extreme water levels being exceeded during peak tides will almost become a daily phenomenon for 90% of the U.S. coast before the end of the 21st century.[37]

Given the multiplicity of projections for climate change, sea level rise and other factors that increase the risks of flooding, a body of research has developed to address varying levels of risk tolerance. For example, studies have variously recommended that intermediate projections should be used for residential and low impact business areas; high risk scenarios should be used for

---

[29] Compact, 2020. Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (Compact). February 2020. Unified Sea Level Rise Projection Southeast Florida. A document prepared for the Southeast Florida Regional Climate Change Compact Climate Leadership Committee. 36p.

[30] NOAA Technical Report, 2017 at: https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf (Accessed January 2022.)

[31] These include vertical land movement based on glacier isostatic adjustment; shifts in oceanographic factors such as circulation patterns; changes in the earth's gravitational field and rotation; and the flexure of the earth's crust and upper mantle due to melting of land based ice.

[32] Nerem, R. S. et al., 2018. Climate-change–driven accelerated sea-level rise detected in the altimeter era. Proceedings of the National Academy of Sciences 115(9), 2022–2025.

[33] Cazenave, A., Palanisamy, H. & Ablain, M., 2018. Contemporary sea level changes from satellite altimetry: What have we learned? What are the new challenges? Advances in Space Research 62(7), 1639–1653.

[34] Calculated as a 2% annual chance of exceedance.

[35] Sweet, W., Kopp, R., Weaver, C., Obeysekera, J., Horton, R., Thieler, E. and Zervas, C., 2017. GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES, Silver Spring, Maryland. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf (Accessed January 2022.)

[36] Stephens, S. A., Bell, R. G. & Lawrence, J., 2018. Developing signals to trigger adaptation to sea-level rise. Environmental Research Letters 13(10), 104004.

[37] Taherkhani, M., Vitousek, S., Barnard, P., Frazer, N., Anderson, T. and Fletcher, C., 2020. Sea-level rise exponentially increases coastal flood frequency. *Scientific Reports*, 10(1).

infrastructure that has life expectancy of over 50 years; and worst-case scenarios should be used for assessing potential project performance under conditions of extreme sea level rise that are physically plausible but judged to have extremely low probabilities.[38] Moreover, when using any of these scenarios for planning purposes, both short and long-term decisions should recognize that locations with lower elevation thresholds, less variability in extreme water levels, or higher rates of sea level rise have been the most prone to rapid (often-accelerating) increases in event probabilities and will continue to be so in the future.[39,40,41,42,43]

In Florida, geomorphology and climate in the southern region are different from the west and northwest. This adds further impediments to selecting one source of projections for application across the entire state. Regardless, relying on NOAA 2017 projections, Table 6.2.3 summarizes the probable population in different coastal regions affected by sea level rise in 50 years (2070), and Figure 6.2.5 provides a map of the corresponding areas. In Appendix D.2, a few examples of areas affected by sea level rise of 1ft, 3ft and 5ft are mapped in greater detail. These three values are chosen because 1ft is the lowest level and 3ft is an intermediate level for use in assessing residential areas and businesses, and 5ft is a high value related to infrastructure.

**Table 6.2.3: Population Affected by sea level rise in 2070, assuming NOAA 2017 Projections**

| Area | Population Affected by SLR in 2070 based on NOAA 2017 Projections | | | | |
|---|---|---|---|---|---|
| | 1 ft. | 2 ft. | 3 ft. | 4 ft. | 5 ft. |
| ALFL_MOB_TLH1 | 60,393 | 63,860 | 68,503 | 72,927 | 81,000 |
| ALFL_MOB_TLH2 | 62,362 | 65,920 | 72,861 | 84,436 | 94,620 |
| ALFL_MOB_TLH3 | 6,990 | 7,581 | 8,252 | 9,677 | 10,318 |
| FL_TBW1 | 222,502 | 245,193 | 287,892 | 360,349 | 449,179 |
| FL_TBW2 | 235,146 | 250,549 | 276,393 | 326,318 | 407,279 |
| FL_MFL1 | 39,370 | 48,573 | 61,678 | 85,909 | 106,931 |
| FL_MFL2 | 500,441 | 591,179 | 760,926 | 990,921 | 1,522,457 |
| FL_MLB | 170,392 | 184,455 | 210,467 | 243,151 | 291,862 |
| FL_JAX | 253,352 | 271,395 | 313,439 | 348,175 | 389,207 |
| **Total** | **1,550,948** | **1,728,705** | **2,060,411** | **2,521,863** | **3,352,853** |

[38] Sweet, W., Kopp, R., Weaver, C., Obeysekera, J., Horton, R., Thieler, E. and Zervas, C., 2017. GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES, Silver Spring, Maryland. (Accessed January 2022.)
[39] Buchanan, M.K., R.E. Kopp, M. Oppenheimer, and C. Tebaldi, 2016: Allowances for evolving coastal flood risk under 42 uncertain local sea-level rise. Climatic Change, 137(3–4), doi:10.1007/s10584-016-1664-7.
[40] Sweet, W. V., J. Park, J. J. Marra, C. Zervas, and S. Gill, 2014. Sea level rise and nuisance flood frequency changes around the United States, NOAA Tech. Rep. NOS CO-OPS 73, pp. 53.
[41] Kopp, R.E., Horton, R.M., Little, C.M., Mitrovica, J.X., Oppenheimer, M., Rasmussen, D.J., Strauss, B.H. and Tebaldi, C., 2014. Probabilistic 21st and 22nd century sea-level projections at a global network of tide-gauge sites. *Earth's future*, *2*(8), pp.383-406.
[42] Hunter, J., 2012: A simple technique for estimating an allowance for uncertain sea-level rise. Climatic Change, 113(2), 239–252, doi:10.1007/s10584-011-0332-1.
[43] Tebaldi, C., Strauss, B. and Zervas, C., 2012. Modelling sea level rise impacts on storm surges along US coasts. *Environmental Research Letters*, 7(1), p.014032.

**Figure 6.2.5 Florida coastal regions based on NOAA study and the location of gauges**

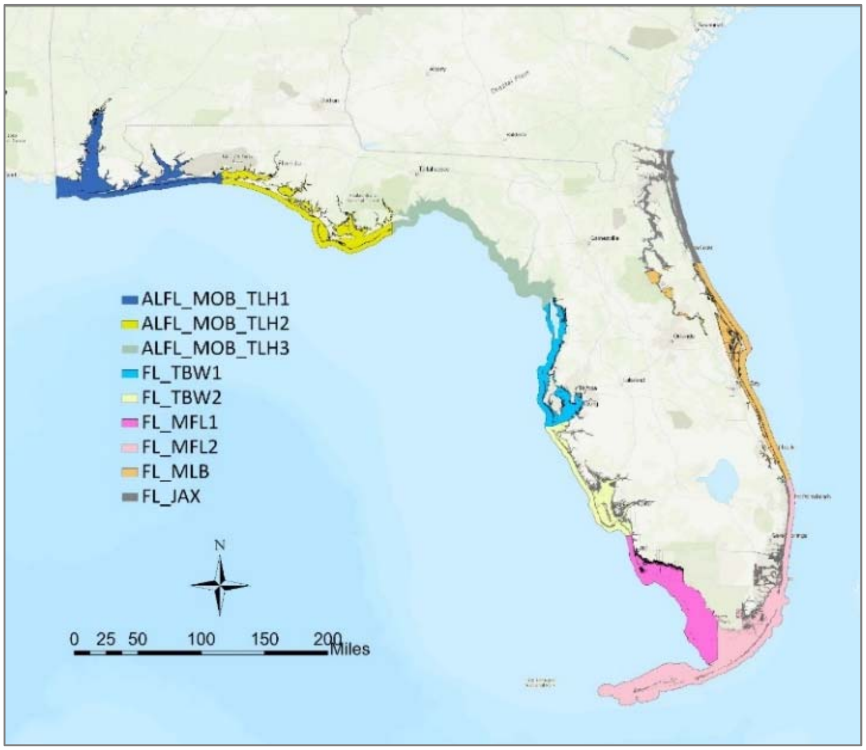
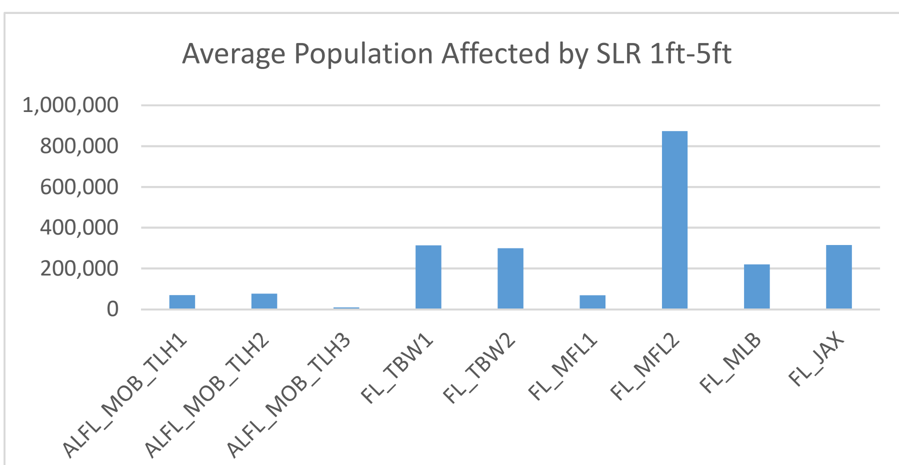



Figure 6.2.6 shows the average population that could be affected by sea level rise that ranges between 1ft and 5ft. This chart is just one way of demonstrating the dissimilar impacts caused by sea level rise in Florida's coastal regions. The corresponding geographic areas are identified on Figure 6.2.5. As expected, the graph shows that sea level rise has the smallest population impact in Wakulla, Taylor, Dixie and Levy counties, and the greatest population impact in Miami-Dade, Broward and Palm Beach counties.

**Figure 6.2.6 Average population affected by SLR of 1ft to 5ft**



### *6.2.2 High Tide Events*

According to NOAA, high and low tides refer to the regular rise and fall of the ocean's waters due to the gravitational pull of the moon and sun and their position relative to the earth.[44] Higher than normal tides typically occur during a new or full moon when the moon is at or near its perigee, or during specific seasons around the country; however, storms or wind pushing seawater[45] over land can also cause higher than normal tides.[46] Further, the 18.6-year lunar nodal cycle can add or subtract up to 2.5 inches to high tides. In a low phase since 2015 for Florida's east coast tides, it will return to the peak (additive) phase in 2034.[47] For Florida's west coast tides, the peak is reached in 2025. Finally, water depth and shoreline geometry can also affect the amplitude of local tides.

The term "King Tide" is commonly used in Florida to refer to exceptionally high tides, but it is also used in other places to refer to extremely low tides. Adding to the confusion, the use of this term is not based on established science. Viewing a King Tide more as a single annual event, the Environmental Protection Agency (EPA) offers the following explanation: "The king tide is the highest predicted high tide *of the year* at a coastal location." [Emphasis added]

High tide events do not operate in isolation. Underlying sea level rise intensifies high tide flooding.[48,49,50] This compounding effect will lead to increasingly deep and frequent tidal flooding over time (e.g., Ezer and Atkinson, 2014; Sweet et al., 2014; Sweet and Park, 2014; Sweet et al., 2016). Under the Intermediate sea level rise scenario, annual projections of High Tide Flood (HTF) days in some areas along the nation's coastline exhibit dramatic increases in frequency over the next 30 to 40 years. For example, one study shows that St. Petersburg will have an average of six HTF days per year in the ten-year period beginning 2023, but will move to an average of 67 days per year between 2033 and 2043.[51] The cumulative impact from tidal flooding that regularly moves above a chosen local threshold (whether duration, magnitude, or frequency) will eventually degrade sector-specific functionalities and/or exceed economic and public-tolerance thresholds.[52]

Annual occurrences of high tide flooding have already increased in a number of U.S. coastal cities since the 1960s—some between five and ten times. According to a recent NOAA report, between

---

[44] *See* https://oceanservice.noaa.gov/facts/kingtide.html. (Accessed May 2022.)

[45] A few freshwater rivers and lakes have detectable tides as well, but in the United States this is mostly limited to the Great Lakes and the Great Salt Lake.

[46] See https://oceanservice.noaa.gov/facts/kingtide.html. (Accessed May 2022.)

[47] Peng, D., Hill, E. M., Meltzner, A. J., &Switzer, A. D. (2019). Tide gauge records show that the 18.61-year nodal tidal cycle can change high water levels by up to 30 cm. Journal of Geophysical Research: Oceans, 124, 736–749. https://doi.org/10.1029/2018JC014695.

[48] Sweet, W., Dusek, G., Obeysekera, J. and Marra, J., 2018. Patterns and Projections of High Tide Flooding Along the U.S. Coastline Using a Common Impact Threshold, NOAA Technical Report NOS CO-OPS 086. Accessible at: Patterns and Projections of High Tide Flooding along the U.S. Coastline Using a Common Impact Threshold (noaa.gov). (Accessed January 2022.)

[49] Climate Central, 2022. https://sealevel.climatecentral.org/ (Accessed January 2022.)

[50] NOAA Flood Expo, 2021. https://coast.noaa.gov/floodexposure/#-9537235,3241453,7z/eyJoIjoiaGlnaFRpZGVGbG9vZGluZ3wxfCJ9 (Accessed January 2022.)

[51] Thompson, P. R., Widlansky, M.J., Leuliette, E., Sweet, W., Chambers, D.P., Hamlington, B.D., Jevrejeva, S., Marra, J.J., Merrifield, M.A., Mitchum, G.T, & Nerem, N.S., 2019. Sea level variability and change [in "State of the Climate in 2018"]. Bull. Amer. Meteor. Soc., 100 (9), S181–S185

[52] Sweet, W., Kopp, R., Weaver, C., Obeysekera, J., Horton, R., Thieler, E. and Zervas, C., 2017. GLOBAL AND REGIONAL SEA LEVEL RISE SCENARIOS FOR THE UNITED STATES, Silver Spring, Maryland. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf (Accessed January 2022.)

2000 and 2015, annual high tide flood frequencies increased by about 125% (from 1.3 days to 3.0 days per year) along the Southeast Atlantic.[53]

Several studies report that flooding at extreme high tides is already happening more frequently in Florida.[54,55] Couple this with the fact that development in Florida is more concentrated near the coast than at higher elevations, and it becomes clear that high tide flooding presents an immediate hazard to the state. Based on a 2014 report, 2,120 square miles of land was located within 3 feet of the high tide line in Florida.[56] More than 300,000 homes were estimated to sit on that land. For land that is less than 6 feet above the high tide line, these numbers jumped to more than 1.4 million homes on 4,660 square miles of land.

In addition to the threat to housing, high tide flooding can damage infrastructure (such as compromising sewage treatment plants), cause transportation problems (such as flooded streets), and introduce new economic challenges (such as temporary business closures). According to the same 2014 report, Florida had 2,555 miles of road, 35 public schools, one power plant, and 978 EPA-listed sites such as hazardous waste dumps and sewage plants on land located within 3 feet of the high tide line in Florida. At 6 feet, these numbers grew to more than 16,000 miles of road, 300 schools, 14 power plants, and 5,509 EPA-listed sites.

The effects will reach even further. Currently, most of the major water control structures along the coastline in Miami-Dade County maintain canal elevations very close to the upper end of the normal tidal elevation range. In some cases, spring tides already exceed the normal canal elevation, which forces gate closures at least twice a day during those periods.[57] Add to this the important implications for the environment. For example, high tide events will increase saltwater intrusion into the slough features of the Everglades. Other direct effects include saltwater intrusion into water supply wells and inundation of natural systems.[58]

### *6.2.3 Storm Surge*

Storm surge is an abnormal rise of water generated by a storm, over and above the predicted height caused by astronomical tides.[59] The term storm surge is not synonymous with storm tide. According to NOAA, storm tide is the *total* observed seawater level during a storm, resulting from the combination of storm surge and the astronomical tide.[60] The rise in water level can cause

[53] Uses median values as the metric. *See* https://tidesandcurrents.noaa.gov/publications/techrpt86_PaP_of_HTFlooding.pdf (Accessed January 2022.)
[54] Climate Central Fact Sheet, 2021. http://sealevel.climatecentral.org/uploads/ssrf/CaliforniaFactsheetSS1.pdf (Accessed January 2022.)
[55] Parkinson, R., Harlem, P. and Meeder, J. 2015. Managing the Anthropocene marine transgression to the year 2100 and beyond in the State of Florida U.S.A, Climatic Change, Vol. 128. DO - 10.1007/s10584-014-1301-2.
[56] Strauss, B., C. Tebaldi, S. Kulp, S. Cutter, C. Emrich, D. Rizza, and D. Yawitz, 2014. "Florida and the Surging Sea: A Vulnerability Assessment with Projections for Sea Level Rise and Coastal Flood Risk." Climate Central Research Report. pp 1-58.
[57] Compact, NA. REGIONAL IMPACTS OF CLIMATE CHANGE AND ISSUES FOR STORMWATER MANAGEMENT, South Florida RCAP Implementation Guidance Series. https://southeastfloridaclimatecompact.org/wp-content/uploads/2015/11/Stormwater-Guide.pdf (Accessed January 2022.)
[58] Obeysekera, J., Graham, W., Sukop, M., Asefa, T., Wang, D., Ghebremichael, K., and Mwashote, B., 2017. Implications of Climate Change on Florida's Water Resources, Chapter 3. In book: Florida's Climate: Changes, Variations, & Impacts, pp. 83-124
[59] Salmun, H., and Molod, A., 2015. The use of a statistical model of storm surge as a bias correction for dynamical surge models and its applicability along the U.S. East Coast. *J. Mar. Sci. Eng.* 3, 73–86. doi:10.3390/jmse3010073.
[60] *See* https://oceanservice.noaa.gov/facts/stormsurge-stormtide.html. (Accessed April 2022.)

extreme flooding in coastal areas, especially when a storm surge coincides with the normal high tide. In this case, the storm tides can reach up to 20 feet or more.[61] Storm surge is not just a beachfront problem—the risk of storm surge can extend many miles inland from the immediate coastline.

Storm surge is a common threat during hurricanes and is frequently accompanied by strong currents and high waves. Flooding from storm surge depends on many factors, such as the track, intensity, size, and forward speed of the hurricane, as well as the unique characteristics of the coastline where it comes ashore or passes nearby.[62] Florida already has intense storm surges during hurricanes and storms, but the future will be even more dramatic.[63] As a result of rising sea levels, the surges will be amplified, causing higher and more frequent loss-producing flooding.[64] The 2014 Climate-Sensitive Hazards study shows that all coastal counties within the state are potential targets for hurricane storm surge, with some areas having higher risk than others. The study highlights that more than a quarter of total census tracts within Charlotte (25%), Collier (34%), Franklin (25%), Lee (28%), and Monroe (65%) are at high or extreme risk to a Category 1 storm surge. Even places like Miami-Dade County, which has very few high or extreme risk Category 1 census tracts, still have a significant number of people at risk. With increasing sea level rise, continuing population growth and accompanying new developments, older analyses can quickly become outdated. Future risk evaluations, including the required economic evaluations by EDR, should consider using more severe scenarios, greater rates of displacement and higher property losses than historical patterns alone would suggest**.**

To provide a general understanding of the number of people potentially affected by the storm surge associated with a Category 3 hurricane in Florida, EDR overlaid the population data from the 2020 Census results with the maximum storm surge from a Category 3 hurricane for each county. The storm surge data is adopted from the NOAA National Hurricane Center and Central Pacific Hurricane Center. The results are presented in Figure 6.2.7 and Table 6.2.4. In total, close to six million people are living in areas that are threatened by the potential storm surges caused by Category 3 hurricanes. While these areas would not be simultaneously affected by a single hurricane, a great number of people will suffer from the consequences of hurricane-induced storm surges even without further sea level rise.

[See figure and table on following pages]

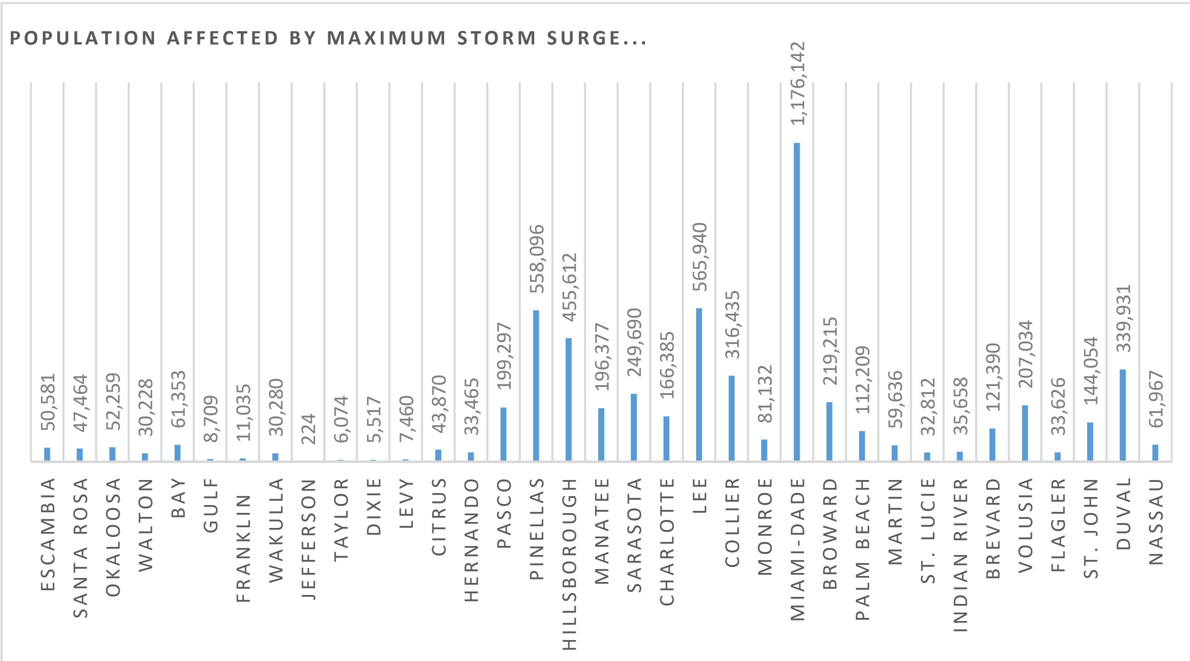
[61] NOAA Surge, 2022. https://www.nhc.noaa.gov/surge/ (Accessed January 2022.)

[62] McInnes, K. L., Walsh, K. J. E., Hubbert, G. D., and Beer, T., 2003. Impact of sea-level rise and storm surges in a coastal community. *Natural Hazards* 30, 187–207.

[63] Parkinson, R., Harlem, P. and Meeder, J. 2015. Managing the Anthropocene marine transgression to the year 2100 and beyond in the State of Florida U.S.A, Climatic Change, Vol. 128. DO  - 10.1007/s10584-014-1301-2

[64] Emrich, C., Morath, D., Bowser, G., and Reeves, R., 2017. Hazards and Vulnerability Research Institute, CLIMATE-SENSITIVE HAZARDS IN FLORIDA Identifying and Prioritizing Threats to Build Resilience against Climate Effects.

**Figure 6.2.7 Potential population affected by Category 3 hurricane-induced storm surge**




[Accompanying table is on following page]

**Table 6.2.4 Potential population affected by Category 3 hurricane-induced storm surges**

| County | Total pop 2020 Census | Pop affected by Cat 3 |
|---|---|---|
| Escambia | 321,905 | 50,581 |
| Santa Rosa | 188,000 | 47,464 |
| Okaloosa | 211,668 | 52,259 |
| Walton | 75,305 | 30,228 |
| Bay | 175,216 | 61,353 |
| Gulf | 14,192 | 8,709 |
| Franklin | 12,451 | 11,035 |
| Wakulla | 33,764 | 30,280 |
| Jefferson | 14,510 | 224 |
| Taylor | 21,796 | 6,074 |
| Dixie | 16,759 | 5,517 |
| Levy | 42,915 | 7,460 |
| Citrus | 153,843 | 43,870 |
| Hernando | 194,515 | 33,465 |
| Pasco | 561,891 | 199,297 |
| Pinellas | 959,107 | 558,096 |
| Hillsborough | 1,459,762 | 455,612 |
| Manatee | 399,710 | 196,377 |
| Sarasota | 434,006 | 249,690 |
| Charlotte | 186,847 | 166,385 |
| Lee | 760,822 | 565,940 |
| Collier | 375,752 | 316,435 |
| Monroe | 82,874 | 81,132 |
| Miami-Dade | 2,701,767 | 1,176,142 |
| Broward | 1,944,375 | 219,215 |
| Palm Beach | 1,492,191 | 112,209 |
| Martin | 158,431 | 59,636 |
| St. Lucie | 329,226 | 32,812 |
| Indian River | 159,788 | 35,658 |
| Brevard | 606,612 | 121,390 |
| Volusia | 553,543 | 207,034 |
| Flagler | 115,378 | 33,626 |
| St. John | 273,425 | 144,054 |
| Duval | 995,567 | 339,931 |
| Nassau | 90,352 | 61,967 |

### *6.2.4 Flash Flooding*

According to the National Weather Service:

> *A flash flood is a flood caused by heavy or excessive rainfall in a short period of time, generally less than six hours. Flash floods are usually characterized by raging torrents after heavy rains that rip through river beds, urban streets, or mountain canyons sweeping everything before them. They can occur within minutes or a few hours of excessive rainfall. They can also occur even if no rain has fallen, for instance after a levee or dam has failed, or after a sudden release of water by a debris or ice jam.*[65]

A flash flood is not just a coastal threat. It is any rapid and extreme flow of high water into a normally dry area or rapid water level rise in a stream or creek above a predetermined flood level.

There have been several attempts to empirically define the risk of flash flooding based on locational characteristics such as slope, land cover, vegetation, soil penetrability, and land use.[66] Among the more recent efforts, the Zogg and Deitsch model was used in the Climate-Sensitive Hazards study to create a Flash Flood Potential Index (FFPI) for each county in Florida.[67] This study concluded that there is a high flash flood risk in the urban areas surrounding Cape Coral, Jacksonville, Miami, Tampa, and Tallahassee. Further, while the Clermont area in central Florida has a high flash flood probability due to the area's extensive lakes and slope changes, very few places in and around Orlando have high flash flood potential. The 2017 Climate-Sensitive Hazards study used the Census tract summary of population by SoVI class by county (SoVI-FL2010). Based on this information, nine counties (Broward, Collier, Duval, Hillsborough, Lee, Leon, Miami-Dade, Palm Beach, and Pinellas) each had more than 50,000 people living in areas with high average FFPI census tracts—including nearly 2,000,000 people in Miami-Dade County alone. Nearly 50% of Monroe County tracts and 30% of Broward County tracts add another 500,000 people to the list of those at high risk from flash flooding should extreme precipitation occur. These numbers would likely be higher if the 2020 Census results were used.

### *6.2.5 Stormwater Runoff*

Like flash flooding, stormwater runoff is caused by precipitation. Although flash flooding is generally a byproduct of heavy or excessive rainfall, any level of precipitation can cause stormwater runoff. According to the EPA:

> *Stormwater runoff is generated from rain and snowmelt that flows over land or impervious surfaces, such as paved streets, parking lots, and building rooftops, and does not soak into the ground. Runoff can pick up and deposit harmful pollutants like trash, chemicals, and dirt/sediment into streams, lakes, and groundwater.*[68]

---

[65] National Weather Service, 2022 https://www.weather.gov/mrx/flood_and_flash (Accessed January 2022.)

[66] Smith, G. 2003. "Flash Flood Potential: Determining the Hydrologic Response of FFMP Basins to Heavy Rain by Analyzing Their Physiographic Characteristics." A white paper available from the NWS Colorado Basin River Forecast Center web site at http://www.cbrfc.noaa.gov/papers/ffp_wpap.pdf (Accessed January 2022.)

[67] Emrich, C., Morath, D., Bowser, G., and Reeves, R., 2017. Hazards and Vulnerability Research Institute, CLIMATE-SENSITIVE HAZARDS IN FLORIDA Identifying and Prioritizing Threats to Build Resilience against Climate Effects.

[68] Urbanization and Stormwater Runoff, 2022. https://www.epa.gov/sourcewaterprotection/urbanization-and-storm-water-runoff. (Accessed April 2022.)

Climate change, including more frequent and intense storms and more extreme flooding events, will increase stormwater runoff.[69] Within the Southeastern United States, an increase in extreme precipitation, combined with increased runoff due to the expansion of impervious surfaces and urbanization, has led to an increased risk of flooding in the urban areas of the region.[70,71] In this region, there have already been several instances of extreme rainfall events—many approaching levels that would be expected to occur only once every 500 years.[72]

According to the EPA, stormwater runoff also washes sediment, nutrients or other pollutants into water sources, causing a reduction in water quality, a threat to drinking water sources, and complications to water treatment processes. For more information on stormwater runoff and the costs of providing stormwater management, please see Chapter 5 of the 2022 Edition of this report.

### *6.2.6 Changes in Annual Precipitation*

Research regarding future changes in annual precipitation contains mixed results and strong caveats, with predictions of rainfall events ranging from fewer than historic patterns to greater frequency due to climate change. Part of the confusion arises from the use of different timescales and metrics, but the majority of it relates to the vastly different results across geographic areas. In general, increases in the incidence of both exceptionally wet and dry summers in comparison to the mid-twentieth century should be expected.[73] Despite that, sources such as NOAA NCEI and CICS-NC show that the number of days with heavy precipitation has increased at most stations, particularly since the 1980s.[74,75] Studies have also shown that the frequency of heavy rain events has been increasing across the Southeastern United States.[76,77,78]

---

[69] EPA Adaptation, 2021: https://www.epa.gov/arc-x/climate-adaptation-and-stormwater-runoff. (Accessed October 2021.)

[70] Shepherd, M., T. Mote, J. Dowd, M. Roden, P. Knox, S.C. McCutcheon, and S.E. Nelson. 2010. "An Overview of Synoptic and Mesoscale Factors Contributing to the Disastrous Atlanta Flood of 2009." Bulletin of the American Meteorological Society no. 92 (7):861-870. doi:10.1175/2010bams3003.1.

[71] Ingram, K., K. Dow, L. Carter, J. Anderson, eds. 2013. Climate of the Southeast United States: Variability, change, impacts, and vulnerability. Washington DC: Island Press and Third National Climate Assessment. Accessed Oct. 13, 2021. Available from https://nca2014.globalchange.gov/report/our-changing-climate/precipitation-change.

[72] For more information see: https://www.climate.gov/news-features/featured-images/prepare-more-downpours-heavy-rain-has-increased-across-most-united-0. (Accessed January 2022.)

[73] Groisman, P.Y., and R.W. Knight. 2008. "Prolonged Dry Episodes over the Conterminous United States: New Tendencies Emerging During the Last 40 Years." Journal of Climate no. 21 (9):1850-1862. doi:10.1175/2007jcli2013.1.

[74] Carter, L., A. Terando, K. Dow, K. Hiers, K.E. Kunkel, A. Lascurain, D. Marcy, M. Osland, and P. Schramm, 2018: Southeast. In Impacts, Risks, and Adaptation in the United States: Fourth National Climate Assessment, Volume II [Reidmiller, D.R., C.W. Avery, D.R. Easterling, K.E. Kunkel, K.L.M. Lewis, T.K. Maycock, and B.C. Stewart (eds.)]. U.S. Global Change Research Program, Washington, DC, USA, pp. 743–808. doi: 10.7930/NCA4.2018.CH19.

[75] Kunkel, K., R. Frankson, J. Runkle, S. Champion, L. Stevens, D. Easterling, and B. Stewart, 2017: State Climate Summaries for the United States. NOAA Technical Report NESDIS 149. National Oceanic and Atmospheric Administration, National Centers for Environmental Information, Asheville, NC, [various] pp.

[76] Easterling, D.R., K.E. Kunkel, J.R. Arnold, T. Knutson, A.N. LeGrande, L.R. Leung, R.S. Vose, D.E. Waliser, and M.F. Wehner, 2017: Precipitation change in the United States. Climate Science Special Report: Fourth National Climate Assessment, Volume I. Wuebbles, D.J., D.W. Fahey, K.A. Hibbard, D.J. Dokken, B.C. Stewart, and T.K. Maycock, Eds. U.S. Global Change Research Program, Washington, DC, USA, 207-230.

[77] Emrich, C.T., and S.L. Cutter. 2011. "Social Vulnerability to Climate-Sensitive Hazards in the Southern United States." Weather, Climate, and Society no. 3 (3):193-208. doi:10.1175/2011wcas1092.1.

[78] Allan, R.P. and B.J. Soden, 2008: Atmospheric warming and the amplification of precipitation extremes. Science, 321 (5895), 1481-1484.

Other studies suggest a decline in average precipitation and an increase in the number of dry days, which could result in an increase in both the severity and duration of drought. For example, one study has predicted that the Tampa Bay region will see a decrease in precipitation in each month of the year.[79] On the other hand, the Florida panhandle has already experienced an increase in recorded precipitation, which is linked to stronger wind circulation (Misra et al., 2011).

At this time, it is unclear whether an increase in annual precipitation will be a significant flood factor for Florida.

## 6.3. Other Considerations for the Assessment

With increasing frequency, the changes in one flooding factor influences and intensifies other factors. For example, sea level rise has been proven to have a non-linear positive impact on storm surge.[80] Combinations of three or more co-occurring flood factors, such as sea level rise, heavy precipitation, extreme high tides, storm surge, flash flooding or stormwater runoff, further heighten the risks.[81] Moreover, coastal areas that are prone to subsidence, such as Florida, will be particularly hard hit by sea level rise and the other flooding factors.[82] Land subsidence is a gradual settling or sudden sinking of the Earth's surface due to removal or displacement of subsurface earth materials, such as soil oxidation, sediments compaction, and sinkhole activity.[83] Florida is not considered to have the worst examples of subsidence (New Orleans, Louisiana and Norfolk, Virginia are more frequently mentioned), but it is still a significant factor in some local areas.

As previously discussed, frequently mentioned examples of combined factors that cause greater and higher flooding include sea level rise with either storm surge or high tide. In these instances, the impact of sea level rise will be felt well before the change in sea level rise (as an independent force) is detectable to residents.[84] This is because sea level rise is relatively gradual, yet continually raises the launch pad for storm surge and high tides. For an example specific to southeastern Florida, the number of major substations exposed to flooding from a Category 3 storm could more than double by 2050 and triple by 2070 under the higher sea level rise scenario (RCP8.5).[85]

Also, the probabilities of hurricane occurrence increase with climate change. Table 6.3.1 shows the changing return periods of Category 1 through 5 hurricanes striking the Miami-Dade region in the 2000 through 2050 period. The probability is shown relative to 1 in this display (e.g. 1 in 6, 1 in 31.5). The computations underlying this analysis were made by Dr. Robert Easton, Professor of Applied Mathematics emeritus, University of Colorado at Boulder. Like several other studies, this

---

[79] Obeysekera, J., Graham, W., Sukop, M., Asefa, T., Wang, D., Ghebremichael, K., and Mwashote, B., 2017. Implications of Climate Change on Florida's Water Resources, Chapter 3. In: Florida's Climate: Changes, Variations, & Impacts, pp. 83-124

[80] Zhang, K., Li, Y., Liu, H. *et al.*, 2013. Comparison of three methods for estimating the sea level rise effect on storm surge flooding. *Climatic Change* 118, 487–500.

[81] Englander, J. 2020, Moving to Higher Ground, Rising Sea Level and the Path Forward, The Science Bookshelf, Boca Raton, Florida.

[82] Ericson, J.P., C.J. Vörösmarty, S.L. Dingman, L.G. Ward, and M. Meybeck, 2006. "Effective Sea-Level Rise and Deltas: Causes of Change and Human Dimension.

[83] *See* FIU Geodesy Lab for discussion. (Accessed April 2022.)

[84] Befus, K., Barnard, P., Hoover, D., Finzi Hart, J. and Voss, C., 2020. Increasing threat of coastal groundwater hazards from sea-level rise in California. Nature Climate Change, 10(10), pp.946-952.

[85] Paustian, K., J. Lehmann, S. Ogle, D. Reay, G.P. Robertson, and P. Smith, 2016. Climate-smart soils. Nature, 532, 49-57.

study shows that although the probabilities of moderate hurricanes decline, the probabilities of major hurricane strikes increase by as much as 50 percent over the period.[86]

**Table 6.3.1 Changing return periods of Category 1 through 5 hurricanes in Miami-Dade[87]**

| Year | Category 1 | Category 2 | Category 3 | Category 4 | Category 5 |
|---|---|---|---|---|---|
| **2000** | 6.0 | 10.0 | 15.0 | 25.0 | 52.0 |
| **2010** | 6.2 | 10.4 | 15.6 | 22.6 | 47.0 |
| **2020** | 6.5 | 10.8 | 16.2 | 20.4 | 42.5 |
| **2030** | 6.7 | 11.2 | 16.8 | 18.5 | 38.5 |
| **2040** | 7.0 | 11.6 | 17.5 | 16.7 | 34.8 |
| **2050** | 7.3 | 12.1 | 18.8 | 15.1 | 31.5 |

As already evident, every coastal flood is wider, deeper and more damaging because of the roughly 8 inches of global sea level rise that has taken place since 1900.[88] This rise alone has increased the annual chance of extreme coastal floods.[89] Considering the expected future increase in the frequency of storms and hurricanes, and with a sea level rise projection of 1 foot by the year 2050 in Florida, Climate Central estimates over a 1 in 6 chance that sea level rise, in combination with hurricane storm surge and high tide, could overtop areas lying 7 feet above sea level.[90] This implies that approximately 25% of the state's total population and housing stock is exposed. Florida's hurricane force wind hazard risk tells a slightly different story, with the highest areas of risk along the southeastern coast and in the panhandle. Nearly 15% of the state is at high risk to hurricane force winds, accounting for almost 3 million people.[91]

While much attention is given to Florida's coastal communities, inland flooding is also a pervasive threat. An analysis based on historical tropical storm and hurricane force winds shows a medium to high risk for tropical storm force winds for the majority of the state, with the highest risk to the east. Counties most affected include Miami-Dade, Palm Beach, and Orange Counties, each with more than 1 million residents in the high risk category. While no counties in the state have tracts included in the extreme risk category, only a small portion of the state (5%) is at low risk to tropical storm force winds.

The following sections describe some of the other risks associated with flooding and sea level rise that have either already been observed or should be expected to occur. EDR's assessment will need to take these into account.

---

[86] Repetto, R., NA. Demos, ECONOMIC AND ENVIRONMENTAL IMPACTS OF CLIMATE CHANGE IN FLORIDA
[87] Source: The computation underlying this analysis were carried out by Dr. Robert Easton, Professor of Applied Mathematics emeritus at University of Colorado at Boulder, using US. Census.
**[88]** ICPP (Intergovernmental Panel on Climate Change), 2013. Climate Change 2013: the Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.
[89] Strauss, B., C. Tebaldi, S. Kulp, S. Cutter, C. Emrich, D. Rizza, and D. Yawitz, 2014. Florida and the Surging Sea: A Vulnerability Assessment with Projections for Sea Level Rise and Coastal Flood Risk. Climate Central Research Report. pp 1-58.
[90] Emrich, C., Morath, D., Bowser, G., and Reeves, R., 2017. Hazards and Vulnerability Research Institute, CLIMATE-SENSITIVE HAZARDS IN FLORIDA Identifying and Prioritizing Threats to Build Resilience against Climate Effects.
[91] Emrich, C., Morath, D., Bowser, G., and Reeves, R., 2017. Hazards and Vulnerability Research Institute, CLIMATE-SENSITIVE HAZARDS IN FLORIDA Identifying and Prioritizing Threats to Build Resilience against Climate Effects.

### *6.3.1 Saltwater Intrusion*

A number of factors—not just those limited to flooding and sea level rise—can induce or exacerbate saltwater intrusion.[92] The issue first came to prominence in Florida nearly 100 years ago with the completion of several major drainage projects. The associated dredging of natural riverbeds lowered the state's water tables, setting off saltwater intrusion that affected more than 1000 Miami wells.[93]

The term generally refers to the displacement of fresh or brackish water by saltwater. According to the USGS:

> *One part of the U.S. that has dealt with saltwater intrusion is Florida. In Florida, saltwater has intruded into groundwater supplies through different compounding ways. For example, saltwater has encroached into aquifers because fresh groundwater levels have decreased relative to sea level, allowing higher gradient water to flow toward the freshwater. Also, leaking saltwater inland canals, leakage between aquifers, or even upwelling of saltwater from depth also have impacted freshwater aquifers.*[94]

Perhaps most importantly for this report, sea level rise increases the risk of saltwater intrusion into drinking water supplies where there are shallow coastal aquifers and associated public drinking water supplies. In 2008, a Florida Atlantic University report indicated, "Saltwater intrusion in potable water sources is one of the most serious early threats caused by sea level rise."[95] The Pensacola and Miami /Palm Beach corridors are especially vulnerable to saltwater intrusion into public water supplies and reduced aquifer recharge.[96] Given the significance of this issue, studies on saltwater intrusion in the water resources (aquifers and wells) have already been performed by Florida's five water management districts. These reports are available directly from the districts, but caution should be used in comparing them since the methodology and reporting may differ from one district to the other.

### *6.3.2 Septic Tanks*

According to the Department of Environmental Regulation, septic tanks are the primary means of "wastewater disposal by approximately 30% of Florida's population. With an estimated 2.6 million systems in operation, Florida represents 12% of the United States' septic systems."[97] To be effective, drainfields for septic tanks must be above the water table and in unsaturated soil. As water tables rise, drainfields begin to collapse and ultimately fail to operate as the bacteria and pathogen filters they were designed to be. In heavy rain events, flooded drainfields can even lead to overland wastewater flows. Both of these situations pose public health risks and potentially contaminate the broader community's water resources.

---

[92] For example, after a major drought in South Florida lasting from 1970 to 1971, saltwater intrusion closed a number of drinking water wells. Another factor is overpumping due to population growth in coastal communities.

[93] Swihart, Tom. 2012. Florida's Water: A Fragile Resource in a Vulnerable State. Hoboken: Taylor and Francis.

[94] *See* Saltwater Intrusion | U.S. Geological Survey (usgs.gov). (Accessed April 2022.)

[95] *See* florida's resilient coasts (fau.edu). (Accessed April 2022.)

[96] Florida Oceans and Coastal Council. Revised June 2009. The effects of climate change on Florida's ocean and coastal resources. A special report to the Florida Energy and Climate Commission and the people of Florida. Tallahassee, FL.

[97] Floridadep.gov. 2022. *Onsite Sewage Program | Florida Department of Environmental Protection*. [online] Available at: https://floridadep.gov/water/onsite-sewage. (Accessed Jan. 2022.)

One of the more comprehensive regional studies of SLR impact on sewer and wastewater systems was developed by Miami-Dade County in 2018. The report addressed the impact of water table levels and soil depth on the county's septic tanks.[98] Among other things, the study identified areas where groundwater levels were already so close to the surface that the existing septic systems were likely negatively affected and no longer providing adequate treatment, especially during periods of seasonally high water tables.[99] Notably, the vulnerable areas were not confined to the coast—the greater driver was tank placement in low lying locations. Further, the study identified areas that are projected to be impacted by 2030 and 2040. The study found that the County can expect an increase in the number of residential systems that may be periodically compromised during storms or wet years from 56% in 2018 (58,349 parcels) to more than 64% by 2040 (67,234 parcels).[100] Studies from Broward County have also shown that sea level rise will challenge existing drainage and wastewater treatment infrastructure that was not designed to be located in saturated soils.

### *6.3.3 Water Supply and Water Quality*

The strength of Florida's brand—and its associated impact on the economy and population growth—is intrinsically linked to having an ample water supply, highly rated water quality across all metrics, and full use of ocean and coastal resources. Climate change is already threatening the state's water-related resources and industries through three channels: 1) changes in precipitation patterns, 2) temperature increases that alter evaporation rates while increasing irrigation needs, and 3) sea level rise.[101] However, climate change effects are not the only sources of water supply and quality issues in Florida. The Everglades ecosystem, Lake Okeechobee and blue-green algae all provide proof of the continuing challenges. The other chapters in this assessment contain many discussions relevant to the supply and quality issues in general (Chapters 2, 3, and 4) and the Everglades case specifically (Chapter 7). For now, this portion of the assessment (Chapter 6) will focus on the issues demonstrating a direct linkage to sea level rise and other flooding effects—that is, the incremental differences from historical patterns and the altered future expectations induced by those events.

As discussed earlier, the harmful effects of flooding, storm surges, saltwater intrusion, and stormwater runoff are all exacerbated by sea level rise. In extreme events, these effects can affect both quality and supply. While developed for a different purpose, the table below is illustrative.

---

[98] *See* https://www.miamidade.gov/green/library/vulnerability-septic-systems-sea-level-rise.pdf?msclkid=7e0a2dcdba6d11ec9b9c3327a26816d2. (Accessed April 2022.) A separate report addressed sanitary sewer and stormwater systems.

[99] Prinos, S.T., M.A. Wacker, K.J. Cunningham, and D.V. Fetterman. 2014. Origins and delineation of saltwater intrusion in the Biscayne aquifer and changes in the distribution of saltwater in Miami-Dade County, Florida. United States Geological Survey Scientific Investigations Report 2014-5025. 116 pp.

[100] *See* https://www.miamidade.gov/green/library/vulnerability-septic-systems-sea-level-rise.pdf (Accessed January 2022.)

[101] Bloetscher, F., Hoermann, S. and Berry, L., 2017. Adaptation of Florida's urban infrastructure to climate change. *Florida's Climate: Changes, Variations, & Impacts*.

| Sea-Level Rise Impacts | Drinking Water Effects | Potential Health Impacts |
|---|---|---|
| **Salt water intrusion** | Disruption to water supply availability, increased fees for customers, and higher groundwater levels and reduced aquifer storage. | Mental health and stress related disorders |
| **Flooding** | Nutrient mobilization from agricultural runoff, nitrogen and phosphorus introduction to water sources, algal blooms, overburden to water treatment facilities. | Possible exposure to pathogenic viruses and microorganisms. Heart effects from increased toxicants in water |
| **Septic tank leakage** | Algal blooms, nutrient mobilization, nitrate and fecal coliform contamination to groundwater. | Possible exposure to cyanotoxins, like microcystin, which is carcinogenic to humans. |
| **Soil Saturation** | Infrastructure pressure which can result in damaged pipes. | Possible exposure to waterborne pathogens (bacteria, viruses, and Giardia parasites such as Cryptosporidium) introduced via broken pipes |

Source: Sea-Level Rise in South Florida: Impacts to Drinking Water and Human Health, Figure 3.[102]

At a minimum, degraded water quality will make it more expensive to restore the water to drinking standards.

In Florida, groundwater is the primary source of water supply and the magnitude of groundwater withdrawals is intense relative to many other states. Over time, the changing climate conditions will affect groundwater storage in the aquifers as well, but little is currently understood about these effects. Overall, Florida will see increased heavy rainfall events and soil moisture trends in the summer and fall which should—all other things being equal—boost or protect groundwater storage. However, accelerating sea level rise and instances of saltwater intrusion introduce new vulnerabilities. The net effect of all of these forces is still to be determined, but are unlikely to be uniform across the state.

## 6.4. State and Local Strategic Initiatives

A lot of the current research has looked at geographies other than Florida; however, several studies have been conducted across and within the state to understand the impact of climate change and flooding on Florida's unique resources. There are also in-state initiatives that contain specific recommendations or management plans for local areas. Some of these interventions and adaptive strategies have already been deployed. At times, these efforts are characterized as resiliency—yet

[102] Figure drawn from http://www.ces.fau.edu/arctic-florida/pdfs/meagan-weisner.pdf?msclkid=f2482d22bb4111ec8b4a1135f966e13e. (Accessed April 2022.)

they often can be found under the rubric of hazard mitigation, disaster preparedness, water quality or BMAP projects, water supply initiatives, or stormwater management.

A number of these initiatives have concentrated on the southern coastal area of Florida since this region is already seeing climate change effects. As discussed in previous sections, these impacts include saltwater contamination of freshwater aquifers; flooding at extreme high tides; and diminishing effectiveness of the South Florida canal system for rainwater runoff.

Following is an overview of a few of these initiatives. Next year's assessment will include a more comprehensive approach to reviewing the local areas in Florida and cataloguing all of the available information, especially as it relates to the cost and type of specific projects.

### *6.4.1 Southeast Florida Regional Climate Change Compact*

Culminating in the formation of a compact in 2010, four counties in southeast Florida (Broward, Miami-Dade, Monroe, and Palm Beach) have worked to develop a coordinated regional effort to address climate change impacts, including sea level rise and high tide flooding.[103] Among other things, the Southeast Florida Regional Climate Change Compact has led to specific guidance on a variety of issues designed to assist county and municipal policymakers, administrators and program staff with implementation of the recommendations contained within the Southeast Florida Regional Climate Change Compact's Regional Climate Action Plan.[104]

The Compact has also adopted a unified sea level rise projection that reflects the anticipated range of regional sea level rise from 2000 to 2120, with an accompanying guidance report.[105] The regionally-based 2019 projection is based on the estimates developed for the IPCC Fifth Assessment Report[106], as well as projections from the National Oceanic and Atmospheric Administration.[107] It anticipates regional sea level rise to be in the range of 10 to 17 inches by 2040 and 21 to 54 inches by 2070 (above the 2000 mean sea level in Key West, Florida). In the longer term, sea level rise is projected to be 40 to 136 inches by 2120.

As identified by the Compact members, the already apparent regional consequences of sea level rise include physical impacts such as coastal inundation and erosion, increased frequency of flooding in vulnerable coastal and inland areas due to impairment of the region's largely gravity-driven stormwater infrastructure system, reduced soil infiltration capacity, and saltwater intrusion of drinking-water supply. In addition, instances of increased surge from tropical storms or hurricanes, increased pollution and contamination, and degradation of the natural resources critical

---

[103] *See* https://southeastfloridaclimatecompact.org/about-us/what-is-the-compact/. (Accessed April 2022.)
[104] RCAP, 2017: Regional Climate Action Plan 2.0 [web tool]. South Florida Regional Climate Change Compact. Accessible at: http://www.southeastfloridaclimatecompact.org/regional-climate-action-plan/. (Accessed April 2022.)
[105] The 2019 projection is the third in the series. *See* https://southeastfloridaclimatecompact.org/unified-sea-level-rise-projections/. (Accessed April 2022.)
[106] IPCC (Intergovernmental Panel on Climate Change). 2014. Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.
[107] Sweet, W., Kopp, R., Weaver, C., Obeysekera, J., Horton, R., Thieler, E. and Zervas, C., 2017. Global and regional Sea Level Rise Scenarios for the United States, Silver Spring, Maryland. https://tidesandcurrents.noaa.gov/publications/techrpt83_Global_and_Regional_SLR_Scenarios_for_the_US_final.pdf. (Accessed January 2022.)

to the region's economy, have all been seen.[108] Expected consequences include socio-economic impacts such as displacement, a decline in property values, a constrained tax base, rising insurance costs, loss of some services, and infrastructure impairment related to roads and septic systems.[109]

Specific recommendations have covered a wide range of topics, including agriculture, energy and fuel, natural systems, public health, public outreach and engagement, public policy advocacy, regional economic resilience, risk reduction and emergency management, social equity, sustainable communities and transportation, and water. The Southeast Florida Regional Climate Change Report indicates that a number of the Compact's municipalities have already started implementing the recommendations.

### *6.4.2 Pensacola Sea Level Rise Vulnerability Assessment*

To help it prepare for sea level rise, the City of Pensacola applied for and received a grant from the Department of Environmental Protection in 2021 to defray the cost of conducting a vulnerability assessment and developing a resilience plan. The City ultimately selected the NOAA 2017 intermediate high curve sea level rise projection, with adjustments to reflect local tide gauge records. The vulnerability maps were produced for sea level rises of 16 inches in 2040, 38 inches in 2070, and 70 inches in 2100. The vulnerability assessment addressed infrastructure, land use, emergency management, potable water, sanitation and sewer, stormwater, and transportation for five priority areas (see the map included in the table below). A summary of the assessment is presented Table 6.4.1.

Following the Vulnerability Assessment, a number of specific recommendations were provided. They include:

- Perform a detailed survey of the City's coastline in order to address all locations identified as Tidally Flooded Areas,
- Conduct a vulnerability assessment of the City's seawalls to develop a comprehensive report describing their existing conditions and identifying potential failures,
- Conduct a survey of coastal stormwater inlet elevations and associated roadway crown elevations,
- Repair, restore, and strengthen seawalls and other shoreline protection,
- Install back-flow prevention on low-lying stormwater pipes, and
- Identify potential land sites for acquisition for future stormwater pumping stations.

---

[108] Southeast Florida Regional Climate Change Compact Sea Level Rise Work Group (Compact). (Accessed February 2020.) A document prepared for the Southeast Florida Regional Climate Change Compact Climate Leadership Committee. 36p.
[109] *Ibid.*

**Table 6.4.1 Summary of Pensacola vulnerability to sea level rise by milestone year**

| | Priority Area 1 | Priority Area 2 | Priority Area 3 | Priority Area 4 | Priority Area 5 |
|---|---|---|---|---|---|
| Critical Infrastructure | No impact | No impact | No impact | 2100 | 2040 |
| Transportation Roads &/or Railroads | 2100 | 2040 | 2070 | R. 2040 RR. 2070 | R. 2070 |
| Vacant residential Land | 2040 | 2040 | N/A | 2070 | 2040 |
| Commercial Land | 2070 | 2100 | 2040 | 2070 | 2070 |
| Government/Public Land/Institutional | 2100 | 2040 | N/A | 2040 | 2070 |
| Distribution &/or Fittings of Potable Water | 2040 | 2040 | 2040 | 2040 | 2070 |
| Sanitary & Sewer System | 2040 | 2040 | 2040 | 2040 | 2040 |
| Storm water | 2040 | 2040 | 2040 | 2040 | 2040 |


### *6.4.3 Local Planning Efforts and Projects*

Other cities and regions in Florida have also recognized the necessity of creating strategic plans and/or designing projects to cope with the discrete consequences of climate change or mitigate stormwater issues and flooding. A few examples are presented below to give a sense of the diversity that can be found in these local initiatives.

- *City of Miami's Comprehensive Citywide Stormwater Master Plan (SWMP)...*According to the 2021 document, "The SWMP provides the structure to establish a database, stormwater model, and capital improvement program (CIP), as well as a policy framework that would protect public safety, infrastructure, and the environment." The plan uses sea level rise scenarios of 1.5 feet and 2.5 feet to determine the impact of flooding on the existing and proposed stormwater management systems.[110]

- *Manatee County Local Mitigation Strategy Plan (2019 Update)...*According to the plan, "The LMS focuses not only on risk of flooding and hurricanes, but with ALL hazards to which a community might be vulnerable, including natural, technological, and societal hazards." For natural and manmade disasters, such events include: "hurricanes and coastal storms; sea level rise, harmful algal bloom, severe storm/weather events; severe storms

[110] City of Miami, 2021. Executive Summary, The City of Miami's Comprehensive Stormwater Master Plan (B-30632A). Accessible at: https://www.miamigov.com/files/assets/public/document-resources/pdf-docs/capital-improvements/miami-stormwater-mp_es.pdf. (Accessed April 2022.)

(lightning, hail storms, etc.); severe winds; tornadoes; floods/severe rain events; coastal and riverine erosion; winter storms/freezes; droughts/heat wave; sinkholes/landslides; wild fires; earthquakes; tsunamis; volcanoes...” The Manatee County Local Mitigation Strategy Plan (2019 Update) offers a framework to develop and implement hazard mitigation measures including: identification of the community’s guiding principles; analysis of mitigation initiatives to determine their effectiveness; prioritization of mitigation initiatives; and identification of funding for mitigation initiatives.[111]

- *St. Johns River Water Management District Resiliency Action Projects*...According to the St. Johns River Water Management District, “Everything the District does has a resilience element. Whether we’re protecting water supplies through our permitting program or restoring natural systems to improve storm surge and flood protection, resilience is part of our philosophy.” The district has a dedicated webpage to address sea-level rise and resiliency partnerships with local governments[112], and recently was included in the proposed 2022-23 Statewide Flooding and Sea Level Rise Resilience Plan, enabling funding for 6 district-sponsored resiliency projects.[113]

### *6.4.4 Florida Department of Transportation*

While the Florida Department of Transportation has yet to produce a stand-alone document quantifying the financial implications of sea level rise on the state’s overall transportation network, several related initiatives have been underway over the last decade. In 2012, researchers from the Florida Atlantic University worked with the Department to develop “a methodology for assessing the potential impacts of sea level rise (SLR) on Florida’s state transportation infrastructure to assist the state with transportation planning.”[114] This study was followed in 2018 by a risk assessment of the Strategic Intermodal System (SIS) highway network. The purpose was to identify SIS facilities potentially vulnerable to coastal and inland flooding and tropical storm/hurricane effects. The study found that “the regional transportation network is significantly vulnerable to storm surge and sea level rise,” and that:

> *Just over a fifth of the total centerline miles of the SIS roadway network being studied (983 miles) is at risk of inundation due to storm surge corresponding to a Category 5 hurricane flooding and has the potential to impact 23 percent of the SIS network-wide daily vehicle miles traveled (about 49 million daily VMT). Potential storm surge flooding corresponding to a Category 1 storm is estimated to impact 5 percent of SIS network-wide daily VMT, while 160 centerline miles of SIS roadways are estimated to be at risk of flooding...*[115]

In April 2020, the Department’s Secretary released a policy statement indicating that its resiliency efforts “will be implemented through the Department’s long-range and modal plans; work

[111] Manatee County, 2019. Manatee County Local Mitigation Strategy Plan. Accessible at: https://www.mymanatee.org/departments/public_safety/emergency_management/hazard_mitigation. (Accessed January 2022.)
[112] *See* https://www.sjrwmd.com/localgovernments/sea-level-rise/. (Accessed April 2022.)
[113] *See* https://floridadep.gov/rcp/resilient-florida-program/documents/2022-23-statewide-flooding-and-sea-level-rise-resilience. (Accessed April 2022.)
[114] Bloetscher, F., Romah, T., Berry, L., Hammer, N., & Cahill, M. 2012. Identification of Physical Transportation Infrastructure Vulnerable to Sea Level Rise. Journal of Sustainable Development 5(12).
[115] *See* http://floridatransportationplan.com/pdf/FDOT-SIS_ResiliencePhaseI-TechMemo_wApp_8-22-18.pdf.

program; asset management plans; research efforts; and internal manuals, tools, guidelines, procedures, and related documents, guiding planning, programming, project development, design, construction, operations, and maintenance."[116] One such tool is made available on the Department's website. Developed by the University of Florida's GeoPlan Center with funding provided by the state, it is offered "to help identify transportation infrastructure exposed to current and future flood risks." The Sea Level Scenario Sketch Planning Tool "analyzes and visualizes current flood risks (100-year and 500-year floodplains and hurricane storm surge zones) as well as future flood risks using sea level rise (SLR) scenarios from the U.S. Army Corps of Engineers (USACE, 2013) and the National Oceanic and Atmospheric Administration (NOAA, 2017)/ National Climate Assessment."[117]

In other instances, specific local conditions have driven the transportation analysis. Storm surges overwashing US 98 on Okaloosa Island undermined the highway foundation during Hurricane Ivan in 2004 and then again during the tropical storms in 2005. To prevent damage from overwash in the future, the Florida Department of Transportation installed buried erosion protection along the edge of the road. The Federal Highway Administration's (FHWA) analysis found that this proactive countermeasure was economically justified when it was done in 2006 and, further, that the benefit–cost ratio will quadruple over the next 50 years as sea levels continue to rise.[118]

## 6.5. Brief Overview of the Risk Assessment

Even after the most credible climate change scenarios are used to inform longer-term assumptions, additional modeling work still needs to be performed to address the likely effects within a specific time dimension and geolocation. In order to analyze the expenditures associated with minimizing adverse economic impacts and evaluating the costs of conducting resilience efforts, EDR must first assess Florida's unique vulnerability to sea level rise, high tide events, storm surge, flash flooding, stormwater runoff, and increased annual precipitation over a 50-year planning horizon. There are several approaches available to EDR for this assessment.

The three key components that are most widely used to define vulnerability (or risk) are exposure, sensitivity and adaptive capacity. The analysis is often conducted using a system of discrete models, rather than one. Not infrequently, the projected value for each individual component is

---

[116] *See* https://fdotwww.blob.core.windows.net/sitefinity/docs/default-source/planning/policy/resilience/resiliency_policy_000-525-053.pdf?sfvrsn=4dae64fd_2. (Accessed April 2022.)
[117] *See* https://sls.geoplan.ufl.edu/. (Accessed April 2022.)
[118] In 2016, the Florida Department of Transportation conducted a study focusing on the vulnerability of a barrier island roadway to overwashing from sea level rise and storm surge. FDOT had modified US 98 after a storm event in 2006, including the installation of buried gabion mats (stainless steel cages filled with rocks) along the shoulders and in the median of the roadway, and the installation of a sheet pile wall along the northern edge of the roadway. The purpose of these structures is to prevent undermining of the roadway foundation during overwashing. A research team conducted an economic analysis using the Equivalent Uniform Annual Costs (EUAC) approach to determine whether the 2006 FDOT strategy was cost effective. This study considered the intermediate (1.6 feet) and high (4.9 feet) global sea level rise scenarios for 2100 developed by the National Research Council. The total expected EUAC values indicated that the original FDOT decision to construct the countermeasure was economically justified even without consideration of the social costs (e.g., lost business) and without consideration of sea level rise. Between 2006 and 2056 the total expected EUAC of the standard roadway is expected to increase from 1.7 to 7.2 times that of the adaptation, meaning the strategy becomes more cost effective as sea levels rise (TEACR, 2016).

subsequently grouped into a representative index.[119,120,121] With differing methodologies, the underlying models all attempt to isolate the key variables or significant driving processes influencing each vulnerability component.[122] Models that incorporate a mapping feature are frequently used in order to identify the specific boundaries of the area that is anticipated to be affected, as well as provide accurate representations of the built environment within it.

In this regard, models that are integrated with geographic information system (GIS) platforms—or other similar geospatial tools—use dynamic computer modeling techniques to analyze and map vulnerability and risks associated with sea level rise, extreme high tides, major rainfall events and storm surge. This approach can take one of two different forms: sector models and integrated assessment models. Sector models focus on an analysis of coastal vulnerability related to a particular coastal process (e.g., coastal erosion or saltwater intrusion in freshwater systems) and, as such, do not directly deal with the evaluation of vulnerability arising from multiple sources of flooding that affect different systems simultaneously. Integrated assessment models cure this deficiency by evaluating the vulnerability of coastal systems to compound flood events, including a cross-sector analysis of the interaction among different impacts and/or changes in other factors affecting the coastal system.[123]

The greatest challenge with using models that are based on mapping features is resolution. Many credible models are unable to produce or use geographic or topographic elements at a lower scale, limiting them to broad regional calculations and displays. This causes a loss of the precision necessary for EDR's assessment and local decision-making. While much slower to run, a high spatial resolution model is essential to the needed simulations and level of required detail.

The development of precision flood, storm surge and hazard models[124] is extremely complex (especially when an attempt is made to integrate them) and becoming more so. For this part of its research, EDR will make a selection among the best currently available regional models[125] that offer both a high level of detail and maximum capacity to incorporate additional and/or up-to-date local data. This selection is not easy. As one prominent researcher in this field noted, "Users need to learn as much as they can about how a model works before using any outputs from it."[126]

The next edition of this report will provide an in-depth analysis of the major models used to support this evaluation within EDR's chosen framework.

---

[119] Pendleton, E. A., S. J. Williams, and E. R. Thieler. 2004. Coastal Vulnerability and Assessment of Fire Island National Seashore to Sea-Level Rise. U.S. Geological Survey Open-File Report 03-439. Available at: http://pubs.usgs.gov/of/2003/of03-439/ (Accessed January 2022.)

[120] Yin, J., Z. Yin, J. Wang, and S. Xu. 2012. National assessment of coastal vulnerability to sea-level rise for the Chinese coast. Journal of Coastal Conservation 16(1):123–133.

[121] Boatenga, I., George Wiafeb, and Philip-Neri Jayson-Quashigah,. 2017. Mapping Vulnerability and Risk of Ghana's Coastline to Sea Level Rise, MARINE GEODESY 2017, VOL. 40, NO. 1, 23–39.

[122] Gornitz, V. M., T. W. White, and R. M. Cushman. 1991. Vulnerability of the U.S. to future sea-level rise. Proceedings of Seventh Symposium on Coastal and Ocean Management, Long Beach, CA, 2354–2368.

[123] McLaughlin, S., and J. A. G. Cooper. 2010. A multi-scale coastal vulnerability index: A tool for coastal managers? Environmental Hazards 9(3):233–248.

[124] For example, models that use catastrophe modeling technology to evaluate hurricane or other natural disaster risk.

[125] For the purpose of this discussion, models based on downscaling techniques are included in this broader reference.

[126] Dlugolecki, A. et al. (2009), "Coping with Climate Change: Risks and opportunities for Insurers." Chartered Insurance Institute, London/CII_3112.

## 6.6. EDR's Desired Modeling Framework

In addition to thousands of scientific papers addressing flooding factors now and in the future, there are a large number of local, national and international collaborative efforts that are either in the process of producing or have already developed models to map at-risk areas and their vulnerability to a variety of flooding factors. One of the most promising models is directly relevant to EDR's statewide assessment needs: CoSMoS (Coastal Storm Modeling System). The following discussion provides an overview of the model and its associated user-friendly web tools, as well as its potential use for both shorter-term hazard mitigation and longer-term adaptation planning.

### *6.6.1 CoSMoS*

Today's Coastal Storm Modeling System (CoSMoS) is the latest iteration of multiple model generations developed by USGS. It is a complex dynamic modeling approach that makes detailed predictions of coastal flooding due to future sea level rise, storms and coastal change. Flood hazard modeling is done explicitly and deterministically with a suite of physics-based numerical models accounting for changes in water levels[127], waves, currents and the interactions between them, which are then scaled down to local flood projections for multiple identified storm events that are appropriate for use in community-level planning and decision-making. CoSMoS further uses the latest scientific data and global models[128] to project sea level rise and storms under the changing climatic conditions expected during the 21st century.[129] According to Barnard et al.:

> *The Coastal Storm Modeling System (CoSMoS) is a multidimensional, deterministic modeling system that can scale down from global atmospheric forcing to local hazards assessments. In examples from the California coast, this modeling approach has been shown to adequately predict waves, water levels, coastal flooding, and coastal change over vast geographic regions with resolution and accuracy fine enough to aid local coastal management planning in real time or for future climate change impacts.*

The model offers more than 40 discrete scenarios that are generated through the use of multiple storm intensities (annual, 20-year, and 100-year return) for a set of 10 sea-level rise simulations ranging from 0.00 to 6.6 feet, as well as an extreme 16-foot simulation and a no-storm condition. This provides a sense of the added risk when multiple conditions are co-occurring, while allowing users to choose the scenario that best meets their local management requirements and planning horizons, including the ability to specify degrees of risk tolerance. Management options[130] are also provided for beach nourishment and the presence of hard structures to limit erosion (both cliff recession and sandy shoreline). According to O'Neill et al.:

---

[127] Water level variations include astronomic tides, winds, sea-level pressure, and steric effects (changes in sea surface height due to expansion or salt content).

[128] Earlier versions of CoSMoS included swell wave projections as boundary forcing, derived from four GCMs. With the growing complexity and inclusion of local wave generation, storm surge, and efforts to capture the range of storm impact responses, it became necessary to identify just one GCM. An appropriate GCM was selected based on comparisons to wave buoy observations (using GCM winds from 1976 through 2010). The Earth-system model from National Ocean and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL-ESM2M) was shown to best represent observed wave conditions in the extremes (winter Hs rmsd of 7–17 cm, extreme Hs bias < 5 cm, Dp < 7° ± 0.5°). Representative storm events came from RCP4.5.

[129] Barnard, P.L.; van Ormondt, M.; Erikson, L.H.; Eshleman, J.; Hapke, C.; Ruggiero, P.; Adams, P.N.; Foxgrover, A.C. 2014. Development of the coastal storm modeling system (CoSMoS) for predicting the impact of storms on high-energy, active-margin coasts. Nat. Hazards, 74, 1095–1125.

[130] Referred to in the literature as management scenarios.

*To clearly identify coastal vulnerabilities and develop appropriate adaptation strategies due to projected increased levels of coastal flooding and erosion, coastal managers need local scale hazards projections using the best available climate and coastal science.*[131]

The more recent releases of CoSMoS and its specialized modules have addressed fluvial effects from rivers and other watershed processes, creating scenarios representative of coastal and watershed conditions for coastal zone management.

### *6.6.2 CoSMoS Tools*

Two web-based tools have been created to transform the raw output[132] from CoSMoS into user-friendly material suitable for adaptation planning. First, the CoSMoS model data is converted to exposure hazard maps using a publicly accessible web application referred to as "Our Coast, Our Future" (OCOF). The OCOF is currently the preferred platform for data visualization, synthesis, and access to all output products from the CoSMoS model.[133] It focuses on physical exposure.

Second, to more clearly communicate the local socio-economic exposure identified through the CoSMoS modelling results to non-technical and non-specific science-educated audiences, the USGS developed the Hazard Exposure Reporting and Analytics (HERA) web tool.[134] According to Erikson et al.:

*The Hazard Exposure Reporting and Analytics web tool translates the flooding hazards into community-based exposure statistics and quantifies populations, property, and critical infrastructure at risk in terms of exposure statistics and monetary values on a community level.*[135]

HERA uses data from different sources (mostly federal) to identify the community boundaries, residents, demographic characteristics, business type, land type, infrastructure and critical facilities.

Assuming they could be adapted to Florida conditions, the combination of CoSMoS, OCOF, and HERA would provide a solid foundation for assessing the state's likely impact from flooding and sea level rise, using some of the best technology and science available. To improve its utility for EDR's assessment, both the model and its associated tools would need modifications to allow the integration of additional Florida-specific demographic and economic data, as well as the output from the various forecasting models run by EDR for other purposes.

---

[131] O'Neill, Andrea C., Li H. Erikson, Patrick L. Barnard, Patrick W. Limber, Sean Vitousek, Jonathan A. Warrick, Amy C. Foxgrover, and Jessica Lovering. 2018. "Projected 21st Century Coastal Flooding in the Southern California Bight. Part 1: Development of the Third Generation CoSMoS Model" Journal of Marine Science and Engineering 6, no. 2: 59. https://doi.org/10.3390/jmse6020059.

[132] All model results are available as GIS shapefiles, with accompanying metadata.

[133] HERA, 2021: https://www.usgs.gov/apps/hera/docs/about/index.html?topic=data-methods-overview. (Accessed January 2022.)

[134] Erikson L, Barnard P, O'Neill A, Wood N, Jones J, Finzi Hart J, Vitousek S, Limber P, Hayden M, Fitzgibbon M, Lovering J, Foxgrover A. Projected 21st Century Coastal Flooding in the Southern California Bight. Part 2: Tools for Assessing Climate Change-Driven Coastal Hazards and Socio-Economic Impacts. Journal of Marine Science and Engineering. 2018; 6(3):76. https://doi.org/10.3390/jmse6030076.

[135] *Ibid.*

## 6.7. Potential Partnership with USGS

As a result of its literature review and analysis of the currently available approaches, assessment tools and models, EDR believes that the USGS's Coastal Storm Modeling System (CoSMoS) and its accompanying tools could provide a significant means to jumpstart Florida in its assessment. While there are some substantial gaps that still need to be addressed by EDR (inland flooding and stormwater runoff issues away from the coast to name two), CoSMoS could accelerate the analysis of Florida's coastal areas, at least that portion extending to the head of the tide. HERA would also provide a platform to begin the economic analysis.

It would take a strong collaborative effort with USGS to adapt CoSMoS to the state's specific needs—or to develop a different, but similar approach. In its approach, the CoSMoS modeling system is not site-specific, but—to date—it has been used extensively only in California[136], which has a much different geology than Florida. In this regard, Florida is one of only two states that are situated entirely within the Coastal Plain province. The geomorphology of Florida is unique because most of the state is underlain by a thick sequence of carbonate sediment (limestone and dolostone) known as the Florida Platform.[137] Further, Florida has an average elevation that is just 100 feet above sea level, with four physiographic regions where most aquifers lie just beneath the sand. The near surface geology of coastal counties consists primarily of unconsolidated sand and porous limestone through which water is easily transmitted, further exacerbating the magnitude and extent of coastal and inland flooding. The extensive barrier island system, upon which much of the tourism-based economy relies, is highly vulnerable to erosion.[138] The development of CoSMoS or a similar model for Florida would have to be cognizant of this unique geomorphology.

At best, current data limitations would confine the reach of CoSMoS to the coastal areas in Florida up to the head of tide—and even then, the data is only available for the counties on the eastern coast. USGS is now in the process of finalizing coastal hazards maps for that area, using an approach similar to CoSMoS. This is, however, a large portion of the High Impact Zone category that EDR has prioritized for the first phase of its assessment. The High Impact Zone contains the state's most flood-prone areas, exposed to the additive effects of tidal flooding, storm surge and sea level rise.

USGS has expressed potential interest in working with EDR on adaptations to CoSMoS and HERA, as well as performing the study needed for the remaining coastal areas of Florida. Assuming these objectives are feasible, the identification of the High Impact Zone for EDR's purposes would be complete. Regardless, the process with USGS would be time-consuming. In the interim, EDR is exploring the use of the South Atlantic Coastal Study (SACS) data and framework for Florida. This study, under the auspices of the US Army Corps of Engineers, is nearing completion and should be available in August 2022. Ultimately, it should have functionality that is similar to CoSMoS and its web-based applications.

---

[136] Efforts are also underway in Puget Sound (Washington), with ongoing discussions of other potential sites.
[137] DEP Geology, 2022: https://floridadep.gov/fgs/research/content/geologic-mapping. (Accessed January 2022.)
[138] Parkinson, R., Harlem, P. and Meeder, J. 2015. Managing the Anthropocene marine transgression to the year 2100 and beyond in the State of Florida U.S.A, Climatic Change, Vol. 128. DO - 10.1007/s10584-014-1301-2.

Remaining on the agenda is an appropriate modelling approach for the Intermediate and Dispersed Impact Zones, but that work is not dependent on the completion of the High Impact Zone, allowing some overlap of the efforts.

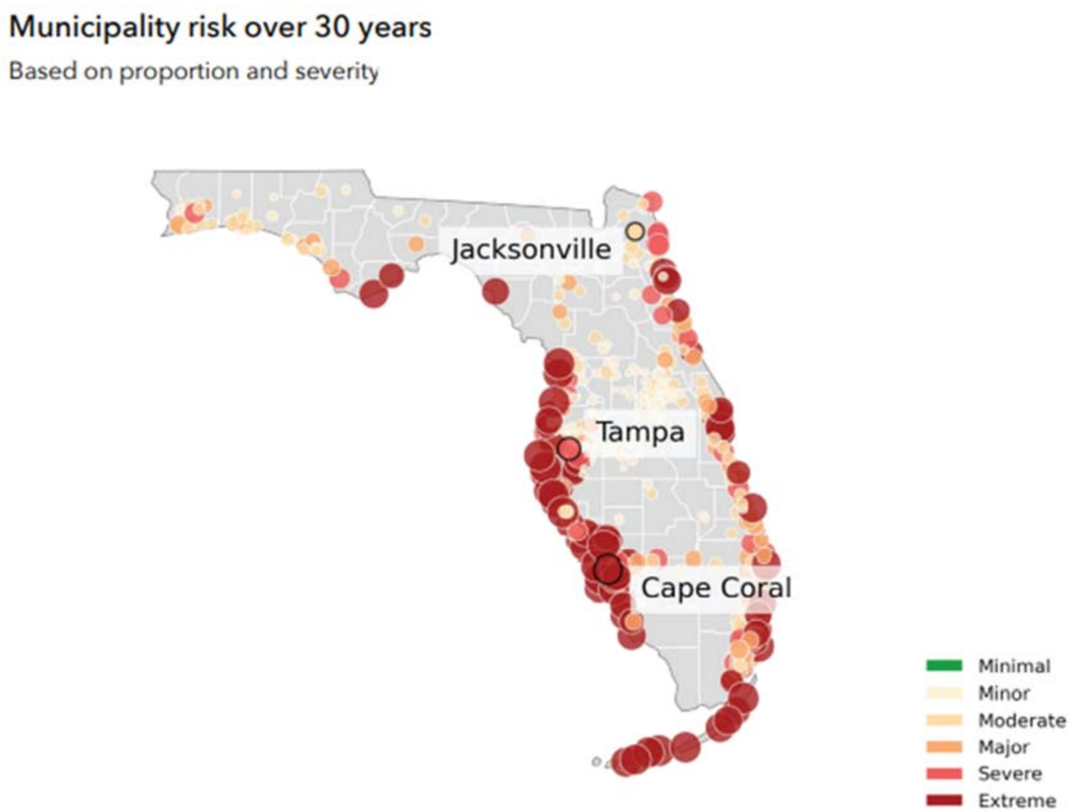
## 6.8. Economic Analysis

As the boundaries of the High, Intermediate and Dispersed impact zones are fleshed out and the mechanism for real-time updates is put into place, the detailed assessment can begin. The key elements are: (1) the existing economic conditions in those areas and the aspects most likely to be impacted in the future; (2) the expenditures associated with minimizing adverse economic impacts; and (3) the costs of conducting resilience efforts. Some of this information will draw on existing local and regional work or studies and available data, but the remainder will need to be estimated—as will the most likely choices for adaptation and hazard mitigation.

A few overarching points are worth noting before beginning the discussion of specific economic impacts. First, among the most well-known economic modelers in this field, the net global economic or welfare impacts from climate change are expected to be increasingly negative moving into the future. Further, negative surprises (effects that are even worse than the “best” predictions) are more likely than positive surprises. Second, EDR has previously demonstrated that, contrary to the oft-repeated myth that government makes money during hurricanes due to the rebuilding activity, state government typically has expenditures far greater than the incremental increase in the revenue estimates and becomes a net loser when all expenditures are taken into account—even before considering the cannibalization of other expenditures that would have taken place. Lastly, as previously noted in this assessment, the combined effects of extreme weather events, tidal flooding, storm surge and sea level rise are expected to be additive or strengthening. Taken together, these points establish the overall economic direction.

The most obvious of all economic effects from flooding and sea level rise is the direct damage to infrastructure and other structures in the built environment. While EDR will be using a different methodology for its analysis, the *3rd National Risk Assessment: Infrastructure on the Brink* was released in October 2021. Developing a set of national metrics to quantify the risk to (1) residential properties; (2) roads; (3) commercial properties; (4) critical infrastructure (airports, fire stations, hospitals, police stations, ports, power stations, superfund/hazardous waste sites, water outfalls, and wastewater treatment facilities); and (5) social infrastructure (government buildings, historic buildings, houses of worship, museums, and schools), the assessment identified the municipal areas[139] identified on the map below as being the most at risk from flooding in Florida.

[139] Actually, the 3rd National Risk Assessment used place interchangeably with municipality.




Source: 3rd National Risk Assessment: Infrastructure on the Brink (October 2021)

Looking 30 years into the future to incorporate changing climate effects, the assessment provided the following measurements for Florida's at risk areas:[140]

- 1,927,660 residential properties at risk today with an additional 379,897 properties (a 19.7 percent increase) in 2051;
- 87,320 miles of roads at risk today with an additional 11,353 miles (a 13.0 percent increase) in 2051;
- 86,515 commercial properties at risk today with an additional 17,302 properties (a 20.0 percent increase) in 2051;
- 1,736 infrastructure facilities at risk today with an additional 214 facilities (a 12.3 percent increase) in 2051; and
- 8,141 social facilities at risk today with an additional 1,534 facilities (an 18.8 percent increase) in 2051.

In terms of dollars, the available numbers are somewhat scattered and widely varying in their respective assumptions and metrics, clearly pointing to the need for a harmonized state assessment as required by the 2021 law. There are many examples, but just a few reports can be used to illustrate the problem—even without making a selection as to which source is superior.

[140] 3rd National Risk Assessment, 2021: https://assets.firststreet.org/uploads/2021/09/The-3rd-National-Risk-Assessment-Infrastructure-on-the-Brink.pdf.

First, the ISO's catastrophe modeling subsidiary, AIR Worldwide, indicated in 2006 that "*catastrophe losses* should be expected to double roughly every 10 years because of increases in construction costs, increases in the number of structures and changes in their characteristics," regardless of whether climate change is leading to increases in the number of storms or their intensity.[141] This expectation was not inconsistent with Florida's history over the period beginning 1995 and ending 2010, when the total reported loss exposure of insured property increased from $774 billion to $2.2 trillion, an annual increase of 7.5 percent per year.[142] To provide a reference point for this period, excluding household contents and commercial goods, the total real property value in the state in 1995 was $658.4 billion and in 2010 was $1.8 trillion. Relative to those data points, the 2019 Annual Report of the Chief Resilience Officer, Executive Office of the Governor, indicated that $2.86 trillion of insured property in Florida was vulnerable to *hurricanes*.[143] The statewide real property value in that year was $2.75 trillion. As for the future, the Chief Resilience Officer's report pointed to projections that $26 billion of residential property in Florida will be at risk of *chronic flooding* by 2045. This is much lower than suggested by the National Risk Assessment and somewhat at odds with another internally reported statistic: 15.5% of Florida's GDP is at risk due to *flooding*.[144] The GDP estimate itself is higher than some of the more recognized economic modeling that currently exists suggests for all climate change and weather impacts combined, including droughts and wildfires. Conversely, the Chief Resilience Officer's report used the NOAA extreme scenario of 1.5 feet of sea level rise by 2030, in conjunction with an estimated 2,555 miles of Florida roads that are three feet below the high tide line, as an indicator of near-term transportation flooding risk that is far below the National Risk Assessment's 2021 number.

A more targeted study by Florida State University (FSU) in 2008[145] focused on Dade, Dixie, Duval, Escambia, Monroe, and Wakulla counties to project regional changes in sea level rise and the accompanying risks of hurricane-related inundation and storm surge. Combining the increased probabilities of occurrence (a decrease in the hurricane return period) with the higher storm surge, the potential losses escalate. The study used damage costs for eight hurricanes between 2004 and 2005 that showed costs ranging from $661 in Dixie County (Hurricane Rita) to $2.21 billion in Dade County (Hurricane Wilma). Extrapolating from the historical data and using its own and IPCC's sea level rise estimates for the year 2080:

> *...show that damages in each of the representative 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.*

---

[141] Emphasis added. *See* https://www.insurancejournal.com/news/national/2006/04/18/67389.htm. (Accessed May 2022.)
[142] https://www.sbafla.com/fhcf/Portals/FHCF/Content/Reports/Annual/SBA_CATF_Annual_ReportFHCF_Final.pdf?ver=2016-06-08-121900-647. (Accessed May 2022.)
[143] *See* https://s3.documentcloud.org/documents/6867224/Florida-Chief-Resilience-Officer-2019-Annual.pdf. (Accessed May 2022.)
[144] The 2019 Annual Report of the Chief Resilience Officer provided no details as to how the statistic was derived.
[145] Harrington, J. and Walton, T., 2008. Climate Change in Coastal Areas in Florida: Sea Level Rise Estimation and Economic Analysis to Year 2080. A report funded by a grant from the National Commission on Energy Policy. Accessible at: https://cefa.fsu.edu/sites/g/files/imported/storage/original/application/2dec40fac4c55a937b4c2497db652815.pdf.

*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.*

Based on this study and a representative hurricane for each county, the projected damage costs in 2080 are shown below for the high IPCC SLR 2001 scenario using 2006 dollars. It is important to note that the cost projections do not account for changes in the population or the built environment—they are more a function of varying sea level rise to alter historical storm surge patterns during hurricanes.

| County | Historic Storm Surge (ft.) | Damage Cost ($) | Projected Storm Surge of 2.13 ft. based on IPCC SLR 2001 Estimate for 2080 (ft.) | Damage Cost ($) | % Increase to Damage Cost* |
|---|---|---|---|---|---|
| Dade | 7.00 | $2.21 B | 9.13 | $2.90 B | 31% |
| Dixie | 9.00 | $0.06 M | 11.13 | $0.08 M | 33% |
| Duval | 5.90 | $72.30 M | 8.03 | $98.00 M | 36% |
| Escambia | 12.00 | $70.70 M | 14.13 | $95.00 M | 34% |
| Monroe | 2.76 | $215.30 M | 4.89 | $370.00 M | 72% |
| Wakulla | 9.00 | $4.42 M | 11.13 | $6.90 M | 56% |

Source: Modified and Adopted from the 2008 FSU Study

*Percentages as reported in 2008 FSU Study. They differ from calculations based solely on the data displayed above due to rounding.

The FSU study also estimated the value of land and acreage at risk of inundation[146] in three of these counties, using five of the IPCC 2001 SLR scenarios and 2005 dollars. As before, the estimates do not consider changes in the value of property over time or new development:

| | | SLR Scenarios from IPCC SLR 2001 (2005$) | | | | |
|---|---|---|---|---|---|---|
| County | Variable | 0.16 ft. | 0.33 ft. | 0.49 ft. | 0.98 ft. | 2.13 ft. |
| Dade | Value of land at risk ($) | $1.05 B | $1.40 B | $2.33 B | $4.81 B | $12.30 B |
| | Area at risk (acres) | 5,486 | 5,861 | 7,903 | 11,627 | 26,467 |
| Duval | Value of land at risk ($) | $10.4 M | $13.7 M | $19.6 M | $344.0 M | $572.0 M |
| | Area at risk (acres) | 1,855 | 1,868 | 1,878 | 10,625 | 18,734 |
| Escambia | Value of land at risk ($) | $126 M | $136 M | $148 M | $194 M | $499 M |
| | Area at risk (acres) | 798 | 899 | 962 | 1,863 | 5,209 |

Source: Modified and Adopted from the 2008 FSU Study

Widely varying estimates exist for even these counties. Some, but not all, of the differences can be explained by the introduction of more sophisticated modeling approaches and new data for subsidence and adaptation. Within this framework, a 2013 study supported by the OECD found that a rise in sea level of 1.3 feet[147] by 2050 could cause average annual flood losses in Miami alone that exceed $25.67 billion—but after incorporating the current and likely future protective measures needed to maintain a probability of flooding that is equal to the current likelihood, this figure drops to $2.96 billion.[148] While adjusting for subsidence, this model did not change storm surge likelihood.

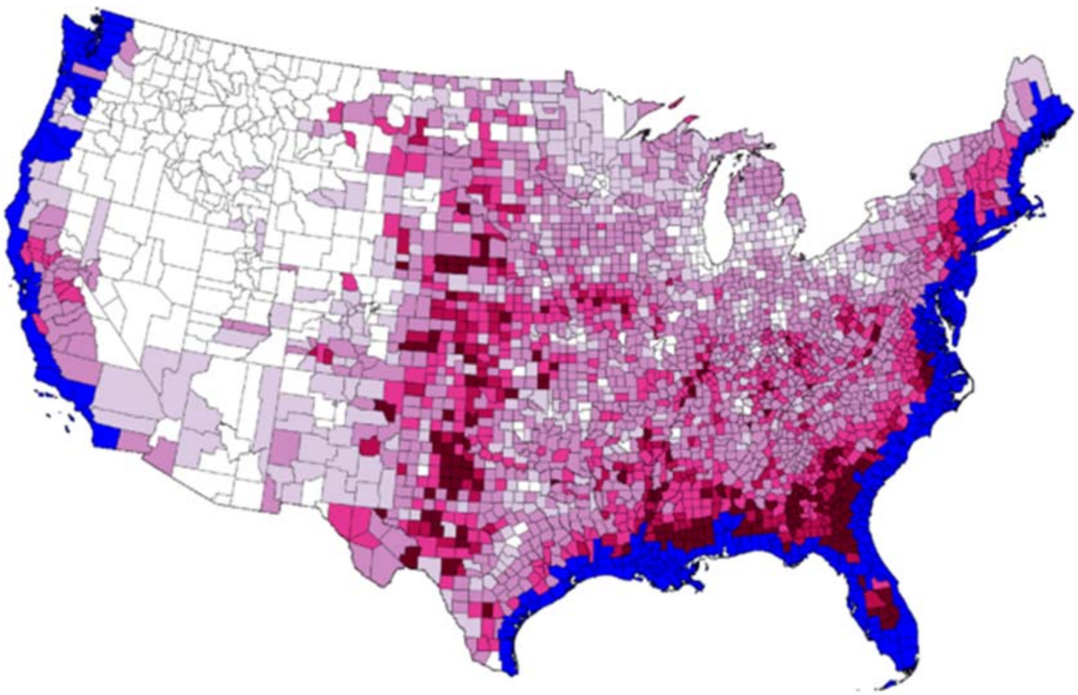
[146] For the purposes of the 2008 FSU Study, inundation is defined as a parcel centroid below the projected mean spring high water.

[147] The scenario highlighted in EDR's assessment assumed a sea level rise of 20 centimeters in 2030, 40 centimeters in 2050, and 70 centimeters in 2070.

[148] Hallegatte, S., Green, C., Nicholls, R.J., Corfee-Morlot, J., 2013. Future flood losses in major coastal cities. Nat. Clim. Change 3, 802–806.

There are, however, a number of other economic and financial effects that are more subtle than the risk to physical structures and infrastructure, but which are no less powerful. These include—but are not limited to—the following impacts, each of which needs to be addressed in greater detail by future editions:

- Negative Effects on Population Growth...Population growth is the state's primary engine of economic growth, fueling both employment and income growth; a downward shift in population growth will harm these key metrics. This could be caused by either or both of the following changes:
    - Shifts away from Florida's coastal areas to locations further inland...This would have relatively little effect statewide, but potentially large local effects.
    - Moves out of the state or forgone moves into the state...At least one researcher has found that the "number of homeowners interested in moving out of the region [South Florida] increases steadily over time as the sea level rises."[149] Another study offering an early look at this issue projected that, by the year 2100, Florida could have a net population loss of 2.5 million—assuming a sea level rise scenario of 5.9 feet and no concerted effort to adopt adaptive measures.[150] The map below is from a third study of expected climate-driven migration published in 2020.



Source: Robinson C., Dilkina B., Moreno-Cruz J., 2020. Modeling migration patterns in the USA under sea level rise. PLoS ONE 15(1): e0227436. https://doi.org/10.1371/journal.pone.0227436. Based on a scenario of 1.8 meters of sea level rise. Blue colors represent counties that will experience any level of sea level rise inundation. Red/purple colors represent counties that will see increased migration, with the shade proportional to the increase.

[149] Treuer, G., Broad, K., Meyer, R., 2018. Using simulations to forecast homeowner response to sea level rise in South Florida: Will they stay or will they go? Global Environmental Change 48, 108-118.

[150] Hauer, M.E., 2017. Migration induced by sea-level rise could reshape the US population landscape. Nature Climate Change, 7(5), pp. 321-325.

- Declines in Property Value and the Tax Base...Property taxes accounted for 23.8% of all county revenues and 14.7% of all municipal revenues in the local fiscal year ending September 30, 2020. Given this revenue source's relative importance to local government budgets and the state's education financing program, any threat has potentially serious financial ramifications. The risks include:
  - Loss in home value appreciation...According to a 2019 analysis[151] of flooding and sea level rise by the First Street Foundation, Florida has the highest estimated losses among the 17 states on the Eastern Seaboard, with property value losses exceeding $5.4 billion between 2005 and 2017 from flooding occurring either directly on the property or on nearby roads. Miami Beach is the country's second hardest impacted city; altogether, seven of the top twenty cities were in Florida.
  - Potential buyers heavily discounting or refusing to buy homes in neighborhoods where high-tide flooding is likely to occur or is already occurring...Several researchers have already found a suggested impact from sea level rise and other flooding factors on home prices.[152] One recent study has priced the purchase discount at 7%, but shows why that has not yet been fully realized in the marketplace.[153] Counter to the potential loss associated with this risk will be the offset from those buyers who elect to purchase elsewhere in Florida—potentially driving up demand and prices in those areas. While this would mitigate the statewide impact, there would still be large local effects.
  - Total loss of property from permanent inundation or erosion.
  - Positive offset to loss from investments in hazard mitigation and adaptive measures.
- Rising Insurance Costs and Falling Availability...Regardless of its specific form, a well-functioning insurance market is critical to Florida's future economic health and has feedback loops to both of the above issues. It is likely that the financial sector which contains this market will be among the first to react to the increased risk of flooding and severe weather events. According to the 2021 Insurance Fact Book, 93% of all homeowners have at least basic homeowners insurance; however, flood coverage is excluded under standard policies and is primarily provided through the National Flood Insurance Program.[154] Based on its number of single-family homes potentially affected by storm surge risk in 2020 (from 353,994 for a Category 1 hurricane to 2,851,642 for a Category 5 hurricane) and the reconstruction cost of those homes (from $71.7 billion for a Category 1 hurricane to $580.6 billion for a Category 5 hurricane), Florida was ranked first among all states for risk. In 2017, Louisiana (#1) and Florida (#2) had the highest average homeowners' premiums in the country.

---

[151] *See* https://assets.floodiq.com/2019/02/9ddfda5c3f7295fd97d60332bb14c042-firststreet-floodiq-mid-atlantc-release.pdf. (Accessed May 2022.)

[152] *See*, for example, Keenan, J.M., Hill, T., Gumber, A., 2018. Climate gentrification: from theory to empiricism in Miami-Dade County, Florida. Environ. Res. Lett. 13, 054001. Also *see* the March 2022 Economic & Housing Research Note published by FreddieMac at: https://www.freddiemac.com/research/insight/20220316-sea-level-rise-and-impact-home-prices-coastal-florida. (Accessed May 2022.)

[153] Bernstein, A., Gustafson, M.T., Lewis, R., 2019. Disaster on the horizon: The price effect of sea level rise. Journal of Financial Economics,Volume 134, Issue 2, 253-272.

[154] *See* page 90 of the 2021 Insurance Fact Book (ISBN 978-0-932387-85-1) published by the Insurance Information Institute. A different survey (the 2020 Triple-I Consumer Poll) found that 88% of homeowners had homeowners insurance (page 101). A conservative estimate would average the two to indicate 90.5%. Of those who have homeowners insurance, one of the higher national estimates suggested that up to 27% in 2020 also had flood insurance. Other studies project Florida's specific percentage to range between 17.4% and 40%. In 2019, Florida had a total of 1.7 million national flood insurance policies in effect (direct and Write-Your-Own), providing nearly $440 billion of coverage. Some of the data reported here is further sourced to CoreLogic.

- For those fortunate enough to get coverage, ever higher premiums and rising deductibles have become the norm. Still others face a new reality where they are completely priced out of the competitive market or dropped. Simultaneously, the industry itself will be dealing with the complexity of insuring catastrophic weather events that have a very high probability of occurring—a challenge exacerbated by the generation of greater expected losses and the necessity for larger capital allocations to meet those losses. All else being equal, affordable premiums are predicated on low probabilities of loss.
- The state of Florida is one of only two states (Louisiana is the other) that are deemed by the industry to have state-run property insurance companies. According to the Citizens Property Insurance Corporation of Florida website, it was created by the Florida Legislature in 2002 as a not-for-profit, tax-exempt, government entity to provide property insurance to eligible Florida property owners unable to find insurance coverage in the private market.[155] It operates according to statutory requirements established by the Legislature and is governed by a Board of Governors. The board administers a Plan of Operation approved by the Florida Financial Services Commission, an oversight panel made up of the Governor, Chief Financial Officer, Attorney General and Commissioner of Agriculture. Citizens is funded by policyholder premiums; however, Florida law also requires that Citizens levy assessments on most Florida policyholders if it experiences a deficit in the wake of a particularly devastating storm or series of storms. An exception was made in 2006 when the Legislature directly appropriated $715 million to reduce Citizens' 2005 plan year deficit.[156] Since Citizens functions as an insurer of last resort, it captures greater than normal risk—risk that the private market is generally unwilling to bear at an affordable cost for consumers.[157] While the state of Florida does not explicitly back the program, it has multiple ties that pose a risk for state government finances.
- Similar in nature to private reinsurance, the Florida Hurricane Catastrophe Fund (FHCF) was created by the Florida Legislature in 1993. The law requires all admitted insurers writing residential property insurance in Florida, including Citizens Property Insurance Corporation, to obtain FHCF reimbursement coverage for a portion of their catastrophic hurricane losses. The cost for this coverage is typically lower than the private market "because it does not include a profit factor or risk load in its rates and because it is exempt from federal taxes."[158] According to its website, it is a tax exempt state trust fund that is intended to be self-supporting, with funding primarily from actuarially-determined premiums paid by the residential property insurance companies, and, in some circumstances, revenue bonds backed by emergency assessments on a variety of property and casualty insurance premiums.[159] The fund's current maximum obligation is limited to $17

[155] *See* https://www.citizensfla.com/who-we-are. (Accessed May 2022.)
[156] *See* Section 44 of SB 1980, 2006.
[157] Generally, a person is eligible for coverage by Citizens if: (1) no comparable private-market offers of coverage are received; or (2) comparable private-market offers of coverage are received, but the premiums are more than 20 percent higher than a comparable Citizens policy.
[158] *See* https://www.sbafla.com/fhcf/Portals/FHCF/Content/Reports/Annual/20210614_2020_FHCFAnnualReport.pdf?ver=2021-06-14-123243-403. (Accessed May 2022.)
[159] *See* https://www.sbafla.com/fhcf/. (Accessed May 2022.)

billion per contract year, but FHCF's liability is further constrained by the amount it can actually raise from bonding and the other available claims payment sources. While the effective cap affects all insurance companies, arguably the greatest concern is the impact on Citizens in the more extreme weather scenarios.

  - Offering flood insurance to homeowners, renters and business owners, the National Flood Insurance Program is currently authorized through September 30, 2022. At the end of the 2021 calendar year, the Program had over $20.5 billion in outstanding debt with the U.S. Treasury[160] and $1.3 trillion of insurance in force with capacity to pay future claims of $16.7 billion. In March 2021, the Program reported that Florida had over 1.7 million policies, the greatest number of policies among all states and about one-third of all policies nationwide. As to its ability to continue as the dominant flood insurance provider it is today, serious questions exist regarding the Program's long-term financial viability and future role.

- Harm to the State's Brand and Beaches...In a separate study, EDR found that sandy beaches are the most important feature of Florida's brand, accounting for 25.5% of the state's attractiveness to visitors. Moreover, their value goes far beyond tourism to incorporate residential recreation, coastal protection from severe weather events and other ecosystem services."[161] Sea level rise will exacerbate current levels of beach erosion and coastal squeeze along Florida's 825 miles of beaches.[162] According to a 2002 report produced by the U.S. Environmental Protection Agency entitled Saving Florida's Vanishing Shores, a 1-foot rise in sea level would erode most Florida beaches by 100 to 200 feet. One professional approximation of the average width of a sandy beach in Florida is about 100 feet[163]—a metric that implies that development-blocked beaches would largely disappear if no protective or restorative measures are taken. Among other important effects, severe beach erosion would have serious repercussions for the tourism industry, as well as government revenues. EDR estimates that tourists generated 14.5% of the state's total sales tax revenues in FY 2018-19.

Finally, there will be indirect and induced effects from all of the issues described above, as well as other effects that are more opaque. Most importantly, this latter category includes environmental damage that will ultimately spillover to the economy, such as the loss of seagrass and certain species and ecosystems.

## 6.9. Next Steps and Future Actions

EDR is undertaking a multistage process to estimate the needed expenditures by all levels of government which are required to achieve the Legislature's intent of minimizing the adverse economic effects of flooding. The Legislature's end goal is very specific: to decrease the likelihood

[160] Congress canceled $16 billion of debt in October 2017. This is the amount remaining after that action.
[161] See http://edr.state.fl.us/Content/returnoninvestment/BeachReport.pdf. (Accessed May 2022.)
[162] As described by Pontee, coastal squeeze occurs when the high water mark is fixed by a defense or structure and the low water mark migrates inwards in response to sea level rise, thereby causing a reduction of the beach area. See Pontee, N., 2013. Defining coastal squeeze: a discussion. Ocean & Coastal Management, 84, p.204–207. In addition, certain habitats (such as salt marshes and tidal flats) can migrate landward in response to sea level rise, but limitations caused by development and other manmade structures can prevent this from occurring. For a discussion of the likelihood of sea level rise causing additional erosion, *see*, for example: Vousdoukas, M., Ranasinghe, R., Mentaschi, L., Plomaritis, T., Athanasiou, P., Luijendijk, A., Feyen, L., 2020. Sandy coastlines under threat of erosion. Nature Climate Change, 10(3), p. 260 - 263. Nature Publishing Group. ISSN 1758-678X.
[163] Email on file from Dr. Stephen Leatherman, Department of Earth & Environment, Florida International University.

of severe dislocations or disruptions in the economy and preserve the value of real and natural assets to the extent economically feasible. In the first stage, EDR must quantify the risk by conducting what is essentially a stylized inventory. This can be accomplished by applying geospatial technology to identify the precise boundaries of different risk or hazard zones. Currently, EDR is envisioning three initial zones, with the intent to focus on an evolving selection of them to match the availability of information and data. These impact zones are primarily defined by their proximity to the coastal area and susceptibility to flooding-related issues. The working categories are as follows:

- *High Impact Zone* is based on a variety of federal data sources (preferably on the USGS data) and modeling of the coastal areas which currently extends to the head of the tide. These areas are affected by a multiplicity of factors occurring persistently, rather than periodically or as a consequence of one-off events.

- *Intermediate Impact Zone* is the area beyond the High Impact Zone that may still be affected by storm surge, as well as the area along rivers or larger lakes where significant flooding either is recurrent or will likely be recurrent in the future.

- *Dispersed Impact Zone* is the area outside the High and Intermediate Impact Zones that still experiences localized flooding challenges, but where those are primarily caused by factors such as higher levels of precipitation in urban or urbanized areas, the weaker impacts of storms and hurricanes, or nuisance flooding.[164]

An additional comment is needed with respect to the Intermediate Impact Zone. Much of the discussion in this first Edition has focused on the state's coastal areas. Another important factor is inland flooding which, among other causes, can be linked to stress affecting the state's rivers. To show the potential breadth of this issue, the map on the following page identifies the state's major rivers.

[See map on following page]

---

[164] As used here, nuisance flooding refers to low levels of inundation—regardless of source—that do not pose significant threats to public safety or cause major property damage, but can disrupt routine day-to-day activities, put added strain on infrastructure systems such as roadways and sewers, and cause minor property damage.

Setting the appropriate boundaries is more challenging than it appears at first blush. One of the major issues revealed by the literature review is the discrepancies among different data sources. Therefore, a goal of EDR's assessment is to ensure that the most recent and reliable data will be used for the analysis. In addition, different regions, cities or counties have used different methodologies for assessment. A unified assessment methodology will help the state to have a harmonized view of the future.

Once the boundaries are clearly established, the quantity and value of all physical structures within each zone (including infrastructure) can be identified. Then, provision must be made to overlay key economic and environmental features. Ultimately, a new model will be needed to map different flooding scenarios and the potential impacts associated with them. A broad overview of EDR's research plan for these elements is as follows:

- Step 1: Assessment of Data Availability, Potential Economic Risks, and State of Current Knowledge – August 2021 through June 2022
- Step 2: Identification of Areas Most At-Risk, Initial Testing of the Florida Flooding Assessment Model (FFAM), and Preliminary Static Estimates – July 2022 through July 2023

- Step 3: Expansion of FFAM to the Entire State – August 2023 through July 2024
- Step 4: Full Linkage of FFAM to EDR's Statewide Economic Model[165] to Generate Dynamic Estimates – August 2024 to June 2025

After gaining an understanding of the flooding domain through scenario building that is inclusive of risk, the next stage is to identify likely choices for adaptation and hazard mitigation, as well as the probable near-term and longer-term costs and consequences. The forward looking aspect of this part of the analysis is extremely nuanced and will need to incorporate more than physical geography and topography. For example, some studies have already found a strong relationship between the likely deployment of adaptive measures and wealth, both for individuals and cities. Other studies have found the local level of development to be an important factor. Still another study found that communities containing major tourism destinations would have additional considerations:

> *... since the final decision whether to travel to a destination or not is made by individual tourists, tourists are key stakeholders in any adaptation process. Therefore, it is essential to consider and understand their attitudes towards proposed adaptation options and how different adaptation options may affect the appeal of the destination for the tourists.*[166]

This is the part of the overall assessment that will be most informed by the local planning efforts already underway in Florida. In large part, it can be performed concurrently with Steps 2 through 4 from the overview discussed above.

Finally, a gap analysis will be developed to show the difference between the projected level of spending required to achieve the Legislature's intent of minimizing the adverse economic effects of flooding and the current levels of investments.

Still to be determined is the best way to treat the interaction between the flooding and sea level portion of the annual assessment and the other standard volumes: water supply, demand and quality; infrastructure investments for stormwater and wastewater; and the Everglades.

[165] The Statewide Model is a dynamic computable general equilibrium (CGE) model that simulates Florida's economy and government finances. For a more complete description of this model, see various studies and presentations at Return on Investment (state.fl.us). (Accessed May 2022.)
[166] Atzoria, R., Fyallb, A., Millerc, G., 2018. Tourist responses to climate change: Potential impacts and adaptation in Florida's coastal destinations. Tourism Management, 69, p. 12-22.

# Appendix D: Flooding

### Appendix D.1 Comparison of Regional SLR Projections

| Gauge Station | Low | Intermediate | High | Highest or Extreme | Sources |
|---|---|---|---|---|---|
| Fernandina Beach | 0.38 | 0.68-1.35 | 2.10 | N/A | NOAA2012 |
| | 0.38 | 0.68 | 1.63 | N/A | USACE2013 |
| | 0.68 | 1.16 | 1.63 | 2.10 | CARSWG2016 |
| | 0.72 \| 0.98 | 1.41 \| 2.23 | 2.56 \| 4.49 | 3.02 \| 5.41 | NOAA2017 |
| Mayport | 0.44 | 0.76-1.42 | 2.17 | N/A | NOAA2012 |
| | 0.46 | 0.76 | 1.70 | N/A | USACE2013 |
| | 0.76 | 1.23 | 1.70 | 2.17 | CARSWG |
| | 0.72 \| 0.98 | 1.41 \| 2.23 | 2.56 \| 4.49 | 3.05\| 5.41 | NOAA2017 |
| Daytona Beach | 0.44 | 0.74-1.40 | 2.60 | N/A | NOAA2012 |
| | 0.44 | 0.74 | 1.69 | N/A | USACE13 |
| | 0.74 | 1.21 | 1.69 | 2.16 | CARSWG |
| | 0.62 \| 0.89 | 1.31 \| 2.13 | 2.49 \| 4.40 | 2.95 \| 5.31 | NOAA2017 |
| Lake Worth Pier (NOAA uses the Miami Beach Gauge.) | 0.71 | 1.01-1.67 | 2.43 | N/A | NOAA2012 |
| | 0.71 | 1.01 | 1.96 | N/A | USACE2013 |
| | 0.71 | 1.48 | 1.96 | 2.43 | CARSWG |
| | 0.72 \| 0.98 | 1.38 \| 2.23 | 2.49 \| 4.40 | 2.89 \| 5.28 | NOAA2017 |
| Miami Beach | 0.46 | 0.75-1.42 | 2.17 | N/A | NOAA2012 |
| | 0.46 | 0.75 | 1.70 | N/A | USACE2013 |
| | 0.76 | 1.23 | 1.70 | 2.17 | CARSWG |
| | 0.72 \| 0.98 | 1.38 \| 2.23 | 2.49 \| 4.40 | 2.89 \| 5.28 | NOAA2017 |
| Virginia Key (NOAA uses the Miami Beach Gauge.) | 0.56 | 0.86-1.52 | 2.27 | N/A | NOAA2012 |
| | 0.56 | 0.86 | 1.80 | N/A | USACE2013 |
| | 0.86 | 1.33 | 1.80 | 2.27 | CARSWG |
| | 0.72 \| 0.98 | 1.38 \| 2.23 | 2.49 \| 4.40 | 2.89 \| 5.28 | NOAA2017 |
| Vaca Key | 0.53 | 0.83-1.49 | 2.25 | N/A | NOAA2012 |
| | 0.53 | 0.83 | 1.78 | N/A | USACE2013 |
| | 0.83 | 1.30 | 1.78 | 2.25 | CARSWG |
| | 0.72 \| 1.02 | 1.41 \| 2.23 | 2.49 \| 4.49 | 2.95 \| 5.35 | NOAA2017 |
| Key West | 0.43 | 0.73-1.39 | 2.15 | N/A | NOAA2012 |
| | 0.43 | 0.73 | 1.67 | N/A | USACE2013 |
| | 0.73 | 1.20 | 1.67 | 2.15 | CARSWG |
| | 0.72 \| 1.02 | 1.38 \| 2.23 | 2.46 \| 4.49 | 2.92 \| 5.35 | NOAA2017 |
| Naples | 0.38 | 0.68-1.35 | 2.10 | N/A | NOAA2012 |
| | 0.38 | 0.68 | 1.63 | N/A | USACE2013 |
| | 0.68 | 1.16 | 1.63 | 2.10 | CARSWG |
| | 0.72 \| 0.98 | 1.38 \| 2.23 | 2.49 \| 4.46 | 2.89 \| 5.31 | NOAA2017 |
| Fort Myers | 0.46 | 0.76-1.42 | 2.17 | N/A | NOAA2012 |
| | 0.46 | 0.76 | 1.70 | N/A | USACE2013 |
| | 0.76 | 1.23 | 1.70 | 2.17 | CARSWG |
| | 0.72 \| 0.98 | 1.38 \| 2.23 | 2.49 \| 4.46 | 2.89 \| 5.31 | NOAA2017 |
| St. Petersburg | 0.45 | 0.75-1.41 | 2.17 | N/A | NOAA2012 |
| | 0.45 | 0.75 | 1.70 | N/A | USACE2013 |
| | 0.75 | 1.22 | 1.70 | 2.17 | CARSWG |
| | 0.79 \| 0.92 | 1.44 \| 2.33 | 2.56 \| 4.56 | 2.95 \| 5.41 | NOAA2017 |
| Clearwater Beach | 0.46 | 0.76-1.42 | 2.18 | N/A | NOAA2012 |
| | 0.46 | 0.76 | 1.71 | N/A | USACE2013 |
| | 0.76 | 1.24 | 1.71 | 2.18 | CARSWG |

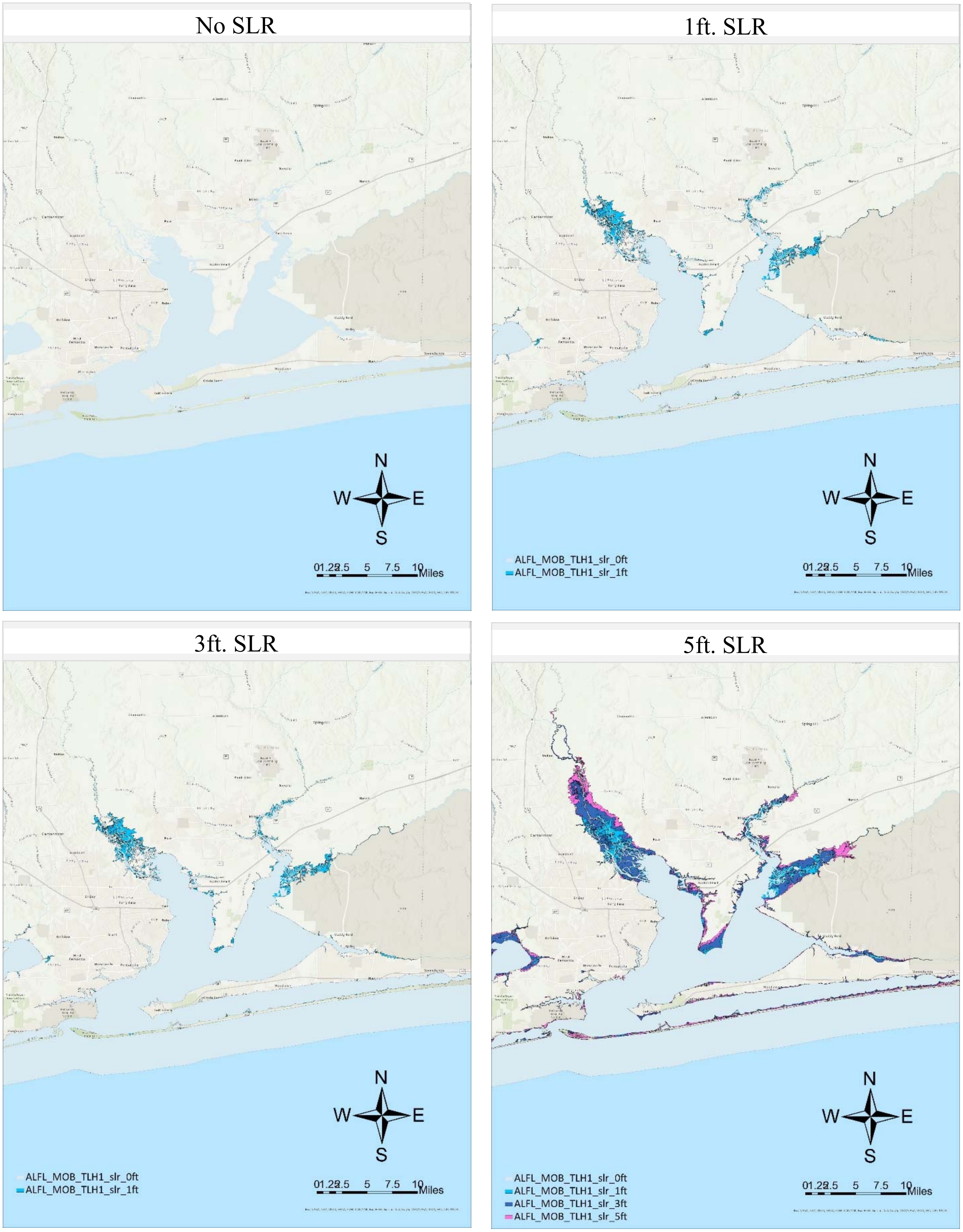
| | | | | | |
|---|---|---|---|---|---|
| | 0.79 \| 1.08 | 1.44 \| 2.33 | 2.56 \| 4.56 | 2.95 \| 5.45 | NOAA2017 |
| Cedar key | 0.34 | 0.64-1.30 | 2.06 | N/A | NOAA2012 |
| | 0.34 | 0.64 | 1.59 | N/A | USACE2013 |
| | 0.64 | 1.12 | 1.59 | 2.06 | CARSWG |
| | 0.66 \| 0.89 | 1.31 \| 2.46 | 2.43 \| 4.33 | 2.82 \| 5.22 | NOAA2017 |
| Apalachicola | 0.26 | 0.56-1.22 | 1.98 | N/A | NOAA2012 |
| | 0.26 | 0.56 | 1.51 | N/A | USACE2013 |
| | 0.56 | 1.03 | 1.51 | 1.98 | CARSWG |
| | 0.62 \| 0.85 | 1.28 \| 2.10 | 2.36 \| 4.30 | 2.76 \| 5.15 | NOAA2017 |
| Panama City | 0.14 | 0.44-1.10 | 1.86 | N/A | NOAA2012 |
| | 0.14 | 0.44 | 1.39 | N/A | USACE2013 |
| | 0.44 | 0.92 | 1.39 | 1.86 | CARSWG |
| | 0.62 \| 0.85 | 1.28 \| 2.10 | 2.36 \| 4.23 | 2.72 \| 5.12 | NOAA2017 |
| Pensacola | 0.40 | 0.70-1.36 | 2.12 | N/A | NOAA2012 |
| | 0.40 | 0.70 | 1.65 | N/A | USACE2013 |
| | 0.70 | 1.17 | 1.65 | 2.12 | CARSWG |
| | 0.69 \| 0.92 | 1.31 \| 2.13 | 2.40 \| 4.30 | 2.79 \| 5.18 | NOAA2017 |

**Appendix D.2 Sea Level Rise Scenarios for Different Florida's Coastal Regions**

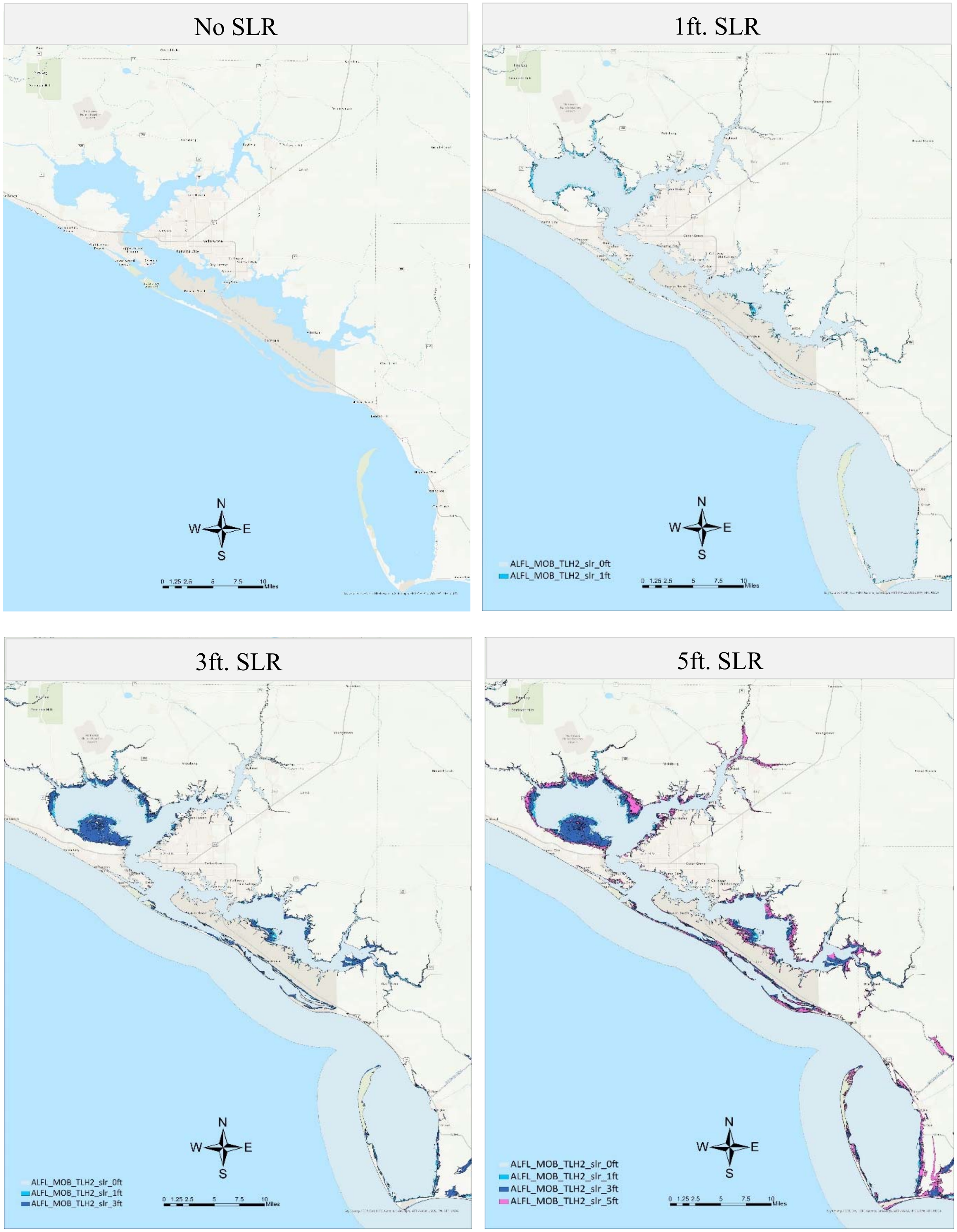
Following maps show the three projections of 1ft. (Lowest Scenario), 3ft. (Intermediate Scenario) and 5ft. (High scenario) sea level rise for seven areas along the Florida coasts: Escambia-Santa Rosa Area, Panama City- Apalachicolala Area, Tampa Bay Area, Cape Coral-Fort Myers Area, Miami Area, Key West, and Jacksonville Area. These locations have been chosen to highlight due to their popularity and high population. The penetration length of sea level into land is different in different areas. This is due to the topography and geomorphology of different areas. Also, in these projection that are based on NOAA 2017, that has decadal-scale estimates through 2100, has a broader and higher range for GMSL rise by 2100 (0.3–2.5 m), and provides estimates through the year 2200. It is also downscaled to a 1-degree gridded basis to provide a systematic spatial framework to more broadly support regional/local decision making, and most importantly the projections are available regionally (Compact, 2020; NOAA, 2017).

[See maps on following pages]

Escambia-Santa Rosa Area...

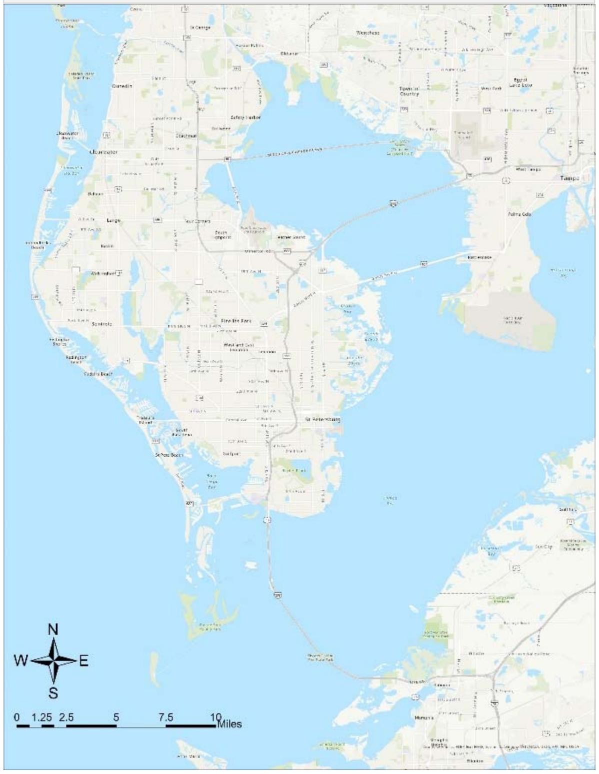


Panama City-Apalachicola Area...

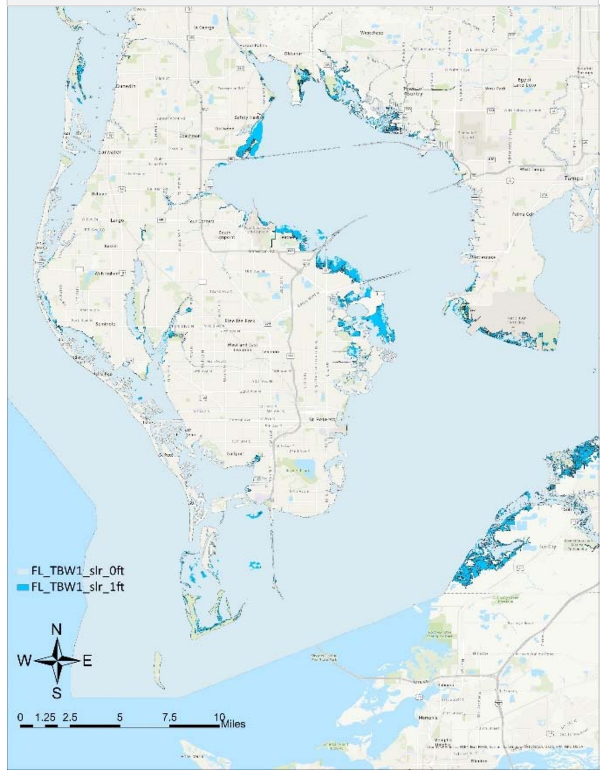


Tampa Bay Area...

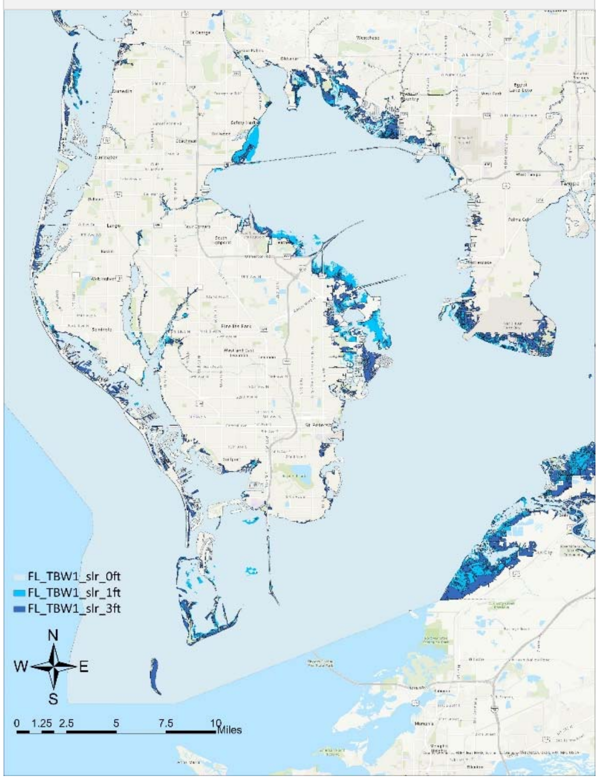
No SLR



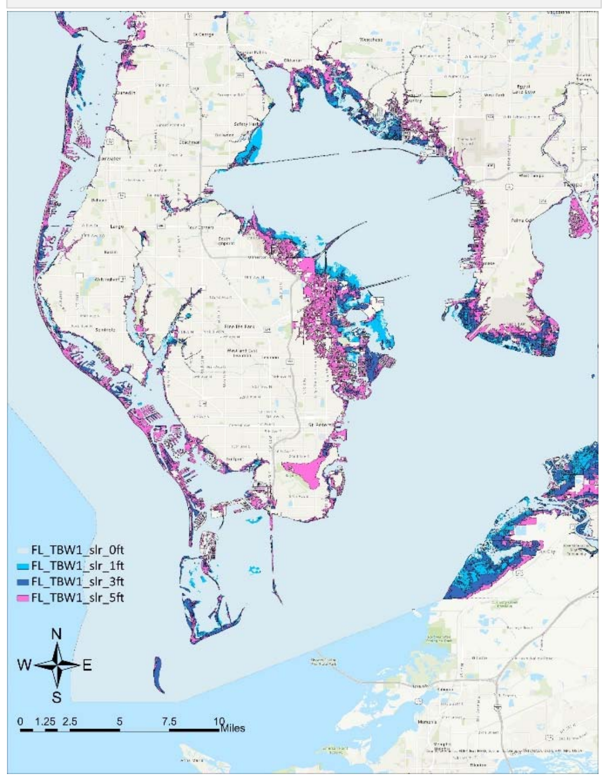

1ft. SLR




3ft. SLR

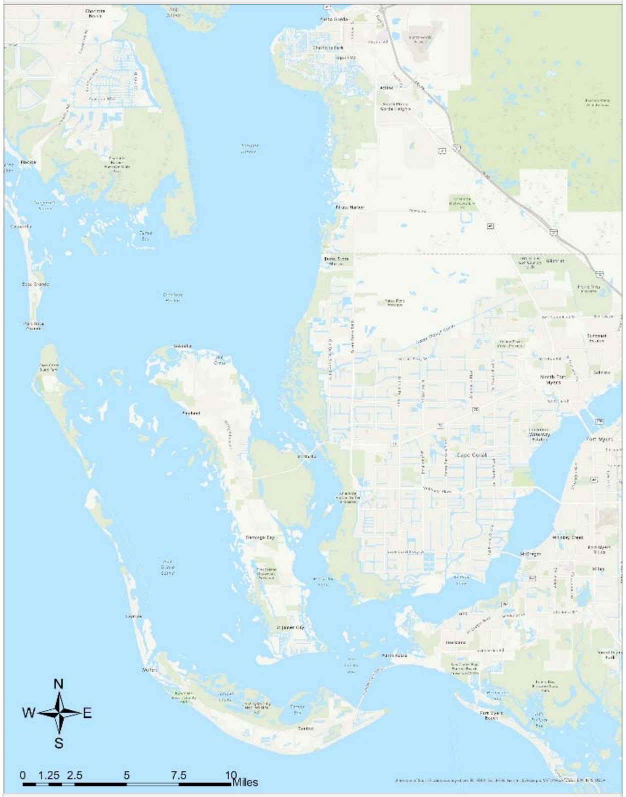



5ft. SLR

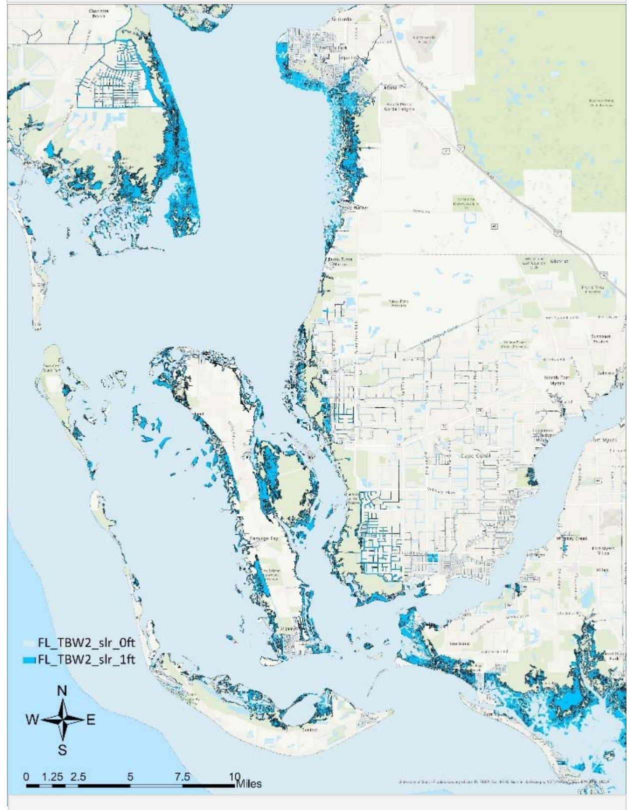


Cape Coral-Fort Myers Area...

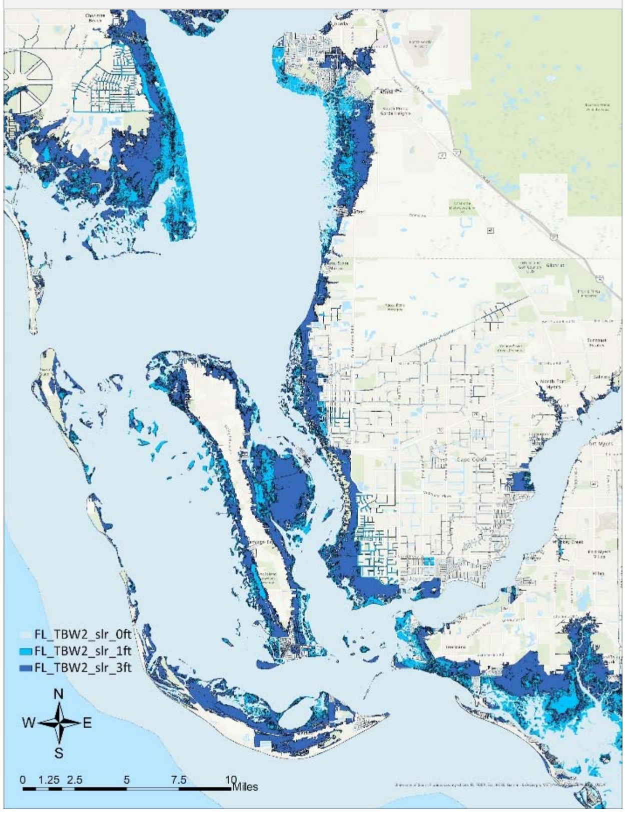
No SLR



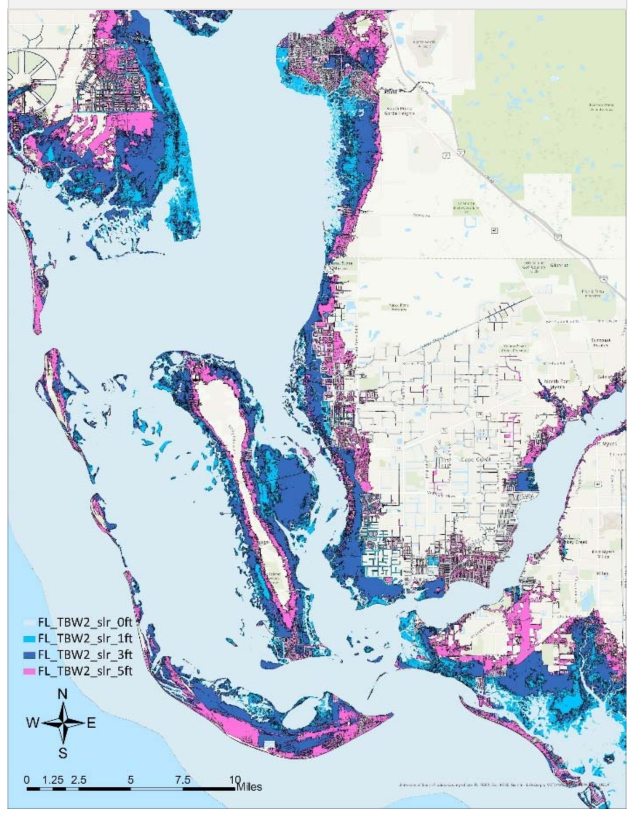

1ft. SLR



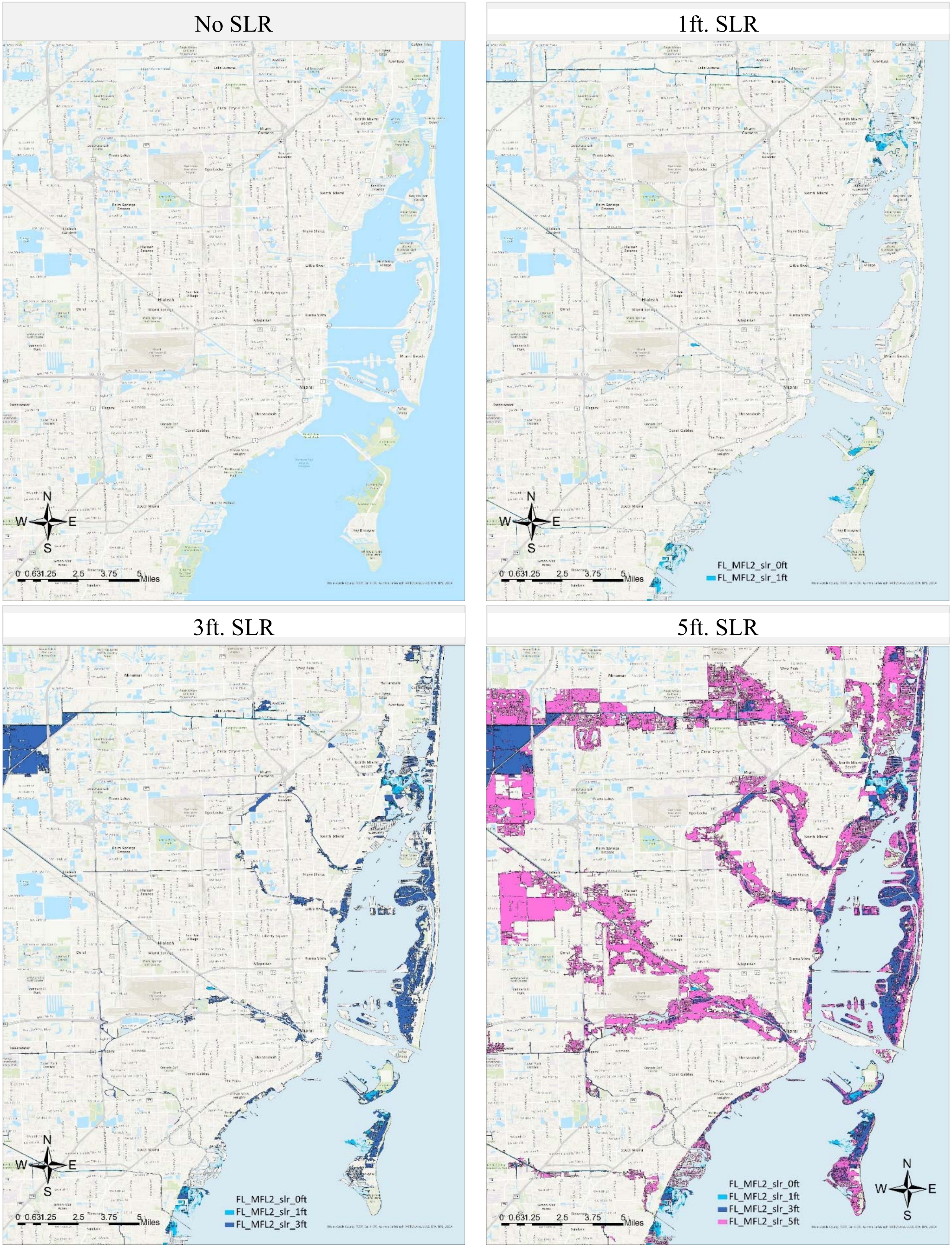

3ft. SLR




5ft. SLR



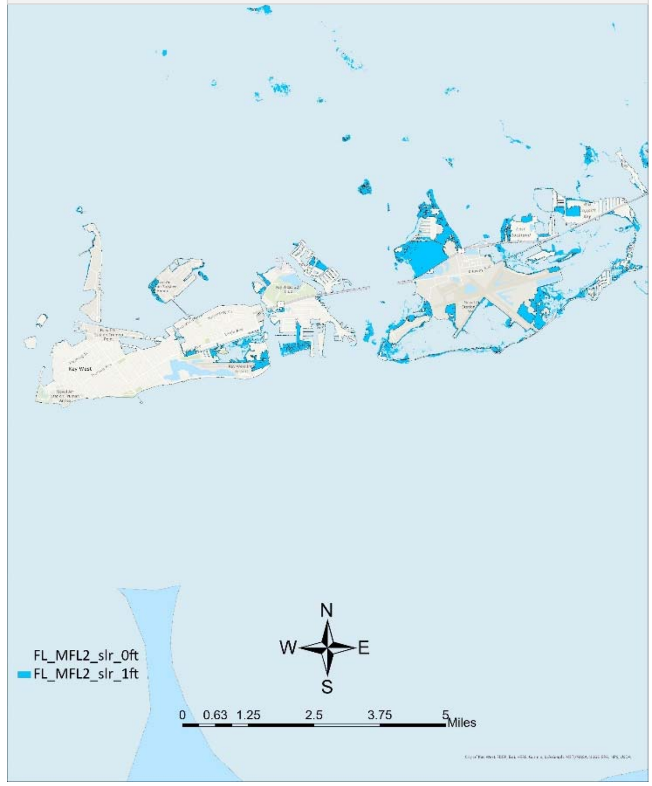
Miami Area...


No SLR
1ft. SLR
3ft. SLR
5ft. SLR
N
W
E
S
0 0.631.25 2.5 3.75 5 Miles
FL_MFL2_slr_0ft
FL_MFL2_slr_1ft
FL_MFL2_slr_3ft
FL_MFL2_slr_5ft

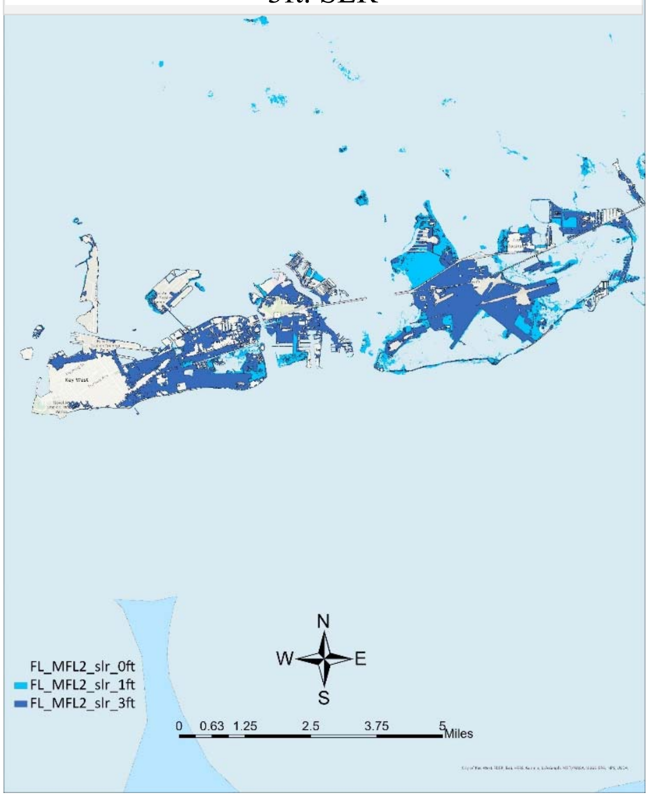
Key West Area...

No SLR

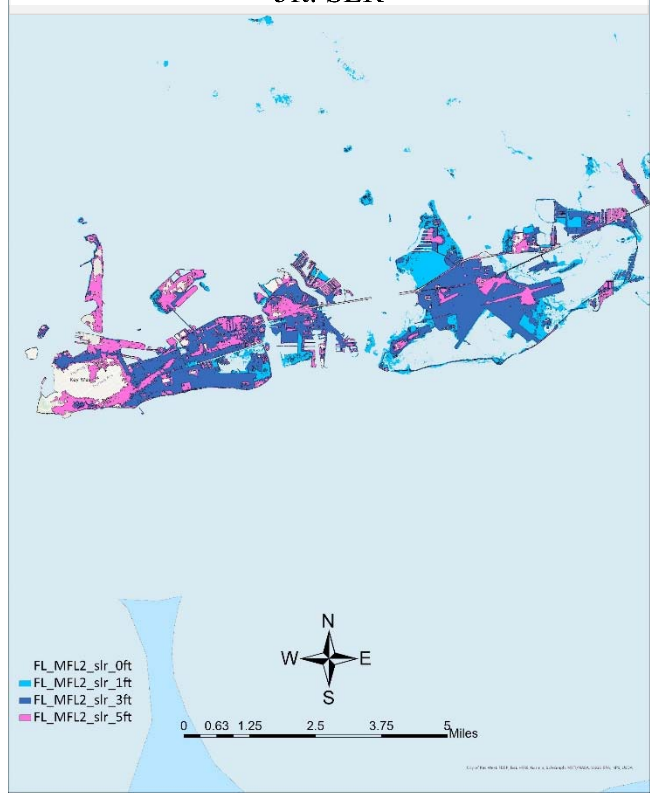

1ft. SLR




3ft. SLR

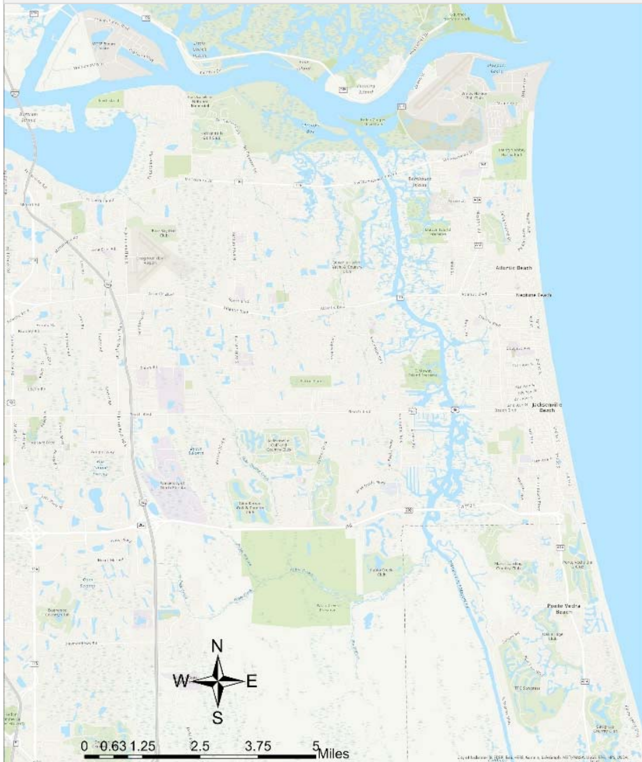



5ft. SLR

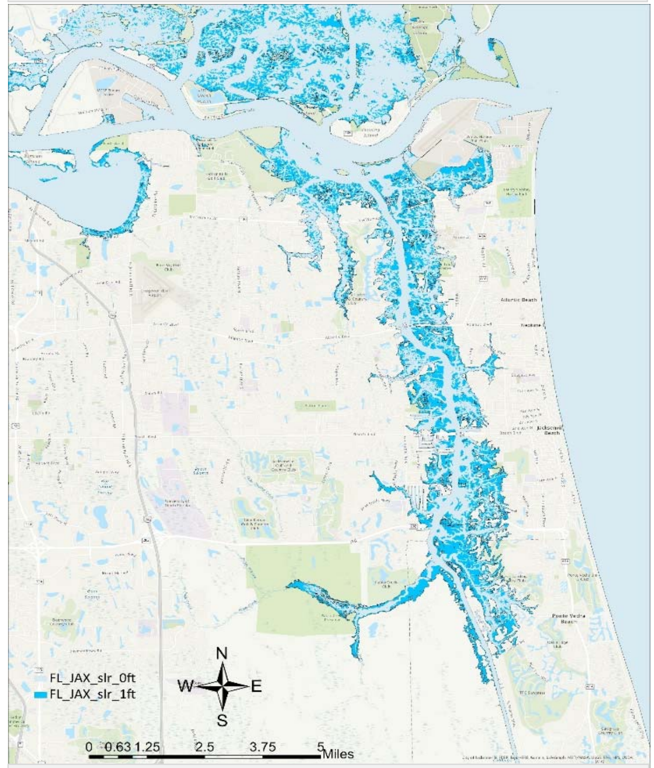


Jacksonville Area...

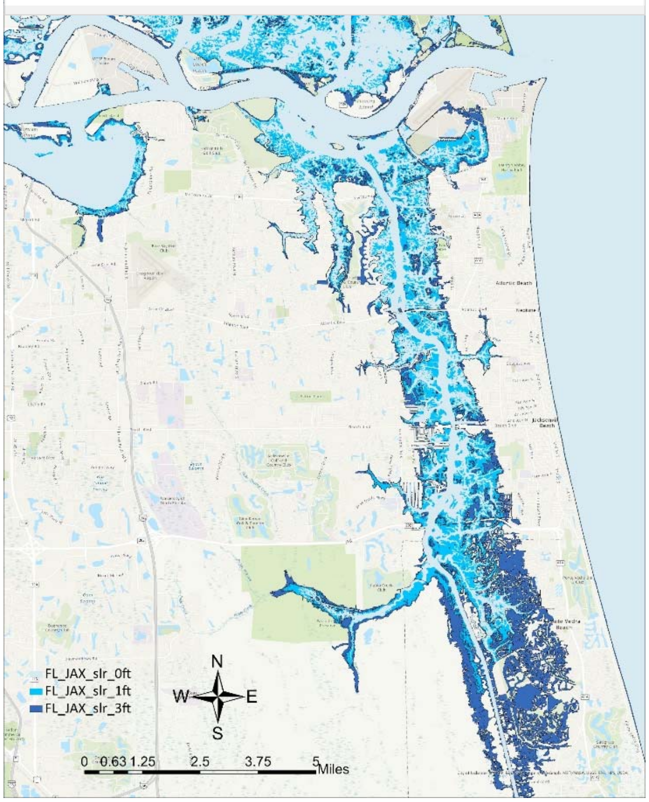
No SLR



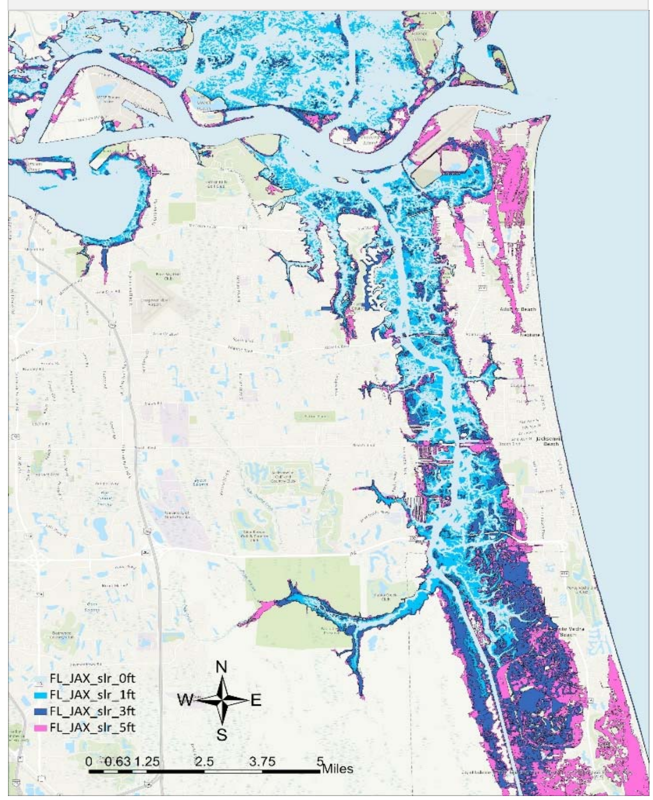

1ft. SLR




3ft. SLR




5ft. SLR



# Appendix E: Acronyms

**Table E.1 List of All Acronyms Used in this Report**

| Acronym/Label | Meaning |
|---|---|
| AFR | Annual Financial Report |
| AG | Agriculture (Agricultural Self-Supply) |
| AICR | Akaike Information Criterion for Robust Regression |
| APWA | American Public Works Association |
| ASR | Aquifer Storage and Recovery |
| AWS | Alternative Water Supply |
| BEBR | University of Florida's Bureau of Economic and Business Research |
| BICR | Bayesian Information Criterion for Robust Regression |
| BMAP | Basin Management Action Plan |
| BMP | Best Management Practices |
| BOCC | Board of County Commissioners |
| BOT | Board of Trustees of the Internal Improvement Trust Fund (DEP) |
| C&SF Project | Central and Southern Florida Project for Flood Control |
| CAMA | Coastal and Aquatic Managed Areas (DEP) |
| CARSWG | Coastal Assessment Regional Scenario Working Group |
| CARL | Conservation and Recreation Lands |
| CCI | Construction Cost Index (developed by the Engineering News-Record) |
| CEPP | Central Everglades Planning Project |
| CERP | Comprehensive Everglades Restoration Plan |
| CFWI | Central Florida Water Initiative (region includes parts of SFWMD, SJRWMD, & SWFWMD) |
| CII | Commercial/Industrial/Institutional (Self-Supply) |
| CIP | Capital Improvement Plan |
| CoSMoS | Coastal Storm Modeling System |
| CPI | Consumer Price Index |
| CSEC | Central Springs and East Coast Region (SJRWMD) |
| CSO | Combined Sewer Overflow |
| CTV | County Taxable Value |
| CUP | Consumptive Use Permit |
| CWA | Clean Water Act |
| CWNS | Clean Watersheds Needs Survey |
| CWSRF | Clean Water State Revolving Fund |
| CY | Calendar Year (January 1 through December 31) |
| DACS | Florida Department of Agriculture and Consumer Services |
| DACSI&A | Florida Forest Service Inholdings and Additions |
| DEAR | Division of Environmental Assessment and Restoration (DEP) |
| DEP | Florida Department of Environmental Protection |
| DFS | Florida Department of Financial Services |
| DO | Dissolved Oxygen |

| Acronym/Label | Meaning |
|---|---|
| DOR | Florida Department of Revenue |
| DOS | Florida Department of State |
| DRP | Division of Recreation and Parks Optimum Boundaries (DEP) |
| DSS | Domestic Self-Supply |
| DW | Drinking Water |
| DWINSA | Drinking Water Infrastructure Needs Survey and Assessment |
| DWRA | Division of Water Restoration Assistance (DEP) |
| DWSRF | Drinking Water State Revolving Fund |
| EAA | Everglades Agricultural Area |
| ECFTX | East-Central Florida Transient (groundwater model) |
| EDR | Office of Economic and Demographic Research |
| EEL | Environmentally Endangered Lands |
| EFA | Everglades Forever Act |
| ENP | Everglades National Park |
| ENR CCI | Engineering News-Record Construction Cost Index |
| EPA | U.S. Environmental Protection Agency |
| FEB | Flow Equalization Basin |
| FEMA | Federal Emergency Management Agency |
| FFPL | Florida Forever Priority List |
| FFS | Florida Forest Service (DACS) |
| FFY | Federal Fiscal Year (October 1 through September 30) |
| FHWA | Federal Highway Administration |
| FIB | Fecal Indicator Bacteria |
| FIPS Code | Federal Information Processing Standard Code |
| FLP | Forest Legacy Program |
| FNAI | Florida Natural Areas Inventory |
| FRDAP | Florida Recreation Development Assistance Program |
| FSAID | Florida Statewide Agricultural Irrigation Demand (version referred to by Roman numeral) |
| FWC | Florida Fish and Wildlife Conservation Commission |
| FWCI&A | FWC's Inholdings and Additions |
| FY | State Fiscal Year (July 1 through June 30) |
| GIS | Geographic Information System |
| GMSL | Global Mean Sea Level |
| GR | General Revenue |
| GRU | Gainesville Regional Utilities |
| GWUP | Group Water Use Permit |
| HERA | Hazard Exposure Reporting and Analytics |
| IWUP | Individual Water Use Permit |
| JV | Just Value |
| L/R | Landscape/Recreational (Self-Supply) |
| LA | Load Allocations (for Nonpoint Sources) |
| LATF | Land Acquisition Trust Fund |
| LEC | Lower East Coast Region (SFWMD) |

| Acronym/Label | Meaning |
|---|---|
| LFA | Lower Floridan Aquifer |
| LFY | Local Fiscal Year (October 1 through September 30) |
| LGIS | Local Government Infrastructure Surtax |
| LKB | Lower Kissimmee Basin Region (SFWMD) |
| LMUAC | Land Management Uniform Accounting Council |
| LWC | Lower West Coast Region (SFWMD) |
| MEOW | Maximum Envelope of Water |
| MFL | Minimum Flows and Minimum Water Levels |
| MGD | Millions of Gallons per Day |
| MOM | Maximum of Maximum |
| MOS | Margin of Safety |
| NAICS | North American Industry Classification System |
| NEEPP | Northern Everglades and Estuaries Protection Program |
| NFHL | National Flood Hazard Layer |
| NFRWSP | North Florida Regional Water Supply Partnership (includes parts of SJRWMD & SRWMD) |
| NLCD | National Land Cover Database |
| NOAA | National Oceanic and Atmospheric Administration |
| NPDES | National Pollutant Discharge Elimination System |
| NW – II | Region II (NWFWMD) |
| NW – Oth | Regions I, III, IV, V, VI, & VII (NWFWMD) |
| NWFWMD | Northwest Florida Water Management District |
| NWS | National Weather Service |
| OFS | Outstanding Florida Springs |
| OLS | Ordinary Least Squares |
| PG | Power Generation (Self-Supply) |
| POTW | Publicly Owned Treatment Works |
| PS | Public Supply |
| PSC | Florida Public Service Commission |
| PWS | Public Water System |
| RAP | Reasonable Assurance Plan |
| RCP | Representative Concentration Pathways |
| REDI | Rural Economic Development Initiative |
| RFLPP | Rural and Family Lands Protection Program |
| RO | Reverse Osmosis |
| RPS | Recovery and Prevention Strategies |
| RWSP | Regional Water Supply Plan |
| SD | School District |
| SF – LEC | Lower East Coast Region (SFWMD) |
| SF – LKB | Lower Kissimmee Basin Region (SFWMD) |
| SF – LWC | Lower West Coast Region (SFWMD) |
| SF – UEC | Upper East Coast Region (SFWMD) |
| SFWMD | South Florida Water Management District |
| SJR – CSEC | Central Springs and East Coast Region (SJRWMD) |

| Acronym/Label | Meaning |
| --- | --- |
| SJRWMD | St. Johns River Water Management District |
| SLR | Sea Level Rise |
| SLOSH | Sea, Lake, and Overland Surge from Hurricane |
| SOLARIS | Florida State Owned Lands and Records Information System |
| SRWMD | Suwannee River Water Management District |
| STA | Stormwater Treatment Area |
| STAR Report | Statewide Annual Report (published by DEP) |
| STV | School District Taxable Value |
| SW – H | Heartland Region (SWFWMD, partially in CFWI) |
| SW – N | Northern Region (SWFWMD, partially in CFWI) |
| SW – S | Southern Region (SWFWMD) |
| SW – TB | Tampa Bay Region (SWFWMD) |
| SWFWMD | Southwest Florida Water Management District |
| SWIM | Surface Water Improvement and Management |
| TAZ | Traffic Analysis Zone |
| TMDL | Total Maximum Daily Load |
| TN | Total Nitrogen |
| TP | Total Phosphorus |
| UEC | Upper East Coast Region (SFWMD) |
| UF | University of Florida |
| USACE | United States Army Corps of Engineers |
| USDA | U.S. Department of Agriculture |
| USGS | U.S. Geological Survey |
| WBID | Water Body Identification Number |
| WCA | Water Conservation Area |
| WDPS | Water Planning Coordination Group |
| WIFIA | Water Infrastructure Finance and Innovation Act |
| WLA | Wasteload Allocation (for Point Sources) |
| WMD | Water Management District |
| WPSPTF | Water Protection and Sustainability Program Trust Fund |
| WRDWP | Water Resource Development Work Program |
| WSA | Water Supply Assessment |
| WTP | Water Treatment Plant |
| WUP | Water Use Permit |
| WW | Wastewater |
| WWTF | Wastewater Treatment Facility |
| WWTP | Wastewater Treatment Plant |