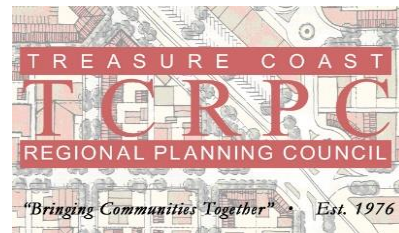


Sea-Level Rise Case Study: Town of Jupiter, Florida

Using UF's GeoPlan Sketch Tool and NOAA's Coastal
Flood Exposure Mapper and Sea-Level Rise Viewer



Photo Credit: D. Ramey Logan

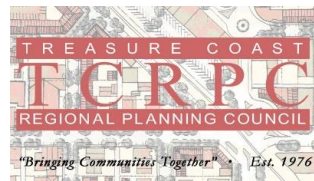


Sea Level Rise Case Study: Jupiter, Florida

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This publication was funded in part, through a grant agreement from the Florida Department of Environmental Protection, Florida Coastal Management Program, by a grant provided by the Office for Coastal Management under the Coastal Zone Management Act of 1972, as amended, National Oceanic and Atmospheric Administration Award No. NA15NOS4190217. The views, statements, findings, conclusions and recommendations expressed herein are those of the author(s) and do not necessarily reflect the views of the State of Florida, NOAA or any of their sub-agencies.



Executive Summary

Southeast Florida's coastline is a transition zone for unique natural ecosystems; marine, coral reefs and oyster bars, shellfish beds, sea grass beds, barrier islands, bays, estuaries, lagoons, beaches, and wetland habitats. As these ecosystems overlap with development and are intertwined with residential and commercial processes, there are challenges in maintaining quality of life, transportation, tourism, and coastal environments. Yet there are also opportunities for shoreline habitats to provide protection to the built environment, as mangroves buffer storm surge and filter pollution, and living shorelines prevent erosion. Sea level rise (SLR) is further complicating the balance between Florida's unique mosaic of ecosystems and the diverse population, public infrastructure, private property and economy in Florida. To understand how to maintain this balance, the first step is to understand risk.

This document is a vulnerability case study of Jupiter, Florida. Selected because of its positioning adjacent to one of South Florida's largest natural inlets, the Loxahatchee River, and the town's existing interest in increasing resiliency, this study will review the applicability of several hazard assessment tools. The methods outlined below will serve as a template to begin the initial phases of conducting comprehensive vulnerability assessments all throughout Florida; the steps presented will provide as a guide to establishing the necessary preliminary framework. Specifically, this review will provide background information on the area of interest, describe exposure to inundation under projected sea-level rise and storm hazards, and then assess the potential sensitivities of coastal wetlands, infrastructure, and human populations in the area using NOAA's Sea-Level Rise Viewer and Flood Exposure Mapper.

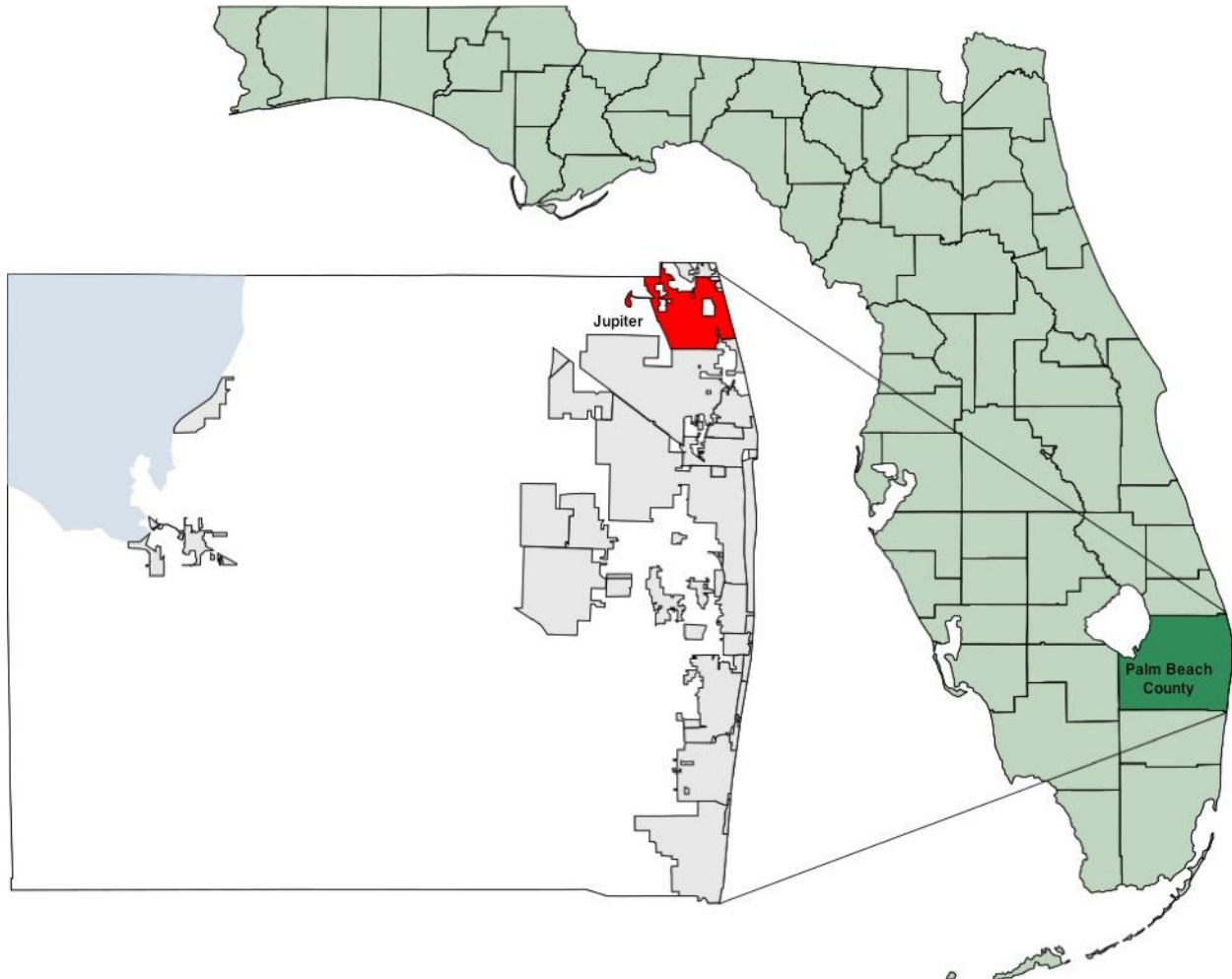
In the coming decades, sea level is projected to rise several feet. The impact of this rise will be complex however—present day sea level and projected increases are not uniform along our coastlines. Additionally, other factors must be taken into consideration when assessing exposure to hazard, such as temporary sea level increases from storm surge, increased flooding frequency and duration, and other changes such as population growth and coastline fluctuations and land use changes. While not all of these can be modeled with absolute certainty, the provided tools provide excellent approximations and can serve to inform hazard managers, land use planning, and adaptation policies.

Just as inundation due to sea-level rise, storm surge, and flooding will occur unevenly along South Florida's coastlines, the impact of these hazards will also vary due to the sensitivities of populations, the ability of ecosystems to adapt, and the placement and resiliency of the region's infrastructure. This case study specifically shows the projected inundation of Jupiter and uses the described tools to qualitatively assess the impacts of this inundation in terms of environmental change and exposed populations, in addition to simplified quantitative assessments of impacted infrastructure.

Assessing vulnerability in such a multi-faceted manner will provide a foundation on which to effectively address the resiliency needs in the region; highlighting areas that appear especially exposed and sensitive are an important first step in determining the prioritization of hazard impact mitigation resources. The assessment below displays conditions under two feet of sea-level rise, projected to occur sometime between 2050 and 2060 according to the U.S. Army Corps of Engineers' (USACE) "high" scenario.

There are innovative solutions to coastal hazards that both protect ecosystems and leverage ecosystem services for protection. When planning for SLR impacts, it is most beneficial to maintain a balance of both engineering and natural solutions. Adaptation recommendations to increase resilience within the study area include habitat restoration, monitoring, and infrastructure improvements. Long-term actions will need to consider elevation of high-risk road segments. Of particular importance will be the identification of especially vulnerable communities, or populations within those communities, based on an assessment of differential vulnerabilities. One method of assessing this is estimate a population's *sensitivity* to a given stressor—in this case, not only asking where will flooding occur, but how significant that flooding will be

for the populations that are impacted based on socioeconomic and sociodemographic data. In depth interviews and site-specific social research are recommended to assess vulnerability, however this component will not be discussed in great deal in this study.



“Things are changing. To be resilient and prosperous it is absolutely essential that we proactively engage.”

From the Southeast Florida Regional Climate Compact, 2016.

Project Background

In 2011, the Florida Department of Economic Opportunity (DEO) initiated a five-year project to integrate SLR adaptation into planning, including the local comprehensive plan, hazard mitigation plan, and post-disaster redevelopment plan¹. The initiative is supporting this project of special merit in piloting adaptation planning guidance in coastal communities as well as compiling lessons learned and conducting information dissemination and outreach. By providing statewide guidance on how to use existing tools and collaborative trainings to create a unified multi-region coastal resilience network for Florida, an iterative set of co-benefits are produced from the state to the local level.

Through funding from the National Oceanographic and Atmospheric Administration (NOAA) and the Florida Department of Environmental Protection (DEP), DEO is working with the South Florida Regional Council (SFRC) and Florida's nine other Regional Planning Councils to create regional Vulnerability Assessments and conduct a series of trainings, which will allow for:

- Support of local resiliency planning efforts;
- Identification of areas that are experiencing coastal flooding or at risk for coastal flooding and SLR; and
- Translation of science to design and implementation of adaptation policy, particularly with respect to policy changes such as the redevelopment component within Florida Statute 163.

Using the tools described in this report to assess coastal exposure and sensitivity to sea-level rise are a critical component of addressing coastal vulnerabilities and mitigating losses. The results inform adaptation planning for the study area and provide an example for applications statewide.

Tools Buffet Event

On October 27th, the South Florida Regional Planning Council and Treasure Coast Regional Planning Council held a joint *Train the Trainers* workshop; the event was entitled the *Tools Buffet*, and was held at the Lake Worth CMAA Recreation Complex from 9:30 to 12:30. Roughly 30 were in attendance. Dr. Keren Bolter kicked off the event with a brief introductory presentation to the Train the Trainers project and the causes and implications of sea-level rise in South Florida, in addition to the handful of tools provided by NOAA and the University of Florida being covered in the workshop's breakout groups. At 10:45, after a brief break, attendees broke off into one of three groups based on an assigned number indicated on their agenda—one group covered UF's GeoPlan Tool, the second covered NOAA's Flood Exposure Mapper, and the last group covered NOAA's Sea-Level Rise Viewer.

Twenty-minute demonstrations were given in each of the groups, followed by ten-minute question and answer sessions where presenters attempted to gather feedback on attendees' perceptions of tool usability—most attendees were at least marginally familiar with the tools, and many had used them previously. After each 30-minute session, groups rotated to a new station to receive training for the next tool. After each team had received demonstrations for each of the three tools, the entire group reconvened for closing statements; the organizers also provided attendees with feedback surveys to document the successes and areas for improvement of the event. Overall, feedback was highly supportive, and attendees found the training to be extremely helpful—many specifically requested information on holding additional trainings in their region or specific organizations.

¹ For more information on DEO's resources for Adaptation Planning, please visit <http://www.floridajobs.org/adaptationplanning>

Frequently Asked Questions

1) Why is the sea level rising?

There are two kinds of SLR: global and local. Global SLR is occurring mainly due to thermal expansion and melting of land ice. Land ice accounted for about 65% of the total SLR budget from 1993 to 2008. (Church et al., 2011). Local SLR rates depend on natural geologic processes as well as land use processes and groundwater withdrawal. These processes include glacial isostatic rebound and subsidence. The local SLR rates in the Treasure Coast and Southeast Florida are very similar to the global SLR rates.

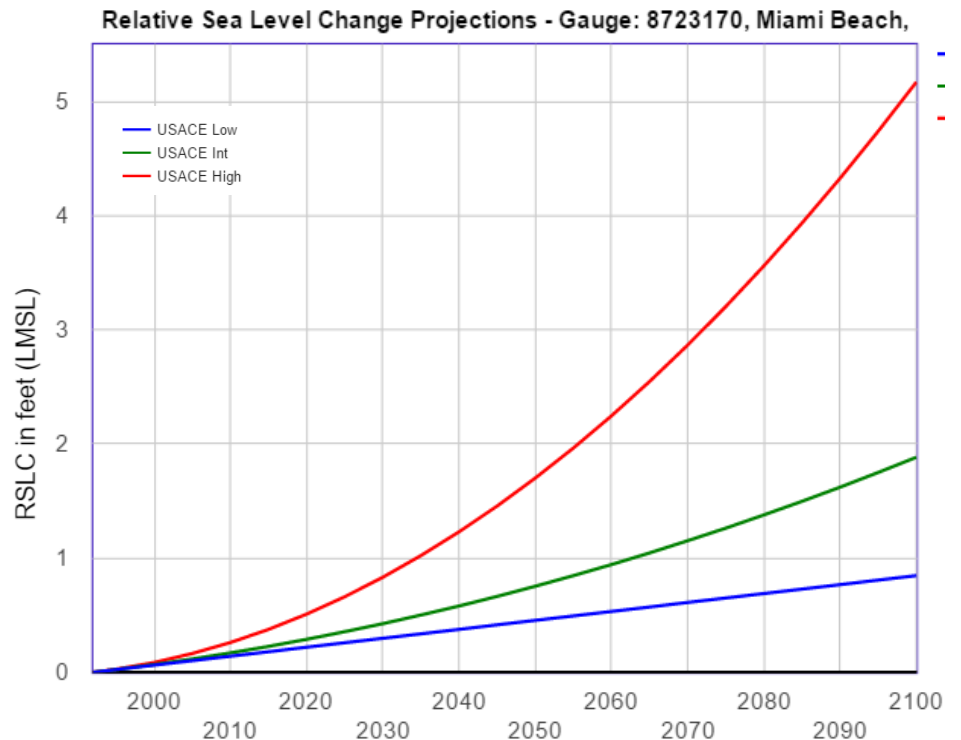
2) How much has sea level risen in the past?

In the Treasure Coast and Southeast Florida, sea level has risen 5.5 inches in the past 50 years (1963-2012), according tide gauge data (UCSUSA.org). Sea level is measured by tide gauges and, more recently, satellite altimetry.

3) What are future projections?

There are a range of projections from entities including the National Oceanic and Atmospheric Administration (NOAA), the U.S. Army Corps of Engineers (USACE), the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4), and the National Research Council (NRC). These projections are described in Appendix A. The table and graph below illustrate the USACE projections used in this study.

USACE Projections	Feet	
	Intermediate	High
Year		
1992	0	0
2000	0.07	0.09
2010	0.17	0.26
2020	0.29	0.51
2030	0.43	0.83
2040	0.58	1.23
2050	0.75	1.7
2060	0.94	2.25
2070	1.15	2.87
2080	1.38	3.56
2090	1.62	4.33
2100	1.88	5.17



4) Which projections and scenarios were used for this study and why?

The USACE projections were used in the analysis because these are the projections that are embedded within the Geoplan Sketch tool. These are also the projections used by the Southeast Florida Regional Climate Compact. The high scenario was used for 2040, 2060, 2080, and 2100, using both mean sea level and mean higher high water. While the results showed minimal long-

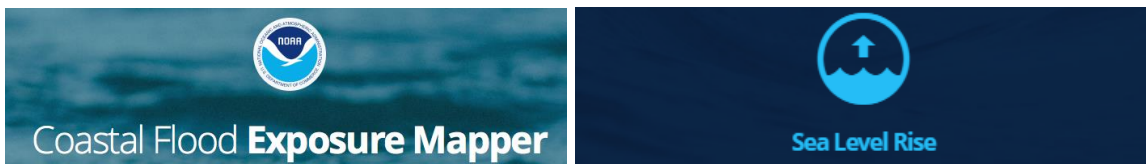
term tidal flooding in 2040, short-term events, such as storm surge, can impact the vulnerable areas indicated even today.

5) What is used as baseline sea level (current, or 0 in the above table), and what is mean higher high water (MHHW)?

Mean higher high water is the average of the daily highest tide over an agreed upon period. That period is called the National Tidal Datum Epoch, and presently runs from 1983 to 2001; the midpoint year is 1992, which explains it's listing at "0" in the above table. This datum (or reference point) has been chosen as a standard so that all measurements and projections can be referenced to the same time and height—this 19-year cycle has been shown to smooth out astronomical anomalies and various other global cycles that cause discrepancies in sea level height from year to year. Just as our three-dimensional models of the Earth are updated sporadically when more advanced representations become available, eventually the national tidal datum will be updated as well to refer to a more recent date—in the mean time however, it's crucial that we all refer to the same baseline.

6) What are the NOAA Coastal Flood Exposure Mapper (CFEM) and Sea-Level (SLR) Viewer?

The Coastal Flood Exposure Mapper helps stakeholders to start community discussions about hazard impacts with maps of local areas that show people, places, and natural resources exposed to coastal flooding. Select a section to view maps showing flood hazards or different aspects of community exposure to those flood hazards, including infrastructure and ecosystem exposure to flooding. The interactive web viewer allows the user to select maps showing either just coastal flood hazards or where societal, infrastructure, and ecosystem assets are exposed to coastal flood hazards for any location in the Coastal United States. The user can zoom in and pan to set extent to get county-wide or neighborhood resolution visualizations.



The SLR Viewer is a similar tool provided by NOAA that provides a different set of tools for investigating flood exposure. A slightly more advanced ecosystem layer is provided, and the Social Vulnerability Index, or SoVI, is utilized in lieu of individual demographic variables as mapped above. Users are also able to view specific levels of inundation, rather than viewing 1-6 feet all simultaneously. In cases where the same data is displayed, the two tools use the same sources.

7) What is vulnerability?

Vulnerability is a concept that has evolved immensely over the last several decades; as communities become increasingly interested in sustainability and resiliency, planners and hazard managers must consider not only the extent of sea-level rise or inundation during flood events, but also how socioeconomic factors and environmental conditions will affect the impacts of that inundation. In this document we will loosely define vulnerability as a condition that is based on three factors: exposure, which we will define as the extent of inundation and what is flooded; sensitivity, a further investigation into what is inundated and, more importantly, how significant that impact will be; and adaptive capacity, which is the ability of a community to address these sensitivities, thereby increasing their resiliency (and decreasing their vulnerability). The maps below will primarily address exposure and, to a limited extent, sensitivity—adaptive capacity requires further analysis beyond the scope of this document, however recommendations on how best to continue this assessment, and viable strategies to increase resiliency, will be addressed.

- High- and moderate-risk flooding (designated by the Federal Emergency Management Agency) (up to 2 zones)
- Categories 1, 2 and 3 hurricane storm surge (up to 3 zones)
- SLR of 1, 2, and 3 feet above MHHW (up to 3 zones)

The darker the color on the map, the more flood hazard zones there are for that area.

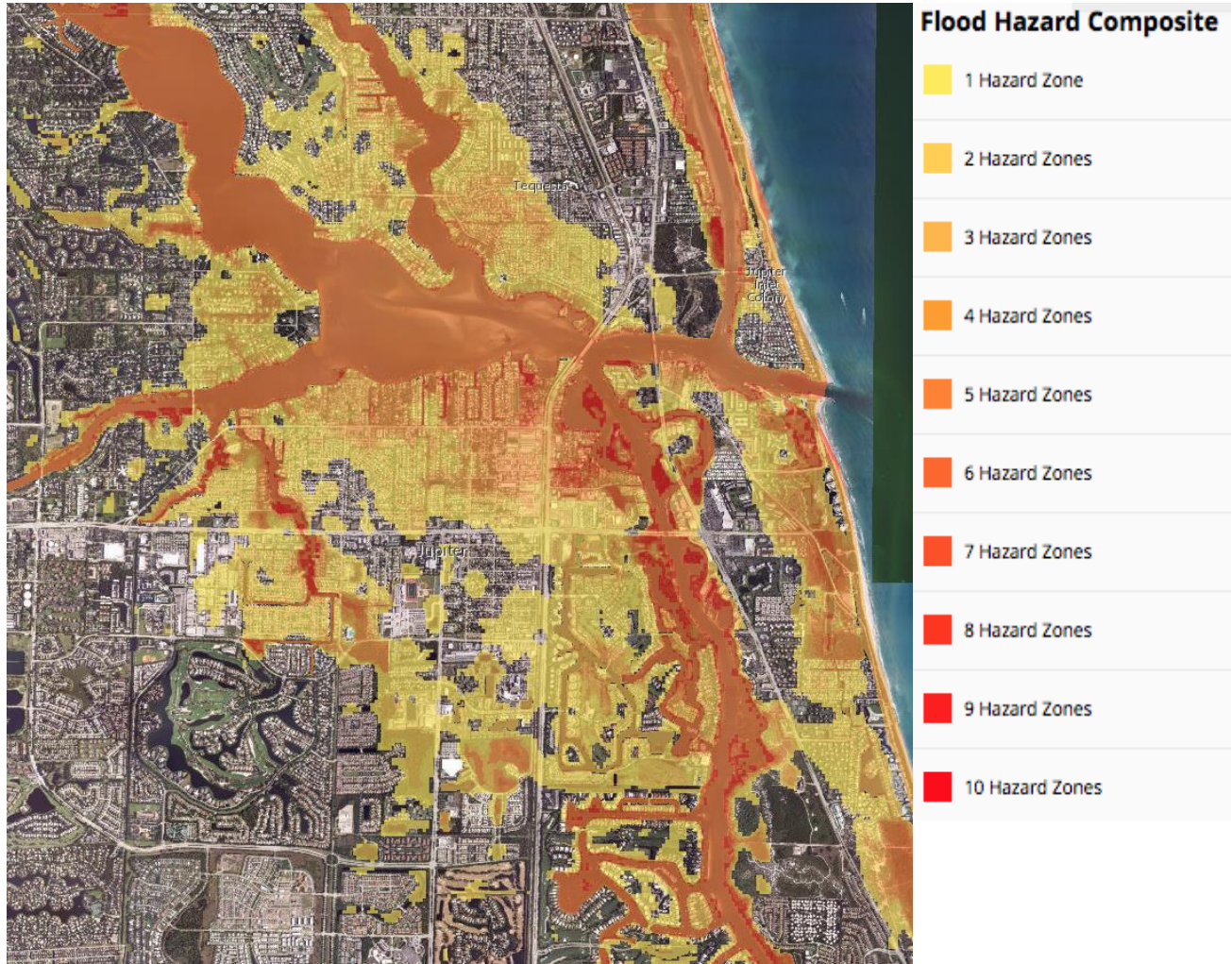


Figure 2: Source <https://coast.noaa.gov/floodexposure/#/map>

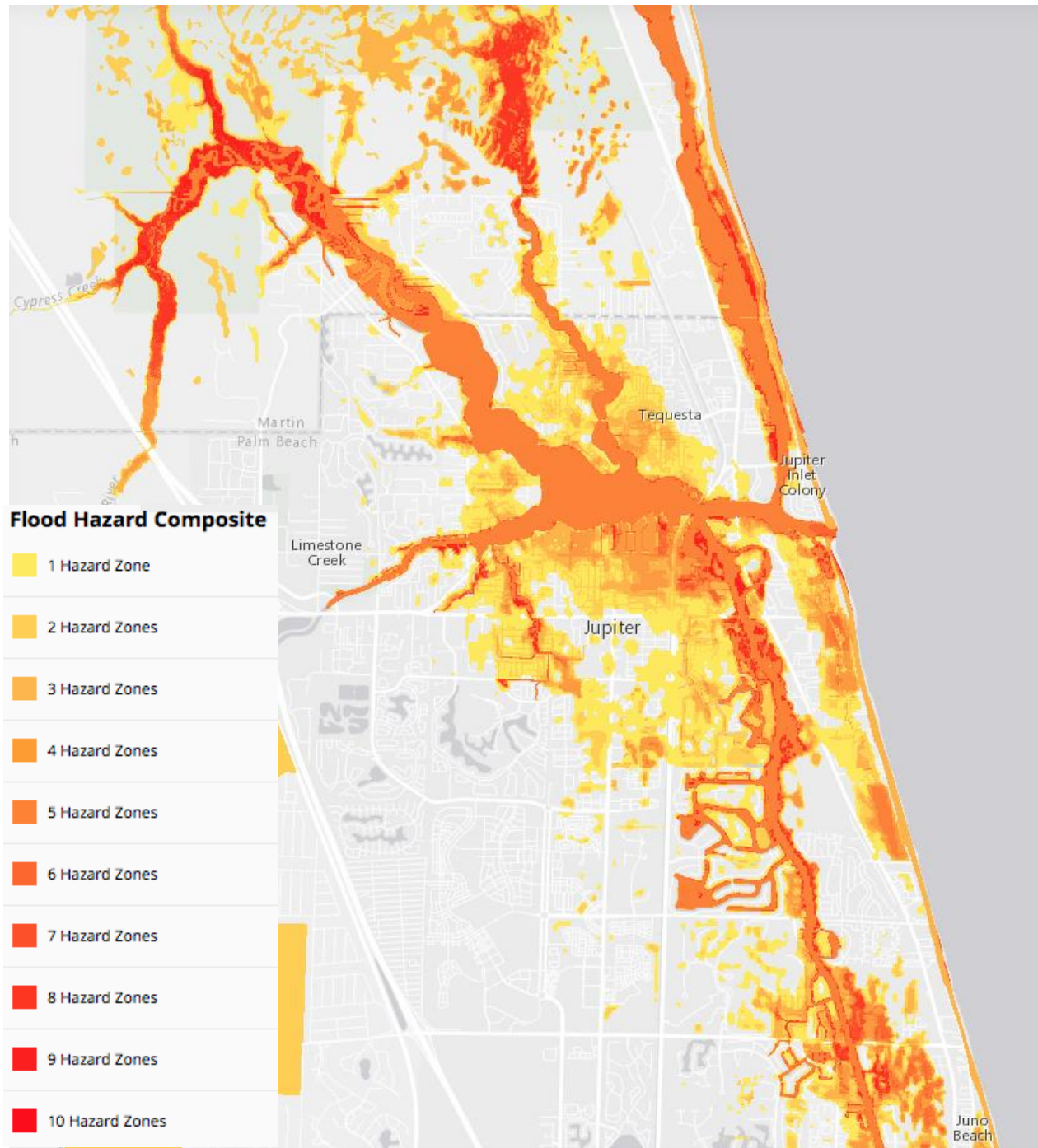


Figure 3: Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 4 illustrates in red low-lying coastal areas prone to flooding during extreme high tides, also known as shallow coastal flooding. These local designations are made by National Weather Service (NWS) offices using National Oceanic and Atmospheric Administration (NOAA) tide gauge readings. When the water levels go above a threshold designated by NWS, shallow coastal flooding occurs.

Shallow coastal flooding is usually caused by the extreme high tides that occur a few times per year when the sun, moon, and earth align, or during storm events. Rainfall or wind pushing water over land can increase flooding levels.



Figure 4: Flood susceptible areas shown in red. Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 5 shows high-risk (1% annual chance, or 100-year floodplain) areas in red and moderate-risk (0.2% annual chance, or 500-year floodplain) areas in orange flood zones designated by the Federal Emergency Management Agency (FEMA). Some parts of the flood zone may experience frequent flooding while other areas are only affected by severe storms. Figure 6 shows the area at a slightly larger scale and is drawn in with a satellite imagery base layer.

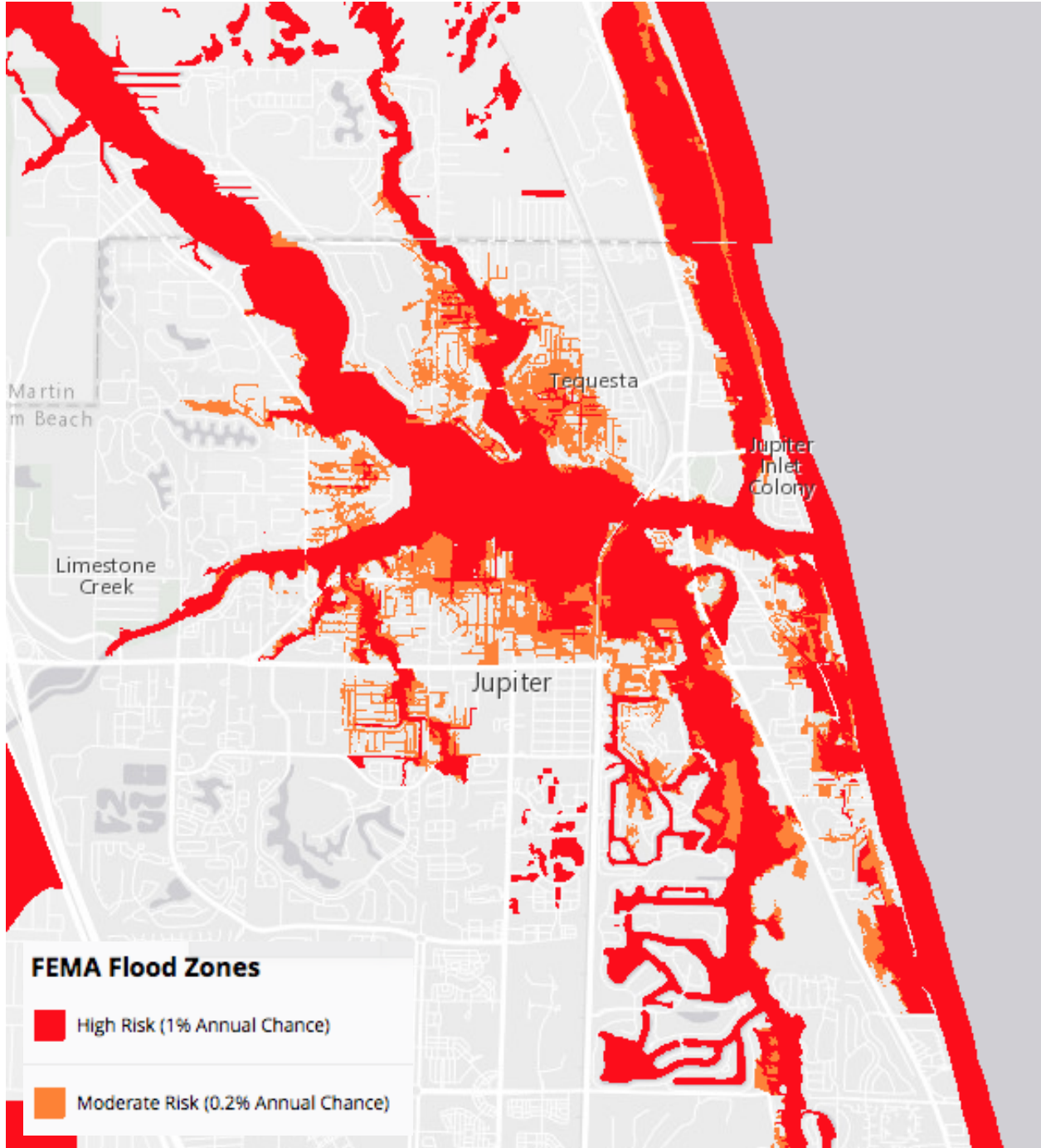


Figure 5: Source <https://coast.noaa.gov/floodexposure/#/map>

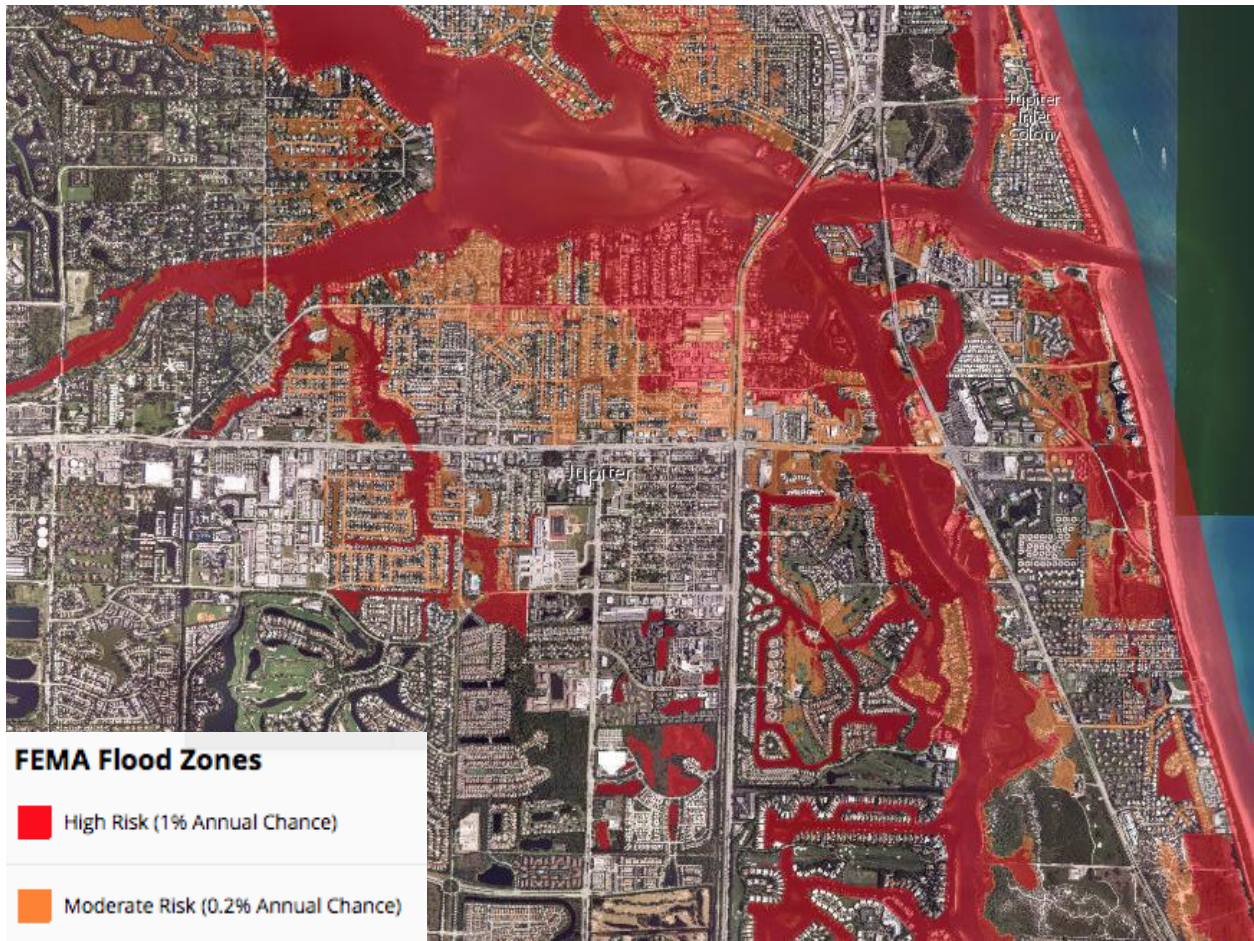


Figure 6: Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 7 overlays poverty levels with shallow coastal flooding areas to indicate that there are some vulnerable areas in which between 15.1% and 25% or more of the population live below the poverty line. Figure 5 overlays flood-prone areas with projected population growth to indicate that vulnerable areas on the barrier islands will have increasingly vulnerable populations as growth is projected to be over 2.6%.

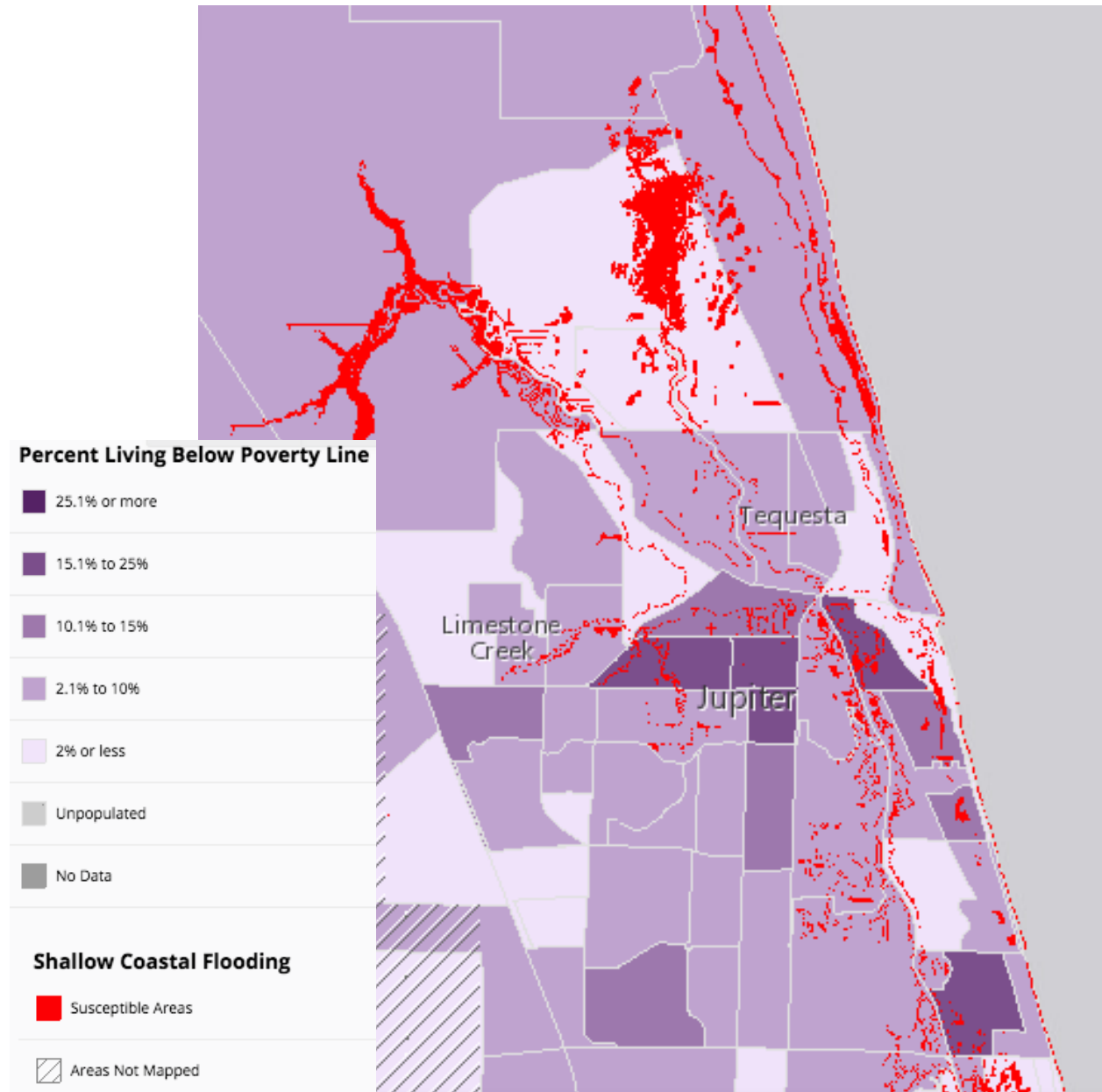


Figure 7: Source <https://coast.noaa.gov/floodexposure/#/map>

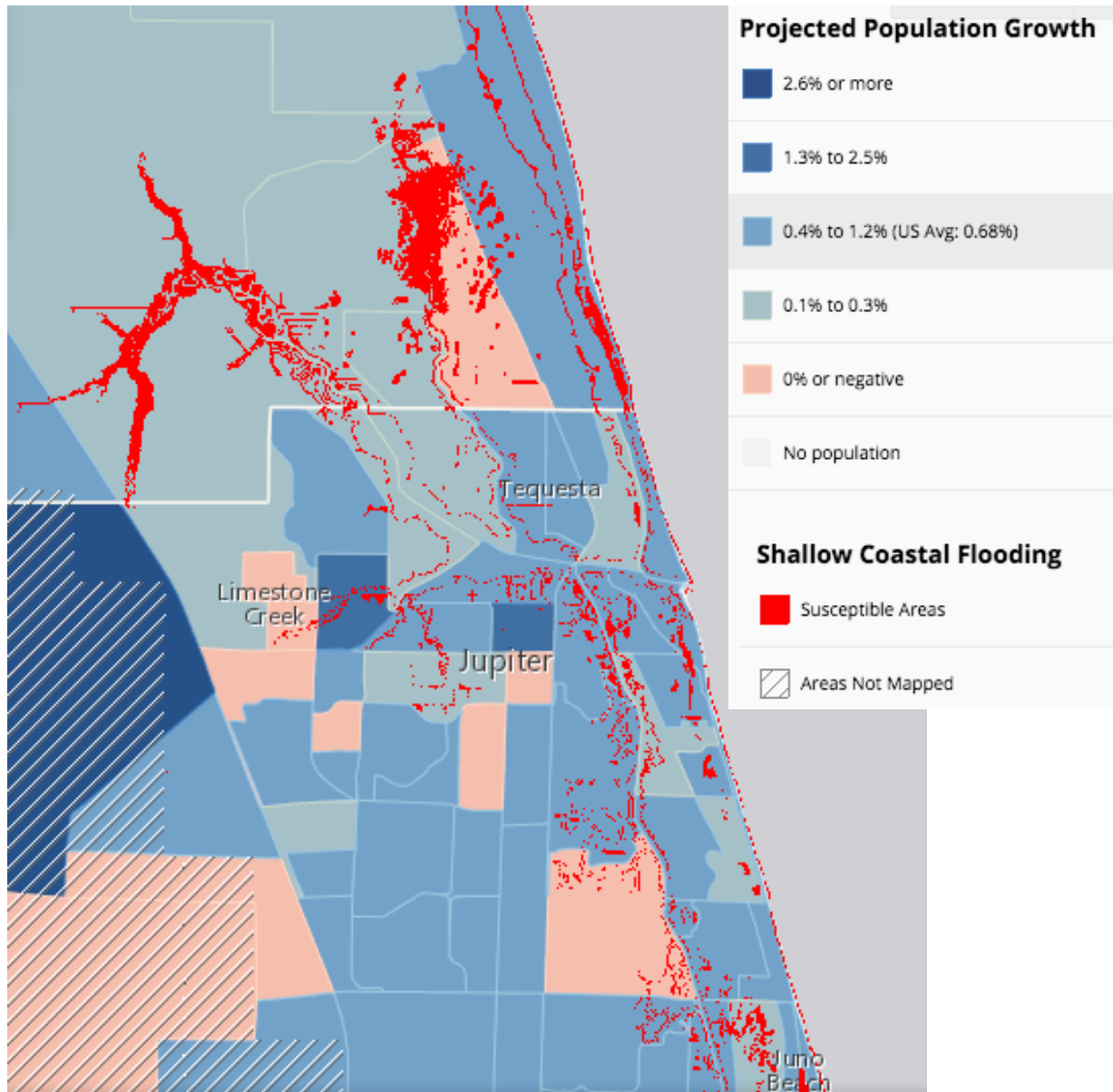


Figure 8: Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 8 uses projected annual population change for 2012 to 2017 in or near coastal flood-prone areas. Increases in population could lead to more jobs, development, and public services, which is problematic if increases are in a hazard-prone area. Social vulnerabilities could increase if the types of people moving into the area are more susceptible, or *sensitive*, to hazard impacts.

Data shown in Figure 9 were derived from storm surge inundation maps created by the National Hurricane Center (NHC) Storm Surge Unit with the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. SLOSH is used to calculate storm surge heights and the extents of inundation for hurricane evacuation studies.

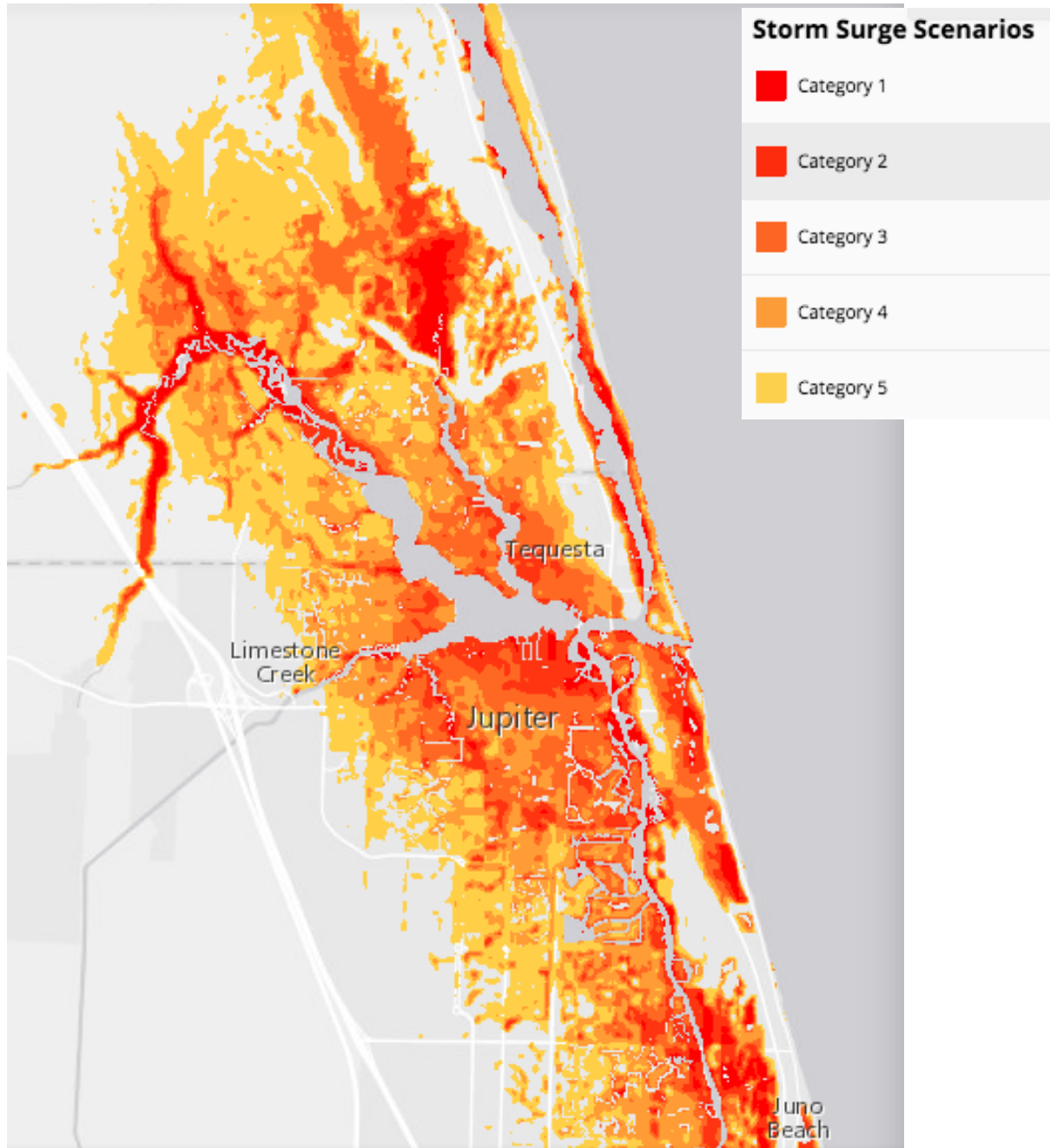


Figure 9: Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 10 shows SLR scenarios of 0 to 6 feet, which represent a rise in water above the average of the highest high tides (called mean higher high water, or MHHW) for hydrologically connected areas. Figure 11 shows a close up of the region directly adjacent to the Loxahatchee River; the transparency of the sea-level rise layer has been increased to aid in visualizing the developed land below.

Figure 10: Source <https://coast.noaa.gov/floodexposure/#/map>

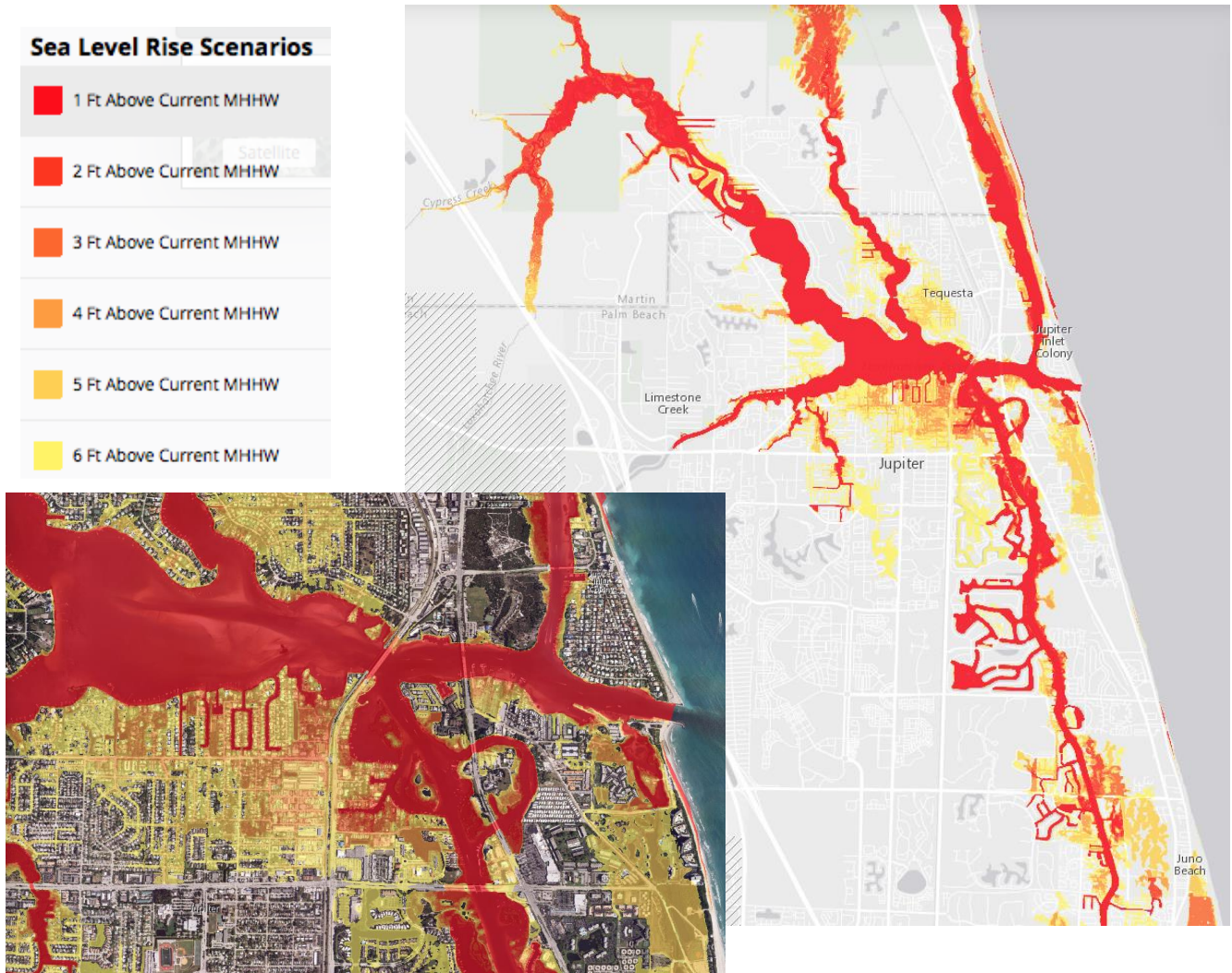


Figure 11: Source <https://coast.noaa.gov/floodexposure/#/map>

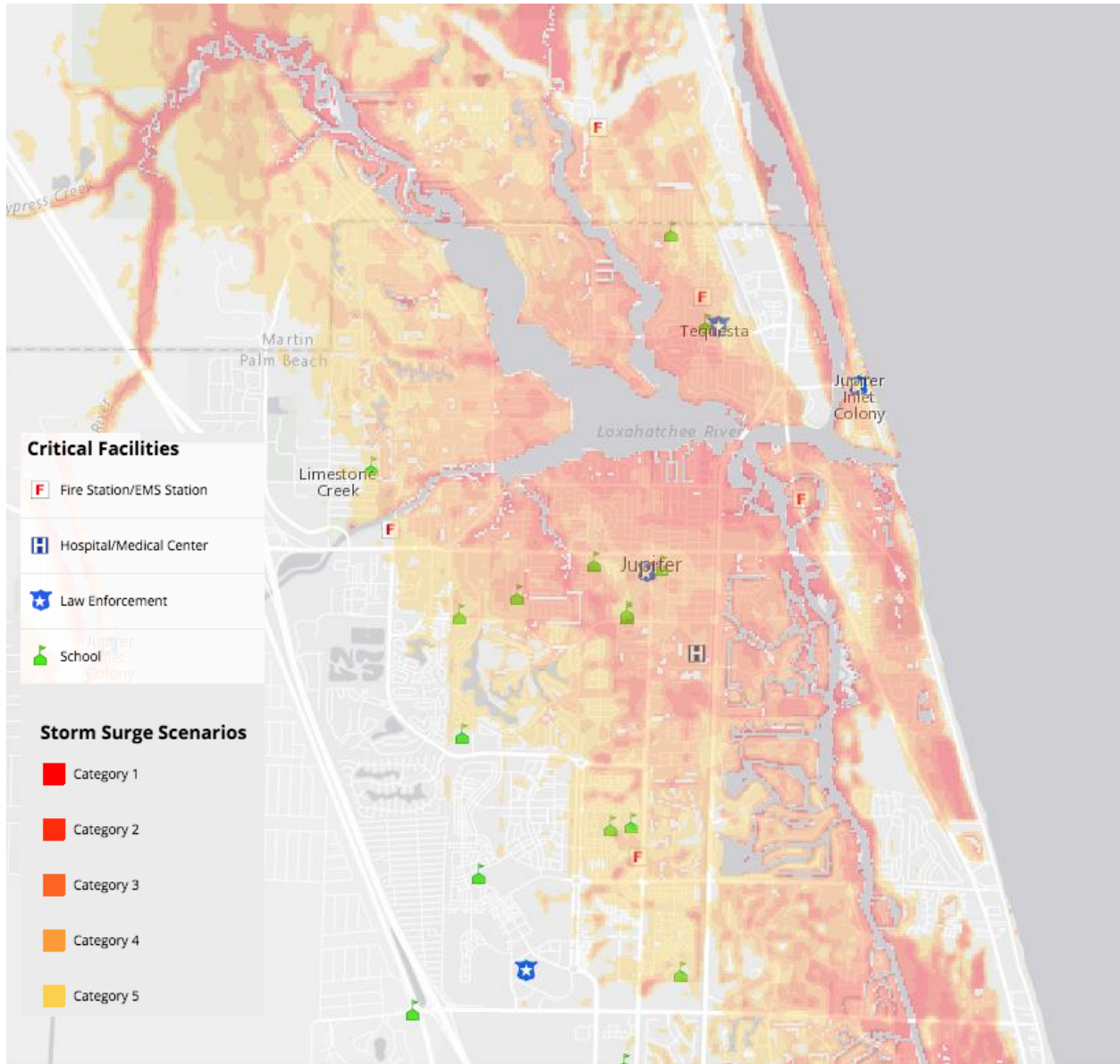


Figure 12: Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 12 shows critical facilities that are potentially vulnerable to storm surge. Determining the exposure of the town’s emergency response facilities may prove important when developing disaster response scenarios. The transparency of the surge layer has been turned up so visualizing the point data underneath is possible. Hazard response managers can use this information to determine how response times might be impacted during extreme weather events, or what schools may be safest to designate as meeting locations, shelters, or supply centers.

SLR Scenario Sketch Planning Tool: Impacts to Transportation Infrastructure

The threat of SLR creates uncertainty in the reliability and integrity of the transportation infrastructure network of many coastal communities. Potential network vulnerability to coastal flooding in these places should be assessed years before the impacts are projected to occur. Comprehensive analysis and the

identification of roadway impacts such as frequently submerged segments, poor roadway drainage and degraded road beds are paramount in the near term to effectively plan for resiliency in the future.

The Florida Sea Level Scenario Sketch Planning Tool (Sketch Tool) is designed to identify the transportation infrastructure in Florida that are most likely to be impacted by tidal inundation from the projected sea level rise rates generated by the U.S. Army Corp of Engineers (USACE).

The Florida Department of Transportation (FDOT) provided funding to the University of Florida's Geo Plan Center to develop the Sketch Tool as an interactive, web based, geospatial application to be widely used for coastal resiliency planning.

For the Town of Jupiter case study, the Sketch Tool was used to identify transportation infrastructure vulnerabilities near the town's waterfront areas adjacent to the Loxahatchee River, Indian River Lagoon and the Jupiter Inlet. The Sketch Tool exercise focused on the area bounded by Beach Road to the North, Indiantown Road to the South, Alternate A1A to the west and US Highway 1 to the East.

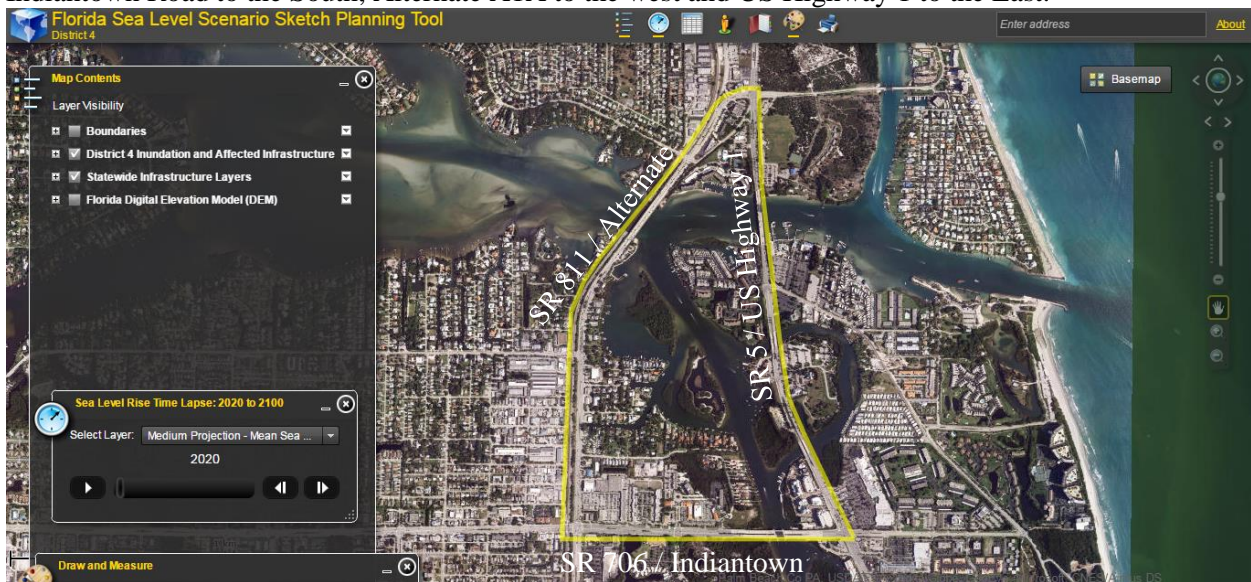


Figure 13: Study Area

The Sketch Tool generates SLR scenarios by processing the following pre-loaded data layers: inundation surfaces, tidal datum and transportation features. The inundation surfaces are derived from USACE projections at three rates of sea level rise (Low, Medium and High). The tidal datum is derived from NOAA tide station reports for the region's median sea level (MSL) and mean higher high water (MHHW). The transportation features represent roadways, airports, seaports and rail infrastructure from FDOT's NAVTEQ, RCI and SIS datasets. When these data layers are selected and active, the tool spatially queries the transportation features which intersects the inundation surfaces for the chosen time period, SLR rate and tide level. These features are flagged as potentially vulnerable infrastructure and displays in an attribute table as data outputs.

The sea level rise scenarios for this case study were generated using the projected USACE high rate, the Mean Higher High Water (MHHW) tidal datum for time periods 2040, 2060, 2080 and 2100 and the following sample segments from the NAVTEQ State Road dataset:

- SR 5 (US Highway 1)
- SR 706 (Indiantown Rd)
- SR 811 (Alternate A1A)

Based on the data outputs, from 2040 to 2060, there will be no significant inundation threats to the sample roadway segments selected. By 2080, however, the projected MHHW level resulting in 50 inches of inundation will cause an approximate 0.57 mile segment of SR 811 to be under water. During this same time period SR 5 and SR 706 will mostly be unaffected. By 2100, the projected MHHW level will result in 70 inches of inundation causing a significant portion of the lands bordering the Intracoastal Waterway and the Loxahatchee River to be submerged. Within the study area, the roadway impacts will be approximately 0.20 miles of SR 5, 0.82 miles of SR 706 and 1.77 miles of SR 811.

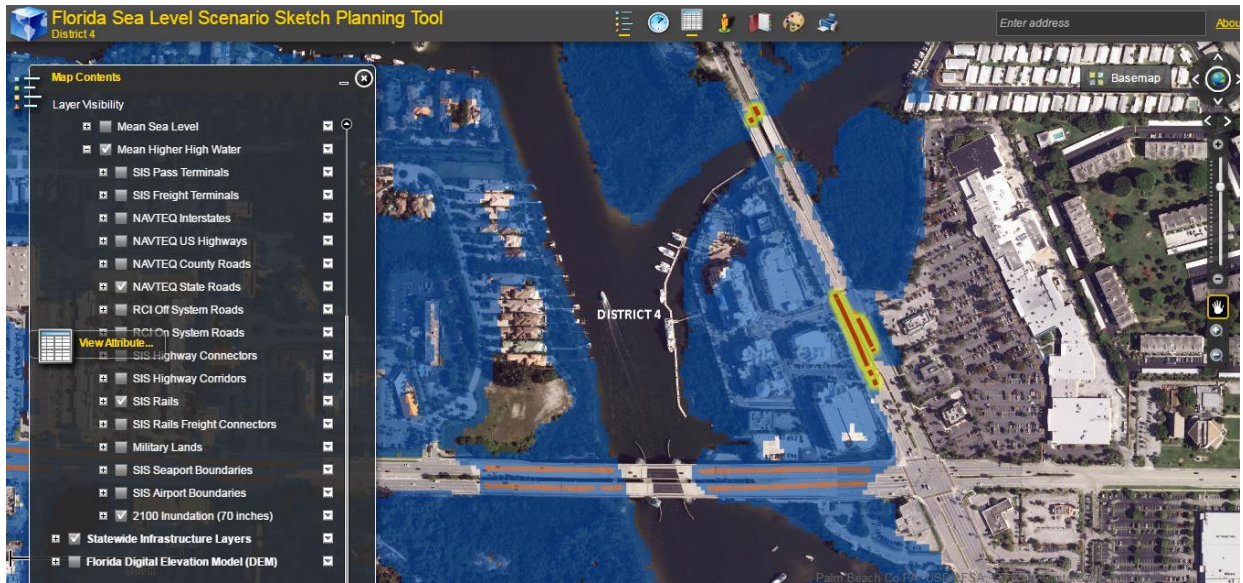


Figure 14: SR 5 (US Highway 1) inundation by 2100 at MHHW level

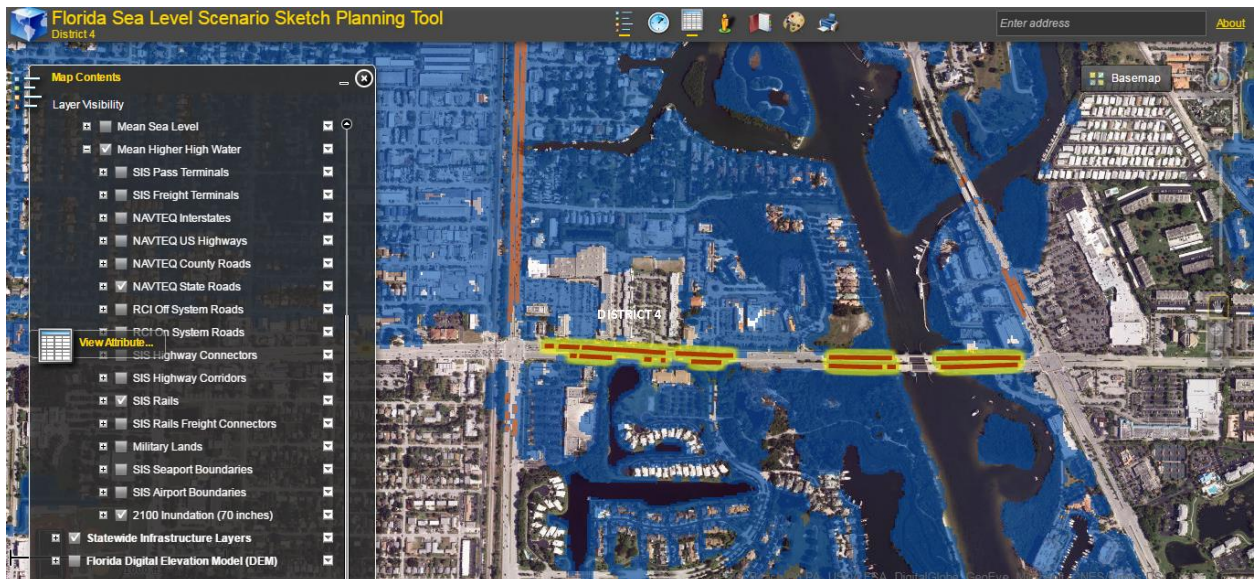


Figure 15: SR 706 (Indiantown Rd) inundation by 2100 at MHHW level

In addition to the roadway network, rising seas will also have an impact on the rail infrastructure traversing this coastal community. Within the study area, portions of the FEC railroad adjacent to SR 811 was shown

to be below sea level by 2080 at the MHHW projection. The inundation of the rail bed in this area is projected to increase over time from approximately 77 feet by 2080 to approximately 1,798 feet by 2100.

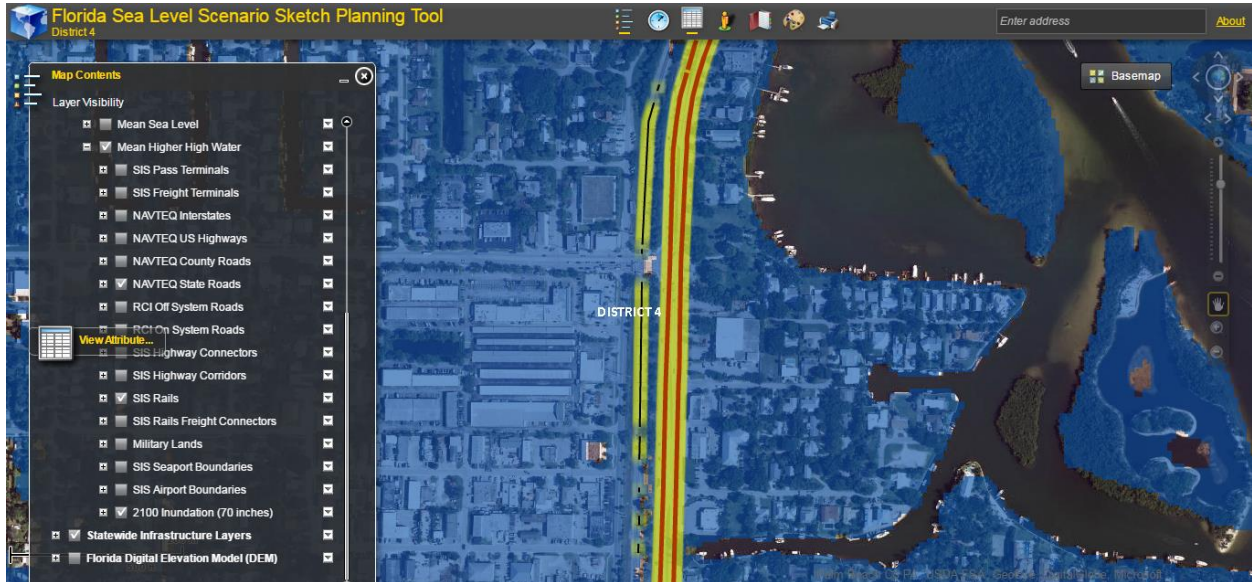


Figure 16: SR 811 (Alternate A1A) and FEC Railroad inundation by 2100 at MHHW level

	1 foot SLR	2 feet SLR	3 feet SLR	4 feet SLR	5 feet SLR	6 feet SLR
High social vulnerability population	265	310	387	561	812	1197
Medium social vulnerability population	259	368	622	1293	2831	5336
Low social vulnerability population	268	428	726	1273	1905	3154
Property value (millions of dollars)	298	438	695	1178	1788	2700
Population	792	1107	1736	3127	5548	9688
Homes	590	819	1215	2052	3363	5669
Heliports	0	0	0	0	0	1
EPA listed sites	4	5	8	12	19	28
NPDES sites	4	5	6	7	9	15
RADINFO sites	0	0	2	4	9	12
TSCA sites	0	0	0	1	1	1
Hazardous materials facilities	0	0	0	1	1	1
Hazardous waste sites	0	0	2	4	9	12
Minor hazwaste source sites	0	0	1	3	6	8
Unspecified hazardous waste sites	0	0	1	1	3	4
Wastewater sites	4	5	6	7	9	15
Nonmajor wastewater sites	4	5	6	7	9	15
Land (acres)	231	356	634	1089	1599	2349
Protected land (acres)	25	68	113	169	223	274
Local protected land (acres)	16	53	88	130	171	207
State protected land (acres)	9	15	25	39	52	68

Table 1: Source: <http://riskfinder.climatecentral.org>

Table 1 above tabulates populations, facilities, and other points or places of interest that are projected to be inundated under the given sea-level rise scenarios. Based on this assessment, there appears to be a threshold that is crossed between three and four feet of sea-level rise—inundated land, homes, and overall property value increase dramatically. Depending on the projections that are used, this threshold may not be crossed until closer to 2080 when looking only at sea-level rise; however this level of inundation may still be experienced through unusually high tides, precipitation induced flooding, or storm surge events.

Situation Analysis for SLR Scenarios and Flood Risk

Regarding the SLR scenarios assessed, it was initially envisioned to use shorter planning horizons. In particular, 2040 was an important benchmark in terms of long range transportation plan and project lifetime guidelines. However, when exploring the study area with the Geoplan tool, it was clear that daily high tide impacts would not be apparent until later decades. It is important to understand that the occurrence of these daily high tide events will be preceded by less frequent but equally severe flooding events in the same areas during extreme tides, heavy precipitation, and storm surge. When these and other components overlap for compound flooding, the impacts may be even more dangerous. It is important to consider the worst case scenario when planning for emergency situations. Therefore, going out to later decades in looking at daily events allows for a snapshot of the possibilities for shorter-term extreme events.

The Florida Peninsula is a porous plateau of karst limestone, known as the Florida Platform (Florida Geological Survey, 2001; USGS). In areas with coastal aquifers, the flow of water is intimately connected between surface and groundwater, and between seawater and freshwater. The Biscayne aquifer overlies the Floridan Aquifer to the south. The sponge-like limestone bedrock that underlays much of the Peninsula serves many beneficial purposes, particularly related to water supply and water quality. However, it also presents potential vulnerabilities related to rising seas.

For much of Florida’s porous limestone geology, seawater intrudes into the bedrock along the coast. SLR exacerbates the landward advancement of a wedge of seawater that underlies the Biscayne Aquifer. Groundwater is pushed higher towards the land surface as it floats above the deeper saltwater. SLR allows the existing wedge of seawater to further protrude inland impacting the aquifer. The lens of freshwater is pushed inland, threatening coastal well fields with contamination from saltwater intrusion. In addition, groundwater elevations increase as the lens floats above the saltwater. This process of “lifting the water table” causes a threat of inland flooding as the capacity of the ground to absorb and store storm water is reduced. Figure 17 below depicts the eventual result of excessive saltwater intrusion landward.

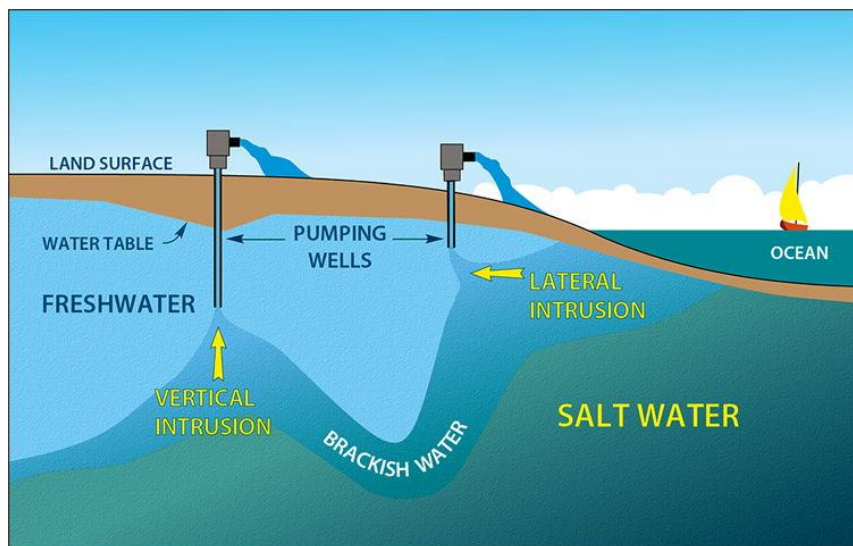


Figure 17: Salt water intrusion into wells. Source: St. Johns River Management District

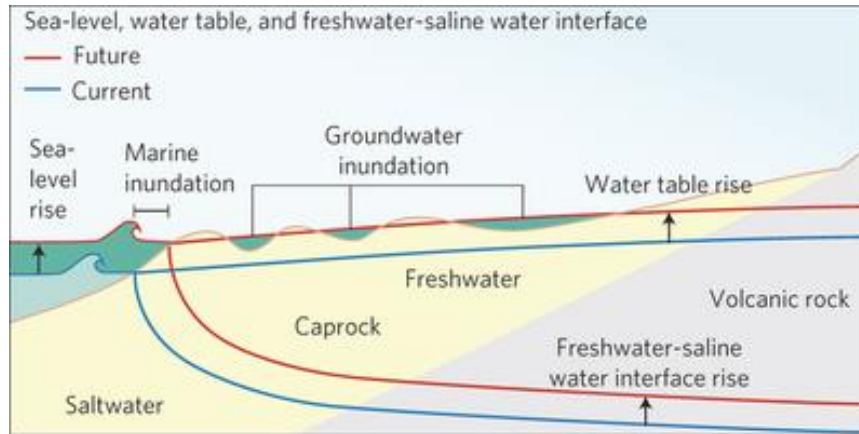


Figure 18: Coastal saltwater intrusion and ground water lifting. Source: <http://www.futura-sciences.com/planete/actualites/climatologie-zone-cotiere-eaux-souterraines-doublent-risque-inondation-42648/>

Figure 18 is another look at salt-water intrusion under the stresses of future sea level. Flooding is a multi-dimensional threat influenced by interconnected processes occurring above and below ground. Tidal flooding and increased sea surface elevations occur during storm surge from tropical storm events and during the fall king tides (Figure 22). Coastal flooding and surge risk are related to water piling against the coastlines continental shelf and below ground in terms of storage, drainage, and flow. Figure 20 roughly displays some of the currents at work that contribute to storm surge. Coastal flooding can occur when increased precipitation causes surface water to overtop, but also when groundwater lifting limits the soil storage capacity.

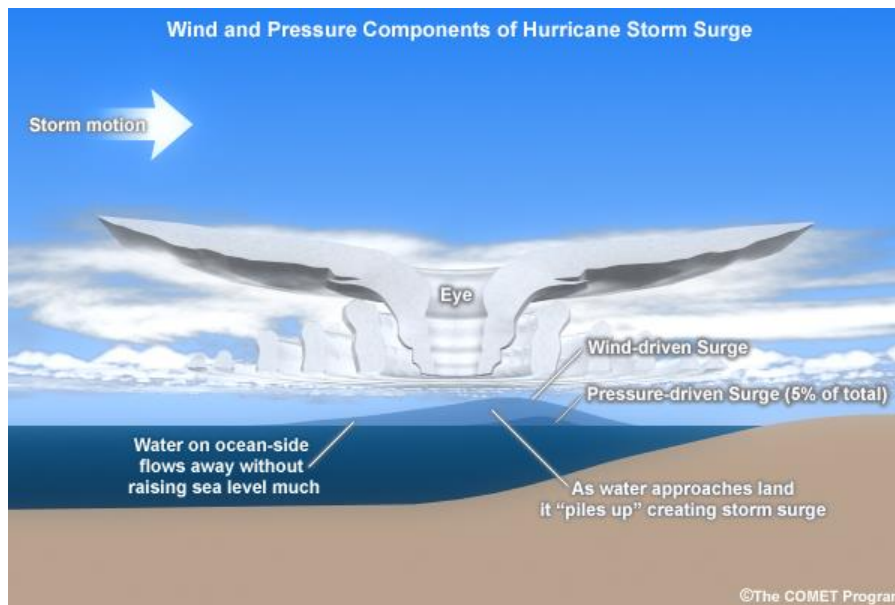


Figure 20: Storm surge can swell well beyond current high tide levels. Source: https://www.fema.gov/pdf/plan/prevent/nhp/slosh_display_training.pdf

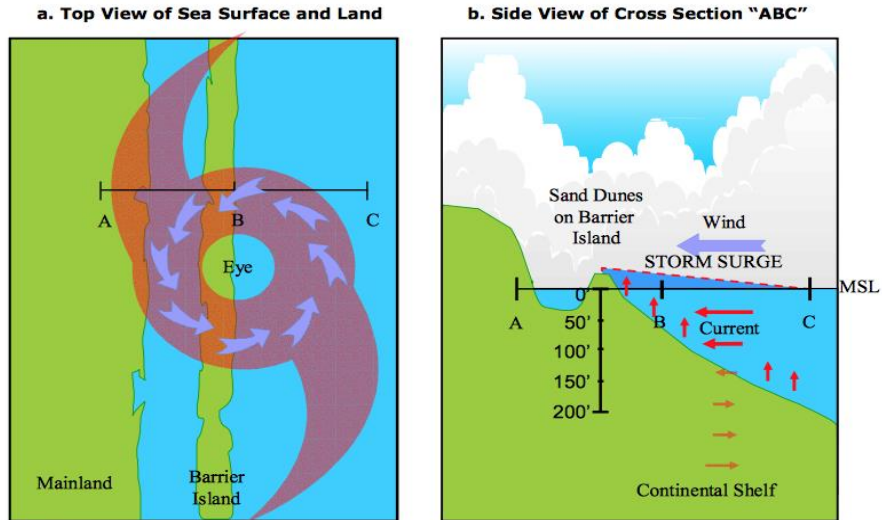


Figure 21: Storm generated currents cause water to pile up against the continental shelf at storm landfall. Source: https://www.fema.gov/pdf/plan/prevent/nhp/slosh_display_training.pdf

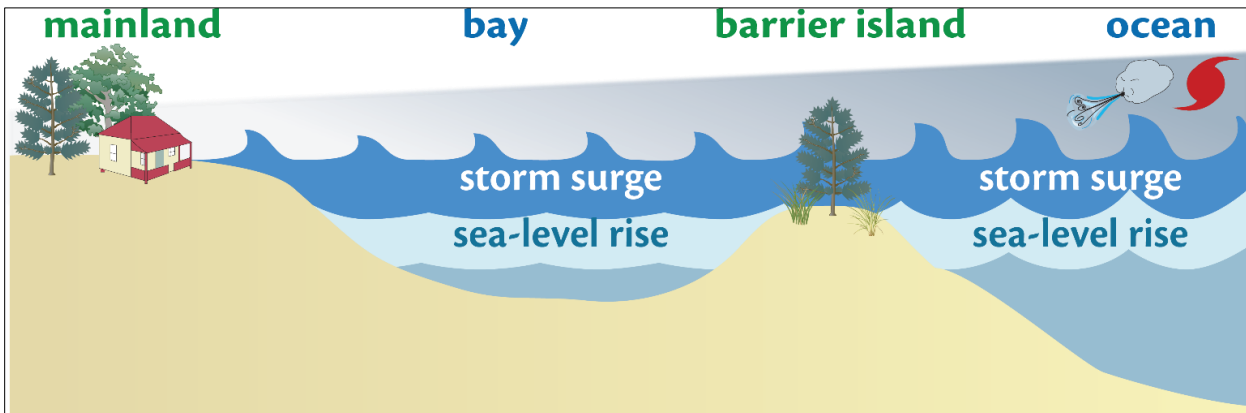


Figure 22: Sea-level Rise and Storm Surges on Barrier Islands: Conceptual diagram illustrating the effects of sea-level rise and storm surges on barrier islands. When sea-level rise combines with strong storms, barrier islands experience high storm surges which increases the effects of flooding and erosion. Diagram from http://ian.umces.edu/link/tos_barrier_learn

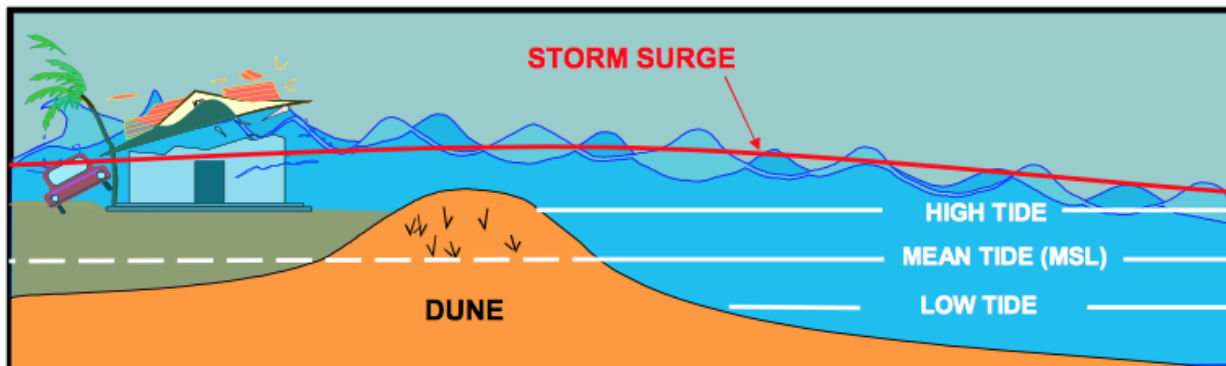


Figure 23: Storm surge can swell far beyond current high tide levels. Source: https://www.fema.gov/pdf/plan/prevent/nhp/slosh_display_training.pdf

Recommendations for Adaptation

Once the vulnerable road segments have been identified, this likelihood exposure must be overlaid with magnitude of impacts to assess vulnerability. As priorities areas are pinpointed, short and long term adaptation actions can be tailored for each specific area depending on unique characteristics and needs. Figure 24 briefly describes the general adaptation strategies, which are also outlined in further detail in Appendix A. Protection, accommodations, managed retreat (strategic relocation), avoidance, and procedural practices allow for a consideration of a variety of solutions which are natural, engineered, or policy driven.

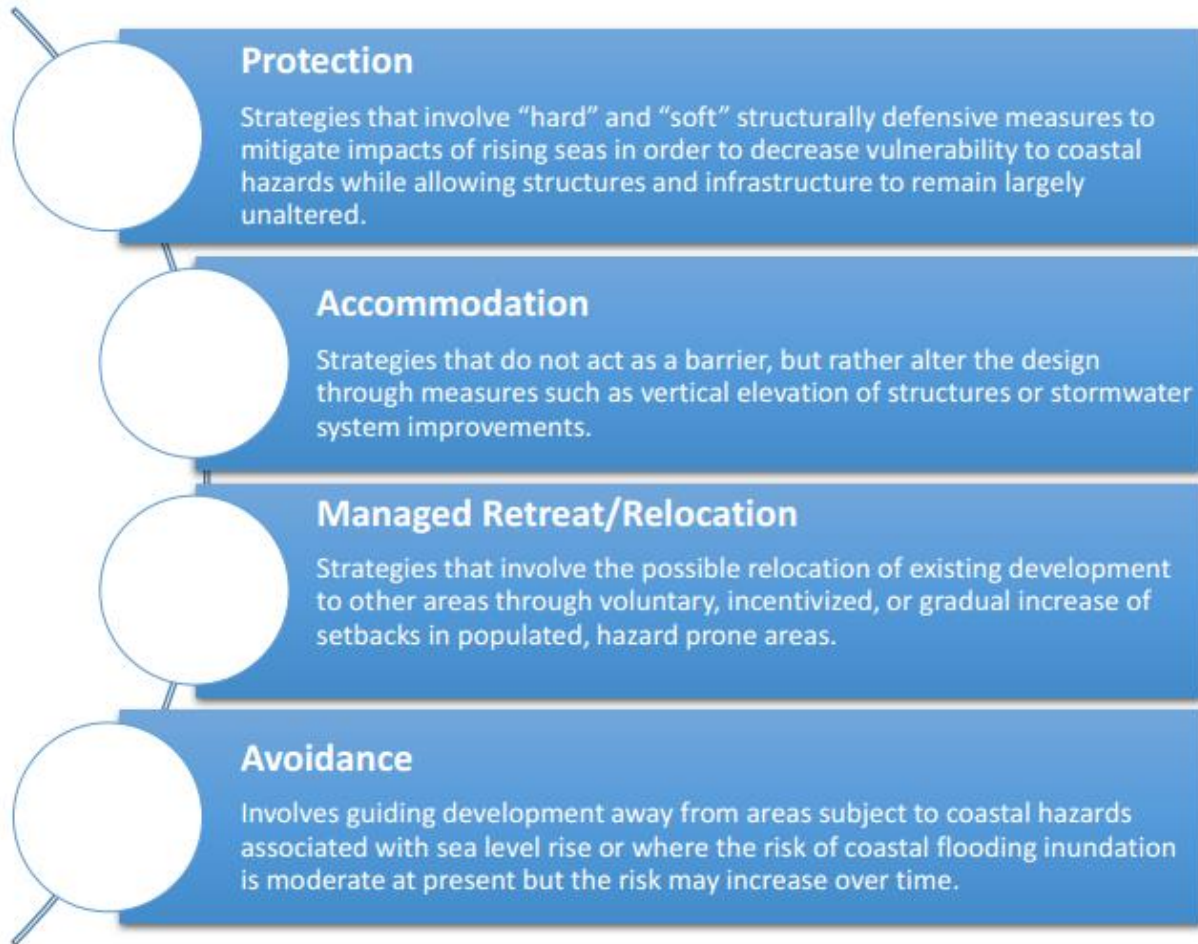


Figure 24: Protection, Accommodations, Managed Retreat, and Avoidance

Source: Adaptation Action Areas Guidebook <http://www.floridajobs.org/docs/default-source/2015-community-development/community-planning/crdp/aaaguidebook2015.pdf?sfvrsn=2>

Table 2: Potential adaptation approaches by project type, addressing purpose and magnitude (Adapted from U.S. Army Corps of Engineers (USACE) ETL 1100-2-1, Procedures to Evaluate Sea Level Change: *Impacts, Responses, and Adaptation*).

Protect	Accommodate	Retreat
<ul style="list-style-type: none"> • Dune/beach nourishment/ vegetation i.e. Living Shorelines • Expand design footprint and cross section of existing structures, including raising for clearance and access • Add secondary structures and structures to protect backshore • Improve resilience of backshore facilities • Construct levees or implement flood proofing measures • Construct drainage systems and shoreline protection, dikes or cells • Construct tidal gates, install saltwater intrusion barriers 	<ul style="list-style-type: none"> • Upgrade and strengthen existing structures and roadways • Upgrade drainage systems • Increase maintenance and dredging • Add sediment to shoreline or adapt underwater morphology • Modify building codes • Accept changes to ecosystems • Sediment management • Change water extraction • Freshwater injection /diversion • Modify land use 	<ul style="list-style-type: none"> • Re-purpose project area • Relocate buildings and infrastructure • Land-use planning and hazard mapping • Modification of land use • Allow/facilitate habitat conversion • Allow buffers for ecosystem migration

Recommendations for Further Research and Conclusion

Further research should be conducted in light of the findings presented here to investigate underlying issues contributing to inherent social vulnerability as predicted in the SoVI, in addition to ecosystem losses as a result of SLR. While both the SLR Viewer and Flood Exposure Mapper provide baseline data for land coverage type (e.g. marshland, transitional wetland, etc.), modeling ecosystem response under SLR is complicated for a variety of reasons, especially at large scales due to local influences. More advanced ecosystem management tools, such as NOAA’s C-CAP Land Cover Atlas² and the SLAMM Model³ can be used to examine development trends, marsh transgression, and forest coverage. The merits of using ecosystems and natural areas as providers of coastal protection is a growing field of interest. However, gaps exist in the process of merging traditional hard infrastructure with soft infrastructure methods, in addition the necessary policy for implementation.

It is evident that SLR poses a significant threat to coastal communities due to their proximity to oceans and other large bodies of water. A comprehensive adaptive strategy should include performance measures that identify, monitor and prevent SLR roadway impacts which may directly affect the health and safety of residents, in addition to relevant sociodemographic factors featured in the Social Vulnerability Index or other similar metric. The tools presented here can be integral components in furthering the resiliency goals of local planners and policymakers.

² <https://coast.noaa.gov/ccapatlas/>

³ <http://www.warrenpinnacle.com/prof/SLAMM/>

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Appendix A: Overview of Sea Level Rise Projections

Two commonly used sets of sea-level rise (SLR) projections are from the National Oceanic and Atmospheric Administration (NOAA) and the U.S. Army Corps of Engineers (USACE). Confusion has arisen around the differences between the two. This document is intended to help clarify the differences. Both NOAA and USACE collaborated with multiple partners (federal agencies, universities, and external organizations/ experts) in developing SLR projections. NOAA has adopted 4 projections and USACE has adopted 3. The lowest two projections from NOAA and USACE are the same, resulting in 5 total projections (see graph below) between the two agencies. The NOAA high projection estimates up to 2 meters of SLR by 2100, while the USACE high projection estimates up to 1.5 meters of SLR by 2100.

U.S. Army Corps of Engineers Sea Level Change Projections

The USACE utilizes three sea level change projections for evaluating the effects of SLR on coastal projects. Each projection represents a future scenario of sea level change, resulting in global sea level rise values of 0.2 meters, 0.5 meters, and 1.5 meters by 2100. With input from multiple partners, these projections were adapted from the National Research Council's report [*Responding to Changes in Sea Level: Engineering Implications*](#).

USACE Low Curve (8 inches or 0.2 meters by 2100): Represents a linear extrapolation of the historic rate of global SLR (of 1.7 mm/yr) based on observed sea level measurements. The USACE Low and NOAA Low are equivalent.

USACE Intermediate Curve (1.6 feet or 0.5 meters by 2100): Computed from the modified NRC Curve I considering the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) projections and modified NRC projections with the local rate of vertical land movement added. The USACE Intermediate Curve and NOAA Intermediate Low are equivalent.

USACE High Curve (5 feet or 1.5 meters by 2100): Computed from the modified NRC Curve III considering the IPCC AR4 projections and modified NRC projections with the local rate of vertical land movement added. "This 'high' rate exceeds the upper bounds of IPCC estimates from both 2001 and 2007 to accommodate the potential rapid loss of ice from Antarctica and Greenland, but it is within the range of values published in peer-reviewed articles since that time" (USACE, 2013, p.2).

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USACE Sea Level Change Calculator: <http://www.corpsclimate.us/ccaceslcurves.cfm>

NOAA Sea Level Change Projections

Under the Global Change Research Act of 1990, the U.S. National Climate Assessment (NCA) is commissioned by U.S. Congress every four years to consider future SLR trends and synthesize current scientific literature on global SLR. The NCA is a multi-agency effort, led by NOAA, and provides four global mean SLR scenarios which can be used for assessing potential impacts. These four scenarios estimate that mean global sea level will rise at least 0.2 meters (8 inches) and no more than 2.0 meters (6.6 feet) by 2100. Each of the scenarios incorporates different amounts of thermal expansion from ocean warming and ice sheet loss, resulting in a range of projected SLR amounts.

NOAA Low Curve (8 inches or 0.2 meters by 2100): Represents a linear extrapolation of the historic rate of global SLR (of 1.7 mm/yr) based on observed sea level measurements. The NOAA Low and USACE low are equivalent.

NOAA Intermediate Low Curve (1.6 feet or 0.5 meters by 2100): Based on upper end of the IPCC AR4 global SLR projections resulting from climate models using the B1 emissions scenario. The NOAA Intermediate Low and USACE Intermediate are equivalent.

NOAA Intermediate-High Curve (3.9 feet or 1.2 meters by 2100): “Based on an average of the high end of semi-empirical, global SLR projections. Semi-empirical projections utilize statistical relationships between observed global sea level change, including recent ice sheet loss, and air temperature”. (NOAA, 2012, p.2)

NOAA High Curve (6.6 feet or 2.0 meters by 2100): “The greatest uncertainty surrounding estimates of future global SLR is the rate and magnitude of ice sheet loss, primarily from Greenland and West Antarctica” High rate “...derived from a combination of estimated ocean warming from IPCC Fourth Assessment Report (AR4) global SLR projections and a calculation of the maximum possible glacier and ice sheet loss by the end of the century.” (NOAA, 2012, p.2)

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Appendix B: Adaptation Strategies

Adaptation Planning - Planning for Coastal Flooding and Sea Level Rise⁴

Adaptation to sea level rise are the steps a community takes to become more resilient to the impacts of rising seas over a period of time. Adaptation strategies are complimentary of each other, rather than mutually exclusive, and may be applied comprehensively based on the context of a community's varying needs and vulnerabilities. Several adaptation strategies a community may use to address current and future coastal flooding include†:

1. **Protection** - Protection strategies involve "hard" and "soft" structurally defensive measures to mitigate the impacts of current and future flooding, such as seawalls or beach renourishment, in order to maintain existing development.
2. **Accommodation** - Accommodation strategies do not act as a barrier to inundation but rather alter the design, construction, and use of structures to handle periodic flooding. Examples include elevating structures and stormwater retrofits that improve drainage or use natural areas to soak up or store water and runoff (i.e., green infrastructure).
3. **Strategic Relocation** - Strategic relocation involves the possible relocation of existing development to safer areas through voluntary or incentivized measures in populated, hazard prone areas that reduce the intensity of development and/or gradually increase setbacks over time. Such options usually involve the transition of vulnerable land from private to public ownership, but may also include other strategies such as transfer of development rights, purchase of development rights, and rolling easements.
4. **Avoidance** - Avoidance involves anticipatory actions taken to direct new development away from vulnerable lands to safer areas. Examples include land conservation, conservation easements, transfer of development rights, and increased coastal setbacks.
5. **Procedural** - Procedural strategies aim to generate vulnerability and adaptation information, increase awareness of vulnerabilities and adaptation options, or incorporate such information into plans or policies. Examples include vulnerability assessments, community outreach and education activities, new comprehensive plan language addressing sea level rise, and real estate disclosures.

†Adaptation strategies and explanations were adapted from the following sources:

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⁴ <http://www.floridajobs.org/community-planning-and-development/programs/community-planning-table-of-contents/adaptation-planning>