



Sea Level Rise Case Study for
Evacuation Routes in Martin and St.
Lucie Counties
Using the GeoPlan Sketch Tool and NOAA
Coastal Flood Exposure Mapper

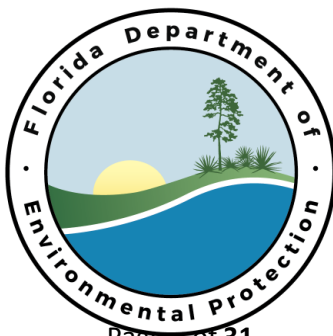


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Executive Summary

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 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 the risk.

This document is a case study of two major evacuation routes in Martin and St. Lucie County. It is a selected scenario planning exercise and demonstration of geospatial hazard assessment tools. The study should serve as a guide to begin the preliminary discussions necessary to develop a framework for a comprehensive vulnerability assessment. The case study specifically shows the projected inundation of county designated coastal evacuation routes and how future sea level rise (SLR) will affect the ability of coastal communities to safely evacuate from man-made or natural disasters. The vulnerability assessment will focus on two main evacuation routes in Martin and St. Lucie County; State Road A1A and US Highway 1. The assessment will highlight the segments of these routes which are projected to be inundated due to sea level rise scenarios. The U.S. Army Corps of Engineers (USACE) projections will be used.

Increasing resilience will ensure safety and inform emergency management practices in the case of extreme events. The resulting impacts outlined here within Martin and St. Lucie Counties' evacuation route network show distinct tipping points in which extensive coastal flooding becomes a daily threat in several road segments along the evacuation routes by 2060 and becomes even more pervasive by 2080. Even sooner, there will be similar threats during extreme tides and storm surge events.

There are innovative solutions to coastal hazards that both protect ecosystems and leverage ecosystem services for protection. When planning for sea level rise impacts, it is most beneficial to maintain a balance of both engineering and natural solutions. Adaptation recommendations to increase transportation 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.

Project Background

In 2011, the Florida Department of Economic Opportunity (DEO) initiated a five-year project to integrate sea level rise (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 Planning Council (SFRPC) 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 evacuation planning methods 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.

“In order to get a grip on it, one must be able to relate resilience to other properties that one has some means of ascertaining, through observation.”

*From Martin-Breen & Andries (2011) Resilience: A literature review.
The Rockefeller Foundation: New York City, p. 11*

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 sea level rise (SLR): global and local. Global sea level rise 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 sea level rise rates depends 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.

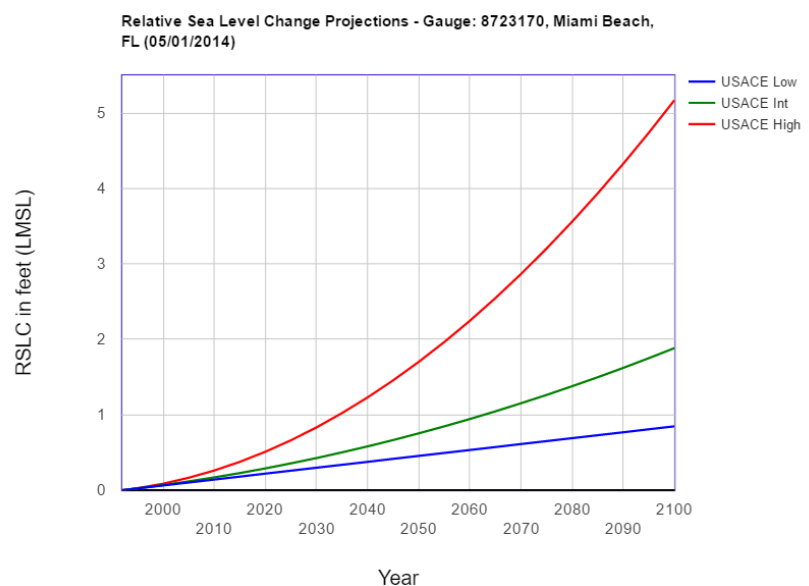
2) How much has sea level risen in the past?

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 (Source: 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
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) What is the University of Florida (UF) GeoPlan Center Sketch Planning Tool?

The Sketch Planning is a useful planning tool for preliminary assessment of vulnerable transportation infrastructure due to sea level change. The Geoplan Sketch Planning Tool offers a variety of sea-level rise analyses related to transportation. This tool can be used as a data source, an online visualizer or as a GIS add-on modelling software package. Through each avenue, it is intended to promote stakeholder engagement, scoping/ inventory, assessment/analysis, and planning.



5) What is the NOAA Coastal Flood Exposure Mapper (CFEM)?

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 exposure and ecosystem exposure. 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.

6) 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.

Study Area Summary

The study area was chosen to allow for a more in-depth exploration of transportation assets, particularly evacuation routes in low-lying areas that are vulnerable to coastal flooding due to sea level rise and extreme tides in a high priority area within the Treasure Coast. While the Southeast Florida Regional Climate Compact has done extensive analyses on the counties south from Palm Beach County, there has been less evaluation done for Martin and St. Lucie Counties. Figure 1 shows the areas of St. Lucie and Martin County that are vulnerable to two feet of sea level rise as indicated in blue for hydrologically connected areas and green for low-lying inland areas.



Figure 1: NOAA Sea Level Rise Viewer showing areas of St. Lucie and Martin County that are vulnerable to two feet of sea level rise.

The following figures allow for an overview of the large scale vulnerability within the study area using the Coastal Flood Exposure Mapper. Figure 2 shows areas prone to flooding from one or more of the following hazards:

- Shallow coastal flooding (up to 1 zone)
- 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)
- Sea level rise 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.

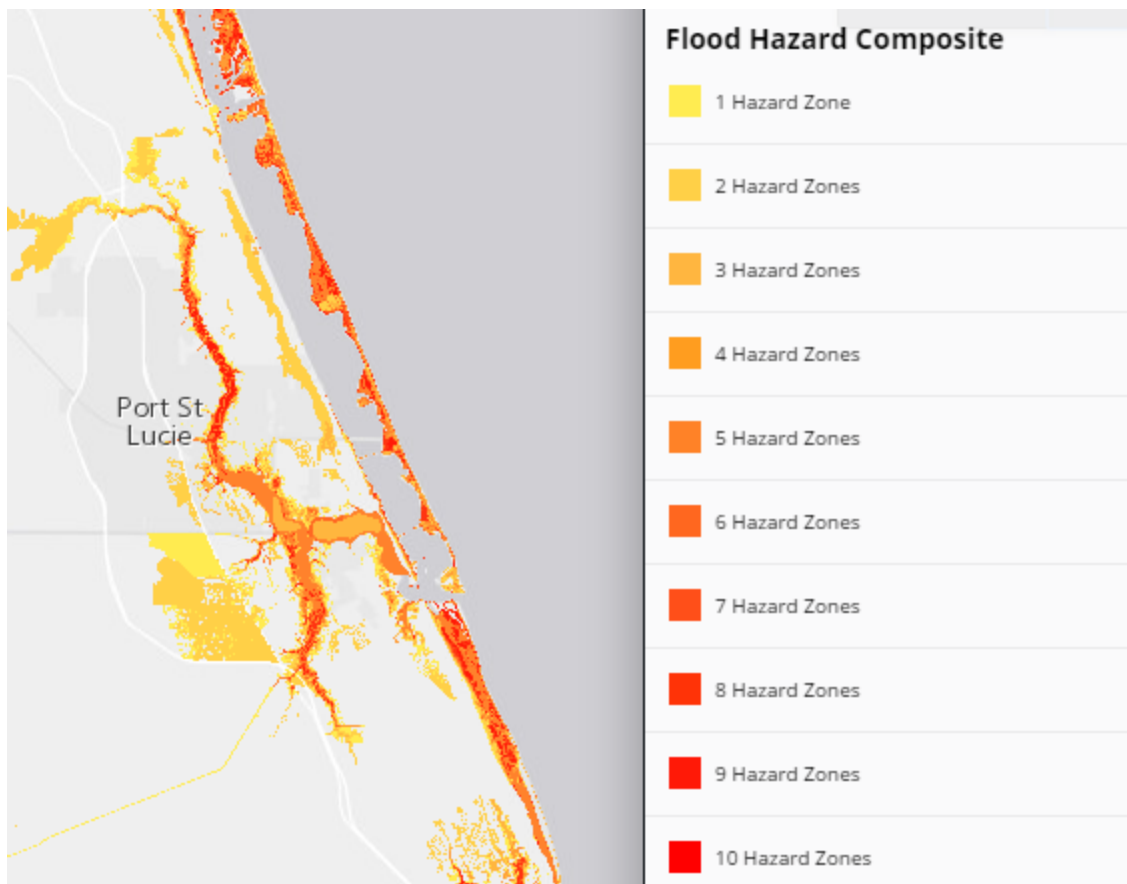


Figure 2: Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 3 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.

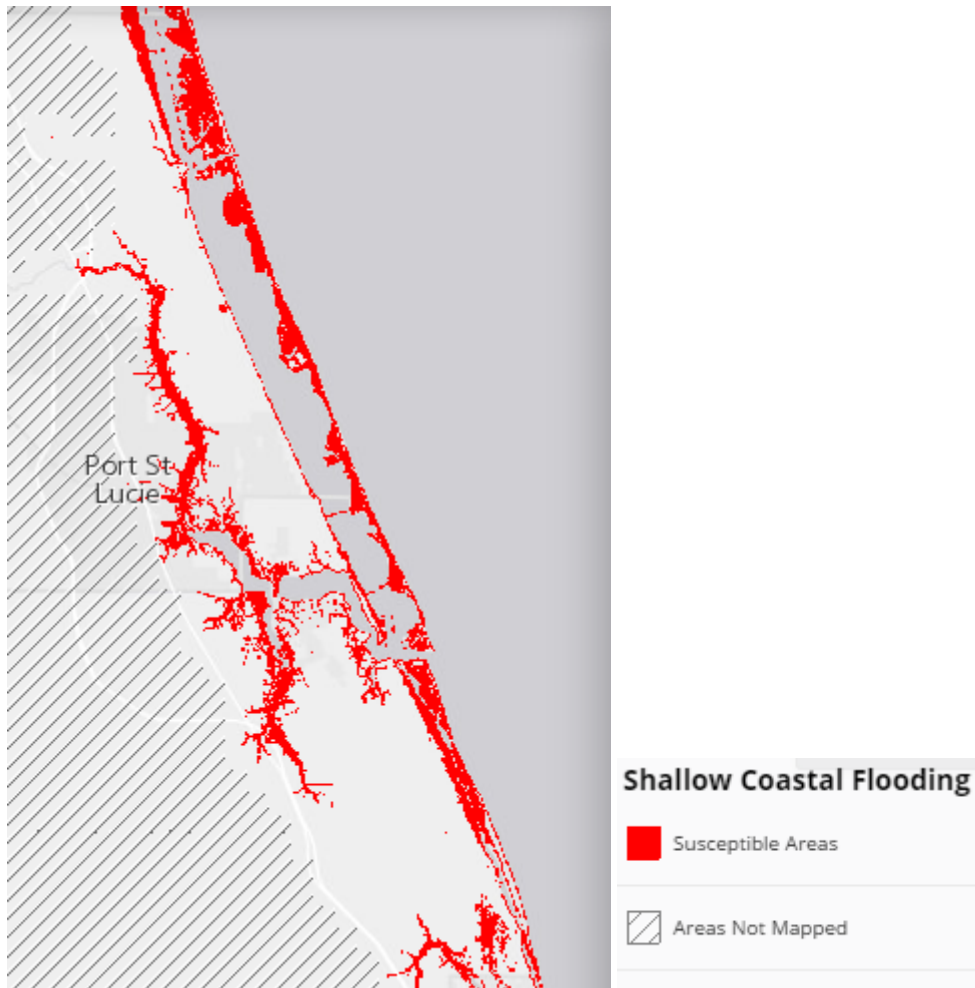


Figure 3: Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 4 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.

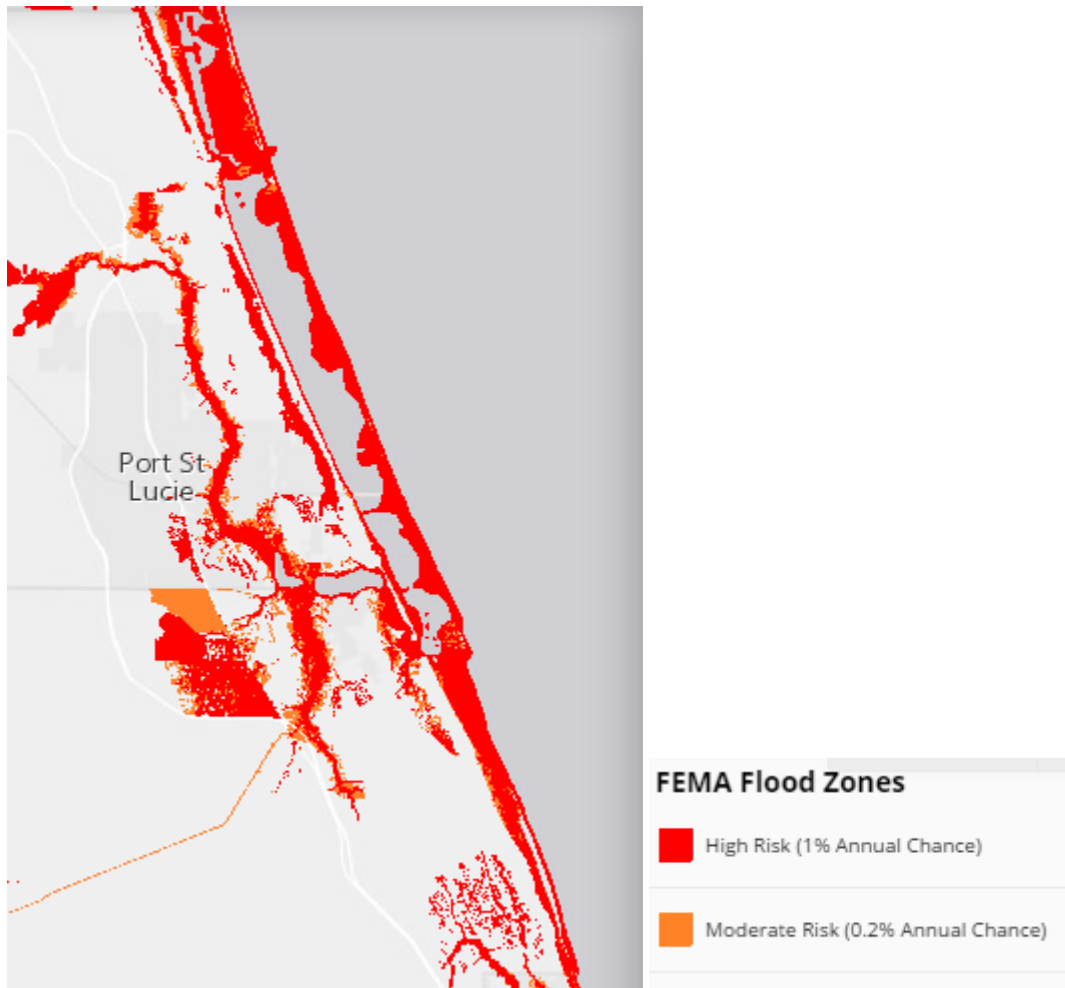


Figure 4: Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 5 overlays poverty levels with shallow coastal flooding areas to indicate that there are some vulnerable areas in which 25.1% 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%.

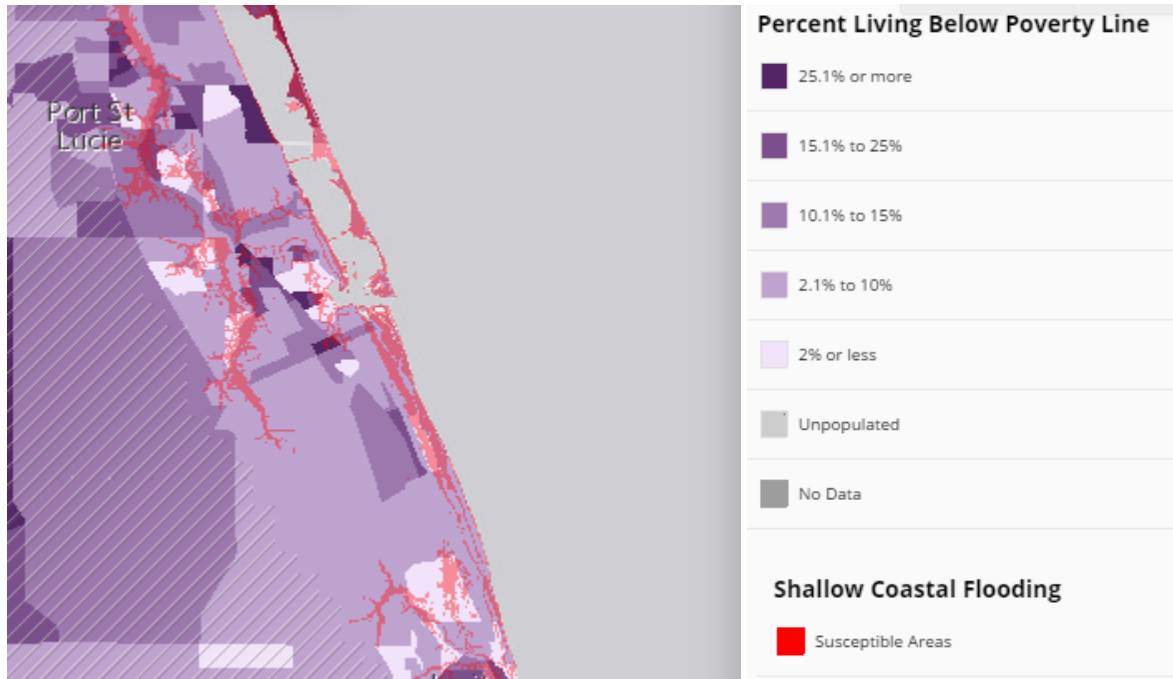


Figure 5: Source <https://coast.noaa.gov/floodexposure/#/map>

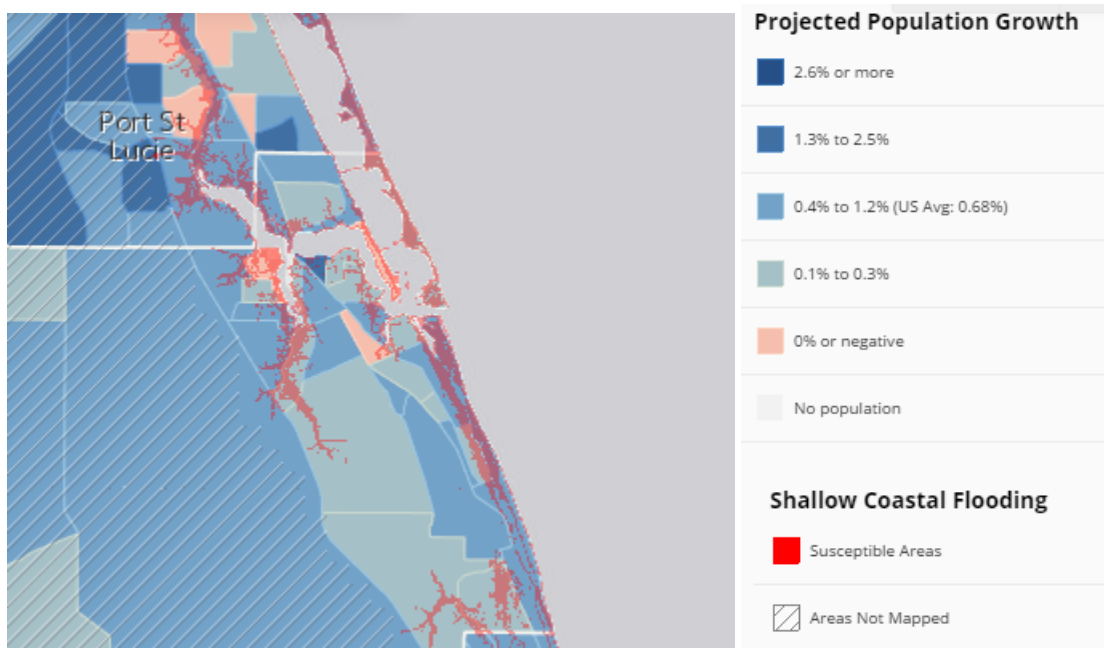


Figure 6: Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 6 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 to hazard impacts.

Data shown in Figure 7 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.

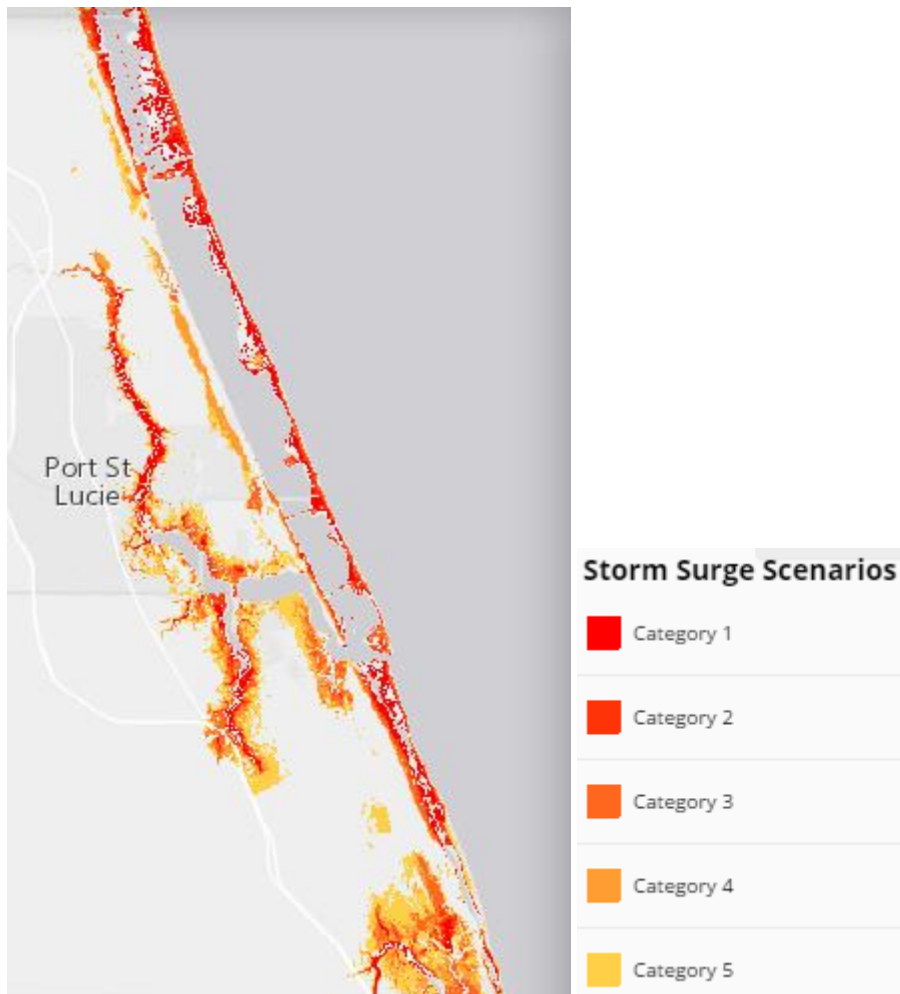


Figure 7: Source <https://coast.noaa.gov/floodexposure/#/map>

Figure 8 shows sea level rise 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 8: Source <https://coast.noaa.gov/floodexposure/#/map>

Situation Analysis for Sea Level Rise Scenarios and Flood Risk

Regarding the sea level rise 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.

Flooding is a threat in many dimensions which are connected 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 9). Coastal flooding and surge risk are related to water below ground in terms of storage, drainage, and flow. Coastal flooding can occur when increased precipitation causes surface water to overtop, but also when groundwater lifting limits the soil storage capacity (Figure 10).

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, 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. Sea level rise 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. Sea level rise 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.

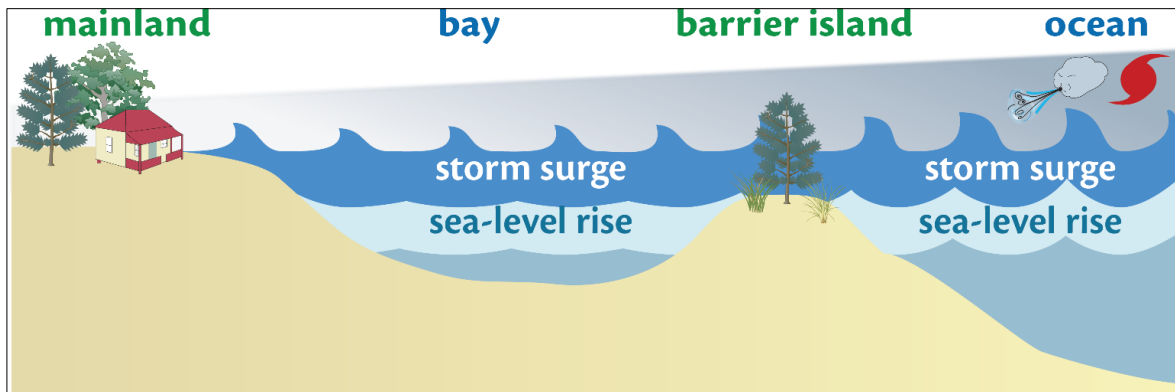


Figure 9: Sea-level Rise and Storm Surges on Barrier Islands: Conceptual diagram illustrating the effects of sea-level rise and storm surges on barrier islands. When sea-level rise combines with strong storms, barrier islands experience high storm surges which increases the effects of flooding and erosion. Diagram from http://ian.umces.edu/link/tos_barrier_learn

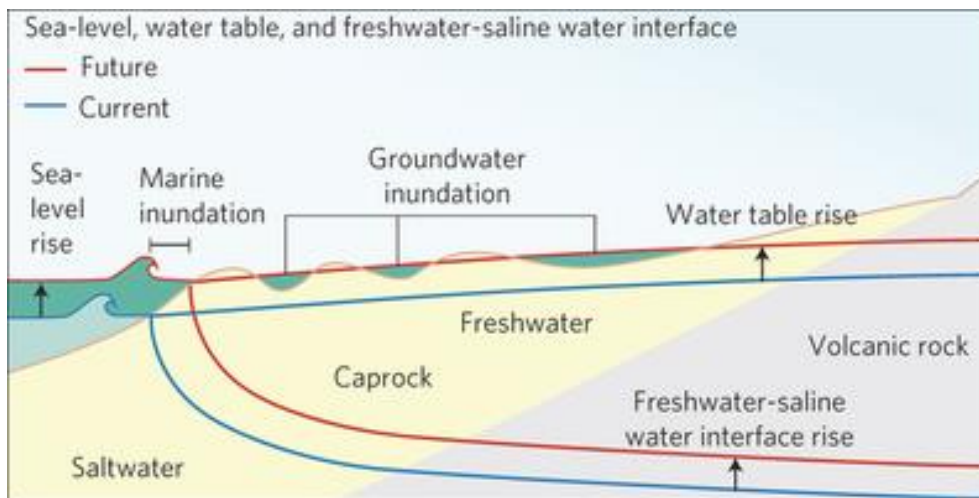


Figure 10: Saltwater Intrusion on Barrier Islands: Conceptual diagram illustrating saltwater intrusion and ground water lifting

Sea Level Rise Vulnerability Overview in Martin and St. Lucie Counties

Martin County currently has a population of 151,263 (2013, United States Census Bureau). With the strict growth management regulations limiting sprawl to undeveloped areas inland, most development is along the coast, with dense populations along the low-lying coastline. Just over 25 miles of roadway in Martin County are vulnerable with 3 feet of sea level rise, according to a Roadway inundation analysis performed on NAVTEQ data provided by the Florida Department of Transportation in 2009. Although much of this vulnerable roadway is in residential areas, evacuation routes for coastal neighborhoods, particularly on Hutchinson Island, portions of Sewall's Point, and southern Jupiter Island were shown to be heavily impacted with a 3-foot scenario.

St. Lucie County currently has a population of 286,832 (2013, United States Census Bureau). St. Lucie County has the greatest acreage of wetlands among all of the counties in the Treasure Coast Region (Merritt, 2010). St. Lucie County has 28 miles of vulnerable roadway with 3 feet of sea level rise, but like Martin County, these are mainly low volume roads. There are several vulnerable evacuation routes around A1A near and on Hutchinson Island. With a 3-foot SLR scenario, travel may be impacted to the north, and the southern causeway may be the preferred egress/ingress route, impacting Martin County congestion during an evacuation.

Merritt (2010) states that St. Lucie County's barrier islands have several narrow parts which could be breached by a hurricane, causing an inundation threat to SR A1A. Therefore, these areas would be maintained through protection of the land or construction of a bridge. SR A1A is required for hurricane evacuation and emergency evacuation at the FPL St. Lucie nuclear power plant.

Review of GeoPlan Sketch Tool

In recent years, the Florida Department of Transportation (FDOT) has expressed concerns over the continuation and acceleration of sea level rise impacts in the future and the need to integrate this critical issue into its planning processes. To further this objective, FDOT provided funding to the University of Florida’s Geo Plan Center to develop the Florida Sea Level Scenario Sketch Planning Tool. The Sketch Planning Tool is an interactive, web based, geospatial application 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 main components of the application and its functionalities are described below in an excerpt from the technical documentation:

The Sketch Planning Tool includes a set of three tools (1) Florida Sea Level Scenarios Map Viewer, (2) GIS Data Layers (SLR Inundation surfaces and affected infrastructure layers), and (3) Sea Level Change Inundation Surface Calculator for ArcMap.

With the map viewer, users can visualize when and where inundation is projected to occur and which transportation facilities are potentially vulnerable to inundation due to SLR. The map viewers display SLR inundation scenarios and affected transportation infrastructure for time periods (2040, 2060, 2080, 2100), three rates of SLR (Low, Intermediate, High), and two tidal datums (Mean Sea Level and Mean Higher High Water).

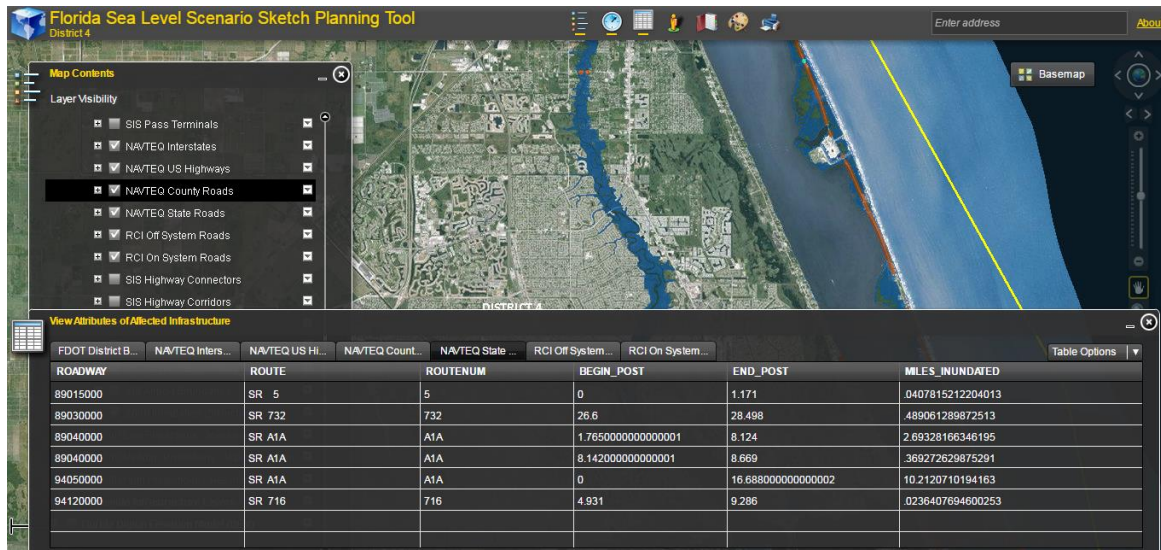


Figure 11: Screenshot of map viewer and data table interface

The inundation layers (called “inundation surfaces”) were generated using three rates of SLR from the U.S. Army Corp of Engineers (USACE) sea level change methods: Low (Historic rate), Medium (Intermediate Curve), and High (High curve) and Florida tide gauge data from the National Oceanic and Atmospheric Administration (NOAA). Projected inundation was mapped at five tidal datums, but only two are displayed in the map viewer: Mean Higher High Water (MHHW) and Mean Sea Level (MSL).

The UF GeoPlan Center generated statewide and regional scenarios in 10-year increments (2040 – 2100) following the USACE methods. The projections were mapped using a 5-meter Digital Elevation Model (DEM). The mapped inundation projections were then intersected with transportation GIS layers to identify vulnerable infrastructure.

The main features of the viewer is the Map Contents widget, Time Slider Widget and the dynamic Attribute Table.

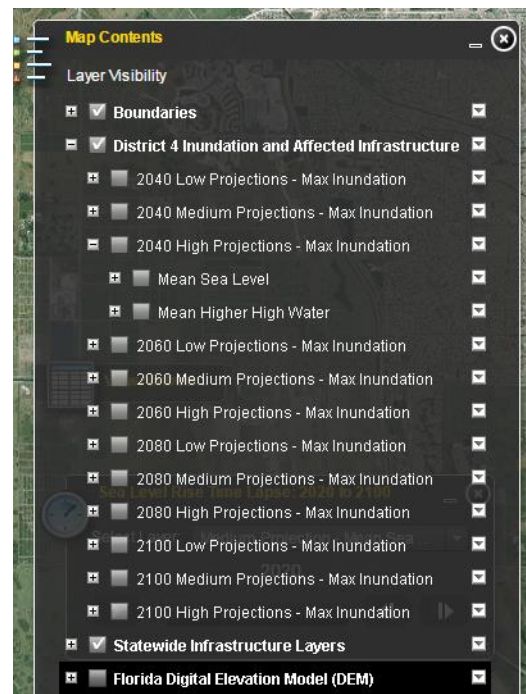
Map Contents Widget

The Map Contents widget lists the data layers that are displayed in the map viewer. There are three main folders which organize the data:

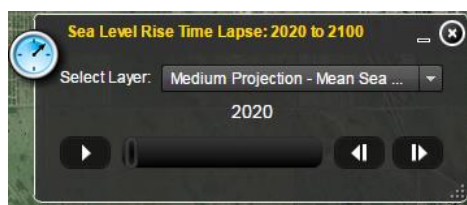
Boundaries: Contains boundaries for FDOT Districts, Counties & MPOs.

District Inundation and Affected Infrastructure: Contains SLR inundation surfaces and affected infrastructure layers.

Florida Digital Elevation Model (DEM): Contains the DEM Mosaic compiled for and used in this project.



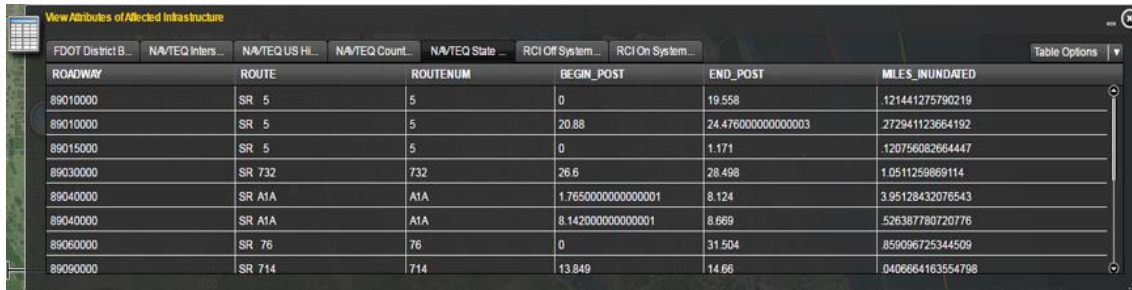
Time Slider Widget



The time slider widget allows you to run an animation showing sea level change inundation at high, medium, or low levels (each at Mean Sea Level). The slider starts at the year 2020 (no inundation) and changes are displayed for the years 2040, 2060, 2080, and 2100.

Attribute Table

With the Attribute Table widget, users can explore attributes of infrastructure features potentially at risk to sea level change inundation and view the approximate miles or acres of the feature inundated under various sea level scenarios. In addition, the attribute records can be exported to a comma-separated file (.csv) which can then be used in Microsoft Excel.



The screenshot shows a software interface titled "View Attributes of Affected Infrastructure". It features a table with several columns: ROADWAY, ROUTE, ROUTENUM, BEGIN_POST, END_POST, and MILES_INUNDATED. The table contains 10 rows of data, each representing a different roadway segment and its associated inundation statistics.

ROADWAY	ROUTE	ROUTENUM	BEGIN_POST	END_POST	MILES_INUNDATED
89010000	SR 5	5	0	19.558	121441275790219
89010000	SR 5	5	20.88	24.476000000000003	272941123664192
89015000	SR 5	5	0	1.171	120756082664447
89030000	SR 732	732	26.6	28.498	1.0511259869114
89040000	SR A1A	A1A	1.7650000000000001	8.124	3.95128432076543
89040000	SR A1A	A1A	8.142000000000001	8.669	526387780720776
89060000	SR 76	76	0	31.504	859096725344509
89090000	SR 714	714	13.849	14.66	0406664163554798

Viewing SLR Scenarios

The current version of the Sketch Planning Tool is based on the ESRI ArcGIS API for Flex platform and is subdivided into separate user interfaces for each FDOT district. Sea level rise scenarios can be viewed by accessing the map viewer for a specific district, locating the Map Contents widget, choosing a time period (2040, 2060, 2080, 2100), selecting a tidal datum to display the inundation surfaces and selecting the infrastructure layers. Once these data layers are active, the tool spatially queries any segments of the infrastructure layers which intersects the inundation surfaces. These segments are flagged as potentially vulnerable infrastructure and displays in the Attribute Table widget as data outputs.

Methods and Summary of Network Impacts

For this assessment, SLR scenarios were generated for the following roadway segments:

State Road A1A: from MacArthur Blvd to the south in Martin County to Seaway Drive to the north in St. Lucie County (approximately 21 miles)

US Highway 1: from Ocean Blvd to the south in Martin County to Seaway Drive to the north in St. Lucie County (approximately 19 miles)

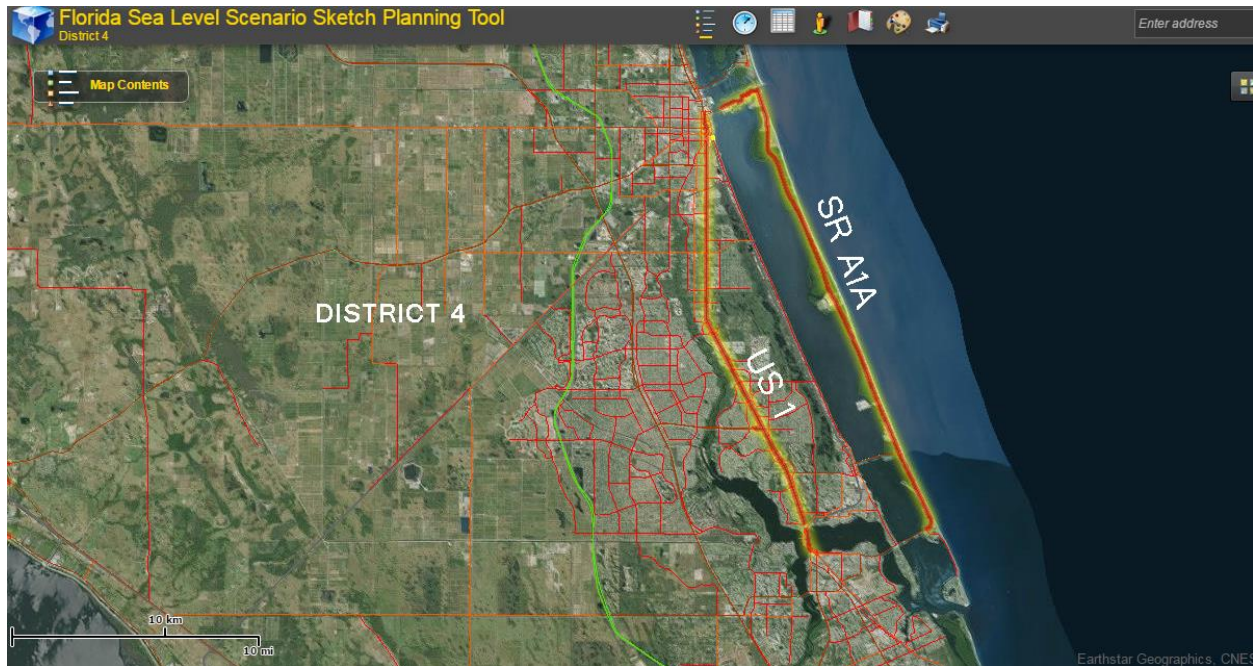


Figure 12: Roads assessed within the study area

Potential tide inundation and flooding due to sea level rise can greatly impact evacuation scenarios in this area. State Road A1A is the only designated evacuation route on the barrier island in Martin and St. Lucie County. Using the FDOT District 4 map viewer, the sea level rise projections reveal that A1A is mostly unaffected up until year 2060, but begins to show significant impacts by 2080. For the 2080 time period, at the mean higher high water tide level, approximately 15 miles of roadway will experience 50 inches of inundation. These values at this tide level will increase to 20 miles of roadway and 70 inches of inundation by 2100.

US Highway 1 is another significant evacuation route in this region. The sea level rise projections for US Highway 1 in this area shows minimal impact. Based on the data outputs from the Sketch Tool, this portion of US Highway 1 is not projected to experience tidal inundation until 2100. By year 2100, roughly 2,059 feet of US Highway 1, located just north of the Roosevelt Bridge, is projected to be submerged under 70 inches of water at the mean higher high water tide level. The data table of sea level rise projections provides a summary of the total length of roadway inundation for State Road A1A and US Highway 1 at each time

period and tide level. The following figures and data tables illustrate and quantify vulnerable road segments for the various scenarios.

Data Tables of Sea Level Rise Projections for State Road A1A and US Highway 1

State Road A1A	
	Miles Inundated
2040 High Projection	
Mean Sea Level, 5 inches inundation	0.00
Mean Higher High Water, 22 inches inundation	0.04
2060 High Projection	
Mean Sea Level, 17 inches inundation	0.00
Mean Higher High Water, 34 inches inundation	2.42
2080 High Projection	
Mean Sea Level, 33 inches inundation	1.50
Mean Higher High Water, 50 inches inundation	15.00
2100 High Projection	
Mean Sea Level, 52 inches inundation	15.00
Mean Higher High Water, 70 inches inundation	20.00

Table 1: State Road A1A

US Highway 1	
	Miles Inundated
2040 High Projection	
Mean Sea Level, 5 inches inundation	0.00
Mean Higher High Water, 22 inches inundation	0.00
2060 High Projection	
Mean Sea Level, 17 inches inundation	0.00
Mean Higher High Water, 34 inches inundation	0.00
2080 High Projection	
Mean Sea Level, 33 inches inundation	0.00
Mean Higher High Water, 50 inches inundation	0.00
2100 High Projection	
Mean Sea Level, 52 inches inundation	0.00
Mean Higher High Water, 70 inches inundation	0.39

Table 2: US Highway 1

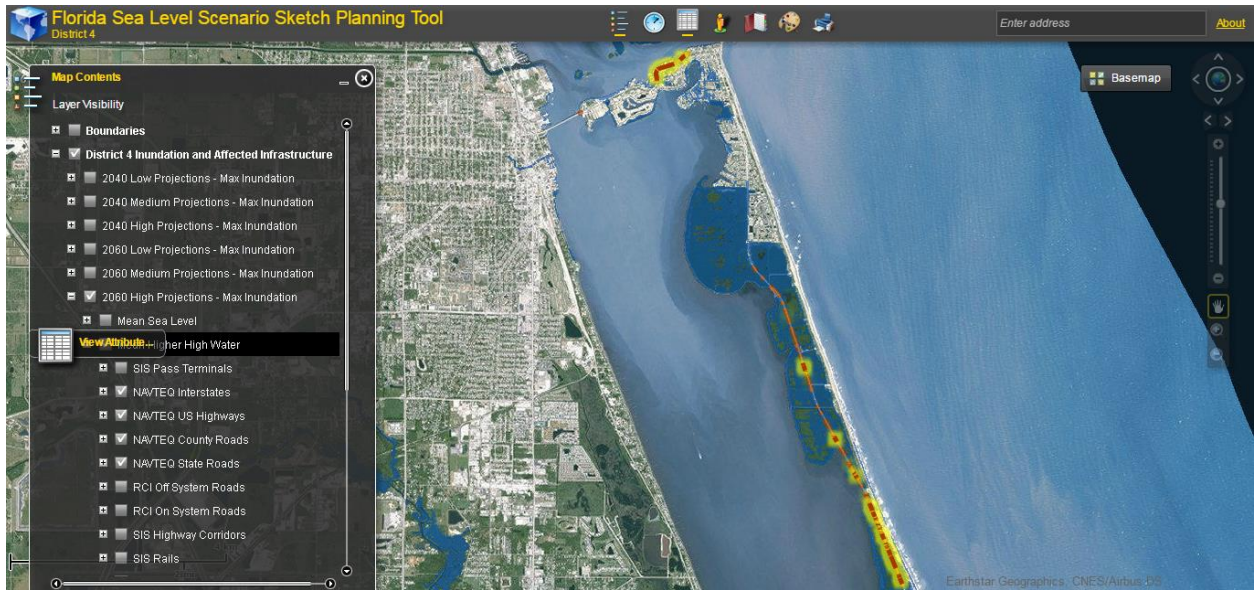


Figure 13: State Road A1A inundation by 2060

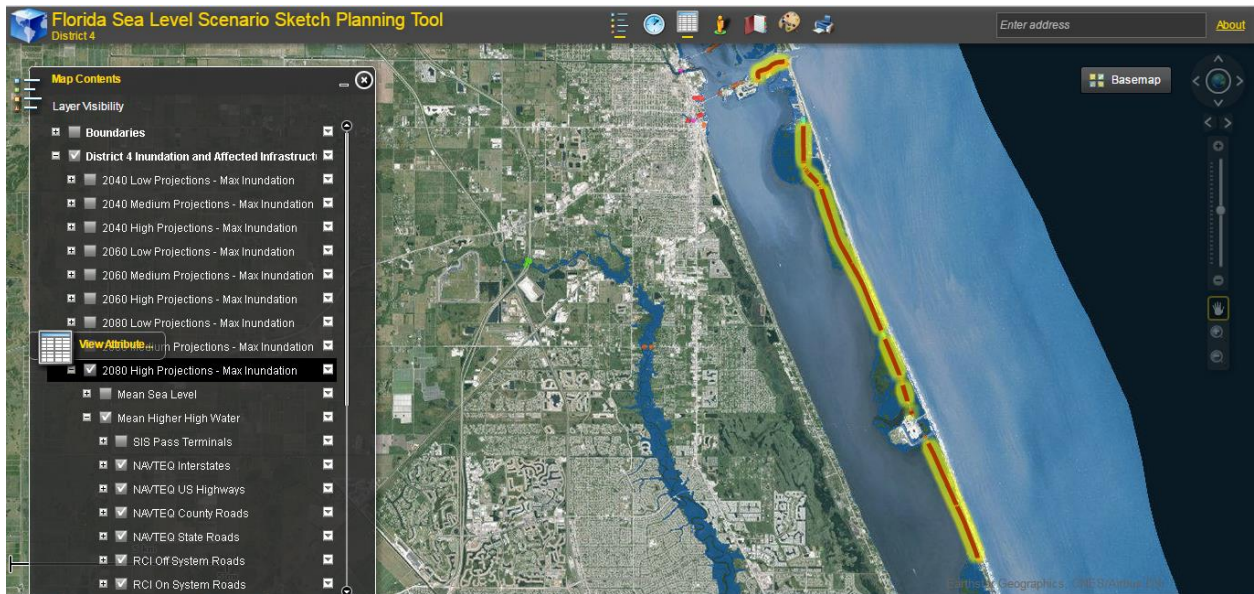


Figure 14: State Road A1A inundation by 2080

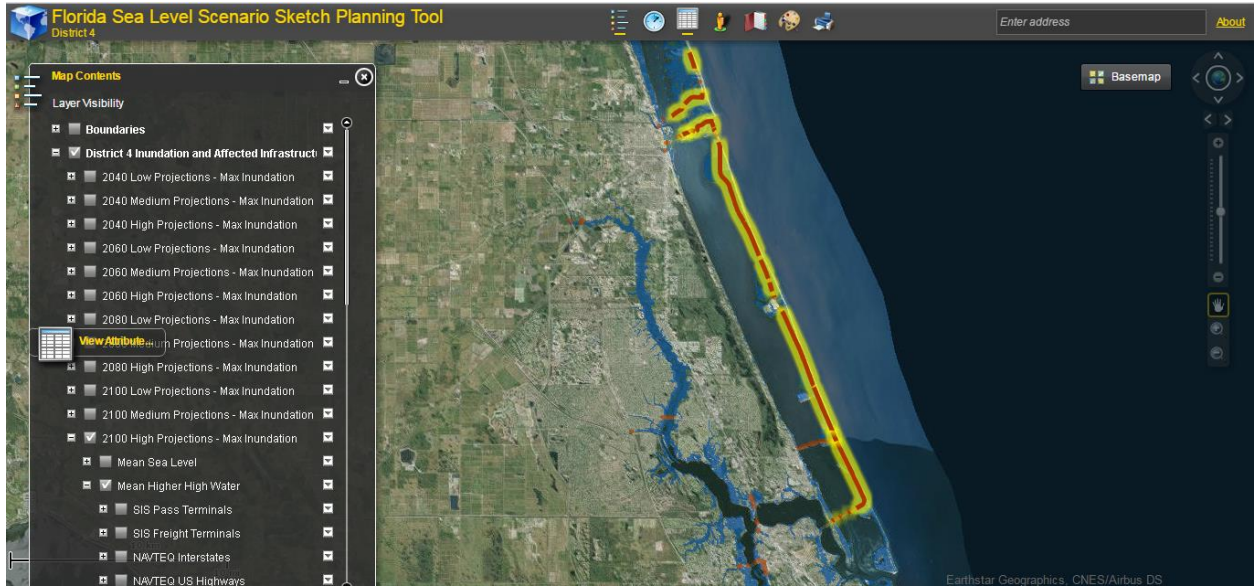


Figure 15: State Road A1A inundation by 2100

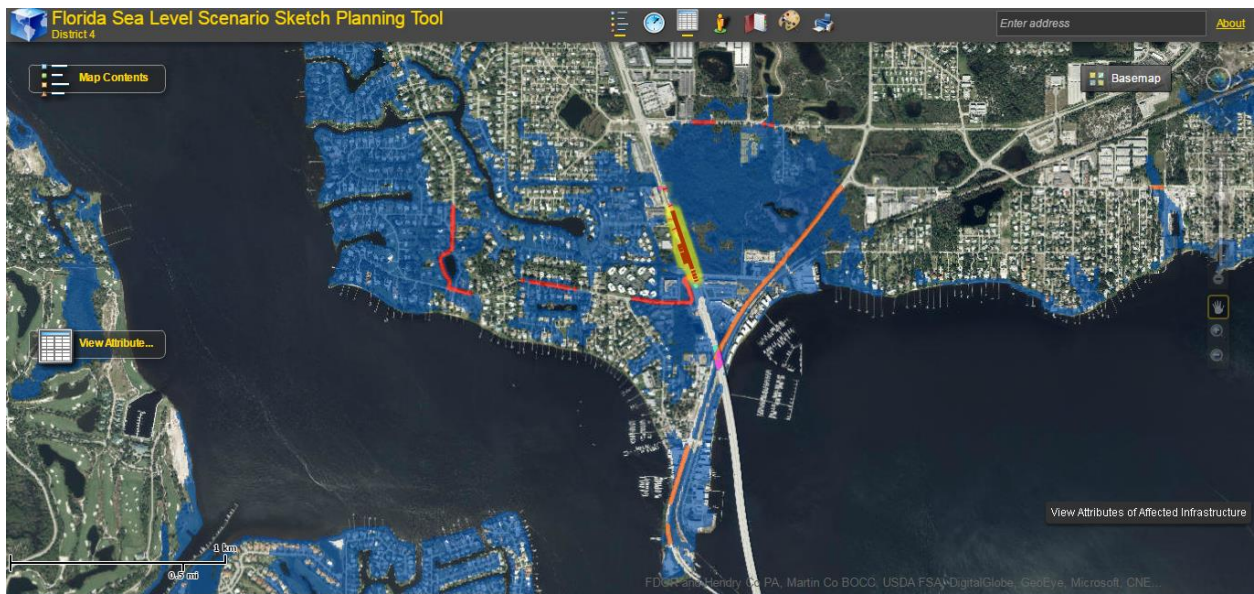


Figure 16: US Highway 1 inundation by 2100

Conclusion

It is evident that sea level rise poses the greatest threat to coastal communities due to their proximity to oceans and other large bodies of water. Consequently, the risk of roadway flooding in these areas from tidal inundation, groundwater lifting and higher storm surges will increase. Spatial information technologies such as the GeoPlan Sketch Tool helps to increase the visual understanding of the future expansion of coastal water bodies and the potential inundation of vulnerable transportation facilities and infrastructure. By highlighting the location of projected impacts, the technology also helps to inform FDOT's process of planning, prioritizing and directing resources toward transportation infrastructure design, construction, improvements and maintenance.

Based on the evaluation of the two evacuation routes in the study area, State Road A1A will require greater planning considerations than US-1 in the coming years. However, despite the projected minimal impacts to US-1, it is still projected to experience about two thousand feet of tidal inundation just north of the Roosevelt Bridge in Martin County. This can be viewed as a potential weak point in the evacuation route network for both Martin and St. Lucie County. The progressive approach would be to consider other factors which may lead to roadway failure at this location prior to 2100, including base saturation and roadway bed damage from increases in ground water levels related to rising seas.

As a designated evacuation route for both Martin and St. Lucie counties, State Road A1A is a critical traffic artery and the primary route for evacuating barrier island communities during an emergency event. By 2060, it is very likely that the segment of State Road A1A traversing the study area, will experience regular flooding due to high tides and other SLR factors as it is designed today. This consistent saturation may cause the weakening of the roadway's base structure and, as a result, limit emergency route options in this area. A comprehensive adaptive strategy should include performance measures which identify, monitor and prevent SLR roadway impacts which may directly affect the health and safety of local residents.

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 17 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.

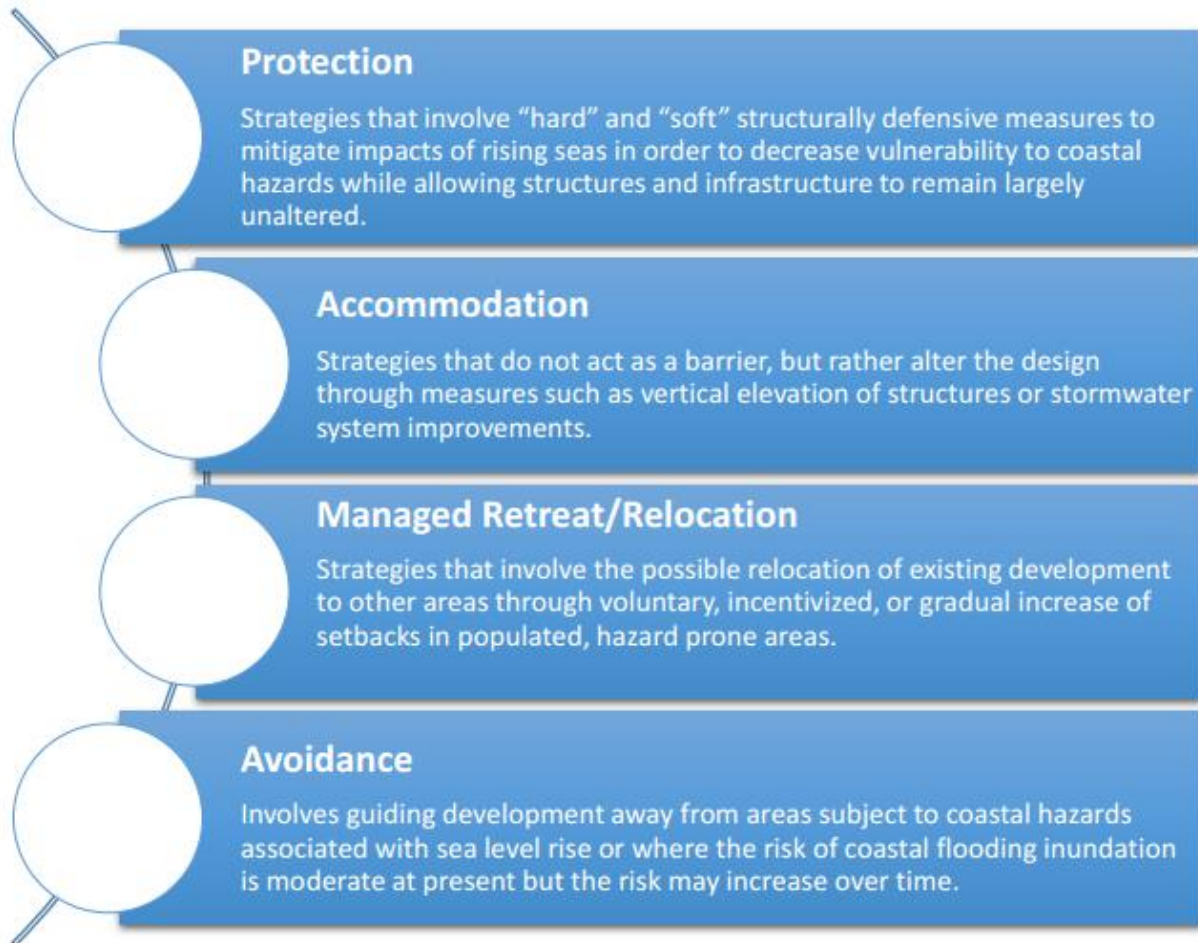


Figure 17: Protection, Accommodations, Managed Retreat, and Avoidance

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

Table 3: 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 -Add structures to protect backshore -Improve resilience of backshore facilities -Construct levees or implement floodproofing measures -Construct drainage systems -Construct shoreline protection structures, dikes or cells -Construct tidal gates, install salt water 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

In order to determine the impacts of impaired evacuation efficiency, there are many factors to be considered. In addition to knowledge of compromised road segments, traffic disruptions, congestion patterns and population densities are important to consider. For further research, it is recommended to consider factors such as population growth rates, traffic count statistics, and other traffic-related data². These data can be filtered to focus on dates during which evacuations were in effect. Another important resource is the Statewide Regional Evacuation Study for the Treasure Coast Region. This report updates the area evacuation population estimates, evacuation clearance times and public shelter demand³. The Regional Transportation Analysis has a 2016 update which has data, including more recent population statistics and roadway improvements, as well as revised methods such as the Transportation Interface for Modeling Evacuations (TIME) user interface.

² <http://www.dot.state.fl.us/planning/statistics/gis/trafficdata.shtm>

³ http://www.tcrpc.org/special_projects/RES/RES_Home.html

References

- Church, John A., Neil J. White, Leonard F. Konikow, Catia M. Domingues, J. Graham Cogley, Eric Rignot, Jonathan M. Gregory, Michiel R. van den Broeke, Andrew J. Monaghan, and Isabella Velicogna. "Revisiting the Earth's sea-level and energy budgets from 1961 to 2008." *Geophysical Research Letters* 38, no. 18 (2011).
- DEO: Adaptation Planning in Florida
<http://www.floridajobs.org/fdcp/dcp/AdaptationPlanning/AdaptationPlanninginFlorida.pdf>
- DEO: Adaptation Funding Resources
<http://www.floridajobs.org/fdcp/dcp/AdaptationPlanning/AdaptationFundingOpportunities.pdf>
- DEO: How Countries, States, and Florida Address Sea Level Rise - A Compendium of Climate Adaptation Research
<http://www.floridajobs.org/fdcp/dcp/AdaptationPlanning/CompendiumNationalStateLocalAdaptationProjects.pdf>
- DEO: Implementing "Adaptation Action Area" Policies in Florida
<http://www.floridajobs.org/fdcp/dcp/AdaptationPlanning/AAAPolicy.pdf>
- DEO and Florida Division of Emergency Management. (n.d.) Post-Disaster Redevelopment Planning: Addressing Adaptation during Long-term Recovery.
<http://www.floridajobs.org/fdcp/dcp/PDRP/Files/PDRPSeaLeveRiseAddendum.pdf>
- East Central Florida Regional Planning Council. (2004). Land Use Impacts and Solutions to Sea Level Rise in East Central Florida. Retrieved from
http://research.fit.edu/sealevelriselibrary/documents/doc_mgr/446/East_Central_SLR_Adaptation_-_ECFRPC_2004.pdf
- Florida Statute § 163.3164(1), "The Florida Statutes - The Florida Senate." The Florida Senate - The Florida Senate Accessed June 10, 2014
- Florida Department of Economic Opportunity (DEO) Adaptation Planning
<http://www.floridajobs.org/community-planning-and-development/programs/technical-assistance/community-resiliency/adaptation-planning>
- Merritt, Peter. 2010. "Treasure Coast." In James G. Titus, Daniel L. Trescott, and Daniel E. Hudgens (editors). *The Likelihood of Shore Protection along the Atlantic Coast of the United States. Volume 2: New England and the Southeast.* Report to the U.S. Environmental Protection Agency. Washington, D.C.
- Mitchum, G. T. (2011). *Sea Level Changes in the Southeastern United States: Past, Present, Future.* University of South Florida.
- Murley, J., Heimlich, B. N., & Bollman, N. (2008). *Florida's resilient Coasts—A state policy framework for adaptation to climate change.* Florida Atlantic University Center for Urban and Environmental Solutions and National Commission on Energy Policy. Fort Lauderdale, Florida.

National Oceanic and Atmospheric Administration (NOAA)

Achieving Hazard-Resilient Coastal and Waterfront Smart Growth: Coastal and Waterfront Smart Growth and Hazard Mitigation Roundtable Report. (n.d.). NOAA with US EPA
<http://coastalsmartgrowth.noaa.gov/resilience.html>

CanVis tool NOAA CSC www.csc.noaa.gov/canvis

Coastal Flooding Impacts Viewer, NOAA Coastal Services Center. www.csc.noaa.gov/SLR

Coastal & Waterfront SmartGrowth. (2012). NOAA with United States Department of Commerce.
<http://coastalsmartgrowth.noaa.gov/gettingstarted/welcome.html>

Introduction to Stakeholder Participation (2007) NOAA Coastal Services Center.
http://www.csc.noaa.gov/digitalcoast/_/pdf/stakeholder.pdf

Understanding Coastal Inundation. (n.d.) In Digital Coast, NOAA Coastal Services Center.
<http://www.csc.noaa.gov/digitalcoast/inundation/understand>

Understand – Conserving Coastal Wetlands for Sea Level Rise Adaptation. (n.d.) In Digital Coast, NOAA Coastal Services Center. <http://www.csc.noaa.gov/digitalcoast/wetlands/understand>

What Will Adaptation Cost? An Economic Framework for Coastal Community Infrastructure (2013) NOAA Coastal Services Center.
http://www.csc.noaa.gov/digitalcoast/sites/default/files/files/publications/12072013/What_Will_Adaptation_Cost_Report.pdf

U.S. Army Corps of Engineers (USACE) ETL 1100-2-1, Procedures to Evaluate Sea Level Change: Impacts, Responses, and Adaptation, August 2014
http://www.publications.usace.army.mil/Portals/76/Publications/EngineerTechnicalLetters/ETL_1100-2-1.pdf

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).

USACE (2013). *Incorporating Sea Level Change into Civil Works Programs*. ER 1100-2-8162.

http://www.publications.usace.army.mil/Portals/76/Publications/EngineerRegulations/ER_1100-2-8162.pdf

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)

NOAA (2012). *Global Sea Level Rise Scenarios for the United States National Climate Assessment*. Climate Program Office (CPO) – NOAA Technical Report OAR CPO-1.

<http://cpo.noaa.gov/AboutCPO/AllNews/TabId/315/ArtMID/>

Appendix B: Adaptation Strategies

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

Adaptation Planning - Planning for Coastal Flooding and Sea Level Rise

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:

- Frank et al. (2015). [Planning for Sea Level Rise in the Matanzas Basin: Opportunities for Adaptation](#). National Estuarine Research Reserve Science Collaborative, pages 240-253.
- Love et al. (2013). [Preparing for Tomorrow's High Tide: Recommendations for Adapting to Sea Level Rise in Delaware](#). Delaware Sea level Rise Advisory Committee, pages 11-16.
- Schechtman, J., & Brady, M. (2015). [Cost-efficient Climate Adaptation in the North Atlantic](#). National Oceanic and Atmospheric Administration and Sea Grant.