Analysis of the Vulnerability of Southeast Florida to Sea Level Rise

Southeast Florida Regional Climate Change Compact Inundation Mapping and Vulnerability Assessment Work Group

August 2012

SOUTHEAST FLORIDA
REGIONAL COMPACT
CLIMATE CHANGE

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Executive Summary

Southeast Florida (SE FL) is highly vulnerable to sea level rise (SLR) due to its peninsular geomorphology and low topography. Mapping different sea level rise inundation scenarios helps to identify areas at potential risk and aids in planning for a sustainable community. At the October 23, 2009 Southeast Florida Regional Climate Leadership Summit, the local diversity in the data sources, methods and criteria used to generate the currently available SLR inundation scenarios was highlighted as a concern and barrier to achieving regionally-consistent vulnerability analyses. The SE FL Regional Climate Change Compact Steering Committee, made up of the Climate Compact Counties (Monroe, Miami-Dade, Broward and Palm Beach) and the South Florida Water Management District (SFWMD) supported the effort to develop a regionally-consistent methodology for inundation mapping and vulnerability analysis. This document contains the vulnerability assessment of the Southeast Florida region to 1, 2 and 3 foot SLR scenarios. Based on the Compact's SLR projection for the SE FL region, the one foot scenario could occur between 2040-2070, the two foot scenario from 2060 – 2115 and the three foot scenario from 2075-2150. The maps and tables of information contained herein are intended to be used for planning purposes among the four Compact Counties to begin to identify infrastructure at risk and to develop adaptation strategies and policies to address these risks with the intent of becoming a more climate-resilient community.

The Southeast Florida Regional Climate Change Compact Inundation Mapping and Vulnerability Assessment Work Group (a participant list may be found in Appendix A) was formed to address this issue. Geographic Information System (GIS) practitioners, representing the Climate Compact Counties as well as the SFWMD, local universities and federal agencies, worked with National Oceanographic and Atmospheric Administration (NOAA) Coastal Services Center (CSC) experts to understand inundation mapping methodologies, define the local challenges, review available topographic source data and create a consensus set of methods and criteria for inundation mapping. A full discussion of the final inundation mapping methodology is provided in Appendix B.

Facilitated discussions, surveys and workshops were used to develop planning parameters that would be part of the regional SLR vulnerability assessment. These parameters were categorized as physical features (e.g. power plant, schools, hospital, emergency shelters etc.) and as the result of analysis (e.g. taxable value of property, land use, habitats etc.). Uncertainty in the tidal surface and the elevation data is presented on each map in two categories: (1) <u>More likely</u> to be inundated defined as 100-75% certainty of a given location having an elevation below sea level at high tide for a given scenario and (2) <u>Possible</u> inundation defined as 25-74.9% certainty. A full discussion of the vulnerability assessment methodology is discussed in Appendix C.

GIS-staff for each County performed the vulnerability assessment for their respective counties utilizing the above methodologies. The assessments for each Climate Compact County are included which provide both general overviews of the county's vulnerable infrastructure and the specifics on potentially impacted locations. Regional vulnerabilities are also summarized.

Readers should take note that this analysis is based on land and sea elevations only and does not consider flooding related to existing drainage issues, associated with rain events or that may be caused by tropical storm surge. It provides an overview highlighting locations that are low lying in comparison to various sea level rise scenarios. Additional analysis and more sophisticated models would be required to determine hydrologic connections and actual surface water response to rising sea levels. Since this analysis was originally performed, several Counties have used extreme high tide events that occur in the fall of each year to ground truth select locations for inundation from rising seas.

All of the Climate Compact Counties are vulnerable to sea level rise. Greater impacts occur in the southern counties with lessening impacts as one travels northward. Sixty-eight percent (44,885 acres) of unincorporated Monroe County's land mass is vulnerable at the one foot scenario while the percentage of the urban areas of Miami-Dade and Broward and the unincorporated area of Palm Beach is much lower. Please note that the unincorporated areas of Palm Beach are inland with the majority of the vulnerable areas occurring in coastal incorporated cities. In terms of the amount of land which may be vulnerable, the number of acres impacted in Miami-Dade is three times greater than that experienced in Monroe County for the two and three foot scenarios. Nearly 80% of the lands affected regionally in the one foot scenario are conservation lands especially coastal wetlands. Low lying natural systems made up of buttonwood, mangrove, scrub mangrove, and herbaceous coastal saline and freshwater wetlands are significantly impacted in all SLR scenarios.

In terms of the critical infrastructure reviewed, inundation is often confined to marginal areas of the properties or impacting existing drainage infrastructure on site. This is generally true for the region's ports, airports, schools, landfills and hospitals. Monroe County is the exception with potential building and infrastructure inundation especially at the 2 and 3 foot sea level rise scenarios. Three of Monroe's four hospitals, 65% of their schools and 71% of their emergency shelters have property at elevations below sea level at the one foot scenario. Similar facilities in the other Compact Counties are mainly impacted at the 3 foot scenario. Power plants properties in Miami-Dade and Broward as well as energy transmission facilities in Monroe are vulnerable at the one foot scenario. While railroads are negligibly at risk, more than 81 miles of roadway from Miami-Dade through Palm Beach are at elevations below sea level at the one foot scenario, increasing to more than 893 miles at the three foot scenario.

The upper estimate of taxable property values vulnerable across the region is greater than $4 billion with values rising to over $31 billion at the 3 foot scenario. The greater values reflected in the financial impacts are the low density and irregular residential properties proximate to the coast. These coastal residential properties are generally waterfront with ocean access and therefore with high taxable value. Additionally, the roads that access these residential areas are lower than the finish floor elevation of the homes and therefore subject to inundation prior to impacts to the homes.

This vulnerability analysis highlights areas of particular concern where adaptation measures need to be affected for the Climate Compact Counties. Select capital improvements and progressive policies are needed to address these vulnerable areas and facilities in both the short term and long term. Cooperation among the Compact Counties as well as municipalities, local, regional, state and federal agencies will be critical to coordinate policies and adaptation measures to prepare Southeast Florida for the projected impacts of sea level rise.

Chapter 1: Introduction

Nancy Gassman and Donald Burgess, Broward County Natural Resources Planning and Management Division

Developing Regionally-Consistent Inundation Maps and Vulnerability Assessment Methods for Southeast Florida

Southeast Florida (SE FL) is highly vulnerable to sea level rise (SLR) due to its peninsular nature and low topography. Porous limestone geology and the extensive network of surface water canals allows for movement of salt water underground and inland. Mapping different sea level rise inundation scenarios helps to identify areas at potential risk and aids in planning for a sustainable community. At the October 23, 2009 Southeast Florida Regional Climate Leadership Summit, the local diversity in the data sources, methods and criteria used to generate the currently available SLR inundation scenarios was highlighted as a concern and barrier to achieving regionally-consistent vulnerability analyses. The SE FL Regional Climate Change Compact Steering Committee, made up of the Climate Compact Counties (Monroe, Miami-Dade, Broward and Palm Beach) and the South Florida Water Management District (SFWMD) supported the effort to develop a regionally-consistent methodology for inundation mapping and vulnerability analysis.

The National Oceanographic and Atmospheric Administration (NOAA) Coastal Services Center (CSC) worked closely with Broward County and SFWMD to coordinate a two-day technical workshop in April 2010 to develop a unified set of methodologies and criteria for creating sea level inundation maps in the Southeast Florida region. At that workshop, Geographic Information System (GIS practitioners, representing the Climate Compact Counties as well as the SFWMD, local universities and federal agencies, worked with NOAA experts to understand inundation mapping methodologies, define the local challenges, review available topographic source data and create a consensus set of methods and criteria for inundation mapping. These experts formed the Southeast Florida Regional Climate Change Compact Inundation Mapping and Vulnerability Assessment Work Group (a participation list may be found in Appendix A).

They agreed to the following:

- To use Florida Division of Emergency Management (FDEM) Light Detection And Ranging (LiDAR) elevation data where it is available;
- To use regionally consistent digital elevation models (DEMs) provided by SFWMD ;
- To use 50 foot cell size DEMs at the county level for inundation/vulnerability analysis;
- To use Mean Higher High Water (MHHW) tidal datum relative to North American Vertical Datum of 1988 (NAVD88) as the starting elevation for inundation scenarios;
- To use the VDatum Mean Higher High Water (MHHW) tidal grid surface in NAVD88 to be provided by NOAA to ensure smooth transitions across county boundaries;
- To map sea level rise (SLR) inundation scenarios on 1 foot increments up to 3 feet;
- To calculate uncertainty (75/25) using NOAA's recommended methodology;

- To show inundation polygons as areas at or below MHHW for the given scenario, including; unconnected low-lying areas and without differentiation from hydrologically-connected areas;
- To use a minimum mapping unit of ½ acre.

Using these commonly agreed parameters and data sources, the SFWMD produced inundation layers to represent areas potentially vulnerable to 1, 2 and 3-ft sea level rise scenarios. These layers were used by each of the four Compact counties to perform a vulnerability assessment for their jurisdiction. A more detailed discussion of the inundation mapping methodologies may be found in Appendix B.

The Work Group met a second time to outline the specific parameters to include in a regionally consistent vulnerability analysis. Facilitated discussions were used to determine planning parameters that should be part of a regional sea level rise vulnerability assessment. These parameters were categorized as physical features (e.g. power plant) or as the result of analysis (e.g. taxable value of property). Physical features included in the vulnerability analysis include:

Ports and airports	Hospitals
Railroads	Schools
Miles of road by FDOT category	Emergency shelters
Water & wastewater treatment plants	Evacuation routes
Power plants	Marine facilities
Landfills	

Additional analysis was conducted to determine taxable value of property impacted, acres of future land use and acres by habitat type/ land cover land use. Physical features reviewed and the analysis performed by the Work Group was limited by the available GIS layers and relevant data. Methodologies for performing vulnerability analysis using inundation maps in a GIS format were tested and discussed at the next workshop. The group also decided on which regional datasets would be used, on how data would be presented and on how uncertainty would be represented. A complete discussion of the methods for the Vulnerability Analysis may be found in Appendix C.

This document was available for public comment in early 2012. All responses were reviewed and revisions made as appropriate.

How to Use this Document

The Southeast Florida Climate Change Compact Inundation Mapping and Vulnerability Assessment Work Group present maps and tables that demonstrate potential vulnerability for 1, 2 and 3 foot sea level rise scenarios applied to the Southeast Florida region. Based on the Compact's SLR projection for the SE FL region, the one foot scenario is predicted to occur between 2040-2070, 2 foot from 2060 – 2115 and 3 foot from 2075-2150. Uncertainty in the tidal surface and the elevation data is presented on each map in two categories: (1) More likely to be inundated defined as 100-75% certainty of a given location having an elevation below sea level at high tide for a given scenario and (2) Possibly inundated defined as 25-74.9% certainty. The maps and tables of information contained herein are intended to be used for planning purposes among the four Compact Counties to begin to identify infrastructure at risk and to develop adaptation strategies and policies for inclusion in the Regional Climate Action Plan to address these risks with the intent of becoming a more climate-resilient community. More complex modeling is necessary to refine predictive capability of actual inundation. Since this analysis was originally performed, several Counties have used extreme high tide events that occur in the fall of each year to ground truth select locations for inundation from rising seas.

Readers should take note that this analysis is based on land elevation only and does not consider flooding related to existing drainage issues, associated with rain events or that may be caused by tropical storm surge. It provides an overview highlighting locations that are low lying. Additional analysis and more sophisticated models would be required to determine hydrologic connections and actual surface water response to rising sea levels.

Chapter 2: Analysis and Findings for the Southeast Florida Region

Nancy Gassman and Donald Burgess, Broward County Natural Resources Planning and Management Division

Based upon the vulnerability assessments performed by the four counties, the greatest potential impacts due to sea level rise occur in Monroe County with significant but diminishing impacts as one moves north. Sixty-eight percent (44,885 acres) of unincorporated Monroe County's land mass is vulnerable at the one foot scenario while the percentage of the urban areas of Miami-Dade and Broward and the unincorporated area of Palm Beach is much lower (Table 1). Please note that the unincorporated areas of Palm Beach are inland with the majority of the vulnerable areas occurring in coastal incorporated cities. In terms of the amount of land which may be vulnerable, the number of acres impacted in Miami-Dade is three times greater than that experienced in Monroe County for the two and three foot scenarios (Figure 1, Table 1).

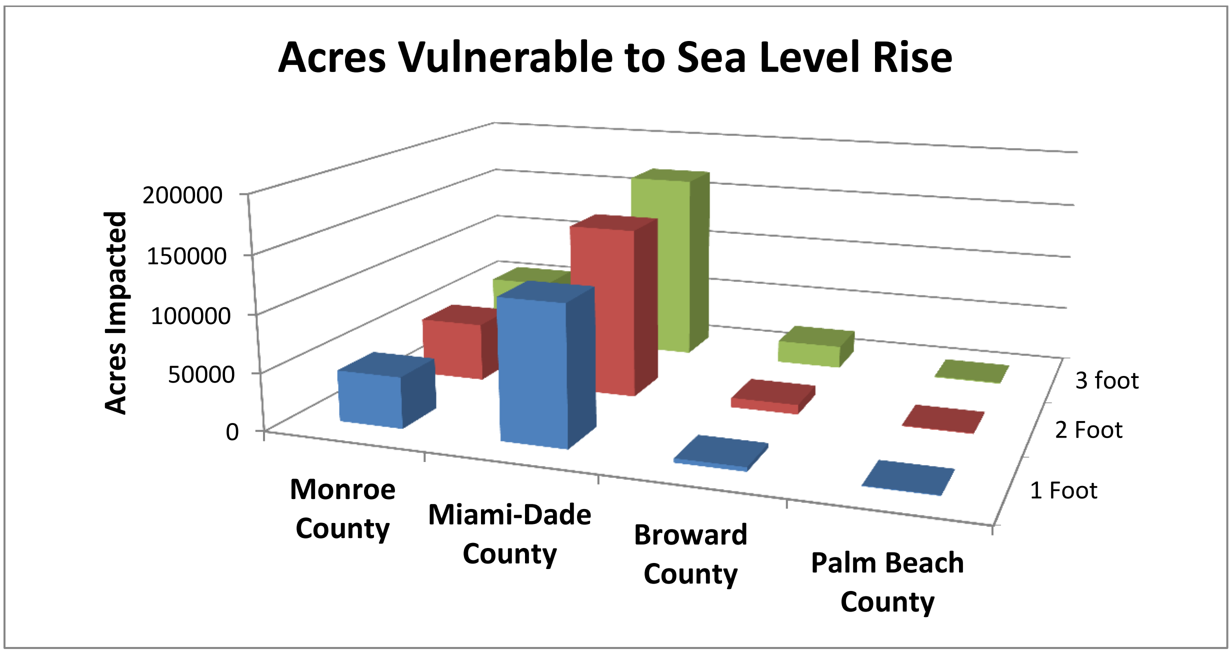


Figure 1 – Acres in Southeast Florida Vulnerable to Sea Level Rise. The graphic shows the acres of land at elevations below sea level for three different sea level rise scenarios as applied to unincorporated Monroe, urban Miami-Dade, urban Broward County and unincorporated Palm Beach. More detail is available in Table1.

This extent of impacts is generally due to the geographic nature of each county:

- Monroe County's developed areas consist of low-lying islands surrounded by water therefore being subject to sea level rise from all directions;
- Miami-Dade County contains extensive inland waterways, older coastal developments and low-lying coastal wetlands in the southern portion which adjoin wetlands preserved within Everglades National Park. Coastal islands along the bays and waterways are subject to a similar fate to the Florida Keys;

- Broward County's inland waterways provide for pathways by which sea level rise may extend inland. Saltwater intrusion barriers along these waterways may slow but cannot prevent inland impacts especially associated with drainage issues; and
- Palm Beach County has a higher topography and has a lack of natural or man-made waterways west of the Atlantic Intracoastal Waterway thus limiting impacts to coastal properties adjacent to this waterway.

Nearly 80% of the lands affected regionally in the one foot scenario are conservation lands especially coastal wetlands. Major areas of land use impacts occur first in natural systems and conservation areas consisting of buttonwood, mangrove, scrub mangrove, and herbaceous coastal saline and freshwater wetlands. While many of these natural systems are presently subject to regular and periodic inundation by salt or brackish water, the longer periods of inundation and/or submersion at greater depths may negatively impact these habitats. As many of these natural areas have a conservation land use, the financial values of these properties is minimally reflected in the taxable value of the properties. The true value of the impacts to these natural and conservation lands relative to their contribution to a healthy ecosystem, to quality of life of our residents and to revenues associated with tourism are not captured here.

Other prominent land uses are impacted at the one foot scenario and continue through the 3 foot scenario. These vary across the Climate Compact Counties. In Monroe, the military and residential conservation land uses are impacted in the early scenarios. Miami-Dade features impacts to electrical generating and agricultural land uses. Broward's early impacts affect recreation and open space as well as residents in irregular areas. Unlike the other counties, Palm Beach impacts begin with residential properties (see Table 1).

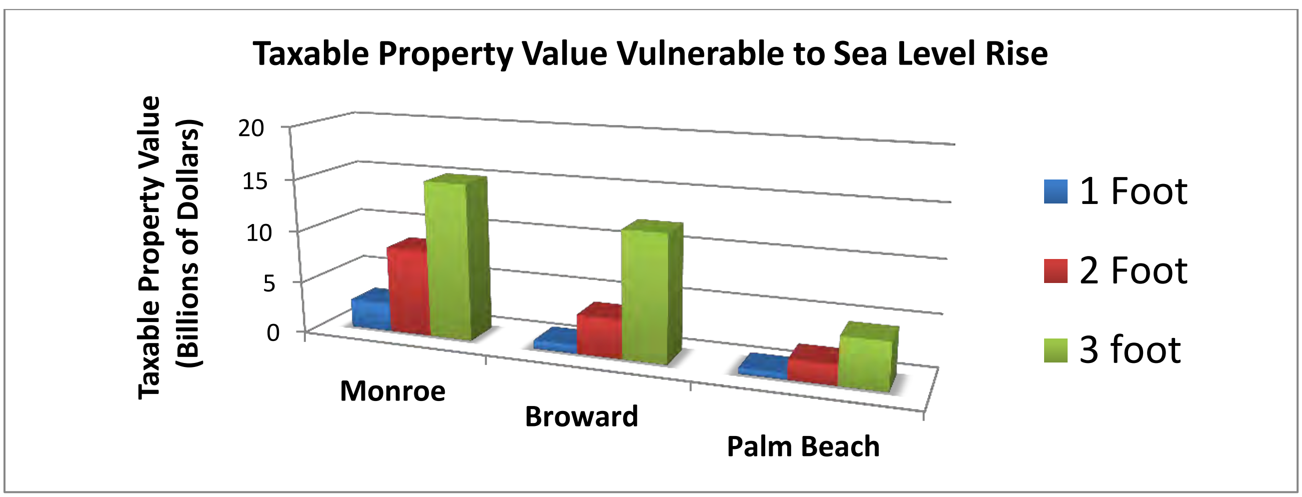


Figure 2 – Taxable Property Value Vulnerable to Sea Level Rise. The graphic shows the estimated taxable property values in billions of dollars potentially vulnerable under three different sea level rise scenarios. Data was not available for Miami-Dade. More detail is available in Table 1.

Despite, the high percentage of natural lands inundated at the one foot scenario, the upper estimate of taxable property values vulnerable across the region is at least $4 billion with values rising to over $31 billion at the 3 foot scenario. The greater values reflected in the financial impacts are the low density and irregular residential properties proximate to the coast. These coastal residential properties are generally waterfront with ocean access and therefore with high taxable value. Additionally, the roads that access these residential areas are lower than the finish floor elevation of the homes and therefore subject to inundation prior to impacts to the homes.

A regional summary of the infrastructure at risk under each of the three sea level rise scenarios is provided in Table 2. In terms of the critical infrastructure reviewed, potential inundation is often confined to marginal areas of the properties or impacting existing drainage infrastructure on site. This is generally true for the region's ports, airports, schools, landfills and hospitals. As you will see below and in Table 2, Monroe is a notable exception.

Marina, Ports and Airports – Determining vulnerability to marinas proved difficult and was only reported by Miami-Dade. Port properties, despite their coastal location, are generally not shown to be vulnerable to sea level rise until the three foot scenario. Two airports in the Keys are at risk in the one foot scenario with Key West being most prominent. Homestead Air Force Base also has impacts beginning with one foot of sea level rise with Opa Locka impacted beginning at the two foot scenario. Fort Lauderdale Airport is vulnerable at the two foot scenario but, as noted above, the potential inundation is limited to low lying stormwater management facilities.

Power Plants – Power plants properties in Miami-Dade and Broward as well as energy transmission facilities in Monroe begin to show vulnerabilities at the one foot scenario. The property surrounding Turkey Point and Fort Lauderdale Power Plant are low lying and show increasing inundation in each progressive scenario. Additional analysis would be required to fully understand impacts to these facilities and their operations.

Railroads, Roads and Evacuation Routes – Railroads in Southeast Florida were built the coastal ridge with elevated beds. Because of this, less than 1% of rails are vulnerable even at the three foot scenario. While some high volume roads are at elevations low enough to become inundated, the majority of impacted roadways are local moderate speed or low volume roads. More than 81 miles of roadway from Miami-Dade through Palm Beach are impacted at the one foot scenario, increasing to more than 893 miles at the three foot scenario. Monroe County reviewed the right-of way along their evacuation routes determining that at 6% are impacted at the one foot scenario with a doubling of the percentage at each additional scenario. Evacuation Routes generally are served by bridges which provide access across waterways to evacuate residents from coastal areas. While evacuation routes were given a broad overview by the majority of the Counties, it was noted that the approach to these bridges may be of concern. The extent of impact was not specifically determined.

Water and Wastewater Treatment Plants – One hundred and two facilities were reviewed regionally. Only those in Monroe County reported impacts to 20% or more of the facilities' property. Water and wastewater transmission systems, pumps and pipes were not considered regional facilities and therefore not analyzed as part of this exercise.

Landfills – Monroe and Broward report impacts to landfills across all three scenarios where 20% or more of the property is determined to be below sea level. As noted previously, inundation is often confined to marginal areas of the properties.

Hospital, Schools and Emergency Shelters – Of the 78 hospitals, 1340 schools and 129 emergency shelters reviewed regionally, the vast majority of impacts are reported in Monroe County.

This regional vulnerability analysis highlights areas of particular concern where adaptation measures need to be affected for the Climate Compact Counties. Select capital improvements and progressive policies are needed to address these vulnerable areas and facilities in both the short term and long term. Cooperation among the Compact Counties as well as municipalities, local, regional, state and federal agencies will be critical to coordinate policies and adaptation measures included in the Regional Climate Action Plan to prepare Southeast Florida for the projected impacts of sea level rise. Individual Counties should continue to review infrastructure of a more local nature to understand adaptation needs within their communities.

TABLE 1. Land Use and Property Values in Southeast Florida Vulnerable to Impacts from Sea Level Rise at 1, 2 and 3 foot Scenarios. This table summarizes potential impacts to land uses and taxable property value for each of the four Counties in the Southeast Florida region caused by sea level rise for three scenarios based on inundation maps generated by the South Florida Water Management District using 2007-2008 LiDAR data from the Florida Division of Emergency Management. Methods used for Inundation Mapping and Vulnerability Analysis are described in Appendix B and C of this document.

Results of Analysis	Sea Level Rise Scenario	Monroe County	Miami-Dade County	Broward County	Palm Beach County	SE FL Region
Acres of Future Land Use Top Three Land Use Categories Impacted	1 foot	Conservation (24,616 acres)	Conservation (107,988 acres)	Conservation (1,044 acres)	Low Residential-1 unit/acre (283 acres)	Monroe and Palm Beach County - unincorporated only
		Residential Conservation (14,342 acres)	Electrical Generation (5,332 acres)	Recreation and Open Space (364 acres)	Low Residential-2 units/acre (191 acres)	
		Military (2,513 acres)	Agricultural (2994 acres)	Residents in Irregular Areas (283 acres)	Low Residential-3 units/acre (81 acres)	
	2 foot	Conservation (26,894 acres)	Conservation (126,809 acres)	Conservation (1,149 acres)	Low Residential-1 unit/acre (292 acres)	
		Residential Conservation (15,421 acres)	Electrical Generation (5,999 acres)	Agricultural (854 acres)	Low Residential-2 units/acre (229 acres)	
		Military (2,994 acres)	Agricultural (7746 acres)	Recreation and Open Space (823 acres)	Low Residential-3 units/acre (115 acres)	
	3 foot	Conservation (27,948 acres)	Conservation (133,088 acres)	Conservation (1,325acres)	Low Residential-1 unit/acre (301 acres)	
		Residential Conservation (15,717 acres)	Electrical Generation (7,000 acres)	Agricultural (2788 acres)	Low Residential-2 units/acre (284 acres)	
		Residential medium (3,293 acres)	Agricultural (10,890 acres)	Right of Way (1936 acres)	Low Residential-3 units/acre (161 acres)	
Acres of Future Land Use number of acres (percent of total acres)		Unincorporated Monroe	Urban Miami-Dade	Urban Broward County	Unincorporated Palm Beach	Monroe and Palm Beach County - unincorporated only
	1 foot	44,885 (68.19%)	121,378 (12%)	3,732 (1.31%)	590 (0.72%)	80,855 acres
	2 foot	51,906 (78.85%)	150,142 (16%)	8,508 (2.98%)	689 (0.85%)	211,245 acres
	3 foot	56,631 (86.04%)	168,895 (18%)	20,404 (7.15%)	868 (0.91%)	246,798 acres

TABLE 1. (cont) Land Use and Property Values in Southeast Florida Vulnerable to Impacts from Sea Level Rise at 1, 2 and 3 foot Scenarios.

Acres of Habitat Type / Land Use/ Land Cover Top Three Land Use Categories Impacted	1 foot	Mangrove (31,956 acres)	Not Analyzed	Wetland Hardwood Forest (1701 acres)	Natural Rivers (951 acres)	
		Scrub Mangrove (9812 acres)	Not Analyzed	Vegetated Non-Forested Wetland (608 acres)	Mangrove Swamp (292 acres)	
		Buttonwood (3,528 acres)	Not Analyzed	Upland Hardwood Forest (195 acres)	Reservoir (99 acres)	
	2 foot	Mangrove (31,393 acres)	Not Analyzed	Wetland Hardwood Forest (2101 acres)	Natural Rivers (972 acres)	
		Scrub Mangrove (9,858 acres)	Not Analyzed	Vegetated Non-Forested Wetland (1212 acres)	Mangrove Swamp (372 acres)	
		Buttonwood (3,999 acres)	Not Analyzed	Residential, Medium Density (722 acres)	Reservoir (201 acres)	
	3 foot	Mangrove (31,548 acres)	Not Analyzed	Wetland Hardwood Forest (2812 acres)	Natural Rivers (976 acres)	
		Scrub Mangrove (9,869 acres)	Not Analyzed	Vegetated Non-Forested Wetland (1864 acres)	Mangrove Swamp (402 acres)	
		Developed Land (7,024 acres)	Not Analyzed	Herbaceous Dry Prairie (2733 acres)	Reservoir (336 acres)	
Acres of Habitat Type / Land Use/ Land Cover number of acres (percent of total acres)	1 foot	50,427 (63%)	Not Analyzed	3,778 (1.37%)	1481 (0.3%)	55,686 acres impacted
	2 foot	59,162 (73.9%)	Not Analyzed	8,619 (3.12%)	1933 (0.37%)	69,714 acres impacted
	3 foot	66,393 (83%)	Not Analyzed	20,625 (7.47%)	2739 (0.52%)	897,57 acres impacted
Taxable Value of Property Upper estimate of taxable property value impacted						Does not include Miami-Dade
	1 foot	$2,763,294,786	Not Analyzed	$828,221,856	$556,659,447	> $4 Billion
	2 foot	$8,388,138,219	Not Analyzed	$3,779,685,458	$1,921,207,483	>$14 Billion
	3 foot	$15,087,755,047	Not Analyzed	$12,109,037,156	$4,495,511,757	> $31 Billion

Table 2. Major Infrastructure in Southeast Florida Vulnerable to Impacts from Sea Level Rise at 1, 2 and 3 foot Scenarios. This table summarizes potential impacts to critical infrastructure for each of the four Counties in the Southeast Florida region caused by sea level rise for three scenarios based on inundation maps generated by the South Florida Water Management District using 2007-2008 LiDAR data from the Florida Division of Emergency Management. Methods used for Inundation Mapping and Vulnerability Analysis are described in Appendix 1 and 2 of this document. Please note that inundation, especially in the 1 and 2 foot scenarios, is often confined to marginal areas of the properties or impacting existing drainage infrastructure on site. The actual structures often, but not always, remain un-impacted. Please see the chapters for each County for a more thorough description of impacts.

Facility Type	Sea Level Rise Scenario	Monroe County	Miami-Dade County	Broward County	Palm Beach County	Southeast Florida Region
Ports		**2**	**2**	**1**	**1**	**6**
# Ports with > 10% property below sea level	1 foot	IND	0	0	0	-
	2 foot	IND	0	0	0	-
	3 foot	IND	1	1	0	≥2
Airports		**6**	**6**	**4**	**12**	**28**
# Airports with > 20% property below sea level	1 foot	2	0	0	0	2
	2 foot	3	2	0	0	5
	3 foot	6	2	1	0	9
Power Plants		**13***	**1**	**2**	**4**	**7**
# Power Plants with > 20% property below sea level	1 foot	1	1	1	0	3
	2 foot	4	1	1	0	6
	3 foot	6	1	1	0	8
Railroads (RR)		No RRs				
percent of miles inundated	1 foot	N/A	0.1%	0	0	0.10%
	2 foot	N/A	0.4%	0.02%	0	0.42%
	3 foot	N/A	0.7%	0.25%	0.05%	1%
Roads by FDOT Category						
number of miles (percent of total miles)	1 foot	ND	72 m (<1%)	9.5 m (<1%)	0 m	>81 miles
	2 foot	ND	257 m (3%)	76 m (1%)	13 m	>346 miles
	3 foot	ND	556 m (6%)	296 m (4%)	41 m (<0.01%)	>893 miles
Water/Wastewater Treatment Plants**		14	6	40	38	**102**
# WTP and WWTP with > 20% property below sea level	1 foot	2	0	0	0	2
	2 foot	3	0	0	0	3
	3 foot	7	0	1	0	8

Table 2. (cont) Major Infrastructure in Southeast Florida Vulnerable to Impacts from Sea Level Rise at 1, 2 and 3 foot Scenarios

Facility Type	Sea Level Rise Scenario	Monroe County	Miami-Dade County	Broward County	Palm Beach County	Southeast Florida Region
Landfills		4	3	7	3	**17**
# Landfills with > 20% property below sea level	1 foot	1	ND	1	0	≥2
	2 foot	1	ND	2	0	≥3
	3 foot	2	ND	2	0	≥4
Hospitals		4	34	26	14	**78**
# Hospitals with property below sea level	1 foot	3	0	0	0	3
	2 foot	3	0	2	0	5
	3 foot	4	3	2	1	10
Schools		17	897	239	187	**1340**
# Schools with property below sea level	1 foot	11 (3>10%)	0	0	0	11
	2 foot	14 (5>20%)	0	0	0	14
	3 foot	14 (9>20%)	3	1	1	19
Emergency Shelters		7	69	36	17	**129**
# Shelters with property below sea level	1 foot	(5/7) 71%	0	0	0	(5/129) 4%
	2 foot	(5/7) 71%	0	0	0	(5/129) 4%
	3 foot	(6/7) 86%	0	0	0	(6/129) 5%
Evacuation Routes						
	1 foot	6.16%	0	ND	ND	ND
	2 foot	12.66%	0	ND	ND	ND
	3 foot	24%	4 m	ND	ND	ND
Marinas						
number of acres impacted	1 foot	IND	21 acres	IND	IND	IND
	2 foot	IND	44 acres	IND	IND	IND
	3 foot	IND	81 acres	IND	IND	IND

IND -- indeterminable ND - not determined by county staff NA - not applicable to this county

* Monroe has no power plants - Their analysis was limited to energy facilities and was not included in the SE FL Region Total.

**Total WTP and WWTP facilities was not available from all Counties. Value shown reflects an estimate or # facilities reviewed.

Chapter 3: Analysis of the Vulnerability of Monroe County to Sea Level Rise

Wayne Whitley and Bryan Davisson - Inundation Mapping and Vulnerability Assessment Work Group Members from Monroe County

Vulnerability to Sea Level Rise - Monroe County Overview

Monroe County occupies the southernmost tip of the state of Florida. It is comprised of a Mainland region as well as the Florida Keys archipelago. The least developed "Mainland Monroe", primarily consists of the Everglades National Park and Big Cypress National Preserve. South of the Mainland, the Florida Keys, a collection of over 4,000 islands divides the Gulf of Mexico from Atlantic Ocean and lies north of the Straits of Florida.

The recent 2010 U.S. Census lists the population of the County at 73,090 with the City of Key West (pop. 24,649) at 34% of the total. Monroe County, also, contains thousands of acres of sensitive native habitat supporting a variety of wildlife including many listed species.

The unique location and low-elevation topography of Monroe County make it acutely vulnerable to the effects of sea level rise. The Sea Level Rise Vulnerability Analysis was prepared for the Florida Keys region of Monroe County to determine the impacts to the area's geographic features and critical facilities.

The analysis was accomplished by performing vector-based geoprocessing operations using numerous GIS datasets (layers). The primary input datasets were the 50-Foot Inundation Grids provided by South Florida Water Management District. This dataset was used in operations which calculated areas/features impacted by 1, 2 and 3 foot sea level rise flood scenarios. All calculations are approximate due to the limitations of data accuracy.

Below is a list of average elevations for the three sections of the Florida Keys and the City of Key West.

<u>Upper Keys – Ocean Reef to Tavernier Creek</u>
Average Elevation: 4.8'
Highest Point: 26.2' in Upper Key Largo (west of SR 905)

<u>Middle Keys – Plantation Key to Knights Key (City of Marathon)</u>
Average Elevation: 4.29'
Highest Point: 27' at Knights Key (US 1 causeway)

<u>Lower Keys – Ohio Key to Stock Island</u>
Average Elevation: 3.17'
Highest Point: 28' at Scout Key (US 1 causeway)

<u>City of Key West</u>
Average Elevation: 4.7'

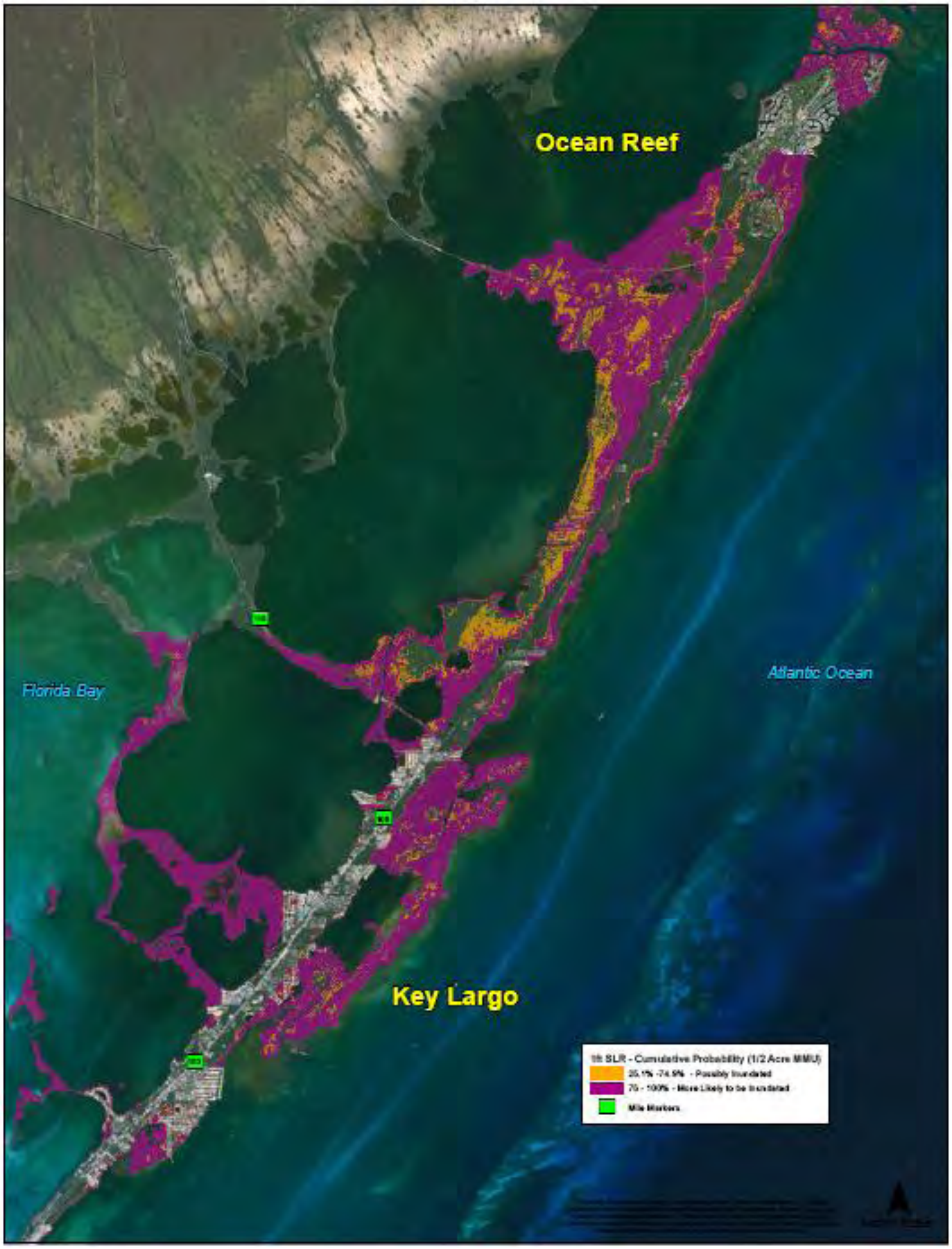
Highest Point: Solares Hill (near Key West Cemetery) at 15.46’

Note: Overseas Highway (US 1) causeway and spoil elevations are included in the averages; Landfill elevations have been removed. Elevation data was compiled using LiDAR generated contours and Digital Elevation Model Source: FDEM 2007

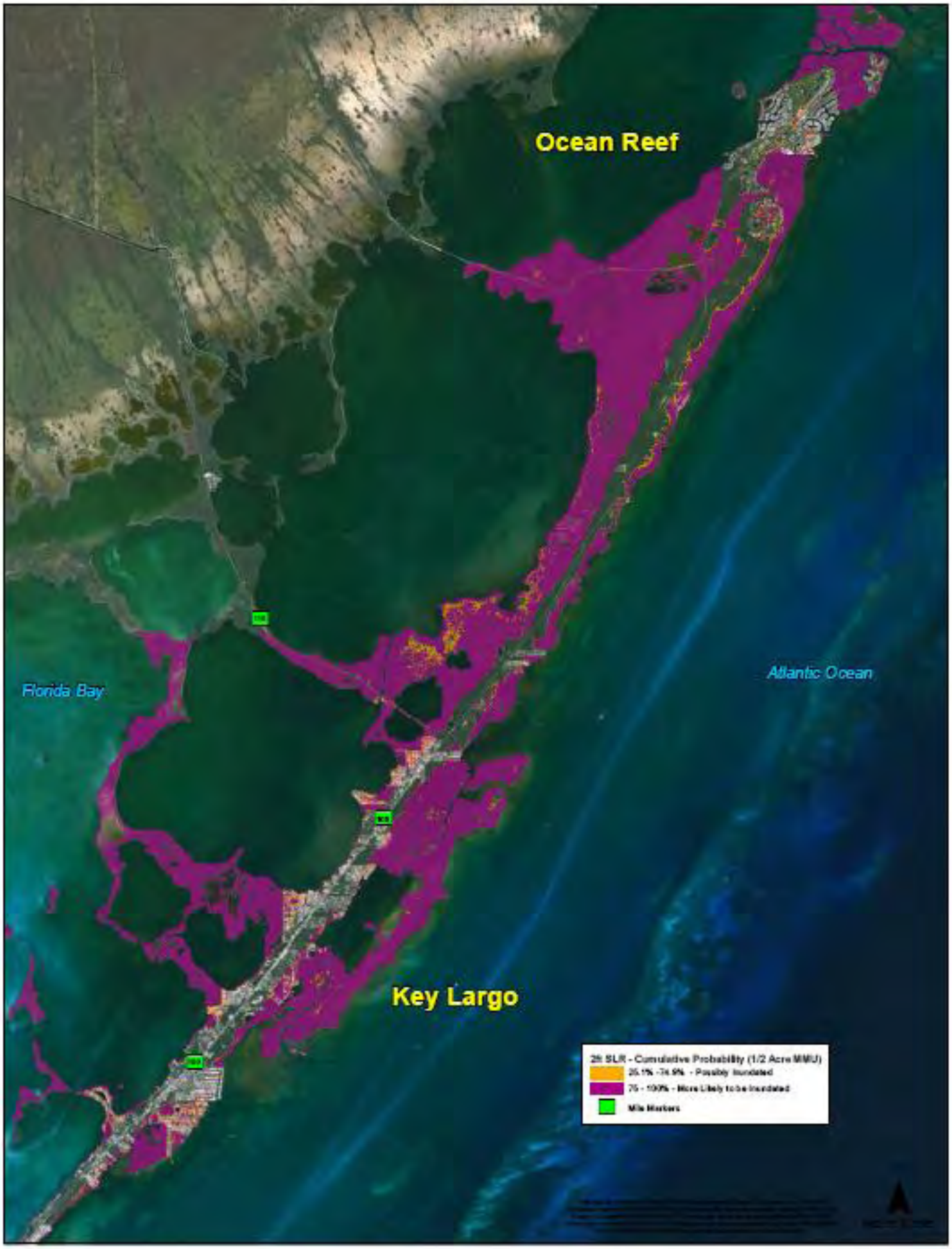
The County-Wide maps provide a general view of the impacted and analyzed areas of the Florida Keys for each Sea Level Rise scenario. Following the maps, brief summaries are included with each analysis.

Countywide Maps – Monroe

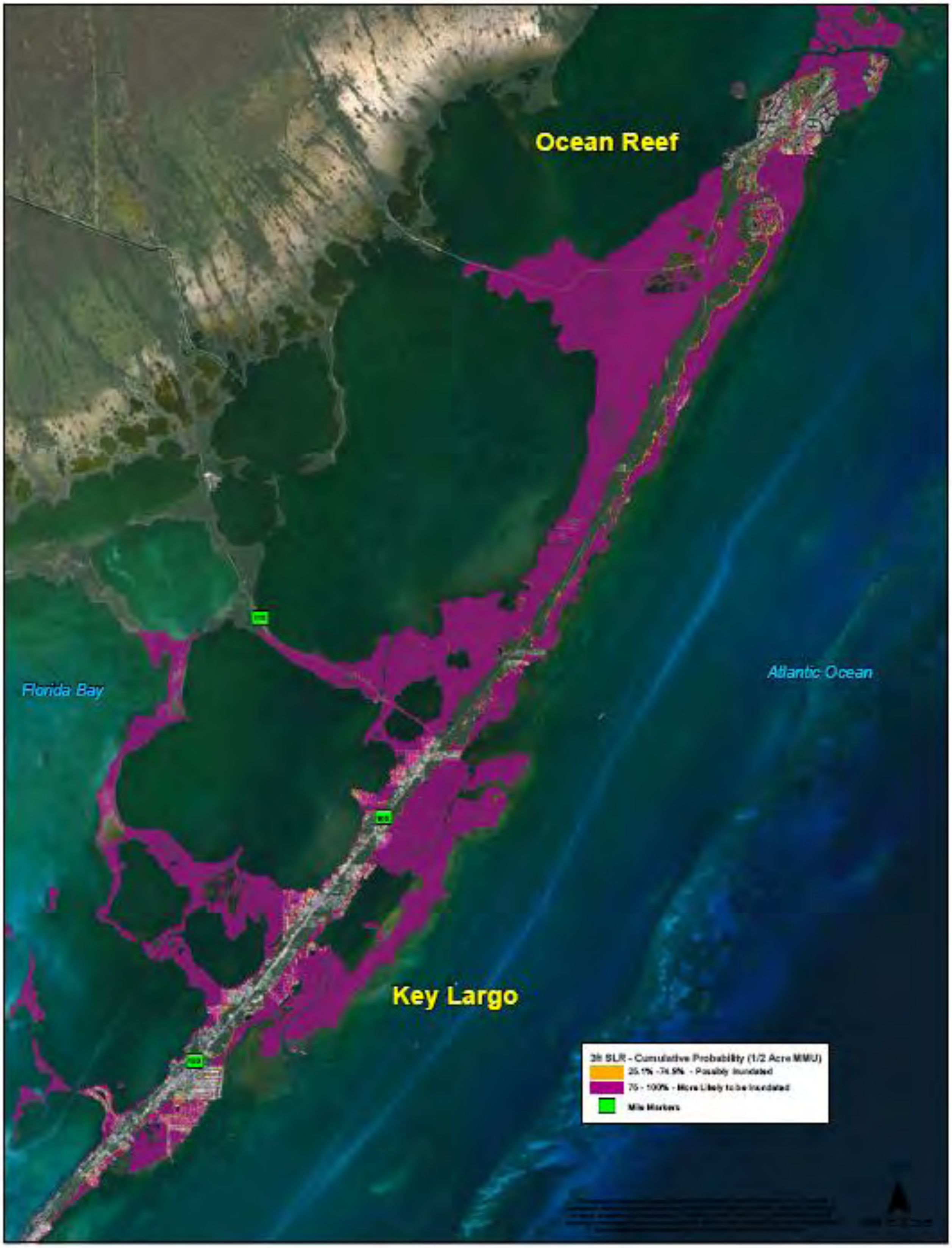
1-Foot Sea Level Rise in Monroe County – Ocean Reef -- Key Largo



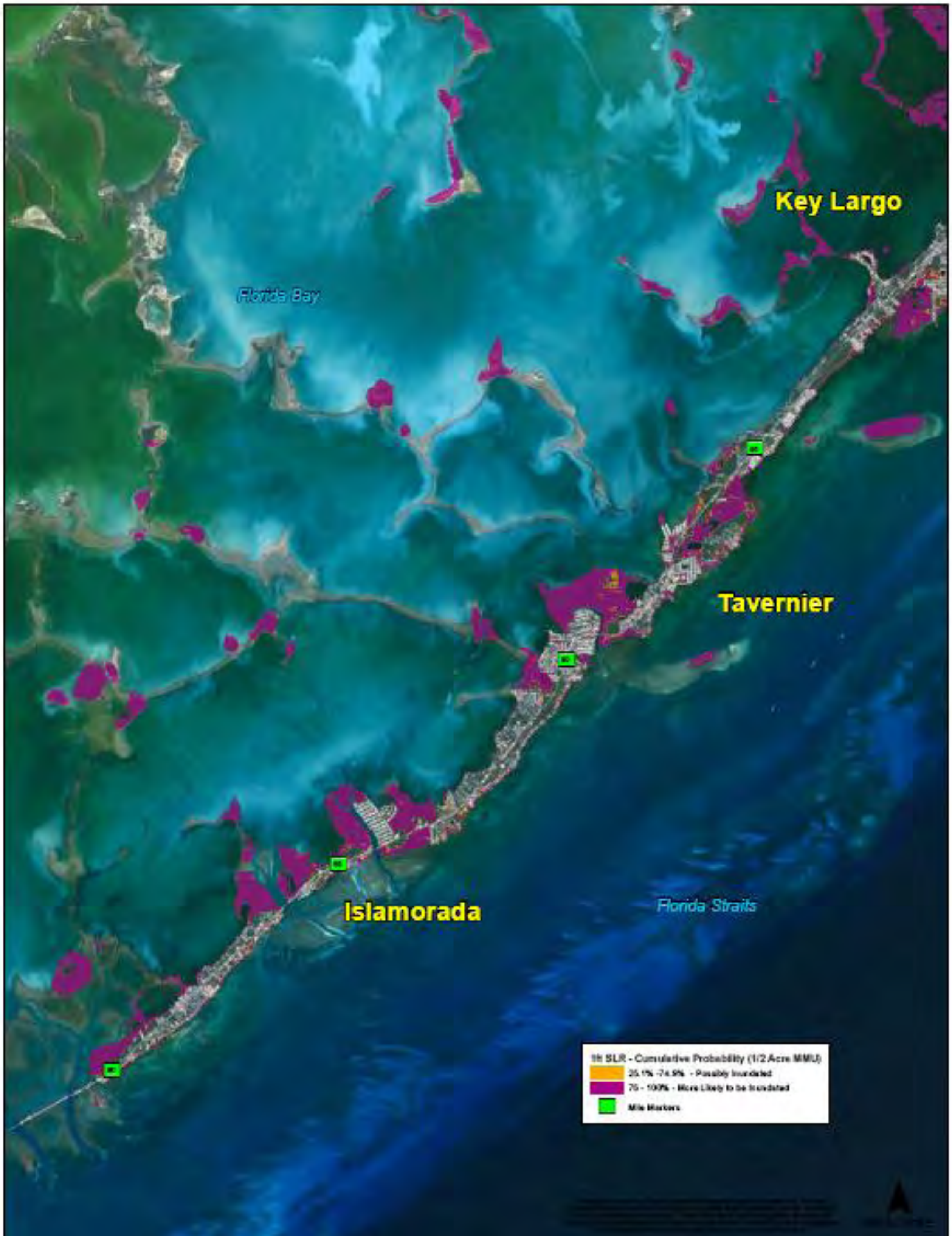
2-Foot Sea Level Rise in Monroe County – Ocean Reef -- Key Largo



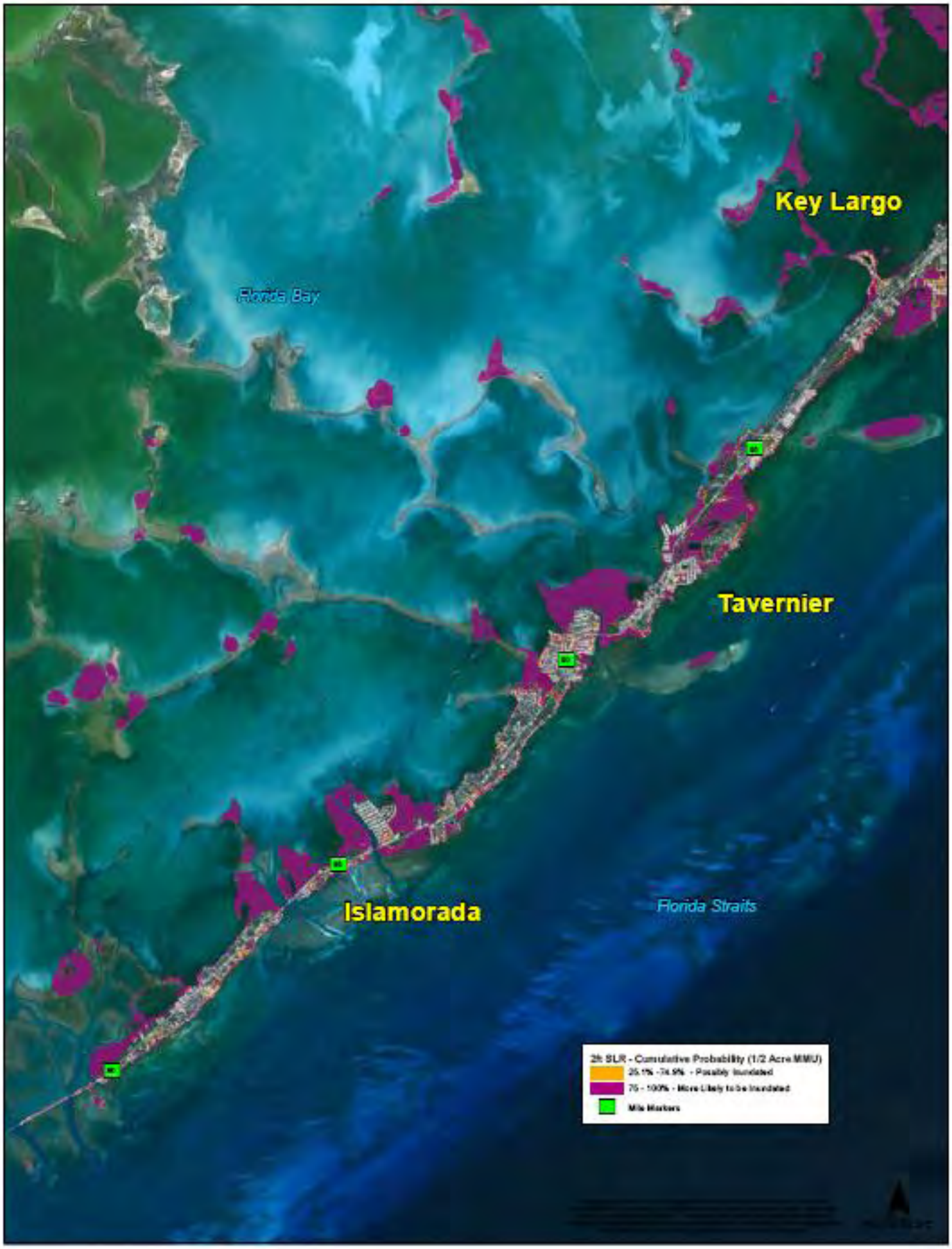
3-Foot Sea Level Rise in Monroe County – Ocean Reef -- Key Largo



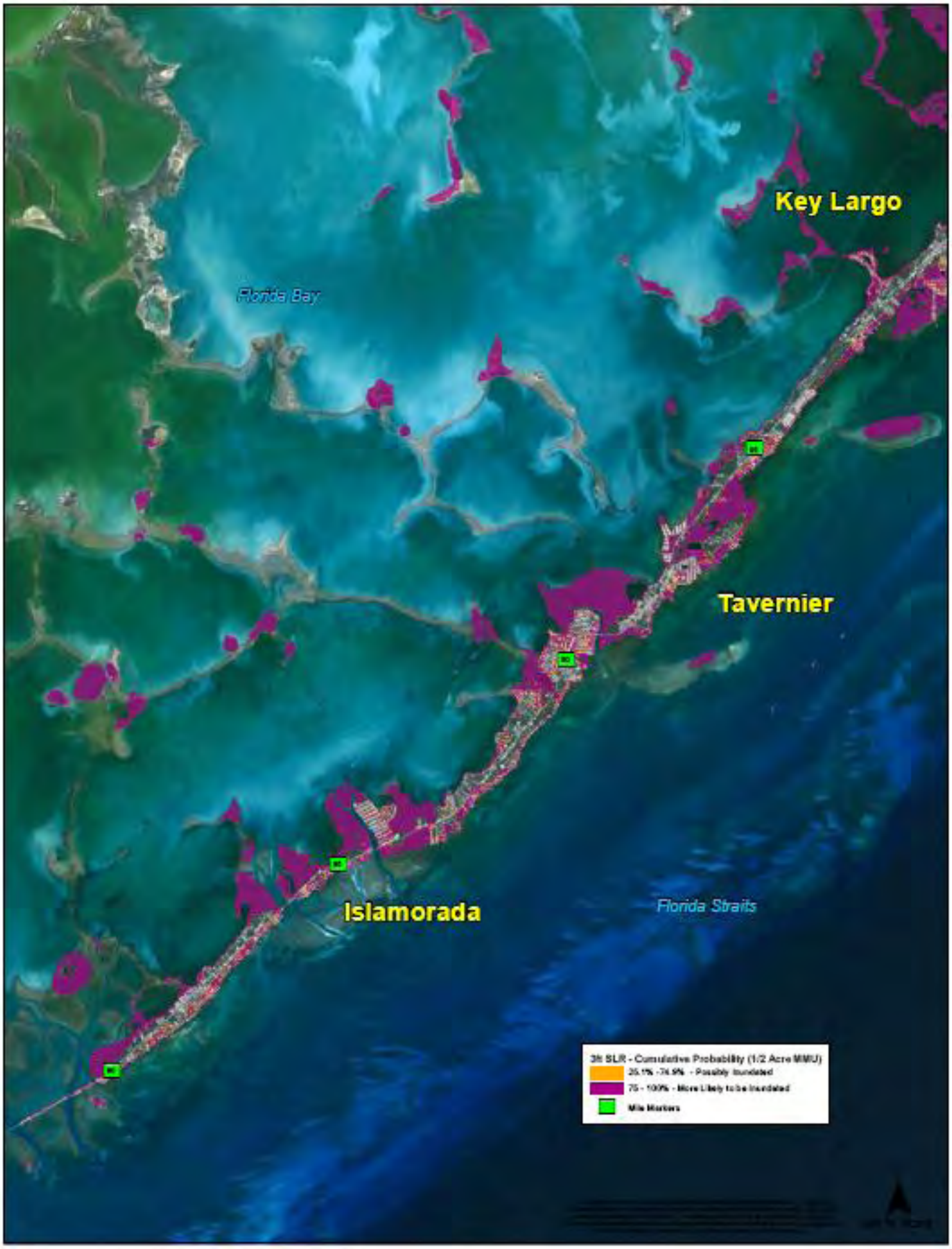
1-Foot Sea Level Rise in Monroe County – Tavernier – Islamorada



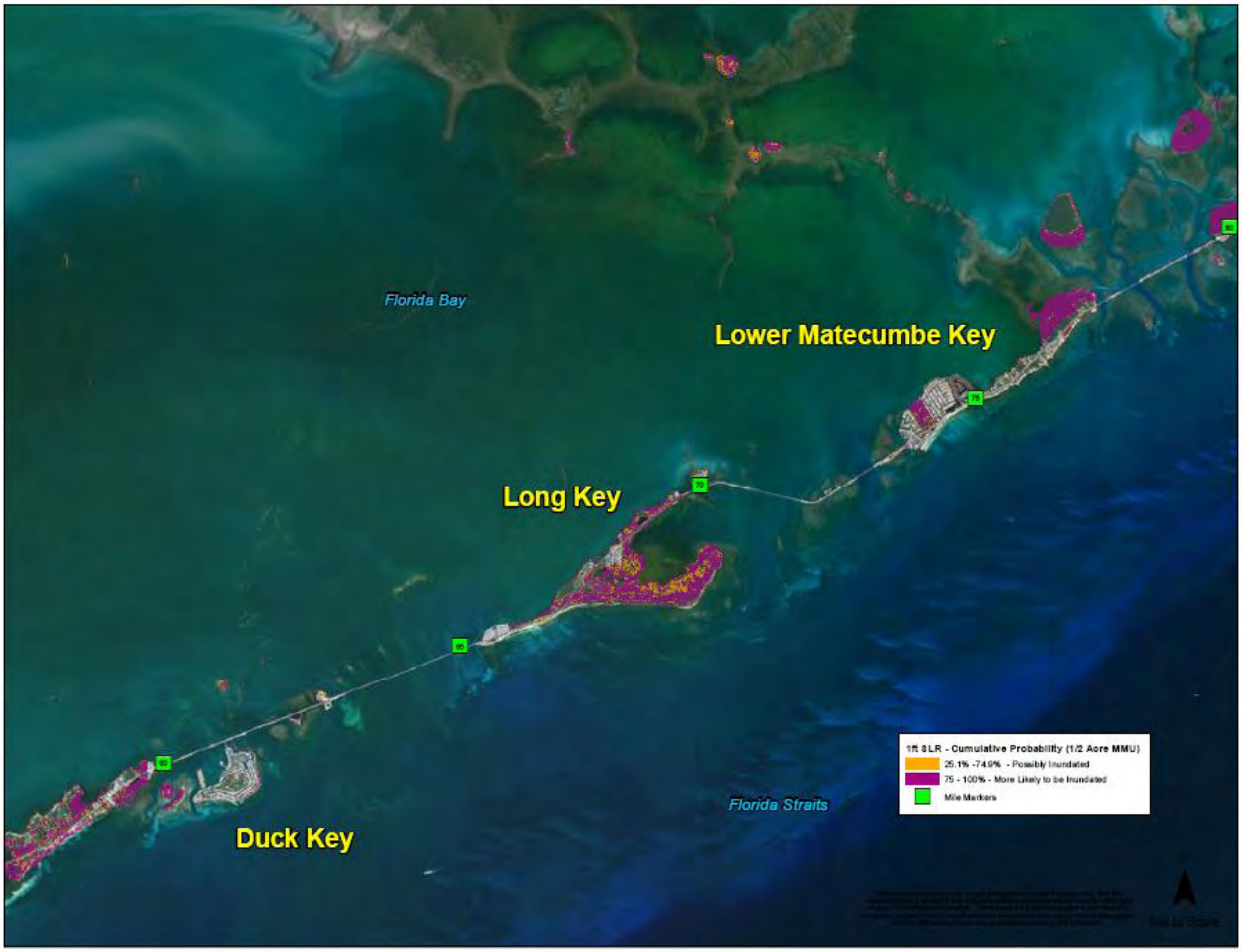
2-Foot Sea Level Rise in Monroe County – Tavernier – Islamorada



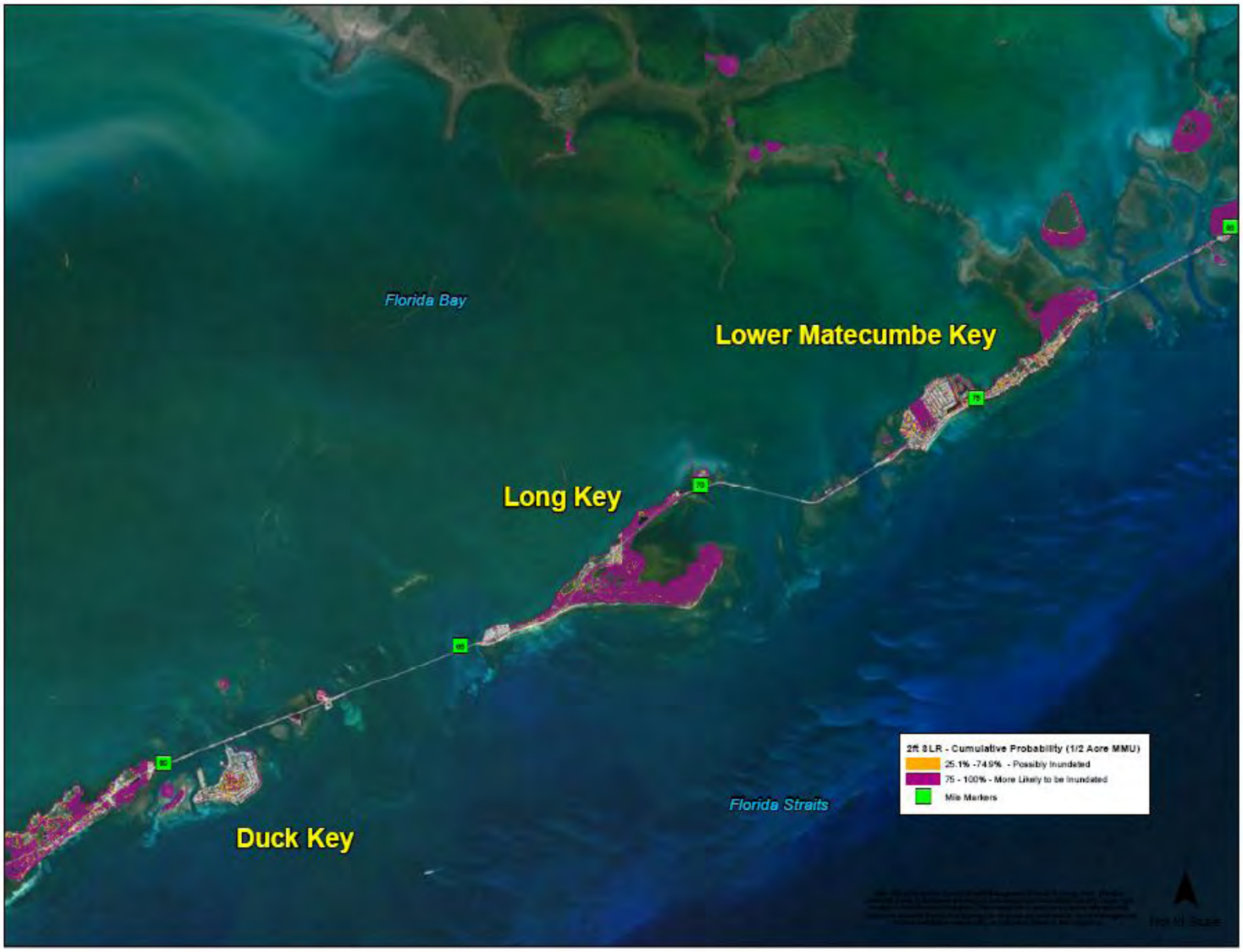
3-Foot Sea Level Rise in Monroe County – Tavernier – Islamorada



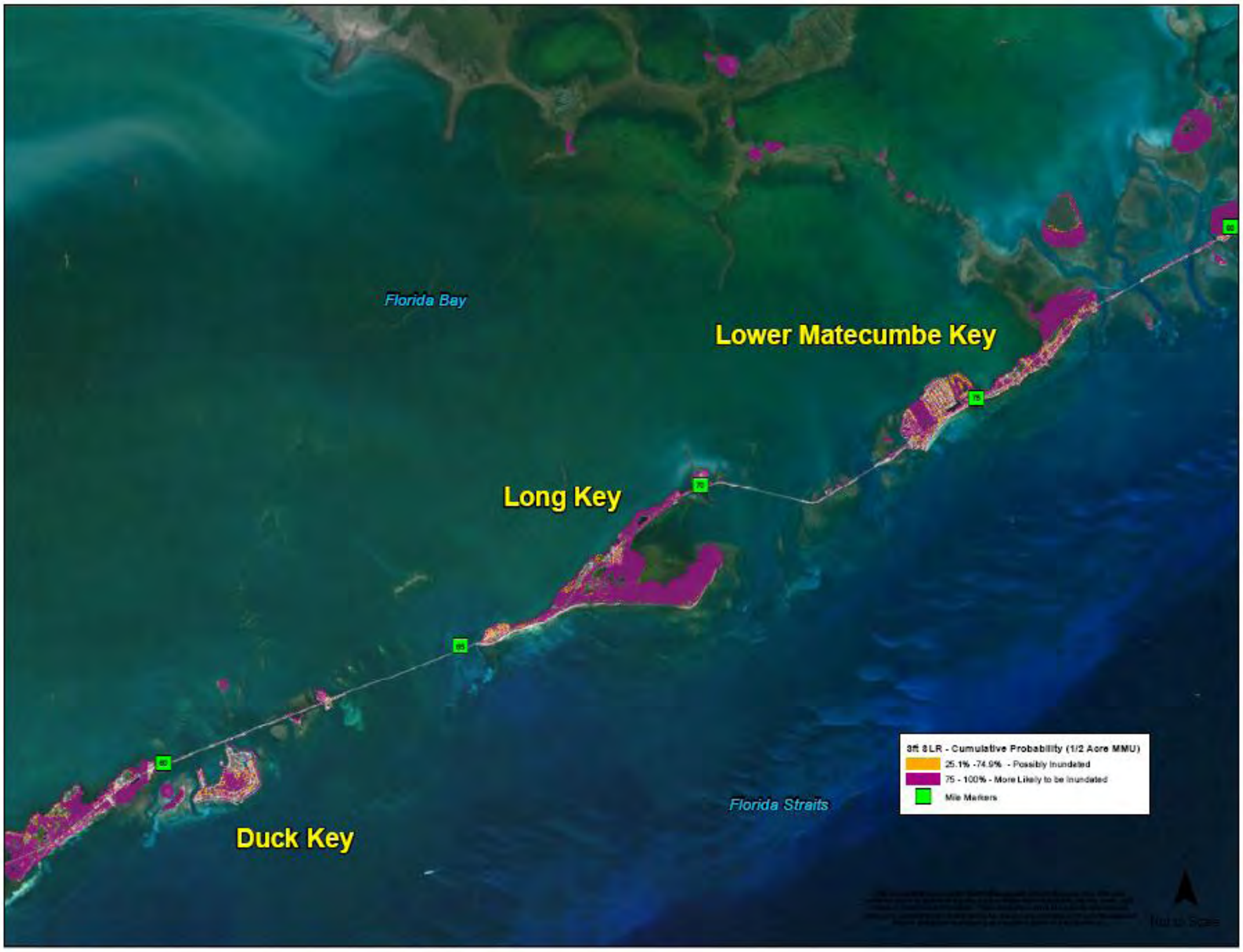
1-Foot Sea Level Rise in Monroe County – Long Key -- Duck Key



2-Foot Sea Level Rise in Monroe County -- Long Key -- Duck Key



3-Foot Sea Level Rise in Monroe County – Long Key – Duck Key

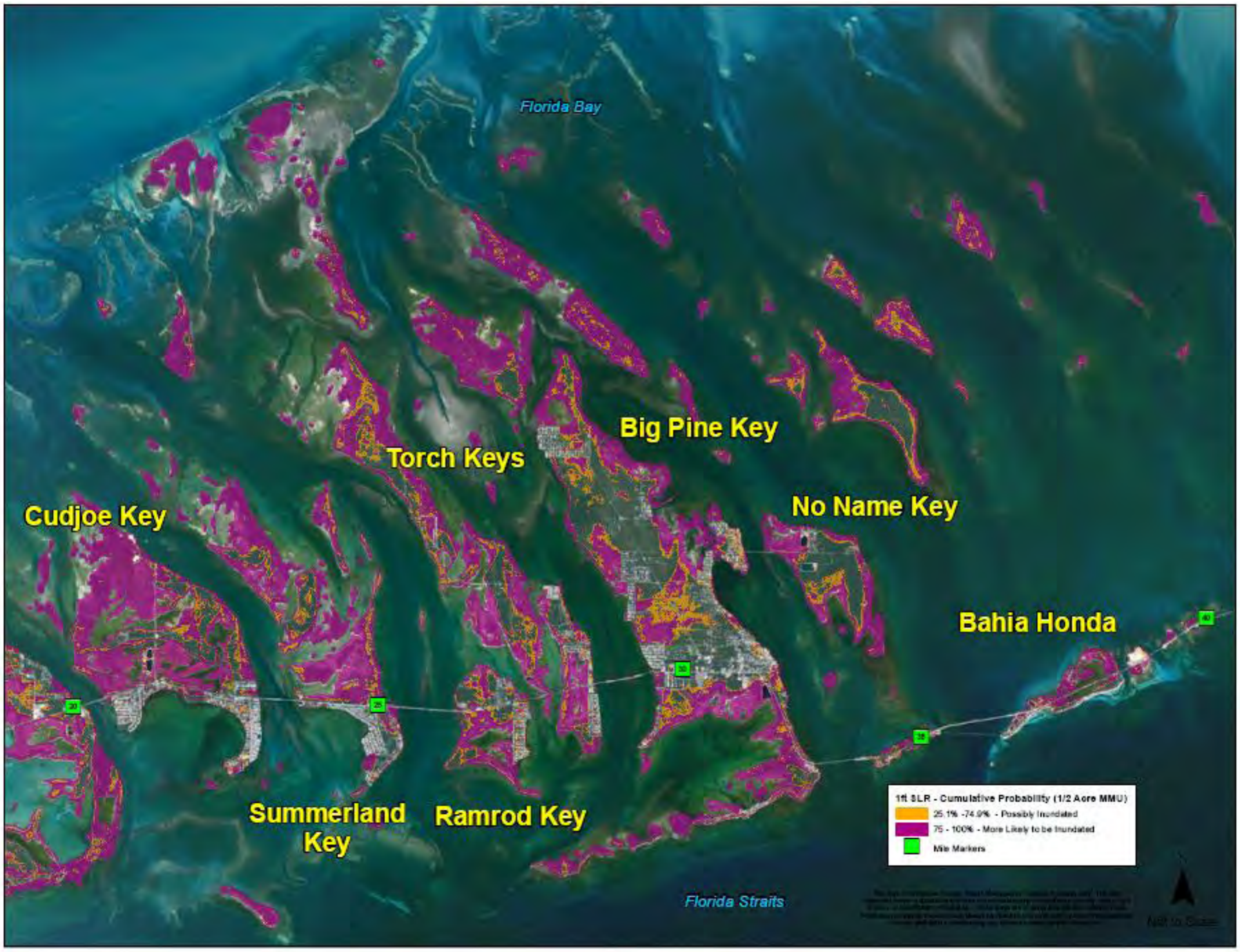


1-Foot Sea Level Rise in Monroe County – Marathon

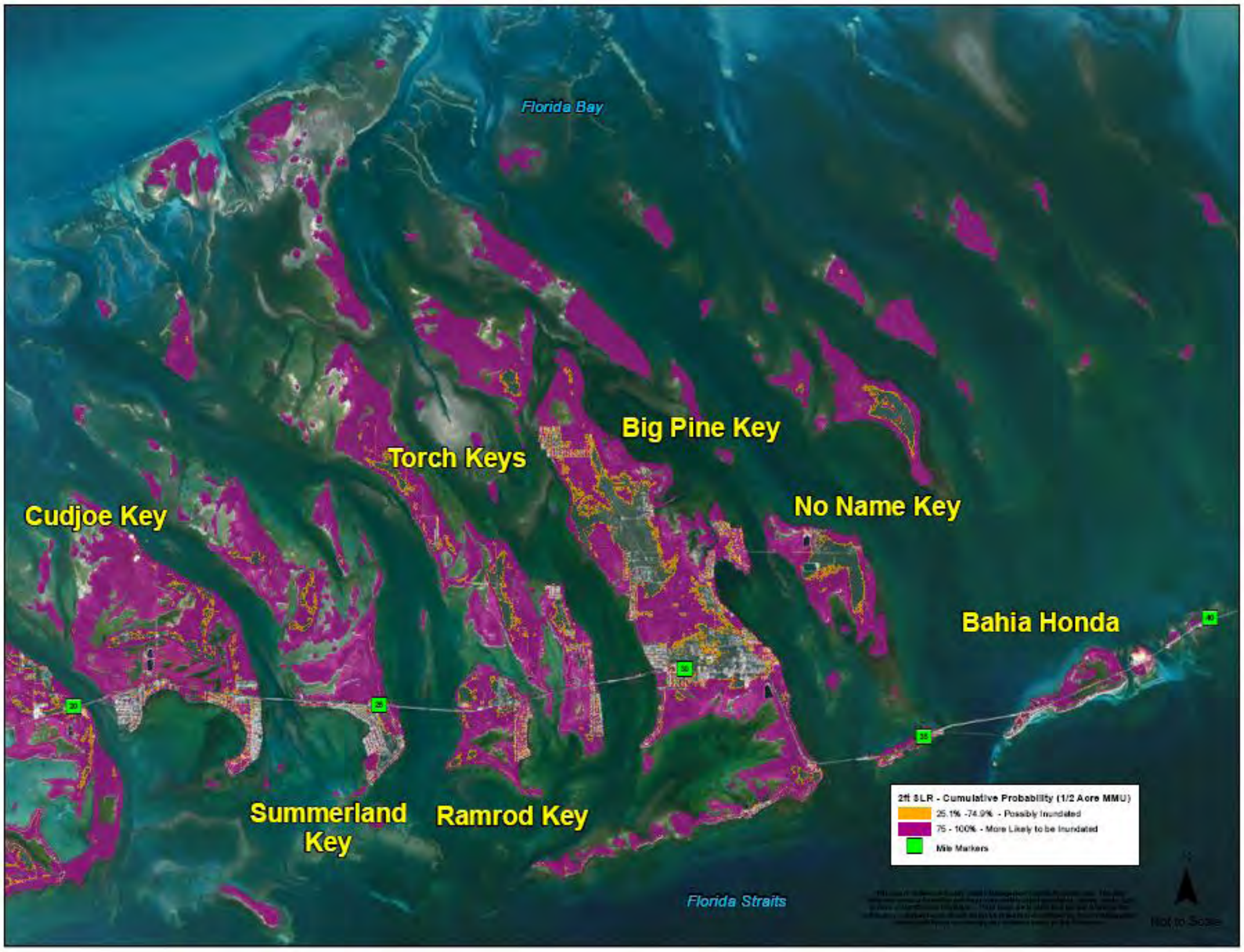
2-Foot Sea Level Rise in Monroe County – Marathon

3-Foot Sea Level Rise in Monroe County – Marathon

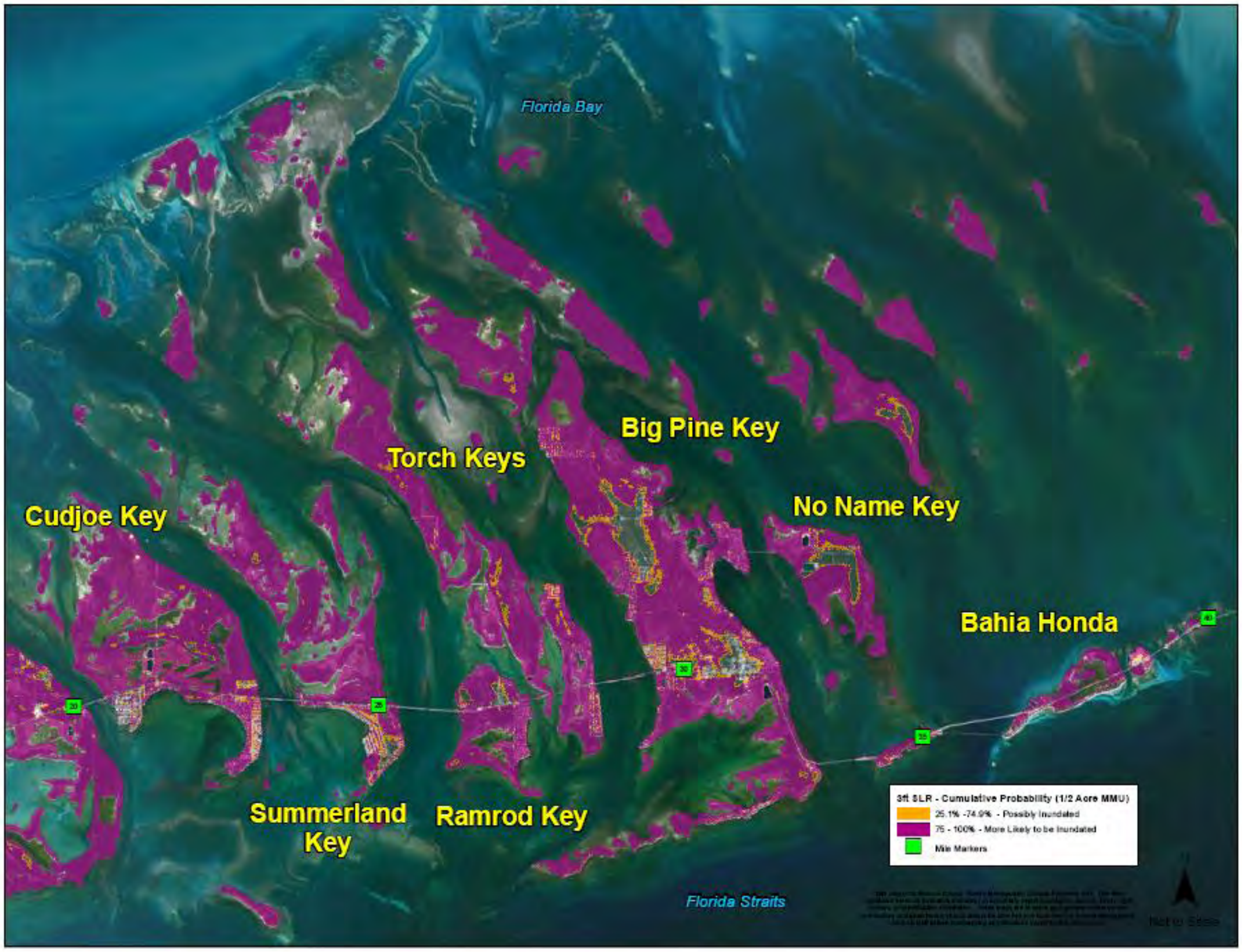
1-Foot Sea Level Rise in Monroe County – Big Pine Key



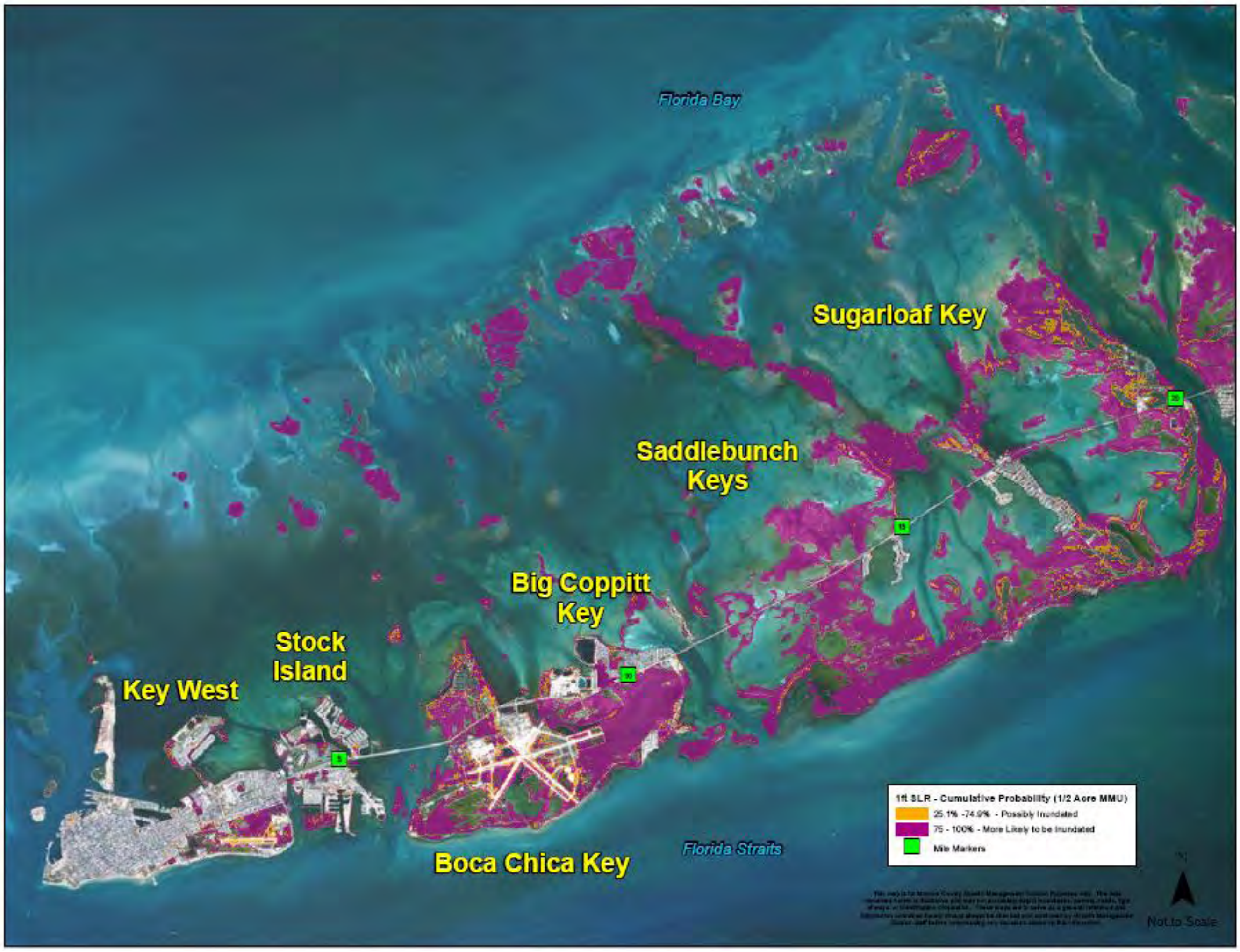
2-Foot Sea Level Rise in Monroe County – Big Pine Key



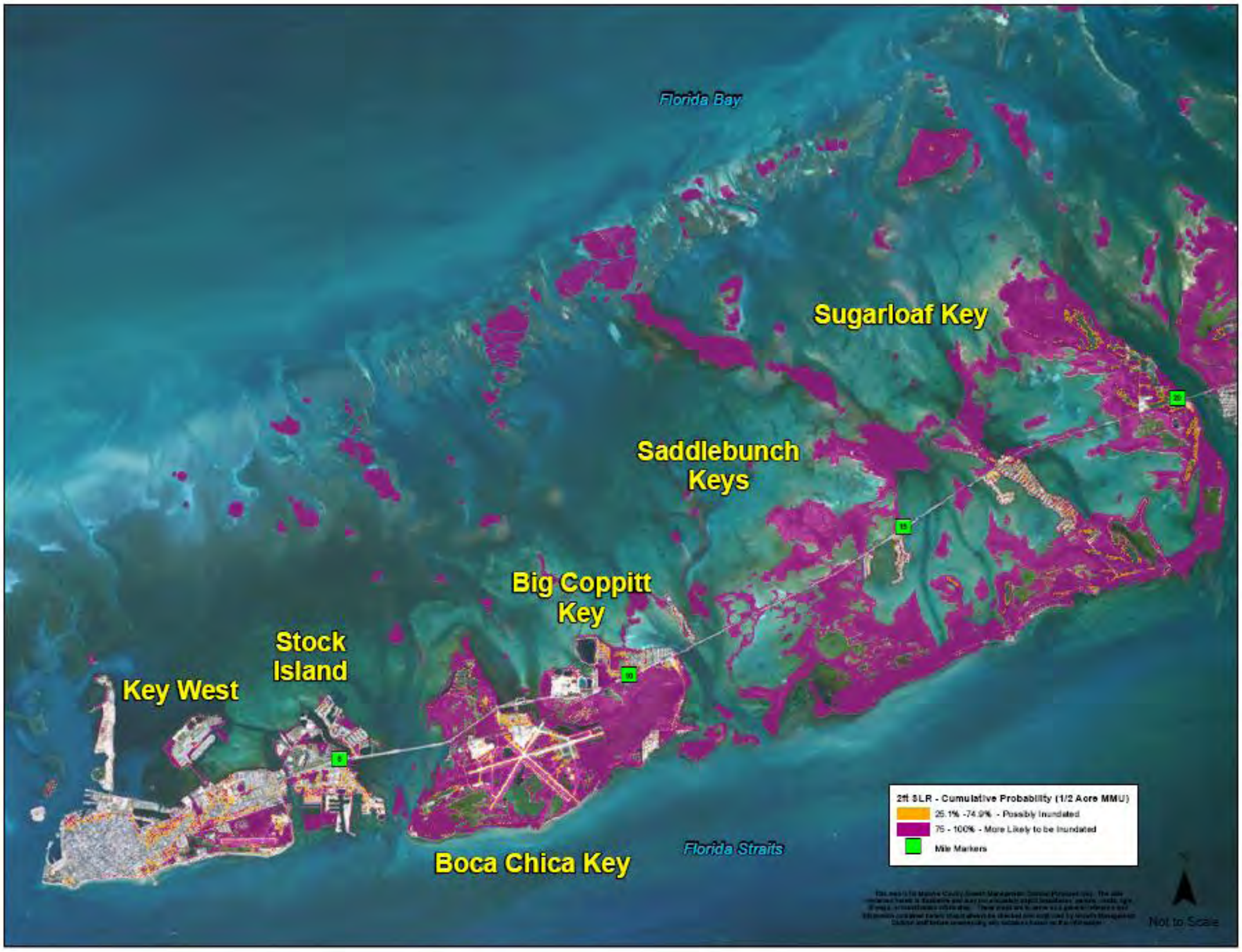
3-Foot Sea Level Rise in Monroe County – Big Pine Key



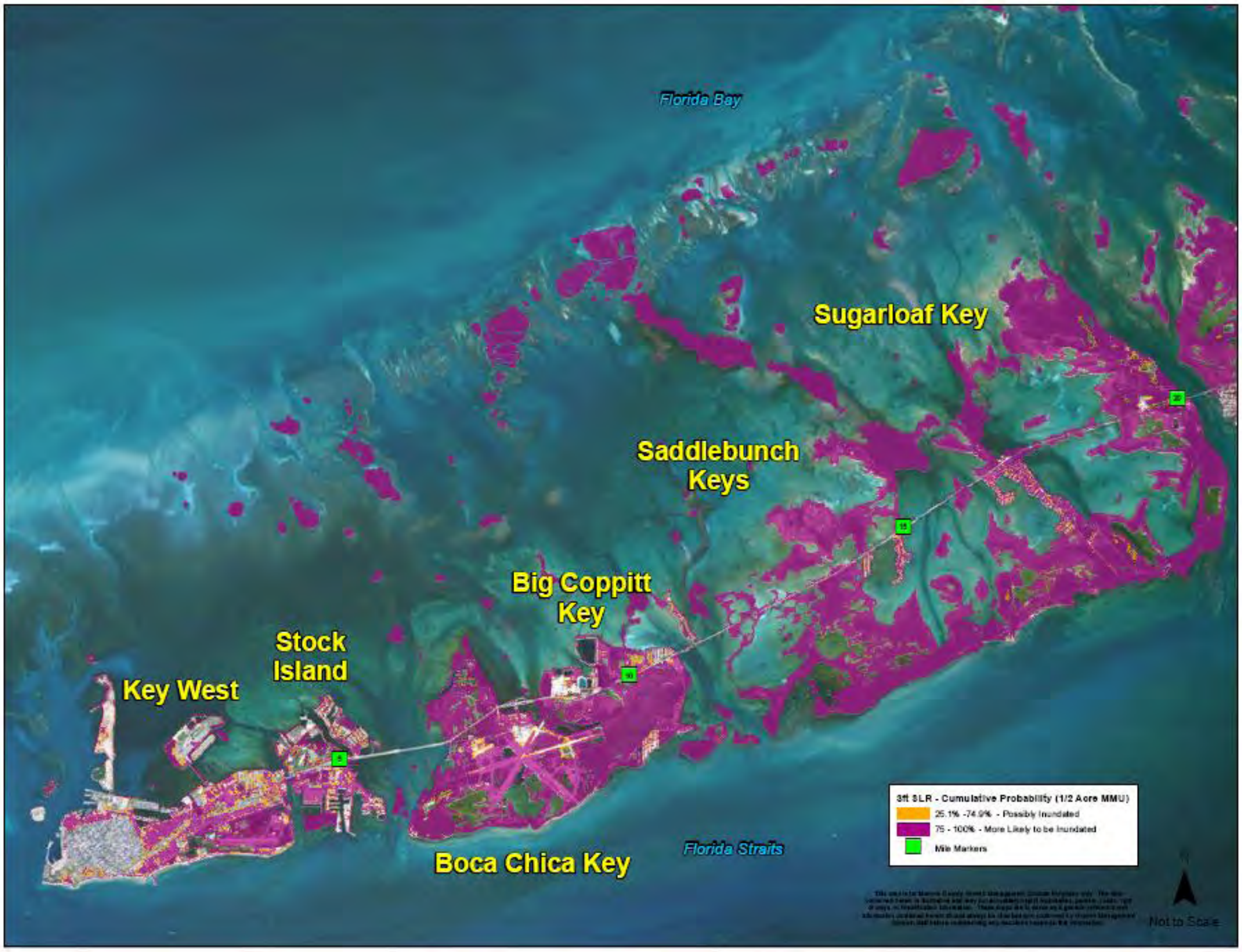
1-Foot Sea Level Rise in Monroe County – Sugarloaf – Key West



2-Foot Sea Level Rise in Monroe County – Sugarloaf – Key West



3-Foot Sea Level Rise in Monroe County – Sugarloaf – Key West



Analysis of Physical Features

Ports and Airports

All six of Monroe County Airports/Airfields were analyzed. With the exception of Summerland Airfield (no impact at 1-foot SLR), all properties have impacts for each SLR scenario. Despite having 51% inundation at the 3-foot scenario, the runway and the majority of the structures on the Marathon Airport property are not impacted. Key West International Airport encounters the highest inundation for each SLR scenario and is almost entirely inundated at the 3-foot scenario (94%).
Two ports are located in Monroe County: Key West Port and Safety Harbor Port (Stock Island). The assumption is that all will be affected in some way, although the extent is indeterminable with this current analysis.

1-foot Sea Level Rise:

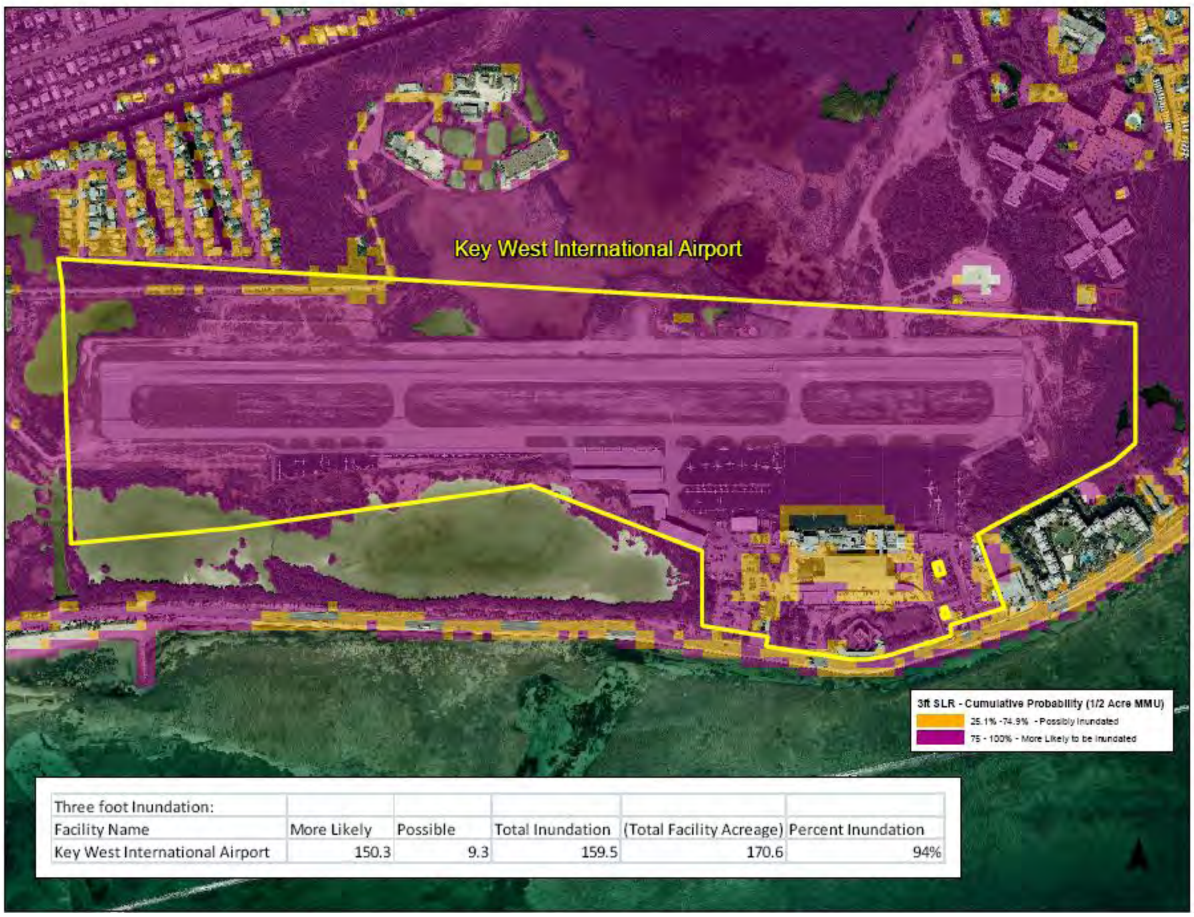
Facility Name	More Likely (acres)	Possible (acres)	Total Inundation	Total Facility Acreage	Percent Inundation
Key West International Airport	42.3	43.1	85.4	170.6	50%
Marathon Airport	5.3	2.4	7.7	188.1	4%
Ocean Reef Airport	0.3	1.0	1.2	20.0	6%
Sugarloaf Airfield	7.3	6.0	13.3	20.1	66%
Tavernier Airfield	0.0	0.3	0.3	5.7	5%

2-foot Sea Level Rise:

Facility Name	More Likely	Possible	Total Inundation	Total Facility Acreage	Percent Inundation
Key West International Airport	112.1	20.6	132.7	170.6	78%
Marathon Airport	16.5	13.0	29.5	188.1	16%
Ocean Reef Airport	4.4	4.6	9.0	20.0	45%
Sugarloaf Airfield	17.5	2.6	20.0	20.1	100%
Summerland Airfield	0.1	0.8	0.9	8.8	10%
Tavernier Airfield	0.4	0.3	0.7	5.7	13%

3-foot Sea Level Rise:

Facility Name	More Likely	Possible	Total Inundation	Total Facility Acreage	Percent Inundation
Key West International Airport	150.3	9.3	159.5	170.6	94%
Marathon Airport	45.3	41.6	86.9	188.1	46%
Ocean Reef Airport	11.6	2.1	13.7	20.0	69%
Sugarloaf Airfield	20.0	0.0	20.0	20.1	100%
Summerland Airfield	2.6	5.2	7.9	8.8	90%
Tavernier Airfield	1.0	0.3	1.3	5.7	23%



Key West International Airport showing the three-foot sea level rise scenario.

Power Plants

There are no power plants in Monroe County; however, thirteen energy facilities were analyzed. The majority of the facilities' properties were inundated at the 3-foot scenario. Inundation was primarily confined to the marginal areas of the properties. Two facilities, FKEC Moody Facility-Key Largo and FKEC-Key Largo Substation, have no inundation for all scenarios. Key West Energy Services-Main Office has 100% inundation at the 3-foot level.

1-foot Sea Level Rise:

Facility Name	More Likely	Possible	Total Inundation	Total Facility Acreage	Percent Inundation
FKEC Ellis Facility Islamorada	0.060	0.005	0.065	2.6	2.5%
FKEC Generating Plant	1.1	0.1	1.2	9.7	12.4%
Florida Keys Electric Cooperated Association (FKEC)	1.1	0.2	1.3	8.5	15.2%
Keys Energy Services Facility Big Coppitt Key	0.1	0.1	0.2	1.8	11.1%
Keys Energy Services Facility Cudjoe Key	1.5	0.3	1.8	5.4	33.3%
Keys Energy Services Substation Stock Island	0.1	0.1	0.1	5.9	1.6%

2-foot Sea Level Rise:

Facility Name	More Likely	Possible	Total Inundation	Total Facility Acreage	Percent Inundation
FKEC Ellis Facility Islamorada	0.065	0.0	0.065	2.6	2.5%
FKEC Generating Plant	1.3	0.09	1.39	9.7	14.3%
Florida Keys Electric Cooperated Association (FKEC)	1.6	0.3	1.9	8.5	22.3%
Keys Energy Services Facility Big Coppitt Key	0.5	0.3	0.8	1.8	28.5%
Keys Energy Services Facility Cudjoe Key	2.2	0.4	2.6	5.4	48.1%
Keys Energy Services Main Office	0.02	0.5	0.52	0.8	65%
Keys Energy Services Substation Kennedy Drive – Key West	0.0	0.01	0.01	0.4	2.5%
Keys Energy Services Substation Stock Island	0.2	0.0	0.2	5.9	3.4%

3-foot Sea Level Rise:

Facility Name	More Likely	Possible	Total Inundation	Total Facility Acreage	Percent Inundation
Big Pine Key Substation	0.2	0.6	0.8	3.0	27.5%
FKEC Ellis Facility Islamorada	0.1	0.1	0.2	2.6	6.1%
FKEC Generating Plant	1.5	0.0	1.5	9.7	15.4%
FKEC Key Largo Substation	0.0	0.0	0.0	1.2	0.0%
Florida Keys Electric Cooperated Association (FKEC)	2.2	0.8	3.0	8.5	35.4%
Keys Energy Services Facility Big Coppitt Key	0.9	0.0	1.0	1.8	52.5%
Keys Energy Services Facility Cudjoe Key	2.8	0.4	3.3	5.4	60.2%
Keys Energy Services Generating Plant	0.3	0.2	0.4	8.1	5.5%
Keys Energy Services Main Office	0.7	0.1	0.8	0.8	100.0%
Keys Energy Services Substation	0.0	0.1	0.1	0.4	31.1%
Keys Energy Services Substation Stock Island	0.5	0.3	0.8	5.9	13.4%

Railroads

There are no railroads in Monroe County. This data was not analyzed.

Water and Wastewater Treatment Plants

Fourteen Water/Wastewater Facilities in Monroe County were analyzed. The majority of the facilities' properties were inundated by the 3-foot scenario with minimal structural impacts. The exceptions were the Wastewater Treatment Facility (83.1%), FKAA Booster Station (71.2%) and FKAA Main Office (63.1%) all in Marathon.

1-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
FKAA Backpumping Station – Stock Island	0.0	0.0	0.1	1.4	4.2%
FKAA Booster Station – Marathon	1.1	0.1	1.2	3.4	35.7%
FKAA Operations Center – Marathon	0.0	0.1	0.1	3.1	2.0%
FKAA Pumping Station - Long Key	0.4	0.0	0.4	1.4	29.3%

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
FKAA RO Plant & Storage Facility - Stock Island	0.0	0.0	0.0	8.3	0.0%

2-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
FKAA Backpumping Station - Stock Island	0.1	0.1	0.1	1.4	10.8%
FKAA Booster Station - Marathon	1.4	0.4	1.7	3.4	51.1%
FKAA Booster Station - Ramrod Key	0.1	0.1	0.2	1.1	14.5%
FKAA Main Office - Marathon	0.0	0.1	0.2	0.6	24.2%
FKAA Operations Center - Marathon	0.1	0.2	0.3	3.1	10.2%
FKAA Pumping Station - Long Key	0.4	0.1	0.5	1.4	38.2%
FKAA RO Plant & Storage Facility - Stock Island	0.0	0.0	0.0	8.3	0.1%
Fleming Key WWTP	0.5	0.1	0.6	11.9	4.9%
Ocean Reef Wastewater Treatment Facility	0.0	0.0	0.0	1.7	0.9%

3-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
FKAA Backpumping Station - Stock Island	0.1	0.1	0.3	1.4	21.8%
FKAA Booster Station - Marathon	1.9	0.5	2.4	3.4	71.2%
FKAA Booster Station - Ramrod Key	0.2	0.3	0.5	1.1	42.6%
FKAA Main Office - Marathon	0.2	0.2	0.4	0.6	63.1%
FKAA Operations Center - Marathon	0.4	0.3	0.7	3.1	22.5%
FKAA Pumping Station - Long Key	0.5	0.1	0.6	1.4	43.6%
FKAA RO Plant & Storage Facility - Stock Island	0.0	0.0	0.0	8.3	0.5%
FKAA Storage Facility - Stock Island	0.0	0.2	0.2	2.3	7.1%
Fleming Key WWTP	1.1	0.7	1.7	11.9	14.6%
Marathon Wastewater Treatment Facility	0.2	1.0	1.3	1.6	83.1%
Ocean Reef Wastewater Treatment Facility	0.0	0.2	0.3	1.7	15.2%

Landfills

The four Landfill properties in Monroe County were analyzed. Inundation for all levels of Sea Level Rise was primarily in natural areas surrounding landfills.

1-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	(Total Facility Acreage)	Percent Inundation
Cudjoe Key Landfill	1.9	1.0	2.9	20.0	14.4%
Key Largo Landfill	1.1	0.1	1.3	15.0	8.4%
Key West Landfill	16.9	2.8	19.7	73.5	26.8%
Long Key Landfill	1.3	1.2	2.4	26.2	9.3%

2-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	(Total Facility Acreage)	Percent Inundation
Cudjoe Key Landfill	3.0	0.2	3.3	20.0	16.4%
Key Largo Landfill	1.3	0.0	1.3	15.0	8.4%
Key West Landfill	20.6	1.0	21.6	73.5	29.4%
Long Key Landfill	2.9	0.8	3.8	26.2	14.5%

3-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	(Total Facility Acreage)	Percent Inundation
Cudjoe Key Landfill	3.8	1.7	5.5	20.0	27.4%
Key Largo Landfill	1.3	0.1	1.3	15.0	8.7%
Key West Landfill	22.2	1.1	23.4	73.5	31.8%
Long Key Landfill	5.3	1.9	7.3	26.2	27.7%

Hospitals

All four Hospitals in Monroe County were included in the analysis. Three of the four properties are inundated at the 1-foot and 2-foot SLR. The DePoo Hospital property in Key West is inundated only at the 3-foot SLR scenario. For all facilities, the structures are not impacted by the area of inundation.

1-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
Fisherman's Hospital - Marathon	0.2	0.1	0.3	5.1	5.6%
Lower Keys Hospital - Stock Island	0.7	0.4	1.1	15.1	7.4%
Mariner's Hospital - Tavernier	0.2	0.0	0.2	8.3	2.8%

2-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
Fisherman's Hospital - Marathon	0.3	0.0	0.4	5.1	7.6%
Lower Keys Hospital - Stock Island	1.4	0.2	1.6	15.1	10.3%
Mariner's Hospital - Tavernier	0.3	0.0	0.3	8.3	4.1%

3-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
DePoo Hospital LFKHS	0.0	0.1	0.1	1.2	8.3%
Fisherman's Hospital - Marathon	0.4	0.1	0.5	5.1	10.4%
Lower Keys Hospital - Stock Island	1.8	0.4	2.2	15.1	14.7%
Mariner's Hospital - Tavernier	0.3	0.0	0.3	8.3	4.1%

Emergency Shelters

Monroe County has seven emergency shelters. All but one (St. Justin Catholic Church in Key Largo) are located in schools. Below are the SLR vulnerability tables for the church property. The church structures are not impacted by the area of inundation. See the School SLR scenarios for the remaining Emergency Shelters.

1-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
St. Justin Catholic Church	5.32	0.40	5.72	16.42	34.8%

2-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
St. Justin Catholic Church	6.17	0.49	6.66	16.42	40.6%

3-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
St. Justin Catholic Church	7.00	0.09	7.09	16.42	43.0%

Schools

Of the seventeen Monroe County School properties included in the analysis only three have no inundation for each SLR scenario: Glynn Archer and Mary Immaculate Star of the Sea Schools in Key West and the Island Christian School in Key Largo. Inundation for the majority of the school properties is primarily restricted to the marginal areas of the property and not impacting any structures. The only exception is Big Pine School; one of the buildings shows complete inundation at the 3-foot level. Six of the County Schools act as Emergency Shelters.

1-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
Coral Shores High School **(Shelter)**	1.0	0.6	1.6	20.1	7.9%
Florida Keys Community College	0.1	0.2	0.3	21.4	1.4%
Gerald Adams School	0.1	0.0	0.1	9.5	1.3%
Horace O'Bryant Middle School **(Shelter)**	0.0	0.0	0.0	9.2	0.1%

Key Largo Elementary/Middle School	0.5	0.3	0.7	28.5	2.6%
Key West High School	0.1	0.1	0.3	25.2	1.0%
Marathon High School	0.3	0.4	0.7	15.0	4.5%
Plantation Key School **(Shelter)**	0.3	0.2	0.6	9.8	5.8%
Sigsbee Elementary School	0.2	1.1	1.4	11.2	12.4%
Sugarloaf Elementary School **(Shelter)**	2.7	4.8	7.5	48.8	15.3%
Treasure Village Montessori Charter School	0.1	0.3	0.4	2.7	15.0%

2-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
Big Pine School	0.0	0.2	0.2	4.5	4.1%
Coral Shores High School **(Shelter)**	1.6	0.0	1.6	20.1	8.1%
Florida Keys Community College	0.6	0.5	1.1	21.4	5.2%
Gerald Adams School	0.2	0.1	0.4	9.5	3.8%
Horace O'Bryant Middle School	0.2	2.2	2.5	9.2	26.7%
Key Largo Elementary/Middle School	0.9	0.4	1.3	28.5	4.7%
Key West High School	0.8	2.7	3.5	25.2	13.9%
Marathon High School	0.8	0.3	1.1	15.0	7.3%
Plantation Key School **(Shelter)**	1.0	0.6	1.6	9.8	15.9%
Poinciana Elementary School	0.1	1.7	1.8	6.9	26.3%
Sigsbee Elementary School	2.4	2.2	4.7	11.2	41.8%

Stanley Switlik Elementary School **(Shelter)**	0.0	0.1	0.2	6.1	2.5%
Sugarloaf Elementary School **(Shelter)**	11.7	7.2	18.9	48.8	38.7%
Treasure Village Montessori Charter School	0.6	0.2	0.8	2.7	27.9%

3-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Facility Acreage	Percent Inundation
Big Pine School	1.1	2.8	3.9	4.5	86.7%
Coral Shores High School **(Shelter)**	1.7	0.0	1.7	20.1	8.4%
Florida Keys Community College	1.4	1.1	2.5	21.4	11.8%
Gerald Adams School	0.4	0.1	0.5	9.5	4.9%
Horace O'Bryant Middle School **(Shelter)**	4.4	2.8	7.2	9.2	78.7%
Key Largo Elementary/Middle School	1.7	0.3	2.1	28.5	7.3%
Key West High School	6.9	4.8	11.7	25.2	46.5%
Marathon High School	1.6	3.6	5.2	15.0	34.7%
Plantation Key School **(Shelter)**	1.9	0.4	2.3	9.8	23.5%
Poinciana Elementary School	2.4	0.5	2.8	6.9	41.0%
Sigsbee Elementary School	5.3	0.2	5.5	11.2	48.8%
Stanley Switlik Elementary School **(Shelter)**	0.2	0.1	0.3	6.1	4.9%
Sugarloaf Elementary School **(Shelter)**	23.3	7.7	31.0	48.8	63.6%
Treasure Village Montessori Charter School	0.9	0.2	1.1	2.7	40.5%

Evacuation Route - Overseas Highway (US 1)

The Overseas Highway (US 1) is the major road corridor and Evacuation Route in Monroe County. Due to time constraints, it was the only County roadway included in the vulnerability analysis. 1,465 acres of the highway's *upland* right-of-way (ROW) was analyzed (from MM 110 on Cross Key to Whitehead Street, Key West). The average elevation of the ROW is 7.14' with its highest point of approximately 28' at the Scout Key causeway (near MM 35). The ROW intersects each inundation layer at various locations.

At the 3-foot level, all islands in the Lower Keys have variable inundation to the US 1 ROW. In the Middle Keys, on Grassy Key, Long Key, Lower Matecumbe Key and Windley Key, the ROW encounters the most inundation. The Upper Keys portion of the US 1 ROW is impacted the least. There was no calculated inundation from MM 95 to MM 106. North of the Jewfish Creek bridge inundation occurs only at the edge of the ROW. In Key West, the Roosevelt Boulevard section of the US 1 ROW is entirely inundated at the 3-foot level whereas the Old Town portions (Truman and Whitehead Streets) have no impacts. The Overseas Highway ROW GIS dataset was generated by Monroe County – Growth Management. Bridges were not included in the analysis.

1-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Coverage (acreage)	Percent Inundation
Right-of-Way	50.14	39.49	89.63	1,465	6.2%

2-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Coverage (acreage)	Percent Inundation
Right-of-Way	125.51	59.89	185.40	1,465	12.7%

3-foot Sea Level Rise:

Facility Name	More Likely (Acres)	Possible (Acres)	Total Inundation	Total Coverage (acreage)	Percent Inundation
Right-of-Way	246.07	105.61	351.68	1,465	24.0%

Marinas

All marina facilities are located on or next to water features. The assumption is that all will be affected in some way, although the extent is indeterminable with this current analysis.

Results of Analysis

Geographic analysis was done on three items:

- Taxable value of property
- Future Land Use
- Habitat / Land Use Land Cover

Taxable Value of Property

The analysis of property values was done using an aggregated parcel methodology in which a 150-foot grid (pGrid) was created and then overlaid on the parcel features to aggregate property values within each grid cell. The table below shows the total taxable value of Monroe County Parcels (Source: MCPAO, January 2011) for each SLR scenario using the pGrid methodology.

Level of Inundation	Total Taxable Value
One Foot	$2,763,294,786
Two Foot	$8,388,138,219
Three Foot	$15,087,755,047

Acres of Future Land Use

The Future Land Use GIS dataset was generated by Monroe County – Growth Management and was most recently updated in December 2010. Incorporated areas *are not* included in the Future Land Use layer. Data was summarized by Land Use type and probability and reported in acres. "Total Coverage" applies only to features which intersect the Inundation Grids. Conservation, Residential Conservation and Military land uses have the highest inundation in all three SLR scenarios. Public Buildings/Grounds have the least impact.

1-foot Sea Level Rise:

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation of that Land Use
Agriculture	5.37	3.05	8.42	19.98	42.14%
Airport District	0.92	4.09	5.01	42.23	11.86%
Conservation	21,321.88	3,294.32	24,616.20	30,297.35	81.25%
Education	2.02	3.91	5.93	60.63	9.78%
Industrial	39.89	22.67	62.56	281.13	22.25%
Institutional	10.90	12.60	23.50	122.33	19.21%
Military	2,102.56	410.50	2,513.06	3,514.5	71.51%
Mixed Use/Commercial	106.91	99.75	206.66	1,929.4	10.71%
Mixed Use/Commercial Fishing	34.79	26.56	61.35	210.05	29.21%
Public Buildings/Grounds	2.82	1.08	3.90	44.56	8.75%
Public Facilities	9.73	4.33	14.06	122.62	11.47%
Recreation	803.02	222.15	1,025.17	1,810.27	56.63%
Residential Conservation	12,804.77	1,537.42	14,342.19	17,092.03	83.91%
Residential High	50.35	39.67	90.02	1,309.11	6.88%
Residential Low	712.02	629.55	1,341.57	3,718.5	36.08%
Residential Medium	261.06	304.83	565.89	5,247.01	10.78%
Total	**38,269.01**	**6,616.48**	**44,885.49**	**65,821.70**	**68.19%**

2-foot Sea Level Rise:

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation of that Land Use
Agriculture	10.38	2.42	12.80	19.98	64.06%
Airport District	12.27	8.53	20.80	42.23	49.25%
Conservation	25,825.17	1,068.47	26,893.64	30,297.35	88.77%
Education	8.16	3.75	11.91	60.63	19.64%
Industrial	83.37	27.49	110.86	281.13	39.43%
Institutional	34.66	21.03	55.69	122.33	45.52%
Military	2,715.74	278.74	2,994.48	3,514.5	85.20%
Mixed Use/Commercial	321.92	198.11	520.03	1,929.4	26.95%
Mixed Use/Commercial Fishing	86.12	35.08	121.20	210.05	57.70%
Public Buildings/Grounds	4.08	0.42	4.50	44.56	10.10%
Public Facilities	17.15	6.14	23.29	122.62	18.99%
Recreation	1,106.39	96.84	1,203.23	1,810.27	66.47%
Residential Conservation	14,910.96	510.64	15,421.60	17,092.03	90.23%
Residential High	174.24	185.60	359.84	1,309.11	27.49%
Residential Low	1,752.98	567.40	2,320.38	3,718.5	62.40%

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation of that Land Use
Residential Medium	993.53	839.13	1832.66	5,247.01	34.93%
Total	**48,057.12**	**3,849.79**	**51,906.91**	**65,821.70**	**78.85%**

3-foot Sea Level Rise:

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation of that Land Use
Agriculture	13.87	1.84	15.71	19.98	78.63%
Airport District	25.56	8.74	34.30	42.23	81.22%
Conservation	27,423.25	524.49	27,947.74	30,297.35	92.24%
Education	13.91	5.02	18.93	60.63	31.22%
Industrial	135.82	31.81	167.63	281.13	59.63%
Institutional	69.84	10.13	79.97	122.33	65.37%
Military	3,137.76	141.71	3,279.47	3,514.5	93.31%
Mixed Use/Commercial	667.39	195.48	862.87	1,929.4	44.72%
Mixed Use/Commercial Fishing	145.15	26.72	171.87	210.05	81.82%
Public Buildings/Grounds	4.91	1.50	6.41	44.56	14.39%
Public Facilities	36.62	13.77	50.39	122.62	41.09%
Recreation	1,276.93	103.34	1,380.27	1,810.27	76.25%
Residential Conservation	15,572.91	144.87	15,717.78	17,092.03	91.96%
Residential High	498.39	189.00	687.39	1,309.11	52.51%
Residential Low	2,617.50	300.29	2,917.79	3,718.5	78.47%
Residential Medium	2,493.94	799.10	3,293.04	5,247.01	62.76%
Total	**54,133.75**	**2497.81**	**56,631.56**	**65,821.70**	**86.04%**

Acres of Habitat Type / Land Use Land Cover

The Monroe County Land Cover Habitat GIS dataset was provided by Monroe County-Growth Management and was produced in September 2009 by Photo Science, Inc. Orthophoto-interpretation (½ MMU) and ground-truthing were used to generate the Land Cover dataset. Incorporated areas *are* included in this dataset. Data was summarized by Habitat type and probability and reported in acres. “Total Coverage” applies only to features which intersect the Inundation Grids. Wetland and Transitional habitats, obviously, have the highest levels of inundation in each scenario. Impervious Surfaces (roads, parking lots etc.) are impacted the least.

1-foot Sea Level Rise:

Type	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
Beach Berm	50.07	21.19	71.26	200.00	35.6%
Buttonwood	2,249.27	1,278.45	3,527.72	4,127.45	85.5%
Developed Land	256.35	490.70	747.05	13,343.24	5.6%
Exotic	46.74	64.06	110.80	488.66	22.7%
Freshwater Wetland	389.96	410.44	800.40	1,040.99	76.9%
Hammock	449.12	1,149.18	1,598.30	8,684.51	18.4%
Impervious Surface	30.07	82.66	112.73	3,047.71	3.7%
Mangrove	27,306.69	2,905.66	30,212.35	31,955.77	94.5%
Pineland	17.17	119.83	137.00	1,749.90	7.8%
Salt Marsh	2,355.92	294.99	2,650.91	2,827.63	93.7%
Scrub Mangrove	9,615.68	196.39	9,812.07	10,096.13	97.2%
Undeveloped Land	324.59	321.86	646.45	2,505.63	25.8%
Total	**43,091.63**	**7,335.41**	**50,427.04**	**80,067.62**	**63.0%**

2-foot Sea Level Rise:

Type	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
Beach Berm	93.83	27.28	121.11	200.00	60.6%
Buttonwood	3,817.67	181.48	3,999.15	4,127.45	96.9%
Developed Land	1,556.05	1,795.56	3,351.61	13,343.24	25.2%
Exotic	171.89	85.76	257.65	488.66	52.7%
Freshwater Wetland	934.43	59.11	993.54	1,040.99	95.4%
Hammock	2,583.45	1,285.92	3,869.37	8,684.51	44.5%
Impervious Surface	258.91	346.14	605.05	3,047.71	19.8%
Mangrove	30,987.19	406.12	31,393.31	31,955.77	98.2%
Pineland	355.77	408.18	763.95	1,749.90	43.7%
Salt Marsh	2,689.79	25.68	2,715.47	2,827.63	96.0%
Scrub Mangrove	9,840.55	17.60	9,858.15	10,096.13	97.6%
Undeveloped Land	900.99	332.85	1,233.84	2,505.63	49.2%
Total	**54,190.52**	**4,971.68**	**59,162.2**	**80,067.62**	**73.9%**

3-foot Sea Level Rise:

Type	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
Beach Berm	137.60	19.18	156.78	200.00	78.4%
Buttonwood	4,042.66	33.64	4,076.30	4,127.45	98.7%
Developed Land	4,880.68	2,144.06	7,024.74	13,343.24	52.6%
Exotic	311.83	60.25	372.08	488.66	76.1%
Freshwater Wetland	1,014.88	16.42	1,031.30	1,040.99	99.1%
Hammock	4,546.67	724.28	5,270.95	8,684.51	60.7%
Impervious Surface	880.51	372.91	1,253.42	3,047.71	41.1%
Mangrove	31,484.03	64.22	31,548.25	31,955.77	98.7%
Pineland	1,046.04	292.19	1,338.23	1,749.90	76.5%
Salt Marsh	2,723.35	7.64	2,730.99	2,827.63	96.6%
Scrub Mangrove	9,863.14	5.40	9,868.54	10,096.13	97.7%
Undeveloped Land	1,448.92	272.10	1,721.02	2,505.63	68.7%
Total	**62,380.31**	**4,012.29**	**66,392.60**	**80,067.62**	**83.0%**

Chapter 4: Analysis of the Vulnerability of Miami-Dade County to Sea Level Rise

Marina Blanco-Pape, P.E., MSME, Marcia Steelman, C.F.M, B.S., M.S. and Lisbeth Britt, B.S., M.A. - Inundation Mapping and Vulnerability Assessment Work Group Members from Miami-Dade County.

Vulnerability to Sea Level Rise - Miami-Dade County Overview

The resulting tables and maps are only presented as a demonstration of the progress of the Terrain Mapping Project produced by SFWMD for and at the request of the Climate Change Compact Counties (Broward, Miami-Dade, Monroe, and Palm Beach).

The analyses used mapped areas that might be inundated by increased tidal elevations above current mean higher high water elevations without taking into account:

- existing ground water levels,
- storm surge,
- tidal anomalies,
- future water management and operations, or
- flood mitigation practices.

Therefore, these results are conservative and preliminary in nature and will be updated as new data, input, and analysis become available on a regional level.

Miami-Dade County already implements a stormwater master planning (SWMP) process that is tied in to the County's Comprehensive Development Master Plan (CDMP). The SWMP process and the recommendations for flood prevention infrastructure and maintenance that results from the planning process are funded by the Miami-Dade County Stormwater Utility. The SWMP is an important component of the County's CDMP, and the progress and effectiveness of the Stormwater Master Plan is monitored by the County. The SWMP and public and private stormwater discharge systems are also evaluated as a part of the National Pollutant Discharge Elimination System permit issued to Miami-Dade County by EPA. The Miami-Dade SWMP already includes existing ground water levels, storm surge, tidal anomalies, current water management operations, and flood mitigation practices in the evaluation and prevention of flooding. Therefore, Miami-Dade already responds to the elements listed above that are not considered in this regional SLR mapping and vulnerability analysis.

Summary:

Some physical infrastructure in Miami-Dade County is at risk beginning at the one foot scenario. A portion of the properties at Homestead Air Reserve Base, the Turkey Point Nuclear Power Plant, and the Cutler Power Plant are at elevations below sea level. Most of these potentially inundated areas on these properties are existing storm water management ponds and ditches and the cooling canals at Turkey Point. The cooling canal system at Turkey Point is extremely critical to the function and safety of the plant and additional analysis is necessary in order to fully understand potential impacts to all components of the facility.

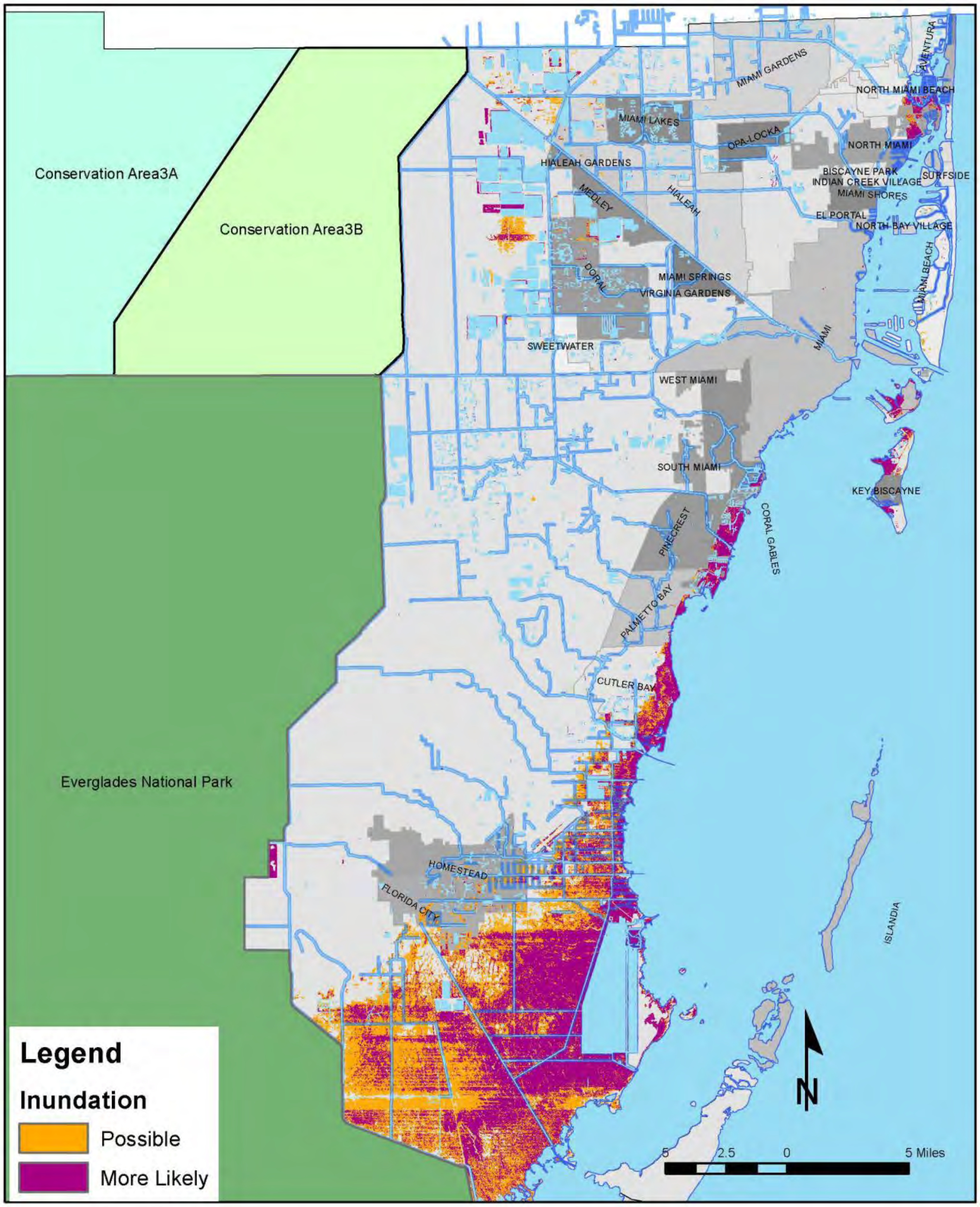
While railroads were not inundated, secondary roads were. The miles of vulnerable roads increased by a magnitude at each scenario with over 500 miles of roads likely inundated at 3- feet of sea level rise. No wastewater facility appears to be impacted at the one, two, or three foot sea level rise scenario. Landfills were primarily impacted in retention or natural areas surrounding the properties. Only three of 35 hospitals showed any inundation in the 3-foot of sea level rise with no building infrastructure affected. Three school properties were affected in the 3-foot inundation. Emergency shelters were not impacted. Evacuation Routes are vulnerable only if bridges are inaccessible from local roadway inundation. Impacts to coastal marina facilities remain a concern but are not yet sufficiently documented.

Under a one foot sea level rise scenario, 12% of the County is impacted with conservation lands being the major land use type inundated. At the two foot scenario, 16% of the land is impacted with agricultural lands added to the conservation lands. At the three foot scenario, 18% of the total land mass of the County is impacted including inland areas around the Northwest Municipal Drinking Water Wellfield. Low lying inland areas like the wellfield are more likely subject to future drainage issue associated with rain events rather than saltwater impacts. In terms of acres inundated, wetland hardwood forest (mangrove) and vegetated non-forested wetlands are among the major habitats impacted.

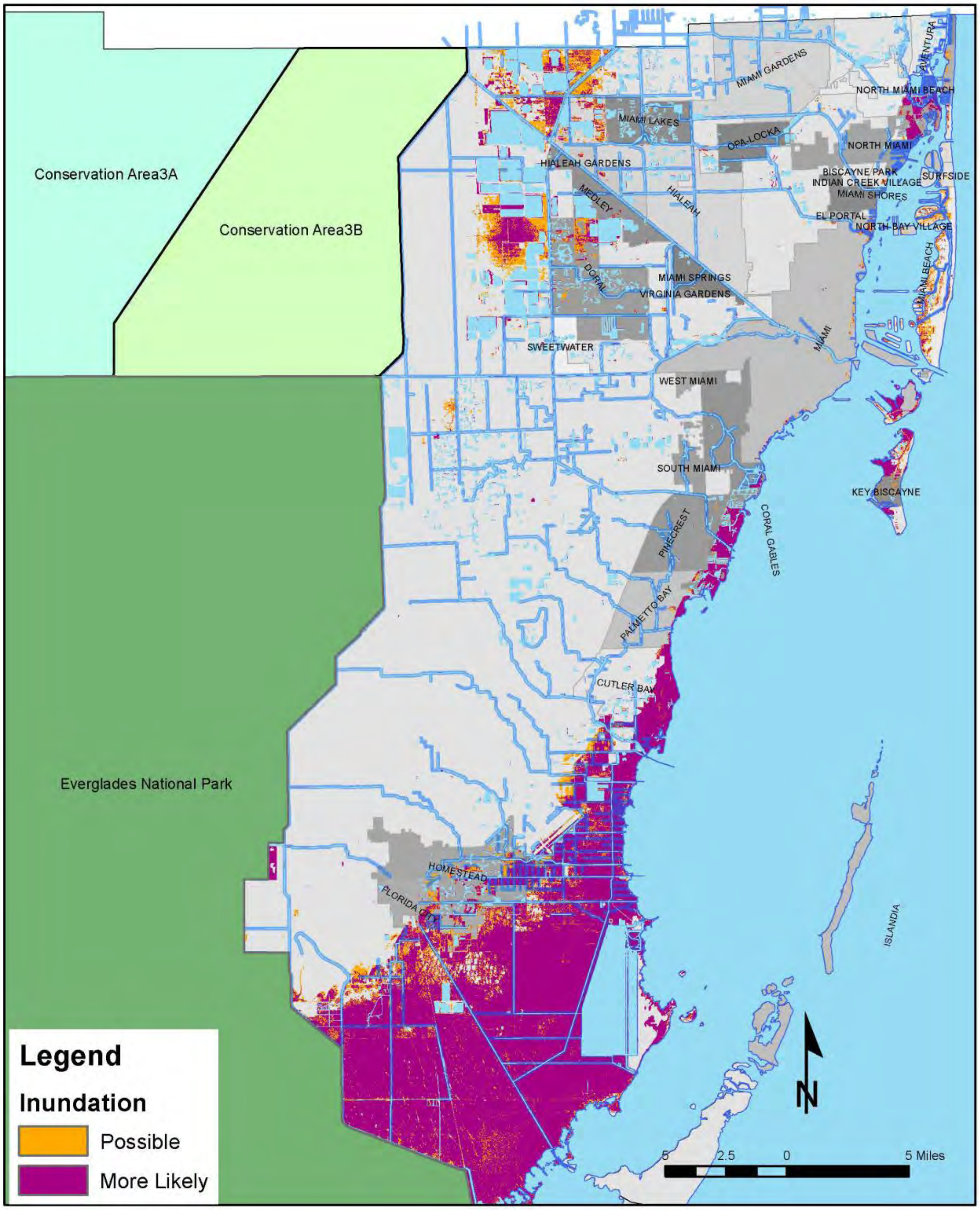
As indicated above, this vulnerability assessment is limited in scope and will be updated as the regional tools become available. In the meantime, Miami-Dade County has already initiated some next steps to enhance sea level rise (SLR) assessment for the County during the SWMP process. The U.S. Geological Survey has been contracted to evaluate average ground water levels throughout the County for the period of record 1999-2009 as compared to the prior decade 1990 - 1999, and also compared to the water level entire period of record. Additionally, as individual water management basins are reevaluated through modeling, the projected sea level rise will be added to the model evaluation. The results will allow Miami-Dade to prepare more detailed SLR vulnerability assessments as each water management basis is remodeled.

Countywide Map 1, 2, & 3 Foot Sea Level Rise - Miami-Dade County

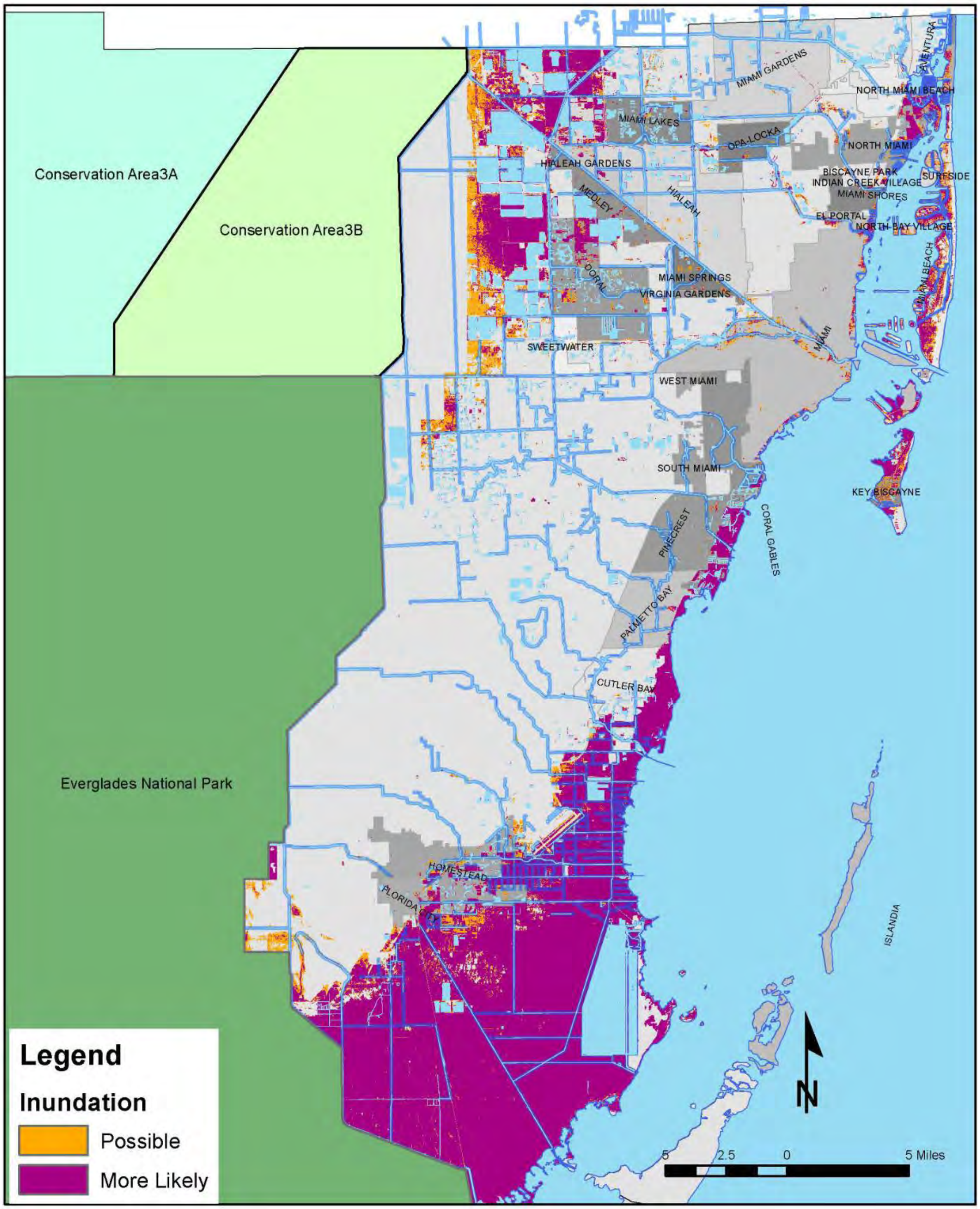
1-foot Sea Level Rise In Miami-Dade County



2-foot Sea Level Rise In Miami-Dade County



3-foot Sea Level Rise In Miami-Dade County



Analysis of Physical Features

Ports and Airports

One area determined by the group to be critical is Homestead Air Reserve Base. The County has already met with planners developing the long term use of the base and provided input on sea level rise. Opa Locka West is vulnerable, but this airport is only a landing strip used for training and so is not considered critical. Below are tables that represent the area that may be below mean high-high water sea level with a 1-, 2-, or 3-foot sea level rise.

1-foot Sea Level Rise:

Facility Name	More Likely	Possible	Total Inundation	Total Area of Facility (Acres)	Percent Inundation
Homestead General Aviation	0	4.92	4.92	770.71	0.6%
Kendall-Tamiami	22.86	2.37	25.23	1,428.48	1.8%
Miami International	36.01	2.38	38.39	2,731.06	1.4%
Opa Locka Executive	16.87	4.71	21.58	1,640.89	1.3%
Opa Locka West	12.08	1.46	13.54	412.03	3.3%
Port of Miami (seaport)	0.61	0.16	0.77	534.5	0.1%
Port of Miami (river port)	2.32	1.26	3.58	136.23	2.6%
USA Homestead Air Base	195.43	80.4	275.83	1,970.96	14.0%

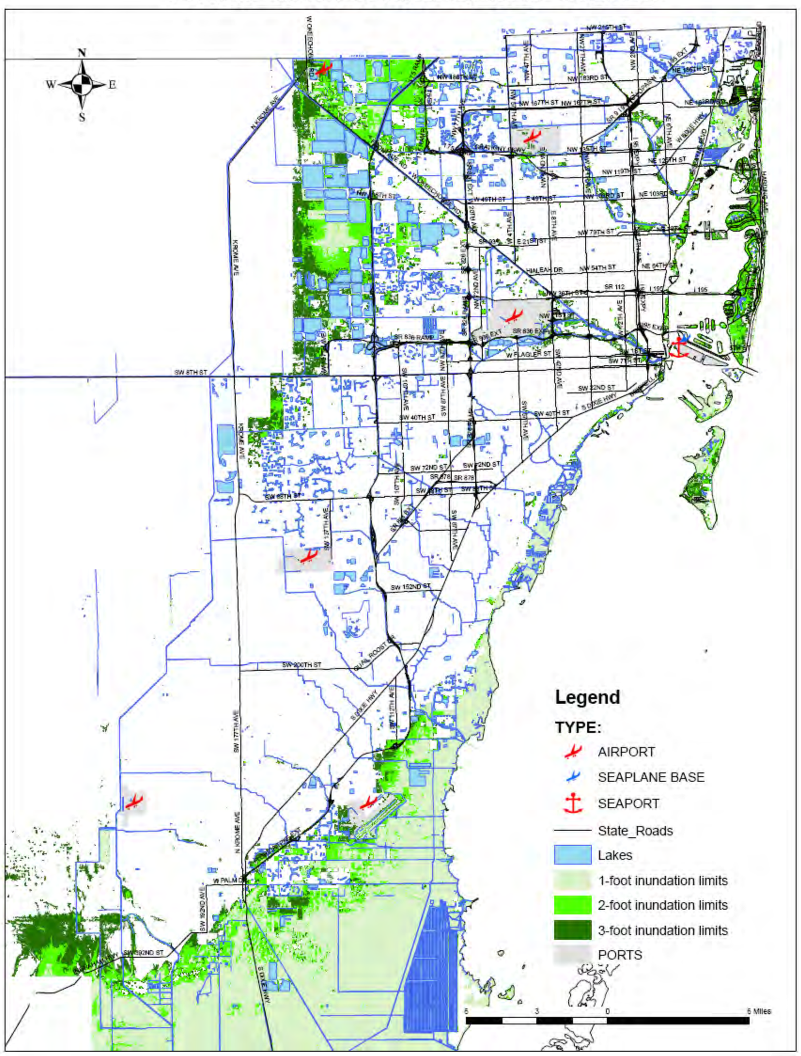
2-foot Sea Level Rise:

Facility Name	More Likely	Possible	Total Inundation	Total Area of Facility (Acres)	Percent Inundation
Homestead General Aviation	5.6	0.66	6.26	770.71	0.8%
Kendall-Tamiami	26.87	1.6	28.47	1,428.48	2.0%
Miami International	42.34	5.63	47.97	2,731.06	1.8%
Opa Locka Executive	30.58	15.93	46.51	1,640.89	2.8%
Opa Locka West	24.2	68.55	92.75	412.03	22.5%
Port of Miami (seaport)	0.89	0.22	1.11	534.5	0.2%
Port of Miami (river port)	4.63	3.61	8.24	136.23	6.0%
USA Homestead Air Base	327.73	119.27	447	1,970.96	22.7%

3-foot Sea Level Rise:

Facility Name	More Likely	Possible	Total Inundation	Total Area of Facility (Acres)	Percent Inundation
Homestead General Aviation	6.58	0.83	7.41	770.71	1.0%
Kendall-Tamiami	31.01	2.82	33.83	1,428.48	2.4%
Miami International	57.47	24.24	81.71	2,731.06	3.0%
Opa Locka Executive	65.51	76.22	141.73	1,640.89	8.6%
Opa Locka West	212.09	96.59	308.68	412.03	74.9%
Port of Miami (seaport)	1.63	0.5	2.13	534.5	0.4%
Port of Miami (river port)	14.73	11.47	26.2	136.23	19.2%
USA Homestead Air Base	573.64	202.52	776.16	1,970.96	39.4%

MIAMI-DADE COUNTY
VULNERABILITY ANALYSIS
SEAPORTS AND AIRPORTS



Power plants

Miami-Dade County has one nuclear power and one coal generation power plant. The generation facilities are not directly impacted. This data below includes impact to the Turkey Point Nuclear Power Plant cooling canals, the coastal wetlands at the Cutler Plant, and some scattered power transfer stations throughout western Miami-Dade County.

Power Plant	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Area of Facility (Acres)	Percent Inundation
1-foot Sea Level Rise	4,812	247	5,059	7,228.77	70%
2-foot Sea Level Rise	5,259	233	5,492	7,228.77	76%
3-foot Sea Level Rise	5,707	233	5,940	7,228.77	82%

Railroads

Railroads did not seem to be particularly affected, perhaps due to the fact that most of the rail beds in Miami-Dade County are elevated above the road and surrounding surfaces. The impact reported is limited to FEC Railroad in the northeast coast of Miami-Dade County and to the portion of the CSX railroad serving the rockmine lakes along NW 12 ST in the western portion of the County. This data is reported in **miles**.

FEC and CSX Railroads	More Likely (miles)	Possible (miles)	Total Inundation (miles)	Total Length of Rail (miles)	Percent Inundation
1-foot Sea Level Rise	0.71	0.09	0.8	320.9	0.1%
2-foot Sea Level Rise	0.91	0.23	1	320.9	0.4%
3-foot Sea Level Rise	1.65	0.79	2	320.9	0.7%

Water and Wastewater Treatment Plants

Miami-Dade has three major water and three major wastewater treatment plants within the County boundary. The analysis was performed by land use category as provided by the Department of Planning and Zoning. The results, therefore, do not include the names of the facilities, only the area possibly or more likely affected by the inundation scenario. A more specific analysis is needed to determine if any equipment would be affected or not.

Water Treatment Plants	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Area within Land Use Category (acres)	Percent Inundation
1-foot Sea Level Rise	0.38	0.16	0.54	210.37	0.26%
2-foot Sea Level Rise	0.85	0.64	1.49	210.37	0.71%
3-foot Sea Level Rise	2.58	1.6	4.18	210.37	1.99%

Wastewater Treatment Plants	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Area within Land Use Category (acres)	Percent Inundation
1-foot Sea Level Rise	11.1	5.32	16.42	460.14	3.57%
2-foot Sea Level Rise	19.91	6.15	26.06	460.14	5.66%
3-foot Sea Level Rise	36.47	8.33	44.8	460.14	9.58%

Landfills

Inundation for all levels of sea level rise were primarily in retention or natural areas surrounding landfills since the landfills themselves are elevated (see graphic on next page). The South Dade Landfill, Munisport, and Dade Recycling are surrounded by low lying areas.

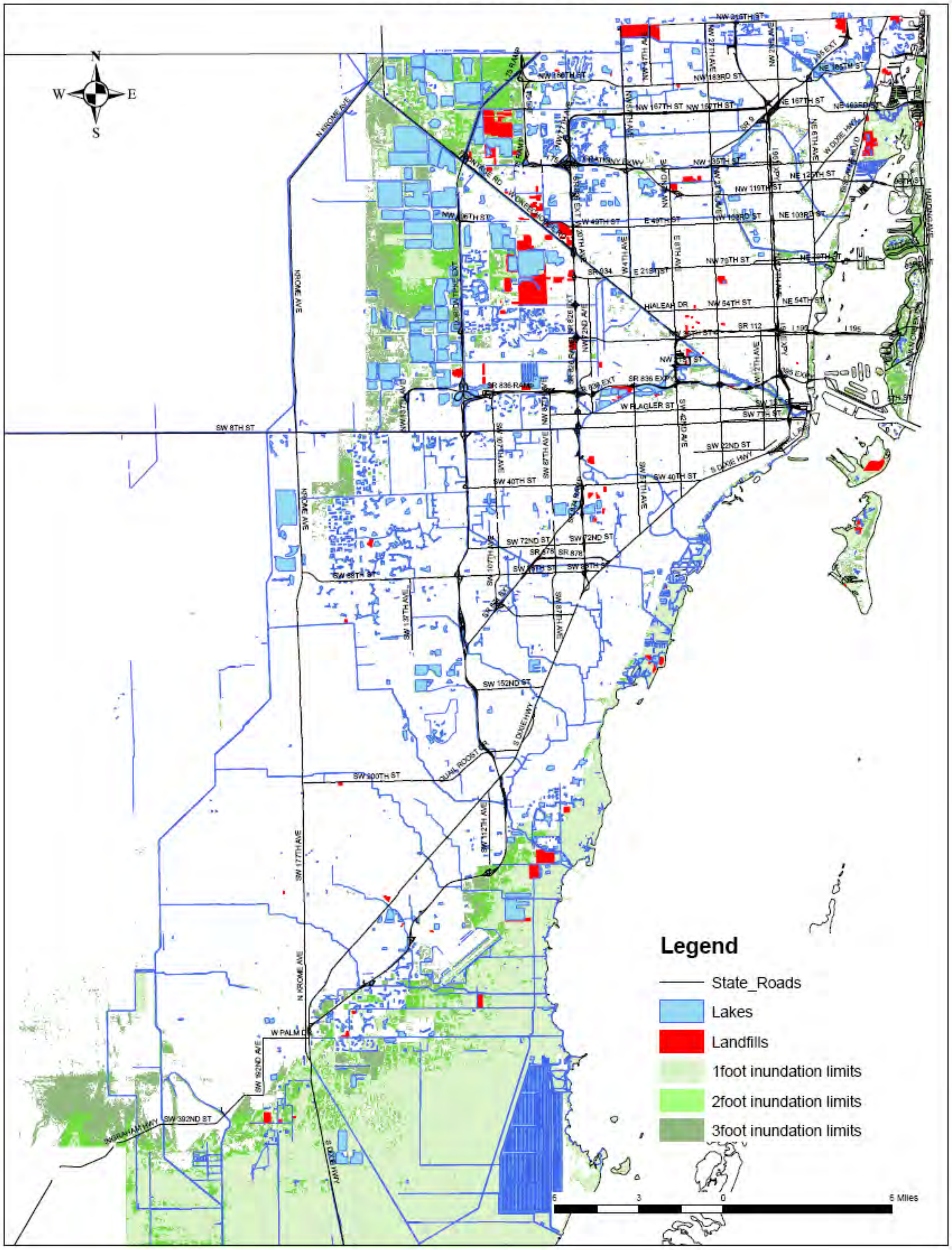
South Dade Landfill, Munisport, & Dade Recycling	More Likely (acres)	Possible (acres)	Total Inundation (acres)
1-foot Sea Level Rise	154	80	234
2-foot Sea Level Rise	266	33	299
3-foot Sea Level Rise	333	30	363

Hospitals

No hospitals in Unincorporated Miami-Dade County were impacted. Of the 34 total hospitals within the county boundaries, only three hospitals were affected in municipalities in the 3-foot sea level rise scenario.

- Selected Specialty Hospital , 955 NW 3rd ST, City of Miami, 33128
- Mount Sinai Medical Center, 4300 Alton Road, City of Miami Beach, 33140
- South Beach Community Hospital, 630 Alton Road, City of Miami Beach, 33139

MIAMI-DADE COUNTY
VULNERABILITY ANALYSIS
LANDFILLS



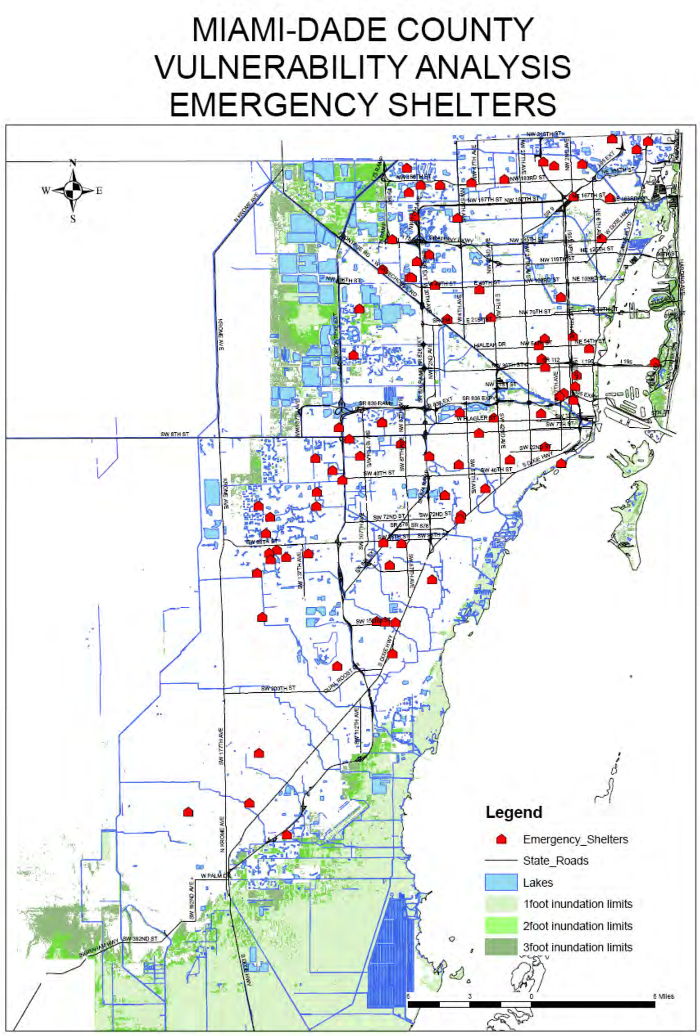
Schools

No schools in Unincorporated Miami-Dade County were impacted. Only three of the 867 schools were affected in municipalities in the 3-foot sea level rise scenario. However, we need more specific survey information on all affected schools, such as elevation certificates and topographic survey to determine if those would be actually impacted.

- Student Services & Attendance, 489 East Drive, Miami Springs 33166
- School Board Administrative – Annex, 1500 Biscayne Boulevard, Miami 33132
- Biscayne Elementary, 800 77th Street, Miami Beach 33141

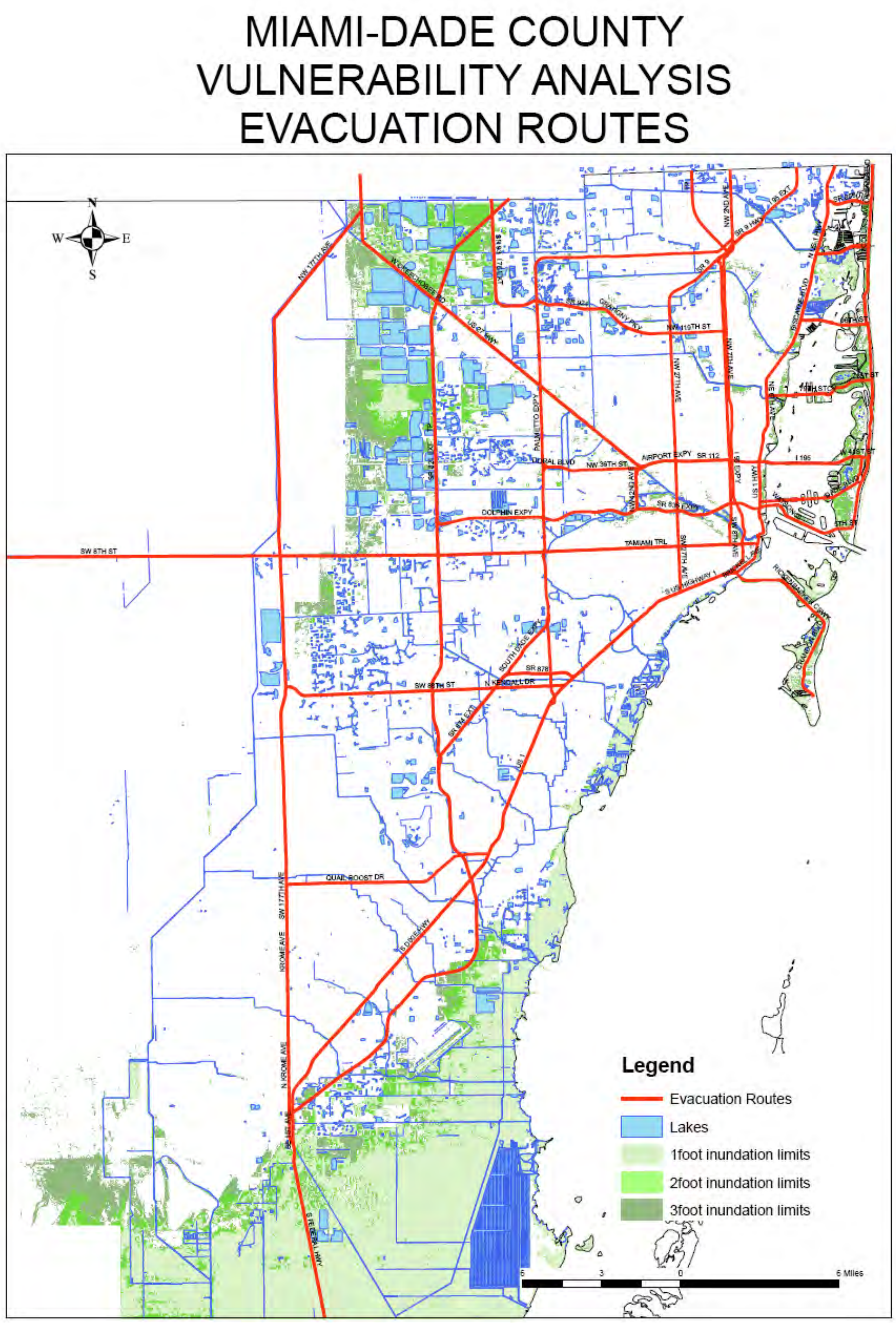
Emergency Shelters

None of the 69 emergency shelters in Miami-Dade County were impacted. However, more specific survey information and finished floor elevation certificates on all shelters are needed to determine actual impacts.



Evacuation Routes

Miami-Dade determined there are at most four miles of impact to all evacuation routes even at the 3-Foot inundation because these routes are built at elevations to provide service in a 100-year storm. US1 Overseas Highway to the Florida Keys and the Rickenbacker Causeway to Key Biscayne have been improved in the past two years. Therefore, the 4 miles of impact are probably an over estimation. The concern for the evacuation routes is flooding of the local access roads leading to them. This information is summarized in the section Roads by FDOT Category.



Marinas

Marine facilities were analyzed using land use category maps provided by the Department of Planning and Zoning. Marine complexes and marine commercial land uses were combined. All marina facilities are located on or next to water features, east of all salinity control structures to give easy access to the ocean. The assumption is that all will be affected in some way, although the extent is only estimated by this current analysis. It is assumed that those docks with fixed infrastructure will be inundated while floating docks will rise with sea levels.

Marine Facilities	Total Inundation (acres)
1-foot Sea Level Rise	31
2-foot Sea Level Rise	75
3-foot Sea Level Rise	150

Results of Analysis

Geographic analysis was done based on the following criteria:

- Miles of road by Florida Department of Transportation category
- Future Land Use
- Habitat / Land Use Land Cover

Taxable Value of Property

Miami-Dade County has chosen not to estimate the taxable value of potentially impacted property until such time as the mapping and analytical methods are more robust. Miami-Dade, through the Stormwater Master Planning Process, has determined that the current assessment tools probably underestimate potential impacts.

Roads by FDOT Category

Roadways are summarized by Functional Class in miles. High volume categories include sections of roadway where bridges were removed from the LiDAR data and represented bare earth rather than the actual roadways.

1-Foot Sea Level Rise – Assumption: 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage (% impacted)
1 – high volume, maximum speed	3	**0.08%**
2 – high speed, channels traffic to FC1	4	
3 – high speed, lower mobility, connects to FC2	3	
4 – moderate speed, through neighborhoods	62	
5 – low volume, i.e. access roads, parking lanes	Not assessed	
Total	**72**	

2-Foot Sea Level Rise – Assumption: 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage (% impacted)
1 – high volume, maximum speed	6	3%
2 – high speed, channels traffic to FC1	11	
3 – high speed, lower mobility, connects to FC2	8	
4 – moderate speed, through neighborhoods	232	
5 – low volume, i.e. access roads, parking lanes	Not assessed	
Total	**257**	

3- Foot Sea Level Rise – Assumption: 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage (% segments impacted)
1 – high volume, maximum speed	12.18	6%
2 – high speed, channels traffic to FC1	26.33	
3 – high speed, lower mobility, connects to FC2	21.22	
4 – moderate speed, through neighborhoods	496.21	
5 – low volume, i.e. access roads, parking lanes	Not assessed	
Total	**555.94**	

Acres of Future Land Use

Coverage of Future Land Use was provided by the Miami-Dade County Planning Department and was most recently updated on September 28, 2010. Data was summarized by Land Use type and probability and reported in acres. The Land Use Types most impacted throughout Miami-Dade County include:

- Everglades National Park
- Vacant, Protected, Privately-Owned Proposed and designated EEL sites until acquired, or protected under any other conservation or environmental mechanism
- Vacant, Protected, Government-Owned or controlled EEL sites included
- Other Nature Preserves and Protected Areas (State Mangrove Preserves, Turkey Point Wilderness Area, Great Cypress Swamp Preserves, and acquired government owned EEL sites)
- Electric Power (Generator and Substation, and Service Yards)
- Row and Field Cropland
- Plant Nurseries (Includes Sod Farms and Ornamental Nurseries)
- Wellfields
- County Operated Parks

1-Foot Sea Level Rise

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Percent Inundation of Land Use
Conservation - Natural Reservations	80681	27307	107988	**12%**
Electrical Generation Facility	4949	383	5332	
Recreation and Open Space	1525	321	1846	
Local Activity Center	208	96	304	
Transportation	406	285	691	
Regional Activity Center	91	54	145	
Employment Center-High	13	8	21	
Utilities	339	521	860	
Industrial	506	169	675	
Single Family Residential	214	56	270	
Multi-family Residential	39	202	241	
Office Park	7	3	10.99	
Agricultural	751	2243	2994	
Total	89,729	31,648	121,378	

2-Foot Sea Level Rise

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Percent Inundation of Land Use
Conservation - Natural Reservations	119646	7163	126809	**16%**
Electrical Generation Facility	5644	355	5999	
Recreation and Open Space	2170	445	2615	
Local Activity Center	377	111	488	
Transportation	1192	958	2150	
Regional Activity Center	220	97	317	
Employment Center-High	43	50	93	
Utilities	1449	769	2218	
Industrial	363	312	675	
Single Family Residential	381	311	692	
Multi-family Residential	111	201	312	
Office Park	16	12	28	
Agricultural	5430	2316	7746	
Total	137,041	13,100	150,142	

3-Foot Sea Level Rise

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Percent Inundation of Land Use
Conservation - Natural Reservations	129490	3598	133088	
Electrical Generation Facility	6433	567	7000	
Recreation and Open Space	3116	774	3890	
Local Activity Center	567	170	737	
Transportation	3229	1498	4727	
Regional Activity Center	478	273	751	
Employment Center-High	160	123	283	**18%**
Utilities	2174	119	2293	
Industrial	1490	382	1872	
Single Family Residential	1219	955	2174	
Multi-Family Residential	621	490	1111	
Office Park	45	34	79	
Agricultural	9276	1614	10890	
Total	158,298	10,597	168,895	

Acres of Habitat Type / Land Use Land Cover

Spatial data for regional use was provided by the South Florida Water Management District and is dated 2004. Miami-Dade chose not to perform this analysis because of concern for the currency of the data coverage. The habitat types were generated for a regional level of detail and should not be applied at a local scale.

Chapter 5: Analysis of the Vulnerability of Broward County to Sea Level Rise

Victoria Morrow, Erin Musgrave and Nina Goetsch - Inundation Mapping and Vulnerability Assessment Work Group Members from Broward County.

Vulnerability to Sea Level Rise - Broward County Overview

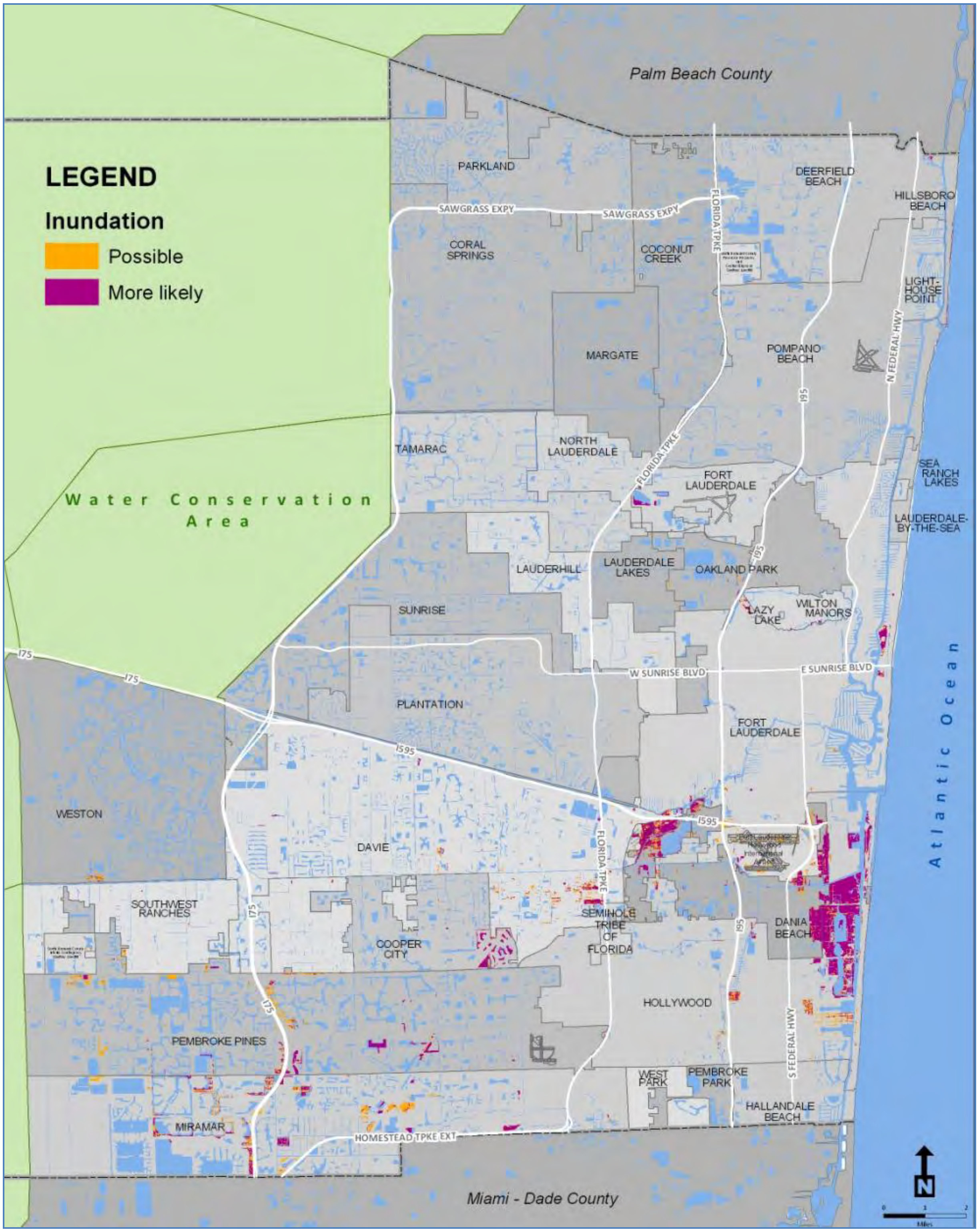
Inundation maps, identifying land at elevations below sea level, highlight areas located near Broward County's coastline, tidal waterways and in the southwest urban core. Inland areas identified as vulnerable are low lying areas which may be of future concern for storm water management but are not directly hydrologically connected to tidal waters.

Some physical infrastructure in Broward County is at risk beginning at the one foot scenario. A percentage of both Port Everglades and the Fort Lauderdale-Hollywood International Airport are at elevations below sea level. Most of these areas on the FLL Airport property are existing storm water management ponds and ditches. While railroads were not inundated, roads were; especially low volume roads and parking areas. The miles of roads vulnerable increased by a magnitude at each scenario with almost 300 miles of roads inundated at 3 feet of sea level rise. While no wastewater facility appears to be impacted at the one foot sea level rise scenario, the Hollywood and Ferncrest facilities were among the most vulnerable at the two and three foot scenarios. Landfills were primarily impacted in retention or natural areas surrounding the property. Only two of 26 hospitals showed any inundation up to 2-foot of sea level rise with no building infrastructure affected. Only one school property was affected and only at the 3 foot scenario. Since most emergency shelters are in schools, they were not impacted. Evacuation Routes to and from the barrier islands are vulnerable due to bridges being inaccessible from local roadway inundation. Impacts to coastal marina remain a concern.

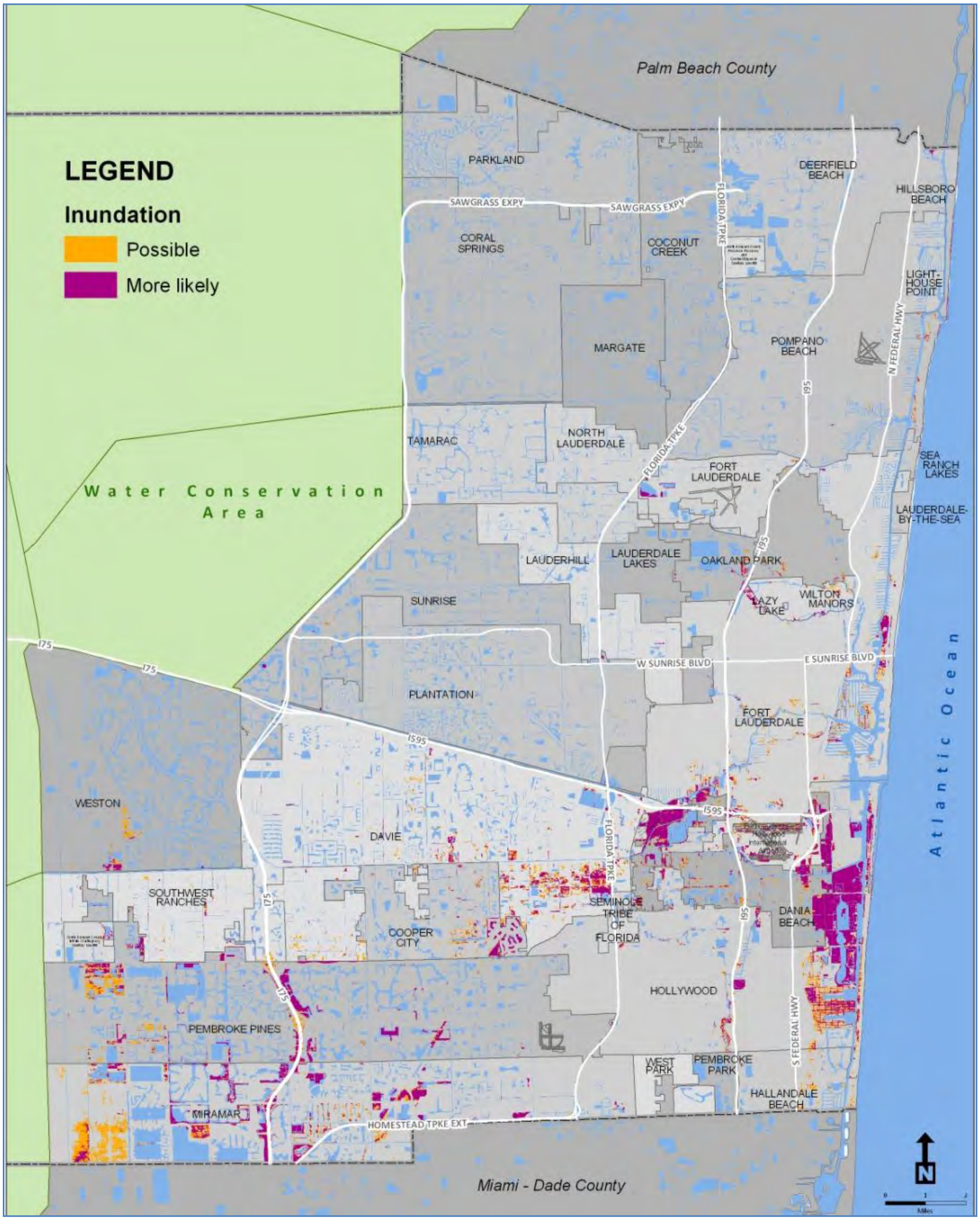
At the one foot scenario, property with a current taxable value of $403-828M was vulnerable. At three feet of sea level rise, properties valued at $6,901-12,109M were impacted. Under a one foot sea level rise scenario, 1.3% of the County is impacted with conservation lands being the major land use type inundated. At the two foot scenario, 3% of the land is impacted with Electrical Generation Facilities among the top ranked impacted. At the three foot scenario, 7% of the total land mass of the County is impacted including 28% of the agricultural lands and 10% of the transit oriented development. In terms of acres inundated, wetland hardwood forest and vegetated non-forested wetlands are among the major habitats impacted.

Countywide Maps – Broward

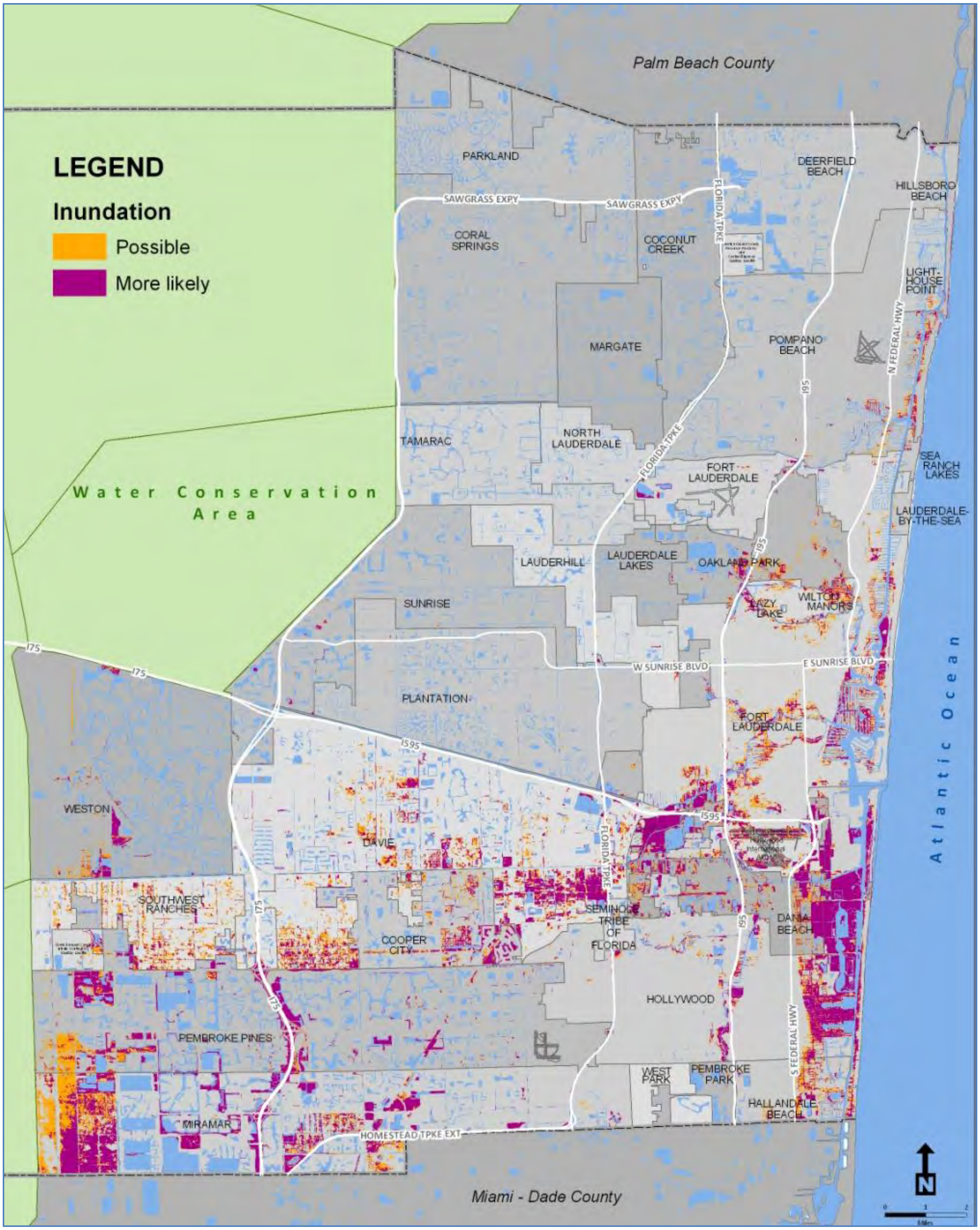
1-Foot Sea Level Rise



2-Foot Sea Level Rise



3-Foot Sea Level Rise



Analysis of Physical Features

Ports and Airports

One of the areas determined by the group to be critical was our ports and airports. Below are tables that represent the area that may be below mean high-high water sea level with a 1,-, 2-, or 3-foot sea level rise. This data is reported in acres. Of the five airports reviewed, Fort Lauderdale Executive Airport, North Perry Airport, and Pompano Beach Airpark had not land below sea level in any of the scenarios. Inundation at Fort Lauderdale-Hollywood International Airport would occur primarily in greenway space between buildings, runways and taxiways under all three scenarios.

Fort Lauderdale Hollywood Airport - Two Foot Sea Level Rise Scenario

One foot Inundation:

Facility Name	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Percent Inundation
Port Everglades	43.67	19.47	63.14	4.31
Fort Lauderdale-Hollywood Int'l Airport	13.09	31.85	44.94	3.37

Two foot Inundation:

Facility Name	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Percent Inundation
Fort Lauderdale-Hollywood Int'l Airport	84.65	55.73	140.38	10.54
Port Everglades	82.21	27.67	109.88	7.50

Three foot Inundation:

Facility Name	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Percent Inundation
Fort Lauderdale-Hollywood Int'l Airport	204.37	111.46	315.83	23.71
Port Everglades Parcels	148.07	51.30	199.37	13.62

Power plants

The developed parcels owned by Florida Power & Light (FPL) surrounding the two known power plants were included in the analysis. The FPL Lauderdale Power Plant has 398 acres of power plant, cooling lakes and related parcels. This analysis was performed on the 218.7 acres of developed land at or associated with the power plant.

1-foot Sea Level Rise:

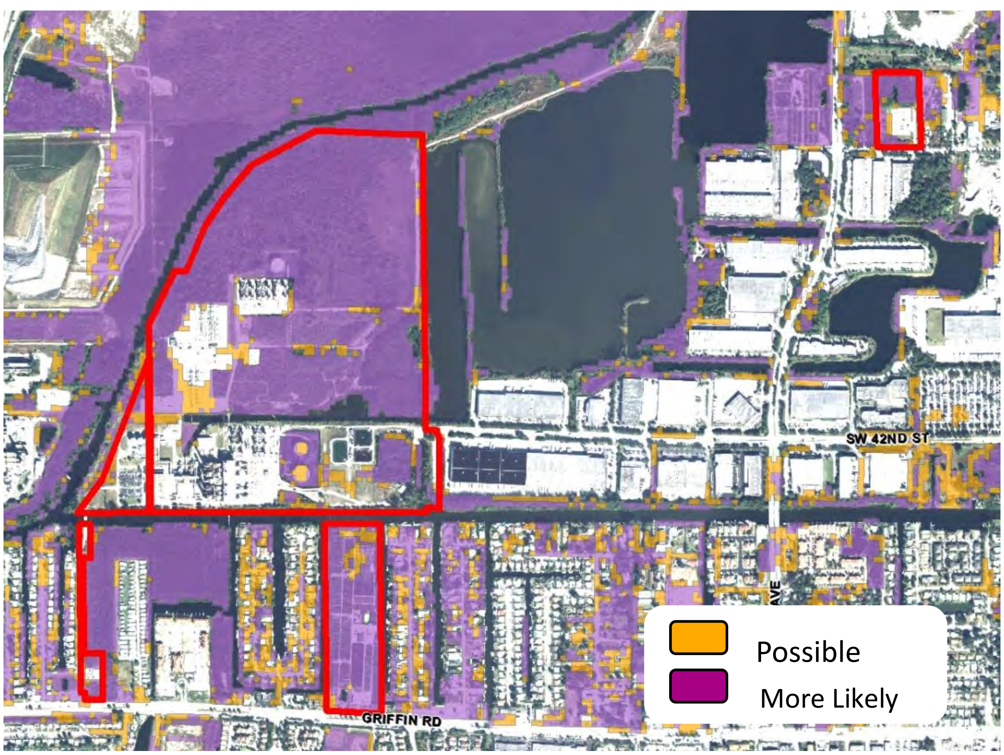
Facility Name	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
FPL Lauderdale Plant	55.95	34.49	90.44	218.7	41.3%

2-foot Sea Level Rise:

Facility Name	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
FPL Lauderdale Plant	107.62	16.85	124.47	218.7	56.9%

3-foot Sea Level Rise:

Facility Name	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
FPL Port Everglades Plant	1.13	0.36	1.49	9.3	1.6%
FPL Lauderdale Plant	136.97	14.29	151.26	218.7	69.2%



The FPL Lauderdale Power Plant developed land is 69% inundated at 3 foot Sea Level Rise Scenario.

Railroads

Railroads did not seem to be particularly affected, perhaps due to the fact that most of the rail beds in Broward County are elevated above the road and surrounding surfaces. This data is reported in **feet**. No portion of the railroad was below sea level at the one foot scenario.

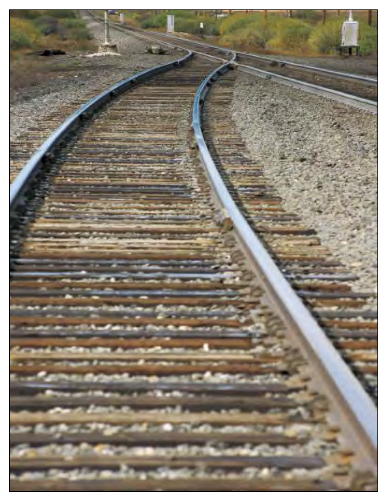
2-foot Sea Level Rise:

Owner Name	More Likely (feet)	Possible (feet)	Total Inundation (feet)	Percent Inundation
CSX	75.70	11.41	87.11	0.03
FEC	0.00	0.00	0.00	0.00
Total	**75.70**	**11.41**	**87.11**	**0.02**

3-foot Sea Level Rise:

Owner Name	More Likely (feet)	Possible (feet)	Total Inundation (feet)	Percent Inundation
CSX	558.11	308.71	866.82	0.33
FEC	50.10	75.16	125.26	0.10
Total	**608.21**	383.86	**992.08**	**0.25**

Water and Wastewater Treatment Plants



The water treatment plant dataset includes twenty-five (25) water treatment plants. Two plants are operated by Broward County. The remaining plants are run by local utilities. Treatment plant complexes range in size from 0.3 to thirty-eight acres. Parcels were chosen by common ownership and visual context.

No portion of the water treatment plants were below sea level at the one foot scenario.

2-foot Sea Level Rise:

Water Treatment Plant Facility Name	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Percent Inundation
System II (South) Water Treatment Plant	0.53	0.06	0.57	5.48

3-foot Sea Level Rise:

Water Treatment Plant Facility Name	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Percent Inundation
System II (South) Water Treatment Plant	0.80	0.42	1.23	11.70
Cooper City Utility	0.98	0	0.98	5.83

The wastewater treatment plant (WWTP) dataset was updated in 2007 and includes fifteen (15) wastewater treatment plants. Data was summarized by Facility Name and probability and reported in acres. The two largest Wastewater Treatment Plants in Broward County were not affected even at the 3-foot level. Water treatment plants were left out intentionally from the analysis due to Homeland Security concerns about publicizing their locations.

No portion of the wastewater treatment plants were below sea level at the one foot scenario.

2-foot Sea Level Rise:

Wastewater Treatment Plant (WWTP) Facility Name	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Percent Inundation
Hollywood South Regional WWTP	0.65	0.95	1.60	4.95
Town Of Davie, System II WWTP	0.33	0.05	0.38	1.53
Pembroke Pines WWTP	0.01	0.03	0.04	0.14

3-foot Sea Level Rise:

Wastewater Treatment Plant (WWTP) Facility Name	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Percent Inundation
Hollywood South Regional WWTP	4.04	6.14	10.18	31.39
Ferncrest WWTP	0.04	0.30	0.33	14.83
Sunrise Southwest WWTP	0.42	0.73	1.15	8.38
Miramar Wastewater Reclamation WWTP	1.27	1.10	2.37	8.15
Pembroke Pines WWTP	0.14	1.08	1.22	4.82
Cooper City WWTP	0.60	0.00	0.60	4.61
Town Of Davie, System II WWTP	0.57	0.42	0.98	4.02

Landfills

The impacts of sea level rise to Broward County's seven landfills were reviewed. The South Ash Landfill had the most inundation at one, two and three foot inundation. The flooding appears to be primarily in natural /retention areas. It remains unclear whether the inundation at three feet would affect the operations of this landfill. The largest landfill complex, the Central Sanitary Landfill, is located miles from any inundation at any level.

1-foot Sea Level Rise:

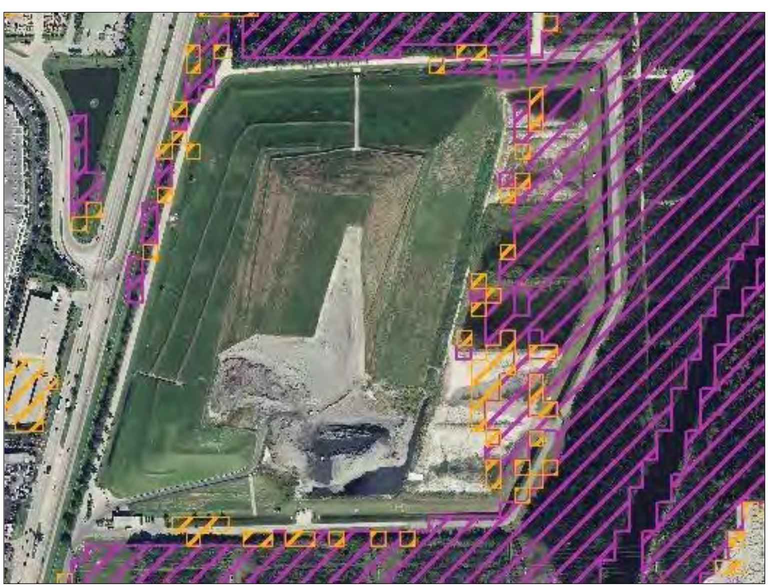
Facility Name	More Likely	Possible	Total Inundation	Percent Inundation
South Ash Landfill	23.63	3.59	27.23	30.60
Hollywood Yard Trash/Closed	3.16	0.34	3.50	17.64
B.C. Interim Contingency Landfill	0.92	2.87	3.79	0.66
Davie Landfill	1.26	0.29	1.55	0.57

2-foot Sea Level Rise:

Facility Name	More Likely	Possible	Total Inundation	Percent Inundation
South Ash Landfill	28.57	1.95	30.52	34.30
Hollywood Yard Trash/Closed	3.90	0.35	4.25	21.44
B.C. Interim Contingency Landfill	10.62	7.06	17.68	3.08
Davie Landfill	2.75	0.17	2.93	1.07

3-foot Sea Level Rise:

Facility Name	More Likely	Possible	Total Inundation	Percent Inundation
South Ash Landfill	34.09	3.38	37.47	42.11
Hollywood Yard Trash/Closed	4.64	1.97	6.61	33.31
B.C. Interim Contingency Landfill	24.71	10.95	35.66	6.20
Davie Landfill	4.14	1.70	5.84	2.14

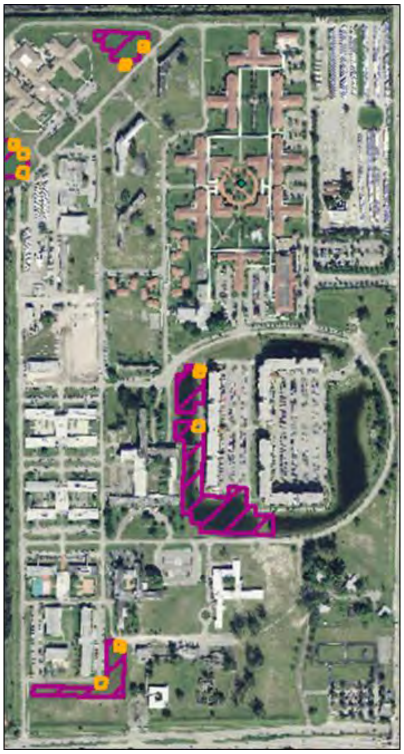


Inundation of landfill property for all sea level rise scenarios was primarily in retention or natural areas surrounding landfills.

In general, inundation near landfills was limited to the margins of the property.

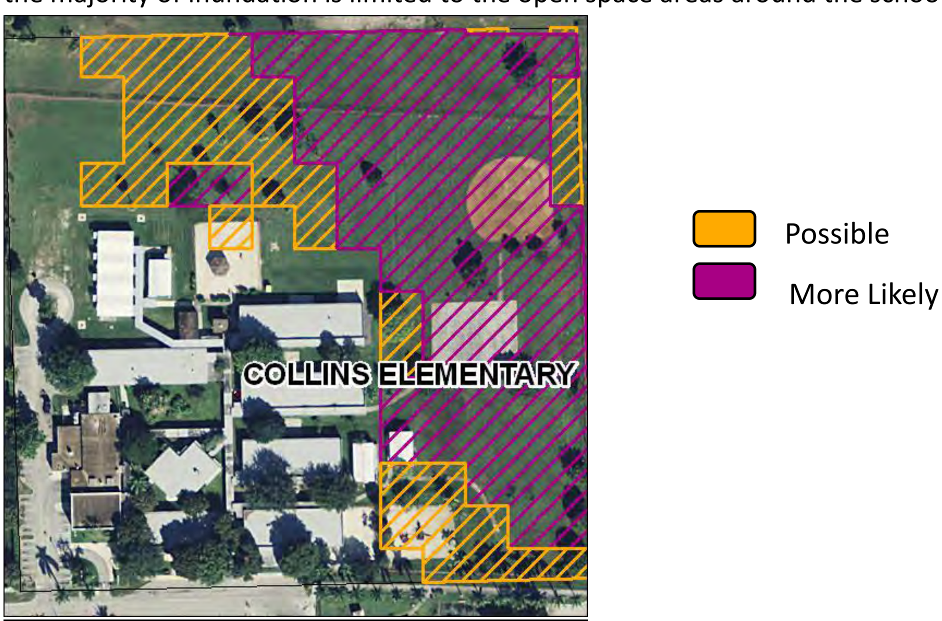
Hospitals

Only two of 26 hospitals showed any inundation up to 2-foot of sea level rise with no infrastructure affected. These images show a 3-foot sea level rise.



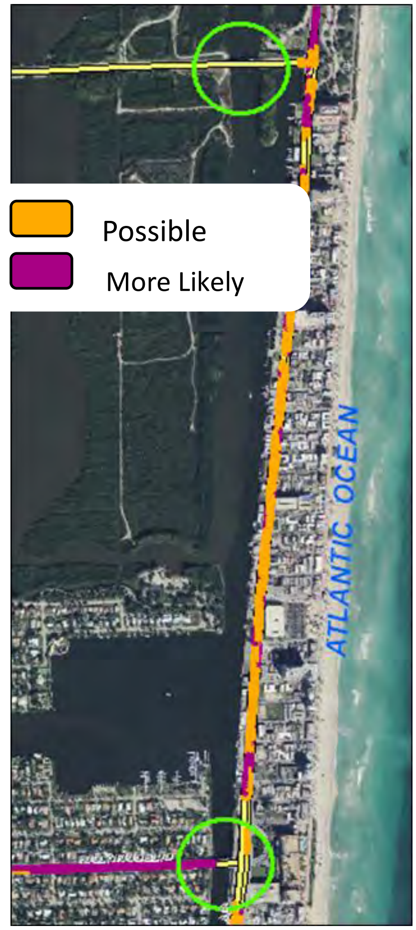
Schools

At a 3-foot sea level rise, only one of the 239 school facilities appears to be affected. Even at this site, the majority of inundation is limited to the open space areas around the school.



Emergency Shelters

All emergency shelters in Broward County are located in schools. There is no inundation risk at 1-foot, negligible risk at 2-foot and some inundation of open spaces along the edges of school properties in the water retention areas. No emergency shelter structures are affected at any of the sea level rise scenarios.

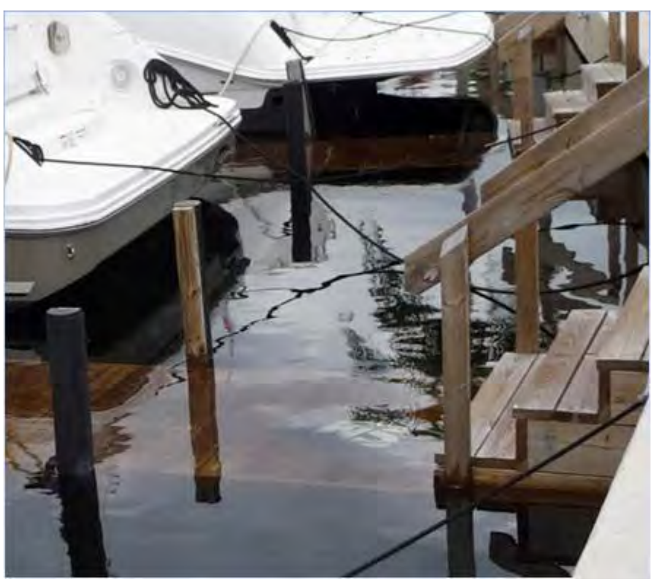


Evacuation Routes

Evacuation Routes to and from the barrier islands are vulnerable due to bridges being inaccessible from local roadway inundation. The image to the right is a 2-foot sea level rise scenario with access bridges circled in green.

Marinas

All marina facilities are located on or next to water features, east of all salinity control structures to give easy access to the ocean. The assumption is that all will be affected in some way, although the extent is indeterminable with this current analysis. It is assumed that those docks with fixed infrastructure will be inundated while floating docks will rise with sea levels.



Results of Analysis

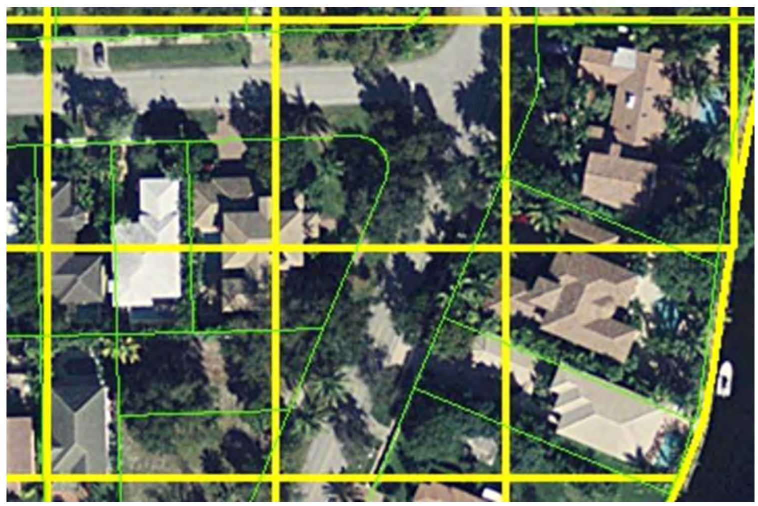
Geographic analysis was done on four items:

- Taxable value of property
- Miles of road by Florida Department of Transportation category
- Future Land Use
- Habitat / Land Use Land Cover

Taxable Value of Property

pGrid (150-ft grid)

The analysis of property values was done using an aggregated parcel methodology in which a 150-foot grid was created and then overlaid on the parcel features to aggregate property values within each grid cell. In the table below, the low end of the range represents the areas more likely to be below the mean high-high water levels with 1-, 2- or 3-foot seal level rise. The high end of the range represents property with at least a possible chance to be inundated in these scenarios.



Level of Inundation	Range of Taxable Value
One Foot	$403,069,831 - $828,221,856
Two Foot	$1,751,104,870 - $3,779,685,458
Three Foot	$6,900,509,868 - $12,109,037,156

Roads by FDOT Category

Roadways summarized by Functional Class in miles. High volume categories include sections of roadway where bridges were removed from the LiDAR data and represented bare earth rather than the actual roadways.

1-Foot Sea Level Rise – 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage
1 – high volume, maximum speed	0.73	127.70
2 – high speed, channels traffic to FC1	0.00	251.28
3 – high speed, lower mobility, connects to FC2	0.28	464.39
4 – moderate speed, through neighborhoods	0.72	820.83
5 – low volume, i.e. access roads, parking lanes	7.74	5,414.99
Total	**9.47**	**7,080.19**

2-Foot Sea Level Rise – 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage
1 – high volume, maximum speed	0.76	127.70
2 – high speed, channels traffic to FC1	0.00	251.28
3 – high speed, lower mobility, connects to FC2	0.93	464.39
4 – moderate speed, through neighborhoods	7.89	820.83
5 – low volume, i.e. access roads, parking lanes…	66.86	5,414.99
Total	**76.44**	**7,080.19**

3- Foot Sea Level Rise – 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation	Total Coverage
1 – high volume, maximum speed	1.17	127.70
2 – high speed, channels traffic to FC1	0.15	251.28
3 – high speed, lower mobility, connects to FC2	3.29	464.39
4 – moderate speed, through neighborhoods	23.97	820.83
5 – low volume, i.e. access roads, parking lanes…	267.35	5,414.99
Total	**295.78**	**7,080.19**

Acres of Future Land Use

Coverage of Future Land Use was provided by the Broward County Planning Council and was most recently updated on September 28, 2010. Data was summarized by Land Use type and probability and reported in acres.

1-foot Sea Level Rise:

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation of that Land Use
Conservation - Natural Reservations	911.43	133.41	1,044.84	4,090.64	25.54
Electrical Generation Facility	63.71	31.49	95.20	562.97	16.91
Recreation and Open Space	236.86	127.31	364.17	10,175.83	3.58
Local Activity Center	24.01	5.40	29.41	1,088.87	2.70
Transportation	168.87	111.01	279.87	11,092.43	2.52
Regional Activity Center	95.79	116.96	212.74	9,092.27	2.34
Employment Center-High	40.15	1.64	41.79	2,041.87	2.05
Utilities	25.30	9.71	35.01	1,775.84	1.97
Industrial	126.87	44.38	171.25	12,862.72	1.33
Low-3 Residential	101.55	130.99	232.54	17,890.76	1.30
Residential in Irregular Areas	164.94	118.13	283.07	29,199.00	0.97
Estate-1 Residential	71.58	85.00	156.58	16,359.02	0.96
Transit Oriented Corridor	11.23	13.12	24.36	2,579.49	0.94
Low-2 Residential	61.93	20.38	82.32	9,089.85	0.91
Office Park	5.65	0.55	6.20	755.53	0.82
Commercial Recreation	24.49	25.14	49.63	6,437.49	0.77
Low-5 Residential	199.88	65.24	265.12	41,617.48	0.64
Low-Medium-10 Residential	42.52	21.23	63.74	11,148.84	0.57
Agricultural	5.80	43.48	49.27	9,958.15	0.49
Medium-16 Residential	36.69	10.63	47.32	9,576.98	0.49
Medium-High-25 Residential	6.60	8.97	15.57	4,347.05	0.36
High-50 Residential	3.33	0.64	3.97	1,212.57	0.33
Right of Way	42.72	57.24	99.96	36,732.88	0.27
Rural Estates	1.61	1.72	3.33	1,254.37	0.27
Rural Ranches	1.66	10.37	12.04	4,833.06	0.25
Commercial	36.65	17.06	53.72	23,152.44	0.23
Community Facilities	6.93	2.47	9.40	6,100.03	0.15
Employment Center-Low	0.00	0.00	0.00	17.20	0.00
Transit Oriented Development	0.00	0.00	0.00	124.50	0.00
Total	**2,518.75**	**1,213.66**	**3,732.41**	**285,170.13**	**1.31**

2-foot Sea Level Rise:

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation of that Land Use
Conservation - Natural Reservations	1,101.98	47.92	1,149.90	4,090.64	28.11
Electrical Generation Facility	111.72	14.25	125.97	562.97	22.38
Agricultural	197.87	656.69	854.56	9,958.15	8.58
Recreation and Open Space	523.53	300.20	823.73	10,175.83	8.09
Transportation	425.41	206.81	632.22	11,092.43	5.70
Regional Activity Center	310.64	132.38	443.03	9,092.27	4.87
Local Activity Center	34.43	15.75	50.18	1,088.87	4.61
Estate-1 Residential	340.89	310.53	651.42	16,359.02	3.98
Utilities	50.12	17.11	67.24	1,775.84	3.79
Transit Oriented Development	1.03	3.44	4.48	124.50	3.60
Transit Oriented Corridor	44.25	34.05	78.30	2,579.49	3.04
Employment Center-Low	0.17	0.34	0.52	17.20	3.00
Low-3 Residential	337.27	117.18	454.45	17,890.76	2.54
Employment Center-High	45.63	5.16	50.79	2,041.87	2.49
Medium-High-25 Residential	43.53	59.15	102.68	4,347.05	2.36
Rural Ranches	35.42	73.25	108.67	4,833.06	2.25
Industrial	218.75	60.73	279.48	12,862.72	2.17
Low-2 Residential	117.05	72.38	189.43	9,089.85	2.08
Commercial Recreation	75.32	50.86	126.18	6,437.49	1.96
Rural Estates	11.98	11.64	23.62	1,254.37	1.88
Office Park	8.21	4.93	13.15	755.53	1.74
Low-5 Residential	409.70	275.84	685.55	41,617.48	1.65
Residential in Irregular Areas	395.30	64.23	459.53	29,199.00	1.57
High-50 Residential	9.07	9.29	18.36	1,212.57	1.51
Right of Way	256.30	288.36	544.66	36,732.88	1.48
Low-Medium-10 Residential	93.84	48.30	142.14	11,148.84	1.27
Medium-16 Residential	64.94	48.45	113.39	9,576.98	1.18
Commercial	123.52	136.25	259.77	23,152.44	1.12
Community Facilities	24.30	30.20	54.50	6,100.03	0.89
Total	**5,412.19**	**3,095.70**	**8,507.88**	**285,170.13**	**2.98**

3-foot Sea Level Rise:

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation of that Land Use
Conservation - Natural Reservations	1,189.81	135.56	1,325.37	4,090.64	32.40
Electrical Generation Facility	142.72	18.38	161.10	562.97	28.62
Agricultural	1,569.78	1,218.23	2,788.01	9,958.15	28.00
Rural Ranches	486.54	688.62	1,175.16	4,833.06	24.32
Rural Estates	69.69	124.89	194.58	1,254.37	15.51
Recreation and Open Space	1,032.19	267.38	1,299.57	10,175.83	12.77
Estate-1 Residential	1,126.00	710.73	1,836.73	16,359.02	11.23
Transportation	875.09	307.55	1,182.64	11,092.43	10.66
Regional Activity Center	624.12	332.69	956.81	9,092.27	10.52
Medium-High-25 Residential	221.27	207.40	428.67	4,347.05	9.86
Transit Oriented Development	7.96	4.26	12.22	124.50	9.82
Local Activity Center	65.58	35.22	100.79	1,088.87	9.26
Transit Oriented Corridor	127.78	81.99	209.78	2,579.49	8.13
Utilities	89.11	32.77	121.89	1,775.84	6.86
High-50 Residential	35.39	34.21	69.59	1,212.57	5.74
Office Park	23.63	18.01	41.64	755.53	5.51
Right of Way	1,040.56	895.99	1,936.55	36,732.88	5.27
Commercial Recreation	224.50	109.93	334.43	6,437.49	5.20
Employment Center-Low	0.69	0.17	0.86	17.20	5.01
Community Facilities	132.32	163.53	295.85	6,100.03	4.85
Low-2 Residential	290.68	146.34	437.03	9,089.85	4.81
Low-3 Residential	609.72	228.55	838.28	17,890.76	4.69
Medium-16 Residential	224.95	221.60	446.54	9,576.98	4.66
Industrial	383.66	178.72	562.38	12,862.72	4.37
Low-5 Residential	1,105.08	657.83	1,762.91	41,617.48	4.24
Employment Center-High	60.08	10.62	70.70	2,041.87	3.46
Low-Medium-10 Residential	230.56	145.44	376.01	11,148.84	3.37
Commercial	428.10	262.79	690.90	23,152.44	2.98
Residential in Irregular Areas	589.11	157.57	746.68	29,199.00	2.56
Total	**13,006.68**	**7,397.01**	**20,403.69**	**285,170.13**	**7.15**

Acres of Habitat Type / Land Use Land Cover

Spatial data was provided by the South Florida Water Management District and is dated 2004. The data is reported in **acres**.

1-foot Sea Level Rise:

Type	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
WETLAND HARDWOOD FORESTS	1,494.26	206.92	1,701.19	5,577.71	30.50
FEEDING OPERATIONS	14.63	0.38	15.01	73.40	20.45
VEGETATED NON-FORESTED WETLANDS	243.45	364.50	607.94	6,341.78	9.59
DISTURBED LAND	29.72	16.80	46.52	575.45	8.08
UPLAND HARDWOOD FORESTS	96.34	99.29	195.63	3,492.33	5.60
LAKES	13.28	1.22	14.50	279.12	5.19
UPLAND MIXED FORESTS	41.34	17.67	59.02	1,170.52	5.04
MIXED RANGELAND	28.05	21.93	49.98	993.05	5.03
NURSERIES AND VINEYARDS	48.13	54.89	103.02	2,354.86	4.37
CROPLAND AND PASTURELAND	101.68	19.19	120.87	5,194.34	2.33
UPLAND SHRUB AND BRUSHLAND	13.99	7.94	21.92	1,231.69	1.78
HERBACEOUS (DRY PRAIRIE)	105.03	89.41	194.45	13,197.03	1.47
UTILITIES	14.44	7.27	21.71	1,954.55	1.11
COMMUNICATIONS	1.78	0.14	1.91	188.39	1.02
RECREATIONAL	66.42	70.80	137.23	14,168.62	0.97
OCEAN AND GULF	24.82	5.60	30.42	3,597.39	0.85
STREAMS AND WATERWAYS	56.13	8.28	64.40	8,005.00	0.80
TRANSPORTATION	31.10	64.92	96.02	17,013.01	0.56
RESERVOIRS	49.72	33.72	83.45	16,960.65	0.49
UPLAND CONIFEROUS FORESTS	0.95	0.40	1.36	425.07	0.32
EXTRACTIVE	2.83	0.86	3.68	1,225.23	0.30
INDUSTRIAL	9.39	2.84	12.22	4,151.25	0.29
SPECIALTY FARMS	0.06	0.81	0.87	430.88	0.20
RESIDENTIAL, LOW DENSITY	9.60	9.96	19.56	12,566.44	0.16
RESIDENTIAL, MEDIUM DENSITY	26.68	76.63	103.31	74,932.18	0.14
INSTITUTIONAL	4.81	3.65	8.46	8,574.09	0.10
COMMERCIAL AND SERVICES	15.81	12.78	28.59	29,267.25	0.10
RESIDENTIAL, HIGH DENSITY	11.39	23.75	35.14	41,608.20	0.08
TREE CROPS	0.00	0.00	0.00	32.06	0.00
WETLAND CONIFEROUS FORESTS	0.00	0.00	0.00	397.51	0.00
WETLAND FORESTED MIXED	0.00	0.00	0.00	131.39	0.00
TOTAL	**2,555.83**	**1,222.56**	**3,778.39**	**276,110.47**	**1.37**

2-foot Sea Level Rise:

Type	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
WETLAND HARDWOOD FORESTS	1,837.98	262.77	2,100.76	5,577.71	37.66
FEEDING OPERATIONS	16.31	0.82	17.13	73.40	23.34
VEGETATED NON-FORESTED WETLANDS	874.47	337.45	1,211.92	6,341.78	19.11
UPLAND MIXED FORESTS	116.04	60.54	176.58	1,170.52	15.09
NURSERIES AND VINEYARDS	195.99	139.59	335.58	2,354.86	14.25
UPLAND HARDWOOD FORESTS	307.71	160.71	468.42	3,492.33	13.41
MIXED RANGELAND	80.26	38.52	118.78	993.05	11.96
DISTURBED LAND	54.49	11.69	66.18	575.45	11.50
CROPLAND AND PASTURELAND	156.59	385.56	542.15	5,194.34	10.44
COMMUNICATIONS	7.10	10.68	17.77	188.39	9.43
UPLAND SHRUB AND BRUSHLAND	48.85	34.95	83.80	1,231.69	6.80
LAKES	14.80	0.04	14.84	279.12	5.32
HERBACEOUS (DRY PRAIRIE)	353.51	316.74	670.25	13,197.03	5.08
TREE CROPS	0.02	1.39	1.40	32.06	4.38
RECREATIONAL	229.63	166.44	396.07	14,168.62	2.80
SPECIALTY FARMS	5.37	5.79	11.16	430.88	2.59
TRANSPORTATION	212.59	194.36	406.95	17,013.01	2.39
UTILITIES	29.70	11.87	41.58	1,954.55	2.13
STREAMS AND WATERWAYS	107.06	23.67	130.73	8,005.00	1.63
RESIDENTIAL, LOW DENSITY	73.84	112.25	186.09	12,566.44	1.48
OCEAN AND GULF	45.47	6.25	51.72	3,597.39	1.44
WETLAND CONIFEROUS FORESTS	1.46	3.79	5.24	397.51	1.32
RESERVOIRS	134.33	30.75	165.09	16,960.65	0.97
RESIDENTIAL, MEDIUM DENSITY	315.73	406.85	722.58	74,932.18	0.96
RESIDENTIAL, HIGH DENSITY	134.01	220.90	354.91	41,608.20	0.85
INSTITUTIONAL	25.75	42.66	68.41	8,574.09	0.80
COMMERCIAL AND SERVICES	89.77	126.07	215.84	29,267.25	0.74
INDUSTRIAL	19.02	9.51	28.53	4,151.25	0.69
EXTRACTIVE	5.49	1.20	6.69	1,225.23	0.55
UPLAND CONIFEROUS FORESTS	1.81	0.46	2.28	425.07	0.54
WETLAND FORESTED MIXED	0.00	0.00	0.00	131.39	0.00
TOTAL	**5,495.14**	**3,124.29**	**8,619.43**	**276,110.46**	**3.12**

3-foot Sea Level Rise:

Type	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
WETLAND HARDWOOD FORESTS	2,334.89	477.31	2,812.20	5,577.71	50.42
NURSERIES AND VINEYARDS	492.68	251.61	744.29	2,354.86	31.61
VEGETATED NON-FORESTED WETLANDS	1,459.69	405.08	1,864.77	6,341.78	29.40
CROPLAND AND PASTURELAND	1,028.15	488.20	1,516.36	5,194.34	29.19
FEEDING OPERATIONS	18.16	2.51	20.66	73.40	28.15
UPLAND HARDWOOD FORESTS	662.94	254.23	917.17	3,492.33	26.26
UPLAND MIXED FORESTS	222.57	79.62	302.19	1,170.52	25.82
MIXED RANGELAND	160.14	89.31	249.44	993.05	25.12
HERBACEOUS (DRY PRAIRIE)	1,352.92	1,379.94	2,732.86	13,197.03	20.71
TREE CROPS	2.08	3.97	6.04	32.06	18.86
DISTURBED LAND	82.37	24.37	106.75	575.45	18.55
UPLAND SHRUB AND BRUSHLAND	131.43	72.09	203.52	1,231.69	16.52
COMMUNICATIONS	20.58	4.93	25.51	188.39	13.54
SPECIALTY FARMS	23.47	16.55	40.02	430.88	9.29
RECREATIONAL	642.91	348.71	991.62	14,168.62	7.00
RESIDENTIAL, LOW DENSITY	441.19	418.28	859.46	12,566.44	6.84
UTILITIES	69.14	40.58	109.72	1,954.55	5.61
TRANSPORTATION	637.24	311.56	948.80	17,013.01	5.58
LAKES	14.95	0.06	15.01	279.12	5.38
RESIDENTIAL, MEDIUM DENSITY	1,438.10	1,281.97	2,720.08	74,932.18	3.63
INSTITUTIONAL	148.40	159.80	308.20	8,574.09	3.59
COMMERCIAL AND SERVICES	483.00	557.08	1,040.08	29,267.25	3.55
RESIDENTIAL, HIGH DENSITY	723.60	655.09	1,378.69	41,608.20	3.31
STREAMS AND WATERWAYS	221.69	37.91	259.60	8,005.00	3.24
INDUSTRIAL	50.65	47.30	97.95	4,151.25	2.36
WETLAND CONIFEROUS FORESTS	6.85	1.01	7.86	397.51	1.98
OCEAN AND GULF	58.01	3.92	61.94	3,597.39	1.72
RESERVOIRS	239.32	31.38	270.70	16,960.65	1.60
UPLAND CONIFEROUS FORESTS	2.58	1.01	3.58	425.07	0.84
EXTRACTIVE	8.69	1.20	9.89	1,225.23	0.81
WETLAND FORESTED MIXED	0.00	0.00	0.00	131.39	0.00
TOTAL	**13,178.40**	**7,446.58**	**20,624.99**	**276,110.46**	**7.47**

Chapter 6: Analysis of the Vulnerability of Palm Beach County to Sea Level Rise

Kelly Ratchinsky and Beth Norton - Inundation Mapping and Vulnerability Assessment Work Group Members from Palm Beach County

Vulnerability to Sea Level Rise - Palm Beach County Overview

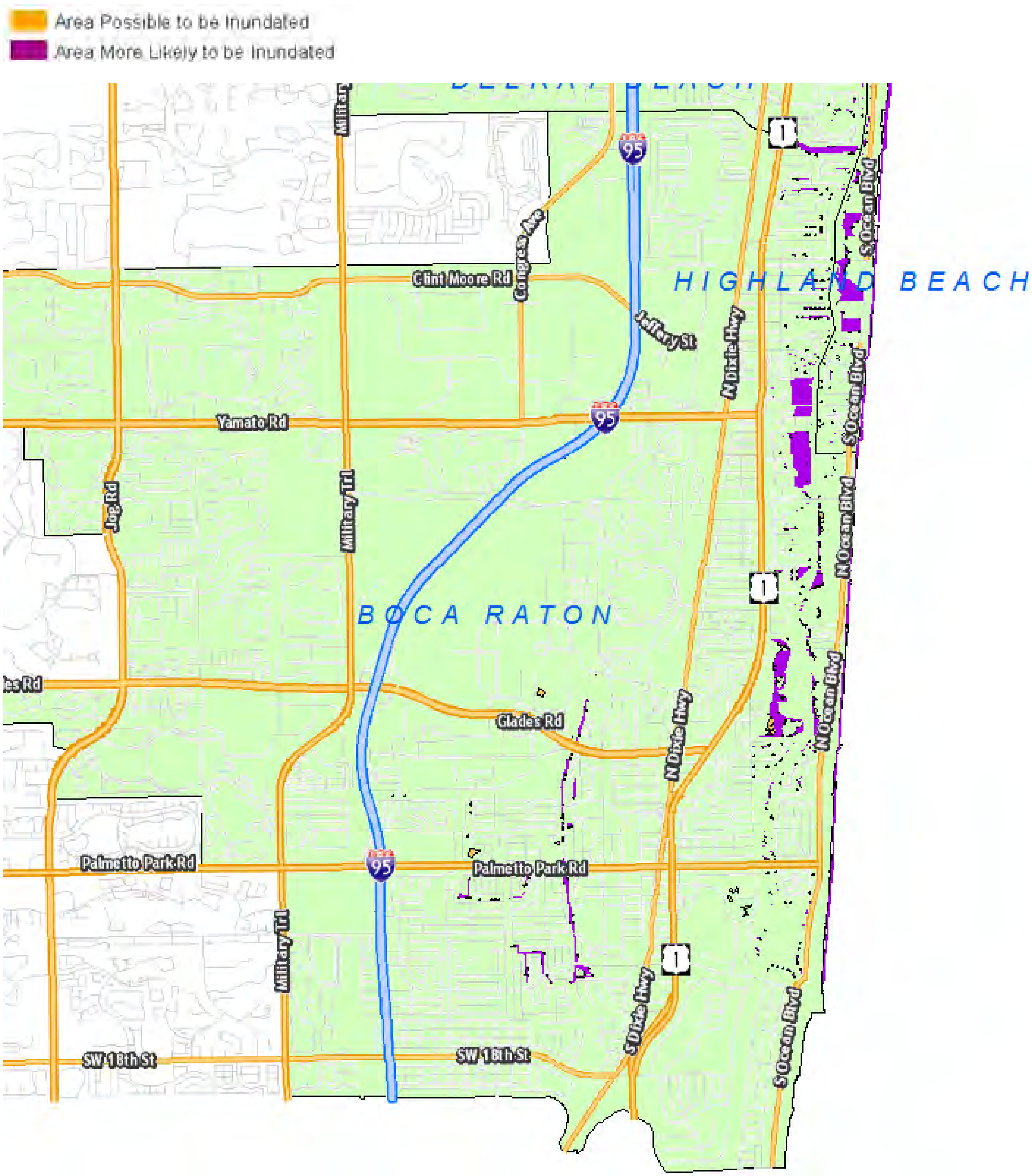
Inundation analysis, identifying land at elevations below sea level, highlight areas located near Palm Beach County's coastline and tidal waterways. The geographical representation of flooding shown on the maps is based on a bath tub analysis for the three sea level scenarios of 1', 2' and 3'. The flooding areas shown do <u>not</u> reflect additional flooding impacts as a result of hurricanes or the additional hydrologic losses through canal structures as a result of the rise in the sea level. The justification of those impacts will require a much more detailed study.

Some physical infrastructure in Palm Beach County is at risk beginning at the one foot scenario. While railroads were not inundated, roads were; especially low volume roads and parking areas. The miles of roads vulnerable increased at each scenario however even at the 3 foot sea level we have a minimal amount of inundation with 41 miles of roads. Facilities such as Waste Water, emergency shelters, Landfills, airports, ports and power plants were unaffected thru all three sea level rise scenarios. One school, one landfill site and one hospital will be impacted at the 3 foot sea level rise scenario; all were in surrounding ditch and parking lot areas. While we do not have Evacuation Routes it can be assumed that access to and from the barrier islands are vulnerable due to bridges being inaccessible from local roadway inundation. Impacts to coastal marina remain a concern.

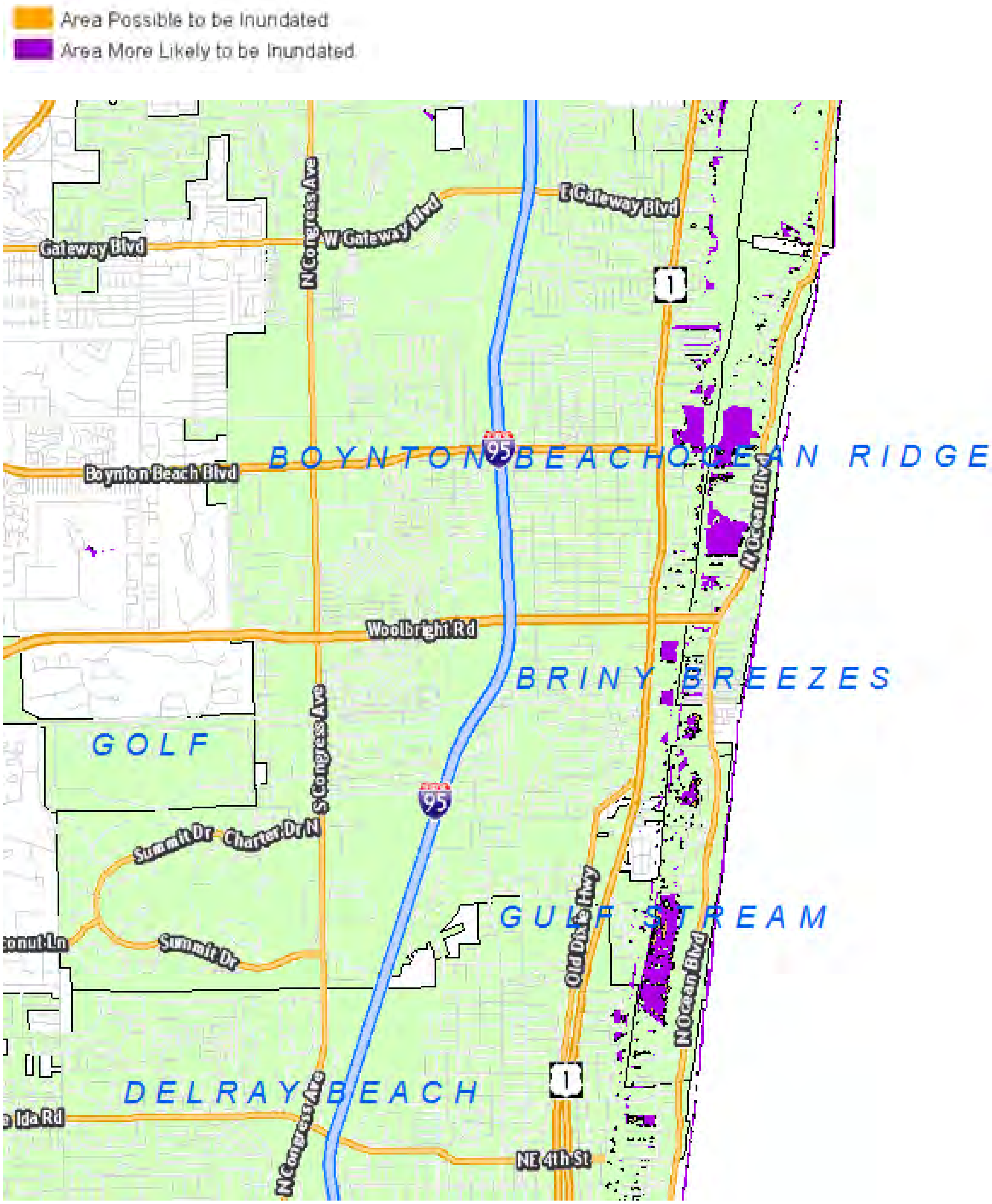
At the one foot scenario, property with a current taxable value of $396-557 Million was vulnerable. At three feet of sea level rise, properties inundated totaled to taxable valued at $3.6-4.5 Billion. Future land use affected is minimal at all three sea level rise scenarios with Peanut Island having the highest % loss of Acreage (29.8%). In terms of Land Use Habitat acres inundated, salt water ponds, salt water marshes and mangrove swamp areas are among the major habitats impacted.

Countywide Maps – Palm Beach

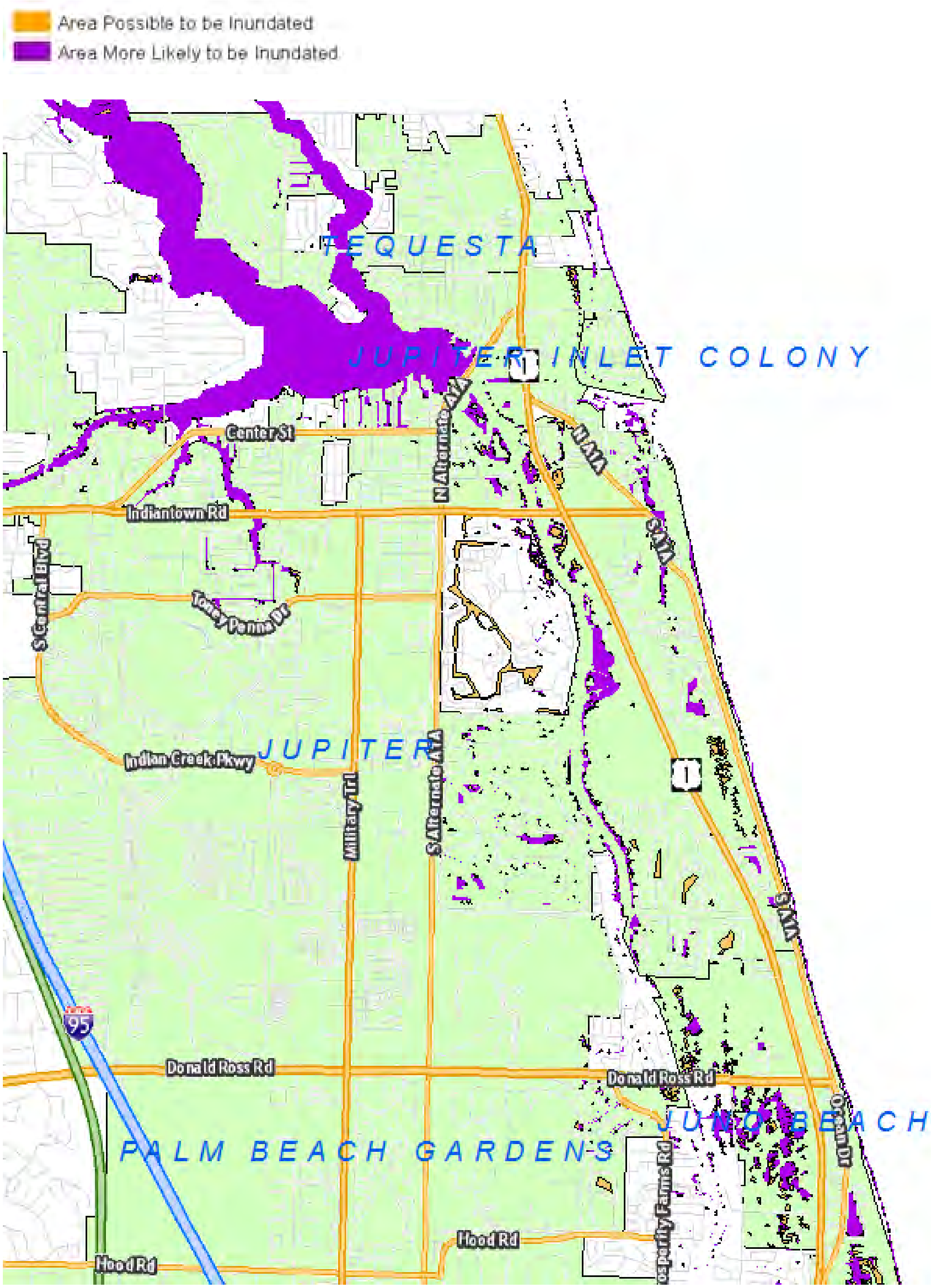
1-Foot Sea Level Rise in Palm Beach County - Boca Raton Area



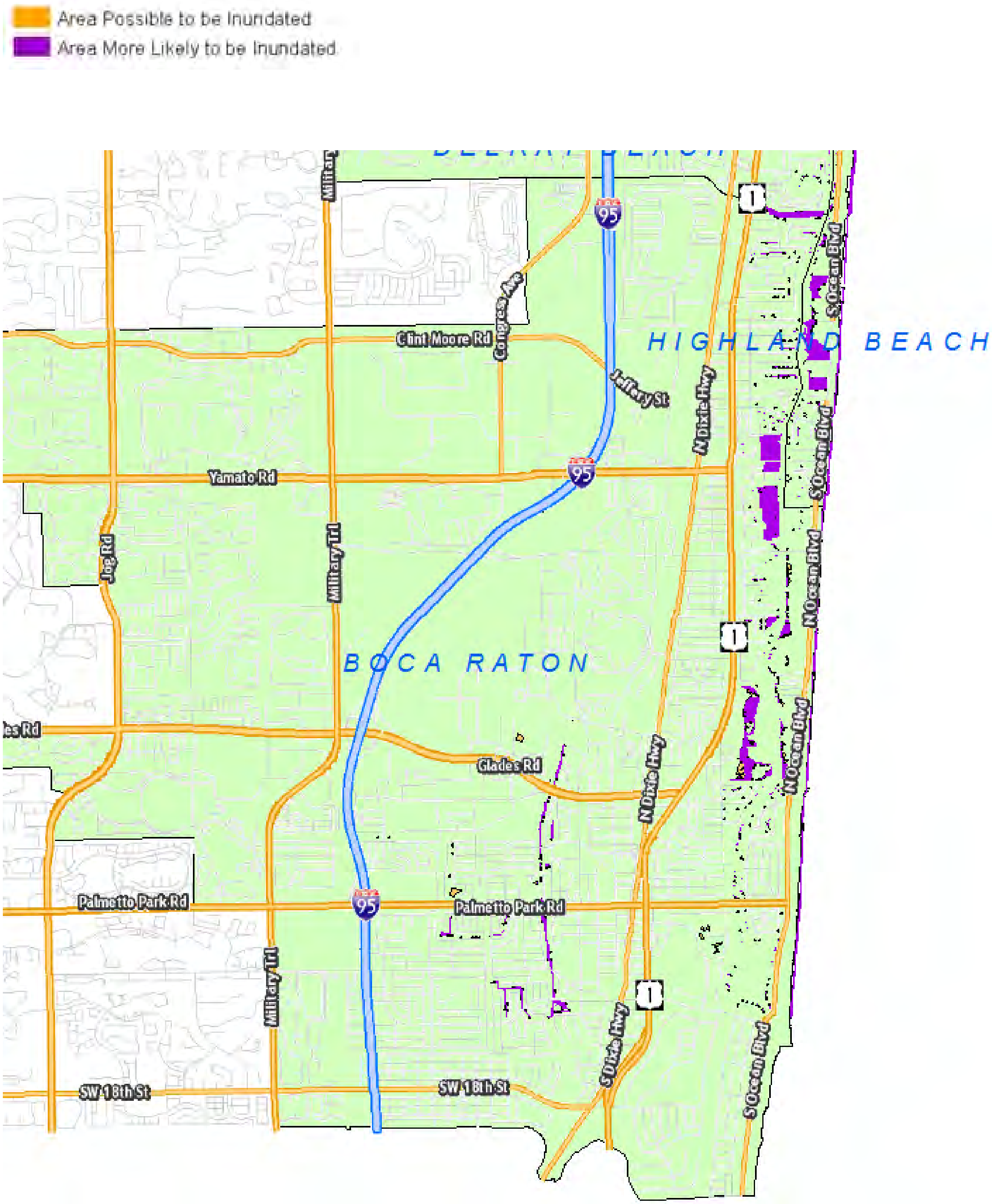
1-Foot Sea Level Rise in Palm Beach County - Boynton Beach Area



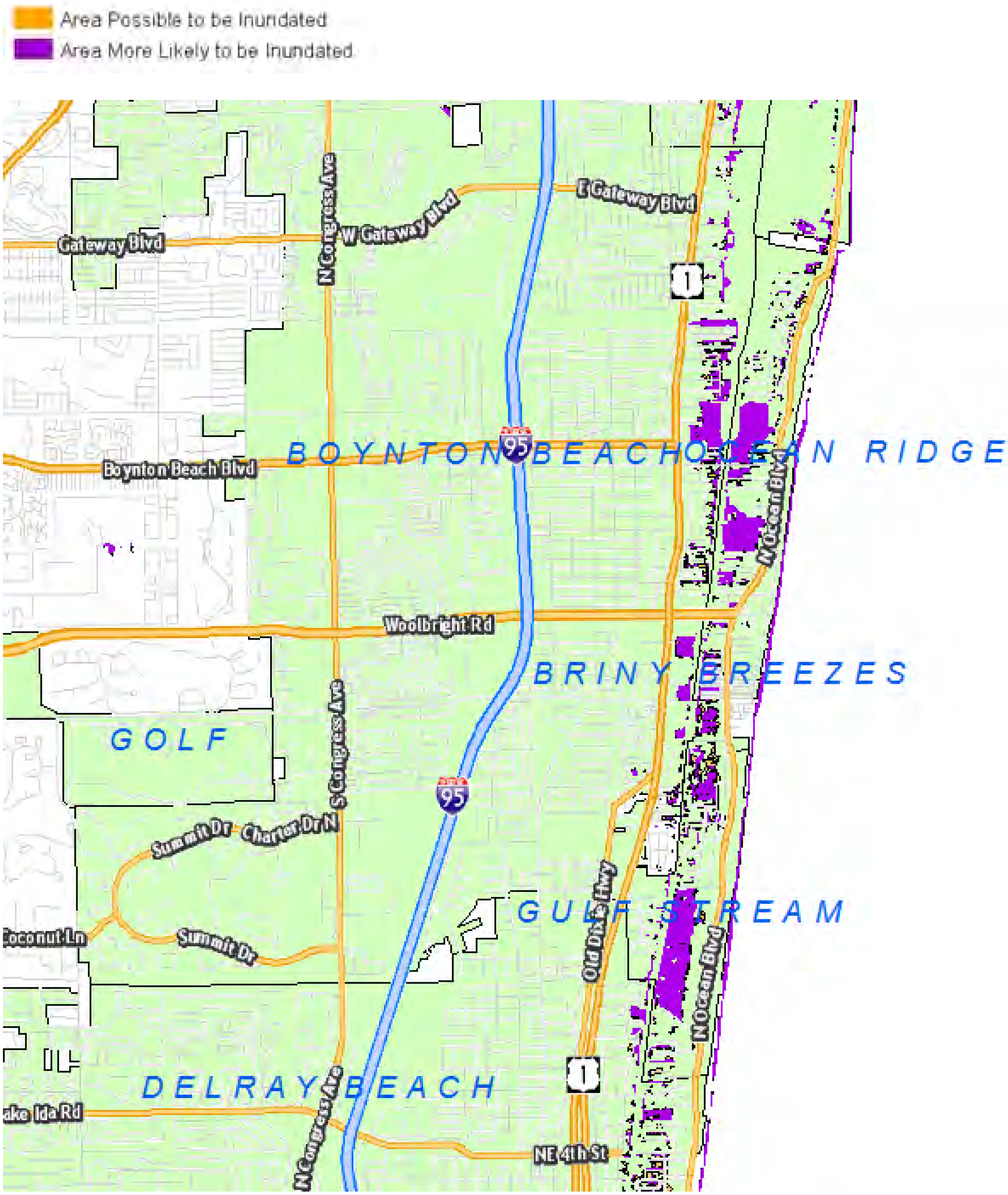
1-Foot Sea Level Rise in Palm Beach County - Jupiter Area



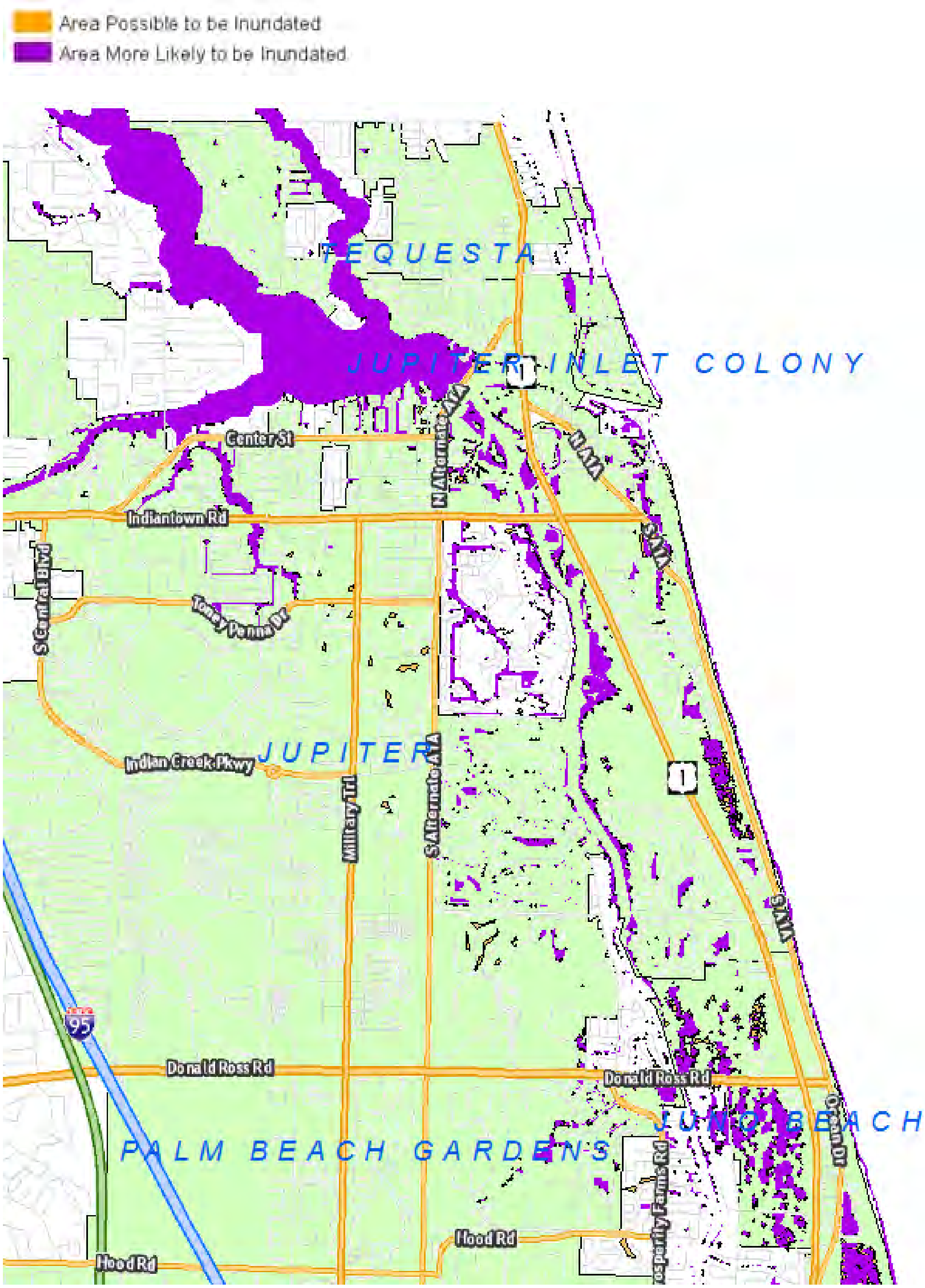
2-Foot Sea Level Rise in Palm Beach County - Boca Raton Area



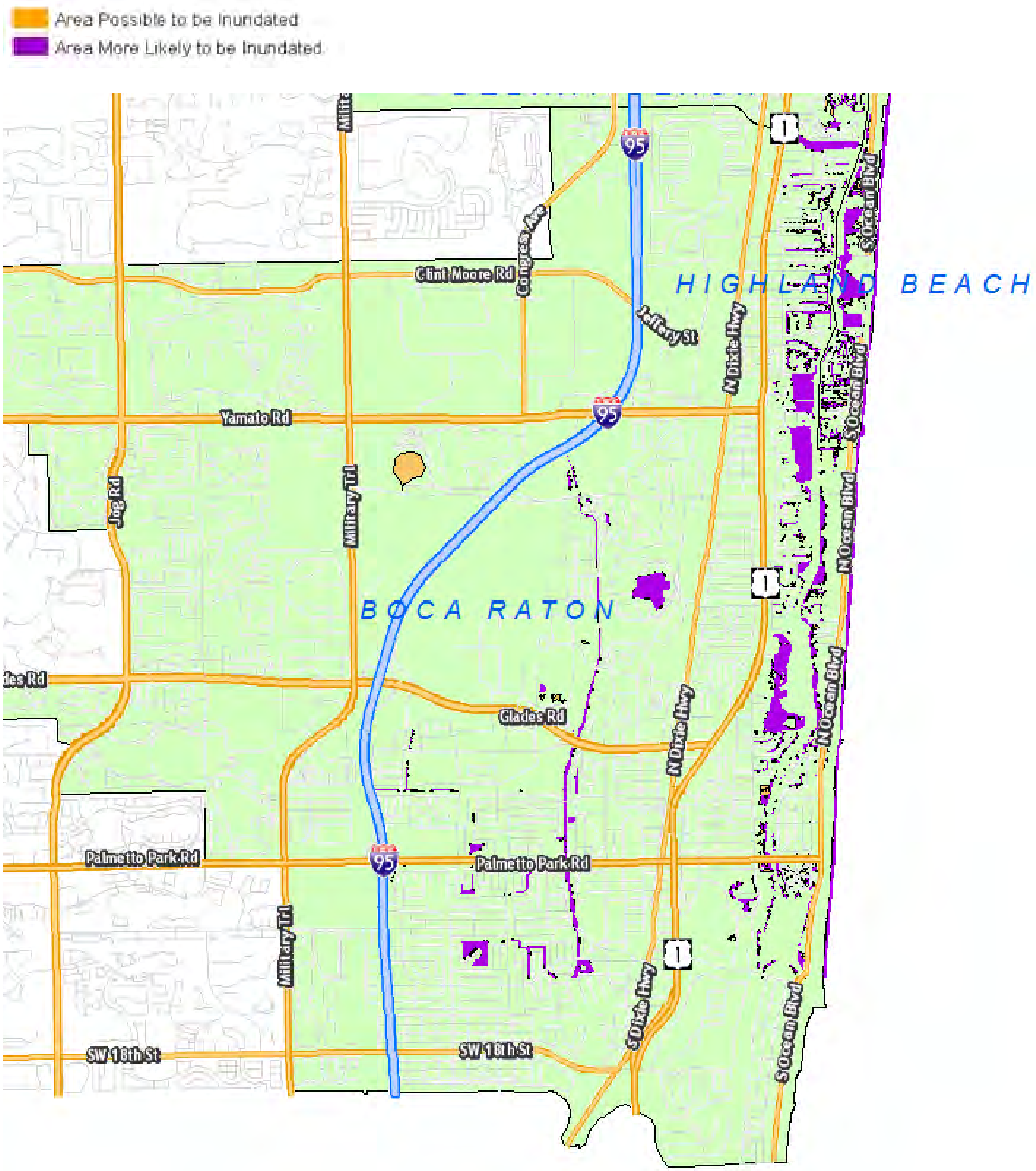
2-Foot Sea Level Rise in Palm Beach County - Boynton Beach Area



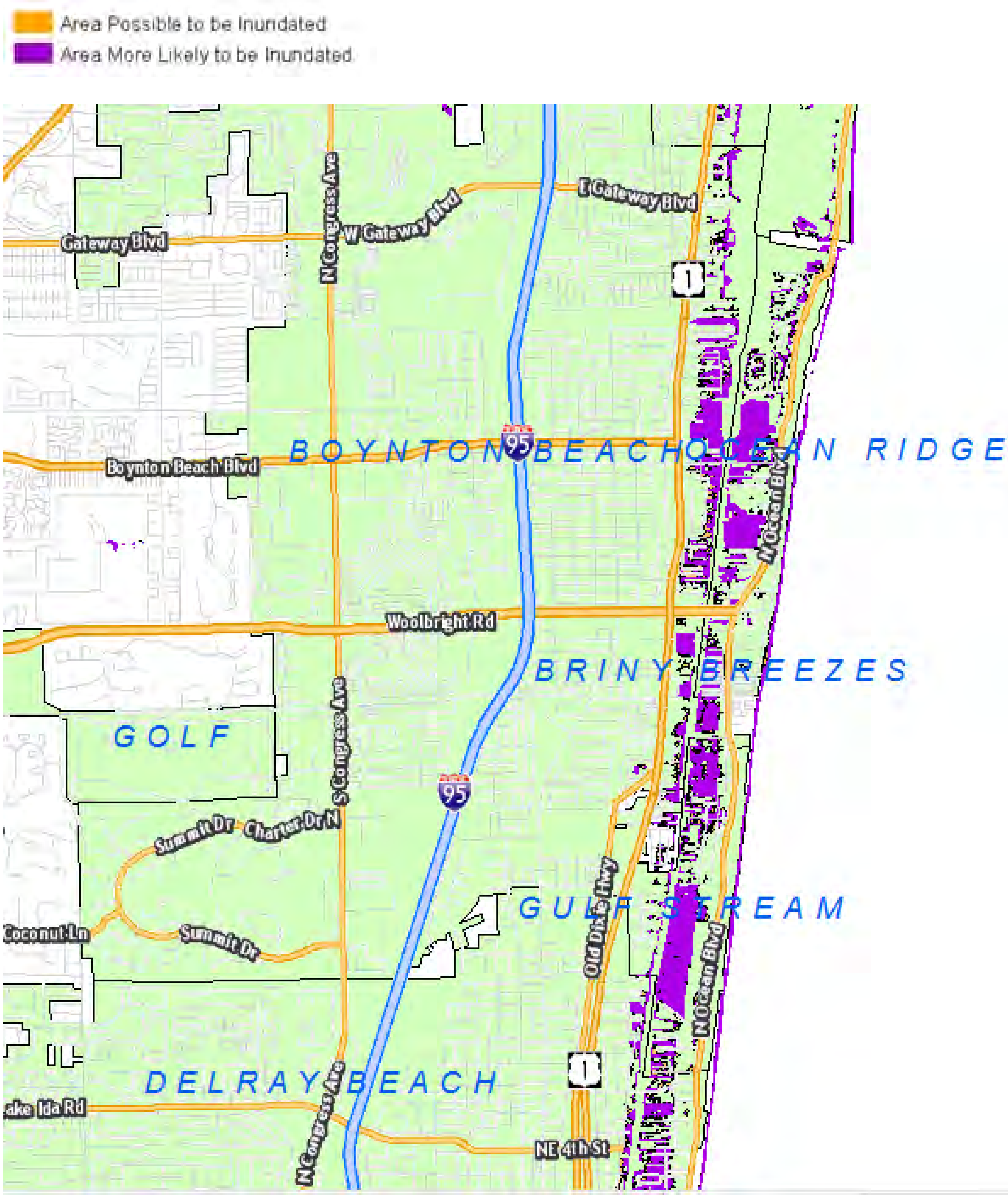
2-Foot Sea Level Rise in Palm Beach County - Jupiter Area



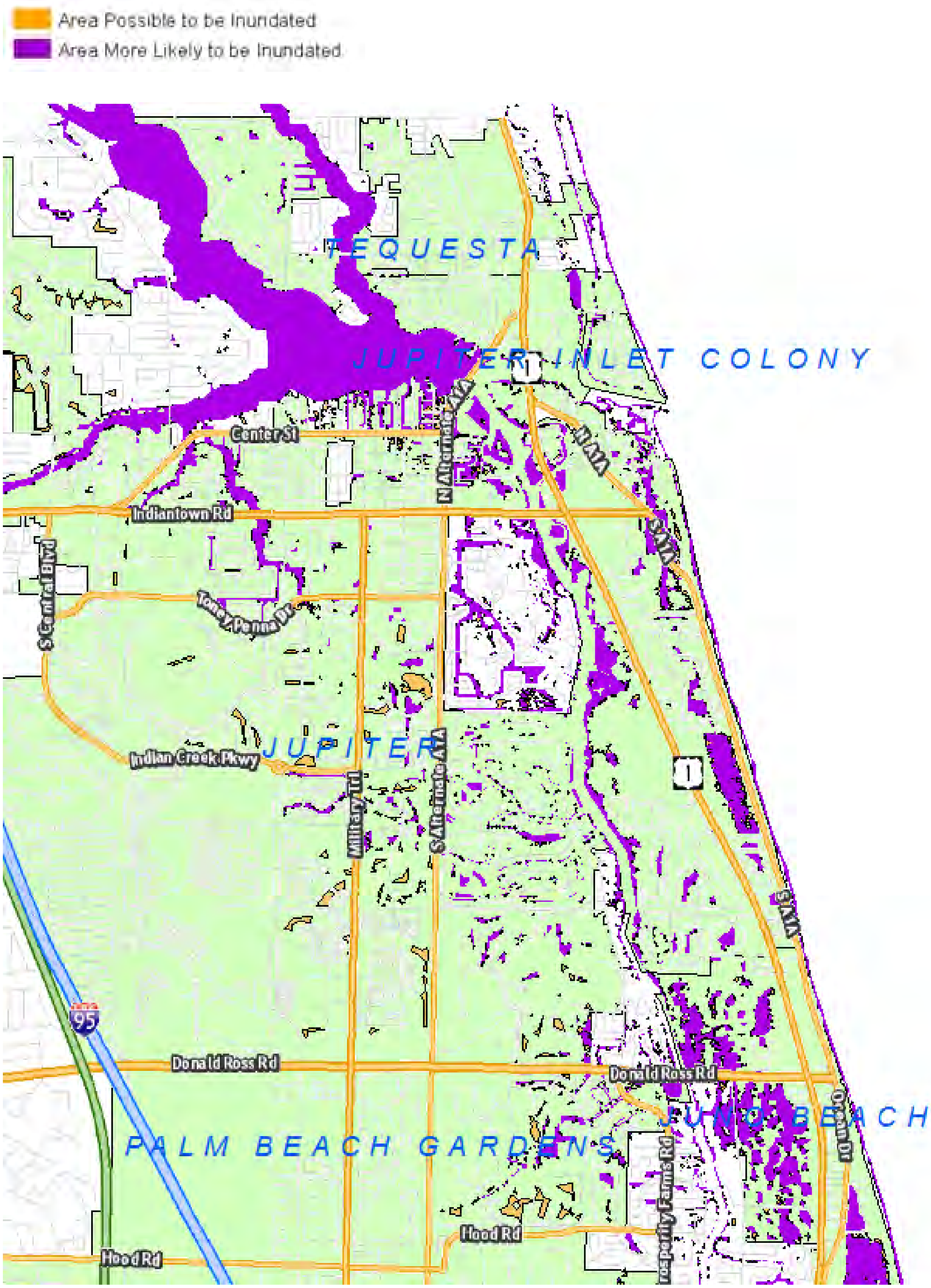
3-Foot Sea Level Rise in Palm Beach County - Boca Raton Area



3-Foot Sea Level Rise in Palm Beach County - Boynton Beach Area



3-Foot Sea Level Rise in Palm Beach County - Jupiter Area



Analysis of Physical Features

Ports and Airports

One of the areas determined by the group to be critical was our ports and airports. There is no inundation at 1, 2 or 3 foot sea level rise scenarios.

Water/Wastewater Treatment Plants

The thirty-eight (38) facilities associated with Wastewater Treatment Plants in Palm Beach County were not affected even at the 3-foot level. Water treatment plants were left out intentionally from the analysis due to Homeland Security concerns about publicizing their locations. There is no inundation at 1, 2 or 3 foot sea level rise scenarios.

Power Plants

There is no inundation of FPL Riviera Beach, Lake Worth Utilities, Western County FPL (20 mile bend), Okeelanta Cogeneration plant at 1, 2 or 3 foot sea level rise scenarios.

Emergency Shelters

There is no inundation at 1, 2 or 3 foot levels

Railroads

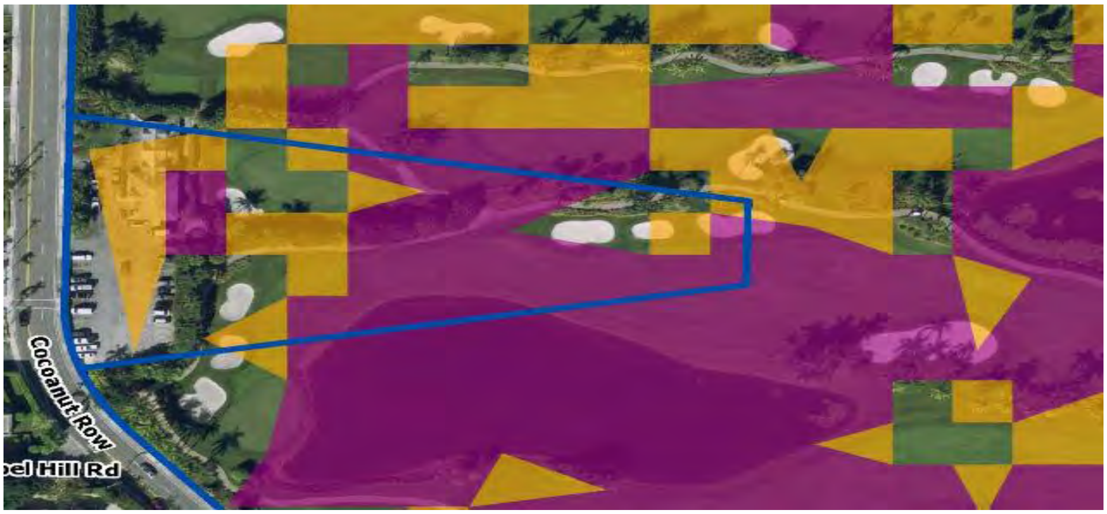
No inundation at the 1 and 2 foot levels.

3 foot inundation:

Owner Name (Three foot, feet)	More Likely (feet of track)	Possible (feet)	Total Inundation	Percent Inundation
CSX	0.0	0.0	0.0	0.00 %
FEC	720.0’	0.0	720.0’	0.05 %

Landfills

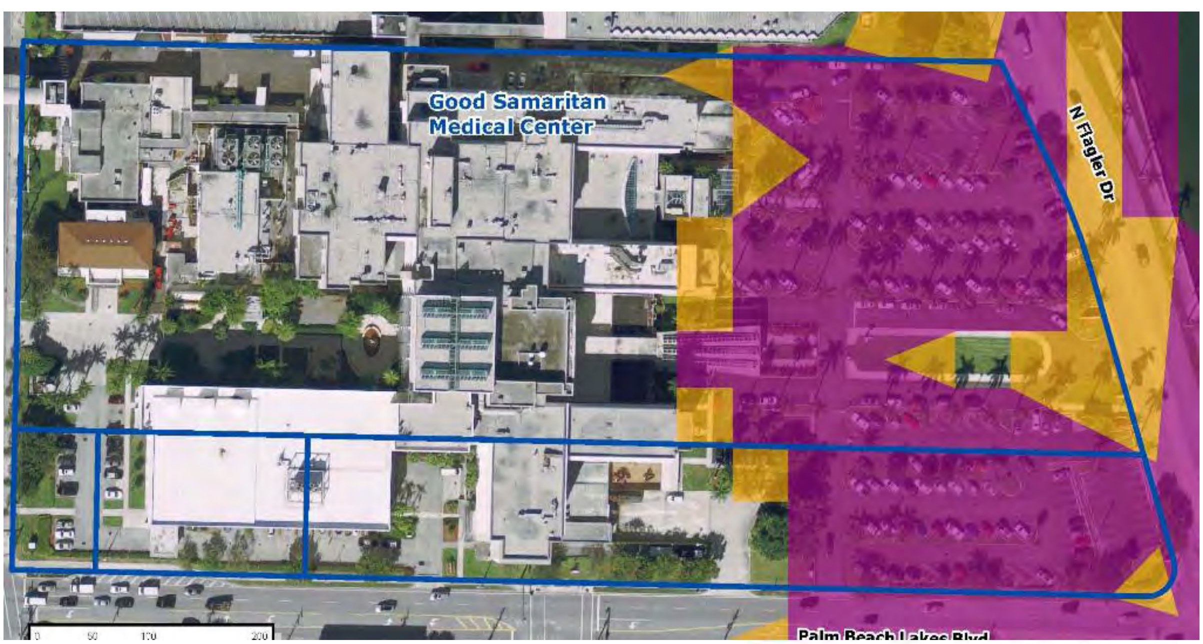
Large landfills were reviewed and little inundation was noted except for a trash transfer station. Inundations for all levels of Sea Level Rise were primarily in retention or natural areas surrounding the North County Landfill, Lantana Rd/441 & Dyer Dump. The trash transfer station show below is the only site that shows any inundation at the 3 foot level.



Area Possible to be Inundated
Area More Likely to be Inundated

Hospitals

Fourteen hospitals were reviewed. Only one hospital showed any flooding at 3 foot sea level rise (Good Samaritan). The core infrastructure and buildings do not appear to be affected.



Area Possible to be Inundated
Area More Likely to be Inundated

Schools

A total of 187 schools were reviewed. No schools are impacted at the one or two foot sea level rise scenarios. At a 3 foot sea level rise, only one building, Palm Beach Elementary School, appears be in jeopardy.

Emergency Shelters

The seventeen (17) emergency shelters in Palm Beach County are located in schools. There is no inundation risk at 1-foot, negligible risk at 2-foot and some inundation of open spaces along the edges of school properties in the water retention areas. No emergency shelter structures are affected at any of the sea level rise scenarios.

Evacuation Routes

Evacuation Routes to and from the barrier islands are vulnerable due to bridges being inaccessible from local roadway inundation.

Marinas

All marina facilities are located on or next to water features, east of all salinity control structures to give easy access to the ocean. The assumption is that all will be affected in some way, although the extent is indeterminable with this current analysis. It is assumed that those docks with fixed infrastructure will be inundated while floating docks will rise with sea levels.

Results of Analysis

Geographic analysis was performed on four items for Palm Beach County:

- Taxable value of property
- Miles of road by Florida Department of Transportation category
- Future Land Use
- Habitat / Land Use Land Cover

Taxable Value of Property

The analysis of property values was done using an aggregated parcel methodology in which a 150-foot grid was created and then overlaid on the parcel features to aggregate property values within each grid cell. In the table below, the low end of the range represents the areas more likely to be below the mean high-high water levels with 1-, 2- or 3-foot seal level rise. The high end of the range represents property with at least a possible chance to be inundated in these scenarios.

Level of Inundation	Range of Taxable Value
One Foot	$396,618,089.00 - $556,659,447.00
Two Foot	$1,251,877,561.00 - $1,921,207,483.00
Three Foot	$3,559,471,158.00 - $4,495,511,757.00

Roads by FDOT Category

All Roadways for Palm Beach County are summarized by Functional Class in miles. High volume categories include sections of roadway where bridges were removed from the LiDAR data and represented bare earth rather than the actual roadways.

1-Foot Sea Level Rise – 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage (Miles)
1 – high volume, maximum speed	0	99
2 – high speed, channels traffic to FC1	0	288
3 – high speed, lower mobility, connects to FC2	0	539
4 – moderate speed, through neighborhoods	0	749
5 – low volume, i.e. access roads, parking lanes	0	6,166

2-Foot Sea Level Rise – 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage (Miles)
1 – high volume, maximum speed	0	99
2 – high speed, channels traffic to FC1	0	288
3 – high speed, lower mobility, connects to FC2	0	539
4 – moderate speed, through neighborhoods	2	749
5 – low volume, i.e. access roads, parking lanes…	13	6,166

3- Foot Sea Level Rise – 50% Percent Inundation = Whole Segment Affected

Functional Class	Total Inundation (Miles)	Total Coverage (Miles)
1 – high volume, maximum speed	0	99
2 – high speed, channels traffic to FC1	0	288
3 – high speed, lower mobility, connects to FC2	0	539
4 – moderate speed, through neighborhoods	8	749
5 – low volume, i.e. access roads, parking lanes…	41	6,166

Acres of Future Land Use

The three tables on this page represent numbers of acres that could be impacted with some flooding for the types of land uses shown for each of the three sea level rise scenarios. Coverage of Future Land Use was provided by Planning Zoning and Building and was updated on May 11, 2011 and covers the unincorporated area of Palm Beach County. Data was summarized by Land Use type and probability and reported in acres.

1-foot Sea Level Rise:

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
HIGH RESIDENTIAL, 12 UNITS PER ACRE	0.36	0	0.36	4,192.49	0
LOW RESIDENTIAL, 1 UNIT PER ACRE	282.48	1.01	283.49	10,777.6	2.63
LOW RESIDENTIAL, 2 UNITS PER ACRE	190.93	0	190.93	16,192.7	1.17
LOW RESIDENTIAL, 3 UNITS PER ACRE	28.07	53.34	81.42	20,206.83	0.4
MEDIUM RESIDENTIAL, 5 UNITS PER ACRE	4.4	0.64	5.05	23,681.19	0.02
PARK	12.38	5.15	17.53	5,810.73	0.3
SPOIL (Peanut Island)	11.22	0	11.22	42.82	26.2
Total	529.84	60.14	590	80,904.36	0.72

2-foot Sea Level Rise:

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
HIGH RESIDENTIAL, 12 UNITS PER ACRE	0.49	0	0.49	4,192.49	0.01
LOW RESIDENTIAL, 1 UNIT PER ACRE	290.6	1.84	292.44	10,777.6	2.71
LOW RESIDENTIAL, 2 UNITS PER ACRE	218.97	10.51	229.48	16,192.7	1.41
LOW RESIDENTIAL, 3 UNITS PER ACRE	102.01	13.58	115.59	20,206.83	0.57
MEDIUM RESIDENTIAL, 5 UNITS PER ACRE	7.74	5.89	13.62	23,681.19	0.05
PARK	22.76	2.56	25.32	5,810.73	0.43
SPOIL (Peanut Island)	11.73	0	11.73	42.82	27.39
Total	654.3	34.38	688.67	80,904.36	0.85

3-foot Sea Level Rise:

Land Use	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
HIGH RESIDENTIAL, 12 UNITS PER ACRE	4.58	0.27	4.49	4,192.49	0.1
INDUSTRIAL	2.5	0	2.5	13,867.02	0.01
LOW RESIDENTIAL, 1 UNIT PER ACRE	300.06	6.03	306.1	10,777.6	2.84
LOW RESIDENTIAL, 2 UNITS PER ACRE	257.77	26.56	284.37	16,192.7	1.75
LOW RESIDENTIAL, 3 UNITS PER ACRE	139.13	22.21	161.35	20,206.83	0.79
MEDIUM RESIDENTIAL, 5 UNITS PER ACRE	55.22	5.35	60.57	23,681.19	0.25
PARK	30.47	5.84	36.31	5,810.73	0.62
SPOIL (Peanut Island)	12.77	0	12.77	42.82	29.82
Total	802.5	66.26	868.46	94,771.38	0.91

Acres of Habitat Type / Land Use Land Cover

The following tables summarize the number of acres of habitat type listed that could be impacted with some flooding for each of the three sea level rise scenarios. Spatial data was provided by the South Florida Water Management District and is dated 2009 V 0.3.0. The data is reported in acres.

1-foot Sea Level Rise:

Land Use Type	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
Australian Pine	1.17	0	1.17	393.84	0.29
Channelized Waterways - Canals*	13.2	29.37	42.57	14,913.41	0.28
Coastal Shrub	1.17	0	1.17	745.41	0.15
Golf Course	45.07	0	45.07	22,283.82	0.2
Mangrove Swamp	278.85	13.3	292.15	583.40	50.07
Mixed Shrubs	5.56	2.17	7.73	42,953.57	0.01
Mixed Wetland Hardwoods	13.96	0	13.96	4,097.98	0.34
Natural River - Stream - Waterway*	950.89	0	950.89	9,271.11	10.25
Parks and Zoos	2.32	0	2.32	6,202.88	0.03
Pine Flatwoods	1.95	0	1.95	51,933.25	0
Reservoirs	73.12	26.08	99.2	28,818.39	0.34
Saltwater Marshes / Halophytic Herbaceous Prairie	11.87	0	11.87	21.04	56.41
Saltwater Ponds	2.4	0	2.4	2.49	96.38
Upland Hardwood Forests	3.91	0	3.91	1,115.26	0.35
Upland Mixed Coniferous / Hardwood	4.52	0	4.52	3,500.98	0.12
Upland Shrub and Brush land	0.26	0	0.26	3,388.66	0
TOTAL	1,410.22	70.92	1,481.14	190,225.49	0.77

* embankments

2-foot Sea Level Rise:

Land Use Type	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
Australian Pine	2.51	0	2.51	393.84	0.63
Channelized Waterways - Canals*	46.68	0	46.68	14,913.41	0.31
Coastal Shrub	16.74	0	16.74	745.41	2.24
Freshwater Marshes / Graminoid Prairie - Marsh	0.92	0.42	1.34	166,842.68	0
Golf Course	151.77	0	151.77	22,283.82	0.68
Mangrove Swamp	371.84	0	371.84	583.4	63.73
Mixed Shrubs	28.77	0	28.77	4,2953.57	0.06
Mixed Wetland Hardwoods	25.11	0	25.11	4097.98	0.61
Multiple Dwelling Units - Low Rise	20.54	0	20.54	24,136.14	0.08
Natural River - Stream - Waterway*	972.2	0	972.2	9,271.11	10.48
Parks and Zoos	7.94	1.96	9.9	6,202.88	0.15
Pine Flatwoods	3.15	0	3.15	51,933.25	0
Reservoirs	137.79	62.76	200.55	28,818.39	0.69
Saltwater Marshes / Halophytic Herbaceous Prairie	16.62	0	16.62	21.04	78.99
Saltwater Ponds	2.48	0	2.48	2.49	99.59
Upland Hardwood Forests	5.69	0	5.69	1,115.26	0.51
Upland Mixed Coniferous / Hardwood	10.15	0	10.15	3,500.98	0.28
Upland Shrub and Brushland	4.23	0	4.23	3,388.66	0.12
Wet Melaleuca	12.78	0	12.78	861.42	1.48
Wetland Forested Mixed	29.6	0	29.6	3,473.97	0.85
TOTAL	1,867.51	65.14	1,932.65	385,539.7	0.5

* embankments

3-foot Sea Level Rise:

Land Use Type	More Likely (acres)	Possible (acres)	Total Inundation (acres)	Total Coverage (acres)	Percent Inundation
Australian Pine	3.15	0	3.15	393.84	0.79
Channelized Waterways - Canals*	65.14	0.3	65.44	14,913.41	0.43
Coastal Shrub	19.24	0	19.24	745.41	2.58
Commercial and Services	55.8	0	55.8	18,379.96	0.3
Disturbed Land	2.85	0	2.85	4,697.63	0.06
Educational Facilities	4.39	0	4.39	6,344.25	0.06
Fixed Single Family Units	114.35	0	114.35	88,060.87	0.12
Freshwater Marshes / Graminoid Prairie - Marsh	2.31	11.81	14.12	166,842.68	0
Golf Course	253.49	0	253.49	22,283.82	1.13
Institutional	0	0.68	0.68	3,351.63	0.02
Mangrove Swamp	402	0	402	583.4	68.9
Melaleuca	1.97	0	1.97	1,305.86	0.15
Mixed Shrubs	69.09	0	69.09	42,953.57	0.16
Mixed Units - Fixed and Mobile Home Units	2.45	0	2.45	100.83	2.42
Mixed Wetland Hardwoods	34.65	0	34.65	4,097.98	0.84
Mobile Home Units	15.77	0	15.77	3,338.3	0.47
Multiple Dwelling Units - High Rise	30.81	0	30.81	5,674.32	0.54
Multiple Dwelling Units - Low Rise	50.17	1.78	51.95	24,136.14	0.21
Natural River - Stream - Waterway*	976.77	0	976.77	9,271.11	10.53
Open Land	2.66	0	2.66	3,892.44	0.06
Parks and Zoos	68.42	2.43	70.85	6,202.88	1.14
Pine Flatwoods	29.26	0	29.26	51,933.25	0.05
Reservoirs*	235.75	100.22	335.97	28,818.39	1.16
Saltwater Marshes / Halophytic Herbaceous Prairie	17.96	0	17.96	21.04	85.36
Saltwater Ponds	2.48	0	2.48	2.49	99.59
Upland Hardwood Forests	28.67	0	28.67	1,115.26	2.57
Upland Mixed Coniferous / Hardwood	13.87	0	13.87	3,500.98	0.39
Upland Shrub and Brushland	8.29	0	8.29	3,388.66	0.24
Wet Melaleuca	17.95	0	17.95	861.42	2.08
Wetland Forested Mixed	91.91	0	91.91	3,473.97	2.64
TOTAL	2,621.62	117.22	2,738.84	520,685.79	0.52

* embankments

Appendix A - Southeast Florida Climate Change Compact -Regional Inundation Mapping and Vulnerability Analysis Work Group

Core Work Group Participants

Nancy Gassman, PhD, Facilitator, Broward County Environmental Protection and Growth Mgmt. Dept.

Diana Umpierre, South Florida Water Management District

Jenifer Barnes, South Florida Water Mgmt. District Hydrologic & Environmental Systems Modeling

Bryan Davisson, Monroe County Growth Management

Wayne Whitley, Monroe County Growth Management

Mairim Avila, Miami-Dade Enterprise Technology Services Department

Marina Blanco-Pape, Miami-Dade County Dept. of Environmental Resources Management

Lisbeth Britt, Miami-Dade County Dept. of Environmental Resources Management

Marcia Steelman, Miami-Dade County Dept. of Environmental Resources Management

Donald Burgess, Broward County Environmental Protection and Growth Management Department

Nina Goetsch, Broward County Environmental Protection and Growth Management Department

Victoria Morrow, Broward County Environmental Protection and Growth Management Department

Erin Musgrave, Broward County Environmental Protection and Growth Management Department

Beth Norton, Palm Beach County

Kelly Ratchinsky, Palm Beach County

Other Participants

Rod Braun, South Florida Water Management. District

Jayantha Obeysekera, PhD, South Florida Water Management District

Dorothy F. Payne, U. S. Geological Survey Florida Integrated Science Center

Kathy Freeman, The Nature Conservancy

Alison Higgins, The Nature Conservancy

Richard Butgereit, Florida Division of Emergency Management

Manny Cela, South Florida Regional Planning Council

Nichole L. Hefty, Miami-Dade Department of Environmental Resources Management

Virginia Walsh, Miami-Dade Water and Sewer Department

Dan Vogler, United States Army Corps of Engineers

Bonnie Finneran, Palm Beach County Department of Environmental Resources Management

John Reiser, Palm Beach County Department of Environmental Resources Management

Academic Interests

Peter Harlem, Florida International University

Keqi Zhang, PhD, Department of Environmental Studies, Florida International University,

Zhixiao Xie, PhD, Geosciences Department, Florida Atlantic University

Diana Mitsova, PhD, School of Urban & Regional Planning, Florida Atlantic University

NOAA Support

Chrissa Waite (nee Stroh), NOAA Coastal Services Center, GIS Integration & Development

Keil Schmid, NOAA Coastal Services Center, Coastal Remote Sensing Program

Brian C. Hadley, PhD, NOAA Coastal Services Center, Coastal Remote Sensing Program

Douglas C. Marcy, NOAA Coastal Services Center, GIS Integration and Development Program

Jerry Hovis, Center for Operational Oceanographic Products and Services, Tidal Datums & Hydrographic Planning

David Newcomer, NOAA/NOS/NGS

Appendix B - Southeast Florida Climate Change Compact -Regional Inundation Mapping Methodology

Regional Methods for Mapping Sea Level Rise Inundation Vulnerability in Southeast Florida

Prepared By:

Diana Umpierre, GISP
Senior Geographer
South Florida Water Management District (SFWMD)

In Coordination With:

Southeast Florida Regional Climate Change Compact
Inundation Mapping & Vulnerability Assessment
Work Group

With Significant Support From:

NOAA's National Ocean Service (NOS), in particular
Coastal Services Center and CO-OPS

March 2012

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March 2012

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Appendices

Cover Photos: *Coastal flooding photos were taken during higher than average high tide events. Numbered from top: Photos 1, 4, 6 and 7 were taken October 2010 by Miami-Dade DERM; photos 2 and 5 were taken September 2009 by The Nature Conservancy and Florida Keys GLEE; and photos 3 and 8 were taken October 2010 by Paul Krashefski (Broward Co Parks & Recreation).*

1.0 INTRODUCTION

This report describes the elevation-related datasets and mapping methods used by the Southeast Florida Regional Climate Change Compact ("*Compact*") Counties and the South Florida Water Management District (SFWMD) to develop regional sea level rise (SLR) inundation vulnerability surfaces. These were generated for 1, 2 and 3-ft SLR scenarios and used by each of the Compact Counties to estimate their specific vulnerability to SLR inundation and to provide valuable information on what concerns to address in the Compact's Regional Climate Change Action Plan.

Mapping the regional vulnerability to SLR inundation helps in identifying areas at potential risk and in planning for climate-resilient communities. In early 2010, the Compact Steering Committee formed an ad-hoc working group to develop and implement regionally consistent methods for mapping and analyzing regional SLR inundation vulnerability. This group, referred to as the *Inundation Mapping and Vulnerability Assessment Work Group* ("Work Group"), was composed of experienced Geographic Information System (GIS) practitioners and scientists representing the Compact Counties and the SFWMD, as well as local universities, non-profit organizations and other government agencies. They were assisted by experts from NOAA's Coastal Services Center (CSC) and Center for Operational Oceanographic Products and Services (CO-OPS) who provided key guidance, recommendations and assistance during development of regionally-consistent datasets and approaches for mapping SLR vulnerability and associated uncertainty.

The following sections describe the datasets and methods used to generate the estimated regional SLR inundation vulnerability surfaces. Among others, they include a discussion of the following key components:

- topographic digital elevation models (DEMs) using the 2007-08 LiDAR data from the Florida Division of Emergency Management (FDEM)
- NOAA's VDatum transformation grids and the initial Mean Higher High Water (MHHW) tidal surface extrapolated inland by CSC
- SLR vulnerability probability surfaces developed from Z-scores and documented elevation uncertainty

2.0 DIGITAL ELEVATION MODELS (DEMs)

2.1 Source Data Description

A key component to inundation mapping is the selection of topographic data sources to develop terrain digital elevation models (DEMs). The Compact inventoried available sources and evaluated their suitability for regional analysis. Important factors in their evaluation included: documented specifications, accuracy/ quality, regional availability and flight dates. After this review, the Compact agreed that the best available topographic sources were the following:

- 2007-08 Florida Division of Emergency Management (FDEM) LiDAR data
- USGS High Accuracy Elevation Dataset (HAED)

FDEM LiDAR

The FDEM LiDAR dataset covered most of the coastal urban SE Florida region and was selected by the Compact for their regional SLR vulnerability analysis. The data was collected via airborne LiDAR, which is a remote sensing technique that uses light pulses emitted from aircraft to measure elevations on the land surface. It produces densely-spaced elevation points (point clouds) that can cover large geographic areas relative quickly and with reasonable good accuracies. (Schmid K, et. al. 2008). The following are key characteristics and specifications of the FDEM LiDAR data collected in the SE FL region. (FDEM 2007).

- Specifications were the same for all areas flown and intended to support storm surge inundation modeling associated with hurricane evacuation planning.
- LiDAR flights were conducted between 2007 and 2008.
- Maximum point spacing in unobscured areas: 4 feet.
- LiDAR bare earth point clouds were delivered in a statewide tiling system of 5000-ft by 5000-ft tiles.
- Breaklines were extracted from LiDAR to improve hydro-enforcement.
- The coordinate system in SE FL was Florida State Plane, East Zone, NAVD 88, feet (GEOID03).
- Accuracy specifications were based on FEMA guidelines and tested with independent survey points.
  - Horizontal: <= 3.8 ft at 95% confidence level
  - Vertical: For open terrain (bare earth): <= .60 ft at 95% confidence level (RMSEz <= .30 ft)
    For other land covers: <= 1.19 ft at 95% confidence level (RMSEz <= .61 ft)
- An independent vendor conducted Quality Assurance (QA) review of vendor deliverables.

Figure 1 depicts the overall FDEM project extent in South Florida, as well as the specific delivery blocks for which SFWMD generated SLR inundation vulnerability data layers.

- Palm Beach East (Block 7)
- Broward (Block 6)
- Miami-Dade (Blocks 3, 4 and 5)
- Florida Keys (Blocks 1 and 2)
- Inland Monroe (Blocks 9 and 10) – *Not Used by the Compact Counties*

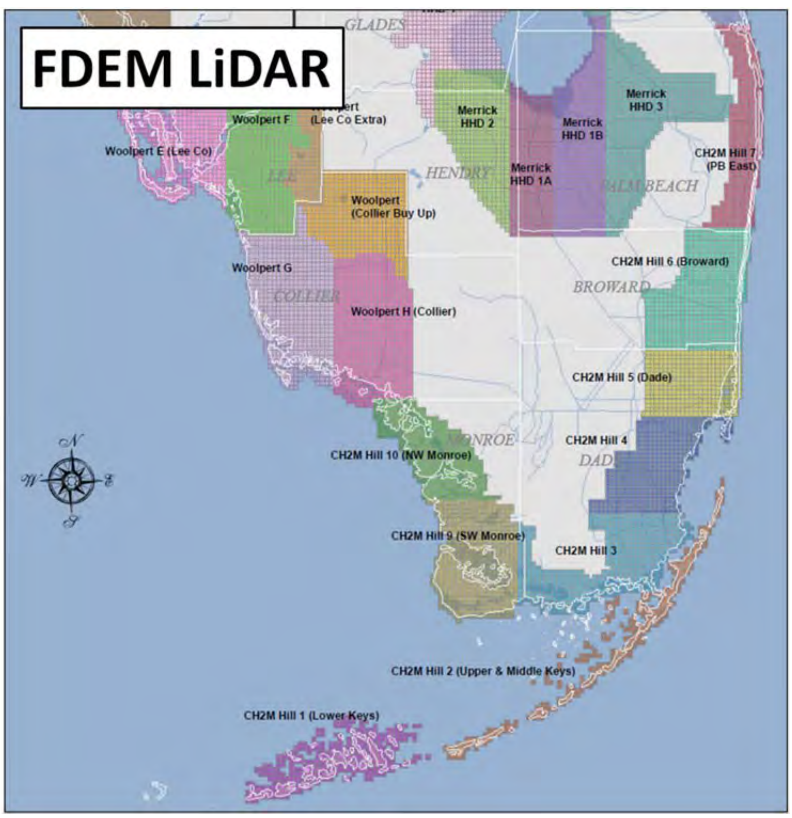


Figure 1 – Geographic Extent of the 2007-08 FDEM LiDAR Dataset within South Florida.

USGS HAED

The USGS HAED dataset was collected between 1995 and 2007 to support Everglades restoration efforts. The majority of the readings were collected from helicopters using an Airborne Height Finder (AHF), which is specialized equipment that drops a plumb-bob and uses a GPS to capture location coordinates and vertical elevation data. A smaller set of readings were collected by deploying surveyors on airboats. Readings were generally taken every 400 meters (~ 1312 ft). Unlike LiDAR, the USGS AHF system was reported as physically able to penetrate the heavy vegetation and murky waters that are common in the Everglades. USGS stated that the AHF system met their 15 cm (~ 0.5 ft) vertical accuracy specification, based on readings at several NGS 1st-order benchmarks. (Jones & Price 2007; USGS 2003). Vertical accuracy was not reported by land cover type.

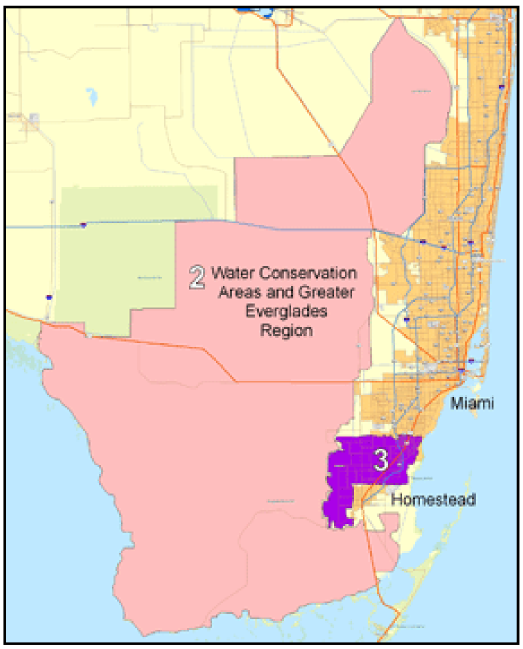


Figure 2 – Geographic Extent of USGS HAED
(Map Credit: USGS, retrieved from http://sofia.usgs.gov/exchange/desmond/desmondelev.html)

Although the USGS HAED was deemed the best available elevation data for the Everglades region, it was not possible to merge this dataset with the FDEM LiDAR dataset due to time and resource constraints. SFWMD did conduct a preliminary comparison of the USGS HAED and the FDEM LiDAR elevation data where these overlapped within inland Monroe to determine the feasibility of developing a merged DEM for all of South Florida. The assessment revealed that although the LiDAR data was commonly higher than the USGS data, the pattern was not consistent. Without field verification, the elevation differences would be too complex to resolve and to determine the proper adjustment methodology and the resulting vertical accuracy of such merged dataset. In addition to this issue, the Compact expressed concern that because the spacing of the readings was large (~ 1312 ft), certain features important to SLR impact analysis would be absent (e.g. canals, levees and elevated land associated with roads).

2.2 DEM Processing

SFWMD generated DEMs from the FDEM LiDAR data at various cell size resolutions. The Compact selected the 50-ft DEMs for their SLR vulnerability assessment. This section describes the processing steps and characteristics of the output DEMs.

SFWMD's DEM processing steps included creating Triangular Irregular Networks (TINs) from bare earth masspoints and breaklines. Five (5)-ft and 10-ft cell size DEMs were generated directly from the TINs using natural neighbor interpolation. Natural neighbor is an interpolation method available in ESRI's ArcGIS tools to develop DEMs from LiDAR data. It was also reported as the method selected by other agencies that have independently generated their own DEMs from the FDEM LiDAR data, specifically Broward and Miami-Dade counties, the United States Army Corps of Engineers (USACE) and Jones Edmunds, an FDEM consultant (Gassman, August 2010). Larger cell size DEMs (25, 50 and 100-ft) were generated from the mean of input 5-ft cells. The following were the main steps automated by SFWMD with custom ArcGIS python scripts and ArcCatalog commands.

- Process each project tile with a 500-ft buffer
  - Produce a TIN /Terrain using bare earth masspoints (LAS class 2) and breaklines (as noted in Table 1)
  - Generate 5-ft and 10-ft DEM rasters for each tile using Natural Neighbor interpolation
  - Run custom adjustment scripts, if needed (e.g. to flatten water bodies or fill tile corner voids)
- Combine tile DEMs (5-ft, 10-ft) into larger, typically county-size, DEMs
- Generate 25, 50 and 100-ft rasters using the mean of 5-ft input cells

Table 1 - Breaklines Types during TIN/Terrain Generation

Feature Class	Type
Masspoints (LAS Class2)	Masspoint
HydrographicFeature	HardLine
Roadbreakline	HardLine
Island	HardLine
SoftFeature	SoftLine
Waterbody	HardReplace
CoastalShoreline	HardErase

SFWMD processing also included a DEM Quality Assurance (QA) review. The primary objective of the DEM QA review was to identify and fix DEM artifacts introduced during processing (i.e. those *not* inherited from the source vendor data). The secondary objective was to get a general sense of qualitative characteristics of the data and communicate these to DEM users via the metadata. More detailed processing and QA information can be found in the DEM published metadata, accessible at SFWMD's GIS Data Catalog website (http://www.sfwmd.gov/gis, using keywords: FDEM LiDAR).

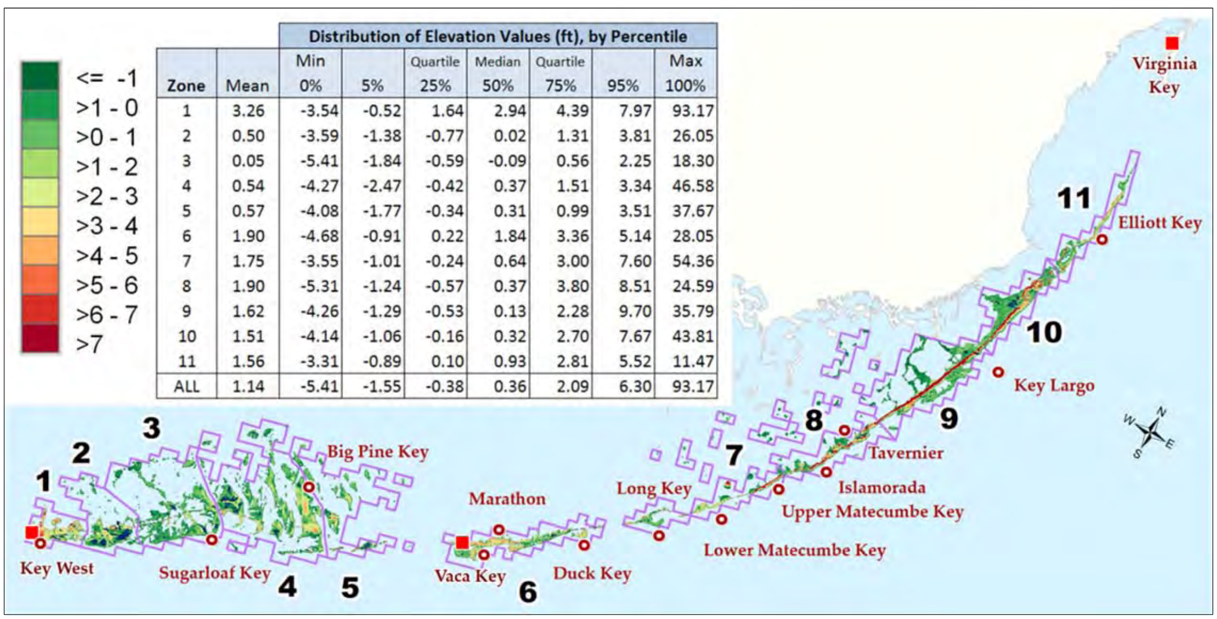
SFWMD's DEMs were also reviewed by NOAA CSC and USGS. NOAA has used these DEMs to help in the development of their web-based SLR viewer (http://www.csc.noaa.gov/slr). USGS has integrated them into the USGS National Elevation Dataset (http://ned.usgs.gov).

As with any elevation data collected via remote sensing technologies, the DEMs generated from the FDEM LiDAR data still have some artifacts that cannot be removed without considerable effort and expense. In fact, federal guidelines agree that it is *not* cost effective to attempt collecting LiDAR data that is 100% free and clean of artifacts. (FEMA, April 2003, p. A-42; NDEP, May 2004, p. 39-40)

Remaining artifacts often include a small number of buildings and some tree canopy. The collection of LiDAR data within inland coastal Monroe County and non-urban areas of southern and western Miami-Dade was particularly challenging because of the extent of mangrove forest and wetlands in those regions. Elevations on mangrove areas could be biased high because they may represent the top of mangrove roots and not the ground surface below the water and the thick, entangled network of mangrove roots that LiDAR light beams cannot easily penetrate. DEMs may also exhibit some banding that commonly aligns with flight paths. Some areas in the DEM could benefit from additional hydro-conditioning and hydro-enforcement to improve surface water flow patterns and hydrologic connections. Because Florida's topography is generally relatively flat, small errors in elevation values are challenging to address without considerable revision and field verification of breakline values.

Despite these known issues, the FDEM LiDAR data is by far one of the best documented regional topographic datasets in urban coastal Florida and was collected using comprehensive baseline specifications. For these reasons, the Compact counties considered it the best available topographic dataset for coastal SE Florida and was utilized it to conduct their SLR vulnerability assessments.

For illustrative purposes, the figures below are included to demonstrate the distribution elevation values in South Florida, based on the SFWMD DEMs that were generated from the FDEM LiDAR data. All elevations are in feet (NAVD88).



		Distribution of Elevation Values (ft), by Percentile						
Zone	Mean	Min 0%	5%	Quartile 25%	Median 50%	Quartile 75%	95%	Max 100%
1	3.26	-3.54	-0.52	1.64	2.94	4.39	7.97	93.17
2	0.50	-3.59	-1.38	-0.77	0.02	1.31	3.81	26.05
3	0.05	-5.41	-1.84	-0.59	-0.09	0.56	2.25	18.30
4	0.54	-4.27	-2.47	-0.42	0.37	1.51	3.34	46.58
5	0.57	-4.08	-1.77	-0.34	0.31	0.99	3.51	37.67
6	1.90	-4.68	-0.91	0.22	1.84	3.36	5.14	28.05
7	1.75	-3.55	-1.01	-0.24	0.64	3.00	7.60	54.36
8	1.90	-5.31	-1.24	-0.57	0.37	3.80	8.51	24.59
9	1.62	-4.26	-1.29	-0.53	0.13	2.28	9.70	35.79
10	1.51	-4.14	-1.06	-0.16	0.32	2.70	7.67	43.81
11	1.56	-3.31	-0.89	0.10	0.93	2.81	5.52	11.47
ALL	1.14	-5.41	-1.55	-0.38	0.36	2.09	6.30	93.17

Figure 3 - Elevation Distribution in the Florida Keys (NAVD88, ft)
The distribution of elevation values was generated using the 25-ft DEM generated from the FDEM LiDAR data. Calculated data is courtesy of Tim Liebermann (SFWMD).

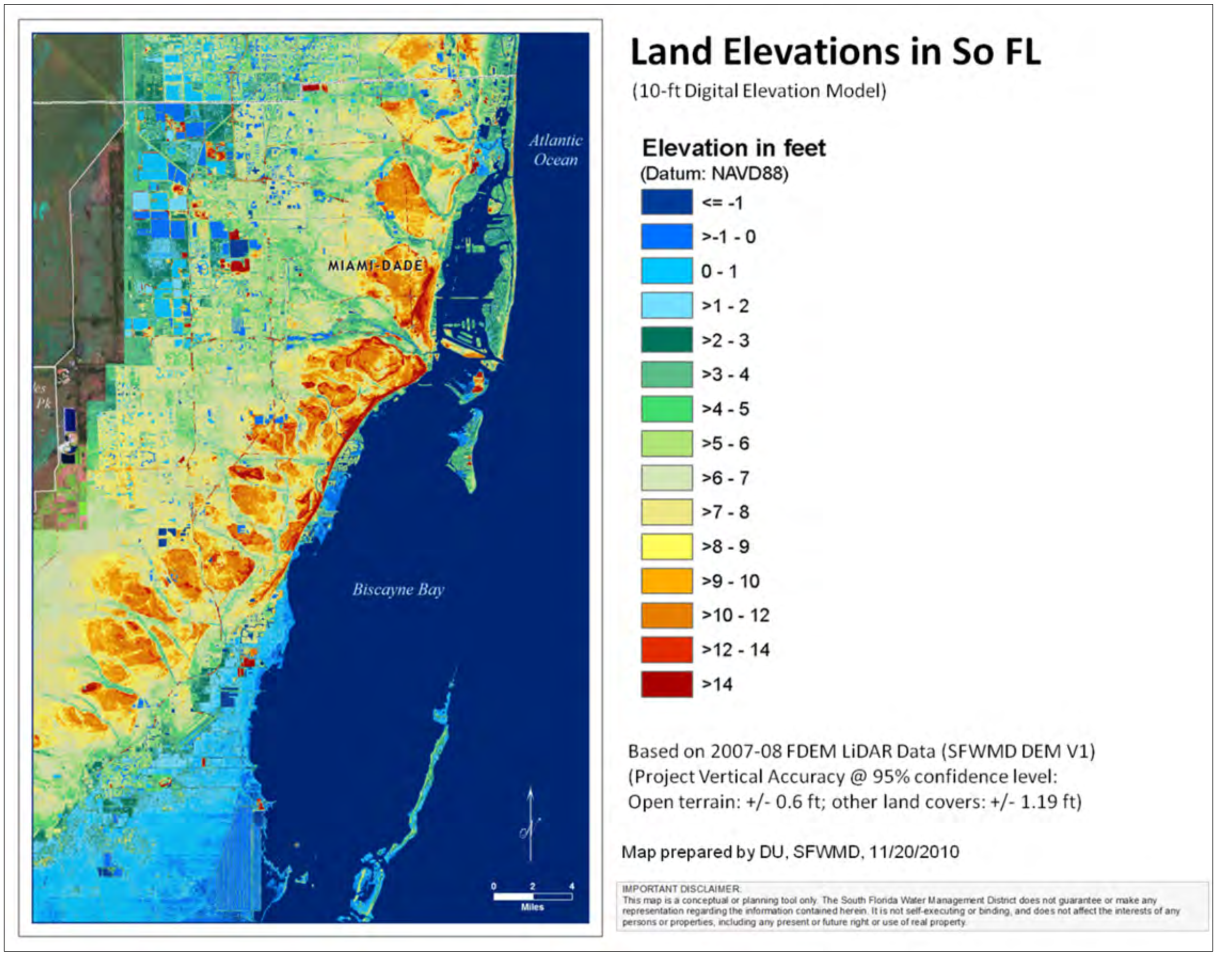


Figure 4 – Land Elevations along Urban Coastal Miami-Dade (NAVD88, ft)
Elevation values were classified in value ranges which were color-coded to help illustrate the general elevation distribution. The map was created using the 10-ft DEM generated by SFWMD from the FDEM LiDAR data.

3.0 SLR Modified Bathtub Approach

Regional SLR inundation vulnerability was mapped by using a modified bathtub method recommended by NOAA CSC and agreed-to by the Compact. The bathtub approach basically entails flooding the land with a water surface that accounts for rising seas. The bathtub effect is simulated by intersecting the land surface with a water surface that includes the added water of a given SLR scenario linearly superimposed over the baseline reference (0-ft SLR) tidal water surface. Both surfaces are referenced to a common vertical datum. The traditional version of the bathtub method applies a flat, single-value water surface to the variable land surface. However, applying a single-value regional water surface across all of SE Florida was not deemed an appropriate approach by either NOAA or the Compact. Water level readings at NOAA stations along the SE Florida coast reveal considerable regional elevation differences. Therefore, a "modified" bathtub approach was implemented based on recommendations by NOAA CSC experts. The modified approach entailed using a modeled, varying water tidal surface that takes into account the observed tidal datum variability in South Florida. This approach has also been used by NOAA CSC for the data displayed in their web-based SLR map viewer. (Marcy et.al. June 2011; NOAA CSC August 2010b). Additional details about the modeled tidal surface are discussed in Section 4.0.

Known Benefits and Limitations

The bathtub approach, whether based on a single-value or a varying water surface, is a relatively quick approach of mapping areas that could be potentially affected by future sea level rise. It is a method used by many government agencies, including NOAA, to provide initial assessments of inundation vulnerability and potential impacts to coastal communities from rising seas. But, most importantly, it provides valuable information that helps initiate discussions among stakeholders and decision makers on what issues to consider as they plan and adapt to sea level rise.

SFWMD, the Compact Counties and their partners, acknowledge that the modified bathtub modeling approach has limitations. For instance, it assumes that land geomorphology, tidal surface variability and other conditions remain constant as the landscape is "inundated", and that there are no additional hydrodynamic effects during storm surges. As a result, the modified bathtub method does not take into account the role of other key factors, which could either exacerbate or lessen future impacts. These factors include anthropogenic activities (e.g. activities caused by humans); higher groundwater levels; coastal barrier island migration; changes in sedimentation rates and deposition patterns; changes in tidal hydraulics due to land geomorphology changes and physical barriers; and other weather/ocean factors (e.g. storm surge, wave activity and anomalous events). (Marcy et.al. June 2011; NOAA CSC August 2010b; NOAA NOS September 2010).

While the scientific community develops and improves more robust models, the modified bathtub modeling approach recommended by NOAA CSC has provided the Compact and SFWMD with reasonable and useful planning-level estimates of areas in SE Florida vulnerable to sea level rise.

4.0 MHHW Tidal Surface

To estimate areas vulnerable to SLR inundation, the input land and water surface elevations must be compared using the same vertical reference system (vertical datum). As recommended by NOAA, the Compact selected the Mean Higher High Water (MHHW) tidal datum for the simulated water surfaces. MHHW represents the average height of the higher high water of each tidal day observed over the National Tidal Datum Epoch (NTDE). Because DEM land elevations are based on the NAVD88 orthometric datum and tidal datums are defined relative to local mean sea level (LMSL), the simulated tidal water surface must be adjusted to NAVD88 and extended inland. (NOAA CSC, October 2007). However, generating a regional tidal surface in NAVD88 is complex for South Florida. Based on NOAA measurements and benchmarks at several long-term and short-term tide stations along the South FL coast, the conversion values from LMSL (and hence from MHHW) to NAVD88 have considerable variability when they are compared at a regional scale, especially within bays and intracoastal areas. Therefore, the Compact agreed that using a single-value conversion factor and a flat water surface was not appropriate for regional SLR analysis. (Gassman, August 2010). Refer to Figure 5 for examples of tidal datum values that reflect this variability, using data provided by NOAA CO-OPS in July 2010.

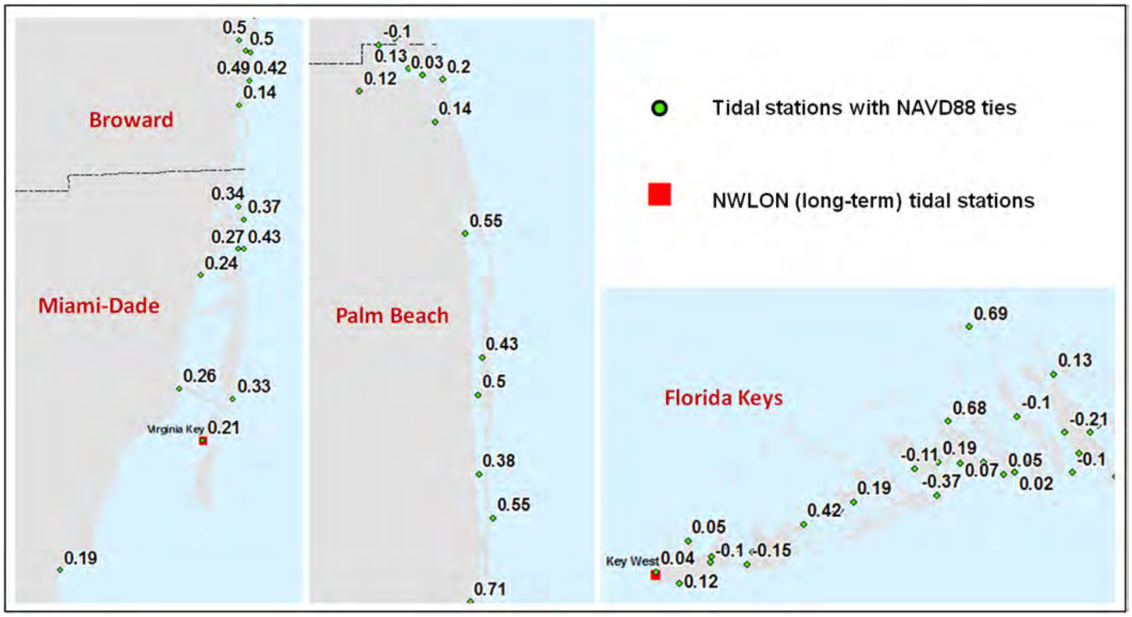


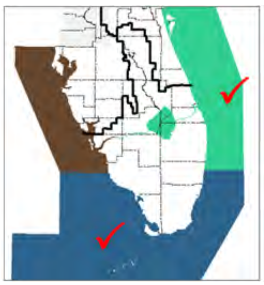
Figure 5 - MHHW tidal datum values in NAVD88 (ft) at locations with geodetic ties
This figure depicts MHHW tidal datum elevations, referenced to NAD88, in feet, at locations that have two or more valid NGS NAVD88 elevations (9 mm tolerance). Data was provided by Jerry Hovis of NOAA CO-OPS in July 14, 2010. Data is also available from NOAA's Tides & Currents website (http://tidesandcurrents.noaa.gov) or CO-OPS SOAP web services (http://opendap.co-ops.nos.noaa.gov/axis/).

To assist SFWMD and the Compact with SLR inundation vulnerability mapping, NOAA CSC developed the base reference MHHW tidal water surface in NAVD88 feet for the SE Florida Compact region. The base water surface provides an estimate of the current, spatially-varying MHHW levels (e.g. without added SLR) and serves as the starting point from which future SLR scenarios can be developed. Due to the complex tidal datum regional variability described above, NOAA CSC developed a spatially-varying MHHW surface using the regional transformation grids that are part of NOAA's National Ocean Service (NOS) VDatum transformation software.

VDatum is a software tool that transforms elevations among several vertical datums, including from tidal datums (e.g. MHHW) to orthometric elevations (e.g. NAVD88). It uses transformation grids developed from observational data, hydrodynamic numerical models and spatial interpolation techniques. For a given model region, VDatum relies on two spatially-varying fields to make its calculations: one for a given tidal datum relative to local mean sea level (LMSL) and the other for the Topography of Sea Surface (TSS), which represent NAVD88 elevations relative to LMSL. The tidal datum fields are derived from simulated water level time series data using the ADvanced CIRculation (ADCIRC) hydrodynamic model which uses unstructured triangular grids. The modeled tidal datums are verified and corrected by applying error fields from comparisons with observational water level data. The final tidal datum fields are interpolated into a regularly structured VDatum marine grid. Finally, for the same marine grid, the

NAVD88-to-LMSL field is derived by fitting tidal model results to tidal bench marks leveled in NAVD88 or calculating orthometric-to-tidal datum relationships at NOAA tidal gauges. (Yang, 2010). Additional details on how the VDatum transformation grids for South Florida were generated will be publicly available in a forthcoming NOAA Technical Memorandum to be titled "*VDatum for Coastal Waters from the Florida Shelf to the Southern Atlantic Bight: Tidal Datums, Marine Grids, and Sea Surface Topography*". Once completed, the publication will be accessible at: http://vdatum.noaa.gov/docs/publication.html.

To develop the base reference MHHW tidal surface, NOAA CSC first merged two VDatum regional transformation grids (Figure 6) and converted the MHHW values to NAVD88 feet. Figure 7 depicts the variability of the MHHW tidal surface, in NAVD88 feet, from one of the regional VDatum grids in the Florida Bay region (FLsouth01).



FLGAeast01:
Florida/Georgia - Fort Lauderdale FL to Sapelo Island GA

FLsouth01:
Florida - South Florida, Naples to Fort Lauderdale FL, and Florida Bay

Figure 6 - VDatum Regional Transformation Grids Used by NOAA CSC
NOAA release date: 04/09/2010

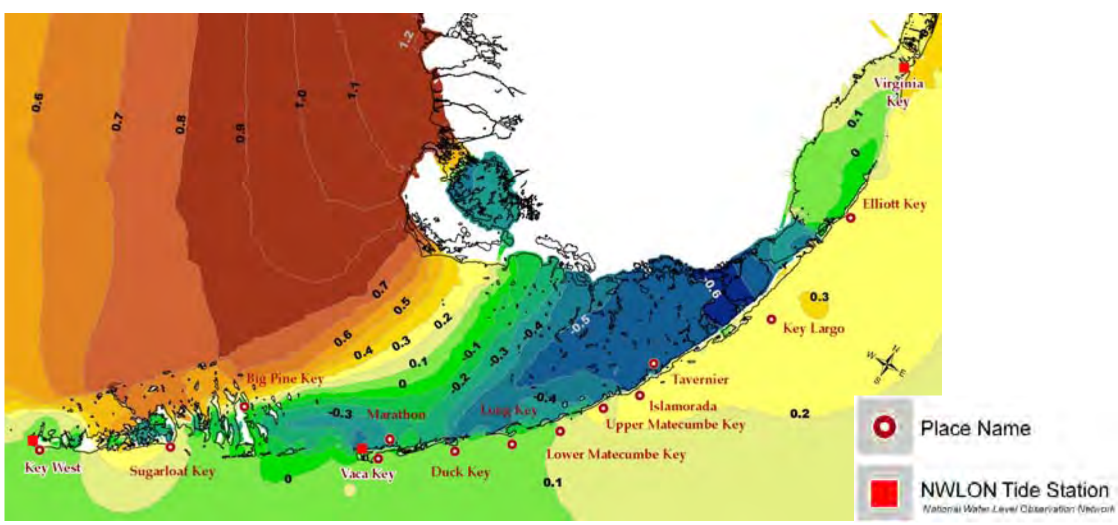


Figure 7 - VDatum MHHW Tidal Variability by Florida Bay, in NAVD88 ft
(FLsouth01) - Without inland extrapolation

By design, the VDatum transformation grids do not extent far inland as there are no tidal stations to validate such surface. Therefore, NOAA CSC conducted additional processing steps in order to extrapolate the tidal surface inland. To lessen unrealistic bias, tidal values by Lake Okeechobee and its largest connected waterways were not included in the extrapolation. The process also included the use of the Nearest Neighbor interpolation method. Figure 8 depicts the final extrapolated MHHW tidal surface, in NAVD88 feet, that was generated by NOAA CSC. It is illustrated using the same elevation color classification scheme as in Figure 7. Additional processing details can be found in the FGDC-compliant metadata in Appendix A.

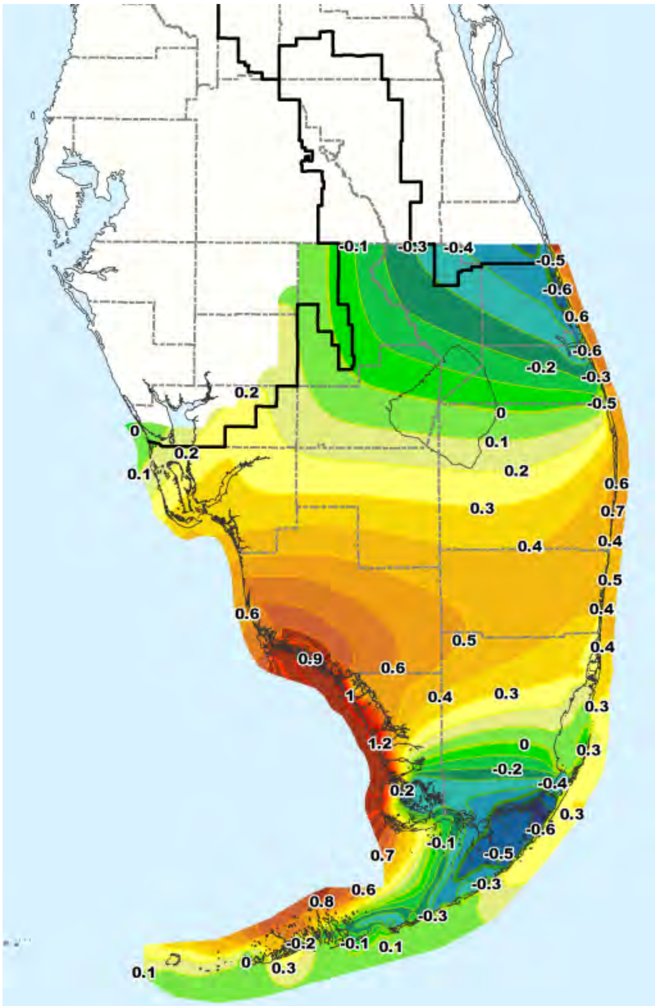


Figure 8 – NOAA CSC's MHHW Tidal Surface, Version 1 (After Inland Extrapolation)
(NAVD88 in ft) – 1500-ft cell size
This figure depicts the MHHW tidal surface, generated by NOAA CSC, after inland extrapolation. Values were color-classified in 0.1-ft elevation intervals. Contour lines, and associated labels, were added to provide a frame of reference and illustrate the distribution of the values in the resulting MHHW tidal surface.

Extrapolating tidal datums inland is challenging because tidal datums have no physical meaning inland and cannot be verified with field data, until that inland location becomes inundated by the ocean tides. Because of the lack of such field data, it is also difficult to quantify this uncertainty and reflect it in the mapped SLR inundation scenarios. As mentioned earlier in this section, part of this complexity is due to the co-dependent dynamics of tides to other natural and human-induced coastal processes, including coastal land erosion, vegetation migration and engineering structures. In some SLR scenarios, it is also possible that the local tide patterns that were used by NOAA to develop the current VDatum transformation grids may no longer be completely valid on a future SLR scenario. (NOAA NOS, September 2010). Other issues discussed among Compact members, but difficult to resolve, were how far inland to extrapolate the VDatum MHHW tidal grid and whether the levees by the Water Conservation Areas could serve as realistic hydrologic barriers. (Gassman, September 2010).

Despite the uncertainty associated with the extrapolated MHHW base tidal surface, assumptions had to be made in order to evaluate potential inundation vulnerability from SLR and equip the Compact coastal communities with preliminary vulnerability data that would help them as they plan and adapt as a region to the likely future effects of SLR. As with any other scientific modeling, these concerns have been acknowledged by providing documentation of the selected methods, and the associated assumptions and uncertainties.

5.0 NOAA CSC UNCERTAINTY MAPPING METHOD

5.1 Z-Scores and Cumulative Probability

SLR inundation vulnerability was mapped by using a methodology that took into account some of the estimated uncertainties associated with land elevation and the tidal water surfaces. This method was proposed by NOAA CSC and agreed to by the Compact. As described below, the methodology involved the calculation of a standardized variable known as Z-score in grid cells that covered the study area and associating these with estimated probabilities. From this, it was possible to map vulnerable areas at two ranges of probability: between 25 to 75% and greater than 75%. Using cumulative probability, we estimated the likelihood that land elevation at a particular location would be less than or equal to a given future SLR elevation scenario. Because there are other factors that help determine if a particular area will or will not be inundated by a higher sea level, it is important to note that the likelihood calculated by this process only estimated the probability that a particular land area is vulnerable to the effects of SLR inundation due its current elevation relative to the given future SLR elevation, using the "bathtub" approach described in Section 4.0. The probability of inundation may be higher or lower when other factors are taken into account, such as hydraulic barriers and increased groundwater table.

The main assumption behind NOAA's uncertainty mapping method is that if vertical errors in the source elevation data (land and tidal water surfaces) follow a normal distribution (i.e. the traditional bell-shaped curve), it is possible to “standardize” a variable (i.e. an elevation value) to get what is referred to as a Z-score, which is the number of standard deviations of that value from the mean of the distribution. Z scores are typically calculated by re-scaling (i.e. standardizing) the distribution such as that the mean (μ) is 0 and the standard deviation (σ) is 1. To standardize values, the following equation is used.

$$Z = \frac{x - \mu}{\sigma}$$

The characteristics of a standard normal distribution are such that any given Z score can be easily associated with a cumulative probability percentage, which refers to the probability that a variable is less than or equal to a specified value. Because of this well-established relationship, standard normal tables are commonly published to help scientists quickly reference z scores to cumulative probability. This relationship is also depicted in the figure below (Fig 9).

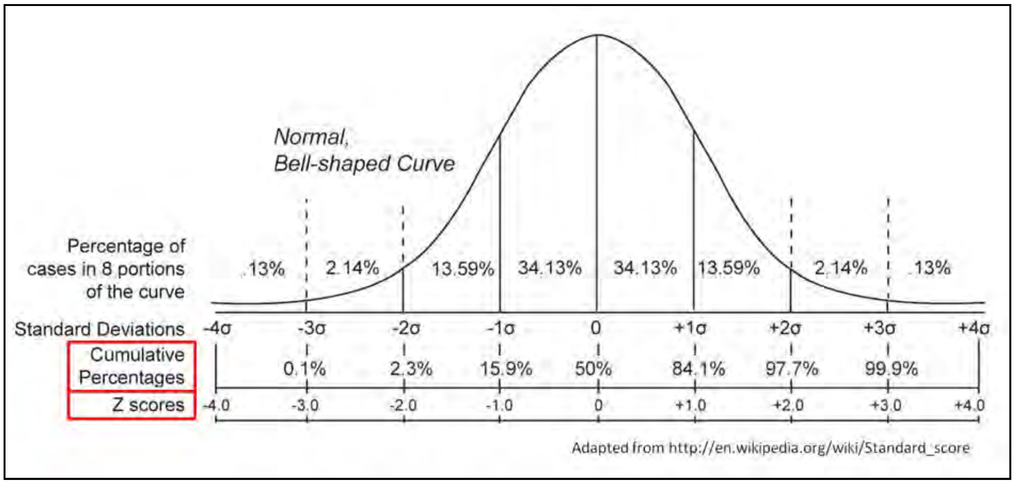


Figure 9 - Standard Normal Distribution

To apply this statistical method to SLR inundation vulnerability mapping, several key assumptions were made. It was assumed that vertical errors are normally distributed. It was also assumed that there is no bias in the error distribution and that the standard deviation is equivalent to the Root Mean Square of the Errors (RMSE) in the elevation data sources. Since there are two elevation sources in SLR inundation mapping, the total RMSE is calculated from the individual RMSE value of the LiDAR (land) elevation surface and of the MHHW tidal water surface. To simplify uncertainty-based mapping, it was assumed that the RMSE in both input surfaces is uniform across the analysis area (i.e. constant). This assumption could be reevaluated in a future effort. The source of the RMSE values used by SFWMD to calculate Z scores are described below.

RMSE of the Land Surface (LiDAR)

As recommended by NOAA CSC, the RMSE for the LiDAR-based land surface was taken from the FDEM LiDAR project specifications, which required all contractors to meet an RMSE of 0.30 feet for open terrain. (FDEM 2007). It is possible that this value is too generous for areas where LiDAR bare earth elevations are likely less accurate, such as by wetlands, mangrove forests and other heavily vegetated regions.

RMSE of the MHHW Tidal Surface

Based on NOAA CSC recommendations, the RMSE for the MHHW tidal water surface was taken from the larger of the maximum cumulative uncertainties (MCU) calculated and published by NOAA for the two VDatum regional grids (FLGAeast01 and FLsouth01) used by CSC to generate the merged and inland extrapolated tidal water surface. It is important to note that this RMSE value does not account for added uncertainty introduced from the inland extrapolation of VDatum grids, which, as described in Section 4.0, is difficult to quantify. The FLGAeast01 regional grid had the larger published MCU, which was 10.8 cm (~ 0.35 feet). The MCU of each regional VDatum tidal surface is a based on a set of calculations that take into account the estimated individual uncertainties of various transformation steps and data sources involved in converting from the International Terrestrial Reference Frame (ITRF) ellipsoid, to NAD83, to NAVD88, to LMSL and finally to the tidal datum with the greatest uncertainty. This process is best described and illustrated at the following NOAA VDatum website, which is also where the MCUs of the VDatum regions are reported: vdatum.noaa.gov/docs/est_uncertainties.html.

Calculation of Z-Scores Using GIS Tools

The Z equation is applied at each grid cell (x,y) of the analysis region with the use of GIS-based raster math tools, with the land and water elevation surfaces as input values. The output of this process is a raster with the standard Z score at each grid cell (x,y). The formulas are illustrated in the figure below (Fig 10).

$$\text{Z}-\text{Score}_{(x,\,y)} = \frac{\text{Tidal Water Surface}_{(x,y)} - \text{Land Elevation}_{(x,y)}}{\text{RMSE}_{(\text{inund})}}$$

where:

$$\text{RMSE}_{(\text{inund})} = \sqrt{\text{RMSE}^2_{(\text{land})} + \text{RMSE}^2_{(\text{water})}}$$

LiDAR (Topo) DEM

MHHW Tidal Surface

$$= \sqrt{0.30^2 + 0.35^2} = 0.46 \text{ ft}$$

Figure 10 - Z-Score Formula Applied in GIS Raster Tools (define the variables in the figure)

To help demonstrate how the method was applied to the study area, the example below (Fig 11) depicts a future SLR scenario where the MHHW tidal surface has an elevation of 7 ft. For simplicity, we assume that only land elevation has errors. Each point represents a cell in the input land surface grid, with a given discrete elevation value that varies from 4.5 to 9 ft. The RMSE of the land elevation is assumed to be 2.5 ft. The graph at each cell point depicts a normal distribution in which the land elevation is assumed to represent the mean. At each cell, the Z score is re-calculated and associated with a cumulative probability. For instance, at cell A, the land surface is depicted as having an 84% probability of being at an elevation that is at or below the given SLR scenario elevation (7 ft); whereas at cell B, the land surface has equal probability of being either above or below that given SLR elevation. When there are errors in both the land surface and the water surface (MHHW), the same concept holds, except that the RMSE of inundation would incorporate the RMSE of both the land and the water surfaces (refer back to Fig 10).

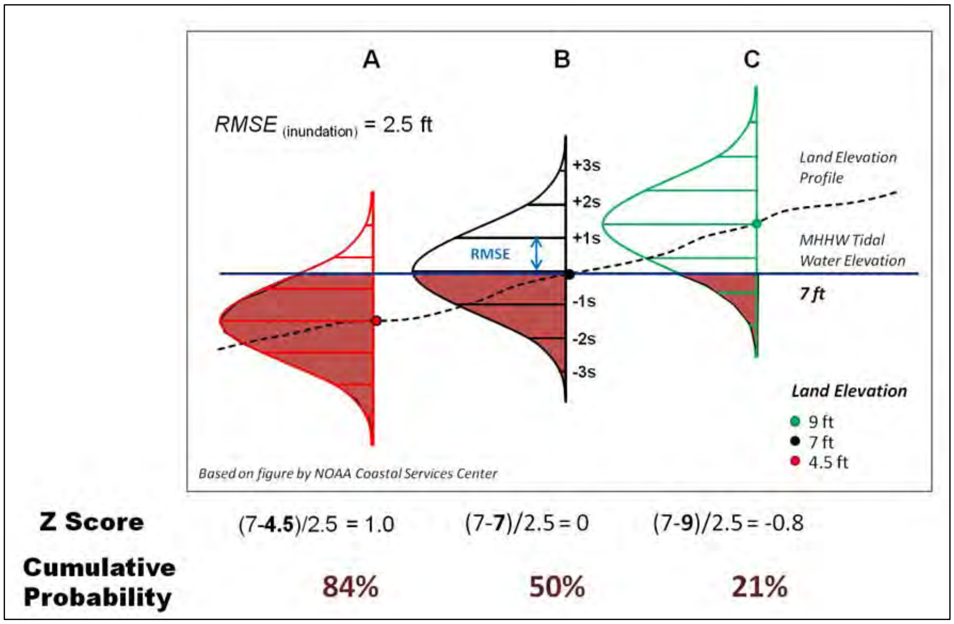


Figure 11 – Z-Score and Cumulative Probability Calculation Example

For additional details about NOAA CSC's Z-score based methodology for portraying inundation uncertainty, refer to their publication titled "*Mapping Inundation Uncertainty*", dated August 2010.

5.2 "Compact" Inundation Vulnerability Reporting

To facilitate the reporting of the statistical results to the public and other stakeholders, the Compact Counties agreed to employ public-friendly terminology to convey the likelihood of inundation vulnerability. Translating statistical results into simpler, public-friendly terminology is common practice among researchers and frequently employed by many government agencies, including NOAA. To accomplish this, the calculated cumulative probabilities 25% or higher were re-classified and mapped into two ranges of probability and associated with a user-friendly term and a common map color, as illustrated below.

Table 2 - Inundation Vulnerability Terminology

Compact's Map Color	Compact's Public-friendly Terminology	Probability of Inundation Vulnerability Statement	Z Scores
	Possible	25% to 74.9% probability that the grid cell (land area) has an elevation less than or equal to the MHHW tide level	Z >=-0.67 and <+0.67
	More Likely	75% or greater probability that the grid cell (land area) has an elevation less than or equal to the MHHW tide level	Z >=+0.67

The classification of SLR vulnerability into these probability groups also helped the Compact Counties to estimate a numerical range of vulnerability, rather than an absolute number, when results of their analysis were quantitative in nature (e.g. number of acres). When this was applied, a low and high estimate was calculated. For instance, one of the parameters calculated by the Compact counties was the total acreage of individual land use categories that would be vulnerable to SLR inundation (due to the land area being at an elevation less than or equal to the MHHW tide level). In this case, the low and high estimates can be interpreted as follow:

- *low estimate* = # of acres of a particular land use category with a 75% or greater probability
- *high estimate* = # of acres of a particular land use category with a 25% or greater probability (possible + more likely)

6.0 SLR Inundation Vulnerability Surfaces

Using GIS tools, several grid layers were generated to help analyze areas that could be vulnerable to SLR inundation. They were generated using the data and methods described in earlier sections of this report, including SFWMD's 50-ft land surface DEMs, NOAA's MHHW tidal surface and NOAA's recommended uncertainty mapping methods. For manageability purposes, the Compact region was sub-divided into 5 analysis areas, roughly following county borders and FDEM project group areas (Fig 12). Monroe County was subdivided into two areas, one for inland Monroe (MR) and the other for the Florida Keys (FK). The inland Monroe (MR) analysis data was not used by the Compact Counties in their vulnerability analysis.

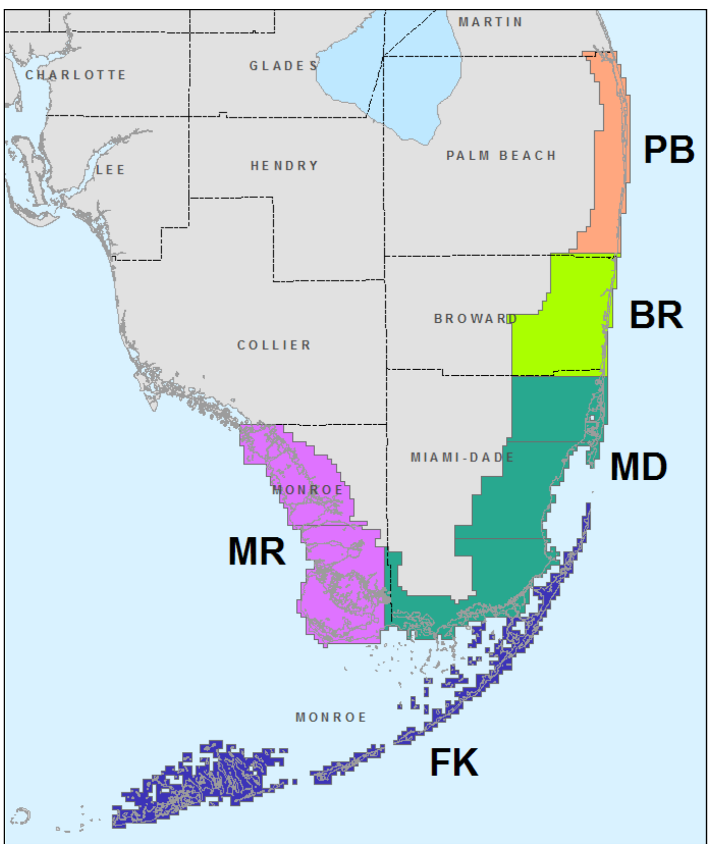


Figure 12 - SLR Vulnerability Analysis Areas

The results of each analysis area were stored in a separate corresponding file geodatabase. For each analysis zone, five grid layers were generated for each SLR scenario (1, 2 and 3-ft feet above current MHHW) for a total of 15 layers. In addition, one baseline layer (0-ft SLR) was generated, which represents areas where the land elevation is at or below the current MHHW tidal surface elevation. This "baseline" grid layer probably includes existing inland water bodies and other low-lying areas near the coast that are already under the influence of the current MHHW tide. The figure below (Fig 13) depicts an example of the grid layers stored in each geodatabase. For technical details on how these layers were generated, refer to the example geoprocessing log in Appendix B. A brief explanation is provided below on what each of these layers represent.

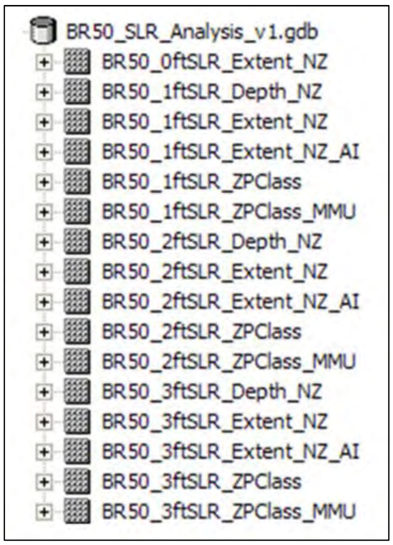


Figure 13 – Example Output Grid Raster Layers Generated for each Analysis Zone
In this example, BR refers to Broward County. Refer to Figure 12 where the prefix for each analysis region is shown.

Vulnerability Grids Using Z-Score/Cumulative Probability

The main output of the analysis were grid layers representing the probability of areas being at an elevation less than or equal to the MHHW tide level of each SLR scenario. The development of these layers first involved generating grids of Z scores using the input variables and math logic described in Section 5.0. The Z-score grids were then re-classified into new grids that were assigned one of two possible integer values, using a conditional statement that evaluated cells representing two ranges of cumulative probability based on the corresponding Z scores listed below.

- A value of 25 was assigned when a Z score was equal to or greater than -0.67 but less than 0.67 (representing ~ 25% to 74.9% probability)
- A value of 75 was assigned when a Z score was equal to or greater than 0.67 (representing ~ 75% or greater probability)

Table 3 describes the two layers that were generated for each SLR scenario, using the 1-ft SLR as example. The only difference between these two layers is that for one of them the Compact's Minimum Mapping Unit (MMU) of ½ acre was applied. Again, refer to Appendix B for additional processing details.

Table 3 - SLR Vulnerability Probability Grid Layers

Grid Layer Name	Description
BR50_1ftSLR_ZPClass	*Probability of areas at or below MHHW + 1 ft of SLR.* Grid cells values are 25, 75 or NoData. This layer was generated by reclassifying the Z-score grid into 2 values to represent the two cumulative probability classes: 25 -> means 25% to 74.9% probability (z >= -0.67 and <0.67) 75 -> means >= 75% probability (z >= 0.67)
BR50_1ftSLR_ZPClass_MMU	*Probability of areas at or below MHHW + 1 ft of SLR that are greater than ½ acre.* Similar as grid layer above, except that it excludes areas that did not meet the Minimum Mapping Unit (MMU) of ½ acre. Cell values represent same as above. This layer was generated by excluding cells that, when connected using a neighborhood of 8 cells, did not meet the MMU. For instance, in the case of a 50-ft grid, this excluded areas of less than 9 connected cells. 50-ft cell = 2,500 sq ft ½ acre = 21,780 sq ft = 8.71 cells (21780/2500) ≈ 9 cells

Figure 14 is an example of how these layers can be used to illustrate SLR vulnerability. Some of the coastal land areas depicted in this map in purple (with probability >= 75%) may include areas already under the influence of current MHHW conditions, such as coastal mangroves.

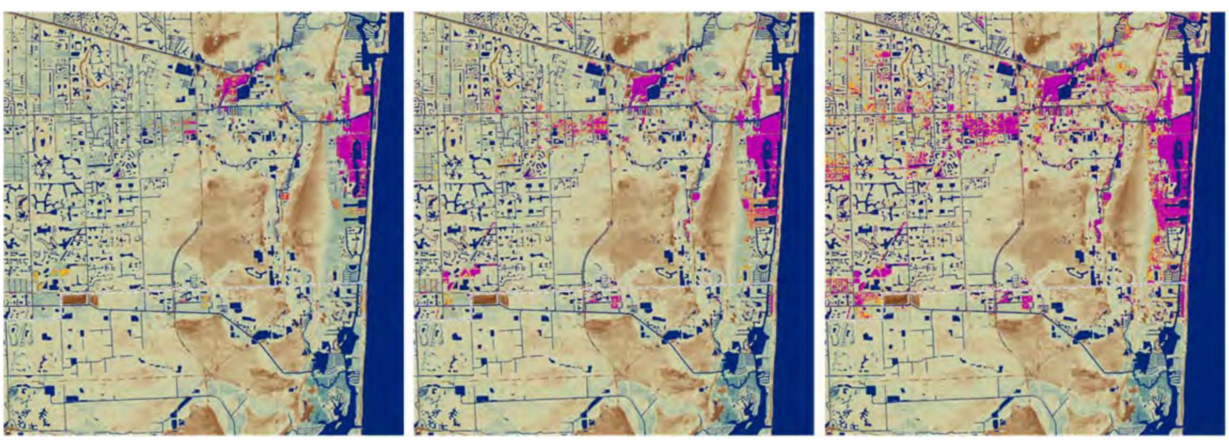


Figure 14 - Example SLR Vulnerability Probability for 1 to 3 ft above MHHW
This figure depicts the probability of vulnerability for three SLR scenarios. Existing water bodies (e.g. ocean, intracoastal waterway, lakes and canals) are shown in dark blue, over the vulnerability grids. Water layers were taken from FDEM LiDAR breaklines and SFWMD's ArcHydro layers. The underlying basemap is a shaded relief DEM from the FDEM LiDAR data, with darker browns representing higher elevations.

75% or greater (More Likely)
25% to 74.9% (Possible)

Vulnerability Grids without Accounting for Elevation Data Uncertainty

An additional set of grid layers were generated for each SLR scenario, but without using Z scores. These layers were derived without taking elevation uncertainty into account or without applying a minimum mapping unit. Table 4 describes these grid layers. Appendix B provides more processing details.

Table 4 - SLR Grid Layers Assuming No Elevation Uncertainty

Grid Layer Name	Description
BR50_0ftSLR_Extent_NZ	*0-ft SLR Extent (Baseline), assumes no sea level rise.* Grid cells with a value of 1 represent areas where the elevation is at or below the MHHW tidal surface (without adding any SLR). This layer probably includes inland water bodies and other low-lying areas near the coast that are already under the influence of the current MHHW tide. Therefore, this layer could be helpful for verifying the extrapolated MHHW tidal surface itself, such as evaluating how well it represents areas known to be affected by current MHHW conditions.
The layers below were generated for each SLR scenario.	
BR50_1ftSLR_Extent_NZ	*1-ft SLR Extent.* Grid cells with a value of 1 represent areas where the elevation is at or below the MHHW tidal surface plus 1-ft SLR.
BR50_1ftSLR_Extent_NZ_AI	*1-ft SLR Added Extent, excludes areas vulnerable at 0-ft SLR.* Grid cells with a value of 1 represent areas vulnerable to 1-ft SLR, but exclude areas already at or below current MHHW (0ft SLR). AI -> stands for the added "inundation". It was generated by subtracting the 0-ft layer from the 1-ft SLR layer.
BR50_1ftSLR_Depth_NZ	*Depth in feet of the 1-ft SLR Extent.* More appropriately, this grid layer represents how many feet above or below is the land surface (DEM cell value) from the MHHW tidal surface with the added SLR. When the land surface is below the water surface, the values are positive and represent the elevation difference. This layer was created as a pilot and was not used by the Compact Counties for their vulnerability analysis. It does not include the influence of the 0-ft SLR conditions.

Figure 15 is an example of how some of these layers could be used to depict how vulnerability varies by SLR scenario.

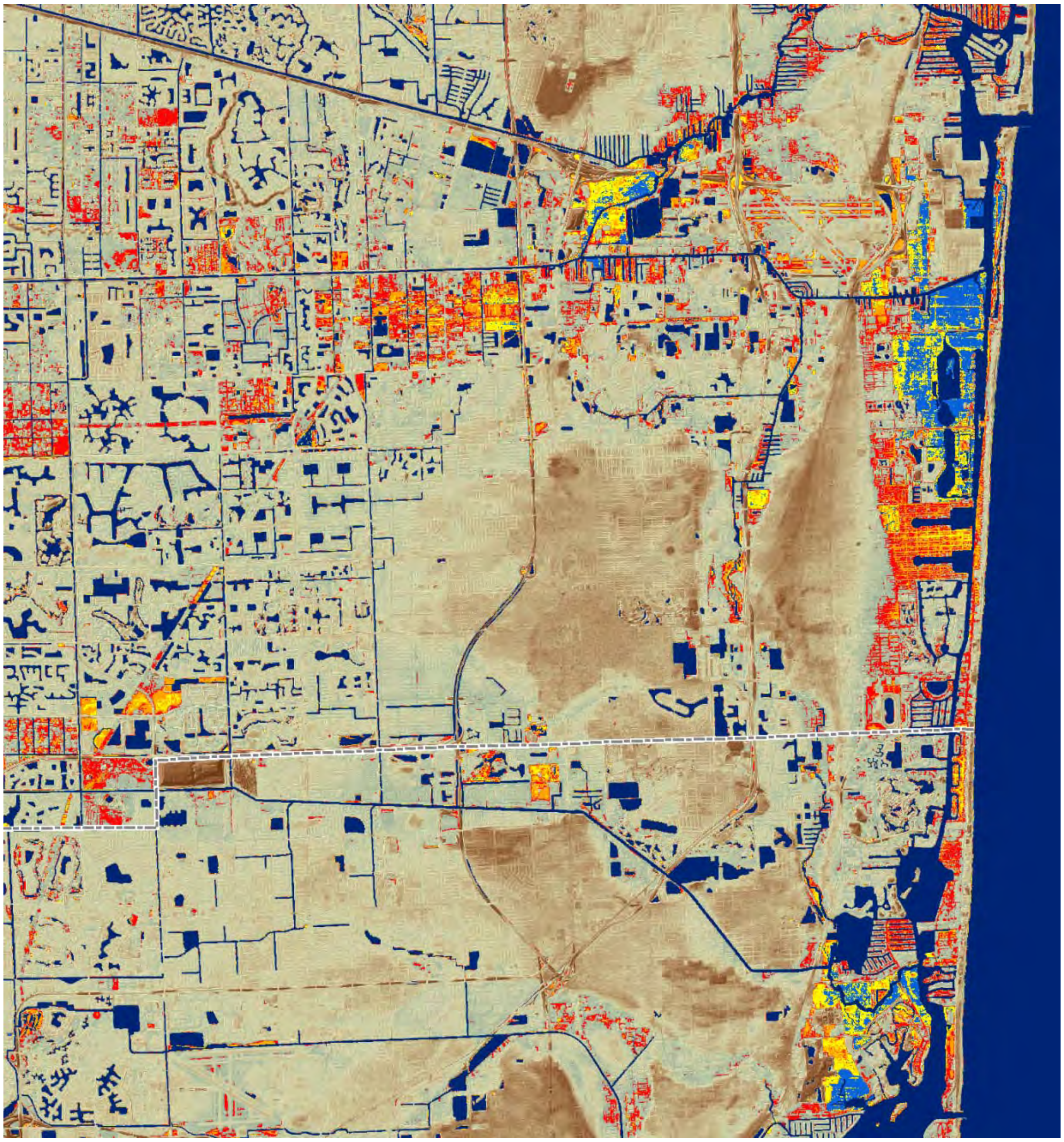


Figure 15 - SLR Vulnerability at 1 to 3-ft above MHHW (Assuming No Elevation Errors)
Assuming no uncertainty in elevation sources, this figure is an example of analysis output showing areas at an elevation that is at or below MHHW with the following additional feet of water:

0 ft (at MHHW)

1 ft 2 ft 3 ft

7.0 CONCLUSIONS AND RECOMMENDATIONS

Although SLR mapping efforts have been conducted for South Florida by others, most of the earlier efforts were based on methods that used less accurate and detailed topographic and water surface data. Very few took into account, or even acknowledged, the vertical uncertainty of the input elevation sources. In several cases, technical documentation associated with those efforts is limited or hard to find. But, perhaps most notably, none of them were the result of a coordinated regional effort, led by four neighboring counties in FL that worked closely with many state, federal, academia and non-profit partners, to come up with an improved estimate of the region's vulnerability to sea level rise.

In support and in partnership with the Southeast Florida Regional Climate Change Compact and NOAA, SFWMD generated SLR vulnerability inundation layers for three possible sea level rise scenarios: 1 foot, 2 feet and 3 feet above current MHHW tide levels. These datasets were used by the Compact counties to do a preliminary assessment of the potential impacts of SLR.

As noted carefully and copiously in this technical report, there are known limitations and uncertainties associated with the analysis conducted. Neither SFWMD, nor the Compact Counties, assume that their recent SLR vulnerability mapping and analysis would be the last attempted by them or other agencies. The science and modeling associated with sea level rise studies are complex and continually evolving. Therefore, none of the results presented should be taken, quoted or assumed as absolute or final. But, hopefully, they are an improvement to other earlier efforts.

One of the recommendations of the Compact's Regional Climate Change Action Plan is to continue to evaluate and improve SLR vulnerability mapping and analysis methods. The rest of this section provides suggestions and recommendations that could improve future SLR inundation vulnerability mapping, as well as expand the geographic extent of the study region to other coastal communities in South Florida.

Topographic/ Land Surface DEM

- *Expand the geographic extent of the study region by carefully merging the FDEM LiDAR data with other best available topographic data.*

Due to time and resource constraints, the land surface DEMs used in the SLR analysis were solely based on the FDEM LiDAR data. Although this dataset included most of the urban coastal areas within the Compact region, it did not cover the full extent of each Compact county. As a result, those areas were not included in the SLR inundation vulnerability mapping conducted by SFWMD. Unfortunately, developing a merged DEM from multiple topographic sources is typically a complex process. Overlapping and adjacent datasets seldom "match" because they were often collected at different time periods and using different technologies, specifications and vendors. Therefore, collecting additional survey points is often necessary where the datasets overlap to help determine the best methods to merge the datasets and calculate the vertical accuracy of the merged areas. Those methods could include making vertical adjustments to one dataset, deciding to omit one, or using filtering/smoothing algorithms to reduce the elevation differences among the joining datasets.

- *Improve the quality of the existing best available topographic data and derived DEMs.*

DEM conditioning is typically necessary to address remaining artifacts that do not properly depict water connectivity and surface water flow patterns. Unfortunately, this can be time consuming and cost-prohibitive. Although GIS tools could automate some aspects of this process, manual edits and additional field data are often necessary to resolve some areas. For instance, SFWMD has developed filtering and decorrugation algorithms that help reduce and smooth 'LiDAR" banding artifacts. However, even after applying automated processes like these, it may still be advisable to validate accuracy with independent field data.

MHHW Tidal Surface

- *Improve the MHHW tidal surface landward extrapolation by using NOAA's latest guidance and data.*

The regional MHHW tidal surface generated by NOAA CSC in July 2010 for the Compact could probably be improved using NOAA's most recent guidance and data. For instance, since that original work, CSC has been experimenting with Euclidean Distance Allocation functions to take the landward-most VDatum grid values and extending them inland perpendicularly to the coastline. They have found that this reduces small errors that may have been introduced by applying the nearest neighbor interpolation across the FL peninsula. It may also be valuable to explore the usability of newer data products generated by NOAA CSC. As part of their web-based SLR map viewer project, CSC has generated a new MHHW extrapolated tidal surface. (Doug Marcy, personal communication, January 2012).

- *Refine, if practical, the MHHW tidal surface along the Florida Keys and other narrow coastal areas.*

In some narrow stretches of coastal land, such as the Florida Keys, the MHHW tide surface is complex and quite variable. To smooth the transition of landward tidal values, it may be beneficial to generate an extrapolated tidal surface with a smaller cell size. The cell size of the original tidal surface generated by CSC for the Compact may have been too large (1500-ft), and it generated a few abrupt inland tidal elevation differences in some areas of the Keys.

Inundation Mapping Methods

- *Consider whether developing and applying spatially-variable error fields for both the land and water surfaces would be practical and beneficial to future SLR vulnerability mapping.*

As described in Section 5, the SLR vulnerability raster surfaces were generated by applying a single, but different, uncertainty value to both the land and water surfaces across the entire study area. This assumption may not be valid in all land areas, such as those covered by wetlands and coastal mangroves. Applying the FDEM RMSE specification value of 0.3 feet for bare earth may have been too generous for these areas. Likewise, the source VDatum tidal grids have different and spatially-variable uncertainty values. The effort to generate and apply more robust error rasters should be outweigh by its potential benefit. Also, there is possibly a larger error which is far more difficult, if not impossible, to take into account quantitatively, which is the error associated with extrapolating the VDatum grids landwards, as there is no field data to help determine the accuracy of such extrapolation.

- *Address the role of inundation depth in estimating the degree of vulnerability.*

The degree of SLR vulnerability is also related to how large is the elevation gradient between the current land surface and the simulated SLR water surface. Areas with higher depth of inundation might experience more significant impacts.

Other Suggestions

- *Follow-up with NOAA CO-OPS to determine if there are opportunities for expansion and improvement of the current tidal station network in South Florida.*

In 2008, NOAA CO-OPS published a study that identified NWLON tidal station network gaps in South Florida. Per NOAA, the study identified “the geographic region for each NWLON station within which a datum computation at a subordinate station with a 3-month time series will be accurate to less than or equal to 0.12 ft.” This is the target criterion they believed would “ensure the accuracy of datum determination at subordinate locations… [and] meet most user requirements.” Using this criterion, they identified “gaps for consideration of new priority NWLON station requirements”. (Gill, March 2008).

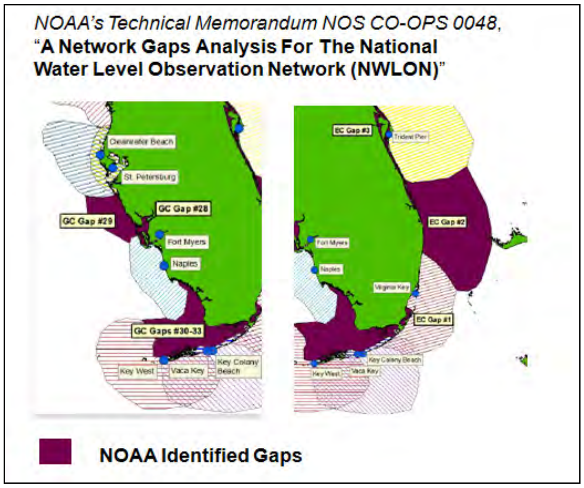


Figure 16 – NWLON Network Gaps Identified by NOAA
Credit: NOAA CO-OPS. (Gill, March 2008).

NOAA also conducted a preliminary assessment of the tidal datums along the Florida Coast in support of the VDatum project. In their evaluation, they proposed additional ellipsoidal and orthometric datums, installation of new stations and reoccupation of several historical stations. (Hovis, April 2010). The Compact may wish to follow-up with NOAA to identify if funding will be available in the future to implement these recommendations.

- *Validate SLR inundation vulnerability maps by using observations gathered from exceptional seasonal high tides.*

To help validate and improve SLR vulnerability mapping, the Compact could take advantage of future exceptional seasonal high tides that "mimic" what future SLR scenarios may look like. The data collected from these events could help validate and improve future mapping efforts.

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- ***Special thanks*** are extended to our NOAA partners [Doug Marcy, Brian Hadley, Keil Schmid (Coastal Services Center) and Jerry Hovis (CO-OPS)] for guiding us on SLR inundation mapping best practices, and developing the Z-score uncertainty methods and the initial VDatum-based MHHW tidal surface for South Florida.
- We also thank Richard Butgereit (FDEM) for the coastal LiDAR data that was critical to this project.
- The special contributions of Tim Liebermann (SFWMD) are also acknowledged, who was instrumental to the development of the LiDAR DEMs.
- Several other SFWMD staff members contributed in varying degrees to the efforts associated with this project. Their support included helping to QA the DEMs and allocating server resources and software.

The author wishes to also recognize the following individuals that were contributors and reviewers of the technical content and processes described in this technical report.

Jayantha Obeysekera, Tim Liebermann (SFWMD)
Victoria Morrow, Erin Musgrave, Nancy Gassman (Broward County)
Douglas Marcy, Brian Hadley (NOAA Coastal Services Center)

ABBREVIATIONS

Compact	Southeast Florida Regional Climate Change Compact
CO-OPS	NOAA's Center for Operational Oceanographic Products and Services
CSC	NOAA's Coastal Services Center
DEM	Digital Elevation Model
FDEM	Florida Division of Emergency Management
FDOT	Florida Department of Transportation
FEMA	Federal Emergency Management Agency
GIS	Geographic Information Systems
GPS	Global Positioning System
HAED	USGS High Accuracy Elevation Dataset
LiDAR	Light Detection and Ranging
LMSL	Local Mean Sea Level
MCU	Maximum Cumulative Uncertainty
MHHW	Mean Higher High Water
NED	National Elevation Data
NOAA	National Oceanographic and Atmospheric Administration
NAVD88	North American Vertical Datum of 1988
NGS	National Geodetic Survey
NGVD29	National Geodetic Vertical Datum of 1929
NWLON	National Water Level Observation Network
NTDE	National Tidal Datum Epoch
QA	Quality Assurance
RMSE	Root Mean Square Error
SD (σ)	Standard Deviation
SE FL	Southeast Florida
SLR	Sea Level Rise
SFWMD	South Florida Water Management District
TIN	Triangulated Irregular Network
TSS	Topography of Sea Surface
USGS	United States Geological Survey
USACE	United States Army Corps of Engineers

Appendix B-A

Metadata for NOAA's MHHW Tidal Surface for South Florida, in NAVD88 feet, Version 1

Mean Higher High Water (MHHW) Tidal Surface for South Florida, in NAVD88 feet, Version 1

Data format: File Geodatabase Raster Dataset

File or table name: MHHW_NAVD88_TidalGrid

Coordinate system: Transverse Mercator

Theme keywords: digital elevation model, DEM, elevation, altitude, height, sea level, Mean Higher High Water, MHHW, tidal datum, sea level rise, climate change, inundation, tidal surface, oceans, elevation, oceans, inlandWaters

Abstract: Mean Higher High Water (MHHW) Tidal Surface for South Florida, in NAVD88 feet, Version 1. This 1500-ft raster grid represents an approximation of the Mean Higher High Water (MHHW) tidal surface, referenced to NAV88 in feet, over land portions of South Florida. It was generated by NOAA Coastal Services Center to support sea level rise (SLR) inundation mapping in Monroe, Miami-Dade, Broward and Palm Beach Counties in Florida. It is intended to serve as the starting sea level elevation to which SLR scenarios can be added, particularly when the 'bathtub' approach is used to estimate SLR inundation. It was created for the Southeast Florida Regional Climate Change Compact Counties and their partners.

FGDC and ESRI Metadata:

Metadata elements shown with blue text are defined in the Federal Geographic Data Committee's (FGDC) *Content Standard for Digital Geospatial Metadata (CSDGM)*. Elements shown with green text are defined in the *ESRI Profile of the CSDGM.* Elements shown with a green asterisk (*) will be automatically updated by ArcCatalog. ArcCatalog adds hints indicating which FGDC elements are mandatory; these are shown with gray text.

Identification Information:

Citation:
Citation information:
Originators: NOAA Coastal Services Center

Title:
Mean Higher High Water (MHHW) Tidal Surface for South Florida, in NAVD88 feet, Version 1
***File or table name:** MHHW_NAVD88_TidalGrid

Publication date: 20100920
Edition: Version 1
Geospatial data presentation form: raster digital data

Other citation details:

Citation Reference: Mean Higher High Water (MHHW) Tidal Surface for South Florida, in NAVD88 feet, Version 1

Online linkage: http://www.sfwmd.gov

Description:

Abstract:

Mean Higher High Water (MHHW) Tidal Surface for South Florida, in NAVD88 feet, Version 1.
This 1500-ft raster grid represents an approximation of the Mean Higher High Water (MHHW) tidal surface, referenced to NAV88 in feet, over land portions of South Florida. It was generated by NOAA Coastal Services Center to support sea level rise (SLR) inundation mapping in Monroe, Miami-Dade, Broward and Palm Beach Counties in Florida. It is intended to serve as the starting sea level elevation to which SLR scenarios can be added, particularly when the 'bathtub' approach is used to estimate SLR inundation. It was created for the Southeast Florida Regional Climate Change Compact Counties and their partners.

Purpose:

This grid was created to support sea level rise (SLR) inundation mapping in southeast Florida, specifically for the counties in the Southeast Florida Regional Climate Change Compact (Monroe, Miami-Dade, Broward and Palm Beach).

Supplemental information:

The Southeast Florida Regional Climate Compact ("Compact") is a resolution that was signed at the October 2009 Southeast Florida Regional Climate Leadership Summit, establishing a partnership between Palm Beach, Broward, Miami-Dade and Monroe Counties to address shared concerns related to climate change. The Compact was subsequently reaffirmed via resolutions passed by each of the county commissions. By invitation, SFWMD is member of the Compact Steering Committee. Among others, the Compact Counties agreed to work together to develop a Southeast Florida Regional Climate Change Action Plan that will include strategies for planning and adapting to the potential effects of sea level rise.

An area of concern highlighted at the Summit was the local diversity of data sources and approaches for mapping potential sea level rise inundation. To address this challenge, NOAA Coastal Services Center (CSC) facilitated a workshop in April 2010 to assist the 4 Compact Counties, SFWMD and other government and academia partners in reaching consensus on certain technical aspects of inundation mapping that would help in the development of regionally consistent SLR inundation scenarios for southeast Florida.

During this workshop, attendees agreed to use Mean Higher High Water (MHHW) tidal datum for the water surfaces. MHHW was deemed the best tidal datum because it represents the higher of the two high waters of any tidal day. It is derived from the average of the higher high water height of each tidal day observed over the latest 19-year National Tidal Datum Epoch (1983-2001). For stations with shorter period of record, NOAA compares simultaneous observations with a primary control tide station in order to derive the equivalent 19-year epoch datum value. For additional information about tides and tidal datums, refer to the NOAA's Tides and Currents website, operated by the Center for Operational Oceanographic Products and Services (CO-OPS). http://tidesandcurrents.noaa.gov/

Due to the geographic variability of tidal datums, the Compact also agreed that using a single conversion value from MHHW to NAVD88 would not be appropriate for South Florida. To address this issue, NOAA CSC offered to generate the MHHW tidal surface, referenced to NAVD88, using VDatum. VDatum is a freely distributed Java application, developed by NOAA's National Ocean Service (NOS), that performs vertical datum transformations, including from orthometric datums (e.g. NAV88) to tidal datums. VDatum data is broken down by regions (project areas). For each region, NOS generated tidal datum transformation grids by a complex process that included numerical hydrodynamic models, spatial interpolation techniques and calibration to local tidal water level stations. In addition, a topography of the sea surface (TSS) transformation grid was generated that provides the basis for converting tidal datums to NAVD88. Refer to NOAA's VDatum website for additional information. http://vdatum.noaa.gov/

To generate the MHHW tidal surface for southeast Florida, NOAA CSC blended two regional transformation grids and interpolated the tidal datum values into land areas within SFWMD. These VDatum regions are referred to as: FL/GA - Fort Lauderdale to Sapelo Island; and FL - South Florida, Naples to Fort Lauderdale and Florida Bay. These regional transformation grids were publicly released by NOAA on 4/9/2010, as version 1. For additional processing details, refer to the Lineage section of this metadata document.

*__Language of dataset:__ en

Time period of content:
- **Time period information:**
  - **Range of dates/times:**
    - **Beginning date:** 1983
    - **Ending date:** 2001

- **Currentness reference:**
  ground condition

Status:
- **Progress:** Complete
- **Maintenance and update frequency:** As needed

Spatial domain:
- **Bounding coordinates:**
  - *__West bounding coordinate:__ -82.393431
  - *__East bounding coordinate:__ -79.965785
  - *__North bounding coordinate:__ 27.645797
  - *__South bounding coordinate:__ 24.383502

- **Local bounding coordinates:**
  - *__Left bounding coordinate:__ 205004.546090
  - *__Right bounding coordinate:__ 991004.546090
  - *__Top bounding coordinate:__ 1203933.742227
  - *__Bottom bounding coordinate:__ 20433.742227

Keywords:
- **Theme:**
  - **Theme keywords:** digital elevation model, DEM, elevation, altitude, height, sea level, Mean Higher High Water, MHHW, tidal datum, sea level rise, climate change, inundation, tidal surface, oceans
  - **Theme keyword thesaurus:** None

- **Theme:**
  - **Theme keywords:** elevation, oceans, inlandWaters
  - **Theme keyword thesaurus:** ISO 19115 Topic Category

- **Place:**
  - **Place keywords:** Florida, South Florida, Palm Beach County, Broward County, Miami-Dade County, Monroe County, Florida Keys, Southeast Florida
  - **Place keyword thesaurus:** None

Access constraints: This dataset is made available to the public in response to the Florida Public Records Law, Florida Statutes, Chapter 119.

Use constraints:

The layer was intended to support SLR mapping in Monroe, Miami-Dade, Broward and Palm Beach Counties. Although the geograghic extent of this layer includes other counties, it may not be suitable for those areas.

This layer is not intended for analysis that may require a higher degree of horizontal and/or vertical accuracy, resolution and control that exceed those of this dataset. It is the responsibility of the data users to use professional judgment to determine if the dataset is suitable to meet their needs. This information is provided "as is".

SFWMD IMPORTANT DISCLAIMER:
This dataset is a conceptual or planning tool only. The South Florida Water Management District does not guarantee or make any representation regarding the information contained herein. It is not self-executing or binding, and does not affect the interests of any persons or properties, including any present or future right or use of real property.

Point of contact:

Contact information:

Contact person primary:

Contact person: Diana Umpierre, GISP

Contact organization: South Florida Water Management District (SFWMD)

Contact position: Sr Geographer

Contact address:

Address type: mailing and physical address

Address:

3301 Gun Club Road

City: West Palm Beach

State or province: Florida

Postal code: 33406

Country: USA

Contact voice telephone: (561) 682-6822

Contact electronic mail address: dumpier@sfwmd.gov

Data set credit:

This grid was generated by NOAA Coastal Services Center, with support from other NOAA offices, including the Center for Operational Oceanographic Products and Services (CO-OPS) and the National Geodetic Survey (NGS).

***Native dataset format:** File Geodatabase Raster Dataset

***Native data set environment:**

Microsoft Windows 2000 Version 5.2 (Build 3790) Service Pack 2; ESRI ArcCatalog 9.3.1.3000

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Data Quality Information:

Attribute accuracy:

Attribute accuracy report:

The only attribute associated with this raster is elevation (vertical position), which is an embedded value in each raster cell. Therefore, refer to the metadata's Vertical

Positional Accuracy Report for additional details.

Logical consistency report:

This raster is representation of the Mean Higher High Water (MHHW) tidal surface for South Florida. Raster cells (also referred to as grids) are coded with floating-point elevation values, in feet, referenced to NAVD 1988.

Completeness report:

The raster covers the complete geographic extent of the areas it was intended for: Monroe, Miami-Dade, Broward and Palm Beach Counties. For visualization purposes, it also includes other portions of SFWMD. However, this layer is not recommended for analysis that extends beyond those 4 counties. The raster does not contain any internal void (NoData) areas.

Positional accuracy:

Horizontal positional accuracy:

Horizontal positional accuracy report:

Because digital elevation grids/cells do not have well-defined points, testing for horizontal accuracy is not applicable.

Vertical positional accuracy:

Vertical positional accuracy report:

Vertical uncertainty has been calculated and documented by NOAA for each region in VDatum. Errors in VDatum may arise from inaccuracies of the modeled transformation grids, or in the source data (observations) used to create VDatum grids. For each region, NOAA reports the Maximum Cumulative Uncertainty (MCU). MCU is the square root of the sum of the squares of the individual uncertainties (standard deviations) in both the transformation and the source data. A detailed explanation of this process and the resulting MCU's for each region can be found at http://vdatum.noaa.gov/docs/est_uncertainties.html

For this particular grid, NOAA recommended taking a conservative approach and reporting the larger MCU value of the two regions used to create the MHHW tidal surface: 10.8 cm (~ 0.35ft), as reported March 2010. Assuming the errors are random, unbiased and normally distributed, MCU is a estimate of the standard deviation (standard error) and the RMSE (root mean square error). This value should NOT be confused with FGDC NSSDA Accuracy(z) which is intended to represent a 95% confidence level and it is typically calculated by using a multiplier (1.96) of the RMSE.

It should be noted that the vertical uncertainty of the MHHW tidal grid generated for inland areas of South Florida is probably larger, but unfortunately difficult to measure. This is because the MHHW surface has been interpolated inland where no tide observation data exists to validate if the gridded tide values are correct.

Lastly, it is important to note that using the commonly used, but simplistic, bathtub method, even when using a VDatum-generated tidal surface, has its own inherent shortcomings. Estimating the potential effects of local sea level rise due to global climate change is a complex and dynamic science. The bathtub approach assumes present physical /environmental conditions will be the same in a future scenario. That assumption does not account for hard-to-predict variables that might be different in the future, such as human (anthropogenic) activities, coastal shoreline migration, land subsidence, coastal hydrodynamics, groundwater effects and other factors.

Lineage:

Process step:

Process description:

NOAA Processing Steps:

1) NOAA CSC obtained transformation grids for MHHW in NAVD88 for two VDATUM regions that cover the Southeast FL Regional Climate Change Compact area: Florida/Georgia - Fort Lauderdale FL to Sapelo Island GA; and Florida - South Florida, Naples to Fort Lauderdale FL, and Florida Bay. These consisted of two GTX, Java binary files.
2) NGS converted the GTX files to comma delimited X,Y,Z files. (Coordinates were in WGS84 decimal degrees).
3) The xyz points for both grids were mapped using ArcMap. The points were spaced ~ 500-ft apart.
4) XYZ points for Lake Okeechobee and for the largest canals/rivers that connect the lake to the east and west coast were removed to remove bias.
5) A TIN was generated from these points, with a tolerance of 700 ft to avoid interpolation beyond the 500-ft spacing (and avoid inland interpolation during this step).
6) The TIN was converted to a 500-ft raster grid.
7) The grid was reprojected from WGS84 to Florida State Plane coordinates, East Zone.
8) The reprojected grid was then resampled to 1500-ft cell size.
9) Centroids for each of the grid cells were generated.
10) Using the nearest neighbor interpolation method, the centroids were used to create a grid that interpolated across southern land portions of Florida.

Process date: 201007

Process contact:

Contact information:

Contact organization primary:

Contact person: Douglas C. Marcy

Contact organization: NOAA Coastal Services Center

Contact position: Coastal Hazards Specialist

Contact address:

Address type: mailing and physical address

Address:

2234 S. Hobson Avenue

City: Charleston

State or province: SC

Postal code: 29405

Country: USA

Contact voice telephone: (843) 740-1334

Contact electronic mail address: doug.marcy@noaa.gov

Process step:

Process description:

SFWMD Processing Steps:

Using ArcGIS Extract by Mask geoprocessing tool, the tidal surface provided by NOAA was clipped using a buffered SFWMD boundary clip layer, that extends into the ocean by about 2 to 5 miles. Portions of SFWMD that do not extend to the coast were excluded (e.g. Kissimmee region).

Process date: 201008

Process contact:

Contact information:

Contact organization primary:

Contact person: Diana Umpierre, GISP
Contact organization: SFWMD
Contact position: Senior Scientist/ Geographer

Contact address:
Address type: mailing and physical address
Address:
3301 Gun Club Road
City: West Palm Beach
State or province: FL
Postal code: 33406
Country: USA

Contact voice telephone: (561) 682-6822

Contact electronic mail address: dumpier@sfwmd.gov

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Spatial Data Organization Information:

***Direct spatial reference method:** Raster

Raster object information:
***Image format:** FGDBR
***Number of bands:** 1

***Row count:** 789
***Column count:** 524
***Vertical count:** 1

***Cell size X direction:** 1500.000000
***Cell size Y direction:** 1500.000000

***Bits per pixel:** 32
***Pyramid layers:** TRUE
***Image colormap:** FALSE
***Compression type:** LZ77

***Raster object type:** Pixel
***Raster display type:** pixel codes
***Raster origin:** Upper Left

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Spatial Reference Information:

Horizontal coordinate system definition:
Coordinate system name:
***Projected coordinate system name:**
NAD_1983_HARN_StatePlane_Florida_East_FIPS_0901_Feet
***Geographic coordinate system name:** GCS_North_American_1983_HARN

Planar:
Map projection:
***Map projection name:** Transverse Mercator

Transverse mercator:
*__Scale factor at central meridian:__ 0.999941
*__Longitude of central meridian:__ -81.000000
*__Latitude of projection origin:__ 24.333333
*__False easting:__ 656166.666667
*__False northing:__ 0.000000

Planar coordinate information:
*__Planar coordinate encoding method:__ row and column
Coordinate representation:
*__Abscissa resolution:__ 1500.000000
*__Ordinate resolution:__ 1500.000000
*__Planar distance units:__ survey feet

Geodetic model:
*__Horizontal datum name:__ D_North_American_1983_HARN
*__Ellipsoid name:__ Geodetic Reference System 80
*__Semi-major axis:__ 6378137.000000
*__Denominator of flattening ratio:__ 298.257222

Vertical coordinate system definition:
Altitude system definition:
Altitude datum name: North American Vertical Datum of 1988
Altitude resolution: 0.01
Altitude distance units: feet
Altitude encoding method: Explicit elevation coordinate included with horizontal coordinates

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Distribution Information:

Distributor:
Contact information:
Contact person primary:
Contact person: Shannon L. Philippus
Contact organization: South Florida Water Management District
Contact position: GIS Data Manager Specialist

Contact address:
Address type: mailing and physical address
Address:
3301 Gun Club Road
City: West Palm Beach
State or province: Florida
Postal code: 33406
Country: USA

Contact voice telephone: (561) 682-2341
Contact facsimile telephone: (561) 682-5929

Contact electronic mail address: gisdata@sfwmd.gov
Contact electronic mail address: sphilipp@sfwmd.gov

Resource description: Refer to Citation.

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Standard order process:
Digital form:
Digital transfer information:
Format name: ARCE
Format version number: ArcGIS 9.2
Transfer size: 0.071

Digital transfer option:
Online option:
Computer contact information:
Network address:
Network resource name: http://www.sfwmd.gov

Fees: There is no charge for downloading South Florida Water Management District's datasets.
Ordering instructions:
Refer to SFWMD's website to see if this dataset is available online.
GIS Data Catalog: http://my.sfwmd.gov/gisapps/sfwmdxwebdc/
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Custom order process:
Custom maps/data to the public's specifications are not available.
Technical prerequisites:
GIS software capable of importing and reading ArcGIS raster formats.

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Metadata Reference Information:

***Metadata date:** 20100920

***Language of metadata:** en

Metadata contact:
Contact information:
Contact person primary:
Contact person: Diana Umpierre, GISP
Contact organization: South Florida Water Management District/ Water Supply Mngt Dept
Contact position: Sr Geographer

Contact address:
Address type: mailing and physical address
Address:
3301 Gun Club Road
City: West Palm Beach
State or province: Florida
Postal code: 33406
Country: USA

Contact voice telephone: (561) 682-6822

Contact electronic mail address: dumpier@sfwmd.gov

***Metadata standard name:** FGDC Content Standards for Digital Geospatial Metadata
***Metadata standard version:** FGDC-STD-001-1998
***Metadata time convention:** local time

Metadata access constraints: None
Metadata use constraints:
None

Metadata extensions:
***Online linkage:** http://www.esri.com/metadata/esriprof80.html
***Profile name:** ESRI Metadata Profile

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Appendix B-B

Example Geoprocessing Log for SLR Inundation Vulnerability Grid Layers

****

Example Geoprocessing Log for SLR Inundation Vulnerability Grid Layers

****

Layers were processed in October 2010 by Diana Umpierre (SFWMD)

The following are the common processsing steps conducted to generate the SLR inundation vulnerability grid layers for each of four Compact counties (Monroe (including Florida Keys), Miami-Dade, Broward and Palm Beach). This example log is based on the 50-ft Broward County DEM, but steps are the same for other areas.

Geoprocessing was conducted using ESRI's ArcGIS Desktop 9.3 (ArcInfo level), with the Spatial Analyst Extension, using ArcCatalog command line and the Raster Calculator tool within ArcMap. Processing was done using ArcInfo grids, but final output layers were exported to raster datasets in a file geodatabase.

All input elevation layers were in the same horizontal coordinate system and vertical datum:
Horizontal: FL State Plane Coordinate System, East Zone, NAD83/HARN, US Survey Feet
Vertical: NAVD 88, US Survey Feet

Notes:

\\<server>\<share>\<analysis_directory>	root path where analysis was conducted
[MHHW_NAVD88_TidalGrid]	input layer, as named within ArcMap, representing NOAA's MHHW Tidal Surface (version 1) – 1500 ft cell size
[2007 Broward 50-ft DEM, v1]	input layer, as named within ArcMap, representing SFWMD's topo DEM for Broward County (version 1) – 50 ft cell size
grd_temp	sub-directory for temporary ArcINFO grid files
fgdb	sub-directory for final output layers, stored in a file geodatabase
MMU	minimum mapping unit ~ 0.5 acre (9 cells)
RMSE	root mean square error (0.46 ft)

Final Output File Geodatabase: **BR50_SLR_Analysis_v1.gdb**

BR50_0ftSLR_Extent_NZ	BR50_1ftSLR_ZPClass	BR50_2ftSLR_ZPClass	BR50_3ftSLR_ZPClass
	BR50_1ftSLR_ZPClass_MMU	BR50_2ftSLR_ZPClass_MMU	BR50_3ftSLR_ZPClass_MMU
	BR50_1ftSLR_Extent_NZ	BR50_2ftSLR_Extent_NZ	BR50_3ftSLR_Extent_NZ
	BR50_1ftSLR_Depth_NZ	BR50_2ftSLR_Depth_NZ	BR50_3ftSLR_Depth_NZ
	BR50_1ftSLR_Extent_NZ_AI	BR50_2ftSLR_Extent_NZ_AI	BR50_3ftSLR_Extent_NZ_AI

Color has been added to text in this log to help follow process logic and input/output layers.

Process Steps:

0ft SLR - To get baseline; assumes no sea level rise.

Zero SLR Extent - **BR50-0ftE** – Grid cells with a value of 1 represent areas where the land elevation is at or below the current MHHW tidal surface elevation (without adding any SLR). These areas might include inland water bodies and/or low areas near the coast that may already be under the influence of the current MHHW tide.

Using ArcMap Spatial Analyst Raster Calculator
-- under SA toolbar options:
> analysis extent: Intersection of Inputs
> analysis cell size: Minimum of Inputs

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-0ftE**=
con(([2007 Broward 50-ft DEM, v1] <= ([MHHW_NAVD88_TidalGrid])),1)

Using ArcCatalog Command Line
workspace \\<server>\<share>\<analysis_directory>

-- copying to file geodb
CopyRaster grd_temp**BR50-0ftE** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_0ftSLR_Extent_NZ** # # # NONE NONE #

-- reverse the values in order to create a mask to be used at a later step (mark grids not affected at 0ft SLR)
Reclassify_sa grd_temp\BR50-0fte VALUE "1 NODATA;NODATA 1" grd_temp\BR50-0ftemsk DATA

1ft SLR

Without Accounting for Elevation Uncertainty

Using ArcMap Spatial Analyst Raster Calculator
-- under SA toolbar options:
> analysis extent: Intersection of Inputs
> analysis cell size: Minimum of Inputs

Inundation Extent - **BR50-1ftE**

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-1ftE**=
con(([2007 Broward 50-ft DEM, v1] <= (1 + [MHHW_NAVD88_TidalGrid])),1)

Depth (for Inundation Extent) - **BR50-1ftD**

\\<server>\<share>\<analysis_directory>\grd_temp\BR50-1ftD=
con(([2007 Broward 50-ft DEM, v1] <= (1 + [MHHW_NAVD88_TidalGrid])), ((1 + [MHHW_NAVD88_TidalGrid]) - [2007 Broward 50-ft DEM, v1]))

Using ArcCatalog Command Line
-- most steps require Spatial Analyst and/or ArcEditor or above

Inundation Extent: Added Inundation - **BR50-1ftE_I**
-- first, using the 0ft SLR, created a mask by reversing values (done at an earlier step)
-- using the mask, generate a grid with only the added inundated areas, over areas already covered by water at current MHHW (0ft SLR)

workspace \\<server>\<share>\<analysis_directory>
ExtractByMask_sa grd_temp\BR50-1ftE grd_temp\BR50-0ftEmsk grd_temp**BR50-1ftE_I**

Using Z-Score/Cumulative Probability

Using ArcMap Spatial Analyst Raster Calculator
-- under SA toolbar options:
> analysis extent: Intersection of Inputs
> analysis cell size: Minimum of Inputs

Z Scores - **BR50-1ftZ**

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-1ftZ**=
((1 + [MHHW_NAVD88_TidalGrid]) - [2007 Broward 50-ft DEM, v1]) / 0.46

P Classified Z Scores (25-75,>75) - **BR50-1ftZP**
-- grid cells are re-classified into 2 values based on two ranges of Z scores
-- 25 is assigned if Z-scores represent 25% to 74.9% probability
-- 75 is assigned if Z-scores represent >= 75% probability

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-1ftZP**=
con(([BR50-1ftZ] >= -0.67 & [BR50-1ftZ] < 0.67),25,con([BR50-1ftZ] >= 0.67,75))

Using ArcCatalog Command Line
-- most steps require Spatial Analyst and/or ArcEditor or above

P Classified Z Scores >= MMU of ½ acre - **BR50-1ftZPC**
-- same as above, but exclude connected cells that are less than the MMU

--- The general steps are as follow:
>> assign a value of 1 to all cells representing 25% or higher probability
>> create a mask of cells that connected make up areas of 1/2 acre or larger, using a neighborhood of 8 cells (so diagonally-connected cells are selected)
>> use this mask to generate a grid with the P-classified Z scores that will only include connected cells that make up areas 1/2 acre or larger

workspace \\<server>\<share>\<analysis_directory>\grd_temp

-- assign a value of 1 to all cells representing 25% or higher probability
Con_sa BR50-1ftzp 1 BR50-1-zpa # '"VALUE" >= 25' -> note: this will not create pyramids

-- a grid with the count of connected cells within an 8-cell neighborhood
RegionGroup_sa BR50-1-zpa BR50-1-zpaRG EIGHT WITHIN

-- this creates a mask w/ only cells that represent 1/2 acres or larger
-- 9 cells is the equivalent to ½ acre in a 50-ft DEM
Con_sa BR50-1-zpaRG BR50-1-zpaRG BR50-1-zpac # '"COUNT" >= 9'

-- using the mask, generate a grid with the P-classified Z scores
-- that will only include connected cells that make up areas 1/2 acre or larger
ExtractByMask_sa BR50-1ftzp BR50-1-zpac **BR50-1ftZPC**

Export final grids to file geodb

Using ArcCatalog Command Line
workspace \\<server>\<share>\<analysis_directory>

P Classified Z Scores (25-75,>75)
CopyRaster grd_temp**BR50-1ftZP** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_1ftSLR_ZPClass** # # # NONE NONE #

P Classified Z Scores >= MMU of ½ acre
CopyRaster grd_temp**BR50-1ftZPC** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_1ftSLR_ZPClass_MMU** # # # NONE NONE #

Inundation Extent
CopyRaster grd_temp**BR50-1ftE** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_1ftSLR_Extent_NZ** # # # NONE NONE #

Depth (for Inundation Extent)
CopyRaster grd_temp**BR50-1ftD** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_1ftSLR_Depth_NZ** # # # NONE NONE #

Inundation Extent: Added Inundation (over what's covered by water at 0ft SLR)
CopyRaster grd_temp**BR50-1ftE_I** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_1ftSLR_Extent_NZ_AI** # # # NONE NONE #

Delete temp grids no longer needed
----

workspace \\<server>\<share>\<analysis_directory>\grd_temp
Delete BR50-1ftE
Delete BR50-1ftE_I
Delete BR50-1ftD
Delete BR50-1ftZ
Delete BR50-1ftZP
Delete BR50-1-ZPA
Delete BR50-1-ZPARG
Delete BR50-1-ZPAC
Delete BR50-1ftZPC

2ft SLR

- for comments related to processing, see 1ft SLR

Without Accounting for Elevation Uncertainty

Using ArcMap Spatial Analyst Raster Calculator

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-2ftE** = con(([2007 Broward 50-ft DEM, v1] <= (2 + [MHHW_NAVD88_TidalGrid])),1)

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-2ftD** = con(([2007 Broward 50-ft DEM, v1] <= (2 + [MHHW_NAVD88_TidalGrid])), ((2 + [MHHW_NAVD88_TidalGrid]) - [2007 Broward 50-ft DEM, v1]))

Using ArcCatalog Command Line

workspace \\<server>\<share>\<analysis_directory>
ExtractByMask_sa grd_temp\BR50-2ftE grd_temp\BR50-0ftEmsk grd_temp**BR50-2ftE_I**

Using Z-Score/Cumulative Probability

Using ArcMap Spatial Analyst Raster Calculator

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-2ftZ** = ((2 + [MHHW_NAVD88_TidalGrid]) - [2007 Broward 50-ft DEM, v1]) / 0.46

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-2ftZP** = con(([BR50-2ftZ] >= -0.67 & [BR50-2ftZ] < 0.67),25,con([BR50-2ftZ] >= 0.67,75))

Using ArcCatalog Command Line

workspace \\<server>\<share>\<analysis_directory>\grd_temp
Con_sa BR50-2ftzp 1 BR50-2-zpa # '"VALUE" >= 25'
RegionGroup_sa BR50-2-zpa BR50-2-zpaRG EIGHT WITHIN
Con_sa BR50-2-zpaRG BR50-2-zpaRG BR50-2-zpac # '"COUNT" >= 9'
ExtractByMask_sa BR50-2ftzp BR50-2-zpac **BR50-2ftZPC**

Export final grids to file geodb

Using ArcCatalog Command Line

workspace \\<server>\<share>\<analysis_directory>
CopyRaster grd_temp**BR50-2ftZP** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_2ftSLR_ZPClass** # # # NONE NONE #
CopyRaster grd_temp**BR50-2ftZPC** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_2ftSLR_ZPClass_MMU** # # # NONE NONE #
CopyRaster grd_temp**BR50-2ftE** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_2ftSLR_Extent_NZ** # # # NONE NONE #

CopyRaster grd_temp**BR50-2ftD** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_2ftSLR_Depth_NZ** # # # NONE NONE #
CopyRaster grd_temp**BR50-2ftE_I** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_2ftSLR_Extent_NZ_AI** # # # NONE NONE #

Delete temp grids no longer needed
----

workspace \\<server>\<share>\<analysis_directory>\grd_temp
Delete BR50-2ftE
Delete BR50-2ftE_I
Delete BR50-2ftD
Delete BR50-2ftZ
Delete BR50-2ftZP
Delete BR50-2-ZPA
Delete BR50-2-ZPARG
Delete BR50-2-ZPAC
Delete BR50-2ftZPC

3ft SLR
- for comments related to processing, see 1ft SLR

Without Accounting for Elevation Uncertainty

Using ArcMap Spatial Analyst Raster Calculator

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-3ftE** = con(([2007 Broward 50-ft DEM, v1] <= (3 + [MHHW_NAVD88_TidalGrid])),1)

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-3ftD** = con(([2007 Broward 50-ft DEM, v1] <= (3 + [MHHW_NAVD88_TidalGrid])), ((3 + [MHHW_NAVD88_TidalGrid]) - [2007 Broward 50-ft DEM, v1]))

Using ArcCatalog Command Line
workspace \\<server>\<share>\<analysis_directory>
ExtractByMask_sa grd_temp\BR50-3ftE grd_temp\BR50-0ftEmsk grd_temp**BR50-3ftE_I**

Using Z-Score/Cumulative Probability

Using ArcMap Spatial Analyst Raster Calculator

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-3ftZ** = ((3 + [MHHW_NAVD88_TidalGrid]) - [2007 Broward 50-ft DEM, v1]) / 0.46

\\<server>\<share>\<analysis_directory>\grd_temp**BR50-3ftZP** = con(([BR50-3ftZ] >= -0.67 & [BR50-3ftZ] < 0.67),25,con([BR50-3ftZ] >= 0.67,75))

Using ArcCatalog Command Line

workspace \\<server>\<share>\<analysis_directory>\grd_temp
Con_sa BR50-3ftzp 1 BR50-3-zpa # '"VALUE" >= 25'
RegionGroup_sa BR50-3-zpa BR50-3-zpaRG EIGHT WITHIN
Con_sa BR50-3-zpaRG BR50-3-zpaRG BR50-3-zpac # '"COUNT" >= 9'
ExtractByMask_sa BR50-3ftzp BR50-3-zpac **BR50-3ftZPC**

Export final grids to file geodb

Using ArcCatalog Command Line

workspace \\<server>\<share>\<analysis_directory>
CopyRaster grd_temp**BR50-3ftZP** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_3ftSLR_ZPClass** # # # NONE NONE #
CopyRaster grd_temp**BR50-3ftZPC** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_3ftSLR_ZPClass_MMU** # # # NONE NONE #
CopyRaster grd_temp**BR50-3ftE** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_3ftSLR_Extent_NZ** # # # NONE NONE #
CopyRaster grd_temp**BR50-3ftD** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_3ftSLR_Depth_NZ** # # # NONE NONE #
CopyRaster grd_temp**BR50-3ftE_I** fgdb\BR50_SLR_Analysis_v1.gdb**BR50_3ftSLR_Extent_NZ_AI** # # # NONE NONE #

Delete temp grids no longer needed
----

workspace \\<server>\<share>\<analysis_directory>\grd_temp
Delete BR50-3ftE
Delete BR50-3ftE_I
Delete BR50-3ftD
Delete BR50-3ftZ
Delete BR50-3ftZP
Delete BR50-3-ZPA
Delete BR50-3-ZPARG
Delete BR50-3-ZPAC
Delete BR50-3ftZPC

Last Cleanup - Delete temp grids no longer needed
----

workspace \\<server>\<share>\<analysis_directory>\grd_temp
Delete BR50-0ftE
Delete BR50-0ftEmsk

Appendix C - Southeast Florida Climate Change Compact - Vulnerability Analysis Methodology

Introduction

Broward County GIS was tasked with the Inundation Mapping and Vulnerability Analysis using the 50-foot cell size inundation grids created by the South Florida Water Management District. The inundation grids were for 1, 2, and 3 feet of sea level rise (SLR) and were generated from the most recent LiDAR DEM and the mean higher-high water vertical datum grid provided by NOAA. While these inundation grids had water features removed from along the coastline, areas such as inland rivers, lakes, and canals were still present. Broward County keeps a fairly accurate water dataset that was digitized at a scale ranging from 1:600 to 1:1200 using 1998 and 1999 aerial photography and is updated as necessary with more recent photography. This data includes all water bodies greater than 10 feet in width. It was decided that this layer can be used to remove the water features from the inundation grid, reducing the number of polygons generated during the raster to poly conversion and helping speed data analysis (Figure 1). This waterless inundation grid with a minimum mapping unit of ½ acre was used for all vulnerability analyses.

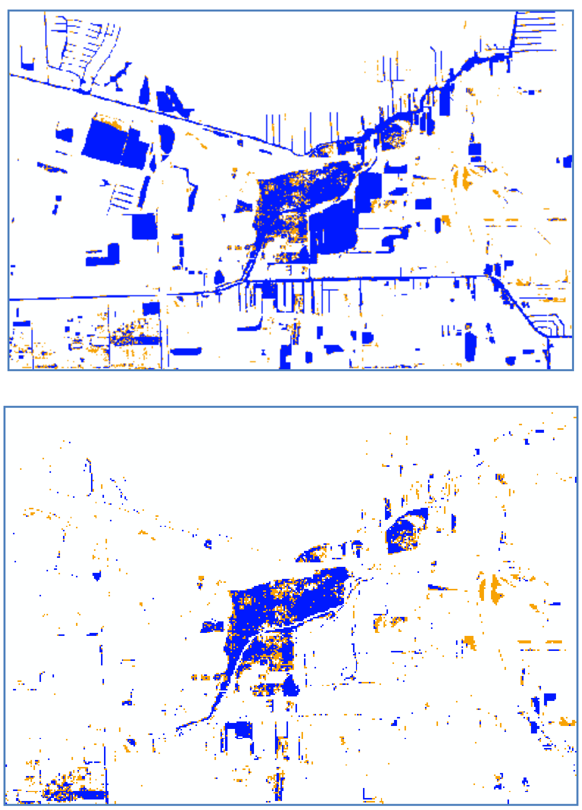


Figure 1: (Top) Inundation grid without water features removed.
(Bottom) Inundation grid after water feature removal

The critical infrastructure data to be evaluated was divided into Physical Features and Results of Analysis by the Compact Committee members and was ranked in order of importance. As a reminder, the list of data is provided below:

Physical Features

- Ports and airports
- Railroads
- Water & wastewater treatment plants
- Power plants
- Drainage infrastructure
- Landfills
- Hospitals Emergency shelters
- Evacuation routes
- Schools
- Endangered species

Results of Analysis

- Taxable value of property
- Miles of road by FDOT category (noting that they include bridges)
- Acres of future land use
- Acres by habitat type

Parcels and Taxable Value

Geographic boundaries of Broward County parcels, or BCPA parcels, are provided by the Property Appraiser's office. They do not contain individual parcel attributes except for folio number and, therefore, must be joined with a tax roll spreadsheet to obtain the latest attribute information. This works fine for most of the records; however, parcel polygons that contain multiple tax records per parcel (notably condos) will return a null value during the join and must be dealt with separately to order to append county taxable values.

For these condo parcels with a null value, taxable value was summarized per folio subdivision then divided equally among corresponding parcels. For example, condo parcel 494318BA0000 (Figure 2) has 15 tax records within it valued at varying amounts. That one parcel would be given a total value of \$4,285,640 - the sum of all folios in subdivision 494318BA divided by one parcel polygon.

FOLIO_NUMBER	COUNTY_TAXABLE
494318BA0010	249710
494318BA0020	286610
494318BA0030	286610
494318BA0040	288780
494318BA0050	288780
494318BA0060	195110
494318BA0070	290920
494318BA0080	290920
494318BA0090	290920
494318BA0100	293080
494318BA0110	293080
494318BA0120	293080
494318BA0130	273000
494318BA0140	295240
494318BA0150	369800

Figure 2: Consolidating Taxable Value for one multi-unit parcel polygon

Similarly, if there are 3 parcels each labeled 494318AN0000 (Figure 3) and the total value of all 19 condo units in 494318AN subdivision is $18,467,780, each 494318AN0000 parcel would be given a value of $6,155,927. While this methodology presents some inaccuracies with different sized building parcels, manually assessing individual folios is unfeasible given current time constraints.

FOLIO_NUMBER *	COUNTY_TAXABLE
494318AN0010	638140
494318AN0020	882270
494318AN0030	638140
494318AN0040	803260
494318AN0050	908360
494318AN0060	865510
494318AN0070	882270
494318AN0080	638140
494318AN0090	731000
494318AN0100	773500
494318AN0110	638140
494318AN0120	807500
494318AN0130	730060
494318AN0140	908360
494318AN0150	638140
494318AN0160	638140
494318AN0170	908360
494318AN0180	734700
494318AN0190	882270
494318AN0200	638140
494318AN0210	638140
494318AN0220	865510
494318AN0230	908360
494318AN0240	771370

Figure 3: Consolidating Taxable Value for multiple multi-unit parcel polygons

Figure 4: Distinct Condo Parcels, keeping '0000' a null value

FOLIO	COUNTY_TAXABLE
494224AJ0000	<Null>
494224AJ0010	23000
494224AJ0020	23000
494224AJ0030	48000
494224AJ0040	23000
494224AJ0050	23000
494224AJ0060	48000

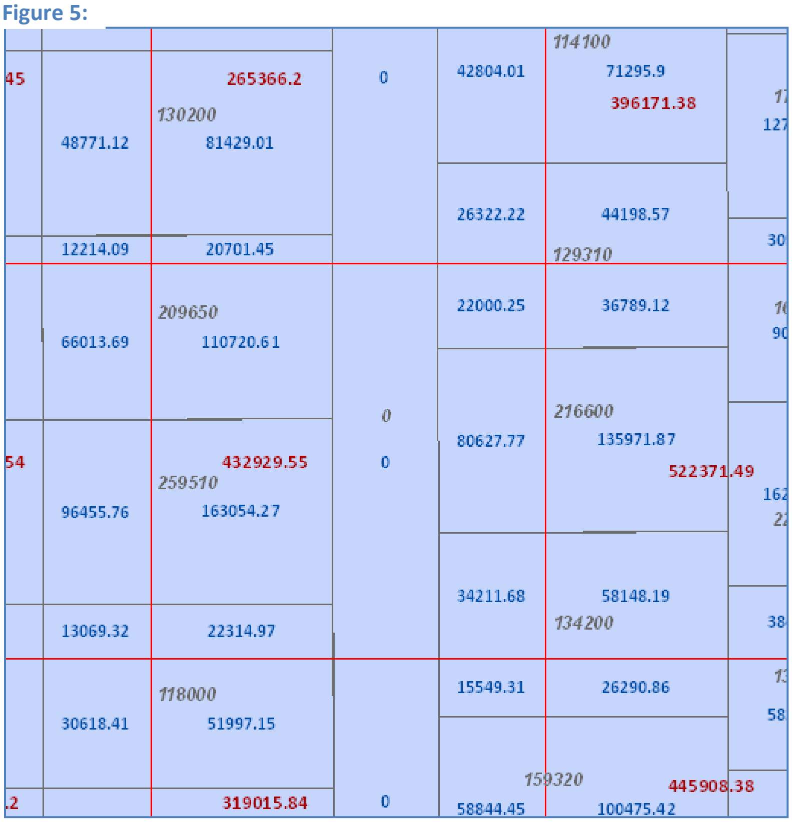
Problems can still arise where condos units are actually given individual parcel polygons, but the grounds keep the '0000' folio extension (Figure 4). In this case, the null value associated with folio 494224AJ0000 SHOULD remain null. To preserve the null value in these cases, criteria was put in place to determine if distinct condo parcels existed in the parcel polygon layer. Subdivisions that had these distinct parcels did not have the '0000' null value updated to a consolidated tax value.

In the end, of the 8,461 condo parcels that initially had a null value, 4,855 parcels were assigned a new county taxable amount using the described methodology, equating to $19,319,397,930 of potentially unaccounted taxable value.

Comparing Aggregated Parcel (pGrid) and Parcel Analysis

As per the recommended methodology, a 150-foot pGrid was generated over Broward County using ArcInfo Workstation. Workstation was used for the pGrid generation because of frequent drawing and '99999'-related ArcMap application errors using the 'Create Fishnet' tool in Arc Toolbox. The pGrid spanned from the southwest (836951,590405) to the northeast corner (959529,735681) corner of the County and was converted into polygons from the initial polyline output. After migrating the pGrid from Workstation to ArcMap, it was intersected with parcels and the taxable values were divided based on the percentage of the parcel within the pGrid. The partial parcel taxable values were then summarized per pGrid (Figure 5).

Figure 5:



Red –pGrid Taxable

Blue – Parcel Portion Taxable

Grey – Original Parcel Taxable

During the sea level rise analysis for the Broward County Climate Change Task Force Committee in mid-2009, it was determined that reporting any parcel inundation results would be best if we worked with just the area of the parcel located on land. Since water features were already removed from the inundation grids, this was not a concern at first. However, initial tests showed that because the pGrid still contained water areas, the percent inundation calculated could actually be misrepresented (Figure 6). Therefore, using the same methodology as that in 2009, after pGrids were generated and taxable values were assessed and joined, the Broward County water layer was used once again and erased from the pGrid extent (Figure 7).

Figure 6: pGrids without water features removed

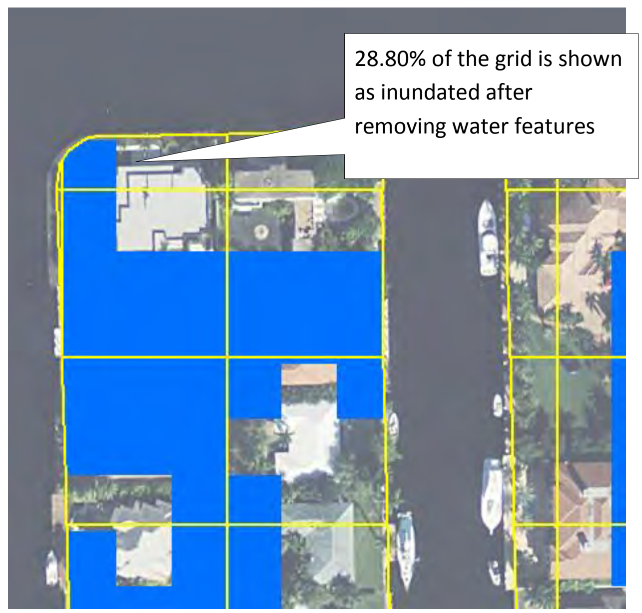


Figure 7: pGrids with water features removed

Using purely the extent of inundation, until more precise methodologies can be agreed upon, grids were selected that had at least 25% inundation. County taxable value was summarized. The results are below:

One Foot	Two Foot	Three Foot
$828,221,857	$3,779,685,458	$12,109,037,157

In comparison, using the same methodology just with parcels and not implementing the pGrid method), the following results were produced:

One Foot	Two Foot	Three Foot
$500,659,372	$2,429,813,855	$10,119,596,199

This gives +65.4% more taxable value affected at 1-foot inundation using the grid method, +55.6% more at 2-foot inundation, and +19.7% more at 3-foot inundation for Broward County. Figures 8 and 9 on the following page shows what may be causing the differences between the two methods.

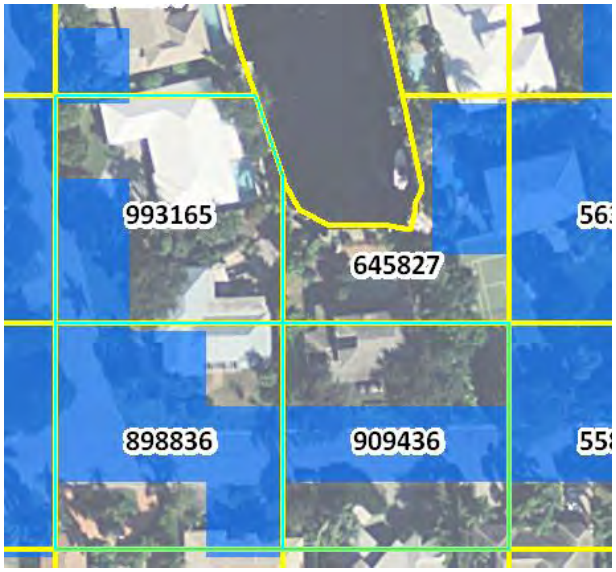


Figure 8: PGrids selected in green with at least 25% inundation. Total taxable value: $2,801,437

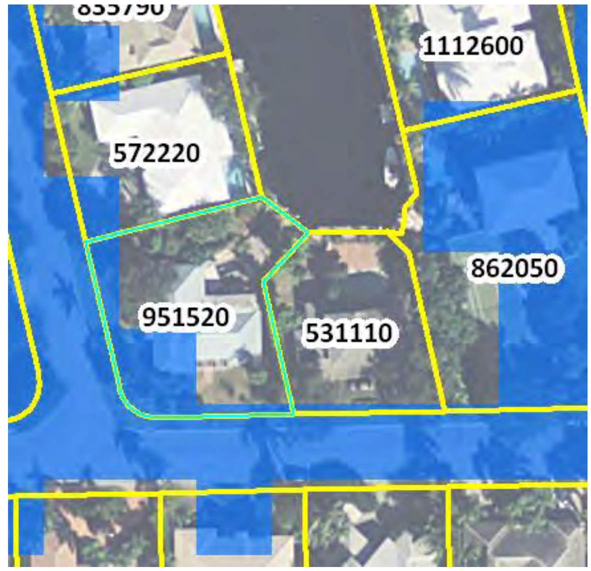


Figure 9: Parcels in same area selected in green with at least 25% inundation. Total taxable value: $951,520

One advantage of using strictly the parcel method is the ability to break down the affected taxable value by type of current land use, as found in the tax roll database. For example, at a 1-foot inundation, the top three affected land uses based on current use code are:

County Taxable	Description
$ 278,371,892	04 Condominium
$ 45,521,740	00 Vacant residential
$ 40,803,340	01 Single family

Miles of Road by FDOT Category

NAVTEQ data used in this analysis was provided by Florida Department of Transportation and is dated from the second quarter of 2009. The initial problem noted with street datasets is that the streets are depicted as centerlines. Therefore, when discussing the inundation of streets, intersecting inundation polygons with streets will only produce results when the inundation crosses over the depicted line. To try and alleviate this problem, street centerlines were buffered and turned into polygons based on several key attributes found within the NAVTEQ table. More specifically, these attributes are TO_LANES, FROM_LANES, LANE_CAT, and DIR_TRAVEL. From the NAVTEQ Reference Manual v3:

TO_LANES/FROM_LANES: Indicates the number of lanes applicable for each direction of travel on the road segment and can be used for cartographic representation of road widths on printed maps. *Does not include turn lanes, emergency lanes, bus lanes, or ramps*.

LANE_CAT: Classifies a road based on the number of lanes in each direction and can be used for cartographic representation of road widths on printed maps. It should be used in conjunction with Dir_Travel to determine street width. Can be "1" (one Lane), "2" (two or three lanes), or "3" (four or more lanes)

DIR_TRAVEL: Can be "B" (Both directions), "F" (From Reference Node), or "T" (To Reference Node)

In addition to these attributes, it was necessary to determine average lane width. Based on aerial photography and spot checking, it was determined that an average lane width of 12 feet would be used to buffer the centerlines. Because LANE_CAT is more generic than TO/FROM_LANES, it was used only if the latter contains an empty value.

Studying the data yielded these initial observations:

- A segment of road classified as DIR_TRAVEL "B" with a TO or FROM_LANE of 2 means that there is one centerline representing two lanes in each direction (4 lanes total)
- A segment of road classified as DIR_TRAVEL "T" or DIR_TRAVEL "F" with a TO or FROM_LANE of 2 means that the road is a one way street with two lanes or a doubly digitized road with two lanes in the specified direction.

The following fields were kept in the dataset, all others were deleted:

OBJECTID	Object ID
Shape	Geometry
LINK_ID	Double
ST_NAME	Text
FEAT_ID	Double
FUNC_CLASS	Text
TO_LANES	Double
FROM_LANES	Double
LANE_CAT	Text
DIVIDER	Text
DIR_TRAVEL	Text

The following fields were added to the dataset:

MILES	Double
BUFFER	Double

MILES field was calculated using the following formula in the field calculator:

MILES = Shape_Length / 5280

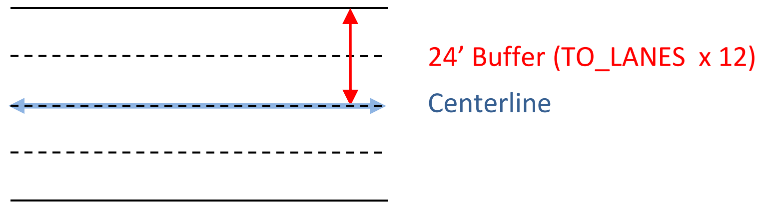
BUFFER field was calculated using the following formula in the field calculator:

```
Dim output as double
If [DIR_TRAVEL] = "B" Then
  If [TO_LANES] = 0 and [FROM_LANES] = 0
Then
      output = [LANE_CAT]*12
  Else
  If [TO_LANES] <> 0 Then
     output = [TO_LANES]*12
  Else
  If [FROM_LANES] <> 0 Then
      output = [FROM_LANES]*12
  End If
  End If
  End If
Else
    If [TO_LANES] = 0 and [FROM_LANES] =
0 Then
      output = ([LANE_CAT]/2)*12
    Else
    If [TO_LANES] <> 0 Then
     output = ([TO_LANES]/2)*12
    Else
    If [FROM_LANES] <> 0 Then
      output = ([FROM_LANES]/2)*12
    End If
    End If
    End If
End If
```

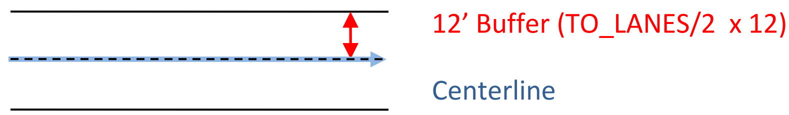
```
BUFFER = output
```

It is important to note that if the DIR_TRAVEL field is either T or F, that the buffer is calculated by taking the number of lanes and **dividing by 2** before multiplying by lane width.

When DIR_TRAVEL = B and TO_LANES = 2



When DIR_TRAVEL = T and TO_LANES = 2



The result was not perfect; however, it was much improved over using just the centerlines.

BLACK = NAVTEQ Centerlines Red = New Polygon Roads

Figure 10: Screenshot of Las Olas Blvd in downtown Fort Lauderdale

The problem with using polygon-based road features is how to assess linear miles of road affected. The mileage of each segment of road was preserved when creating/calculating the MILES field earlier, however, the result of the intersect between polygon roads and polygon inundation is, of course, a polygon.

Two possible methods of analysis were performed. The first method used the percent inundation of a road segment to translate to percent of miles affected. For example, the 5800 block of N Ocean Dr, which is ¼ miles in length, is 35% inundated at a 75% or greater probability. This would be calculated as 0.088 miles of **most likely** affected road (0.25 x 0.35). The second method used a standard percent of inundation similar to the parcel methodology described earlier. Any road segment that was at least 50% inundated (using just pure inundation extent) would be completely classified as affected. So, using our earlier example, if the 5800 block of N Ocean Dr was 50% inundated, the contribution toward affected miles would be all of ¼ miles.

There were some initial concerns with the results. First, NAVTEQ's use of doubly digitized roads sometimes doubled the mileage of affected roads. In the case of N Ocean Dr at 3 foot inundation, both lanes on either side of the median are inundated at either 25 – 74.9% probability or 75% and greater probability (Figure 11). Using either methodology above will result in N Ocean Dr essentially being counted twice in the results. No solution is currently known for fixing this problem. For now, it is noted in the results that the mileage may be skewed slightly by this effect.

Also, because of the cell size of the inundation grid, elevated roadways (most notably interstates) next to natural area had areas of inundation (Figure 12). Realistically, this would not be the case and also can be a problem in the results.

Figure 11: N Ocean Dr doubly digitized. Green represents possible inundation, blue represents more likely inundation. Purple lines are street centerlines. Here, the mileage of N Ocean Dr would be added up twice, once for each side of the road.

Figure 12: Interstate 595 next to Pond Apple Slough in Central Broward. It is highly unlikely that inundation would actually occur on I-595 at this location.

Acres of Future Land Use

Coverage of Future Land Use was provided by the Broward County Planning Council and was most recently updated on September 28, 2010. The analysis of the data was simply an intersect with the inundation polygons. For the final report, data was summarized by Land Use type and probability and reported in **acres**.

Acres of Habitat Type / Land Use Land Cover

Two datasets were analyzed for habitat type: One from the Florida Fish and Wildlife Conservation Committee (FWC) and the second from SFWMD. The latter dataset was discovered after the analysis of the FWC data and provided an interesting contrast. The FWC land use land cover layer was downloaded from the Florida Geographic Download Library (FGDL), listed as gfchab_03. It is dated March 2004, presented in raster format, extends through all of Florida, and is in Albers projection. The metadata lists 2003 Landsat ETM as the source imagery used in the classification process. Because of the state of the downloaded data, several pre-analysis steps were needed in order to prepare it for ArcMap analysis. First, the raster dataset was reprojected to State Plane Florida East HARN then clipped to Broward County's urban boundary. Finally, the raster file was converted to polygons. The data was intersected with the inundation grids to produce the final report by **acres**.

SFWMD's data, entitled Land Cover Land Use 2004, was downloaded from their GIS data catalog. It was already projected into State Plane Florida East HARN and in vector format. The only pre-analysis step required was a clip to Broward County's urban boundary. From the metadata on the download site: "This data set serves as documentation of land cover and land use within the South Florida Water Management District as it existed in 2004-05. Land cover/land use data was photo-interpreted from 2004-05 1:12,000 scale CIR, RGB and stereo panchromatic aerial photography and classified using the SFWMD modified FLUCCS classification system." The data was intersected with the inundation grids to produce the final report by **acres**. (http://my.sfwmd.gov/gisapps/sfwmdxwebdc/openxml.asp?file=metadata/meta_xml1813.xml&xsl=FGDCClassic.xls)

Because of the 4-digit FLUCCS code, the SFWMD land cover land use layer is more detailed than that of the FWC, which uses a generic GRIDCODE for each land use type. It was decided to extract out the first two coded values and use a more general description of land type. Data was summarized by Habitat type and probability and reported in acres. It includes all classifications to the 2-digit level of detail.

Ports and Airports

The airports dataset is a County-wide generalized polygonal layer. It contains the outlines of all four airports and their runways. This was used to select parcels in the area of the airports. Parcels were selected using the previous methods for parcels. Each group of related parcels was saved as a layer named after the airport. One, two and three foot inundation polygons layers were intersected with each airport's parcels.

The Port Everglades dataset was used to select the parcels within the Port. This layer is new and no metadata has been created yet. The analysis of the data was a result of a simple intersect with the inundation polygons. Less than ten percent of Port Everglades is flooded with the two foot sea level rise.

Three airports are not affected by one, two or three foot sea level rise, North Perry, Fort Lauderdale Executive and Pompano Municipal Airpark. At the three foot sea level rise, Fort Lauderdale-Hollywood Int'l Airport floods primarily on the green space between the buildings, runways and taxiways, as seen below. This analysis only looks at the intersection of two datasets. The functioning of the port and airports may be influenced by external factors such as flooded transportation systems. The external factors are not discussed here.

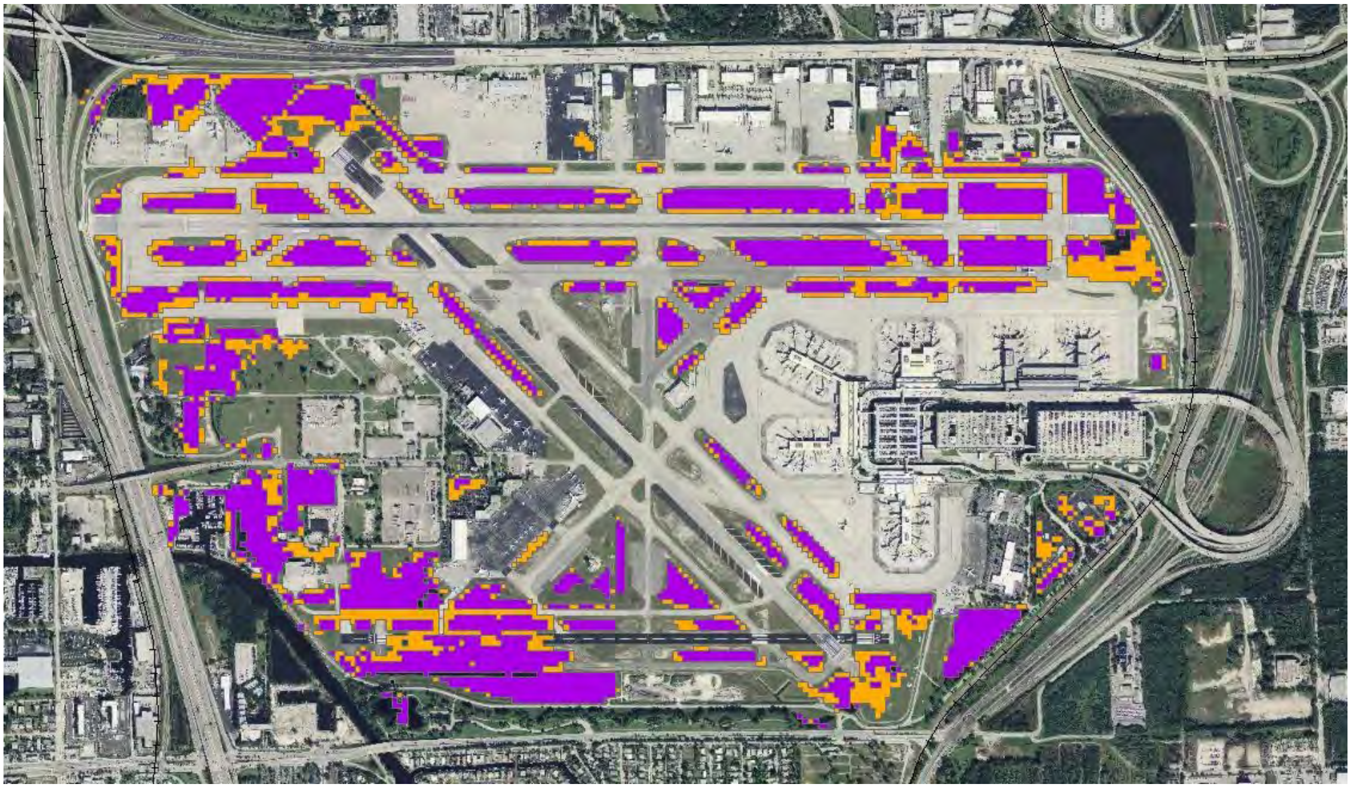


Figure 13: Broward's largest airport at a 3 foot sea level rise. Purple represents a 75% probability, (most likely) and orange, 25% or possible.

Figure 14: This portion of railroad may only be inundated as a result of the adjacent water body.

Railroads

Two primary railroad corridors exist in Broward County, running north and south in orientation through the County. The existing lines of the railroad dataset available for this project did not include spurs, sidings and rail yards. The CSX rail lines were expanded to reflect double tracking. Some corrections to positional geometry were made. The lines were converted using a buffer to a polygonal data type.

Because of the cell size of the inundation grid, railroads adjacent to natural/retention areas had some inundation, as shown. This is a potential source of error. For the final report, data was summarized by Owner Name and probability and reported in **feet.**

Water and Wastewater Treatment Plants

The wastewater treatment plant (WWTP) point dataset was updated in 2007 and includes fifteen wastewater treatment plants. The water treatment plant point data includes twenty-five water treatment plants.

The analysts reviewed the parcels in the vicinity of the point data. Parcels were chosen, based on ownership from the Broward County Property Appraisers GIS parcel dataset and related tax roll information. These parcels were placed into a new feature class. Specific undeveloped parcels were excluded based on a visual review of aerial photography.

The wastewater treatment plant (WWTP) dataset was updated in 2007 and includes fifteen wastewater treatment plants. Parcels were selected using the Parcel Selection Instructions, in the Hospitals Section.

Treatment plant complexes range in size from two to seventy-six acres.

A total of two acres of WWTP are flooded with a two foot sea level rise, and that acreage is located at the fringe of the parcels – mostly near retention areas. There is no flooding at 3 ft for Broward County North Regional WWTP or Sunrise Sawgrass WWTP, the two largest wastewater treatment plants in Broward County.

For the final report, data was summarized by Facility Name and probability and reported in **acres**.

Of concern with this analysis is the lack of understanding about the relationship between rising sea levels, existing water bodies and the WWTP systems. It is recommended that hydrologists play a major part in any further drainage analysis.

Landfills

Parcels, based upon ownership, were aggregated for this analysis of seven landfill sites. The South Ash Landfill had the most flooding at one, two and three foot inundation. The flooding appears to be primarily in natural/retention areas. It remains unclear whether the inundation at three feet would affect the operations of this landfill. The largest landfill complex, the Central Sanitary Landfill, is located miles from any inundation at any level. For the final report, data was summarized by Facility Name and probability and reported in **acres**.

Hospitals

Broward's Hospital layer includes twenty-six hospitals. Negligible flooding occurs to the hospital parcels layer. The two hospitals with some inundation are Memorial Hospital-Miramar and Geocare South Florida State Hospital. Both are shown below. The Broward hospitals experienced less than eleven acres of flooding with the three foot sea level rise. Local adjacent roadways surrounding the hospitals appeared to be inundated which could reduce the functionality of the hospitals.

Parcels were selected that intersected the hospital point dataset and visually inspected to validate the selection, adding any nearby hospital parcels that were not included in the initial intersection. These parcel groups were then used to create final hospital parcel layer. Special care was given to include parcels that shared common ownership based on the owner name field of tax roll table data. Parcels that were completely surrounded by hospital parcels were included. Of those selected parcels, undeveloped parcels (likely storm water management areas) were excluded based on the most current aerial photography.

For the final report, data was summarized by Hospital Name and probability and reported in **acres**

Figure 15: Three foot Sea Level Rise shown at Memorial Hospital-Miramar, left and Geocare South Florida State Hospital, right.

Emergency Shelters

Parcels were used to analyze 35 emergency shelters, which in Broward County are all located in public schools. There was no reportable flooding with a one foot sea level rise at our level of precision. The seven shelters located in Parkland, Margate, Coral Springs and Coconut Creek were untouched by any inundation. The most flooded shelter is West Broward High School. At the three foot SLR the flooding occurs only at the margins of the school property, and no structures are compromised. For the final report, data was summarized by Facility Name and probability and reported in **acres**.

Figure 16: At three foot SLR, the most flooded shelter has only 4.41 acres of inundation, which occurs at the margins of the school grounds.

Evacuation Routes

A dataset for Evacuation Routes was created specifically for this project. Based on local knowledge, it was determined that the set of State-owned roads would constitute the Evacuation Routes. The NAVTEQ streets layer was queried for state roads by using the query ST_NAME LIKE 'SR-%', knowing that the NAVTEQ state road naming conventions in Florida always include the characters "SR-". The results of this query were exported to a new dataset. It was noticed that excess roads were included in this layer and were most likely not part of major evacuation routes.

To find the incorrectly included streets, the data was compared to the Roadway Inventory layer, which is available from the Florida Department of Transportation. This coverage was originally created to depict the roadway functional classifications in Broward County. This coverage has been expanded to include roadway characteristics such as number of lanes, ownership / agency responsible for maintenance, and national highway system, last updated May 2009. A definition query of OWNSP = 'S' was used to select out state owned roadways. Roads included in initial roads "SR-" query that were not part of the newly filtered state roadway inventory were deleted. This clean dataset was used to calculate the linear mileage of the state roads.

The analysis was performed on this data using the Percent Inundation/Percent Affected method discussed in the Miles of Road by FDOT Category section. Some small segments of I-595 and I-95 are shown as inundated at the one foot SLR level. The interstates are of importance as part of our strategic intermodal system. The inundation appears to be a problem with the data. Upon closer examination the segments fall on the elevated portion of these highways, i.e. bridges.

Vehicular evacuation from the barrier islands is restricted to bridges, and access to these bridges may be inundated. At the three foot, 75% probability level, the evacuation network appears inundated in this area.

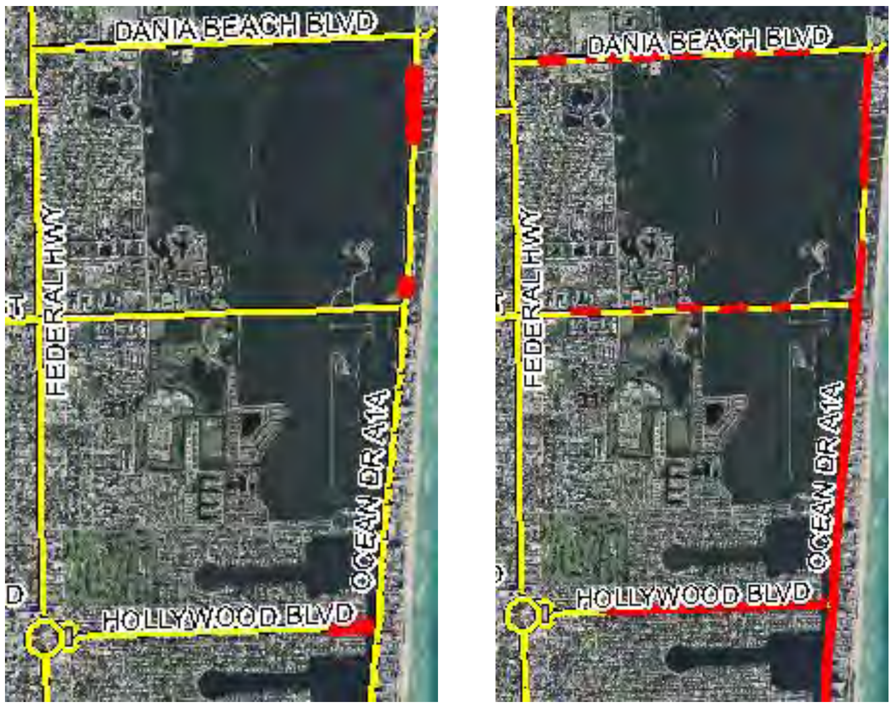


Figure 17: The left image shows a one foot sea level rise. The right image shows three foot SLR. The inundated areas, in red, are exaggerated to be seen at this scale; both reflect at least 75% probability.

For the final report, data was summarized by Street Name and probability and reported in **miles.**

Evacuation Route drawbridges and tunnels

Broward County has sixteen drawbridges on evacuation routes, eleven of those bridges crossing the Intracoastal Waterway. The Kinney Tunnel allows Federal Hwy to cross underneath the New River. All of these features are potential obstacles to evacuation. Analysis of this data was not requested, but the logic of including bridges and tunnels was inescapable once this study began.

An intersect was not performed on the bridges and tunnels point dataset for two reasons. These points would fall on the deleted water areas of inundation layers, thus no intersection. Also, the data has no elevation attributes, so, in reality these features would not intersect the inundation grid.

Thirteen features were declared problematic. Problematic was defined as any bridge or tunnel that could not be utilized in one or both directions, due to inundation at or leading to the feature. All draw bridges and tunnels were passable at one foot, six bridges were problematic at a two foot SLR and thirteen bridges were problematic at the three foot SLR.

Figure 18: This bridge crosses the Intracoastal Waterway. It appears to have nearby inundation, but the blue, flooded streets shown are actually U-shaped streets under the elevated bridge and do not affect its function.

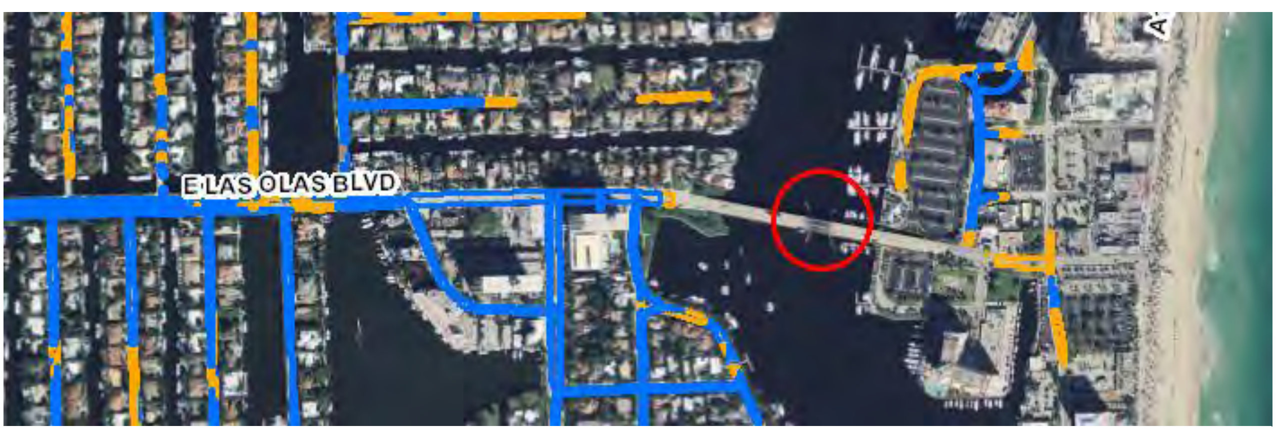


Figure 19: The bridge is circled in red. This bridge over the Intracoastal Waterway is shown with three foot flooding west (inland) of the bridge. With limited detour choices, this bridge may be an obstacle to evacuation of the barrier island.

Power Plants

The Power Plant spatial data was created for this analysis to document the location and acreage of the two existing electric power generating facilities in Broward County using the following methodology.

Parcels were selected by Florida Power & Light (FPL) ownership from the Broward County Property Appraisers parcel layer and related tax roll table. These parcels were in the vicinity of FPL Lauderdale Plant and the FPL Port Everglades Power Plant. The undeveloped or submerged parcels were deleted; this meant that the large FPL cooling lakes are not included in the acreage or analysis. The use or function of some of the FPL-owned parcels was unclear in the aerial photography. Our decision was to err on the side of over-inclusion when combining parcels to represent a given complex.

Thus, only the developed parcels owned by FPL, surrounding the two known power plants were included in the analysis. For this analysis, the FPL Port Everglades Power Plant has 93.2 acres and the FPL Lauderdale Power Plant has 218.7 acres.

Schools

There are 239 K-12 public schools in Broward County. At one foot SLR, four schools are more likely to have inundation only at the natural/retention areas. Ten schools are more likely to be inundated at the two foot level. All of the flooding appears only at the margins of the parcels in natural areas.

Only seven schools are more likely to have greater than one acre of flooding at the three foot SLR. Of those, only one building appears compromised, as shown here.

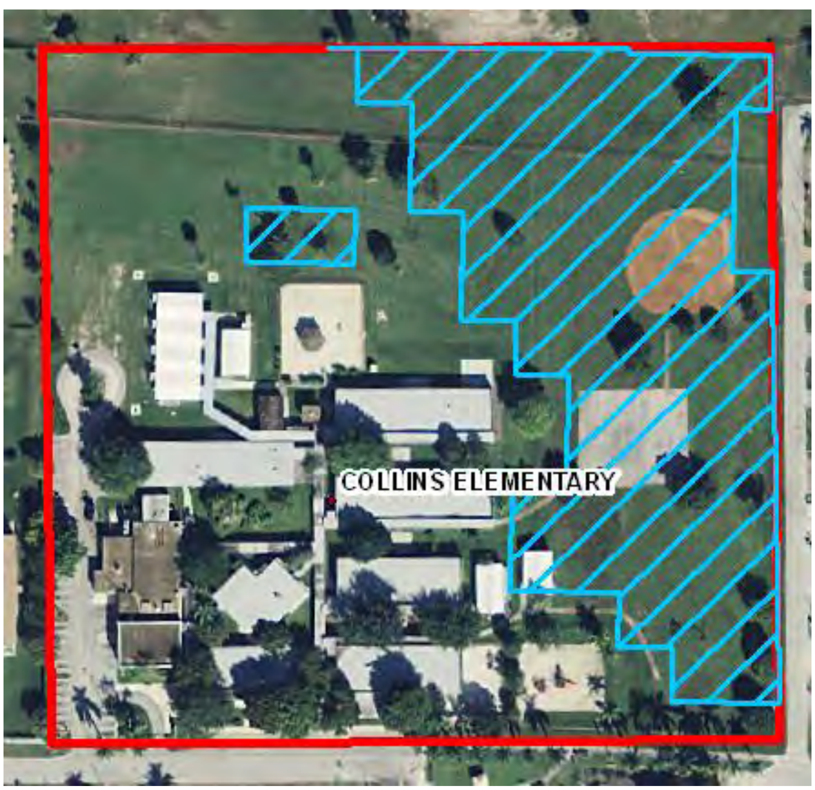


Figure 20: The most inundated school with a three foot SLR and a 75% probability. The 3.44 acres of flooding occurs primarily in the natural areas.