USACE/Broward County Flood Risk Management Study for Tidally Influenced Coastal Areas

Briefing for Climate Change Task Force

Sep 04, 2018

Fort Lauderdale, FL

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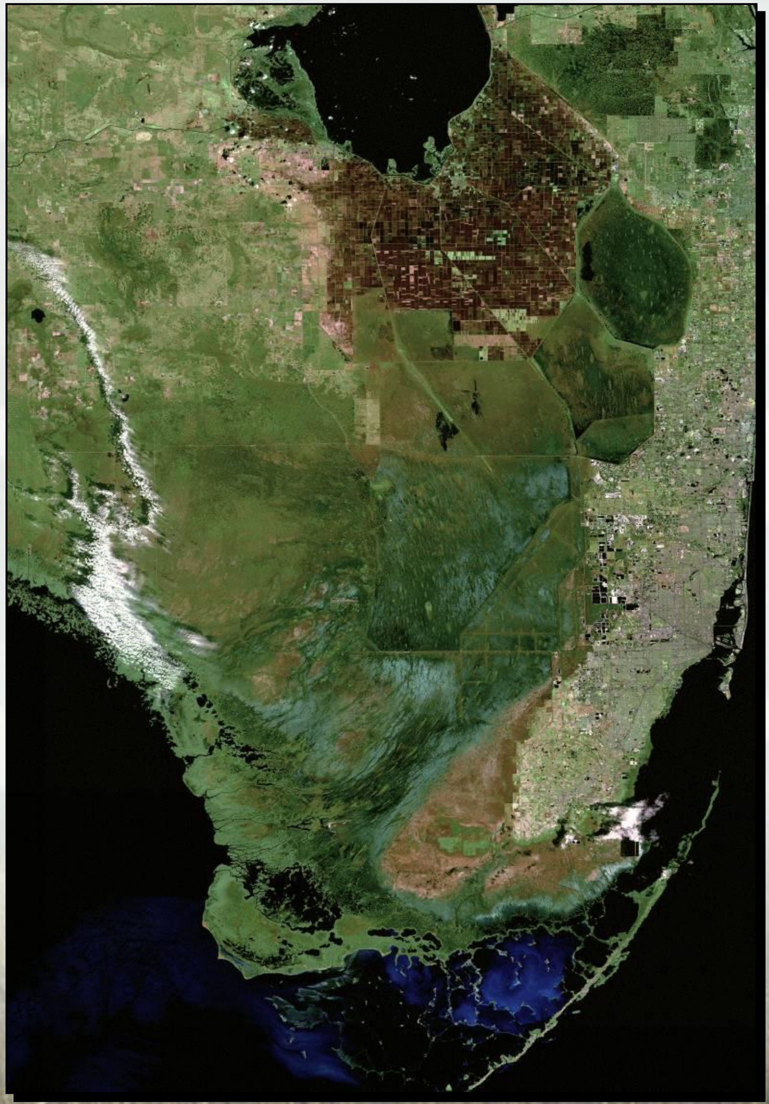
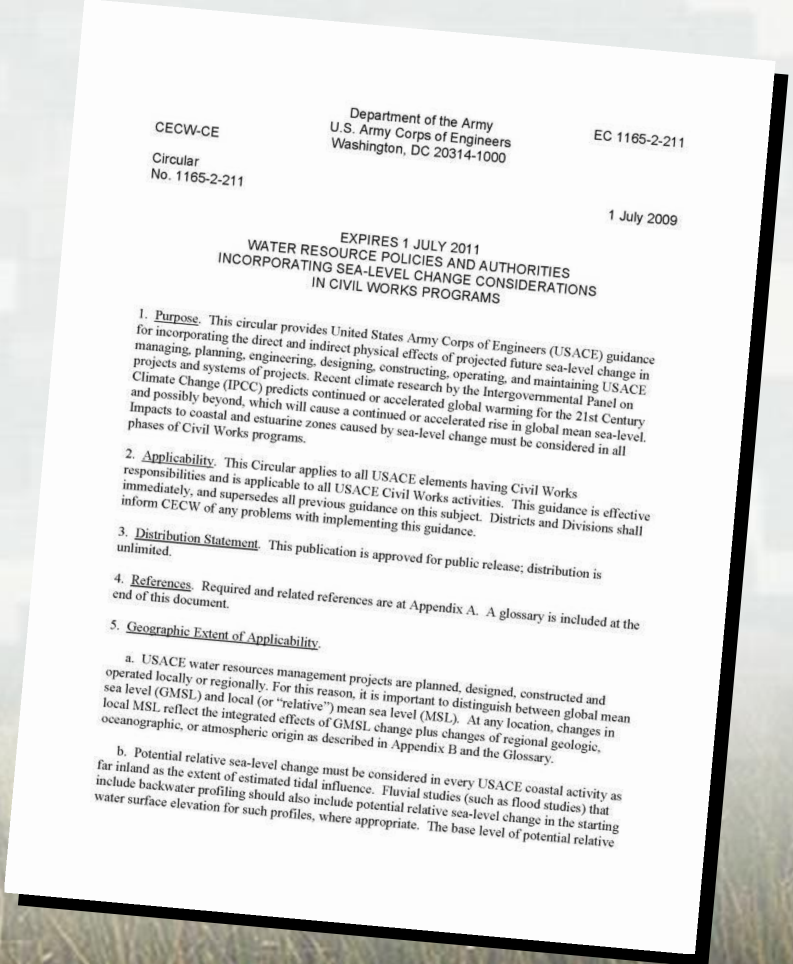
Presentation Outline

- Florida Sea Level Change (SLC) Current Trends and Projections
- Tidal Flood Risk Study (Risk Assessment)
  - Increasing Tidal Street Flooding
  - Study Areas & Seawalls
  - Storm Surge Modeling
  - Economic Risk Analysis
  - Study Findings
- Resilience Options (Risk Management)
  - Raise Seawalls a little or a lot
  - Redevelop when and where



USACE Guidance on Incorporating Sea Level Change Considerations

- EC 1165-2-212 was replaced with ER 1100-2-8162 on 31 Dec. 2013
- Permanent Design Requirement
- Applies to <u>all phases</u> of Corps Civil Works activities as far inland as extent of new tidal influence
- **ETL 1100-2-1, *<u>Procedures To Evaluate Sea Level Change: Impacts, Responses and Adaptation</u>* effective 31 March 2014 to 31 March 2019 calls for analysis of 20, 50 and 100-year epochs**



CECW-CE

Circular
No. 1165-2-211

Department of the Army
U.S. Army Corps of Engineers
Washington, DC 20314-1000

EC 1165-2-211

1 July 2009

EXPIRES 1 JULY 2011
WATER RESOURCE POLICIES AND AUTHORITIES
INCORPORATING SEA-LEVEL CHANGE CONSIDERATIONS
IN CIVIL WORKS PROGRAMS

1. <u>Purpose</u>. This circular provides United States Army Corps of Engineers (USACE) guidance for incorporating the direct and indirect physical effects of projected future sea-level change in managing, planning, engineering, designing, constructing, operating, and maintaining USACE projects and systems of projects. Recent climate research by the Intergovernmental Panel on Climate Change (IPCC) predicts continued or accelerated global warming for the 21st Century and possibly beyond, which will cause a continued or accelerated rise in global mean sea-level. Impacts to coastal and estuarine zones caused by sea-level change must be considered in all phases of Civil Works programs.

2. <u>Applicability</u>. This Circular applies to all USACE elements having Civil Works responsibilities and is applicable to all USACE Civil Works activities. This guidance is effective immediately, and supersedes all previous guidance on this subject. Districts and Divisions shall inform CECW of any problems with implementing this guidance.

3. <u>Distribution Statement</u>. This publication is approved for public release; distribution is unlimited.

4. <u>References</u>. Required and related references are at Appendix A. A glossary is included at the end of this document.

5. <u>Geographic Extent of Applicability</u>.

a. USACE water resources management projects are planned, designed, constructed and operated locally or regionally. For this reason, it is important to distinguish between global mean sea level (GMSL) and local (or "relative") mean sea level (MSL). At any location, changes in local MSL reflect the integrated effects of GMSL change plus changes of regional geologic, oceanographic, or atmospheric origin as described in Appendix B and the Glossary.

b. Potential relative sea-level change must be considered in every USACE coastal activity as far inland as the extent of estimated tidal influence. Fluvial studies (such as flood studies) that include backwater profiling should also include potential relative sea-level change in the starting water surface elevation for such profiles, where appropriate. The base level of potential relative

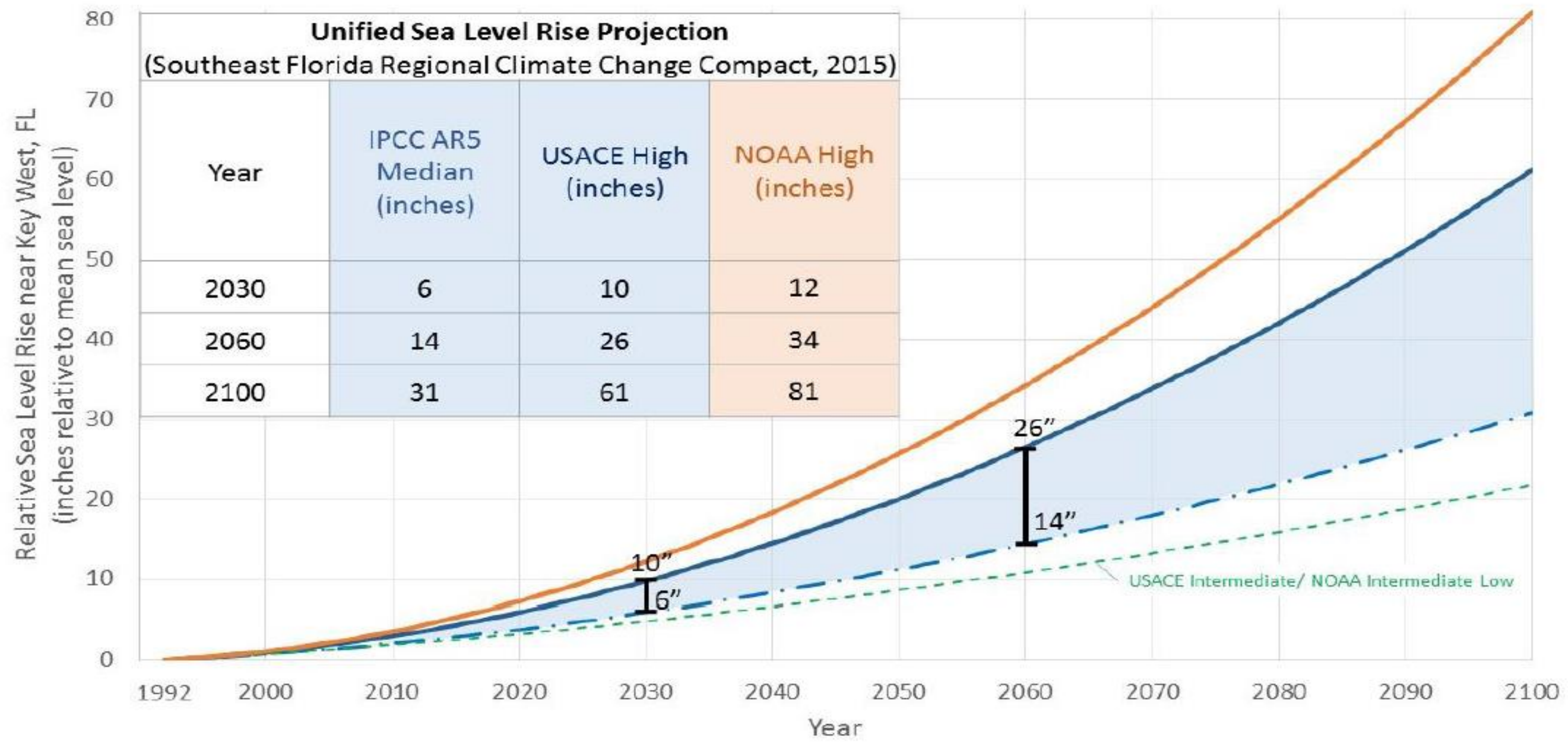
Relative Sea Level Change Scenarios for Key West, FL (feet)

Year	USACE and NOAA Low	USACE Intermediate NOAA Int-Low (Mod. NRC Curve I)	NOAA Int-High	USACE High (Mod. NRC Curve III)	NOAA High
Scenario >	Continue Historic Relative SLC	Global SLC +0.5m by 2100	Global SLC +1.2m by 2100	Global SLC +1.5m by 2100	Global SLC +2.0m by 2100
1992	0.0	0.0	0.0	0.0	0.0
2010	0.1	0.2	0.2	0.3	0.3
2060	0.5	0.9	1.8	2.2	2.9
2100	0.8	1.8	4.1	5.1	6.7
2110	0.9	2.1	4.8	6.0	8.0
2120	0.9	2.4	5.6	7.0	9.3

Notes: USACE projections are for historic, modified NRC Curve I and modified NRC Curve III rates of sea level change developed for Key West, Florida per USACE Engineering Circular (EC) 1165-2-212. This EC is based on guidance in the National Research Council (NRC) report, *Responding to Changes in Sea Level; Engineering Implications* dated September, 1987. The projections are developed using the local historic rate of sea level rise at Key West as reported by NOAA (2.20 mm/yr). NOAA projections use the same EC equations modified for different global SLR scenarios. The USACE and NOAA guidance documents do not address dates beyond 2100. All projections start from 1992 control for the national survey datum.

Unified Sea Level Rise Projection

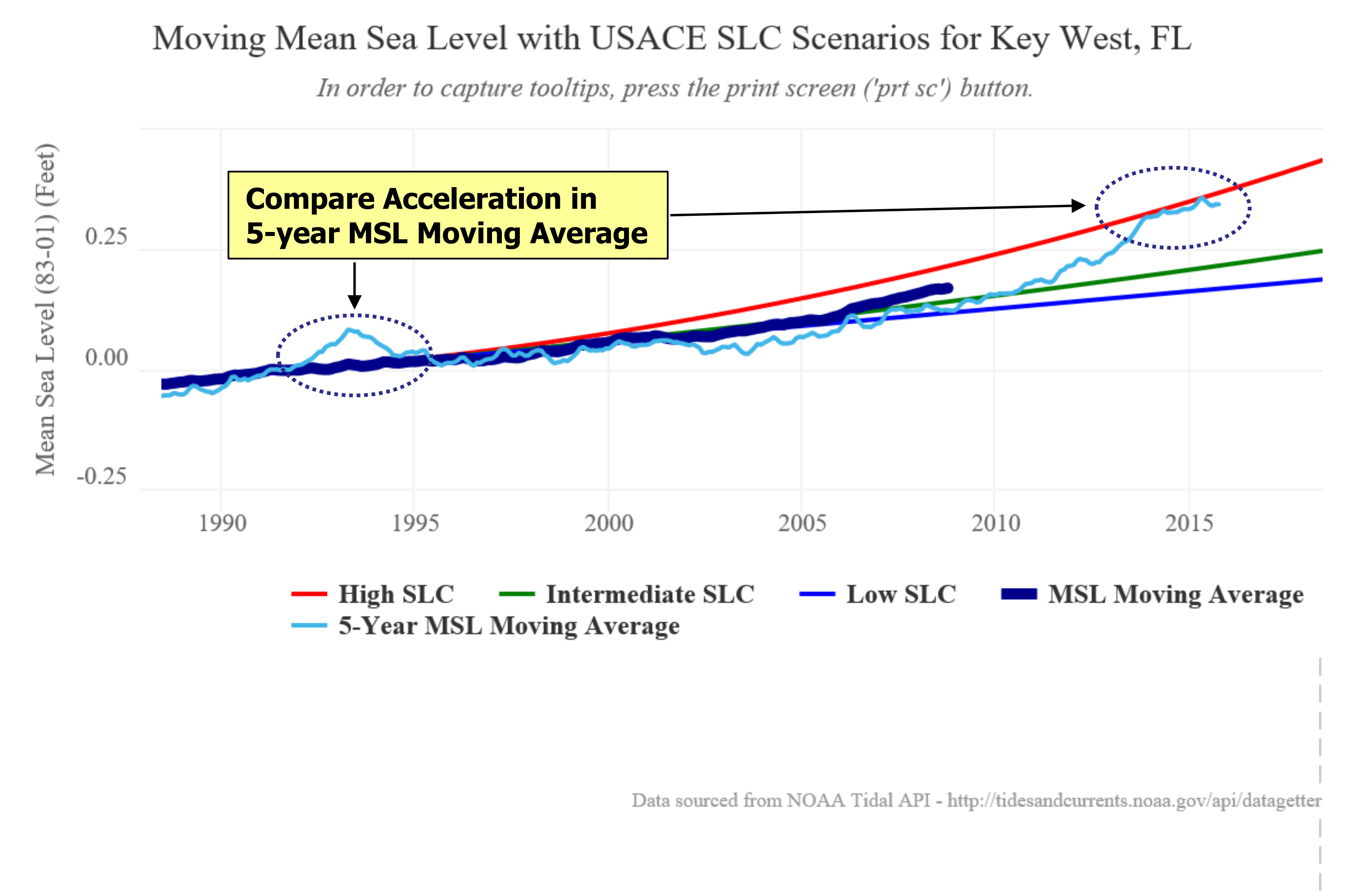
SE FL Regional climate change compact, 2015



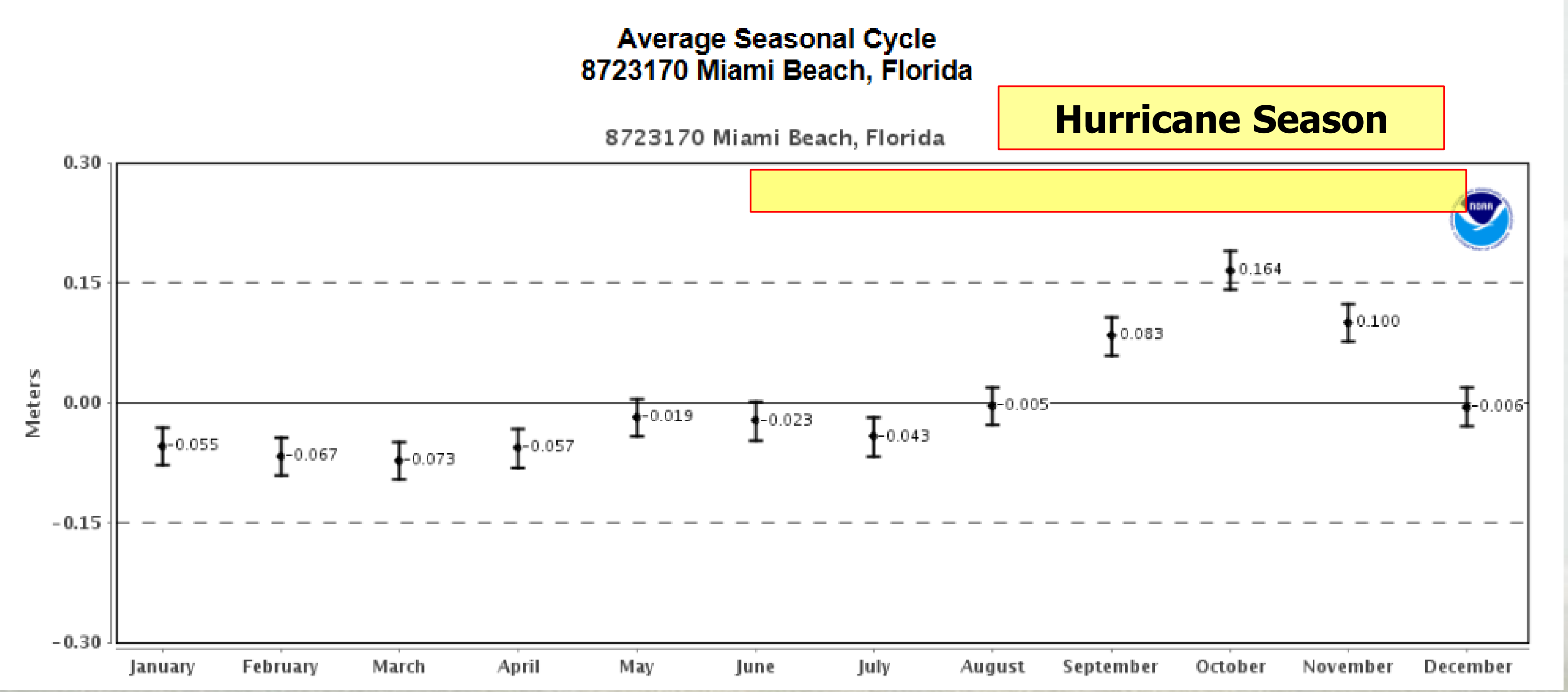
Year	IPCC AR5 Median (inches)	USACE High (inches)	NOAA High (inches)
2030	6	10	12
2060	14	26	34
2100	31	61	81

Figure 1: Unified Sea Level Rise Projection. These projections are referenced to mean sea level at the Key West tide gauge. The projection includes three global curves adapted for regional application: the median of the IPCC AR5 RCP8.5 scenario as the lowest boundary (blue dashed curve), the USACE High curve as the upper boundary for the short term for use until 2060 (solid blue line), and the NOAA High curve as the uppermost boundary for medium and long term use (orange solid curve). The incorporated table lists the projection values at years 2030, 2060 and 2100. The USACE Intermediate or NOAA Intermediate Low curve is displayed on the figure for reference (green dashed curve). This scenario would require significant reductions in greenhouse gas emissions in order to be plausible and does not reflect current emissions trends.

Accelerating sea level change in Florida
30-Years JUN 1988 to JUN 2018, Key West, FL

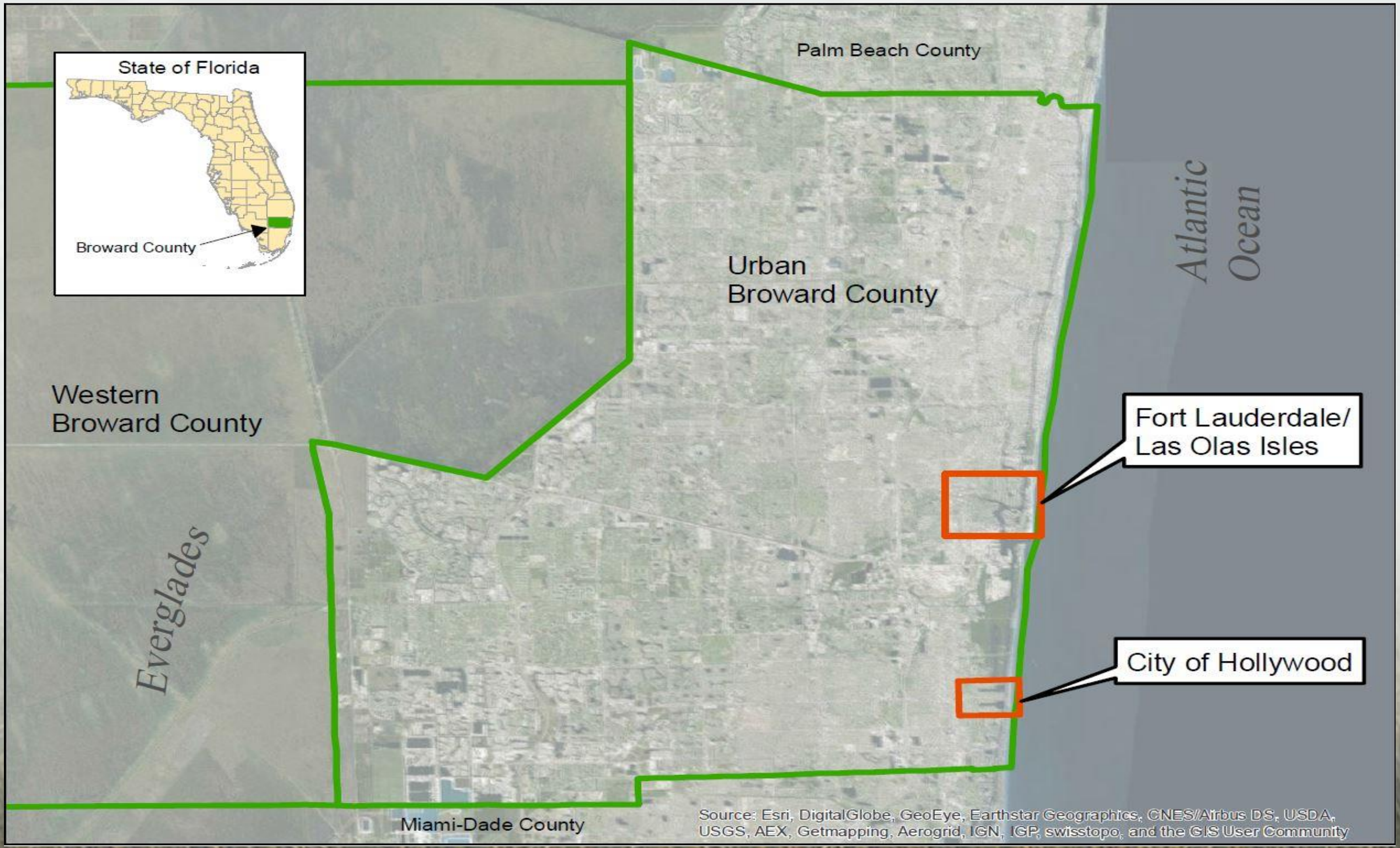


SEASONAL TIDAL CYCLE
MIAMI BEACH, FLORIDA



http://tidesandcurrents.noaa.gov/sltrends/seasonal.htm?stnid=8723170 Change the gauge code in the URL above to get this plot for the desired gauge.

Ft Lauderdale & Hollywood, Broward County Study Focus Areas

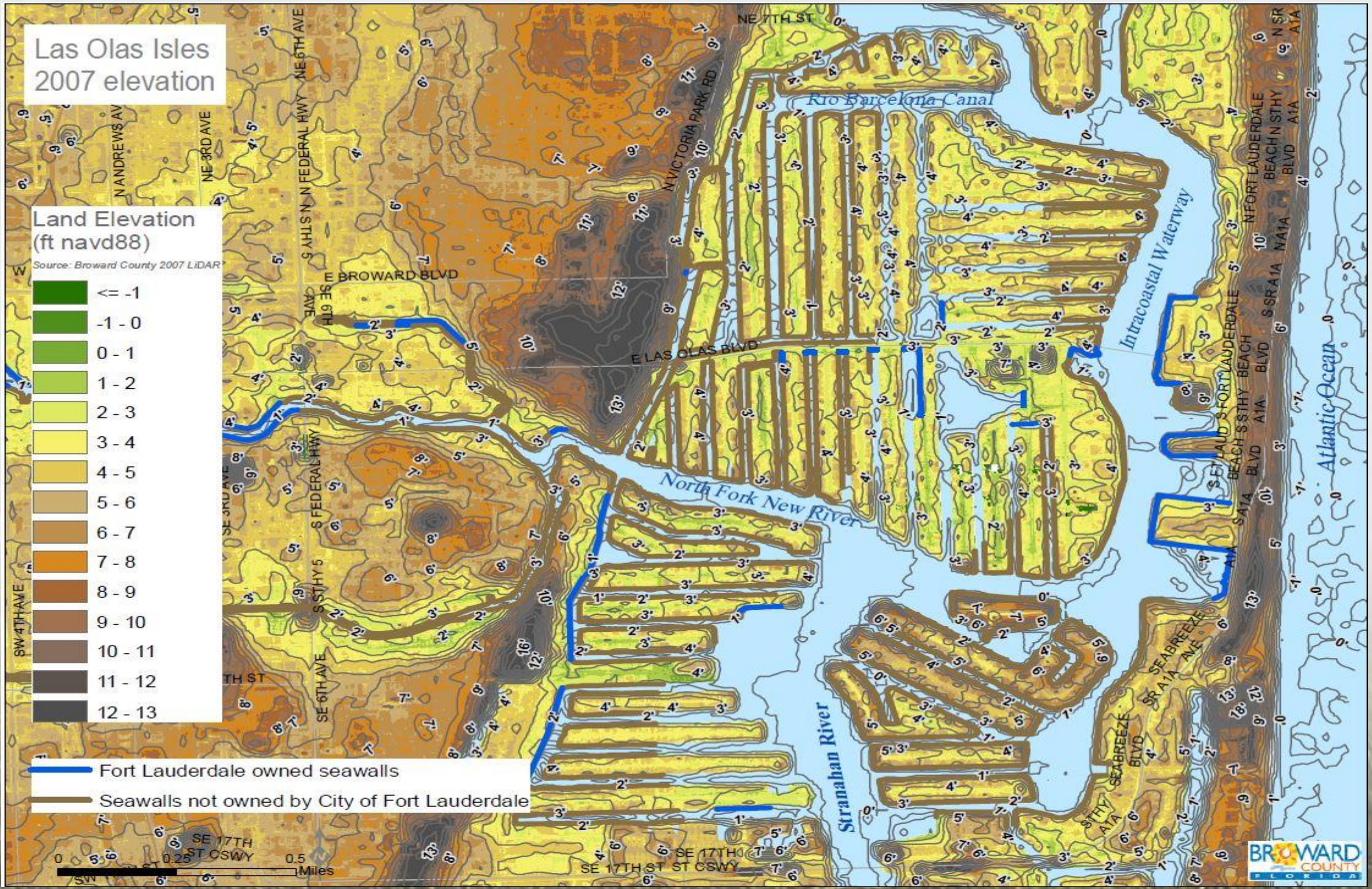



HOLLYWOOD
MARINA
BOAT RAMPS
IDLE SPEED
NO WAKE

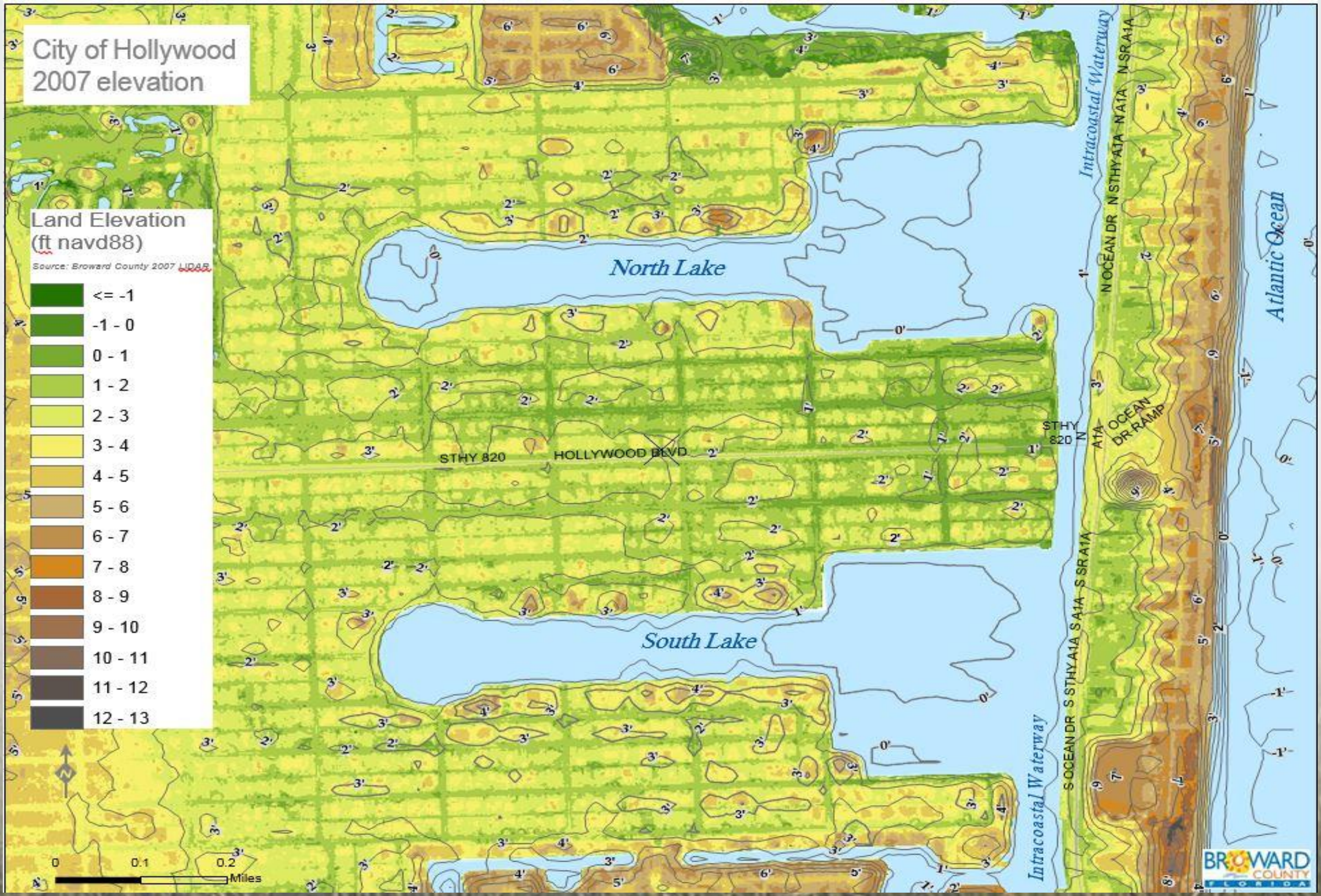
Broward County Study Components

- Surveys to identify existing seawall conditions
- Install tide gauges and collect tide elevation data
- Storm Surge Modeling
  - Add detail to FEMA storm surge model
  - Model existing conditions with seawall gaps & low areas
  - Model Alternative 1 – Hollywood 2.5 ft., Las Olas 4.0 ft.
  - Model Alternative 2 – All seawalls 4.0 feet
  - Model Alternative 3 – All seawalls 6.0 feet
- Economic risk analysis
- Report

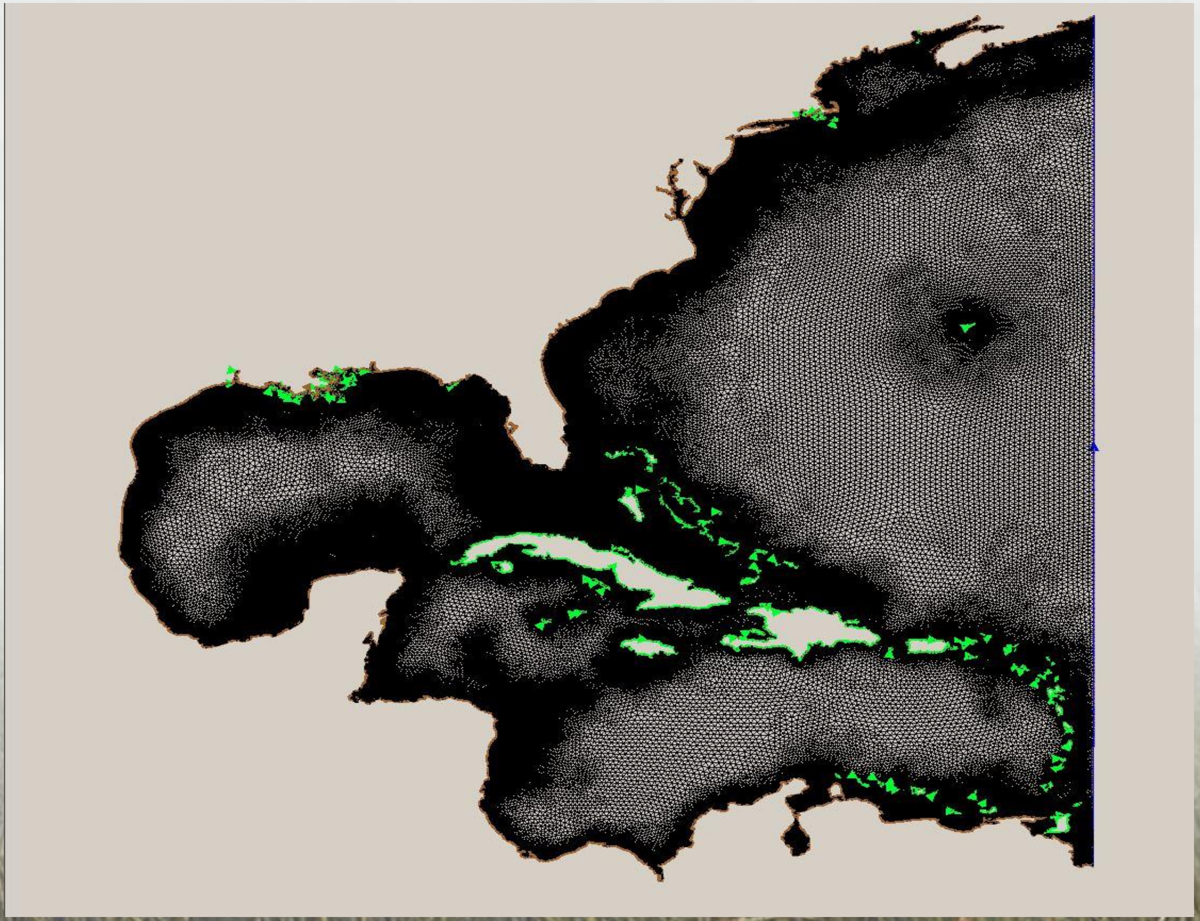
Fort Lauderdale, Las Olas Isles area



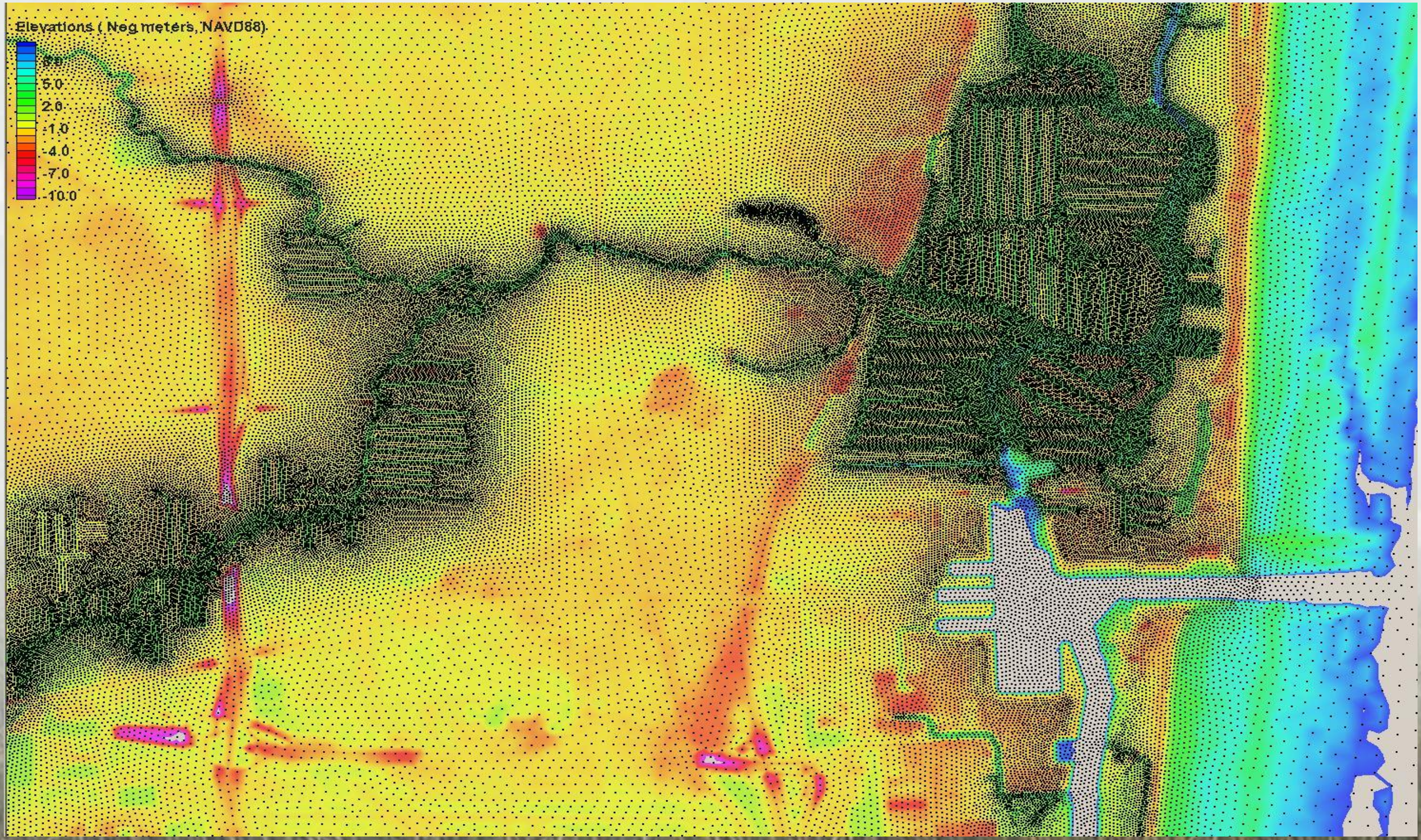
City of Hollywood, FL



FEMA South Florida ADCIRC Basin Model Grid



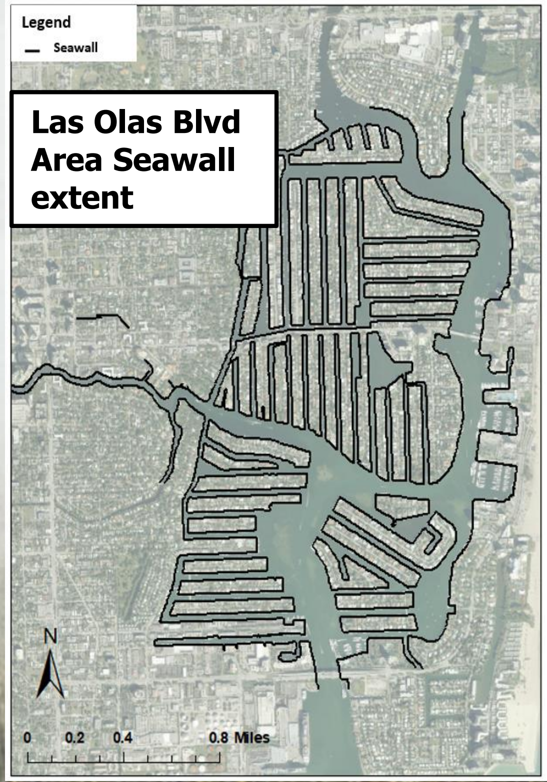
FEMA South Florida ADCIRC Model Grid, Broward County Detail



Enhancement and Validation of SWAN+ADCIRC models

Developed and applied SWAN+ADCIRC model mesh configurations and storm conditions to evaluate flooding and inundation patterns for various seawall configurations. The SWAN+ADCIRC modeling applied the validated mesh and storm forcing from the Federal Emergency Management Agency (FEMA) Region IV South Florida Storm Surge Study (SFLSSS) (FEMA, 2017).

Seawall	Minimum Elevation (ft-NAVD)	
Alternative	Las Olas Boulevard	Hollywood Lakes
1	4	2.5
2	4	4
3	6	6

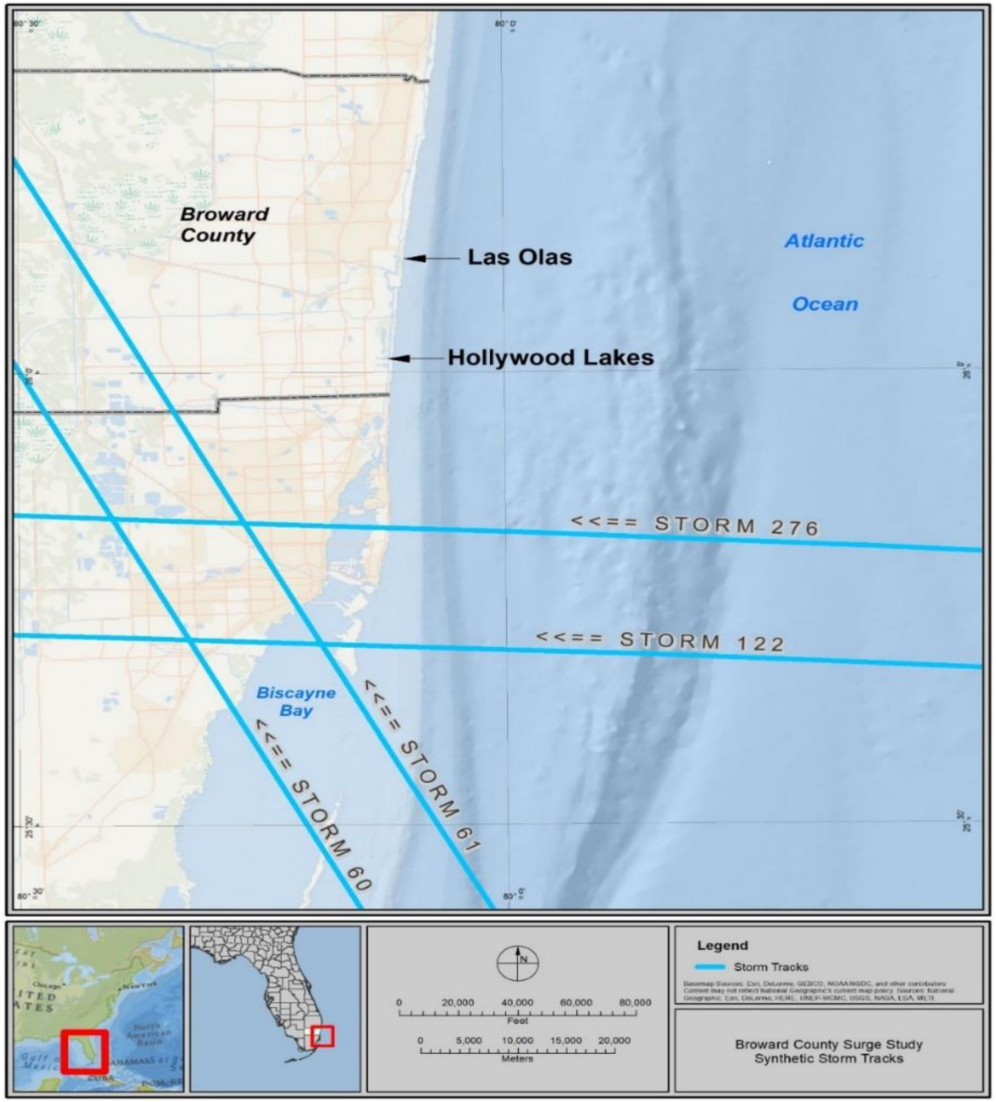


Approximate Maximum Water Elevations

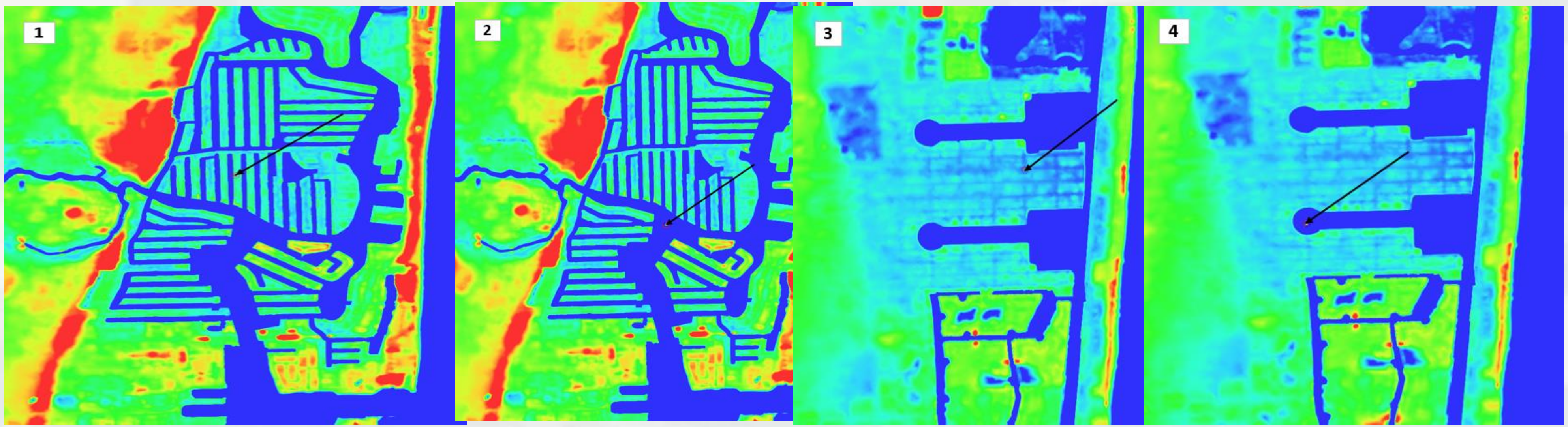
A comparison of the modeled maximum water level results for the existing seawall condition to the water level results for a raised seawall configuration allows examination of any potential effects of the seawall height on the storm surge inundation patterns.

Storm	Forward Velocity	Radius to Maximum Wind	Maximum Wind Speed	Approximate Return Period	Approximate Maximum Water Level Las Olas Boulevard	Approximate Maximum Water Level Hollywood Lakes
	(knots)	(nmi)	(knots)		(ft-NAVD)	(ft-NAVD)
276	10	25	58	25 to 30	3.7	3.2
122	10	13	114	40 to 45	5.0	4.5
60	10	14	114	50 to 100	5.4	6.1
61	10	14	114	50 to 100	6.3	5.7

Storm Tracks



Seawall Alternatives and Modeled Maximum Water Depth



Storm	Seawall Alternative	Maximum Water Depth (ft)			
		Station 1	Station 2	Station 3	Station 4
276	Existing	0.8	6.1	1.9	16.6
276	Alt 1	DRY	6.1	2.1	16.9
276	Alt 2	DRY	6.2	DRY	16.4
122	Existing	2.0	7.2	3.5	18.0
122	Alt 2	2.3	7.4	3.8	18.3
122	Alt 3	DRY	6.9	DRY	17.8
60	Existing	2.9	7.8	4.8	19.2
60	Alt 2	3.0	7.9	5.0	19.4
61	Existing	3.7	8.5	4.5	18.7
61	Alt 2	3.8	8.6	4.7	19.0
61	Alt 3	DRY	8.4	3.0	19.4
Elevation (ft-NAVD)		3.1	-2.3	0.9	-13.3

Modeled Water Level and RMS Equivalency

Run	Representative Scenario (*Return intervals are only estimates)	Water Level (Feet NAVD)	Seawall Height (Feet NAVD)	RMS Equivalency
1-3.	No Action	3, 5 AND 6	Existing	
4	A) Surge of 20 yr storm today OR B) King tide in 2070 WITH gaps filled (Overtopping Occurs)	3	2	
5	A) Surge of 20 yr storm today OR B) King tide in 2070 WITH raised walls (No Overtopping)	3	4	<50 yr storm
6	A) Surge of 45 yr storm today OR B) King tide plus surge of ~3 yr storm in 2070 WITH raised walls (Overtopping Occurs)	5	4	~200 yr storm or 2' sea level rise and 50 yr storm
7	A) Surge of 45 yr storm today OR B) King tide plus surge of ~3 yr storm in 2070 WITH raised walls (No Overtopping)	5	6	
8	A) Surge of ~100 yr storm today OR B) King tide plus surge of ~20 yr storm in 2070 WITH raised walls (No Overtopping)	6	6	~500 yr storm today or 2' sea level rise plus 150 yr storm

Table 5.1 SWAN+ADCIRC Model Simulation Matrix with Notes on Results

Storm Number	Mesh Configuration	Surface Canopy Attribute Setting	ESL Attribute Setting	Las Olas Seawall	Hollywood Seawall	Seawall Overtopping Notes Las Olas Boulevard	Seawall Overtopping Notes Hollywood Lakes
Storm 276	Existing	base	sofl_v10				
Storm 276	Alternative 1	base	sofl_v10	2.5	4.0	No overtopping	
Storm 276	Alternative 2	base	sofl_v10	4.0	4.0	No overtopping	No overtopping
Storm 122	Existing	scc-v3c	sofl_v10g				
Storm 122	Alternative 2	scc-v3c	sofl_v10g	4.0	4.0		
Storm 122	Alternative 3	scc-v3c	sofl_v10d	6.0	6.0	No overtopping	No overtopping
Storm 60	Existing	scc-v3c	sofl_v10g				
Storm 60	Alternative 2	scc-v3c	sofl_v10g	4.0	4.0		
Storm 60	Alternative 3	scc-v3c	sofl_v10d	6.0	6.0	No overtopping	Unstable in ICWW south of South Lake
Storm 61	Existing	scc-v3c	sofl_v10g				
Storm 61	Alternative 2	scc-v3c	sofl_v10g	4.0	4.0		
Storm 61	Alternative 3	scc-v3c	sofl_v10g	6.0	6.0	Some overtopping, greatly reduced from Alternative 2	No overtopping, surge enters from south

Economic Risk Analysis Summary Table

Adaptation Strategy	Number of Days of Flooding in 2070	Surge Protection from 3 to 20-Year Storm Plus King Tide and 2' Sea Level Rise (% of Storms When Overtopping Occurred)	50-Year Return Period Losses with 2 Feet of Sea Level Rise (Total)	50-Year Return Period Losses with 2 Feet of Sea Level Rise (Hollywood)	50-Year Return Period Losses with 2 Feet of Sea Level Rise (Fort Lauderdale)	Range of Median Storm Losses	Evaluation	Selection
No Action	20 to 140	0%	$243M	$147M	$107M	$0 to $268M	Flood frequency exceeds 30 days	
Fill Gaps (4 feet NAVD in FTL and 2.5 feet in HWD)	0 to 25	0%					No surge protection	
Raise walls to 4 feet NAVD	0	25%	$243M	$147M	$107M	$0 to $340M	No cost benefit	
Raise old walls to 6 feet, newer walls remain at 4 feet	0		$233M	$146M	$98M		~$10M savings	
Raise walls to 6 feet	0	75%	$228M	$146M	$96M	$0 to $112M	~$15M- $112M savings	Justifies ~21 miles of seawall adaptation, 24% of study area
Raise walls to 8 feet	0		$51M	$28M	$20M		~$192M savings	

Economic Modeling – Discussion of Alternatives

- **Alternative 1 includes filling gaps, to 4 feet NAVD in Fort Lauderdale and to 2.5 feet NAVD in Hollywood Lakes.**
- **Option 2 raises all seawalls to 4 feet NAVD. 50 year return period losses are $242M for total study area. Losses in Hollywood Lakes are greater than Fort Lauderdale.**
    - **Alternative 2 resulted in a modeled mean loss by storms of $0 to $340M. Losses from storms with Alternative 2 exceeded losses modeled with existing seawall conditions (waiting for Taylor to provide reasoning). Losses in Fort Lauderdale were greater for 2 of 3 storms.**
- **Option 3 raises old seawalls to 6 feet NAVD, other seawalls are assumed to be 4 feet NAVD. 50 year return period losses are $232M. Losses in Hollywood Lakes are greater than Fort Lauderdale.**
- **Option 4 raises all seawalls to 6 feet NAVD. 50 year return period losses are $228M. Losses in Hollywood Lakes are greater than Fort Lauderdale.**
    - **Alternative 3 resulted in a modeled mean loss by storms of $0 to $112M. Losses from Storm 61 with Alternative 3 were $156M less than with existing seawalls. Loses from Storm 122 were greater by $8M for Alternative 3 compared to existing seawall conditions. Losses from storms were greater in Fort Lauderdale for two storms.**
- **Option 5 raises all seawalls to 8 feet NAVD. 50 year return period losses are $51M. Losses in Fort Lauderdale are greater than Hollywood Lakes.**

Flood Frequency

- **Sweet et al. 2018 assumes number of days of flooding above NOAA threshold. In 2070, number of days of flooding ranges between 325 and 365 days at Virginia Key (based on 2017 NOAA Intermediate and Intermediate High curves which approximate blue zone of Compact projection, threshold of 1.5 feet NAVD). These results may be inflated because of nationwide mean approach.**

- **Obeysekera 2018 analysis of number of days of flooding above 2 feet NAVD interpolated for Port Everglades ranges from 20 to 140 days in 2070 (Compact projection). With seawalls at 4 feet NAVD, number of days of flooding is projected to be zero.**

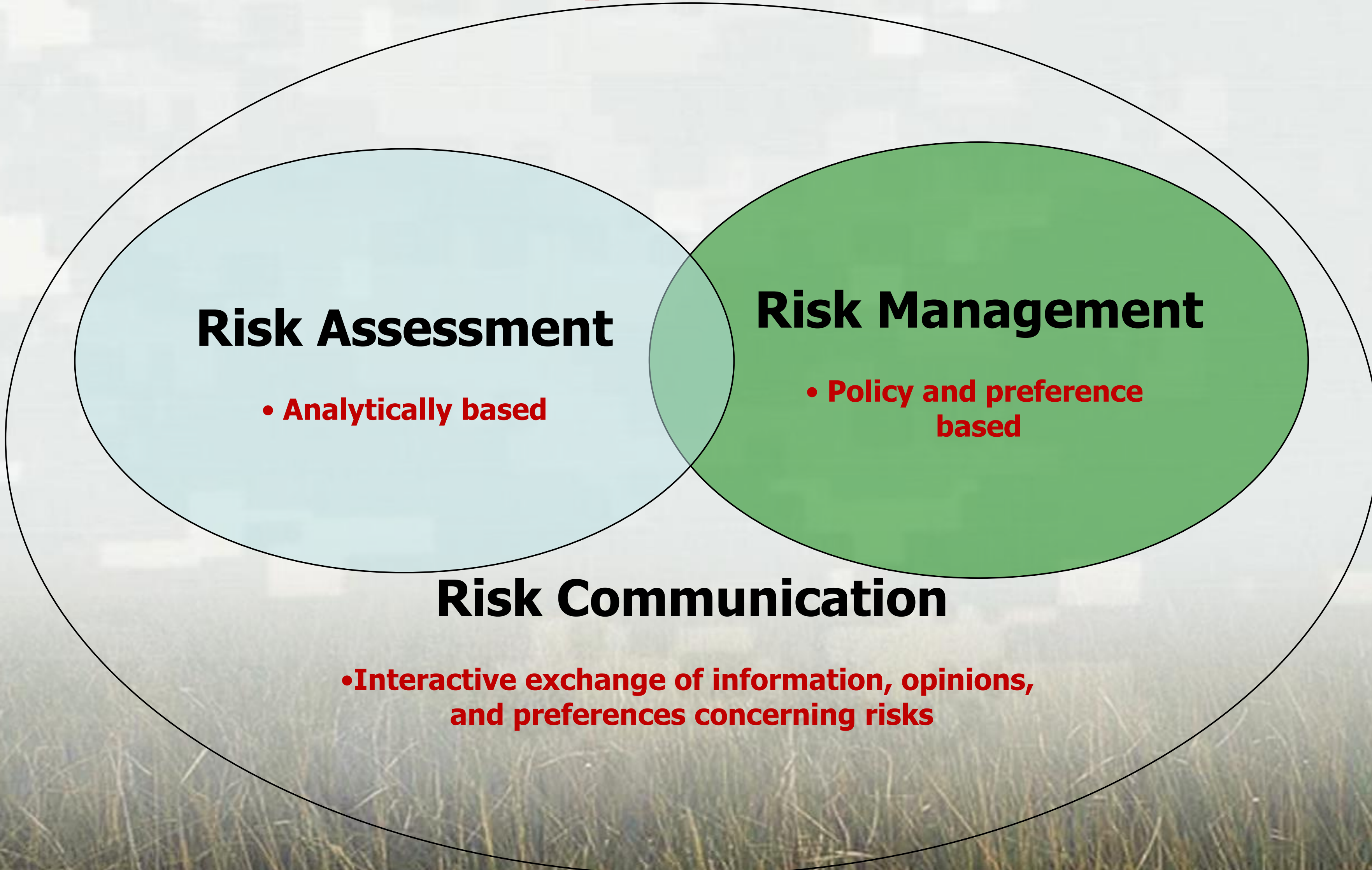
- **Mean sea level in 2070 may range from 1.8 to 2.6 feet NAVD (Compact projection).** ***Mean sea level plus high tide may reach 3.9 feet NAVD in 2070. A wind driven surge or astronomical high tide could increase these estimates.***

  - **If seawalls are raised to 4 feet NAVD, no surge protection will be provided.**
  - **If seawalls are raised to 5 feet NAVD, approximately 1 foot of surge protection will be provided. One foot of surge may occur annually.**
  - **If seawalls are raised to 6 feet NAVD, approximately 2 foot of surge protection will be provided. Two feet of surge may occur approximately every 40 to 80 years (based on FEMA and RMS frequency analyses).**

Risk

- Risk is a measure of the probability and consequence of uncertain future events
- Risk includes
  - Potential for gain (opportunities)
  - Exposure to losses (hazards)

Risk Analysis in Three Tasks



Risk Management Decision

- Sustainable
- Robust – performs well under wide range of future conditions
- Cost-risk trade-offs
  - Regret-based approach
  - If cost-cost trade-off, no firm rule
  - If trade-off of cost vs. safety, precautionary with respect to safety risk, <u>minimize worst-case outcome</u>

Florida Sea Level Rise Concerns
Take Away Points

- USACE SLR projections are based on guidance from the National Research Council, are site specific and include local uplift or subsidence. Does not address wave and storm surge frequency.
- **SLR <u>PERMANENTLY</u> increases coastal flood frequency**
- Leading Indicators of Sea Level Rise, such as the reduction in polar ice caps, and the recent rapid increases in the rate of glacier melting worldwide forecast significant SLR rate increases
- **<u>Long Term</u> Sea Level Rise Adaptation Strategies** are needed at project, community, watershed, and national scales

Thank you!

For additional information, contact:

Glenn.B.Landers@usace.army.mil

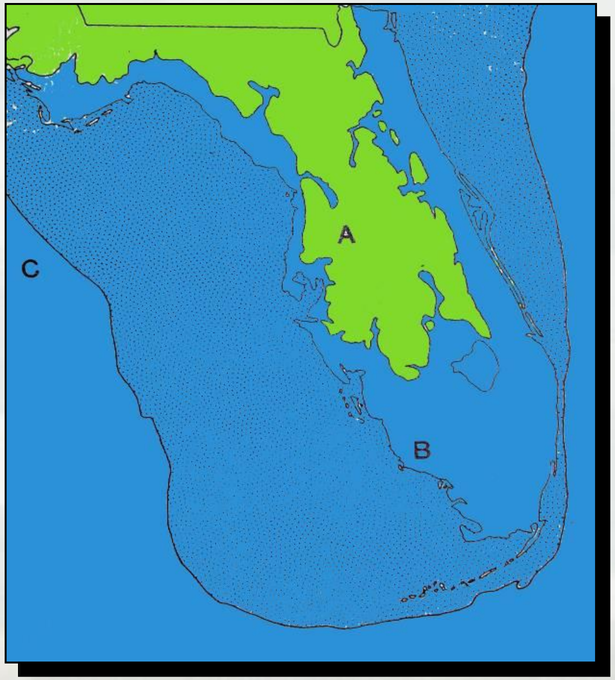
Sea Level Change Beyond 2100

- Anticipate accelerating SLC continuing well beyond 2100
- Very long term SLC may total 2.3m (7.5ft) for each degree Celsius in global warming. In geologic history, this adjustment may have taken a 1000 years or more. Impacts of modern high greenhouse gas levels?
- Protect existing built environment as long as economically feasible
- <u>Buildings AND developed land will depreciate</u> as SLR risks increase
- Develop "Exit strategies" to support timely <u>voluntary</u> actions
- Coastal ecosystems need suitable space for SLC adaptation
- <u>Prioritize long term risk reduction.</u> Shift from projects "optimized" for static future conditions to "robust and adaptable systems"

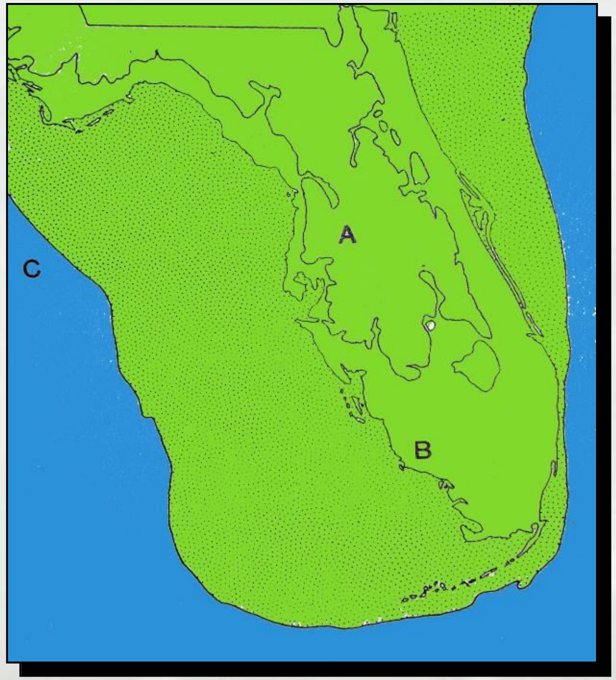
Systems Approach to Adaptation

- Two problems: short AND long term (100 yr++) risk reduction
- Recognize need for interagency collaboration and shared planning
- <u>Address the combined needs of human and natural systems</u>
- <u>Prioritize long term risk reduction.</u> Shift from projects “optimized” for static future conditions to “robust and adaptable systems”
- <u>Encourage Public Investment in “Framework” Infrastructure</u> in low risk areas (water supply, major roads, flood risk reduction, power, sewer, etc.).
- Provide Incentives for Private Development in low risk areas
- <u>Hurricanes and other disasters are opportunities to redevelop in lower risk areas. Implement pre-storm relocation agreements.</u>

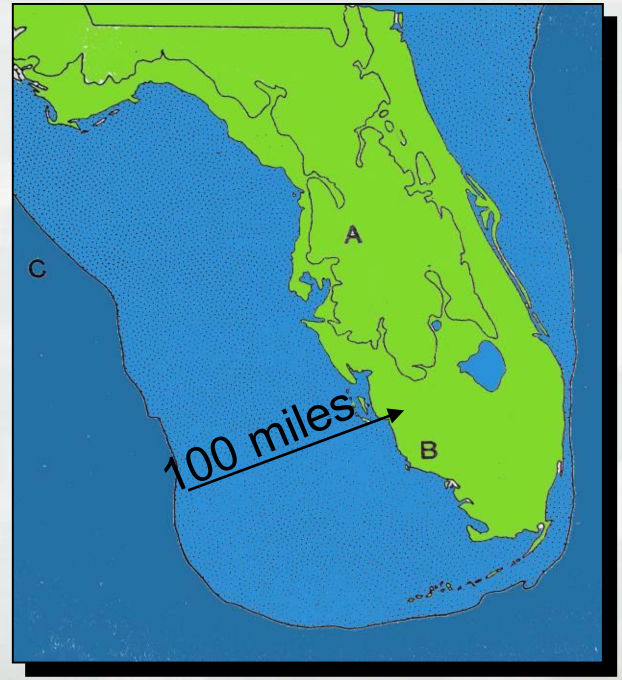
Florida Through Time – Sea Level Change Happens!



120,000 years ago
+ 6 meters (20')*



18,000 years ago
- 120 meters (420')



Today

*~ ½ from Greenland
*~ ½ from Antarctica

Credit: Dr. Harold R. Wanless; University of Miami, Department of Geological Sciences; co-chair of Miami-Dade Climate Change Task Force

ADCIRC/gage Waterlevel – Return Period Analysis

ft- NAVD88 ADIRC Storm					ADCIRC Max WL			RMS		
	RT	AEP %)	NOAA Miami/Virginia Key	Lake Worth Inlet	Las Olas	Hollywood		FLI avg	FLI South	Hollywood Avg
	500							5.3	5.8	6.0
	250							5.0	5.6	5.3
	200							5.0	5.5	5.2
61					6.3					
	100	1			6.2	6.4		4.5	4.9	4.6
60					6.1					
61						5.7				
	50	2			5.4	5.6		4.0	4.3	4.0
60	50					5.4				
122	40 to 45				5.0	4.5				
276	25 to 30				3.7	3.2				
	20	5	2.9	3.0						
	10	10	2.5	2.8						
	5	20	2.1	2.6						

Plot data	ADCIRC Max WL	
RT	Las Olas	Hollywood
100	6.2	6.4
50	5.4	5.6
40	4.6	4.7
30	3.8	3.9
20	3.0	3.0
10	2.8	2.8
5	2.6	2.6