Integrating Vulnerability and Climate Resilience into Coastal Design

Douglas A. Gaffney, PE
Nicole Eldridge, PE
Jack Weaver, EI
Janet Luce

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AtkinsRéalis

CLIMATE CHANGE

How can climate change impact coastal infrastructure?

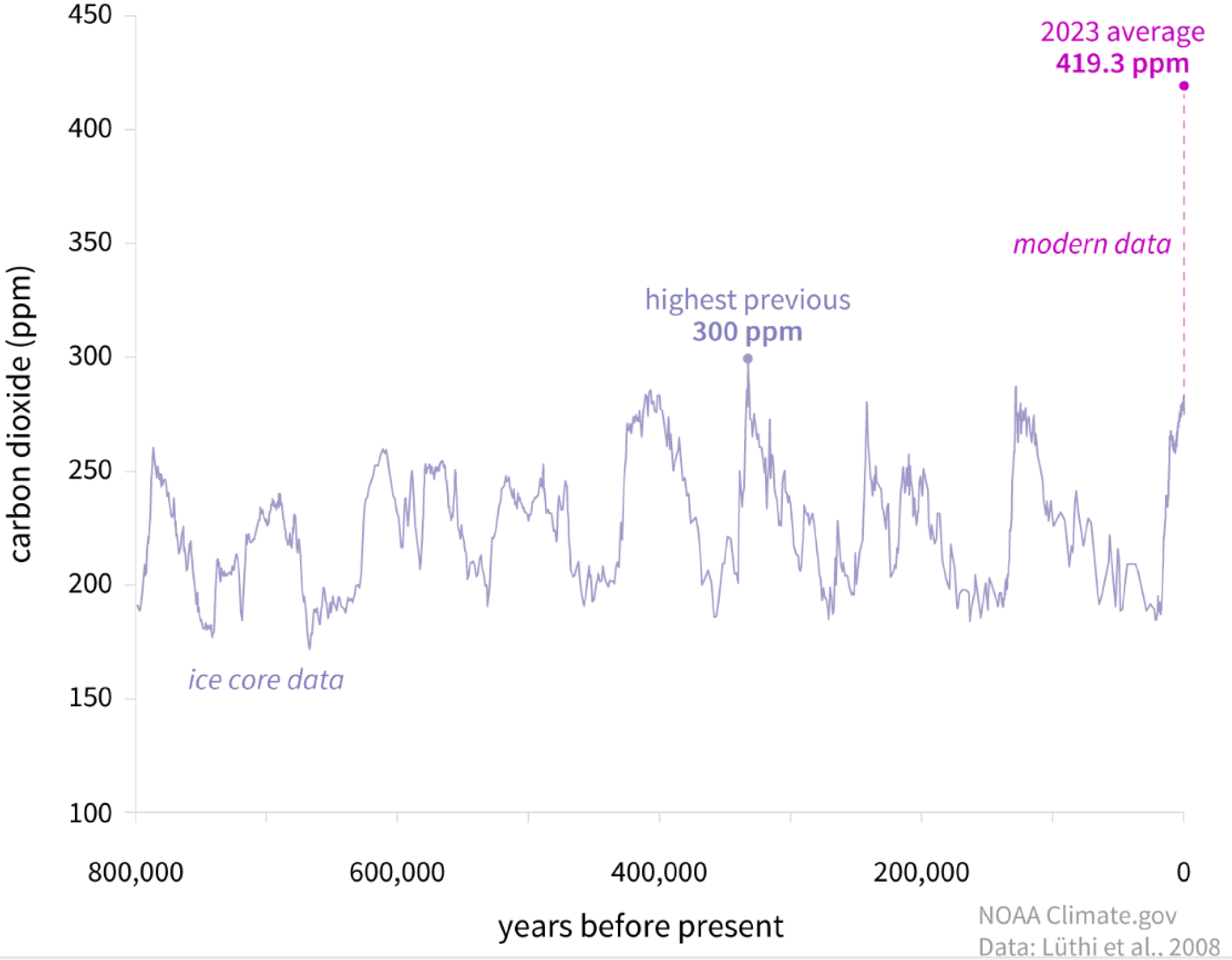
Storms
- Severity
- Frequency
- Surge

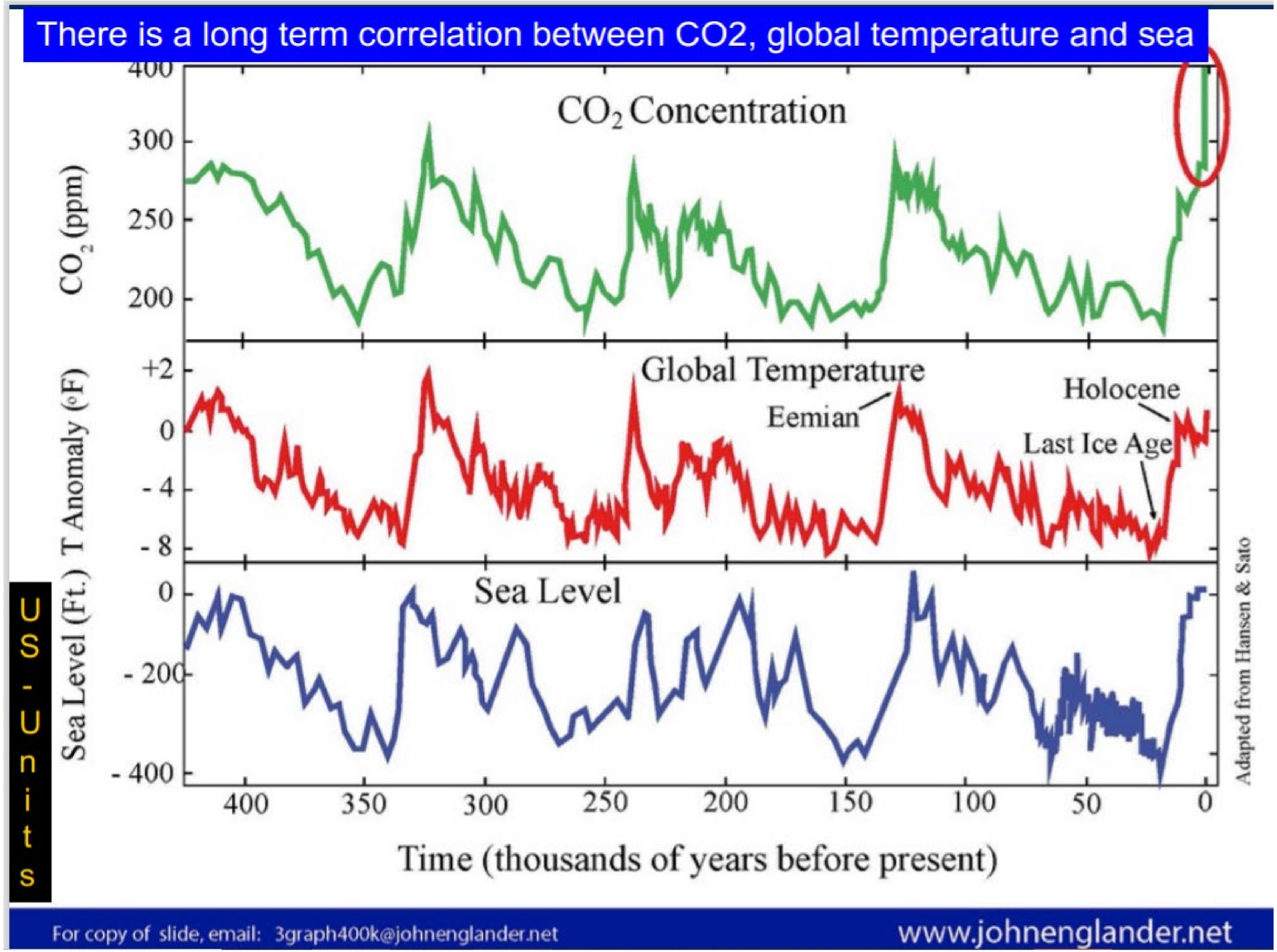
Precipitation
- Flooding
- River Discharge
- Intensity

Sea Level Rise
- Erosion
- Overtopping
- Wave Height
- Saltwater Intrusion

Aerial view Mexico Beach, Florida after Hurricane Michael. Photo: Johnny Milano/The New York Times/Redux

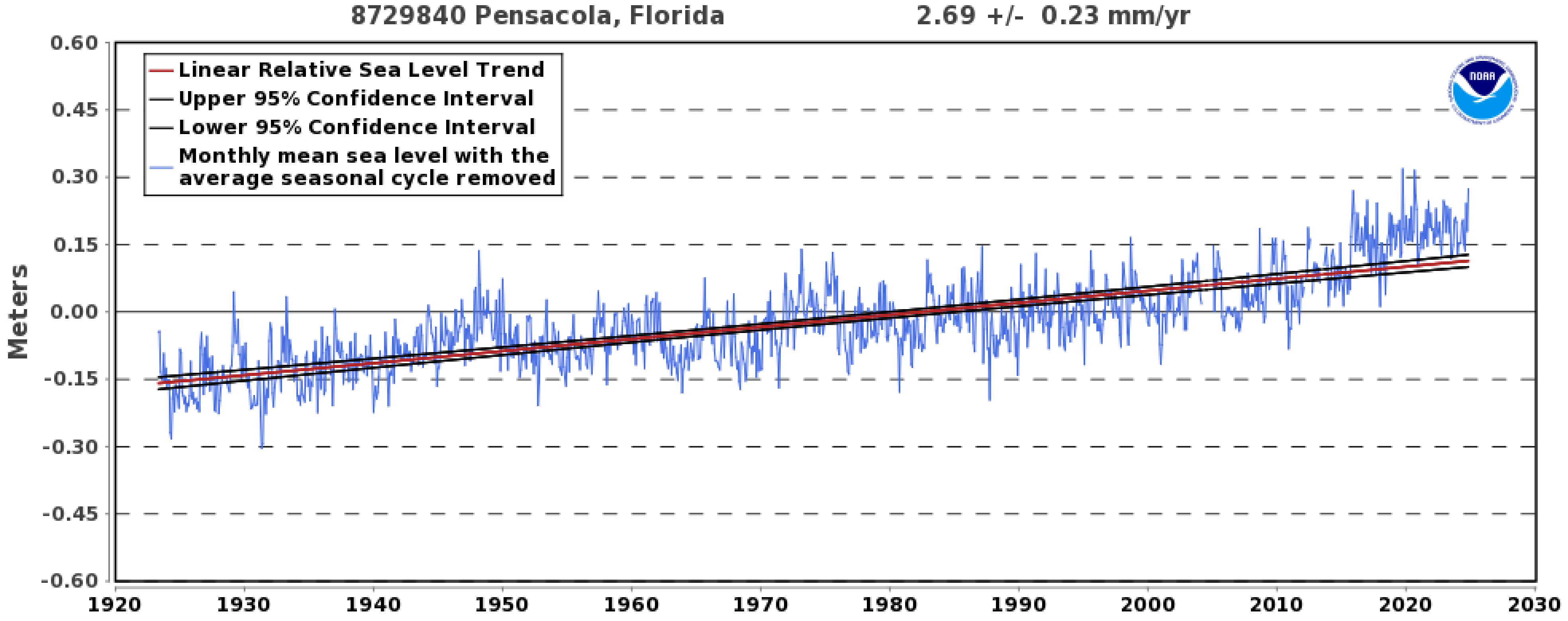
CARBON DIOXIDE OVER 800,000 YEARS

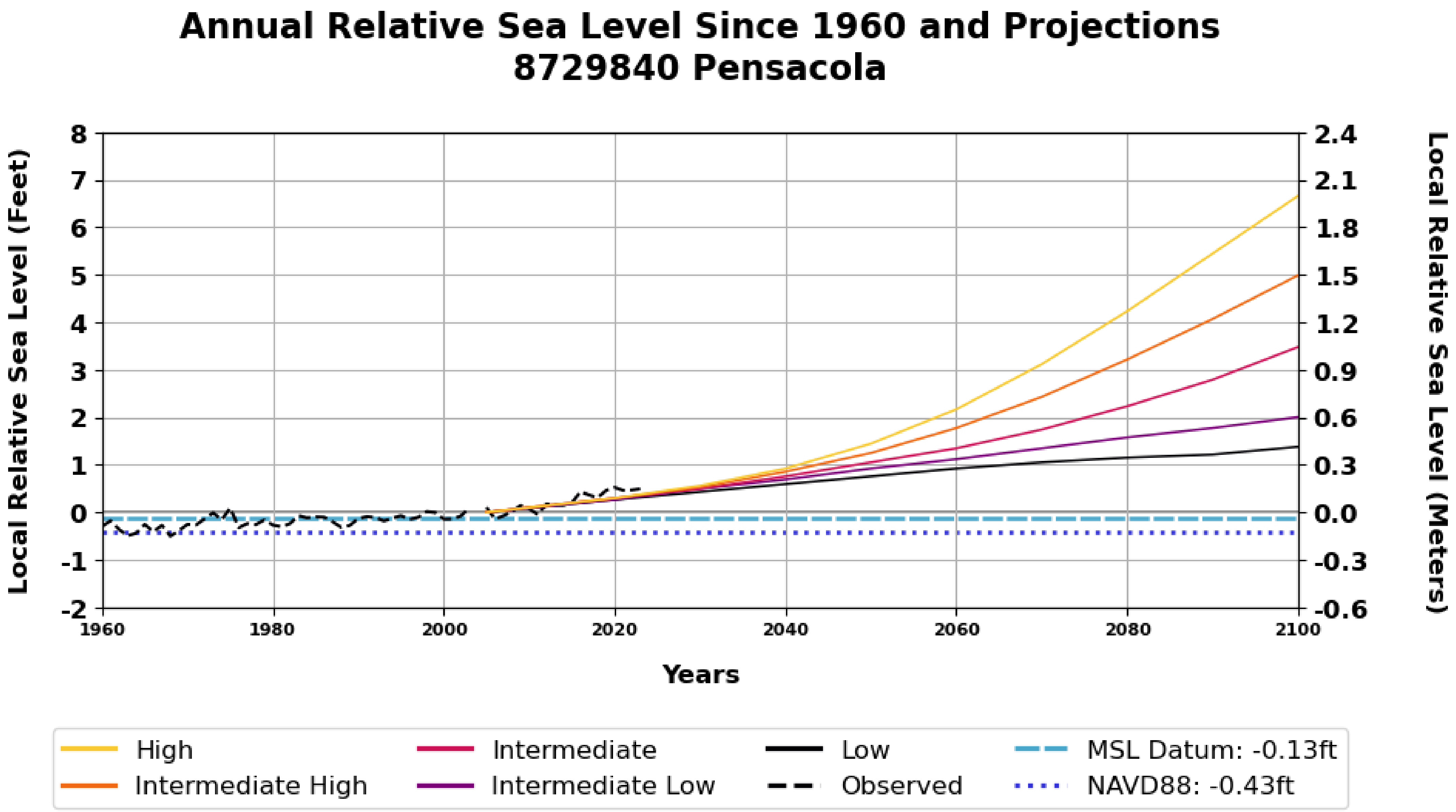




There is a long term correlation between CO2, global temperature and sea
CO₂ Concentration
400
300
250
200
CO₂ (ppm)
Global Temperature
+2
0
- 4
- 8
T Anomaly (°F)
Eemian
Holocene
Last Ice Age
Sea Level
0
- 200
- 400
Sea Level (Ft.)
US - Units
400
350
300
250
200
150
100
50
0
Time (thousands of years before present)
Adapted from Hansen & Sato
For copy of slide, email: 3graph400k@johnenglander.net
www.johnenglander.net

Observed Sea Level Rise




Annual Relative Sea Level Since 1960 and Projections
8729840 Pensacola
Local Relative Sea Level (Feet)
Local Relative Sea Level (Meters)
Years
8
7
6
5
4
3
2
1
0
-1
-2
2.4
2.1
1.8
1.5
1.2
0.9
0.6
0.3
0.0
-0.3
-0.6
1960
1980
2000
2020
2040
2060
2080
2100
High
Intermediate High
Intermediate
Intermediate Low
Low
Observed
MSL Datum: -0.13ft
NAVD88: -0.43ft

VULNERABILITY AND RESILIENCE

What is Vulnerability?
A vulnerable system is defined as:

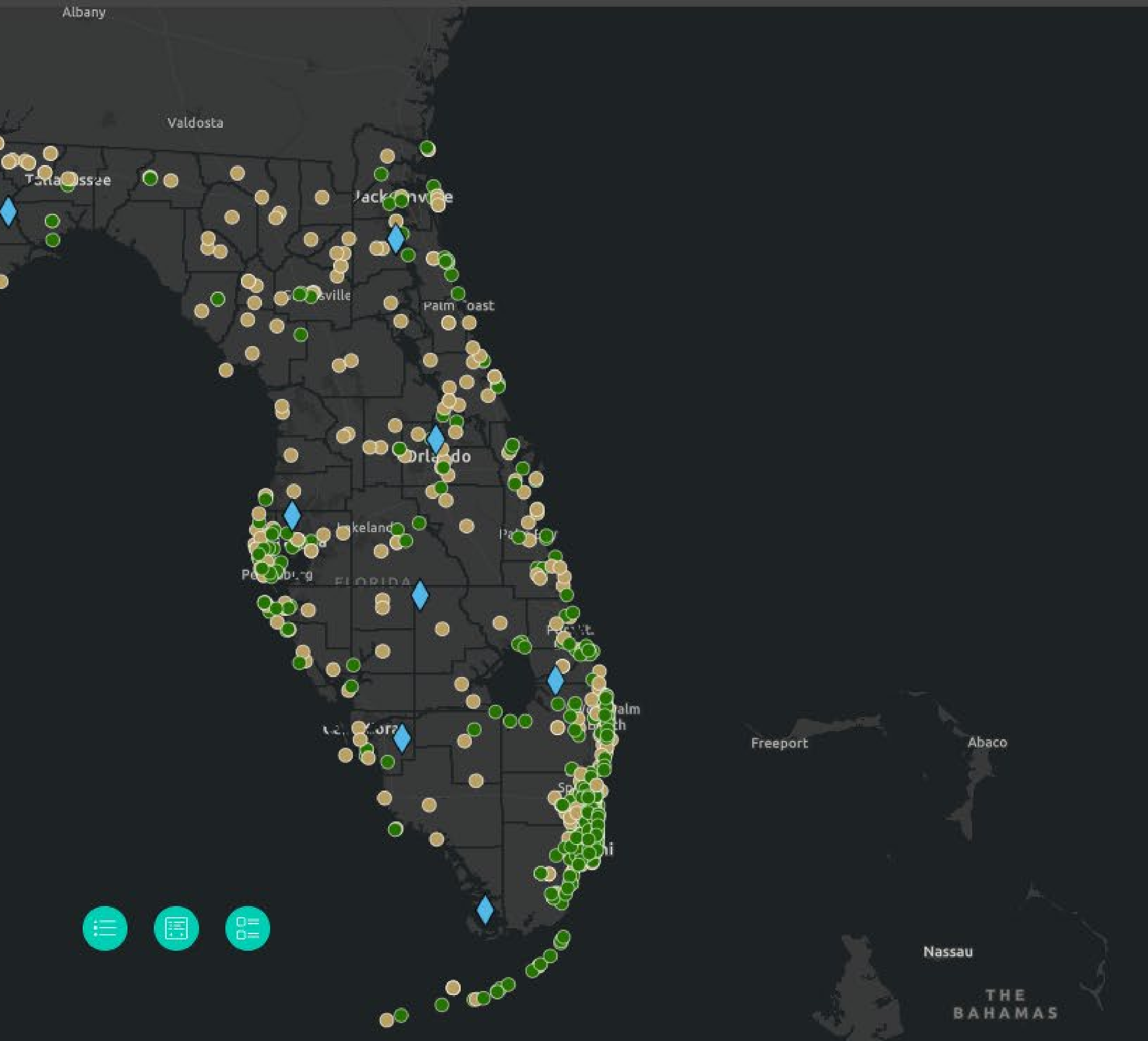
the degree to which a system, or part of it, may react adversely during the occurrence of a hazardous event.

- Acute (short term) – Storm
- Chronic (long term) – background erosion

The opposite of vulnerable can be safe, secure or resilient

Resilient Florida Grants

All Grants | Implementation | Planning | RRE



Funding allows local governments to analyze and plan for vulnerabilities related to flooding and sea level rise, as well as implement projects for adaptation and mitigation.

- *Planning – inventory critical assets that are or expected to be impacted by flooding or sea level rise.*
- *Implementation – develop projects, plans, strategies, and policies that enhance preparations for threats from flooding and sea level rise, including adaptation plans that help to prioritize projects.*

Vulnerability Assessments in FL

Plans, Strategies and Policies

- *Critical Infrastructure*
- *Roads, bridges and causeways*
- *Ports and Waterways*
- *Vegetated Buffers*
- *Structures*
  - *Seawalls*
  - *Revetments*
  - *Beaches and Dunes*

Sanibel Island Causeway after Hurricane Ian, September 2022. Photo: Wilfredo Lee/AP

Resilience Concepts

Robustness

- Strength or ability to withstand a given level of stress without suffering degradation or loss of function

Redundancy

- The extent to which elements are substitutable and capable of satisfying functional requirements in the event of degradation or loss of function

Resourcefulness

- The ability to mobilize resources in the process of recovery

Rapidity

- The capacity to meet priorities and achieve goals in a timely manner to recover functionality and avoid future disruption

Concepts from: Bruneau and Reinhorn, 2006

A resilient system is one that:

Reduces failure probability

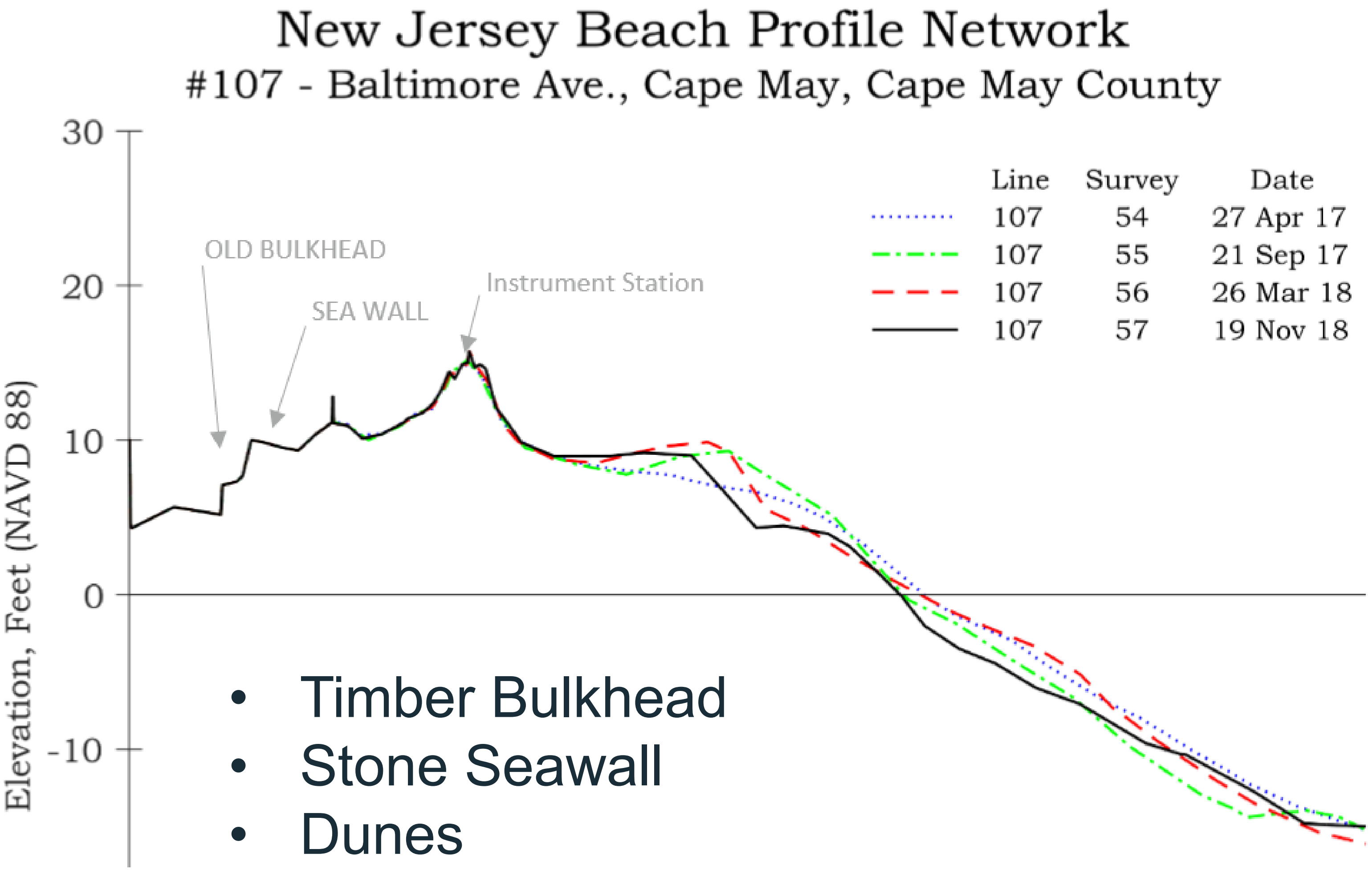
- Robust
- Naturally resilient
- Built-in features

Reduces consequences of failure

- Redundancy
- Smart development

Reduces time of recovery

- Pre-planning
- Easier replacement/repair



- Timber Bulkhead
- Stone Seawall
- Dunes
- Periodic Beachfill

Quantification of physical resilience of structures

Each structure will have its own failure modes and probability

Damage Mechanism

- Linear or non-linear?
- Fragility

Recovery mechanism (restoration)

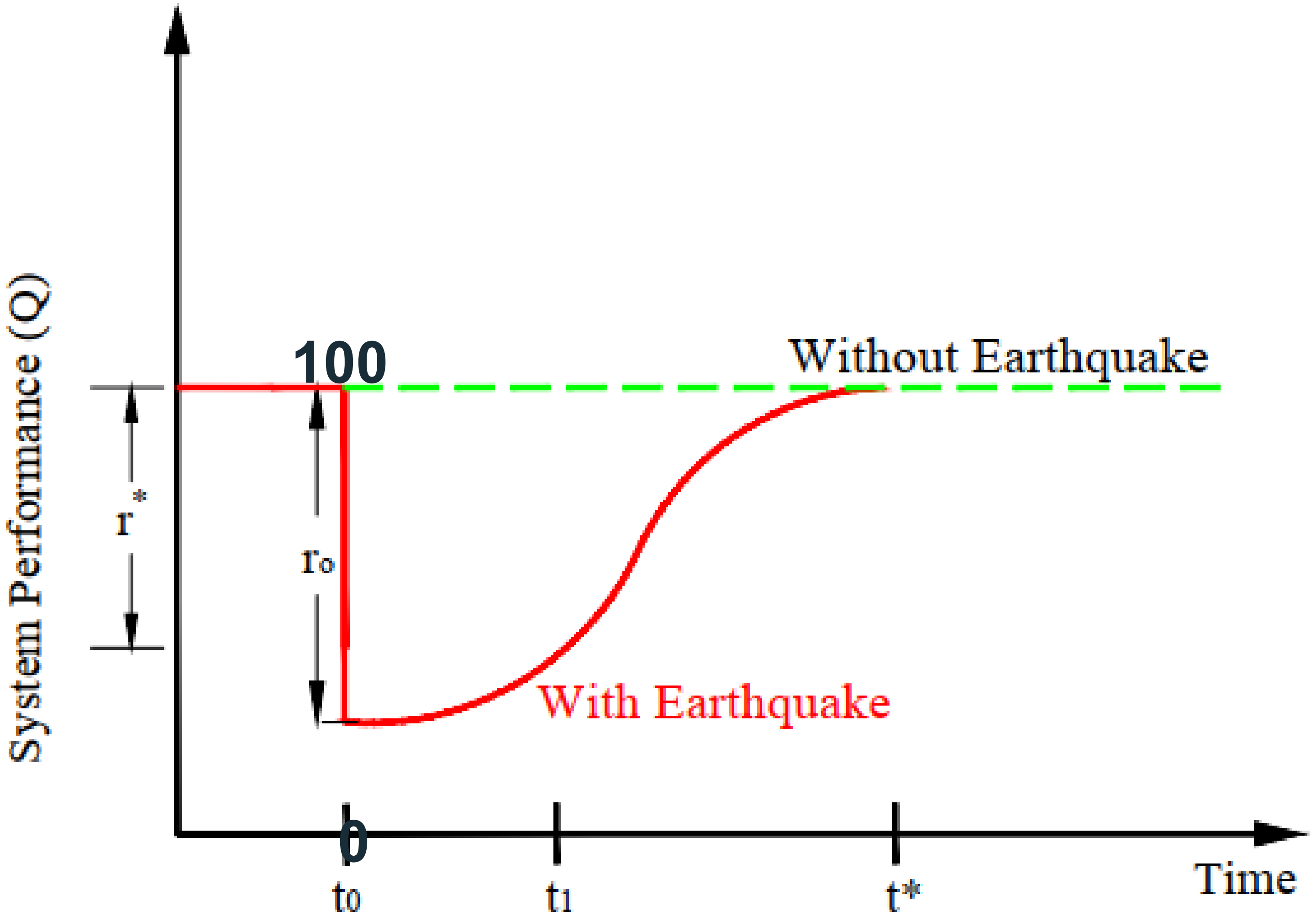
- Incremental
- Natural

Resilience

$$R=\int_{t_0}^{t_1}\left[100-Q(t)\right]dt$$

Concepts from: Bruneau and Reinhorn, 2006

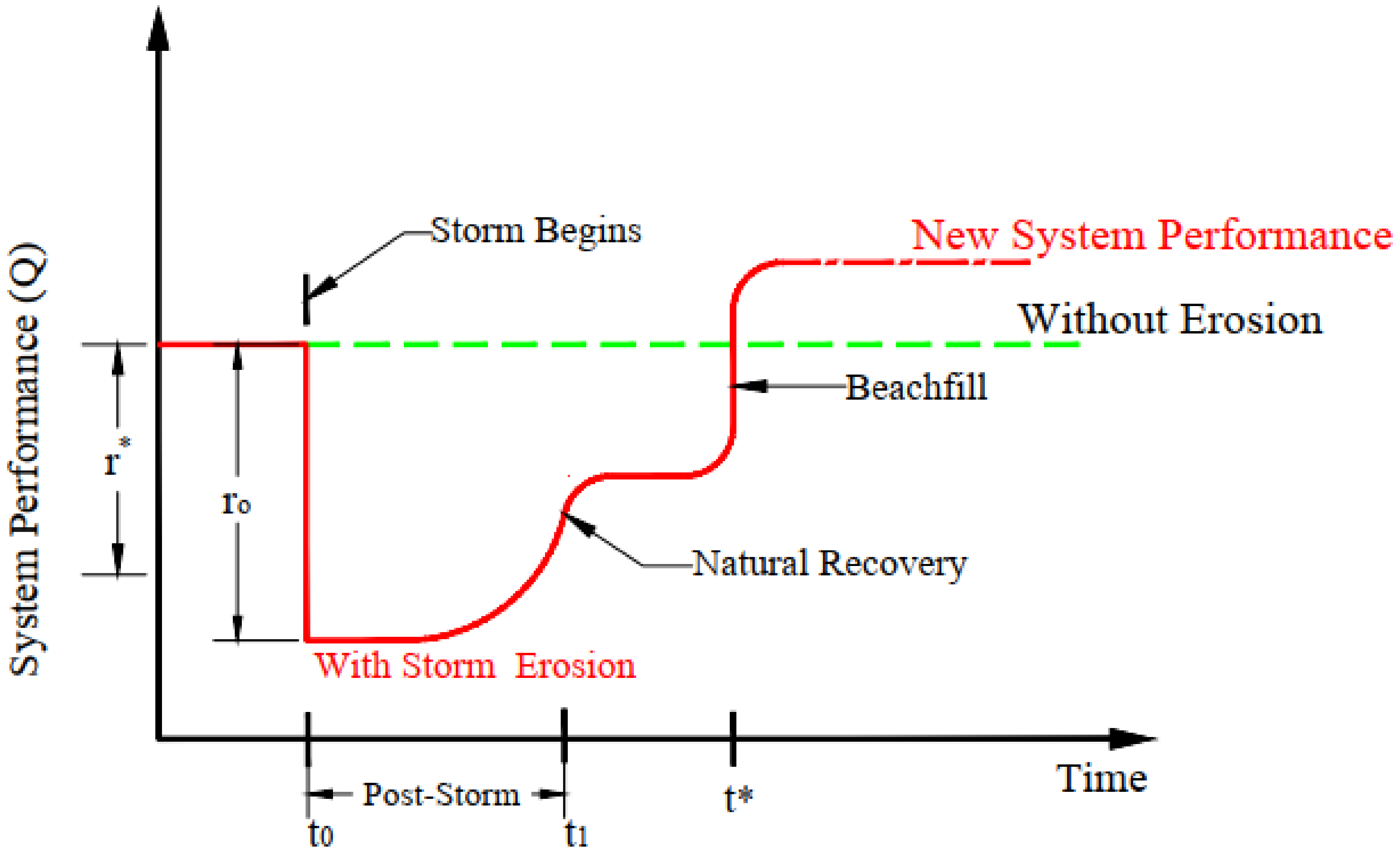
Method of Quantitative Resilience
(Developed from Earthquake & Used by the USACE)



$$R=\int_{t_o}^{t_1}[100-Q(t)]\,dt$$

Example where:
$r_o > r^*$
$t_1 < t^*$

Method of Quantitative Resilience
Beach Example

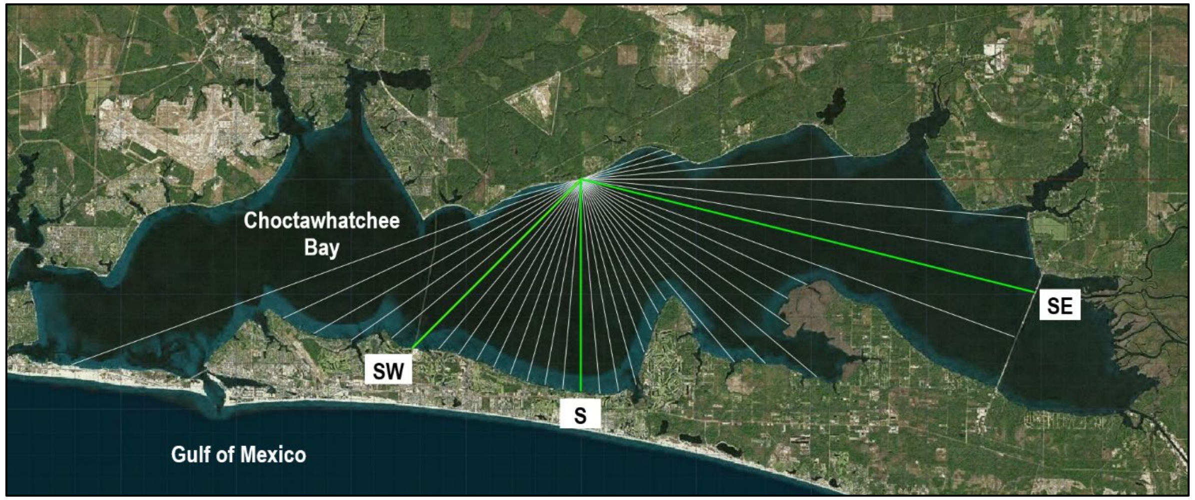


VULNERABILITY ASSESSMENT CASE STUDY

CHOCTAW BEACH VULNERABILITY ANALYSIS OF STATE ROAD 20 IN WALTON COUNTY FL

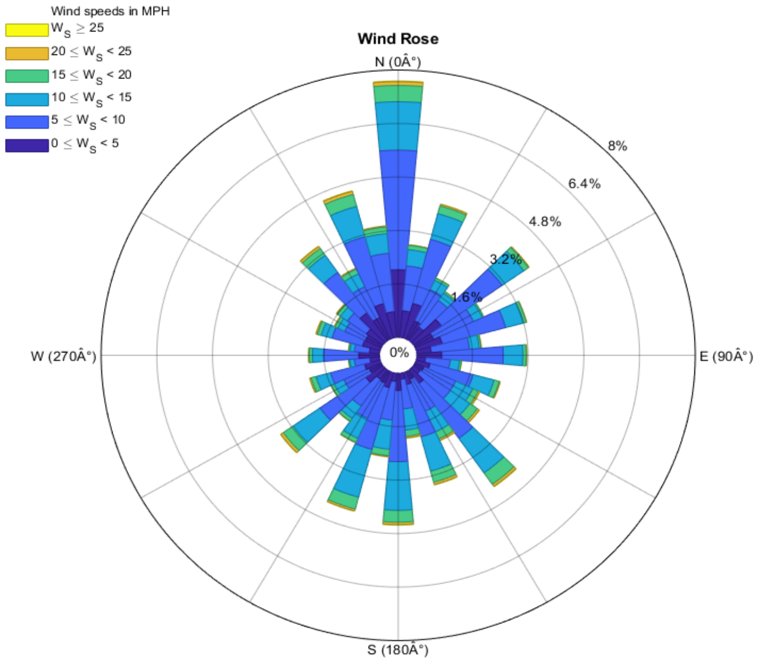
Choctaw Beach Vulnerability Assessment – Site Conditions

- Data Collection
  - NOAA Tidal Datum Elevations
  - FEMA Statistical Stillwater Elevations
  - Wind Speed Data
- Data Analysis
  - Extremal Water Level Interpolation
  - Extremal Wind Speed Analysis
  - Wave Growth Analysis with and without sea level rise



Tidal Elevations (ft NAVD88)	
MHHW	0.64
MHW	0.64
MLW	0.15
MLLW	0.15

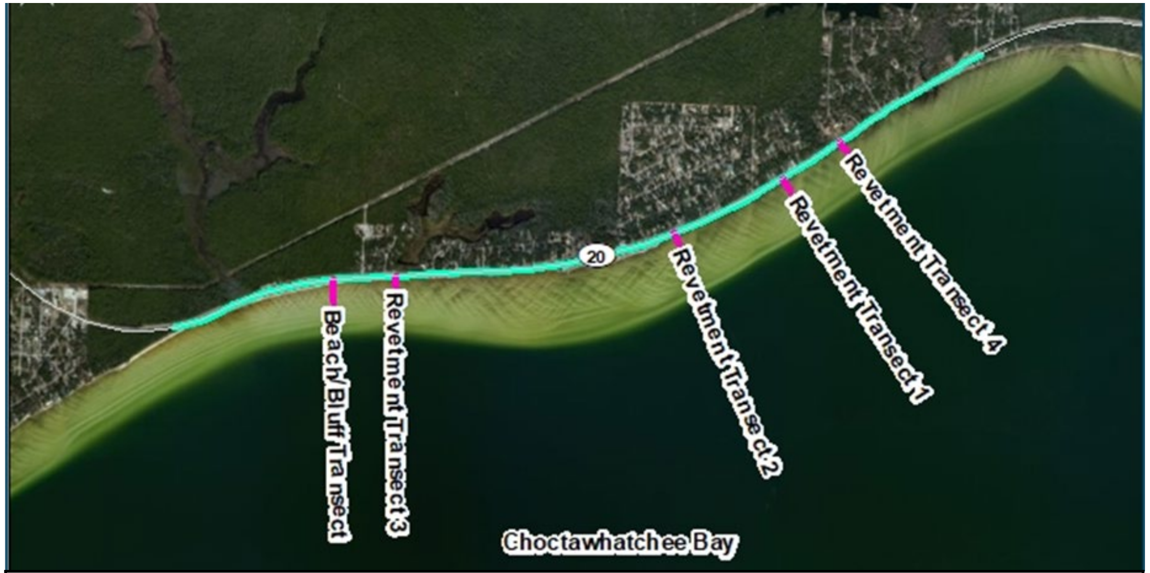
Statistical Stillwater Elevations (ft NAVD88)	
10-year	3.91
15-year (Interpolated)	4.58
25-year	5.30
50-year	6.18
100-year	6.91
500-year	8.69



Surge Only		
Return Period	Wave Height (ft)	Wave Period (sec)
1-year*	2.17	2.87
10-year	3.72	3.72
15-year	4.08	3.89
25-year	4.70	4.17
50-year	5.59	4.54
100-year	6.71	4.89
Surge + SLR		
Return Period	Wave Height (ft)	Wave Period (sec)
1-year *	2.25	2.91
10-year	3.87	3.77
15-year	4.25	3.94
25-year	4.90	4.22
50-year	5.84	4.60
100-year	7.05	5.05

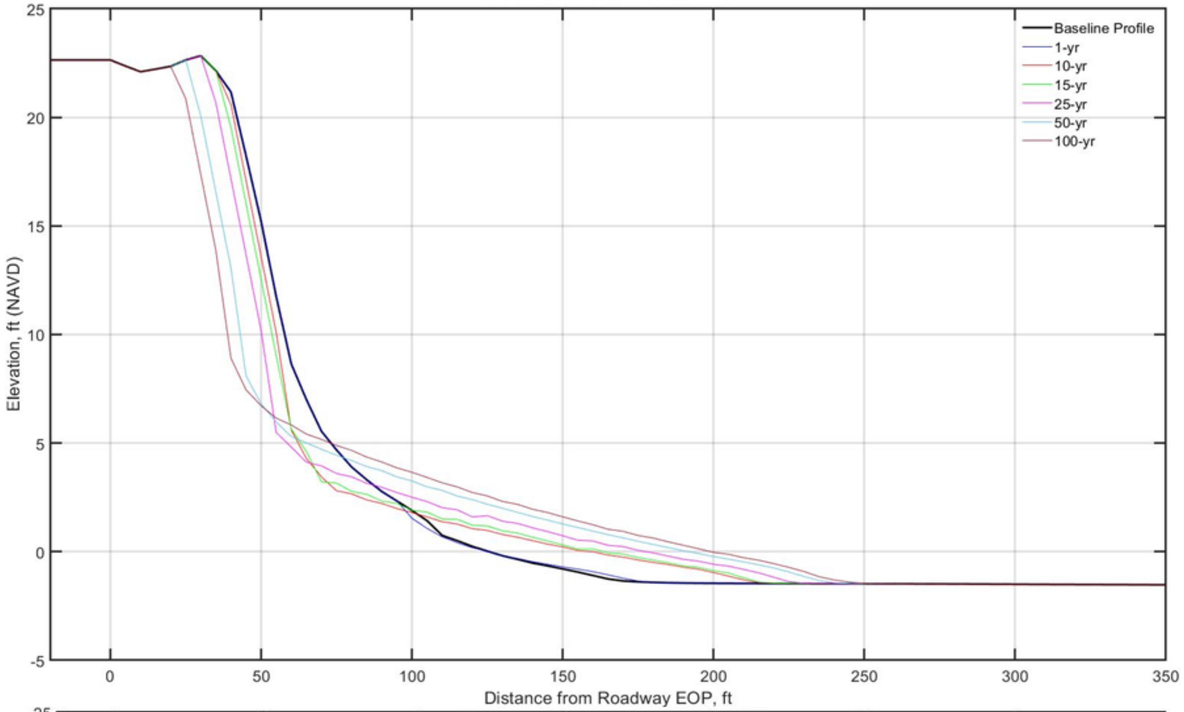
*** Based on MHW or MHW + SLR, respectively.**

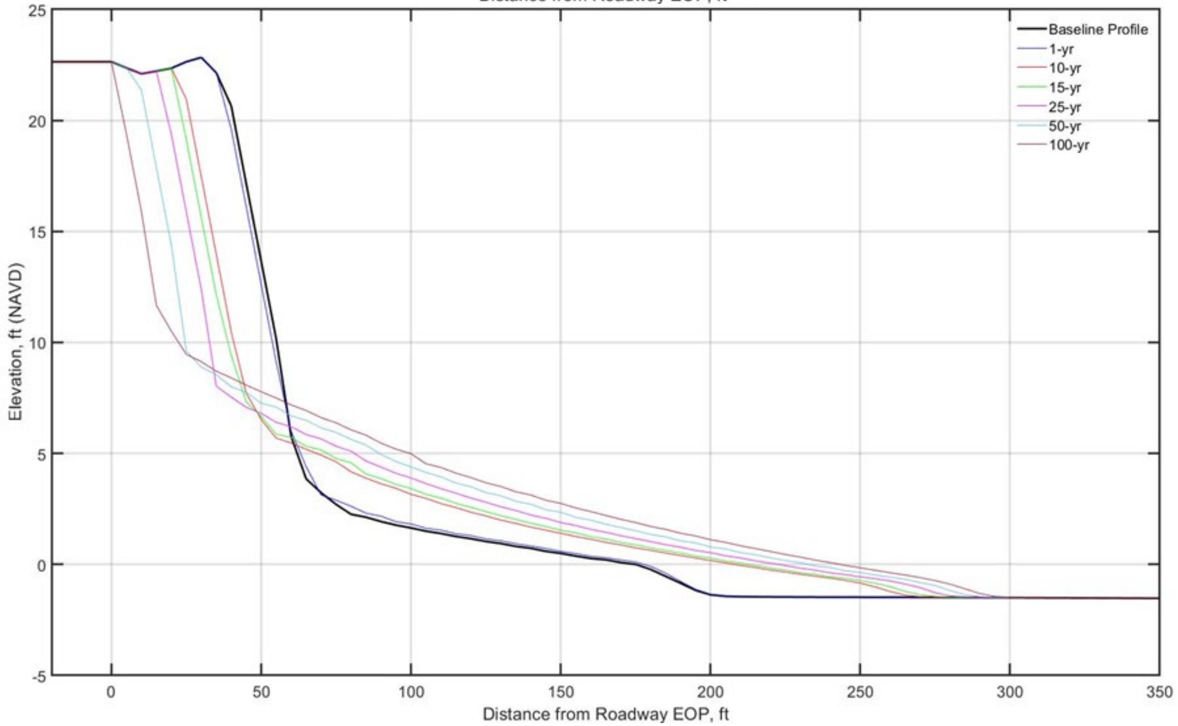
Choctaw Beach Vulnerability Assessment



Surge Only				
Return Period	Freeboard to SR 20 Seaward EOP (ft)			
	Transect 1	Transect 2	Transect 3	Transect 4
1-year	16.33	12.41	8.77	4.69
10-year	10.82	7.19	4.15	0.48
15-year	9.72	6.14	3.22	-0.37
25-year	8.44	4.92	2.16	N/A – Submerged
50-year	6.84	3.40	0.84	N/A – Submerged
100-year	5.37	2.01	-0.34	N/A – Submerged

Surge + SLR				
Return Period	Freeboard to SR 20 Seaward EOP (ft)			
	Transect 1	Transect 2	Transect 3	Transect 4
1-year	12.26	8.47	4.98	1.35
10-year	7.45	3.84	0.78	N/A – Submerged
15-year	6.42	2.86	-0.10	N/A – Submerged
25-year	5.08	1.60	-1.19	N/A – Submerged
50-year	3.30	-0.07	N/A – Submerged	N/A – Submerged
100-year	1.41	-1.82	N/A – Submerged	N/A – Submerged





Choctaw Beach Vulnerability Assessment – Summary and Findings

- Vulnerability assessment performed for the 1-, 10-, 15-, 25-, 50-, and 100-year return periods, with and without sea level rise.
- Five representative transects along the shoreline:
  - One representing a beach backed by a bluff
  - Four representing revetments with varying crest elevations, increasing from Transect 4 (lowest) to Transect 1 (highest)
- Shorelines represented by Revetment Transect 4 deemed most vulnerable, with significant impacts anticipated without sea level rise
- Shorelines represented by the beach/bluff transect and by Revetment Transect 3 may have minimal impacts without sea level rise but are anticipated to have significant impacts when sea level rise is included

Surge Only

Return Period	Beach/Bluff Transect	Revetment Transects			
		Transect 1	Transect 2	Transect 3	Transect 4
1-year					
10-year					
15-year					
25-year					
50-year					
100-year					

Surge + SLR

Return Period	Beach/Bluff Transect	Revetment Transects			
		Transect 1	Transect 2	Transect 3	Transect 4
1-year					
10-year					
15-year					
25-year					
50-year					
100-year					

Shading Key:

No/minimal roadway impacts under design storm event.

Roadway impacts by total water elevation for revetment transects (or erosion within 25 ft of seaward EOP for beach/bluff transect) under design storm event.

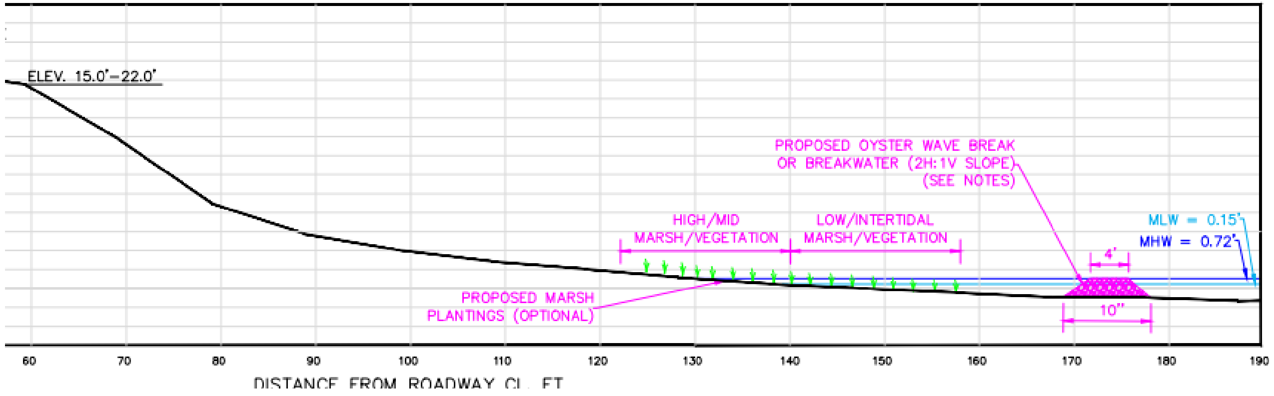
Roadway impacts by stillwater inundation for revetment transects (or erosion undermining seaward EOP for beach/bluff transect) under design storm event.

Choctaw Beach Conceptual Design Alternatives

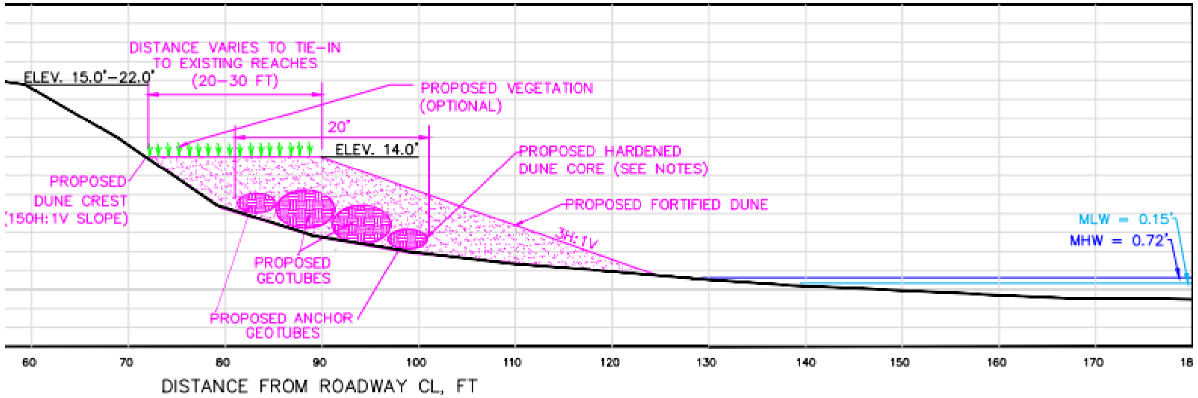
- Conceptual design alternatives developed for three shoreline treatment types:
  - Treatment Type 1: Beach backed by a bluff
  - Treatment Type 2: High Revetment (Revetment Transects 1 and 2)
  - Treatment Type 3: Low Revetment (Revetment Transects 3 and 4)
- Shoreline reaches were generalized to avoid alternating between treatment types too frequently

Choctaw Beach Conceptual Design Alternatives – Treatment Type 1

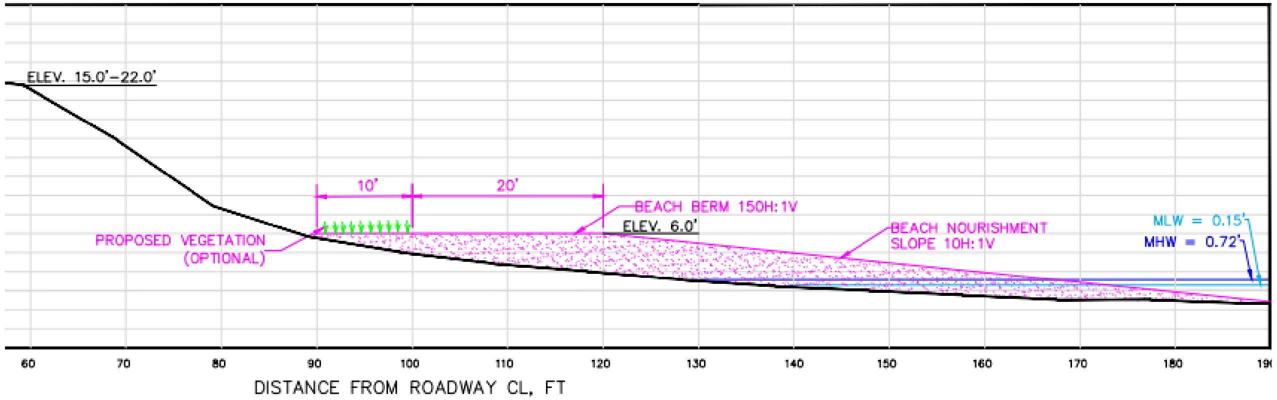
Alternative 1 – Nearshore Oyster Wave Break



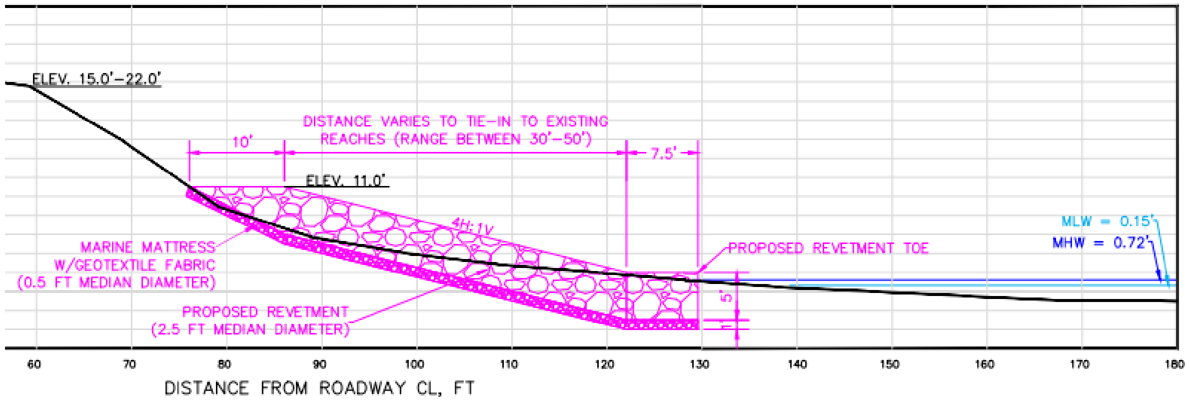
Alternative 2 – Fortified Dune at Base of Bluff



Alternative 3 – Beach Nourishment

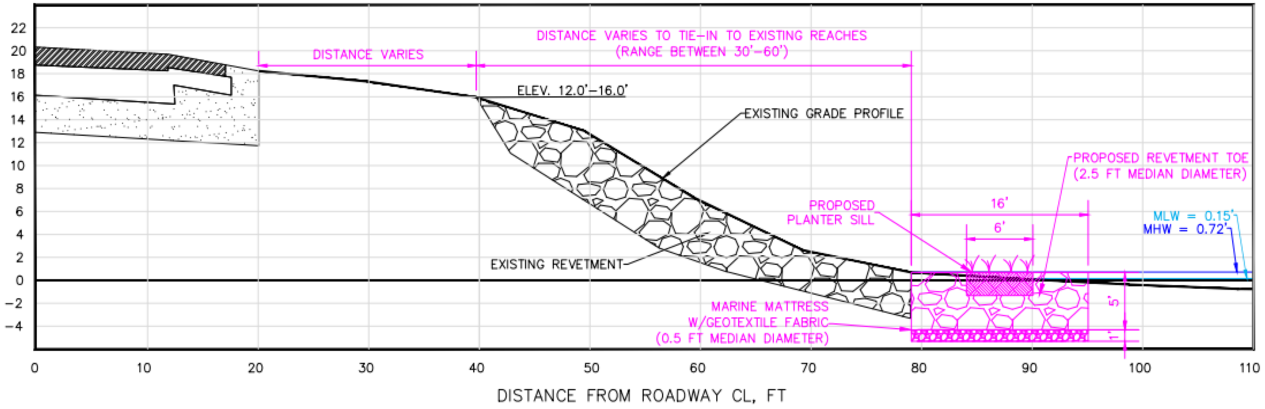


Alternative 4 – Extend Revetment along Bluff

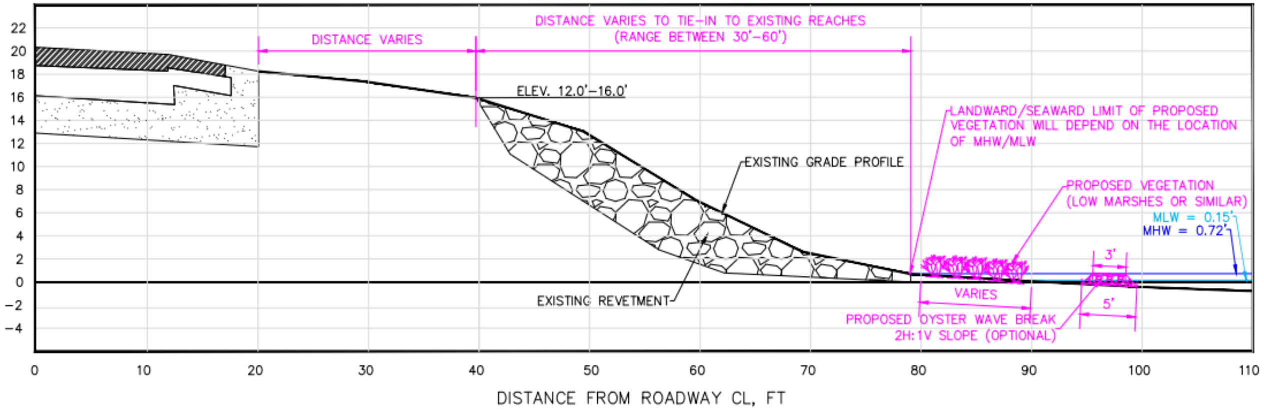


Choctaw Beach Conceptual Design Alternatives – Treatment Type 2

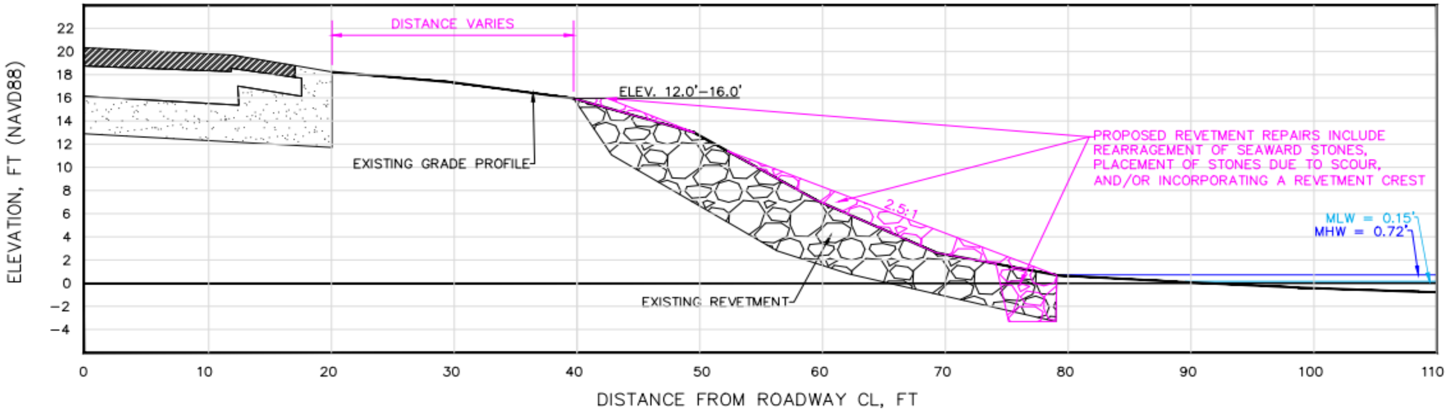
Alternative 1 – Add Stone Toe with Planter Sill to Existing Revetment



Alternative 2 – Add Vegetative Marsh Plantings Seaward of Existing Revetment Toe

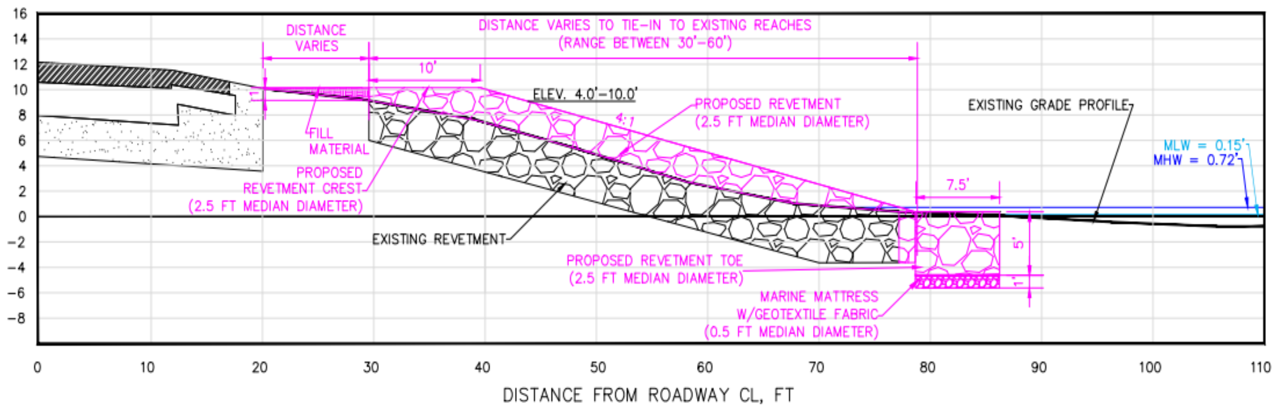


Alternative 3 – Localized Repairs to Existing Revetment

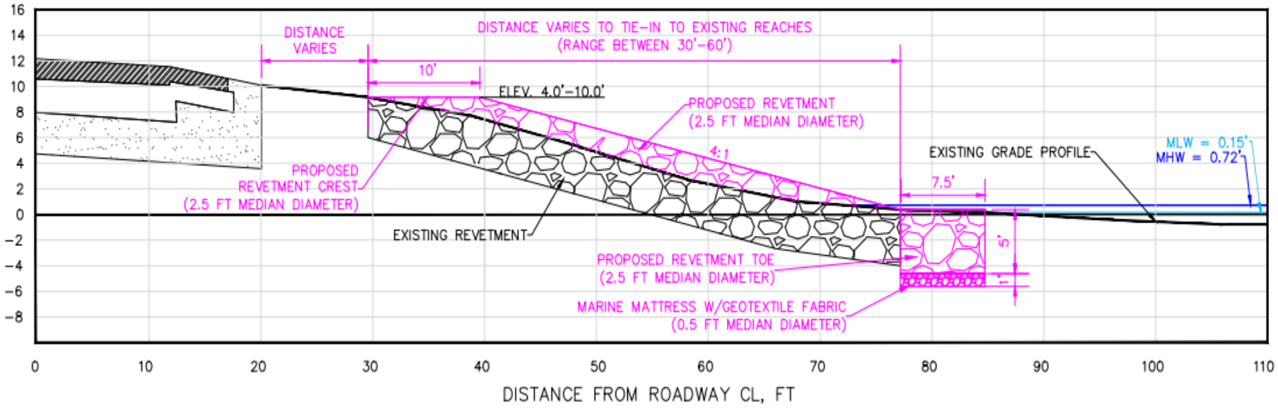


Choctaw Beach Conceptual Design Alternatives – Treatment Type 3

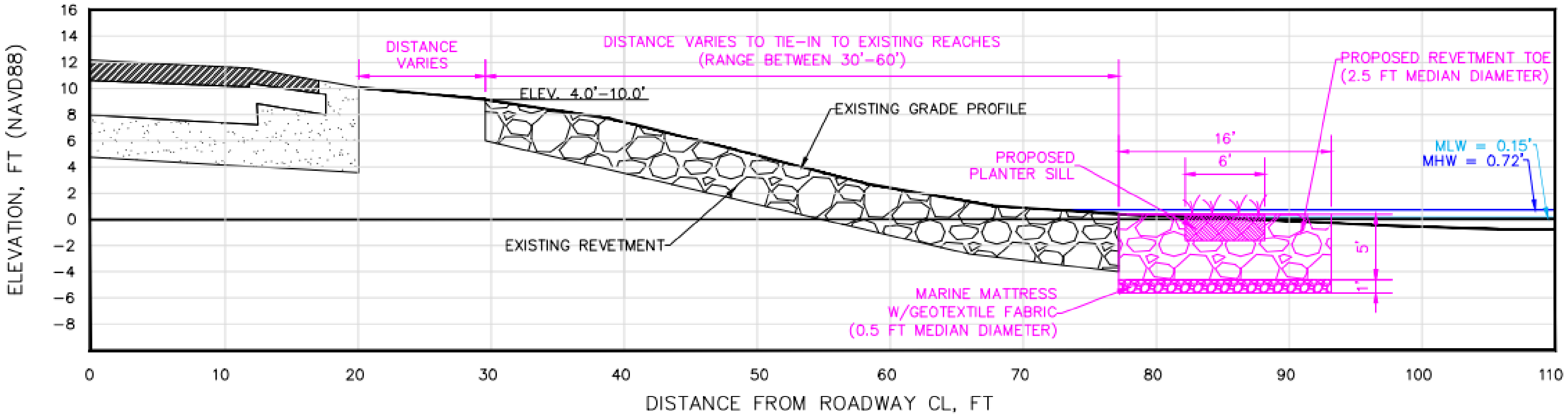
Alternative 1 – Raise Revetment Crest Elevation and Add Toe



Alternative 2 – Widen Seaward Revetment Slope and Add Toe



Alternative 3 – Add Stone Toe with Planter Sill to Existing Revetment



Choctaw Beach Conceptual Design Alternatives

Treatment Type 1 (Beach Bluff)

	Alternative 1: Nearshore Oyster Wave Break or Breakwater	Alternative 2: Fortified Dune at Base of Bluff	Alternative 3: Beach Nourishment	Alternative 4: Extend Revetment along Bluff
Cost				
Ease of Permitting				
Constructability				
Living Shorelines				
Longevity of Design and Maintenance Requirements				
Public Accessibility				
Improvements to Roadway Vulnerability				

Color Coding Key	
	HIGHLY EFFECTIVE / BENEFICIAL
	EFFECTIVE / BENEFICIAL
	MINIMALLY EFFECTIVE / BENEFICIAL

Treatment Type 2 (High Revetment)

	Alternative 1: Add Stone Toe with Planter Sill to Existing Revetment	Alternative 2: Vegetative Plantings Seaward of Existing Revetment Toe	Alternative 3: Localized Repairs to Existing Revetment
Cost			
Ease of Permitting			
Constructability			
Living Shorelines			
Longevity of Design and Maintenance Requirements			
Improvements to Roadway Vulnerability			

Color Coding Key	
	HIGHLY EFFECTIVE / BENEFICIAL
	EFFECTIVE / BENEFICIAL
	MINIMALLY EFFECTIVE / BENEFICIAL

Treatment Type 3 (Low Revetment)

	Alternative 1: Raise Revetment Crest Elevation and Add Stone Toe	Alternative 2: Widen Seaward Revetment Slope and Add Stone Toe	Alternative 3: Add Stone Toe with Planter Sill to Existing Revetment
Cost			
Ease of Permitting			
Constructability			
Living Shorelines			
Longevity of Design and Maintenance Requirements			
Improvements to Roadway Vulnerability			

Color Coding Key	
	HIGHLY EFFECTIVE / BENEFICIAL
	EFFECTIVE / BENEFICIAL
	MINIMALLY EFFECTIVE / BENEFICIAL

Summary

- Vulnerability Assessments can identify areas of risk and help to prioritize a response.
- Resilience can be quantified as a way to determine the best actions to prioritize expenditure of funds.
  - We analyze potential conceptual design alternatives, including living shorelines, that can provide the desired level of protection and resiliency for areas deemed vulnerable.
- In the case of Choctaw Beach, three different treatment types were developed for application to specific sections of the project shoreline.
- Conceptual design alternatives were developed for each treatment type. For each treatment type, each conceptual design alternative was analyzed through an evaluation matrix, which reviewed the pros and cons of the design in relation to cost, ease of permitting, constructability, living shorelines, anticipated design longevity and maintenance requirements, public accessibility (for the beach/bluff shoreline only), and improvements to roadway vulnerability.
- Multiple conceptual alternative designs were developed for each shoreline treatment to improve the resilience of SR 20 in Choctaw Beach, which is important due to its use as a hurricane evacuation route.

References

- Atkins. 2021. Choctaw Beach Vulnerability Analysis of State Road 20. Report for Florida Department of Transportation. September 08, 2021.
- Atkins. 2022. Choctaw Beach Vulnerability Analysis and Conceptual Design along State Road 20. Report for Florida Department of Transportation. July 28, 2022.
- Bruneau and Reinhorn, 2006. Overview of the Resilience Concept. Proceedings of the 8th US National Conference on Earthquake Engineering, April 18-22, 2006.

thank you