TAYLOR ENGINEERING, INC.

Martin County
Four Mile Beach Resilience

FSBPA Tech Conference

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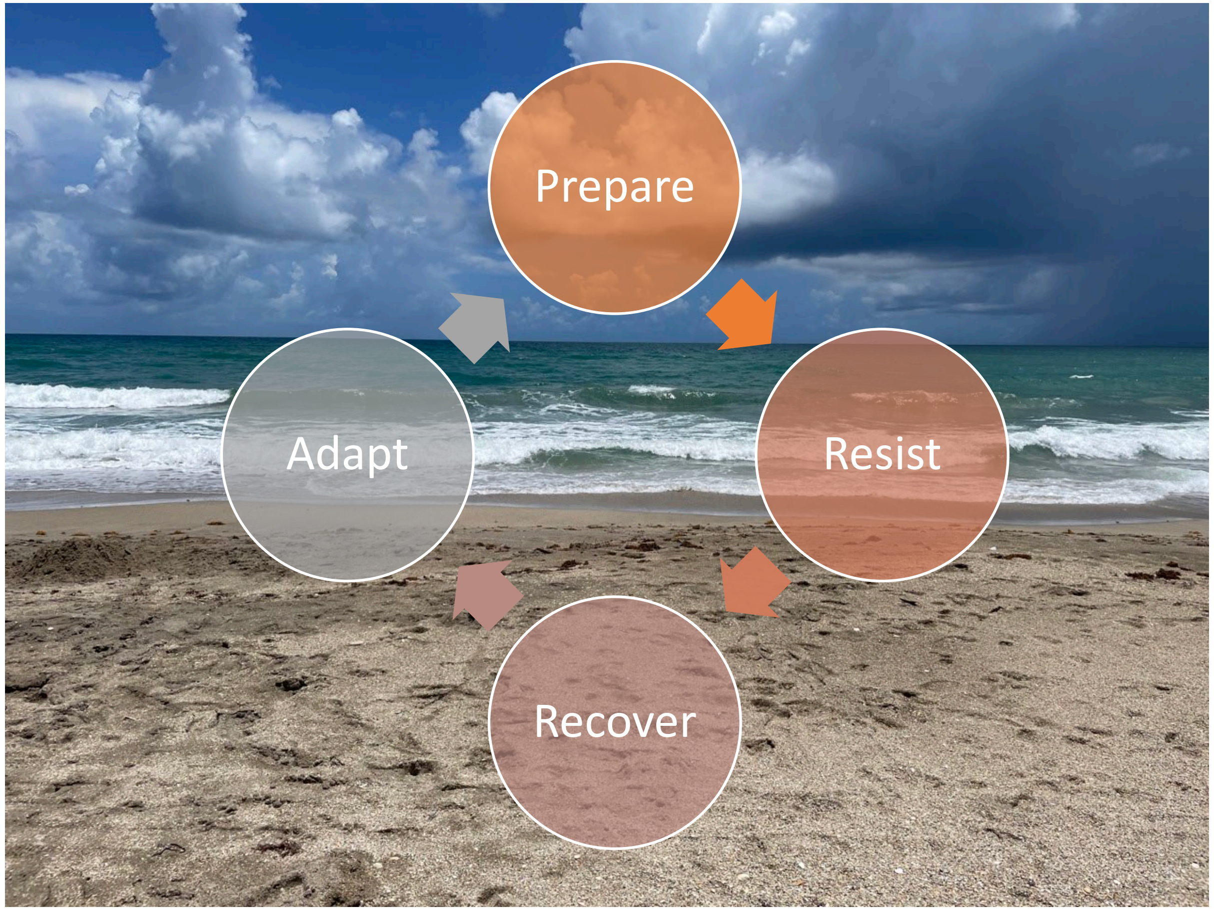
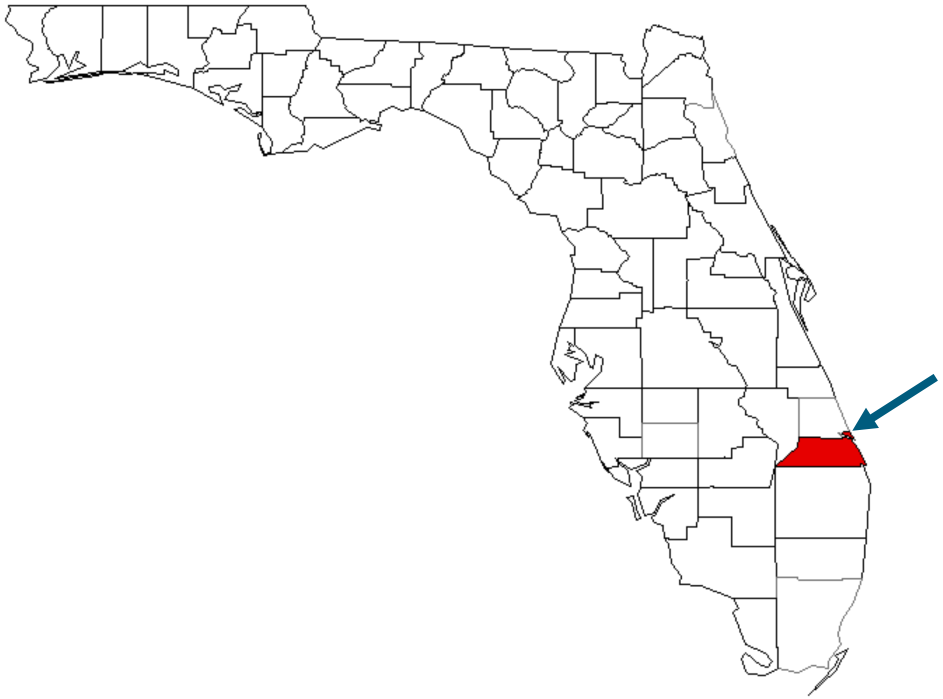
Presentation Outline

- Project Information
- Resilience Metrics
- Beach Resilience Metrics
- Hurricanes Ian and Nicole
- Comparison of Beach Resilience Metrics
- Summary
- Looking Forward
  - prepare, resist, recover, and adapt



Martin County SPP

- Northern-most 4 miles of Martin County (R-1 to R-25)
- Provides storm damage reduction in addition to recreation and environmental benefits



Martin County SPP Resilience

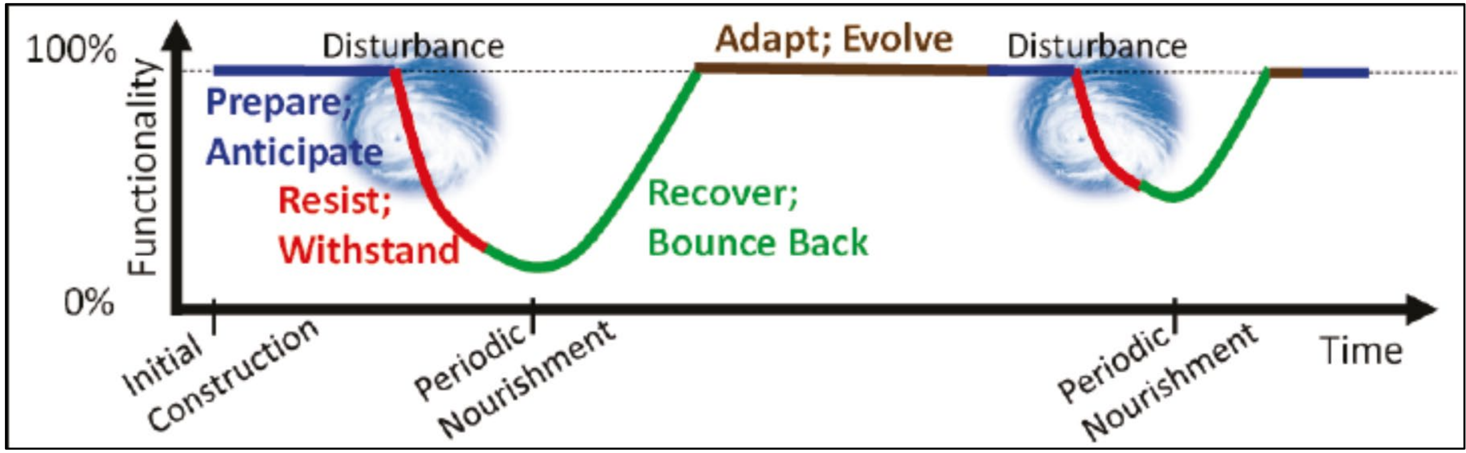
- The County is investigating options to modify the project design in the future to increase the performance of the beach fill and enhance resilience

- Our Path:
  - Summarize project history & available data
  - Analyze historic beach trends
  - Begin discussions with permitting agencies
  - Modeling (XBEACH)
  - … recommendations and next steps

Resilience Defined

- Resilience is defined by *Executive Order 13653* as the ability to:
  - Anticipate,
  - Prepare for,
  - And adapt

  to changing conditions and:
  - Withstand,
  - Respond to,
  - And recover rapidly from disruptions



- Resilience is a ***trait***
- How can we measure resilience? What are the metrics?

Resilience Metrics

- Depends on what system you want to evaluate as resilient:
  - Economic
  - Social/Human
  - Environmental
  - Transportation
  - Power/Energy

- Specific to coastal structures, measure damage caused by:
  - Inundation
  - Wave Damage
  - Erosion

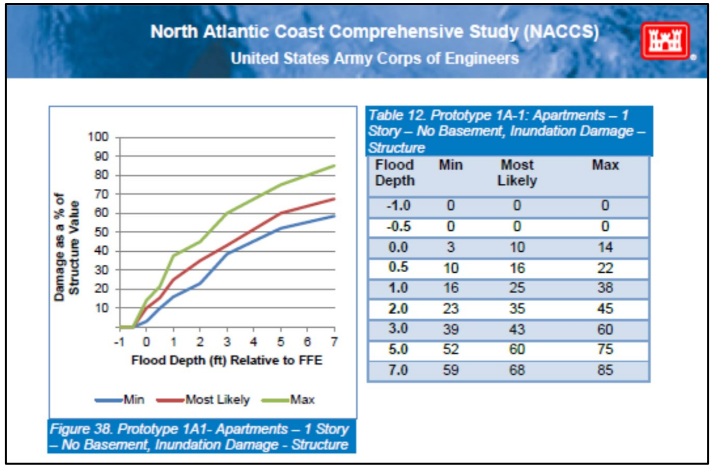


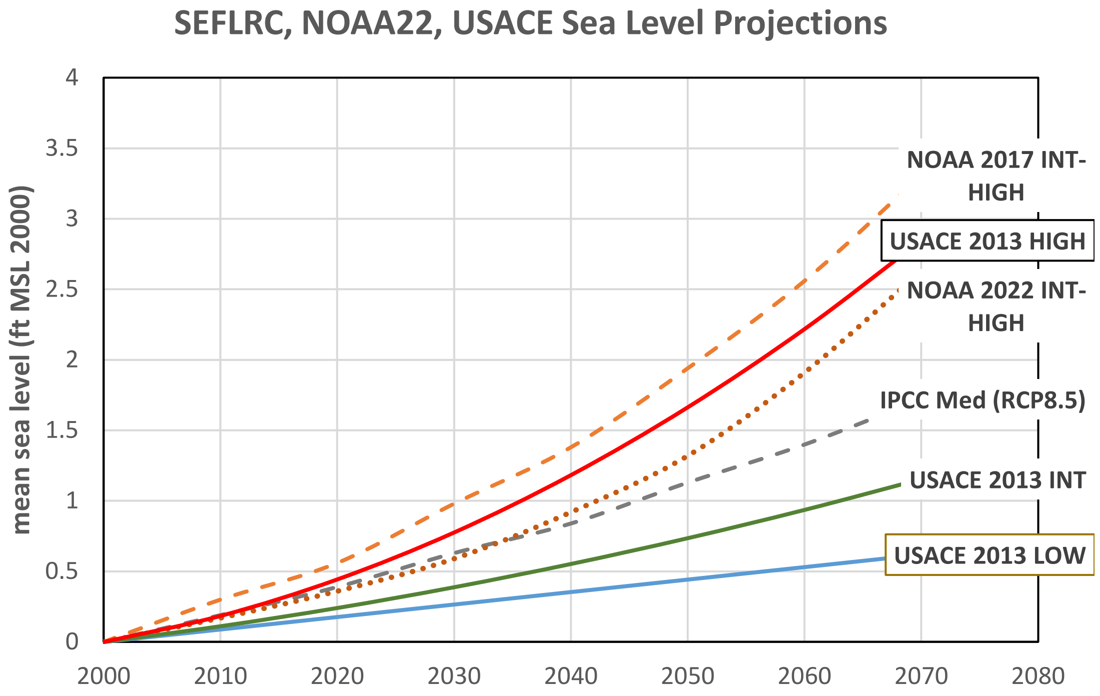
Figure 38. Prototype 1A1- Apartments – 1 Story – No Basement, Inundation Damage - Structure

Table 12. Prototype 1A-1: Apartments – 1 Story – No Basement, Inundation Damage – Structure

Flood Depth	Min	Most Likely	Max
-1.0	0	0	0
-0.5	0	0	0
0.0	3	10	14
0.5	10	16	22
1.0	16	25	38
2.0	23	35	45
3.0	39	43	60
5.0	52	60	75
7.0	59	68	85

Resilience to Sea Level Rise

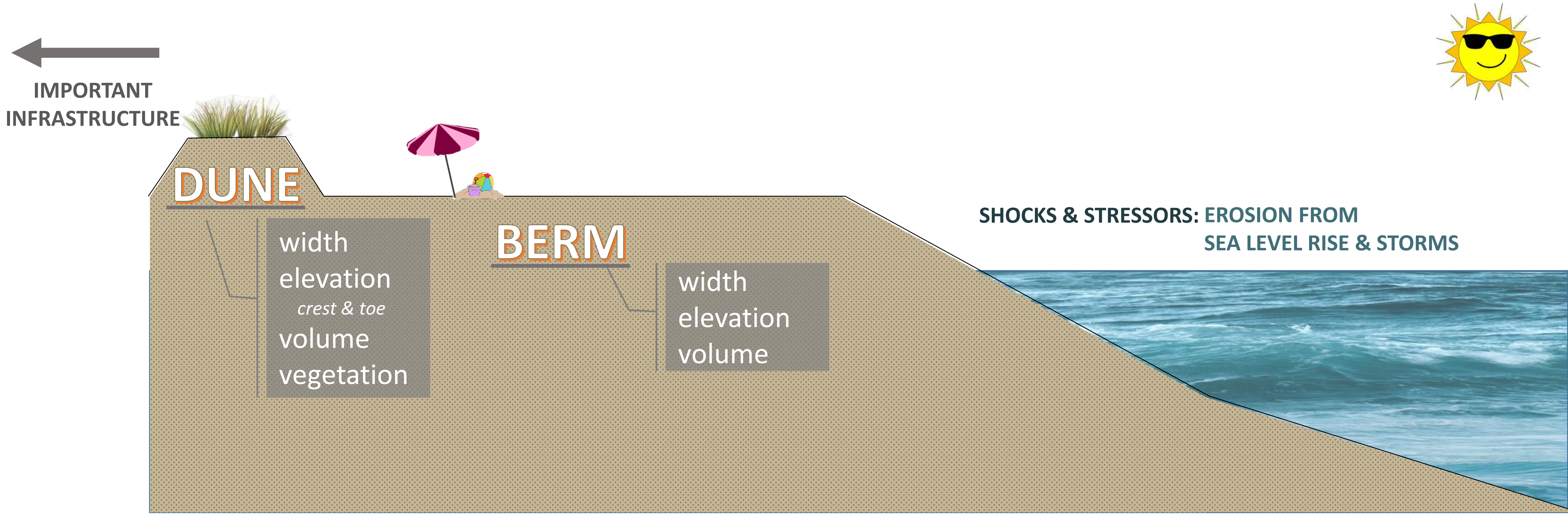
- Resilience is defined as the ability to:
  - Anticipate,
  - Prepare for,
  - And adapt
- Adaptation is an *action*
- Requires planning
- What planning/SLR scenario to use?



- From Martin County SPP's 1993 General Design Memorandum:

67. A contributing factor to the susceptibility to storm damage is relative sea level rise. If the upper limit of relative sea level rise actually occurs, it will increase the shoreline recession and storm damages estimated within this report.

How to Measure Beach Resilience



How to Measure Beach Resilience

- Elevations
  - Contour tracking (MHW, berm, dune)
  - Maximum elevation (dune)
- Width/shoreline position
- Volume analysis
- Vegetation coverage

SHOCKS & STRESSORS

-Sea level rise

-Storm intensity, frequency, and duration

-Recovery rate

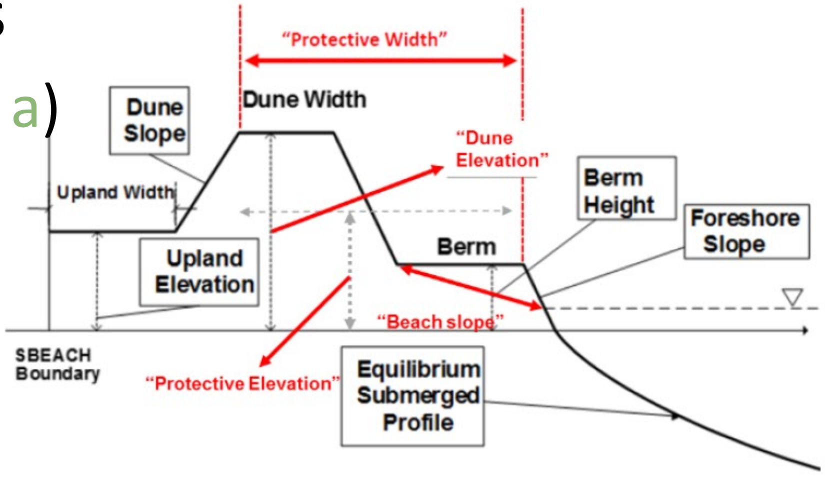
- Beach Change Envelope (USGS)
- Buffer Width (USACE)
- Coastal Vulnerability Index (USGS)
- Coastal Resilience Index (USACE- ASBPA, APTIM)
- (Dune) Engineering Design Parameter (Stevens)

short-term response/storm damage reduction benefits

Dong, Z., Elko, N., Robertson, Q., and Rosati, J., 2018. Quantifying Beach and Dune Resilience Using the Coastal Resilience Index. *Coastal Engineering 2018*.

Coastal Resilience Index

- 5 non dimensional factors
  - Protective Elevation (PE, a)
  - Volume Density (VD, b)
  - Protective Width (PW, c)
  - Crest Freeboard (CF, d)
  - Wave Runup (WR, e)



Dong et.al.,2018 adapted from Rogers et al., 2009

$$CRI = a + b + c + d + e$$

- GIS tool to extract features
  - Dune landward limit, crest, & toe; shoreline; mean beach slope

Dong, Z., Elko, N., Robertson, Q., and Rosati, J., 2018. Quantifying Beach and Dune Resilience Using the Coastal Resilience Index. *Coastal Engineering 2018*.

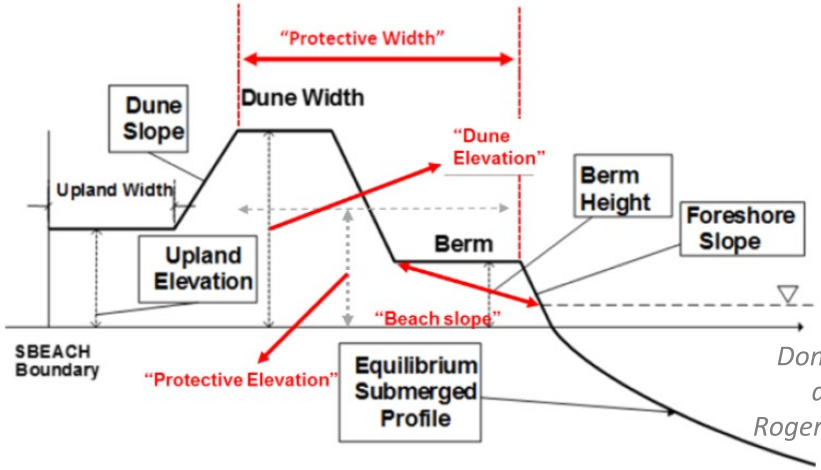
Coastal Resilience Index

$$CRI = a + b + c + d + e$$

- Protective Elevation Factor

$$a = \frac{PE}{PE_0}$$

o -"characteristic constant" for AOI



Dong et.al.,2018 adapted from Rogers et al., 2009

- Volume Density Factor

$$b = \frac{PE*PW*(1-s)}{PE_0*PW_o}$$

% of fine sediment

- Protective Width Factor

$$c = \frac{PW-MR}{PW_o}$$

- Crest Freeboard Factor

$$d = \frac{DE-(MS+MHW)}{CF_o}$$

- Wave Runup Factor

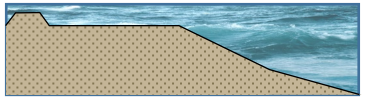
$$e = \frac{WR_o}{WR}$$

Dong, Z., Elko, N., Robertson, Q., and Rosati, J., 2018. Quantifying Beach and Dune Resilience Using the Coastal Resilience Index. *Coastal Engineering 2018*.

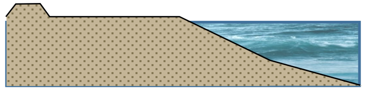
Coastal Resilience Index

- Storm Impact Analysis
  - Maximum storm-induced shoreline recession (MR)
  - Maximum storm surge (MS)
  - Tide Level (TL)

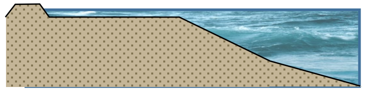
- Inundation Regime
  (MS+TL)>DE or PW<MR



- Swash Regime
  (MS+TL)<<DE or PW>>MR



- Collision or Overwash Regime
  (MS+TL)<DE



- Wave Runup
  - Stockdon, 2006

$$WR = 1.1\left\{0.35\beta_f(H_0L_0)^{1/2} + \frac{[H_0L_0(0.563\beta_f^2+0.004)]^{1/2}}{2}\right\}$$

Engineering Design Parameter (EDP)

Janssen, M.S., and Miller, K., K., 2022. The Dune Engineering Design Parameter and Applications to Forecasting Dune Impacts. *Journal of Marine Science and Engineering 2022.*

- Create fragility curves to allow for probabilistic prediction of dune impacts

$$EDP = \frac{mobilizing\ terms}{stabilizing\ terms} = \frac{intensity}{resilience}$$

- Intensity terms *(Miller and Livermont, 2008; Lemke and Miller, 2020)*
  - SEI- Storm Erosion Index
    - Time varying form of the modified Bruun Rule
    - Wave height, total water level, storm duration
  - IEI- Instantaneous Erosion Intensity
  - PEI- Peak Erosion Intensity

$$SEI = \sum_{t_d} IEI(t_i) = \sum_{t_d} W_*(t_i)\left[\frac{0.068H_b(t_i) + S(t_i)}{B + 1.28H_b(t_i)}\right]$$

"While the methods do not, and should not, replace numerical modeling, they have uses in <u>forecasting, rapid or regional scale assessments, and as a design tool in conceptual design</u>"

Janssen, M.S., and Miller, K., K., 2022. The Dune Engineering Design Parameter and Applications to Forecasting Dune Impacts. *Journal of Marine Science and Engineering 2022.*

Engineering Design Parameter (EDP)

- EDP can be modified to add additional parameters
  - Must be non-dimensional and EDP must be $\frac{intensity}{resilience}$

Table 5. Considered EDPs, underlying parameters (IM and R_f) and physical meaning.

Case	Parameters	EDP	Physical Proxy
1	PEI, Berm Width	$\frac{\text{PEI}}{(Bwidth)}$	Setback
2	PEI, Berm Width, Dune Crest Width	$\frac{\text{PEI}}{(Bwidth+Fwidth)}$	Setback
3	PEI, Dune Volume	$\frac{\text{PEI}^2}{(Dvol)}$	Volume
4	PEI, Foredune Volume	$\frac{\text{PEI}^2}{(Fvol)}$	Volume | '540-rule'
5	PEI, Berm Width and Dune Volume	$\frac{\text{PEI}^2}{(Bwidth^2+Dvol)}$	Shear
6	PEI, Berm Width and Dune Volume	$\frac{\text{PEI}^3}{(Bwidth \times Dvol)}$	Moment
7	PEI, Berm Width and Dune Volume	$\frac{\text{PEI}^4}{(Bwidth^2 \times Dvol)}$	Simplified Mass-moment of Inertia
8	PEI, Berm Width and Dune Volume	$\frac{\text{PEI}^4}{\left[\left(\sqrt{(Bwidth+Fwidth)^2+\left(\frac{1}{3}(CrestZ-ToeZ)\right)^2}\right)^2 \times Dvol\right]}$	Mass-moment of Inertia

- SEI- Storm Erosion Index
  - Wave height, total water level, storm duration
- PEI- Peak Erosion Intensity

$$EDP = \frac{PEI^4}{B_{width}^2 * D_{vol}}$$

Janssen, M.S., and Miller, K., K., 2022. The Dune Engineering Design Parameter and Applications to Forecasting Dune Impacts. *Journal of Marine Science and Engineering 2022*.

Engineering Design Parameter (EDP)

- EDP can be modified to add additional parameters
  - Must be non-dimensional and EDP must be $\frac{intensity}{resilience}$

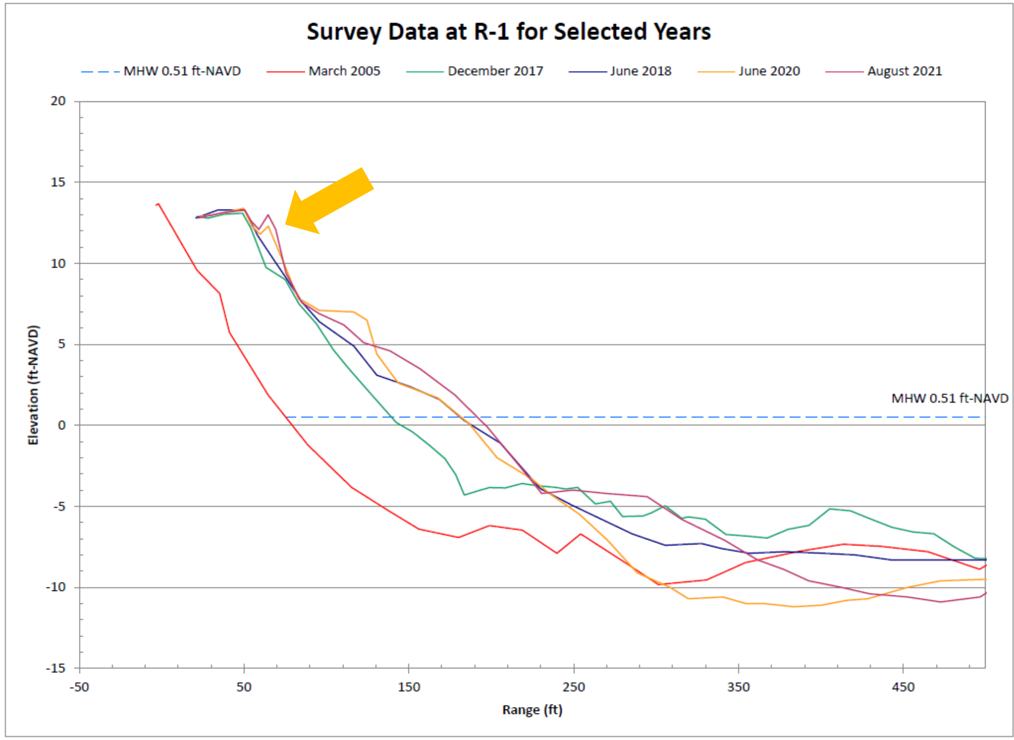
$$EDP = \frac{PEI^4}{B_{width}^2 * D_{vol}}$$

- SEI/PEI- Storm Erosion Index/Intensity
  - Wave height, total water level, storm duration

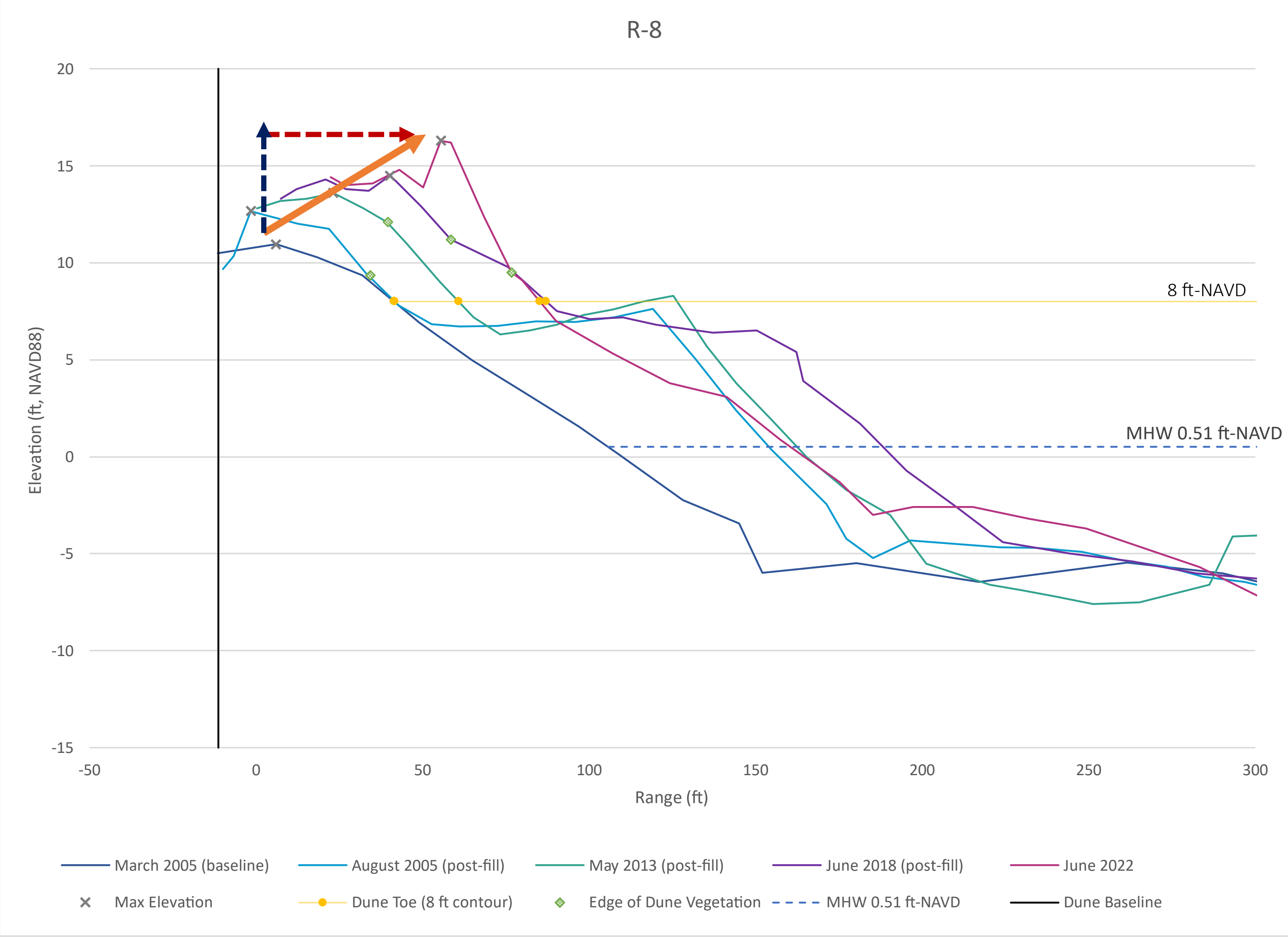
- Low EDP- resilient beach and/or low intensity storm
- High EDP- vulnerable beach and/or high intensity storm

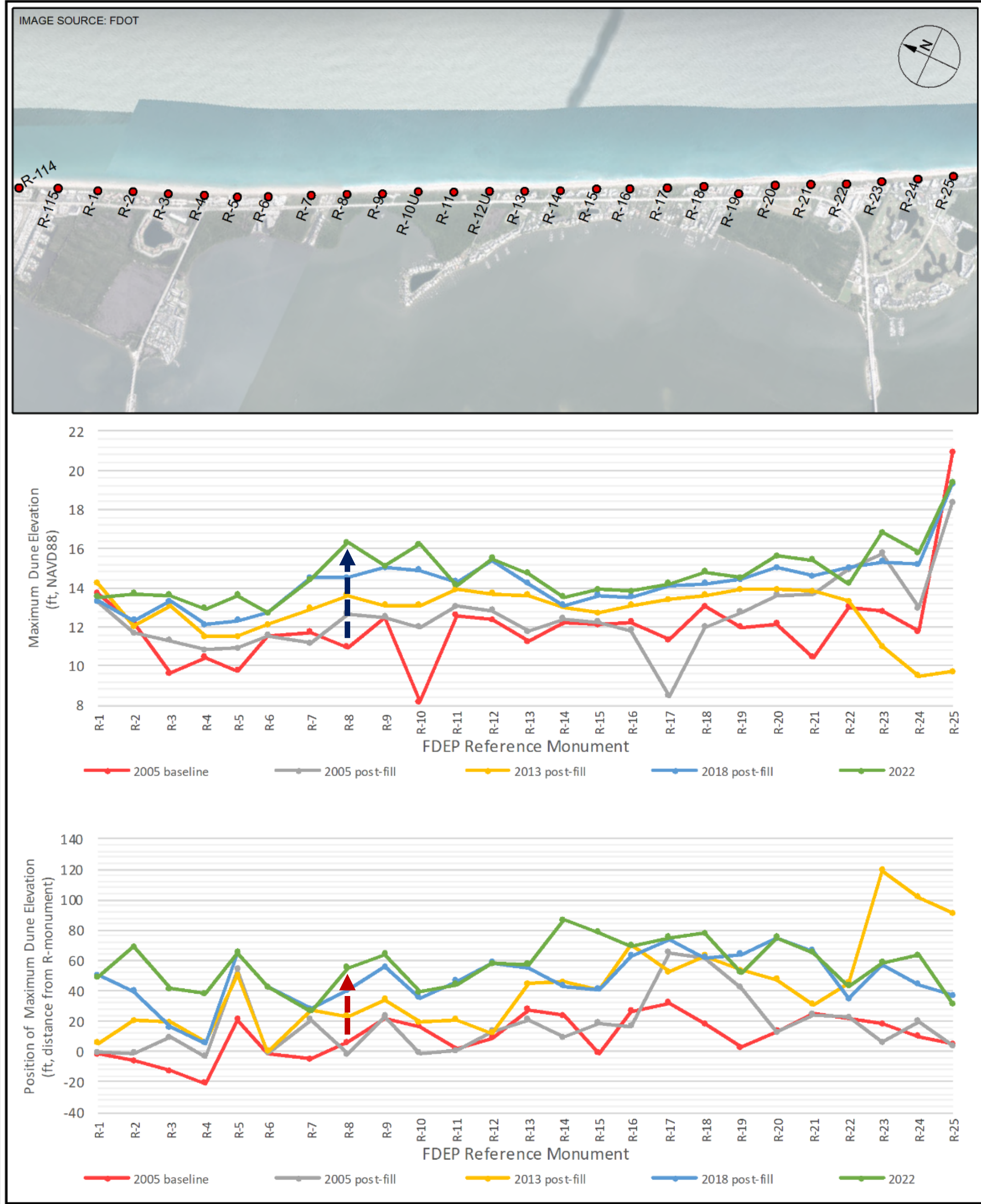
Historic Project Performance

- Performance highly dependent on storm activity
  - Consistent erosion from the sub-aerial and nearshore
  - Slow natural recovery and onshore movement of a sand bar (if conditions allow)
  - Rarely a full recovery and sand moves beyond the monitoring area
- Increased shoreline retreat and/or erosion in the northern portion of the project and increased stability to the south
- Dune growth!



Dune Growth– maximum elevation





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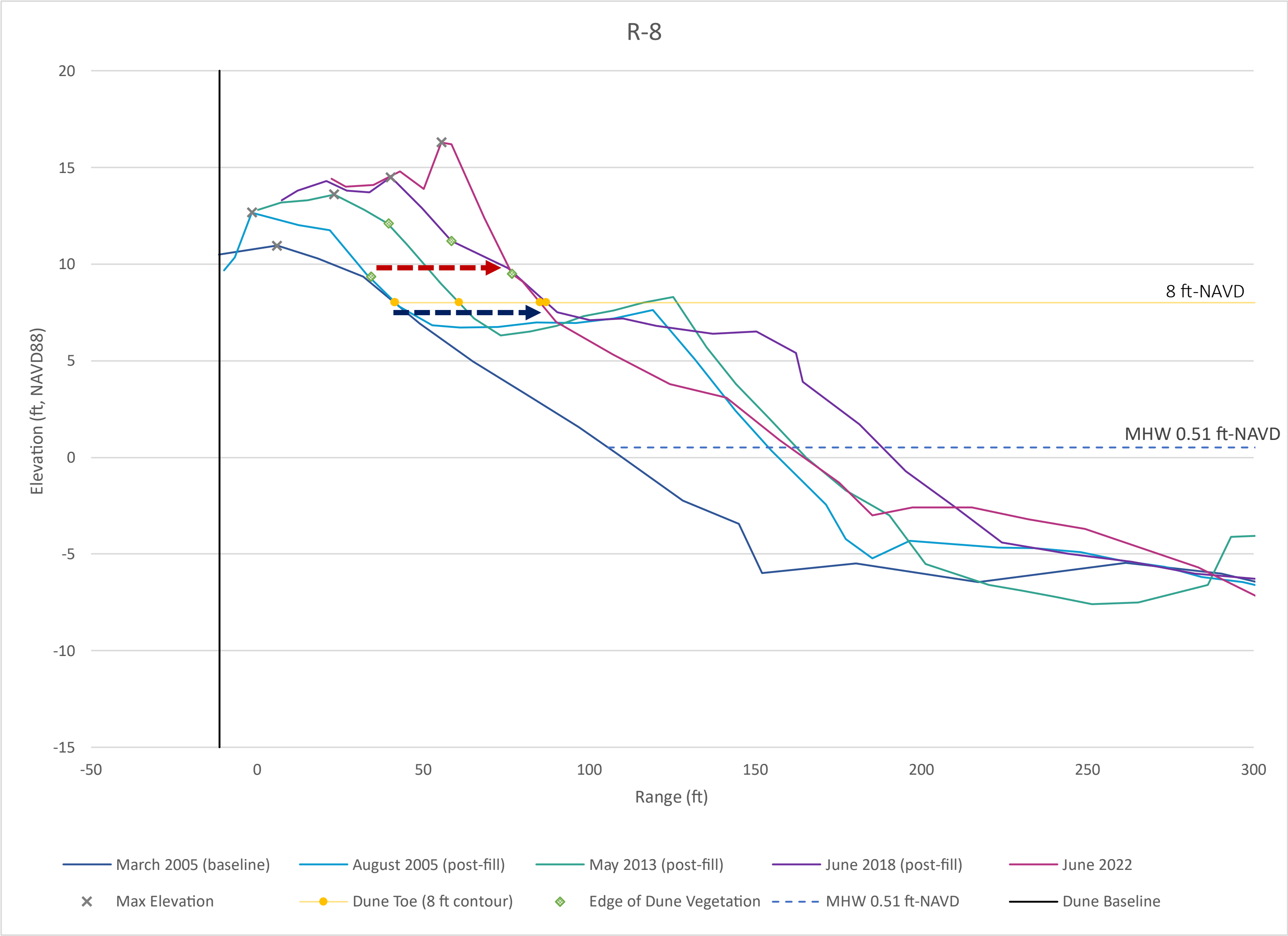
CERTIFICATE OF AUTHORIZATION # 4815

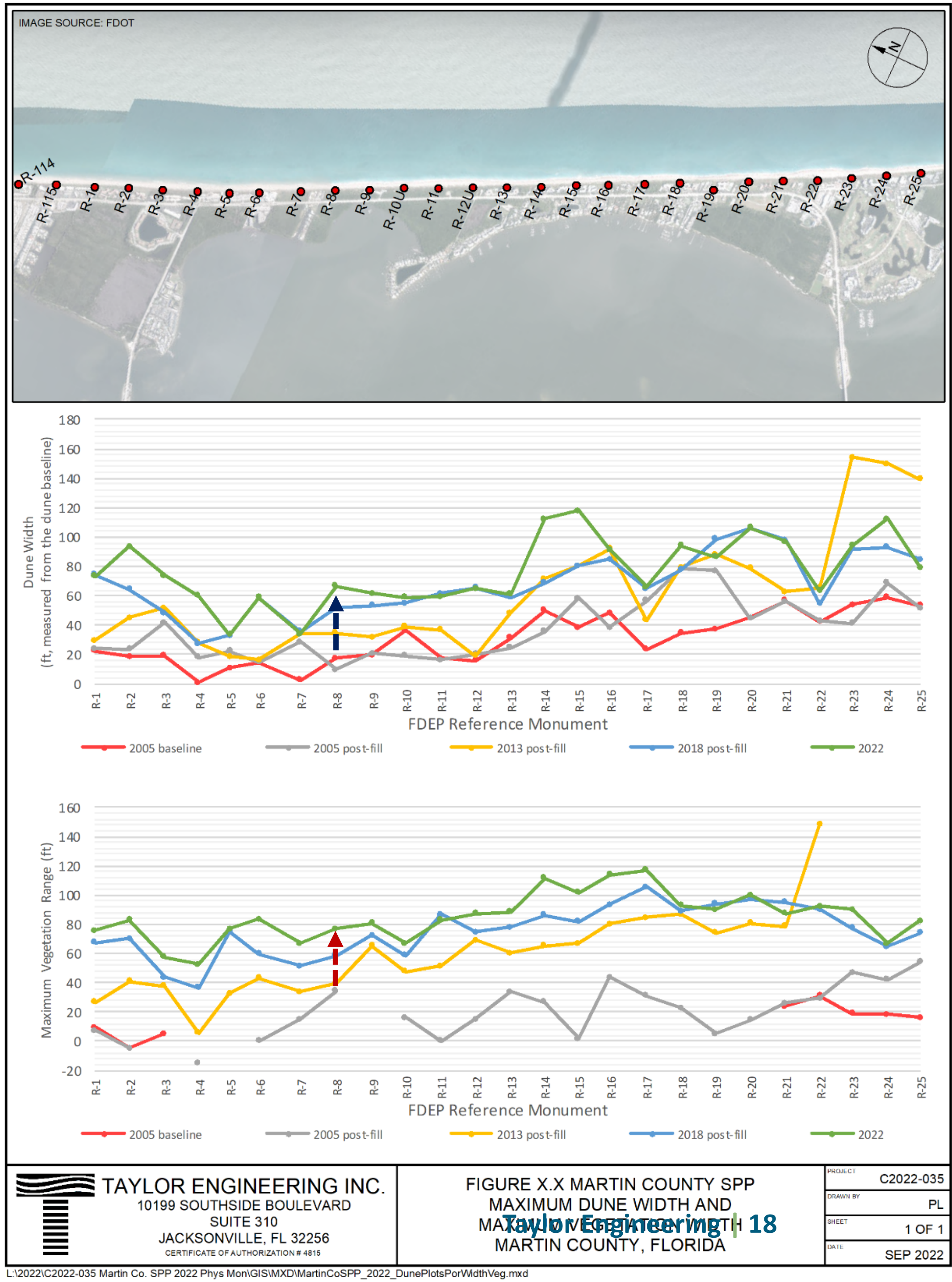
FIGURE X.X MARTIN COUNTY SPP
MAXIMUM DUNE ELEVATION AND
MAXIMUM DUNE ELEVATION POSITION
MARTIN COUNTY, FLORIDA

PROJECT	C2022-035
DRAWN BY	PL
SHEET	1 OF 1
DATE	SEP 2022

L:\2022\C2022-035 Martin Co. SPP 2022 Phys Mon\GIS\MXD\MartinCoSPP_2022_DunePlotsPorPOS.mxd

Dune Growth– dune width and edge of veg





Beach Condition 06/22

Beach Condition 9/26/22 (Pre-Ian)

Beach Condition 9/28/22 (During Ian)

Beach Condition 9/28/22 (During Ian)

Beach Condition 9/29/22 (Post-Ian)

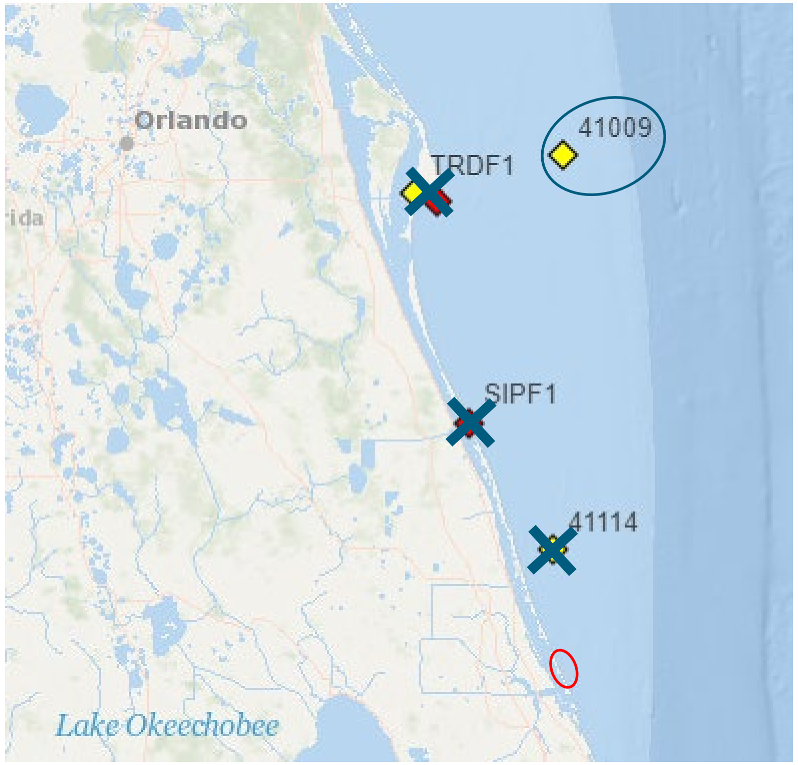
Beach Condition 11/7/22 (Pre-Nicole)

Beach Condition 11/9/22 (During-Nicole)

Beach Condition 11/10/22 (Post-Nicole)

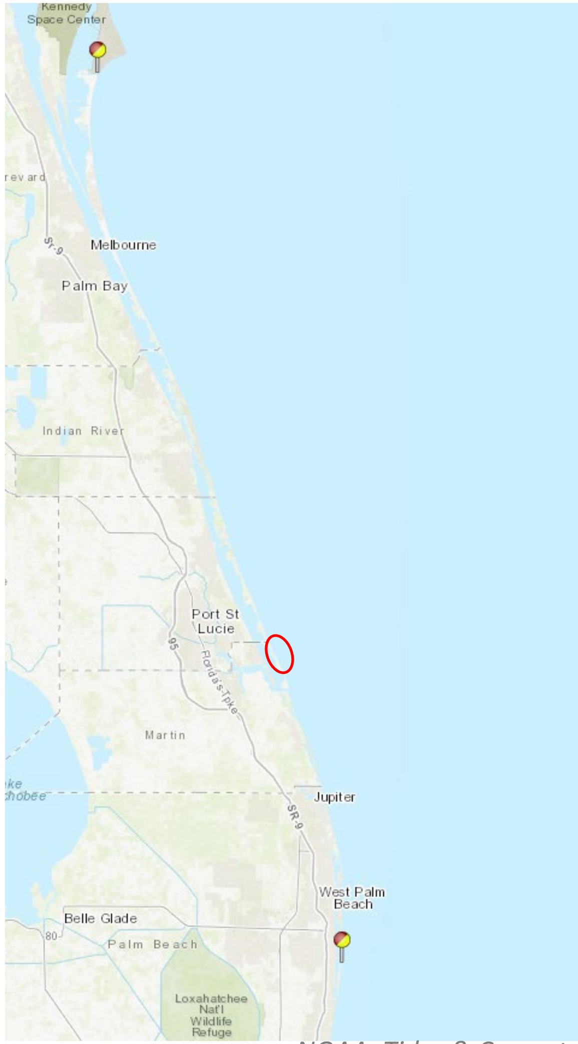
Beach Condition 11/15/22 (Post-Nicole)

Input Parameters- Wave & Water Level Data



NOAA, National Data Buoy Center

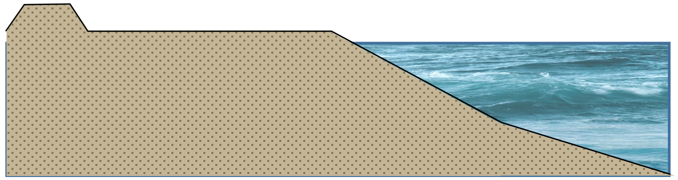
- Jensen Beach Wave Buoy
  - 0.42 miles offshore; depth ~33ft
- NOAA National Data Buoy Center (NDBC)
- USGS Flood Event Viewer
- NOAA Tides and Currents



NOAA, Tides & Currents

Application of Resilience Indices on the SPP

Contour Tracking & Volume Analysis



- Berm width
- Berm elevation
- Berm volume
- Dune width
- Dune elevation
- Dune volume
- ~~Water level~~
- ~~Wave information~~
- ~~Other:~~

Coastal Resilience Index

$$CRI = a + b + c + d + e$$

a= $\frac{PE}{PE_0}$ c= $\frac{PW-MR}{PW_o}$ d= $\frac{DE-(MS+MHW)}{CF_o}$

b= $\frac{PE*PW*(1-s)}{PE_0*PW_o}$ e= $\frac{WR_o}{WR}$

- Berm width
- Berm elevation
- ~~Berm volume~~
- Dune width
- Dune elevation
- ~~Dune volume~~
- Water level
- Wave information- Runup
- Other: fines

Engineering Design Parameter

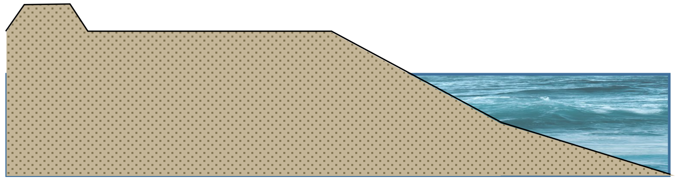
$$EDP = \frac{PEI^4}{B_{width}^2 * D_{vol}}$$

$$SEI = \sum_{t_d} IEI(t_i) = \sum_{t_d} W_*(t_i)\left[\frac{0.068H_b(t_i) + S(t_i)}{B + 1.28H_b(t_i)}\right]$$

- Berm width
- Berm elevation
- ~~Berm volume~~
- ~~Dune width~~
- ~~Dune elevation~~
- Dune volume
- Water level
- Wave information- H_b
- Other: width of active surf zone

Application of Resilience Indices on the SPP

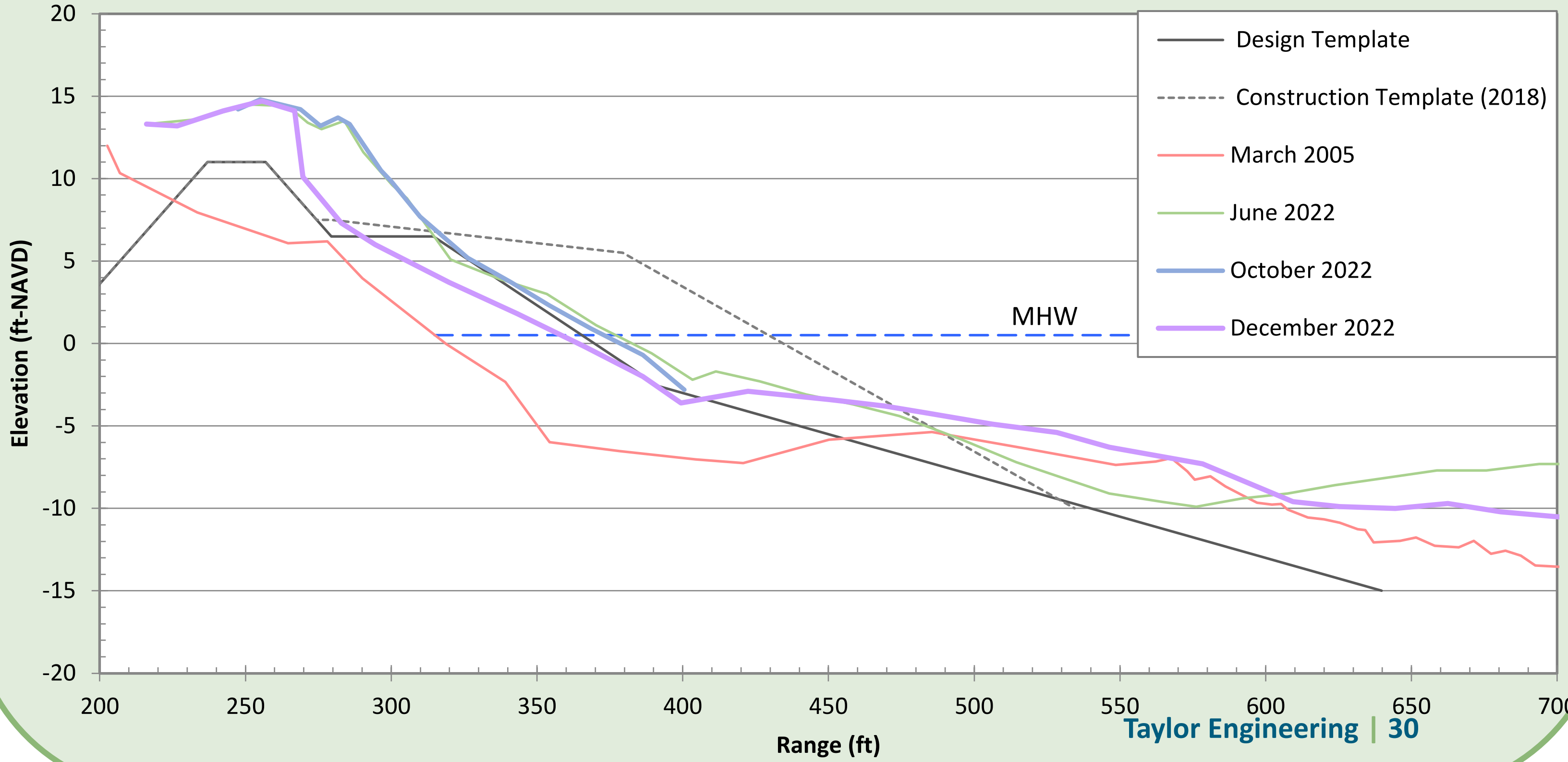
Contour Tracking & Volume Analysis



	Δ shoreline position (ft)	subaerial Δ vol (cy/ft)
DESIGN TEMPLATE	--	--
JUNE 2022	12	-0.3
OCTOBER 2022	8	+0.5
DECEMBER 2022	-7	-11.4

PROJECT AREA

	DESIGN - JUNE	JUNE - OCT	OCT - DEC
Δ shoreline position (ft)	46.6	-1.8	0.2
subaerial Δ vol (cy/ft)	-0.01	-2.6	-2.7



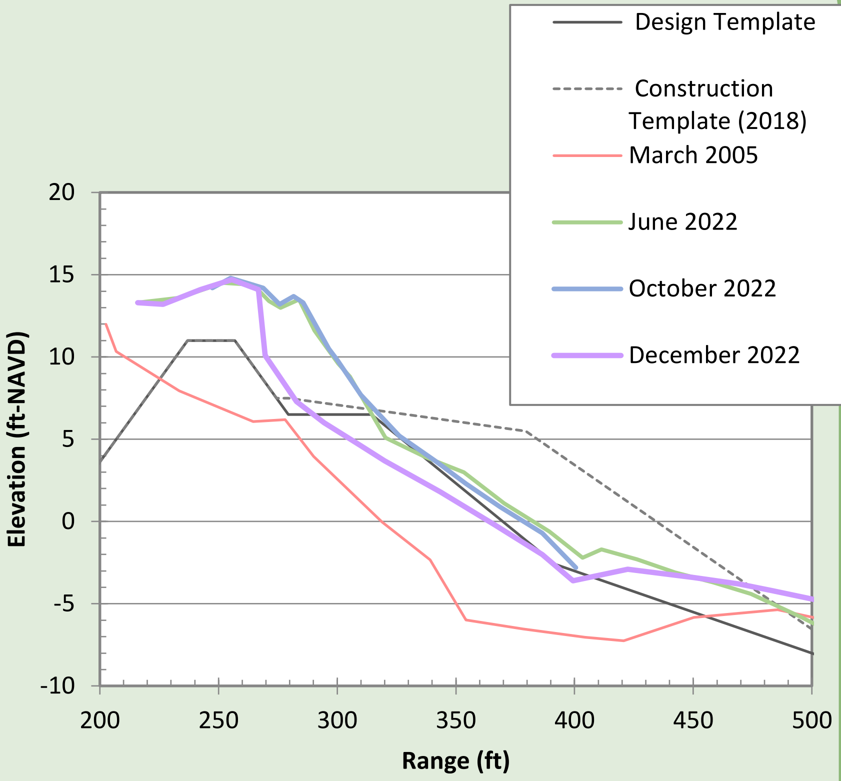
Application of Resilience Indices on the SPP

RESILIENCE INDEX		JUNE-OCT	OCT-DEC
a	PE	-	-0.1
b	VD	-	-0.2
c	PW	-0.3	+0.1
d	CF	-0.2	-0.2
e	WR	-0.9	-0.2
CRI		**-1.4**	**-0.6**

Coastal Resilience Index

$$CRI = a + b + c + d + e$$

		change in resilience factors
DESIGN TEMPLATE	--	
JUNE 2022	6.2	
OCTOBER 2022	4.8	c PW -0.3 d CF -0.2 e WR -0.9
DECEMBER 2022	4.2	a PE -0.1 b VD -0.2 c PW +0.1 d CF -0.2 e WR -0.2



Application of Resilience Indices on the SPP

	DESIGN TEMP	JUNE 2022	OCT 2022	DEC 2022
INTENSITY	2	3	26	46
RESILIENCE	33,600	70,600	64,500	63,400
EDP	**0.00038**	**0.00076**	**6.7**	**70.9**

	DESIGN TEMP	JUNE 2022	OCT 2022	DEC 2022
INTENSITY	↓↓	↓	↑↑	↑↑↑
RESILIENCE	↓↓↓	↑↑	↓↓	↓
EDP	low INT- avg annual conditions low RES- dune volume	low INT- avg conditions high RES- dune volume	high INT- Ian low RES- decrease in berm width	very high INT- Nicole low RES- decrease in dune vol, increase in berm width

Low EDP- resilient beach and/or low intensity storm
High EDP- vulnerable beach and/or high intensity storm

Engineering Design Parameter

$$EDP = \frac{PEI^4}{B_{width}^2 * D_{vol}}$$

DESIGN TEMPLATE 0.00038 ↓↓ Intensity ↓↓↓ Resilience

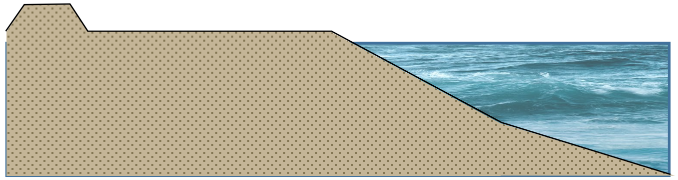
JUNE 2022 0.00076 ↓ Intensity ↑↑ Resilience

OCTOBER 2022 6.7 ↑↑ Intensity ↓↓ Resilience

DECEMBER 2022 70.9 ↑↑↑ Intensity ↓ Resilience

Application of Resilience Indices on the SPP

Contour Tracking & Volume Analysis



Coastal Resilience Index

$$CRI = a + b + c + d + e$$

Engineering Design Parameter

$$EDP = \frac{PEI^4}{B_{width}^2 * D_{vol}}$$

	Δ shoreline position (ft)	subaerial Δ vol (cy/ft)	Coastal Resilience Index	*change in resilience factors*	Engineering Design Parameter	
DESIGN TEMPLATE	--	--	--		0.00038	↓↓ Intensity ↓↓↓ Resilience
JUNE 2022	12	-0.3	6.2		0.00076	↓ Intensity ↑↑ Resilience
OCTOBER 2022	8	+0.5	4.8	c PW -0.3 d CF -0.2 e WR -0.9	6.7	↑↑ Intensity ↓↓ Resilience
DECEMBER 2022	-7	-11.4	4.2	a PE -0.1 b VD -0.2 c PW -0.1 d CF -0.2 e WR -0.2	70.9	↑↑↑ Intensity ↓ Resilience

Conclusions

- Beach resilience directly related to "buffer" volume and recovery time/conditions
- Many ways to measure beach resilience… which way is the best?
    - Martin SPP is a good candidate for testing resilience measures due to its extensive survey data and buoy
    - Resilience indices highly dependent on distribution of terms… should these be beach specific?
    - Selection of parameters is subjective; assumptions often needed

- *How do we make changes to a project over the project lifetime due to SLR or increased erosion rates?* prepare, resist, recover, and <u>ADAPT</u>

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