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Fragility Analysis of Dunes Reinforced with Geosynthetic Sand Containers

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RHODE ISLAND FLOOD MITIGATION ASSOCIATION

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Outline

- Introduction
- Objectives
- Field Observations of a Geosynthetic Sand Containers (GSC) – Reinforced Dune & Beach
- Methodology of Fragility Analysis
- Fragility Curves for the GSC – Beach System
- Summary and Conclusions

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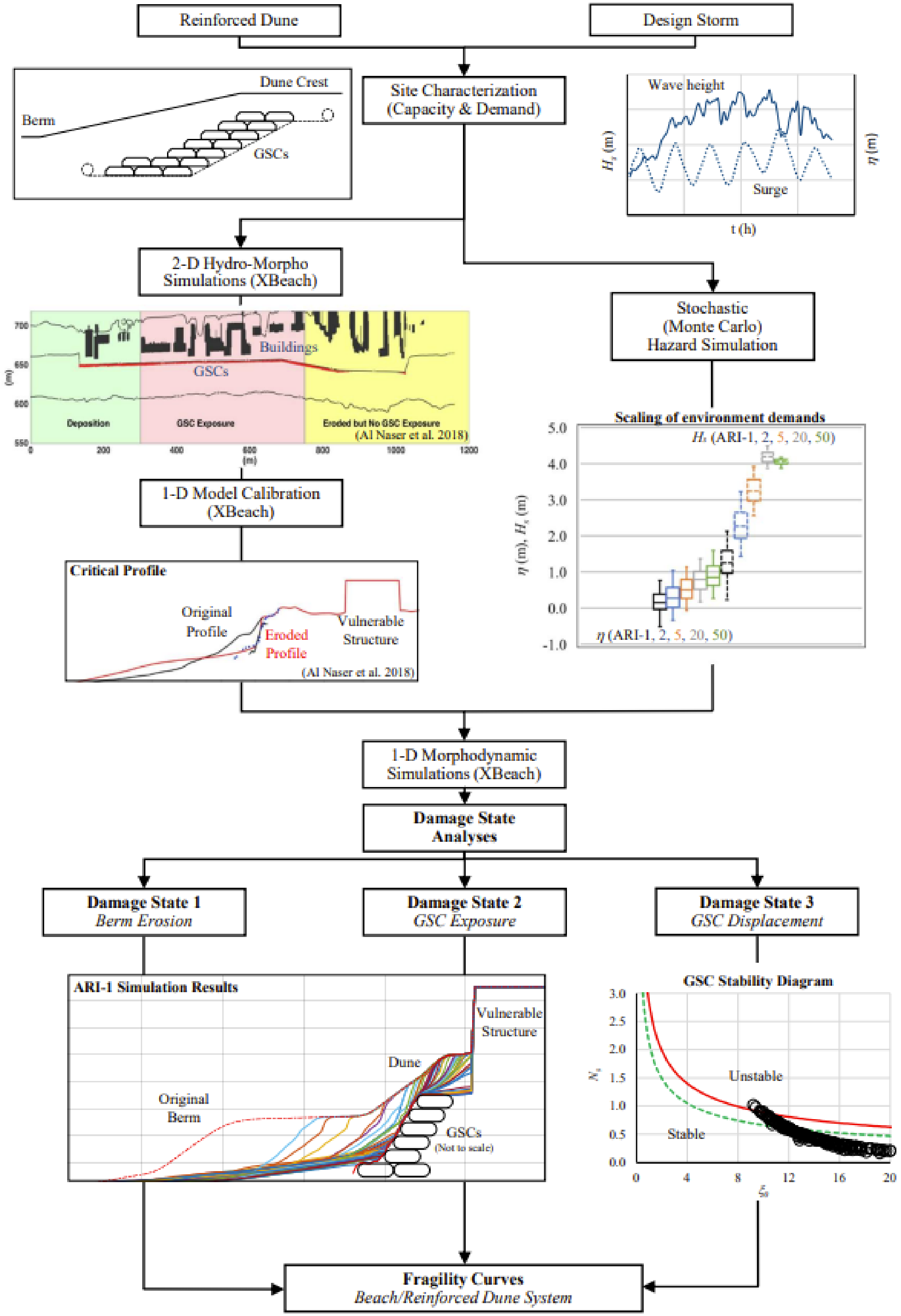
Objectives

- Develop a methodology to conduct a fragility analysis of a GSC-reinforced dune that incorporates:
  - Stochastic 2-D and 1-D erosion modeling using XBeach
  - Recognizable damage states
  - Field data for calibration of the models
- Perform a fragility analysis for a reinforced dune in Montauk, NY USA (the first federally funded reinforced dune in the U.S.)



Field Observations – Montauk, NY

- Development encroachment has resulted in an erosion “hot spot”

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Field Observations – Montauk, NY

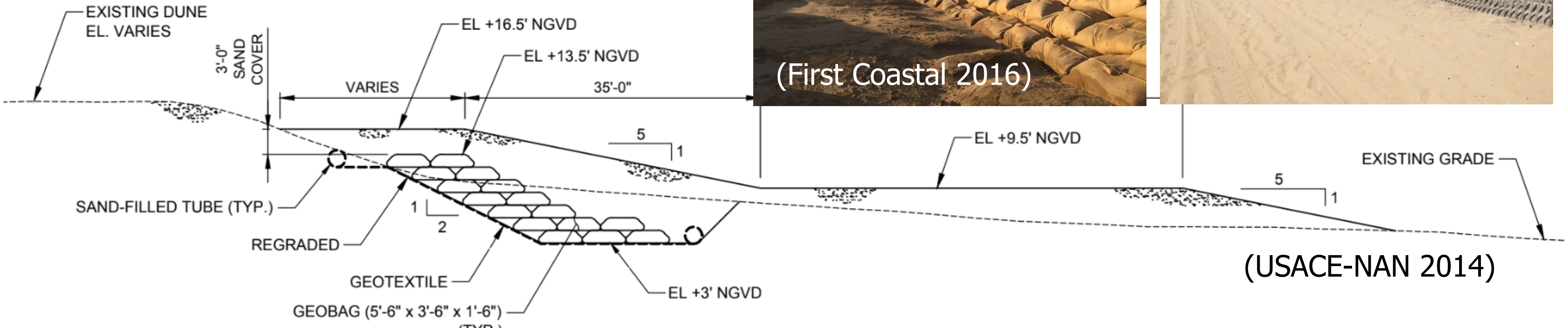
Field Observations – Montauk, NY

- U.S. Army Corps of Engineers New York District – Downtown Montauk Stabilization Project
  - Completed in March 2016
  - Approximately 1 km long
  - Over 14,500 GSCs for reinforced core of dune


(TenCate 2016)


(TenCate 2016)


(First Coastal 2016)



(USACE-NAN 2014)

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Field Observations – Montauk, NY

September 2016 (Tropical Storm Hermine)


January 2017


January 2018


March 2018

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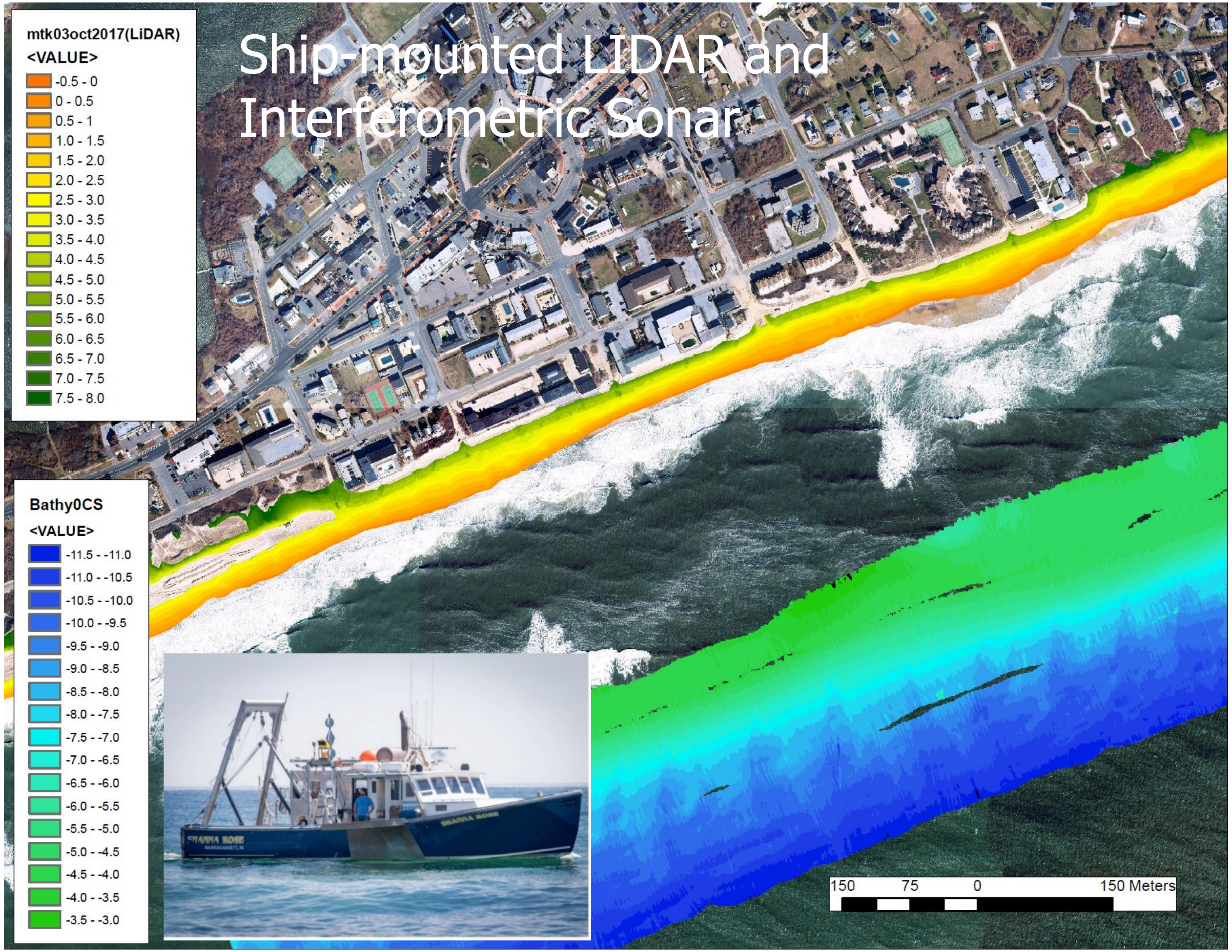
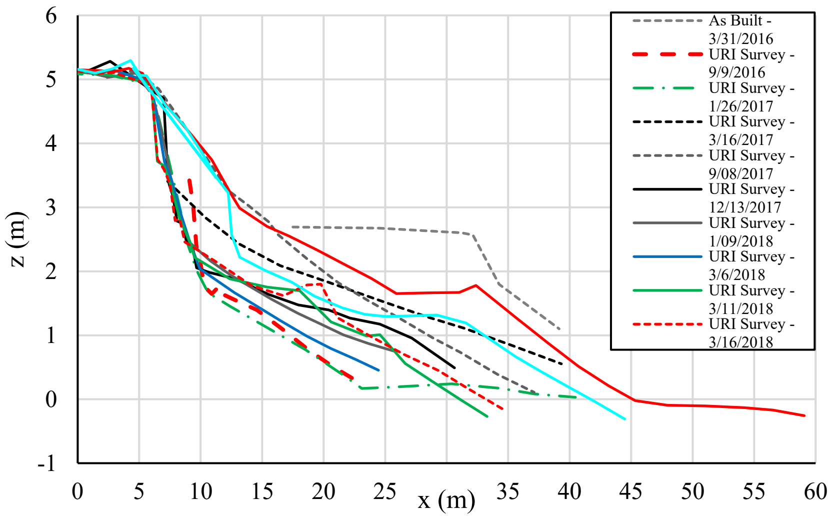
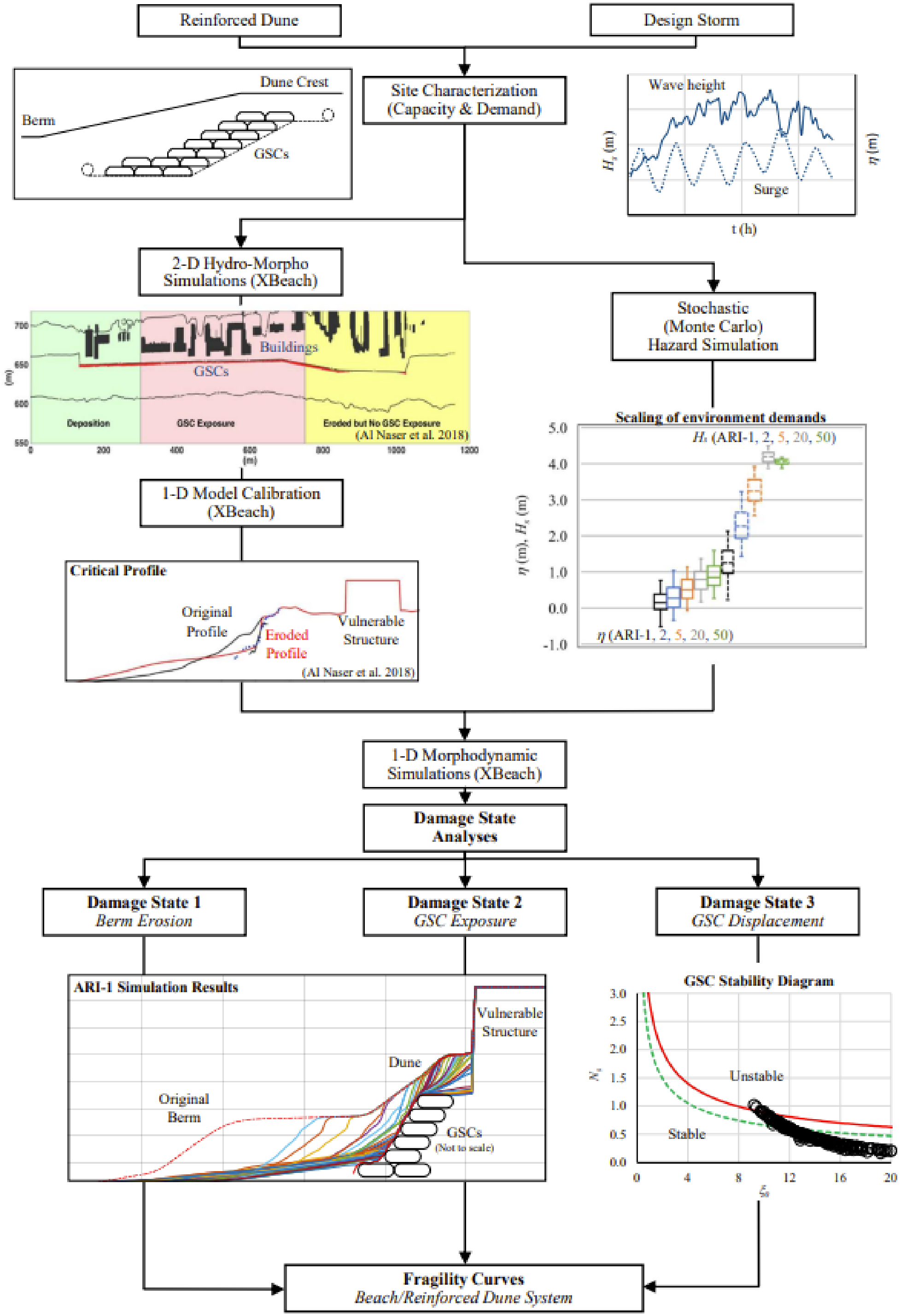
Field Observations – Montauk, NY





Methodology

- Site Characterization
- Model Setup & Calibration
- Monte Carlo Hazard Simulation
- Damage State Analyses
- Development of Fragility Curves



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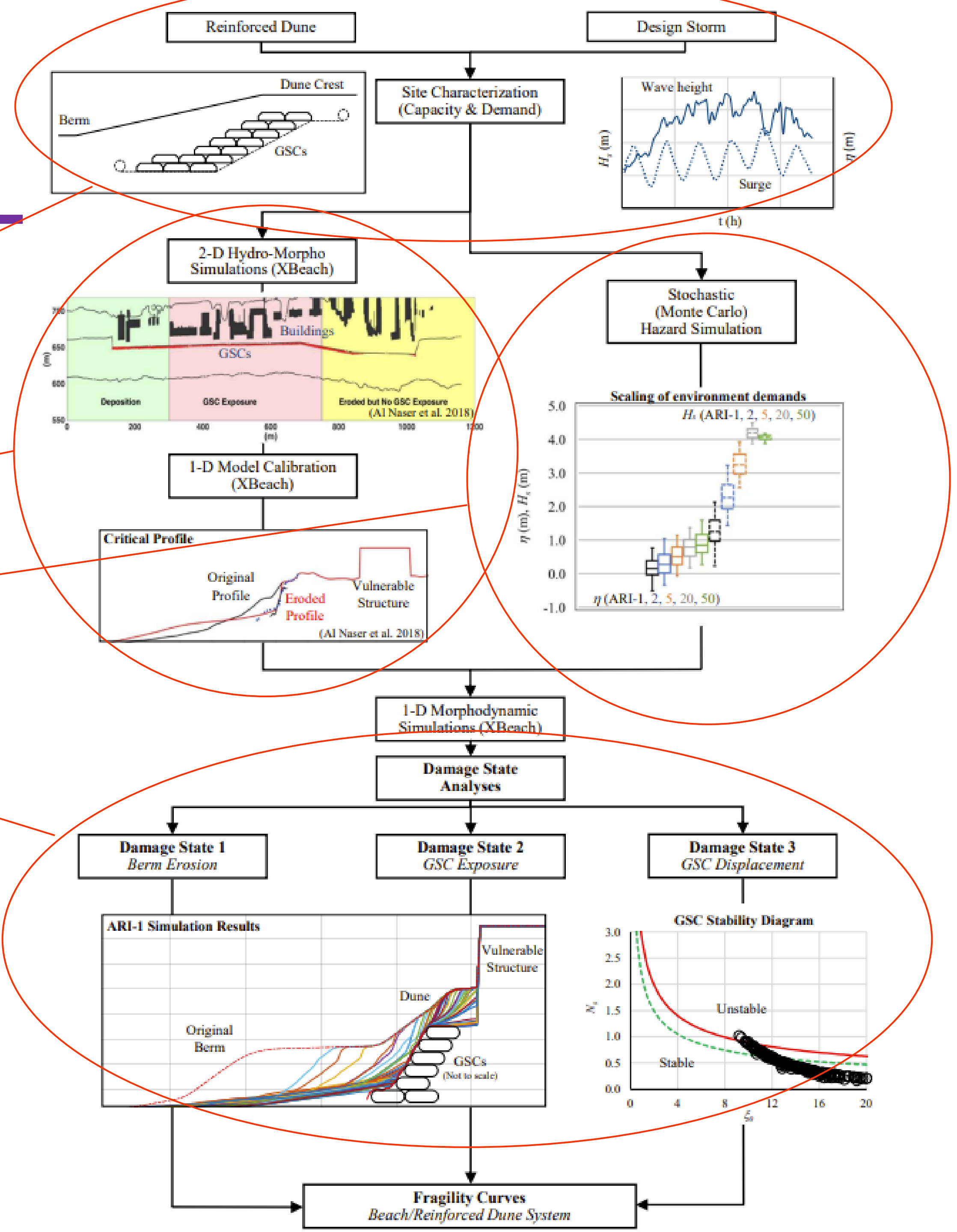

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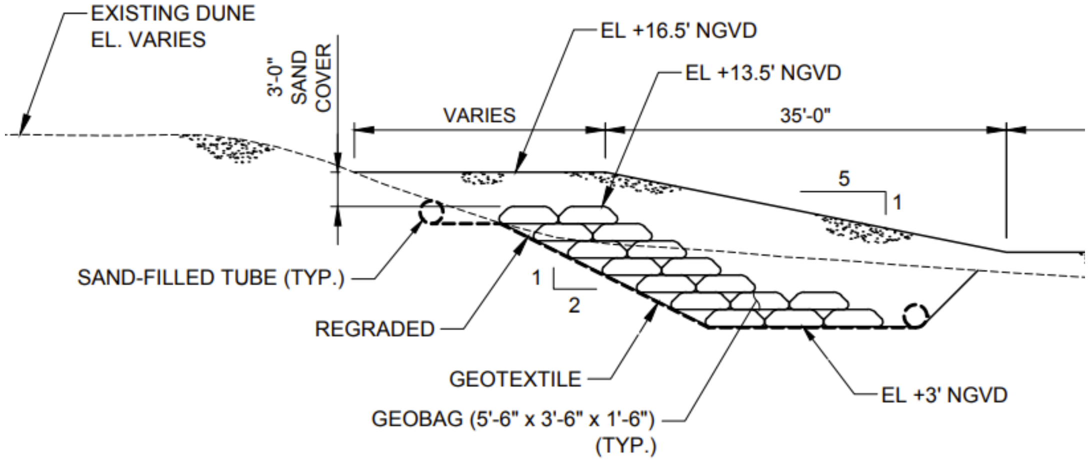
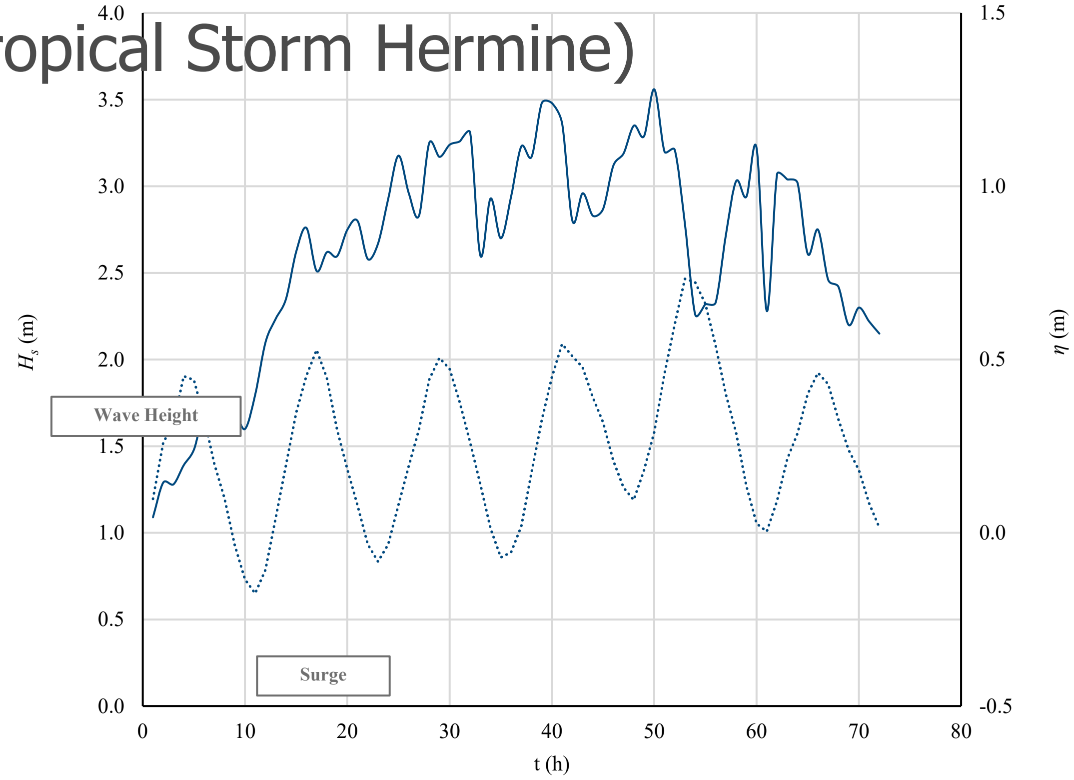
Site Characterization

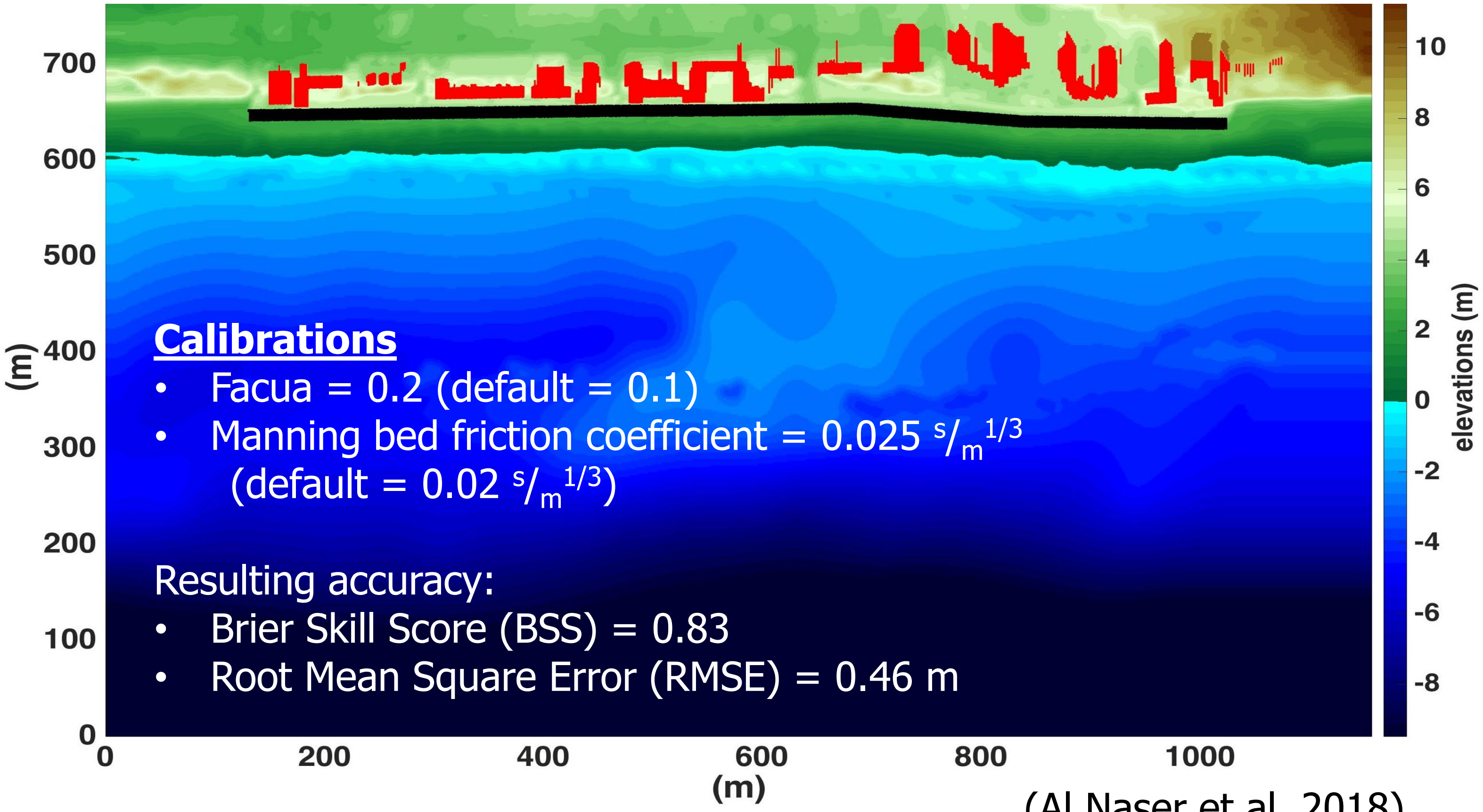
- Capacity – Design GSC-reinforced dune & beach system (Montauk, NY)
  - As-built survey data (USACE-NAN), field surveys, and USGS digital elevation models
  - Nearshore bathymetry (NOAA and field surveys)
- Demand – Design storm time series (2016 Tropical Storm Hermine)
  - H_s (NOAA Buoy Station ID 44017)
  - η (NOAA Tide Station ID 8510560)





Model Setup and Calibration

- XBeach (Roelvink et al. 2015)
  - Developed to simulate hydrodynamic and morphodynamic processes on sandy coasts
  - Site specific model coefficients
- 2-D Simulations were performed (TS Hermine) for calibration of 1-D analyses

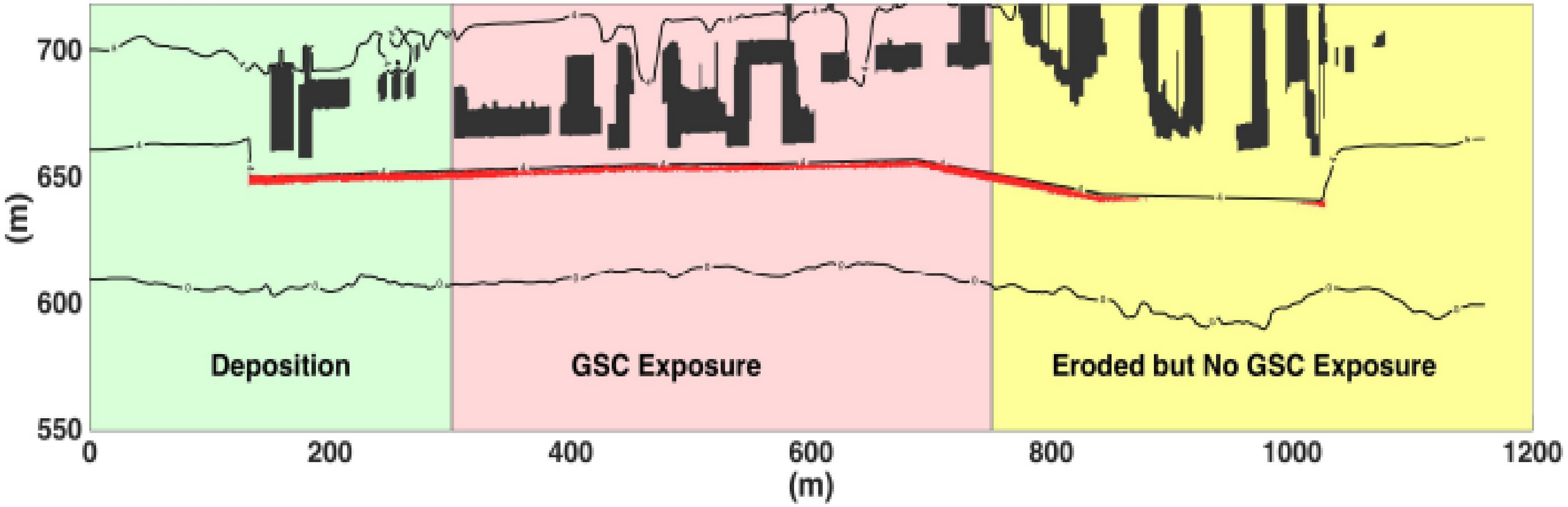


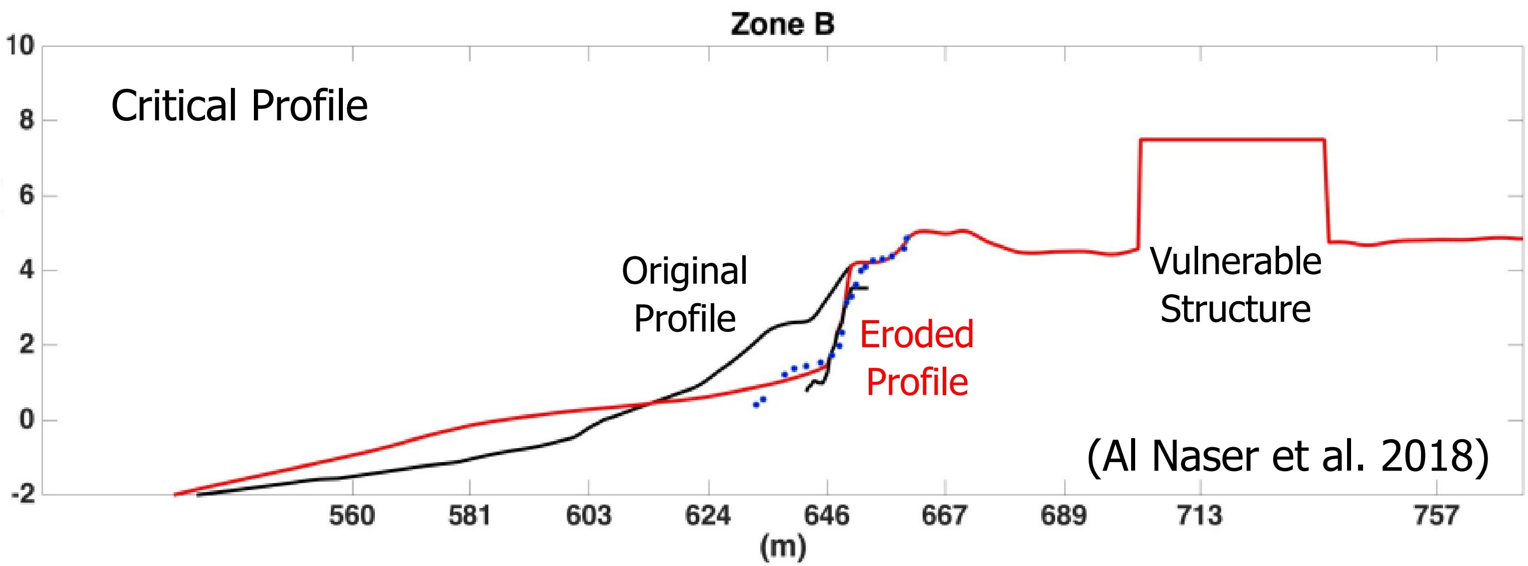
Calibrations
- Facua = 0.2 (default = 0.1)
- Manning bed friction coefficient = 0.025 $^{s}/_{m^{1/3}}$ (default = 0.02 $^{s}/_{m^{1/3}}$)

Resulting accuracy:
- Brier Skill Score (BSS) = 0.83
- Root Mean Square Error (RMSE) = 0.46 m

(Al Naser et al. 2018)

Model Setup and Calibration





Calibration of the XBeach 1-D model based on the 2-D results and field observations

- Facua = 0.25 (2-D = 0.20, Default = 0.1)
- Manning coefficient = 0.030 $^{s}/_{m}{}^{1/3}$
  (2-D = 0.025 $^{s}/_{m}{}^{1/3}$, Def. = 0.02 $^{s}/_{m}{}^{1/3}$)
  $c_f = \sqrt{\frac{gn^2}{h^{1/12}}}$ or $c_f = \sqrt{\frac{g}{C}}$ c_f = bed friction coefficient (-)
  g = gravity (m/s^2);
  n = manning coefficient ($^{s}/_{m}{}^{1/3}$);
  h = depth (m);
  C = Chézy coefficient (m$^{1/2}$/s) = 55 m$^{1/2}$/s
- Beta = 0.05 (Default = 0.01)

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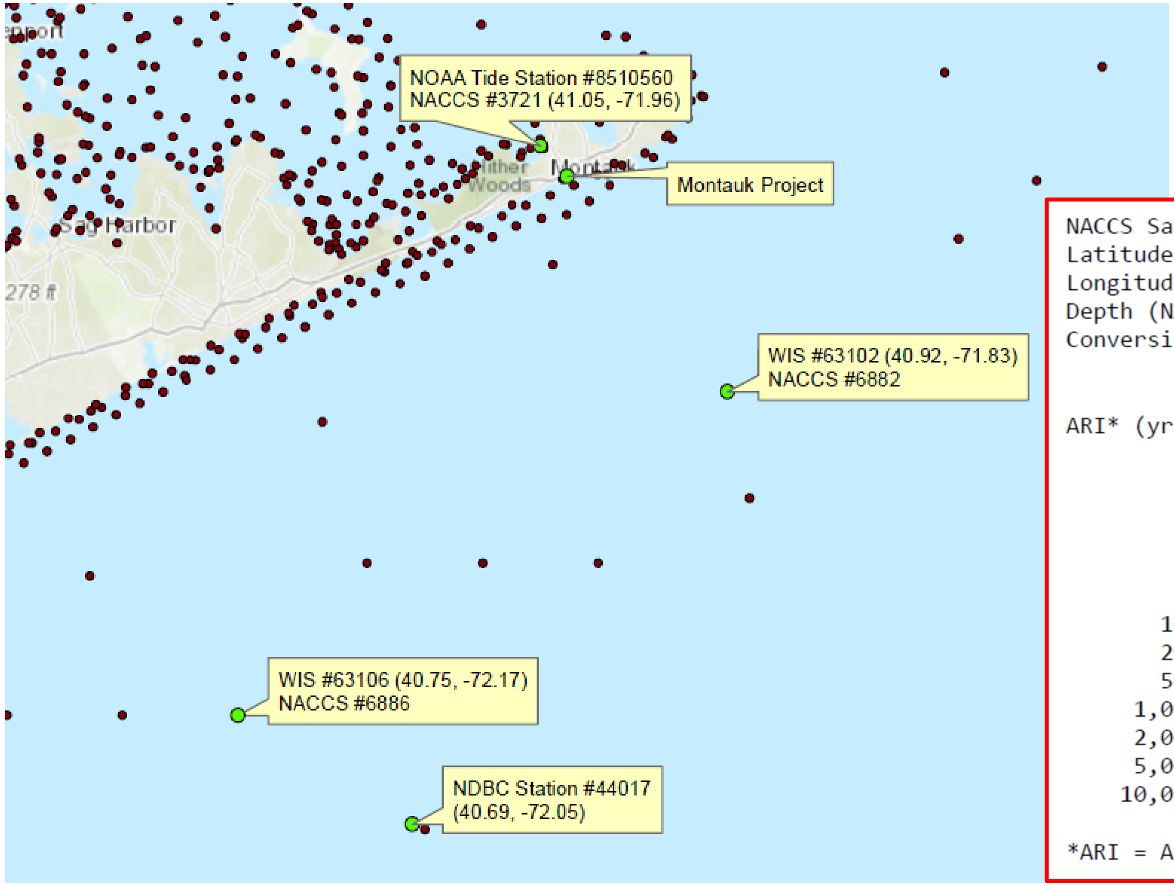
Monte Carlo Simulations

- Surge and wave heights at the XBeach boundaries were estimated using the 2-D Steady State Spectral Wave (STWAVE) program and data from the USACE North Atlantic Coast Comprehensive Study (NACCS)



NACCS Save Point ID: 11341
Latitude: 40.986300
Longitude: -71.951600
Depth (NAVD88): 20.8510 meters
Conversion factor (NAVD88 to MSL): -0.1012

	Water Level (m)		Wave Height (m)	
ARI* (yrs)	Mean	Upper 95% CI	Mean	Upper 95% CI
1	1.01	1.73	4.92	6.16
2	1.19	1.91	6.25	7.49
5	1.41	2.09	7.67	8.85
10	1.55	2.22	9.23	10.36
20	1.67	2.36	10.64	11.75
50	1.81	2.57	11.90	13.00
100	1.93	2.80	12.42	13.52
200	2.11	3.04	12.80	13.90
500	2.44	3.38	13.22	14.32
1,000	2.69	3.63	13.50	14.61
2,000	2.91	3.85	13.78	14.89
5,000	3.16	4.10	14.16	15.26
10,000	3.32	4.26	14.52	15.54

*ARI = Annual Recurrence Interval

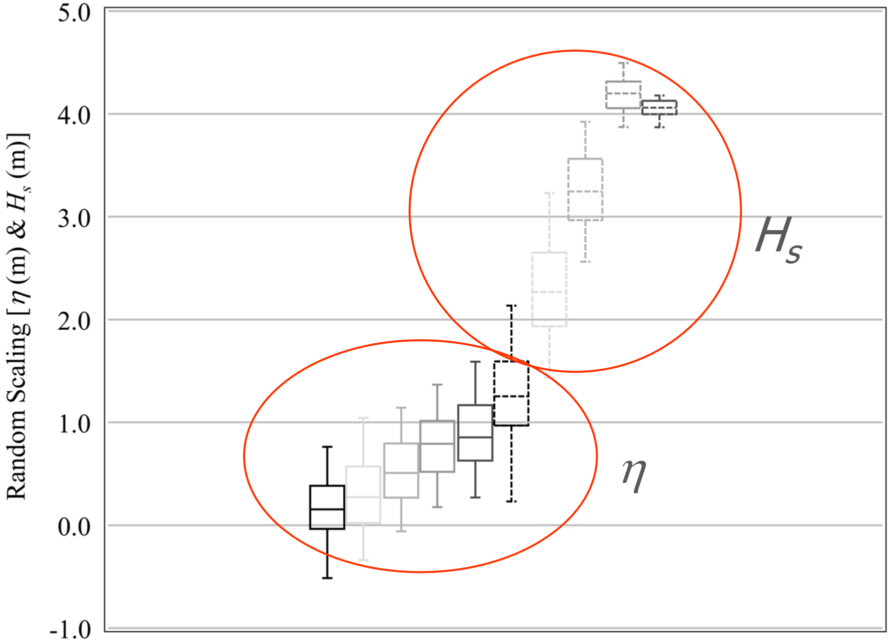
Monte Carlo Simulations

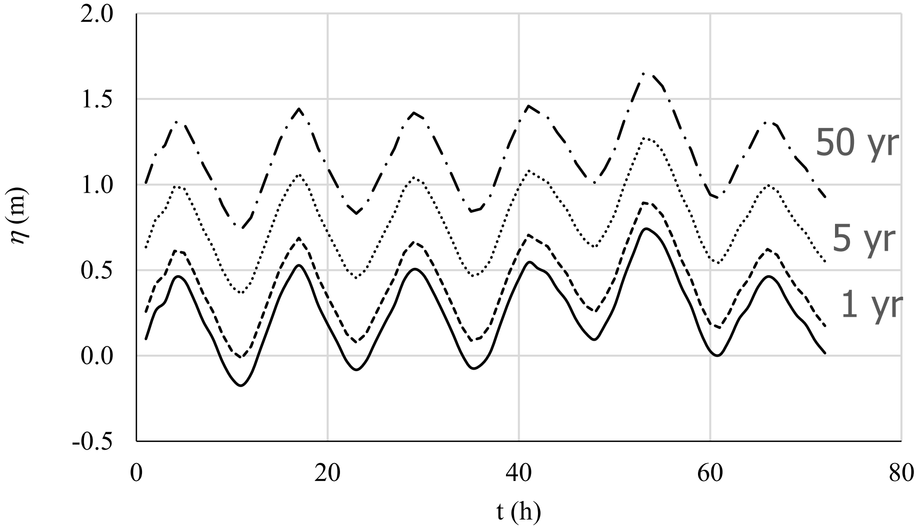
For each Annual Return Interval (ARI) (e.g. 1, 2, 5, 20, and 50):

- Randomize η and H_s using the Mean and Upper 95% CI from NACCS, and a normal distribution of random numbers
- Determine H_s at the offshore XBeach model boundary, assuming η remains spatially constant and the transfer function developed in the STWAVE model
- Determine peak wave period (T_p) associated with H_s assuming the fully developed sea relationship

$$T_p = 15.66 * \sqrt{\frac{H_s}{9.81}}$$

- Compare the randomized η, H_s, and T_p values to peak values of the TS Hermine time series at the offshore XBeach model boundary, and scale the time series accordingly





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Analysis of Damage States

Construction of a GSC-reinforced dune with subsequent beach nourishment is likely to occur in an *erosive environment* to *protect vulnerable infrastructure*. Therefore, Sallenger's (2000) four erosion regimes were used for the characterization:

- Swash – wave runup from a storm event confined to the foreshore
- Collision – wave runup impacts the foredune
- Overwash – wave runup periodically overtops the crest of the dune
- Inundation – wave runup completely inundates, or floods, the dune

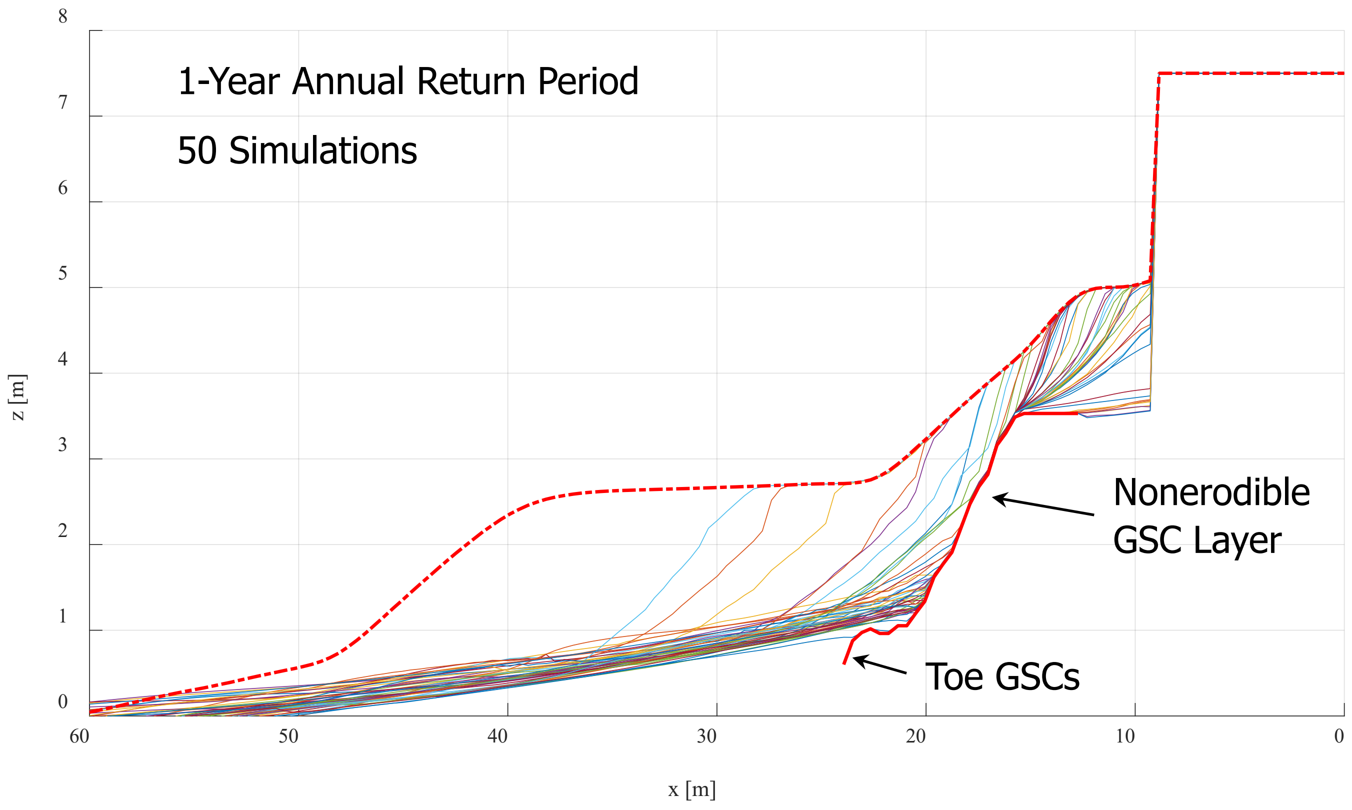
Only damage due to conditions in the *Swash* and *Collision* regimes was quantified

- Limited overwash in ARI-20 and 50 simulations did not lead to additional damage
- Inundation did not occur, even for ARI-50 simulations

Analysis of Damage States

XBeach 1-D simulation results for ARI-1

- **Damage State 1** – complete erosion of the berm
- Observed for 47 out of the 50 ARI-1 simulations
- **Damage State 2** – exposure of the GSCs
- Observed for 41 out of the 50 ARI-1 simulations

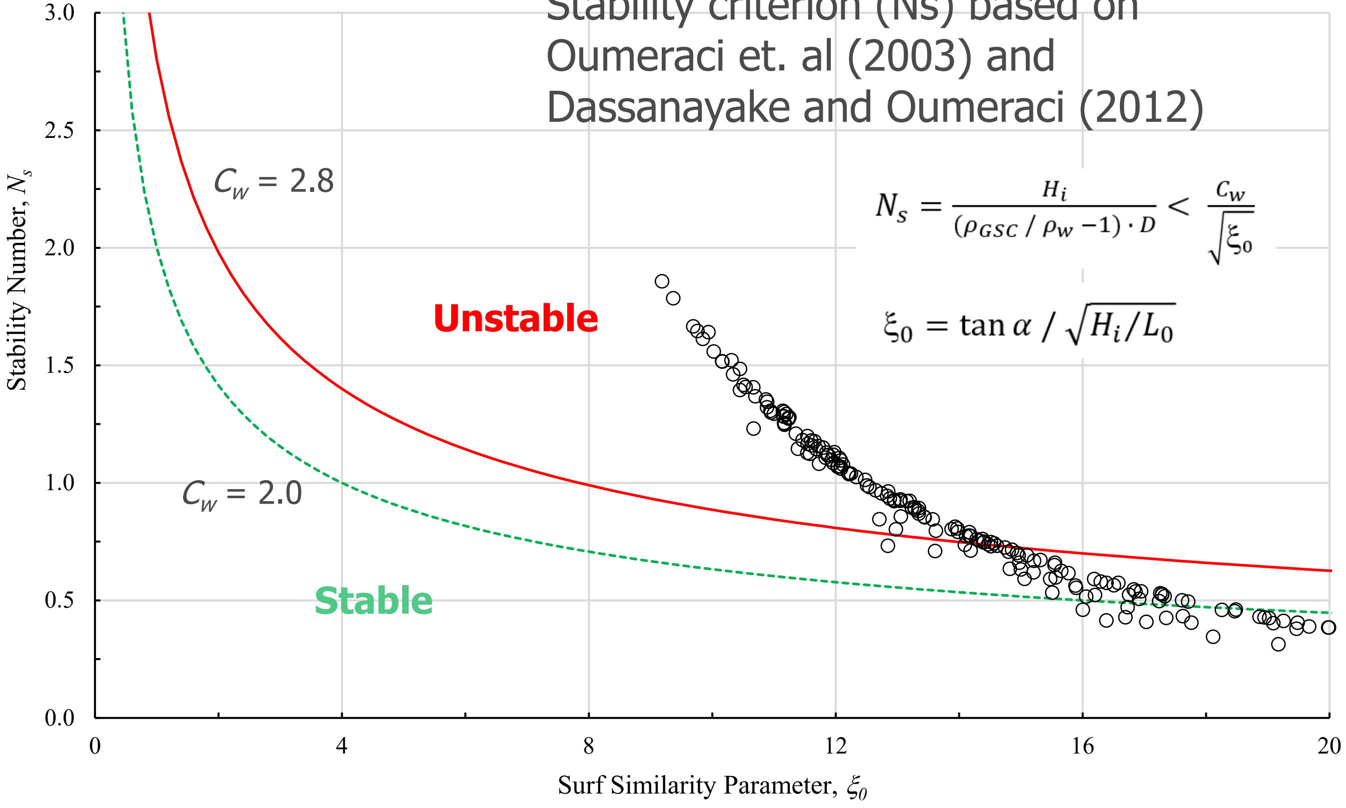


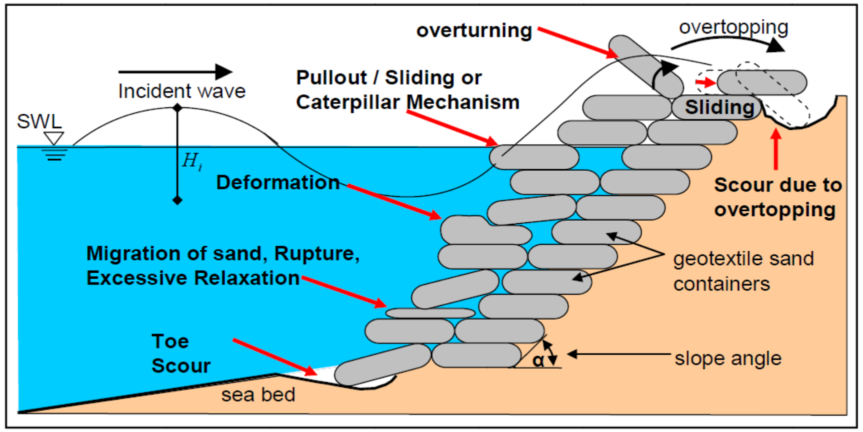
Analysis of Damage States

GSC hydraulic stability results for ARI's 1, 2, 5, 20, and 50

- **Damage State 3** – displacement of GSCs
- C_w = 2.0, threshold for incipient motion of a GSC

Stability criterion (Ns) based on Oumeraci et. al (2003) and Dassanayake and Oumeraci (2012)





Dassanayake and Oumeraci (2012)

Results – Fragility Curves

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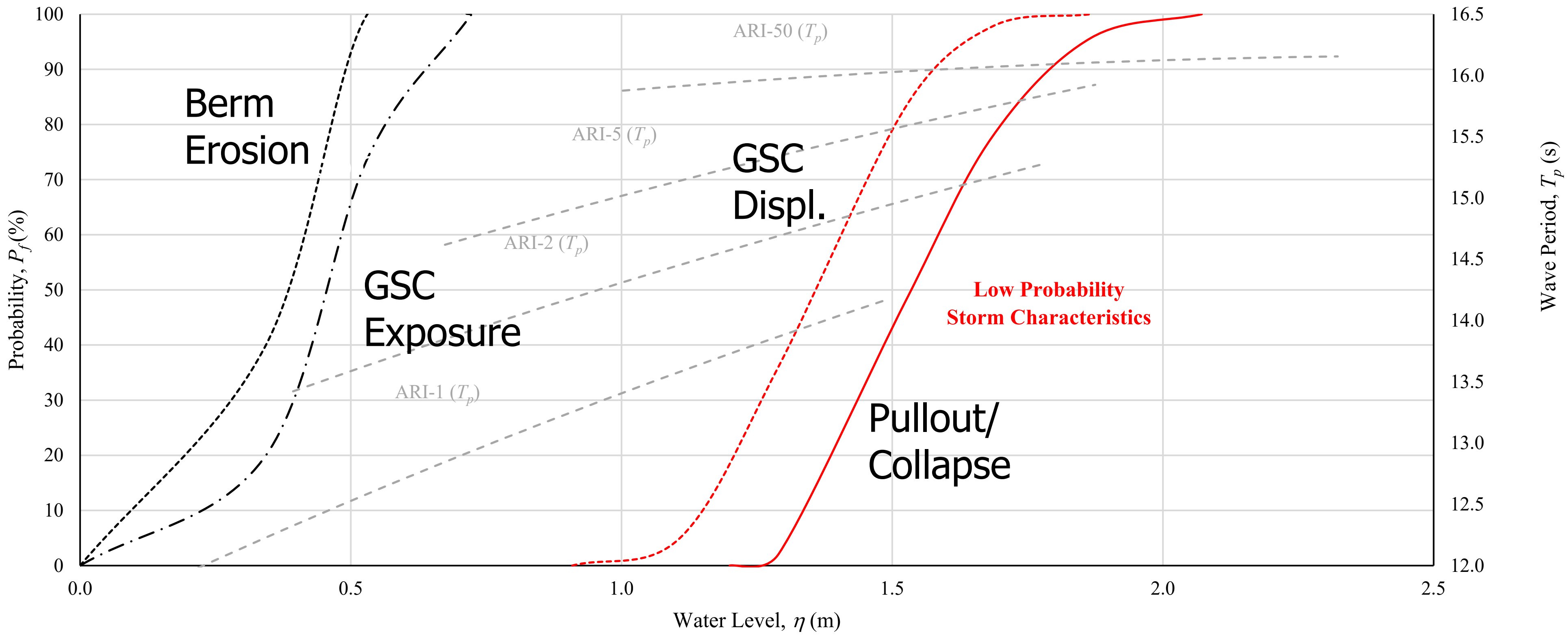
Downtown Montauk GSC-reinforced dune and beach system

- **Damage State 1** – Berm Erosion (-------)
- **Damage State 2** – GSC Exposure (–·–)
- **Damage State 3** – GSC Displacement: Incipient Motion, Cw = 2.0 (-------); Pullout / Collapse, Cw = 2.8 (——)



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Results – Fragility Curves

Damage States 1 and 2 clearly show the vulnerability of the berm and potential for GSC exposure

- As per the USACE Operation, Maintenance, Repair, Replacement, and Rehabilitation Manual, maintenance is required when:
  - Berm elevation drops below 2.6 m (NAVD88)
  - GSCs are exposed
- Summary of design and incurred annual beach maintenance volumes/costs for the USACE Downtown Montauk Stabilization Project:

	Volume (m^3)	**Unit Cost ($\$/m^3$)**	**Total Cost ($k)**
USACE Design Estimate	2,141	46	98.5
Town Maintenance			
Spring 2018	23,000	43	986
Spring 2019	26,000	38.5	1,000
Spring 2020	765	N/A	N/A
Spring 2021	15,000	59	885
Spring 2022	N/A	N/A	N/A

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Conclusions

- Improved resilience of geosynthetic materials has resulted in longer than expected performance of Geosynthetic Sand Containers (GSCs) in coastal environments and the use of GSCs to reinforce natural systems where coastlines are impacted by chronic erosion.
- The proposed methodology for a fragility analysis for GSC-reinforced dunes addresses uncertainty in the environmental demand and capacity of the system to assess performance and understand the tradeoffs (i.e. required maintenance or nourishment) of these coastal protection systems
- A well-documented case study from Montauk, NY demonstrates that a fragility analysis can provide a risk-based hazard assessment to predict maintenance requirements (i.e. Damage States 1 and 2) along with increased capacity of the coastal system due to the GSC-reinforcement (Damage State 3)

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Thank You

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XBeach 1-D simulation results for ARI-20 (No Building)