

Systems Engineering Approaches for Barrier Island Community Resilience

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Presentation Outline

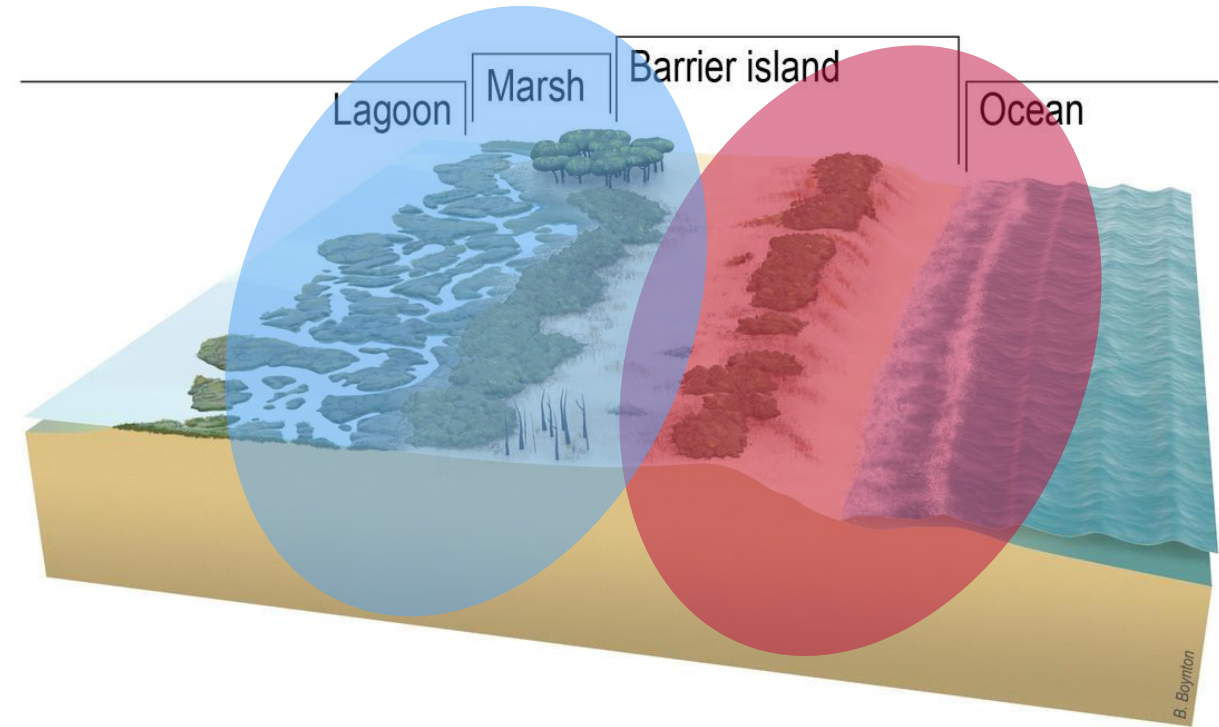
- Overview
- Approach
- Methods
- Results
- Next Steps
- Sneak Peek???

Overview

Overarching Goal

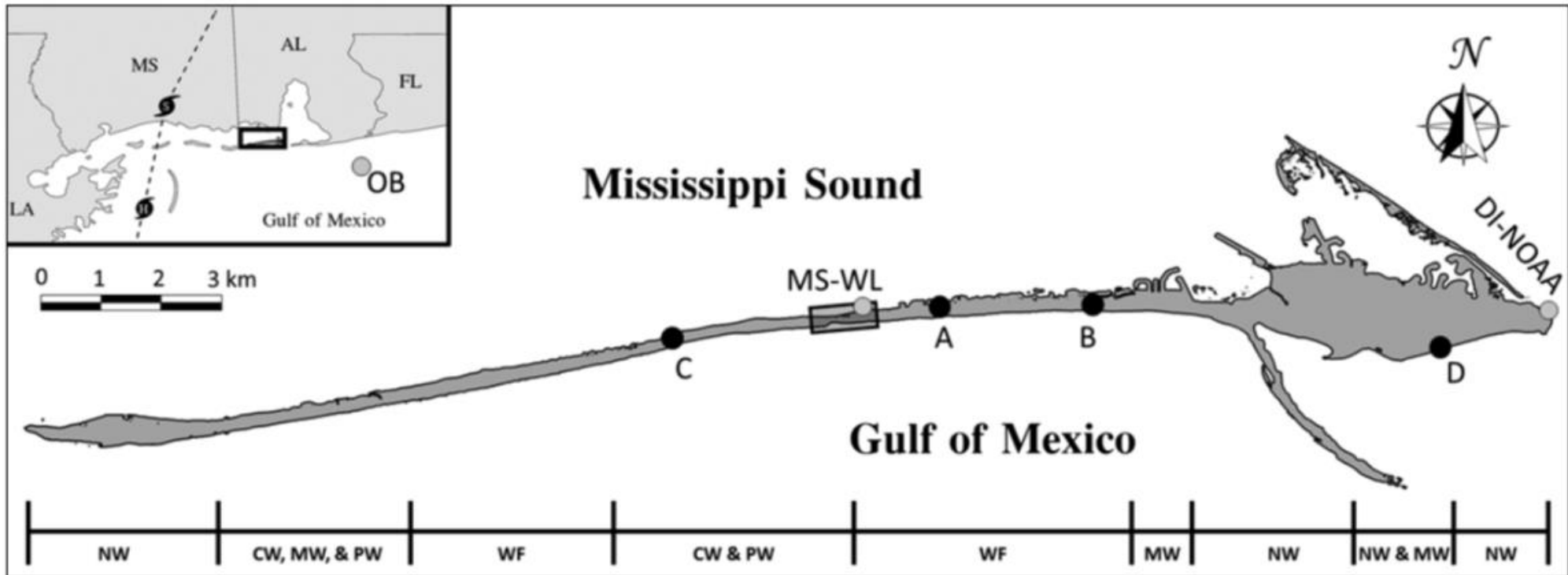
Flood Risk Management (FRM)

- Beach Nourishment
- Dune Restoration
- Fortification (strength, elev.)
- Back Barrier Resilience
- Cross-Section Management



<https://www.usgs.gov/media/images/illustration-describes-barrier-island-ocean-lagoon>

Dauphin Island, Alabama





Dauphin Island, Alabama



Mississippi Sound

Gulf of Mexico

Mobile Bay



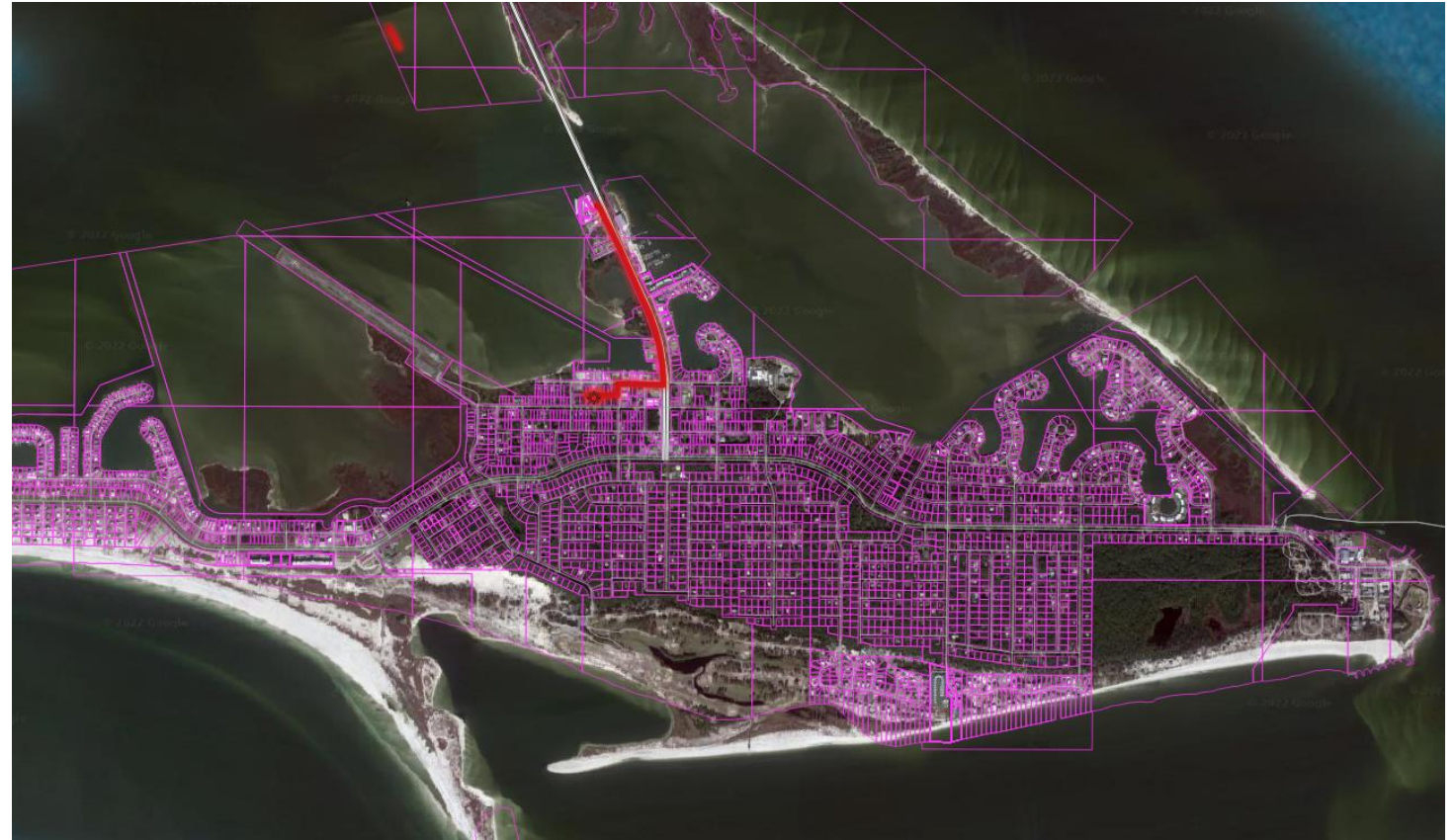
Dauphin Island, Alabama

Mississippi Sound

Gulf of Mexico

Dauphin Island, Alabama

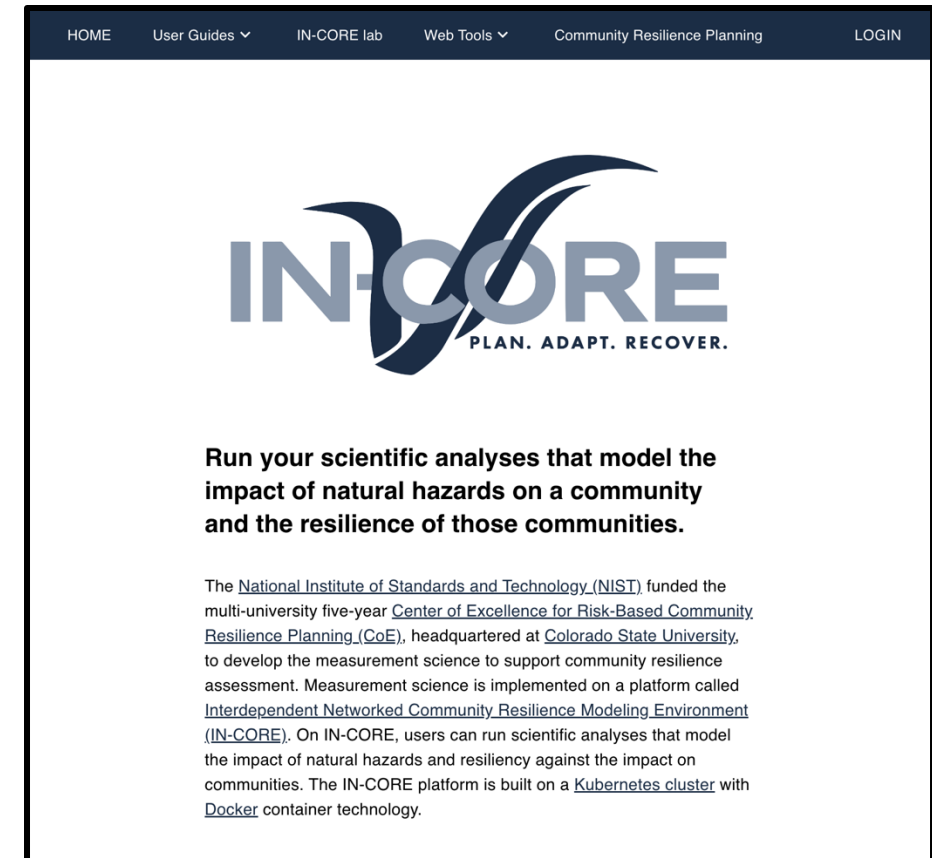
- Parcel Data
- Building Footprints
- Transportation
- Power
- Water
- Sewer
- Critical Facilities



Approach

Approach

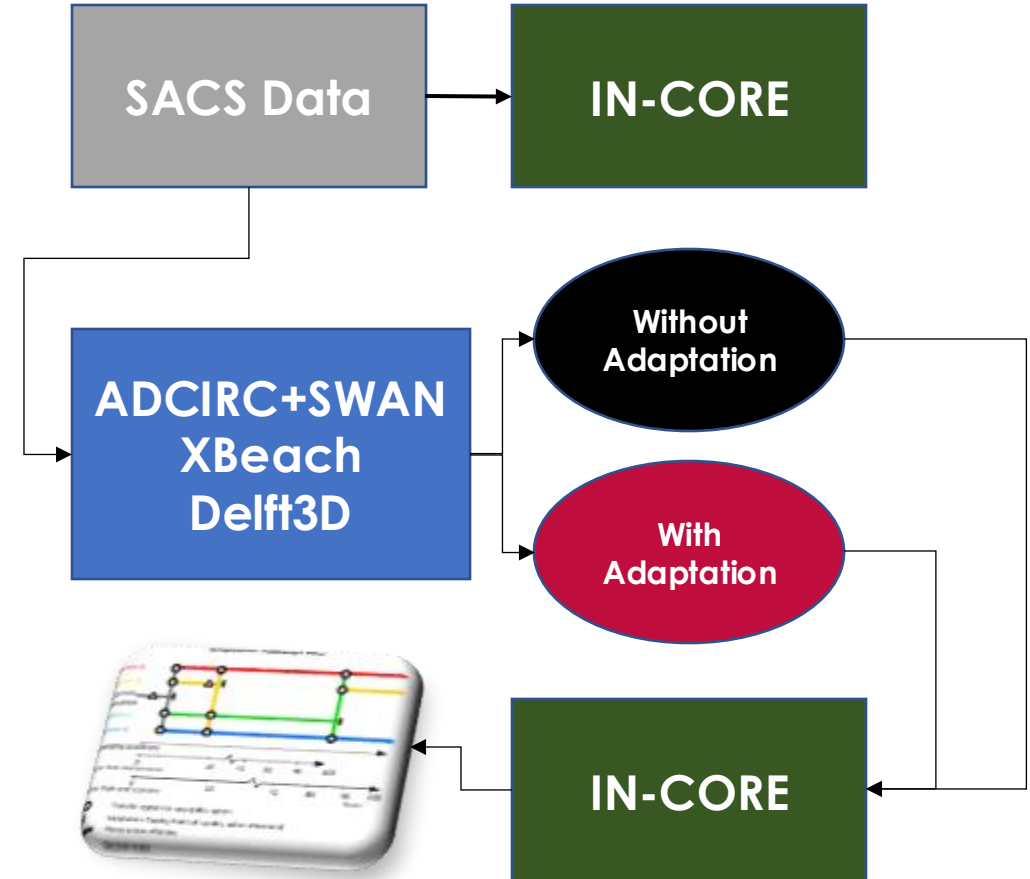
- Analyze Existing Data
- Model Coastal Hazards
 - Existing Conditions
 - Future Conditions
 - With / Without Adaptations
- Model Resilience
 - IN-CORE



<https://incore.ncsa.illinois.edu/>

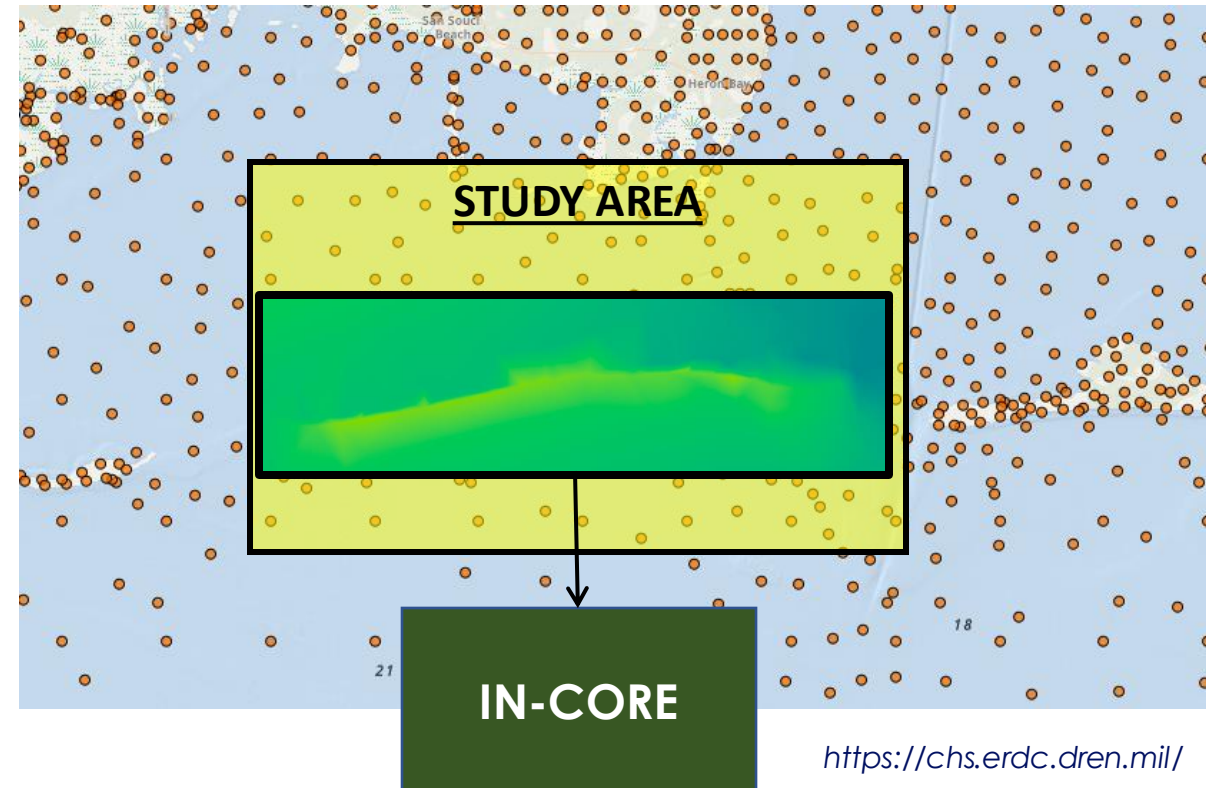
Approach

1. Establish Baseline Community Resilience
2. Model Future Flood Risk Hazards
3. Predict Future Community Resilience
4. Create Adaptation Pathways



Using CHS Data (example)

- South Atlantic Coastal Study
- Coastal Hazards System v2.0
- Coastal Storm Hazards
 - Extratropical Cyclones
 - Tropical Cyclones
- AEP Values



Approach



Combined Wind-Wave-Surge Hurricane-Induced Damage Prediction for Buildings

Hassan Masoomi, S.MASCE¹; John W. van de Lindt, F.ASCE²; Mohammad R. Ameri, S.MASCE³; Trung Q. Do, S.MASCE⁴; and Bret M. Webb⁵

Abstract: Coastal structures are subjected to multihazard events such as hurricanes which consist of hurricane-induced surge and waves as well as winds. Hurricanes are a common natural hazard in the United States and cause considerable damage every year, with resulting annualized losses in the United States in the tens of billions of dollars. Although improvements in construction practices have been notable over time for individual hazards, there is still a dearth of risk and damage prediction methods in the area of multiple hazards that are based on principles of mechanics. In this study, a methodology to develop multihazard damage fragilities is summarized and illustrated for a wood-frame residential-building archetype subjected to hurricane winds, storm surge, and waves. The National Flood Insurance Program (NFIP) requires new buildings along the US coastline to be constructed with the first finished floor set at an elevation that exceeds a minimum necessary elevation. Therefore, two different elevations are considered for the lowest horizontal structural member of the archetype to also examine its effect on damage fragilities. The developed multihazard fragilities are used to calculate the time-dependent probability of each damage state at a given location over the timeframe of an event, i.e., hurricane. In this regard, the spatial and temporal data of wind speeds, flood depths, and significant wave heights for Hurricane Ike are simulated by the ADCIRC + SWAN model (a tightly coupled version of the Advanced CIRCulation model and the Simulating Waves Nearshore model for simulating the propagation of storm surge and waves from deep water to the coastal region). The performance of nonelevated and elevated archetypes is examined at different locations in southeast Texas for Hurricane Ike and a scenario of damage states predicted for this area for the elevated archetype. DOI: 10.1061/(ASCE)ST.1943-541X.0002241. © 2018 American Society of Civil Engineers.

Author keywords: Multihazard; Fragility; Advanced circulation model (ADCIRC); Simulating waves nearshore model (SWAN); Hurricane Ike; Coastal area.

Introduction


Coastal areas are usually a multihazard environment, which means that near-coast structures are exposed to multihazard events such as earthquakes and tsunamis or hurricane wind and hurricane-induced surge and waves. Hurricanes are a common natural hazard in the United States and cause considerable damage almost every year. The annual hurricane-induced damages in the United States are on the order of tens of billions of dollars (Bardach and Shokri et al. 2017). However, the extent of damage for a single hurricane or for hurricanes in a year can be on the order of hundreds of billions of dollars. For example, the damage caused by the 2004–2005 Atlantic hurricane season was more than \$150 billion (Pielke et al. 2008) and estimates for 2017 Hurricane Harvey are expected to exceed \$100 billion (Quesly 2017). However, the costliest weather culprit for property damage as well as crop damage is flooding (NOAA 2017a). Potential hurricane losses are likely exacerbated by population growth, demographic changes, and climate change. Meanwhile, more than 50% of the US population lives in coastal areas (Croust et al. 2004) and the NOAA population forecast trends suggest that coastal areas will be the highest growth areas in the future (NOAA 2017b). However, the current construction practices in coastal communities seem to ignore the effect of multiple hazards on the built environment (McCallough et al. 2013). Improvements in construction practices have been notable for individual hazards in recent decades. For example, flood insurance rate maps (FIRMs) were revised in 1983 and 1992 to consider the effect of wave action on buildings (FEMA 2009a), which was found to significantly increase the survival rate of houses constructed after 1987 in the aftermath of Hurricane Ike (Tomczek et al. 2014). However, there is still a gap for mechanics-based (or physics-based) multihazard analysis and damage prediction methods. McCallough et al. (2013) studied the damages resulting from hurricane winds, surge, and waves during Hurricane Katrina for two residential-building case studies. Considering the importance of multiple hazards in constructing coastal structures, they proposed a framework that combined multihazard engineering with performance-based design in order to effectively improve the performance of structures in multihazard environments.

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Note. This manuscript was submitted on January 8, 2018; approved on July 12, 2018; published online on October 25, 2018. Discussion period open until March 25, 2019; separate discussions must be submitted for individual papers. This paper is part of the *Journal of Structural Engineering*, © ASCE, ISSN 0733-9445.

© ASCE 04018227-1 J. Struct. Eng., 2019, 145(1): 04018227

Masoomi et al. (2019)



Fragility Analysis of Coastal Roadways and Performance Assessment of Coastal Transportation Systems Subjected to Storm Hazards

Yousef M. Darestani¹; Bret Webb, M.ASCE²; Jamie E. Padgett, M.ASCE³; Garland Pennison⁴; and Ehsan Fereshtehnejad⁵

Abstract: Coastal transportation systems are extremely vulnerable due to the coupled impacts of storm surge, waves, and inundation. Existing literature has developed coastal fragility models for bridges. However, to date, flood fragility models for coastal roadways are lacking. For this purpose, the current study proposes a data-driven fragility model based on logistic regression for coastal roadways, with failure probability conditioned on distance to shoreline and inundation duration, using hindcast data for Hurricane Ike. In addition, the effect of bridge and roadway damage on transportation network performance is investigated through a case study on Galveston Island, Texas. The results indicate the spatial distribution of storm impacts on the transportation network, with select roads highly vulnerable if they are located within a couple of hundred meters of the shoreline. In addition, considering roadway damage in addition to bridge damage alone, which is the current state of the art, can have a significant impact on decreasing the performance of the transportation network. Such analyses shed light on potential policy or risk mitigation practices that are expected to be increasingly important in the future as sea level rise further reduces roadway distance to the shoreline or as storm intensity and frequency changes. DOI: 10.1061/(ASCE)CF.1943-5509.0001650. © 2021 American Society of Civil Engineers.

Author keywords: Coastal roadway fragility; Storm hazard; Surge, wave, and inundation; Galveston Island; Hurricane Ike; Coastal transportation network analysis.

Introduction

Storm hazards can significantly impact coastal communities by damaging infrastructure systems due to combined surge, wave, and inundation effects (Padgett et al. 2008; Bass et al. 2018). One critical infrastructure system that has been significantly impacted during past storm events is the transportation network. Damage to the transportation network may cause disruption to evacuations, limit access to emergency services such as hospitals and fire stations, impair the supply of goods, food, and medical aid for elderly, disabled, and medically compromised populations, and slow the restoration process. In addition, the community and its associated infrastructure systems such as buildings, power, water, and telecommunication are highly dependent on functionality of the transportation system, particularly postevent when access is key to any inspections and repairs required (Copper and Chen 1988; Powledge et al. 1989a, b; He and Cha 2020).

The transportation system in coastal regions is mainly composed of roads and bridges, a set of components that is vulnerable to combined storm surge, wave, and inundation impacts. For example, in Hurricane Katrina (2005), more than 44 bridges were damaged in the US Gulf Coast (Padgett et al. 2008). In addition, in Hurricane Ike (2008) nearly 55 bridges (including public and private structures) were damaged in the Houston/Galveston, Texas, region (Stearns and Padgett 2011). Most of the significant damages were due to unseating of bridge decks, and other modes of failure, such as failure of bridge parapets, damage due to debris impact, and scour were also observed (Padgett et al. 2008; Stearns and Padgett 2011; Ataz and Padgett 2013).

In past hurricane events such as Hurricanes Ivan (2004), Katrina (2005), and Ike (2008), roads have also suffered from various types of damage. For example, in Hurricane Ike, nearly 13 km (8 mi) of roads in Follet's Island, Texas, were damaged (Coast and Harbor Engineering 2009), and in Hurricane Katrina (2005), major road segments across multiple states were reported as damaged or with access impaired (Padgett and Arnold 2009). For Hurricane Ike, damage ranged from partial failure of the edge of the pavement to roadway washout from pavement and embankment failure (Carter J. and H. Bermudez, personal communications, 2009; Coast and Harbor Engineering 2009).

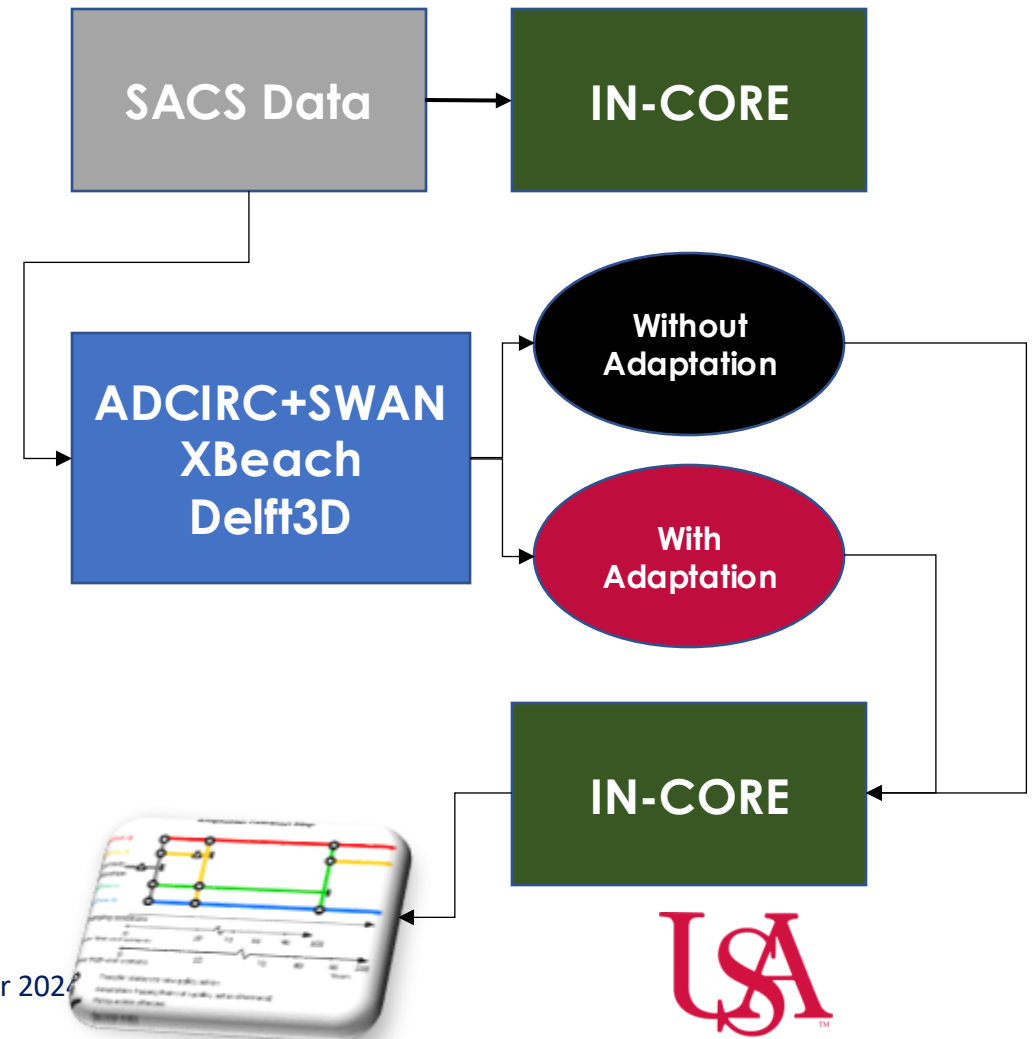
To mitigate such damages, the Federal Highway Administration (FHWA 2016) provides guidance for analysis, design, and operation of highways in the coastal environment that are occasionally

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Note. This manuscript was submitted on November 11, 2020; approved on June 29, 2021; published online on September 15, 2021. Discussion period open until February 15, 2022; separate discussions must be submitted for individual papers. This paper is part of the *Journal of Performance of Constructed Facilities*, © ASCE, ISSN 0887-3828.

© ASCE 04021086-1 J. Perform. Constr. Facil., 2021, 35(6): 04021086

Darestani et al. (2021)



Methods

1D XBeach Modeling

Extreme Event Scenarios

- Present Day MSL
- 2055 MSL*
- 2085 MSL*
- 1% AEP
- 4% AEP
- 10% AEP

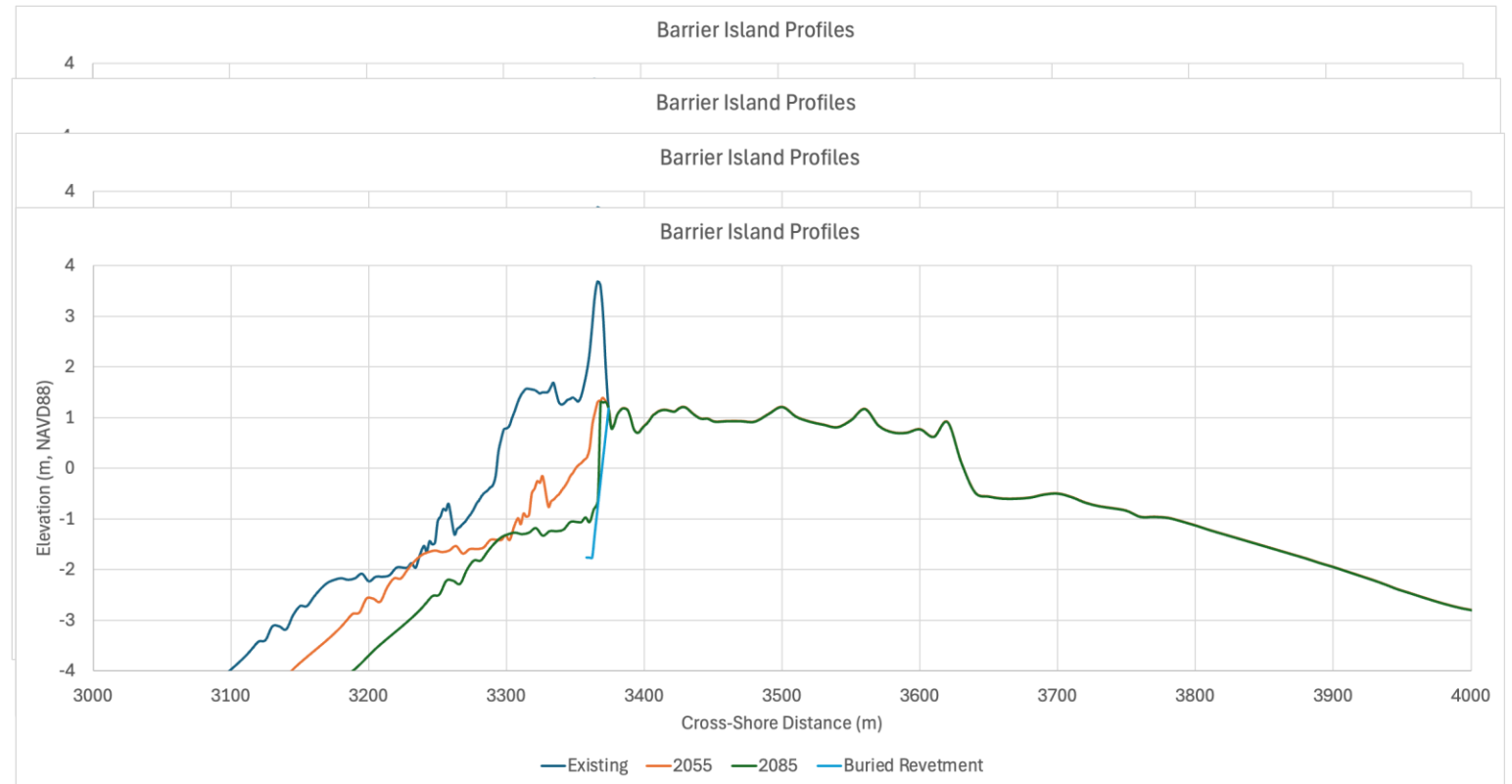
**IPCC AR6 SSP5-8.5 50th Percentile*

Adaptation Scenarios

- Do Nothing
- Beach+Dune Restoration
- Beach+Dune+Island Lift
- Beach+Dune+Lift+Bayside
- Buried Revetment
- Seawall
- Elevate Homes

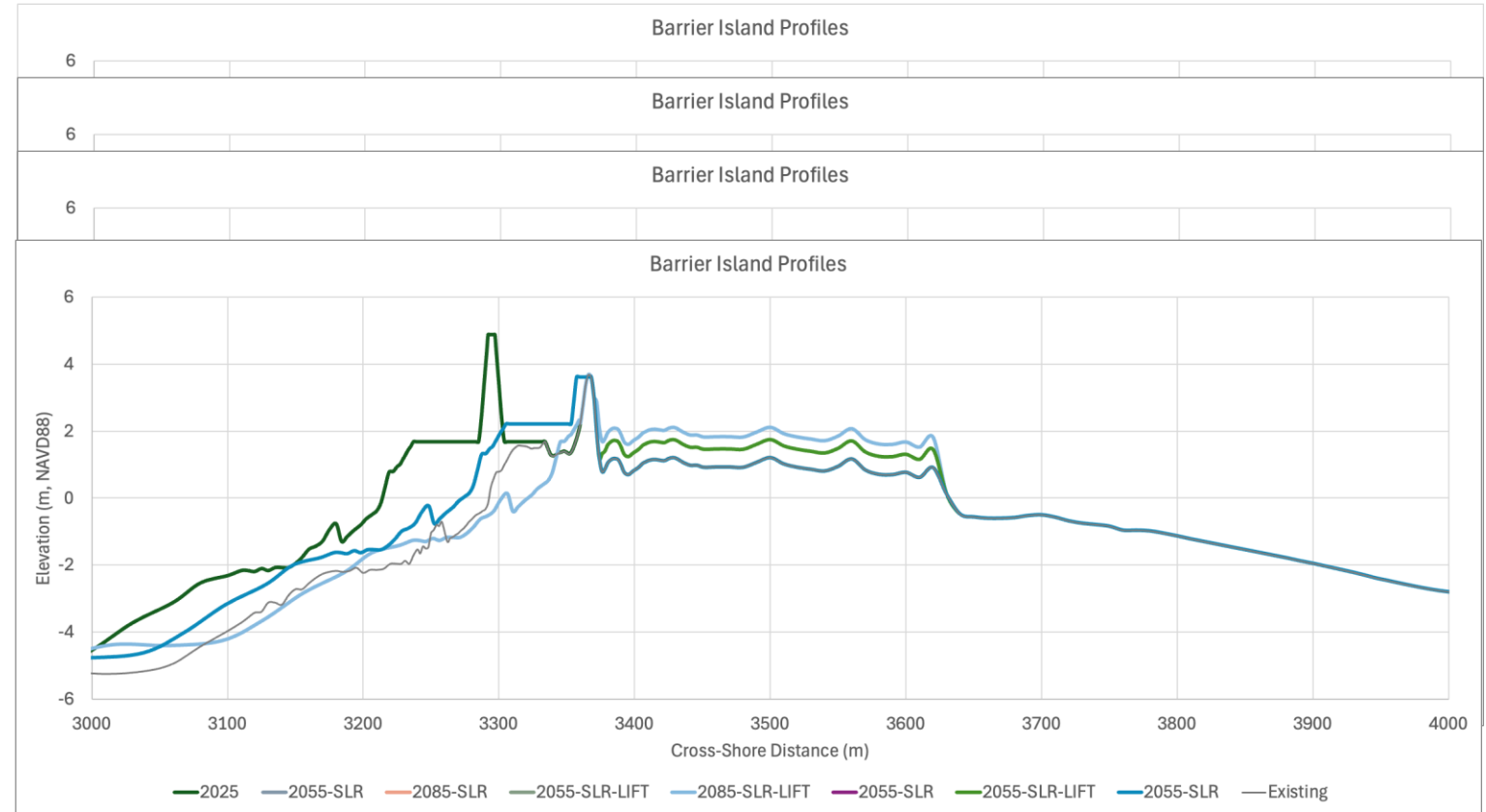
1D XBeach Modeling

- Background Erosion Rate
 - -1.2 m/yr
- Bruun Rule
 - 2055: -30.7 m
 - 2085: -51.2 m



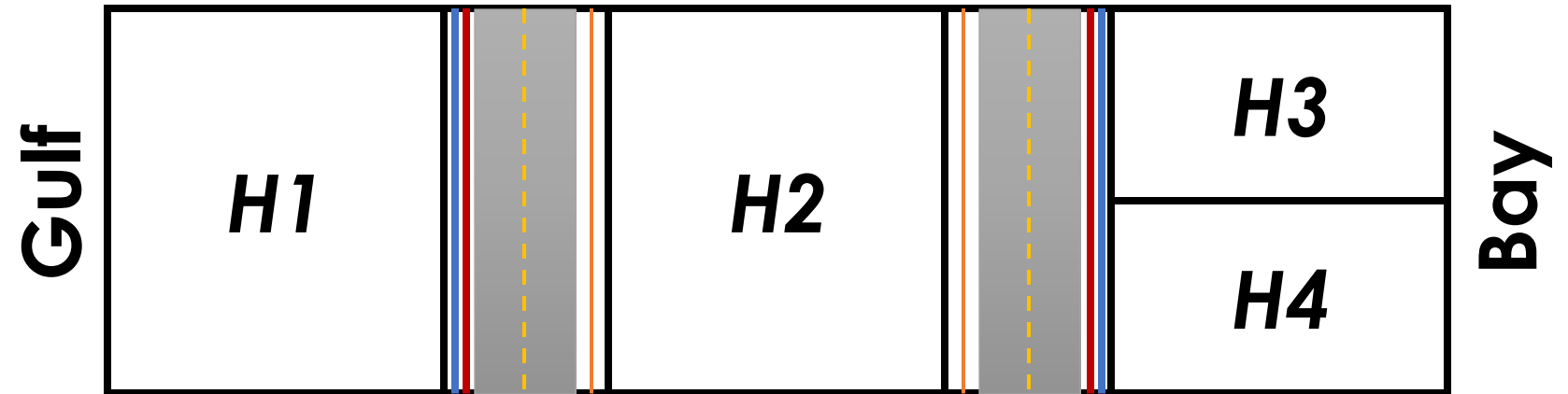
1D XBeach Modeling

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Infrastructure Model

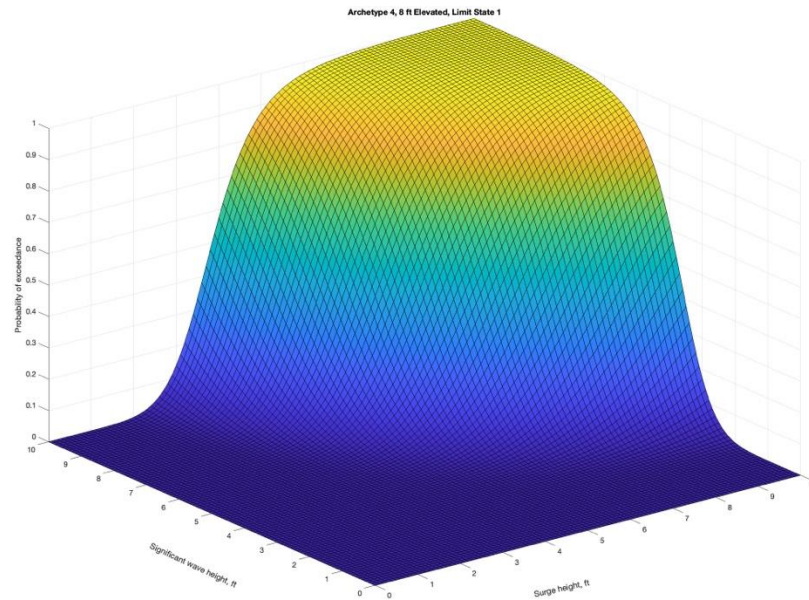
- Homes
- Roads
- Telecoms
- Water
- Sewer



Infrastructure Model

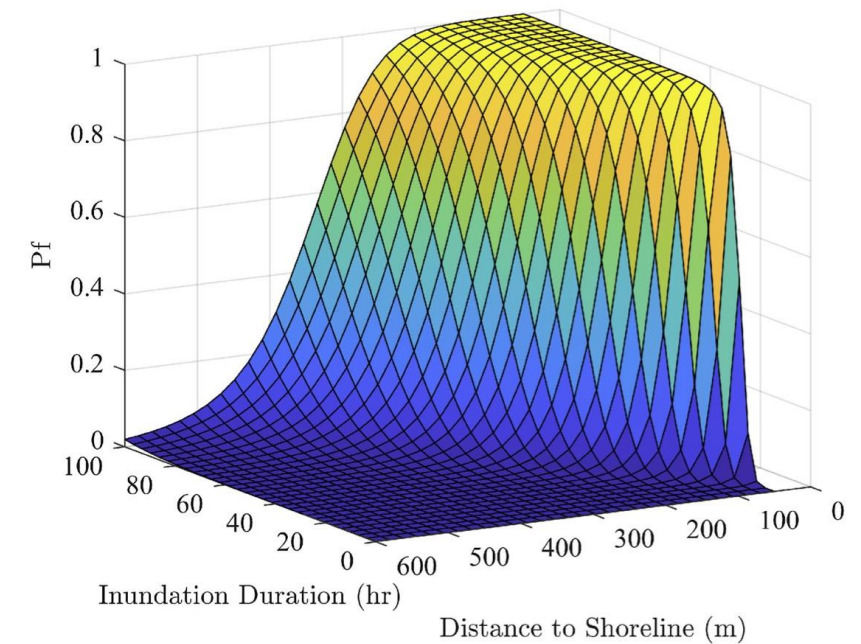
- Homes
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Elevated Structure Fragility



Do et al. (TBD)

Coastal Roadway Fragility



Darestani et al. (2021)

Infrastructure Model

Damage State Classification

DS=1

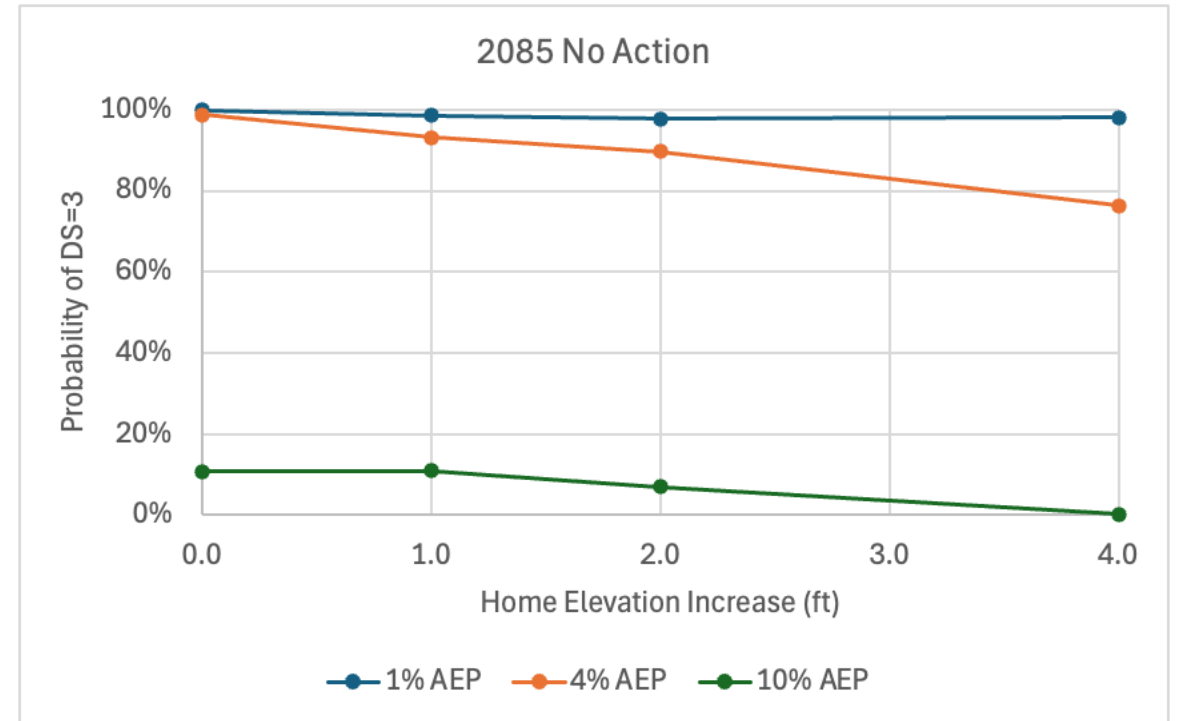
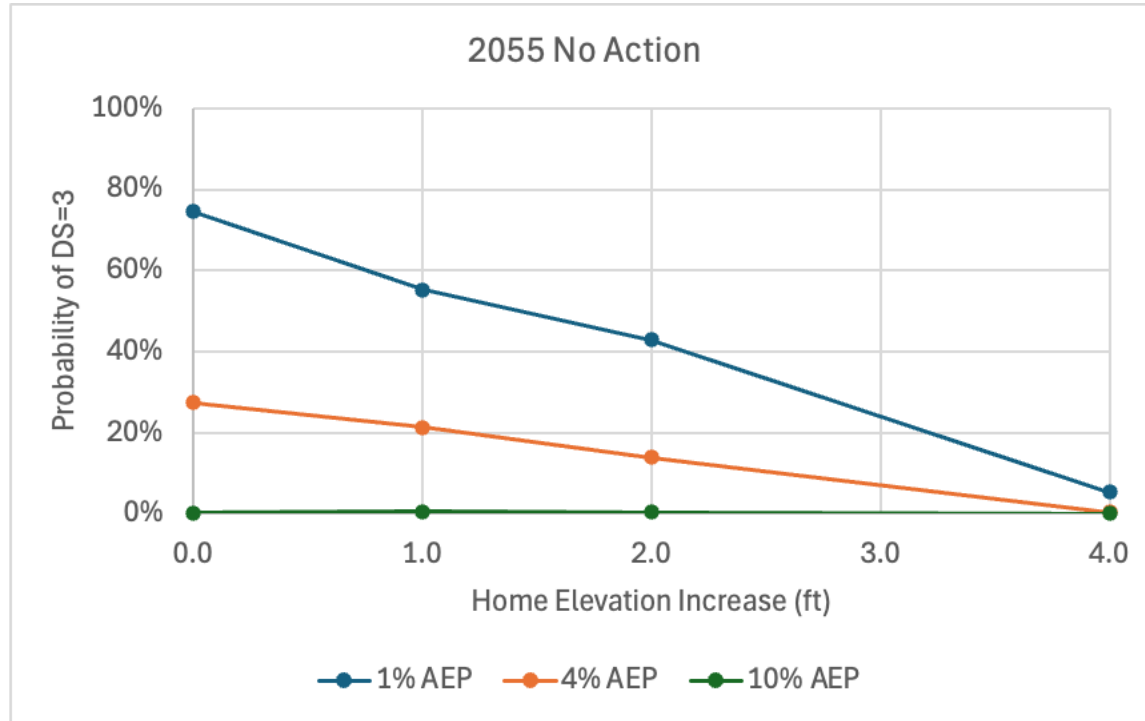
DS=2

DS=3

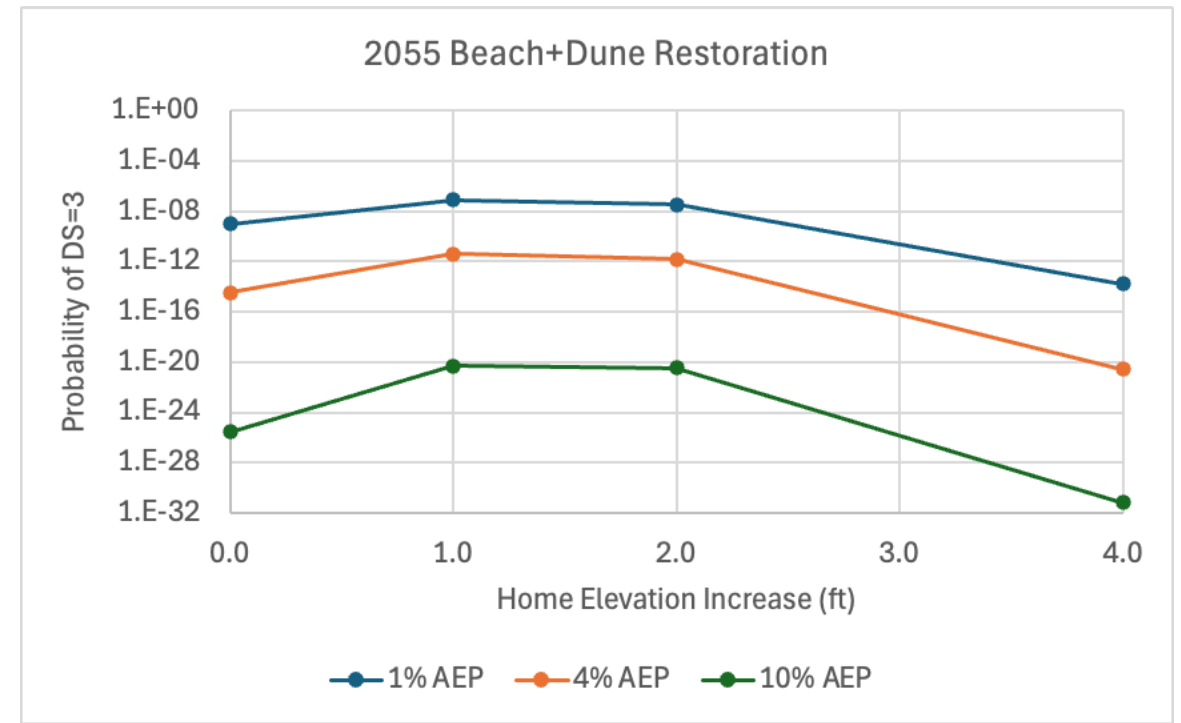
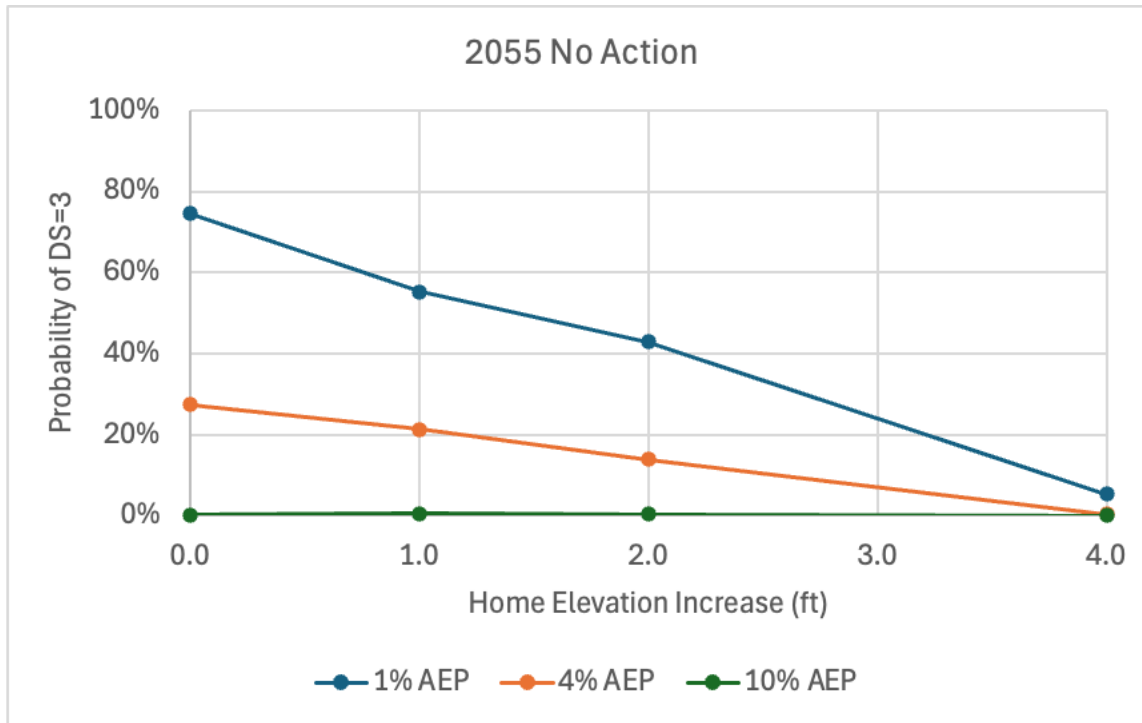
| Flood Damage | |
|--------------|---|
| Affected | <ul style="list-style-type: none"> Any waterline in the crawl space or an unfinished basement when essential living space or mechanical components are not damaged or submerged. Damage to a porch, carport, garage, and/or an outbuilding, etc. |
| Minor | <ul style="list-style-type: none"> Waterline at 1 to 3 inches in an essential living space. When waterline exceeds 3 inches but is below 18 inches, damage may be major or minor depending on the following factors: duration of the flood; contaminates in the water; if waterline reached outlets; and number of essential living spaces flooded. Any waterline in a finished basement. |
| Major | <ul style="list-style-type: none"> Waterline above 18 inches or the electrical outlets in an essential living space. Waterline on the first floor (regardless of depth) of a residence when basement is completely full. When waterline exceeds 3 inches but is below 18 inches, damage may be major or minor depending on the following factors: Duration of the flood; contaminates in the water; if waterline reached outlets; and number of essential living spaces flooded. |
| Destroyed | <ul style="list-style-type: none"> Waterline at the roofline or higher, or complete failure of two or more major structural components (e.g., collapse of basement walls, foundation, walls, or roof). |

Results/Findings

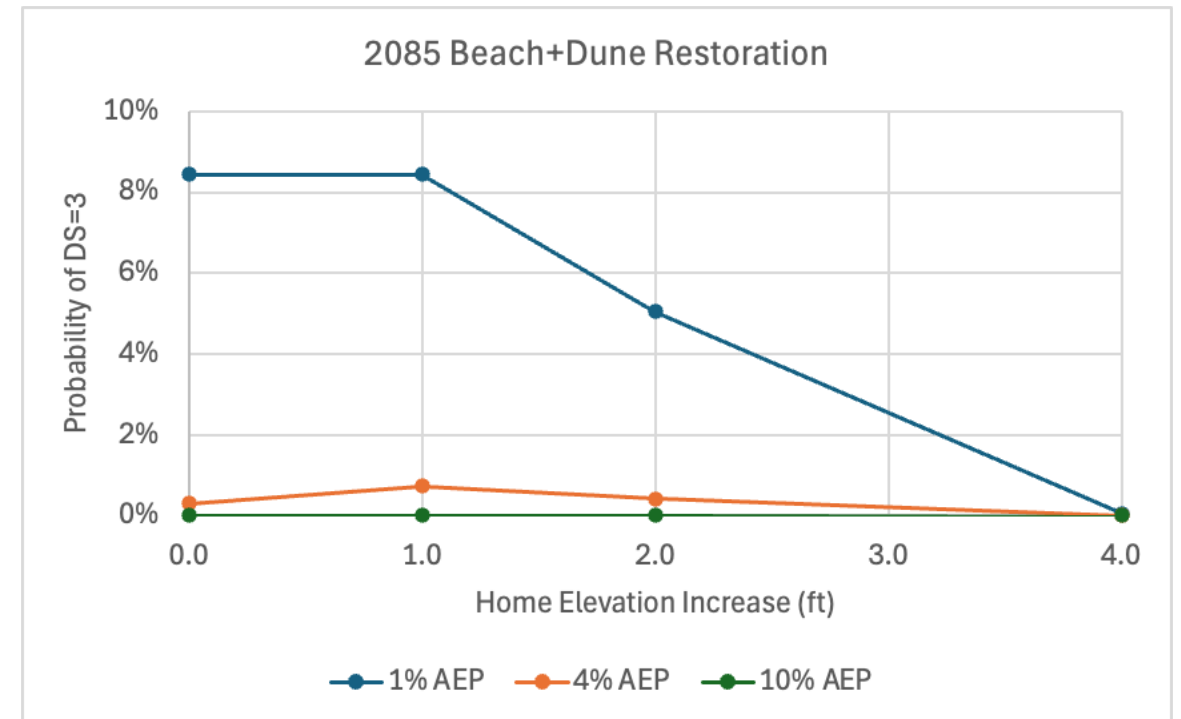
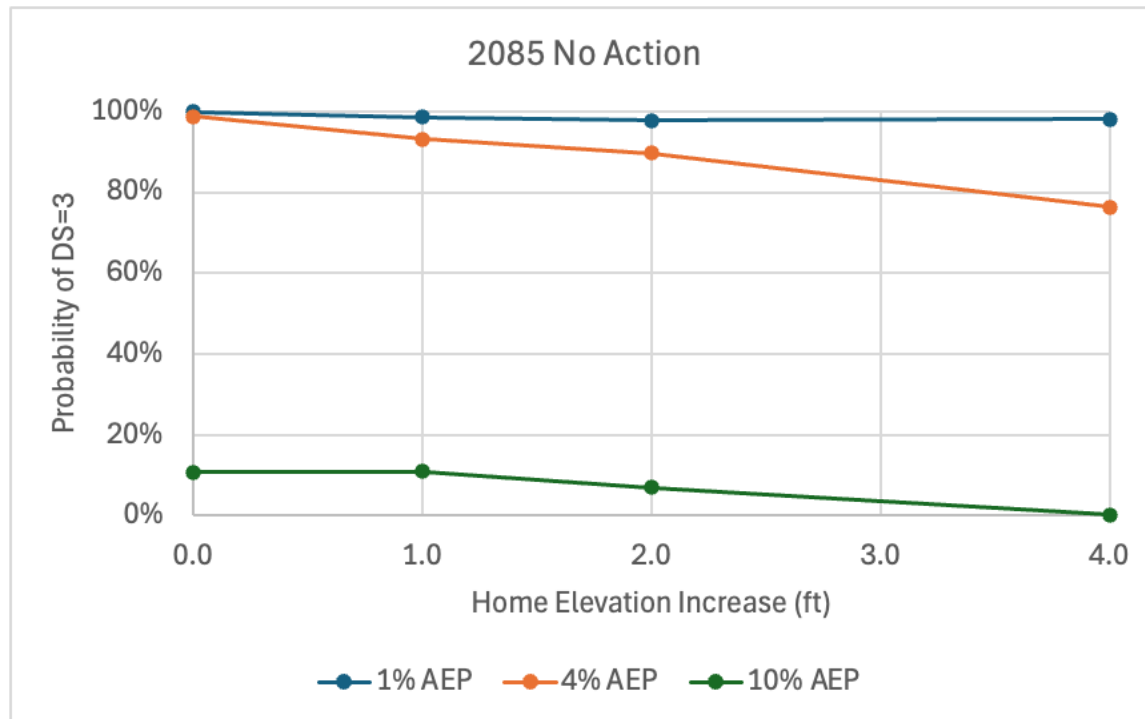
Results/Findings: Elevate Homes - P(f)



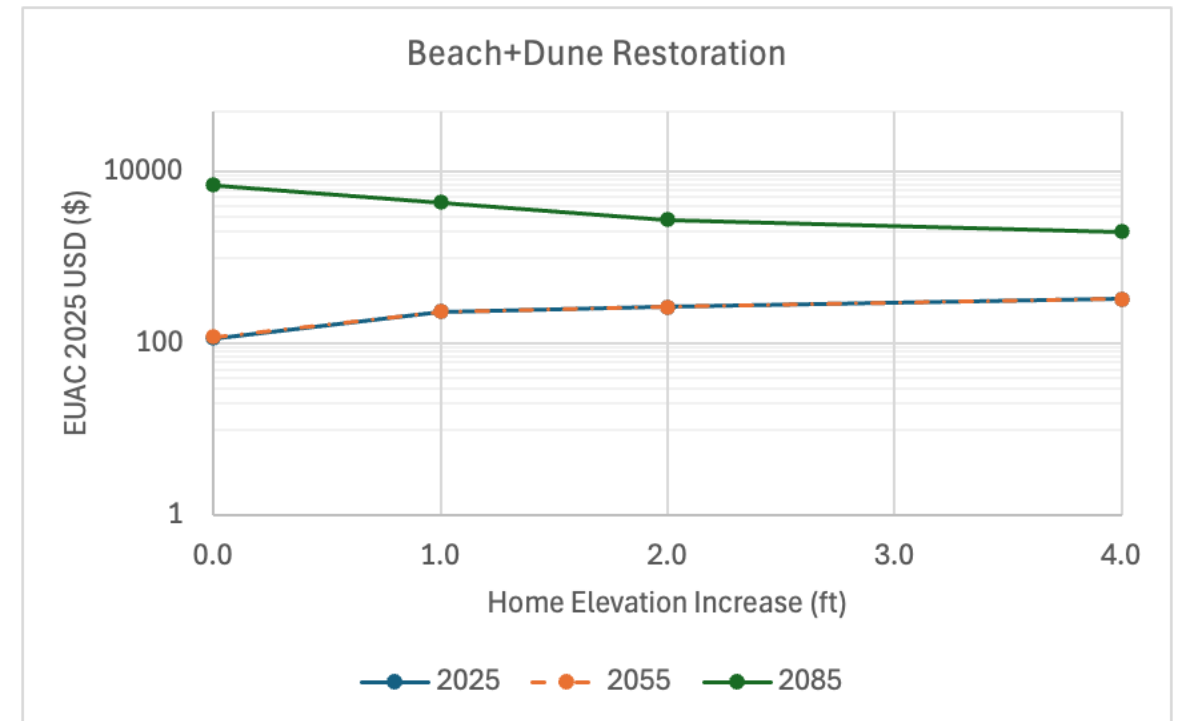
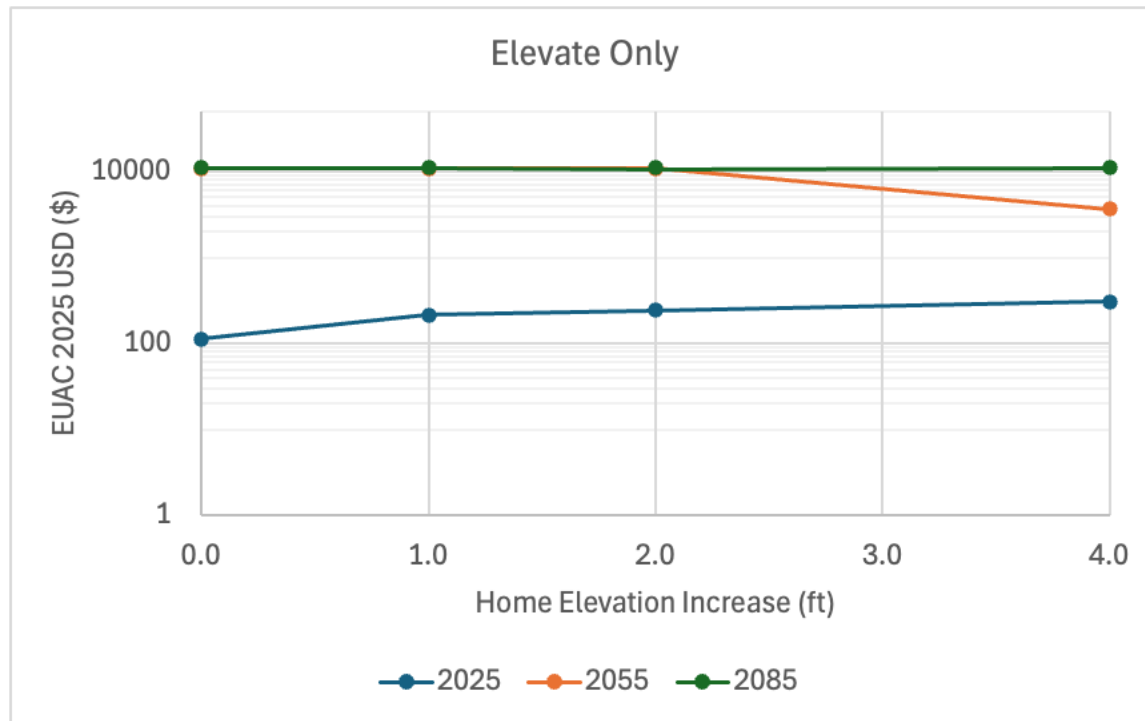
Results/Findings: Elevate Homes - P(f)



Results/Findings: Elevate Homes - P(f)



Results/Findings: Elevate Homes - \$

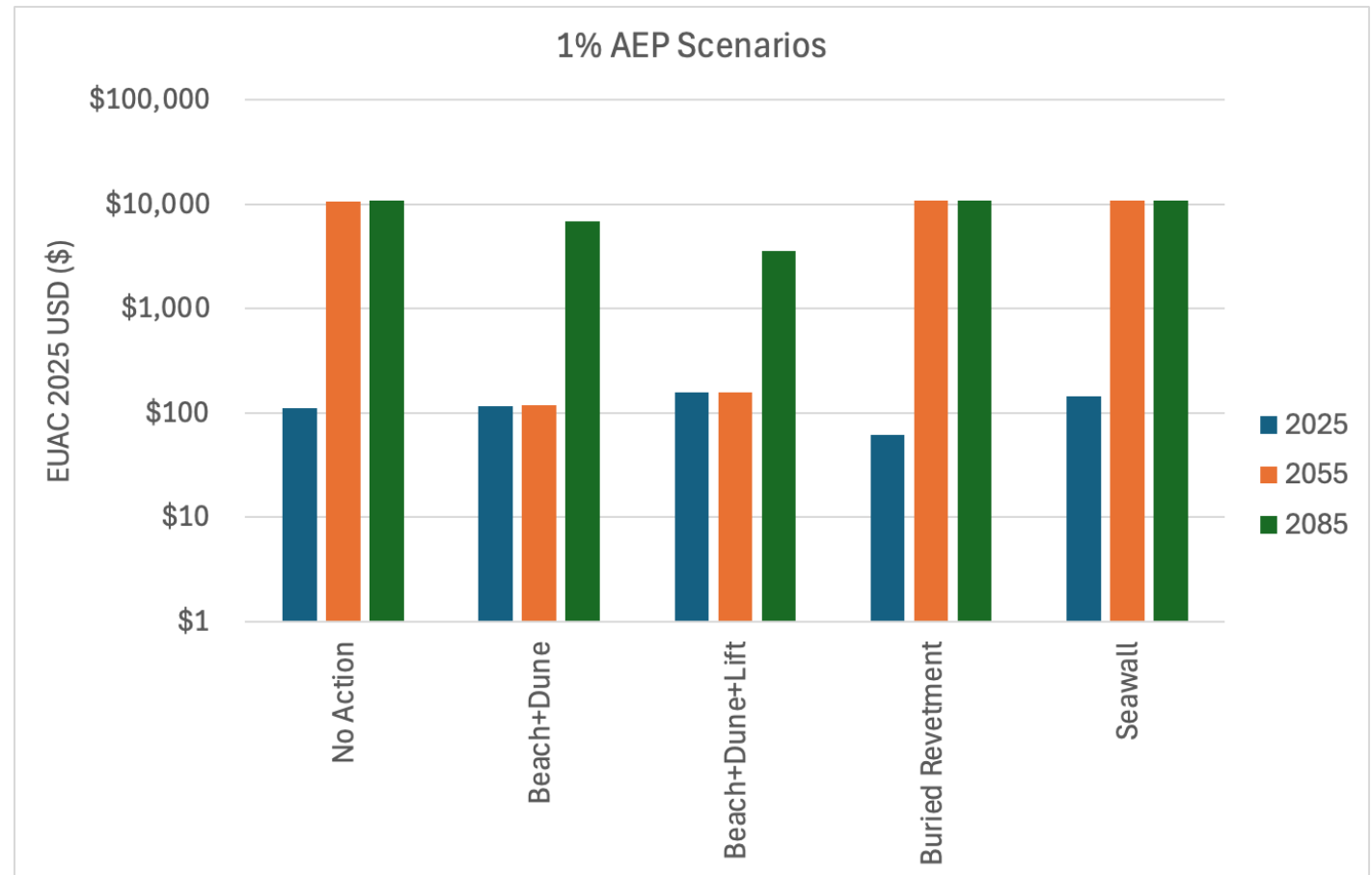


Results/Findings: Adaptation Costs

$$EUAC \text{ of First Cost} = P(i) \frac{(1+i)^N}{(1+i)^N - 1}$$

- P: cost of adaptation
- i: avg CPI (3.7%)
- N: time (30 yrs, 60 yrs)

**Total EUAC = First Cost +
Damage (\$) x Scenario Probability**



Results/Findings: EUAC Ratios

| 1% AEP | | 2055 Conditions | |
|-----------------|------------------|-----------------|--|
| | | do nothing | |
| 2025 Conditions | do nothing | 95.7 | |
| | beach+dune | 92.5 | |
| | beach+dune+lift | 68.4 | |
| | buried revetment | 173.9 | |
| | seawall | 73.8 | |

| 1% AEP / Raised +4 ft | | 2055 Conditions | | | | |
|-----------------------|------------------|-----------------|------------|-----------------|------------------|---------|
| | | do nothing | beach+dune | beach+dune+lift | buried revetment | seawall |
| 2025 Conditions | do nothing | 11.8 | 1.1 | 1.2 | 11.1 | 36.2 |
| | beach+dune | 11.1 | 1.0 | 1.1 | 10.4 | 33.9 |
| | beach+dune+lift | 9.8 | 0.9 | 1.0 | 9.2 | 30.1 |
| | buried revetment | 13.3 | 1.2 | 1.4 | 12.4 | 40.6 |
| | seawall | 10.2 | 0.9 | 1.0 | 9.5 | 31.1 |

Next Steps

Next Steps

1. Complete residential building vulnerability assessment
2. Reassess residential building vulnerability with resilient adaptations (in 2D)
3. Perform economic analysis
4. Finalize videos/tutorials for coastal data integration into IN-CORE



<https://www.expedia.com/Dauphin-Island.dx182896>

Sneak Peek – 2D Modeling

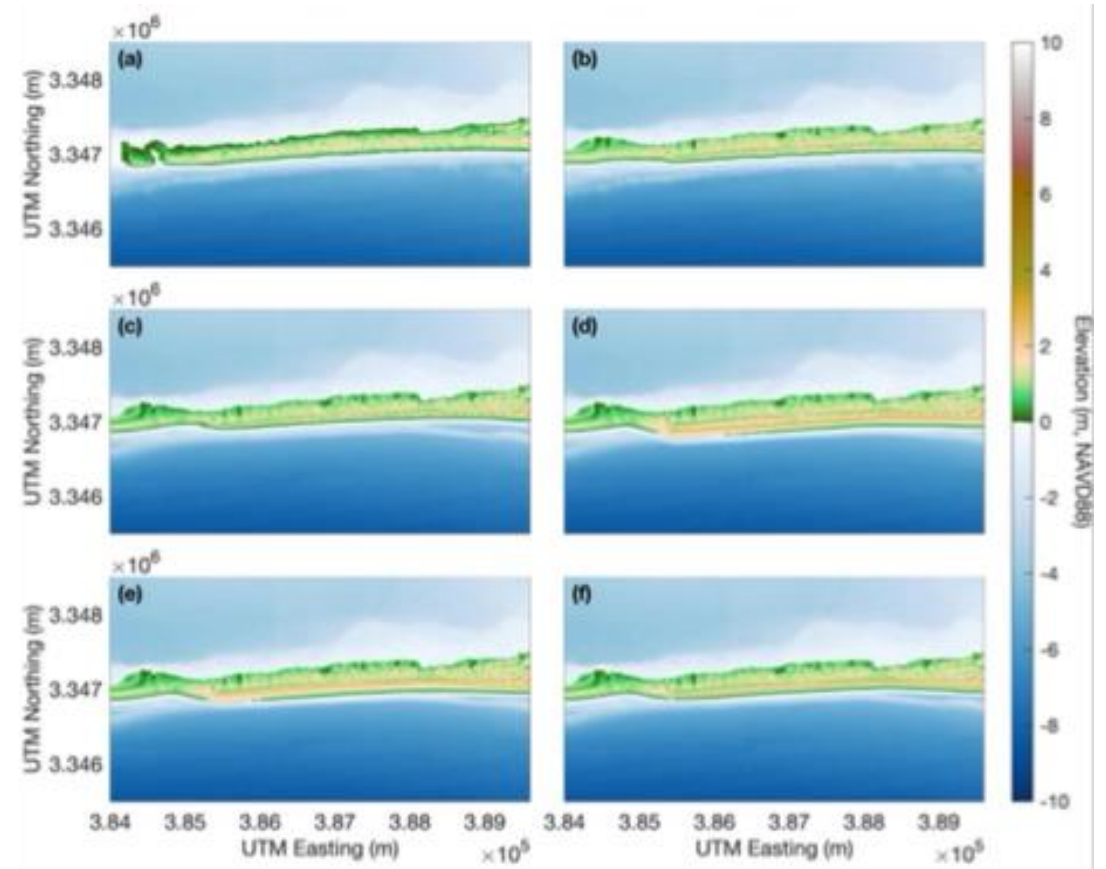
1. 2D XBeach Simulations

- Resilient Adaptations
- AEP and SLR

2. Existing + Future AEP Conditions

- Baseline and Future

3. Preliminary Assessments



Sneak Peek – 2D Modeling

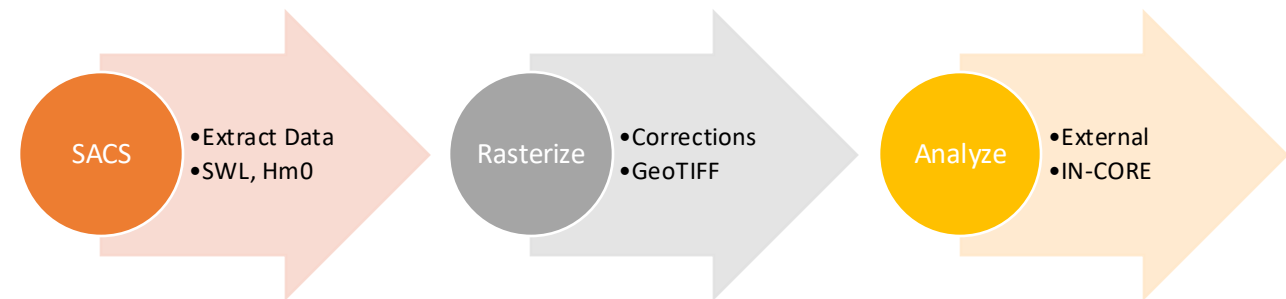
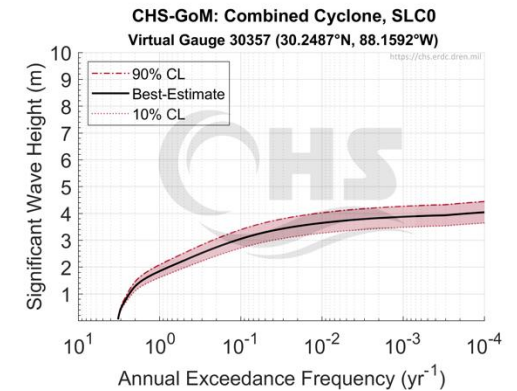
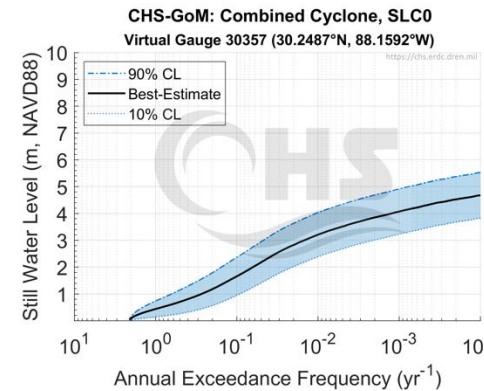
1. 2D XBeach Simulations

- Resilient Adaptations
- AEP and SLR

2. Existing + Future AEP Conditions

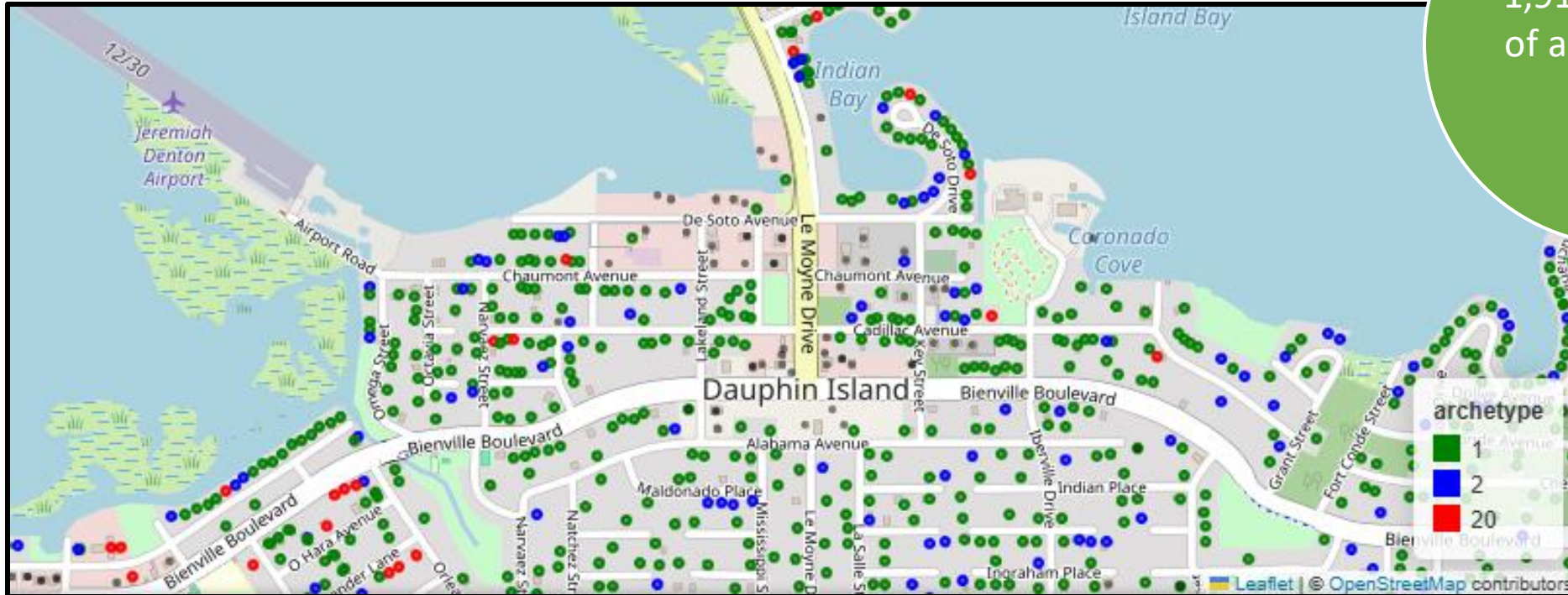
- 0.2% AEP / SLR1 / SLR2

3. Preliminary Assessments



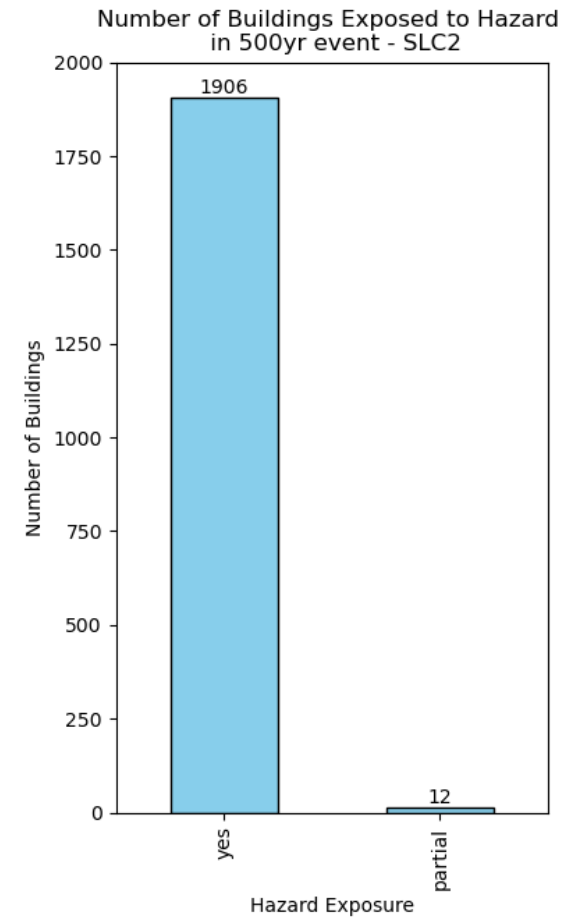
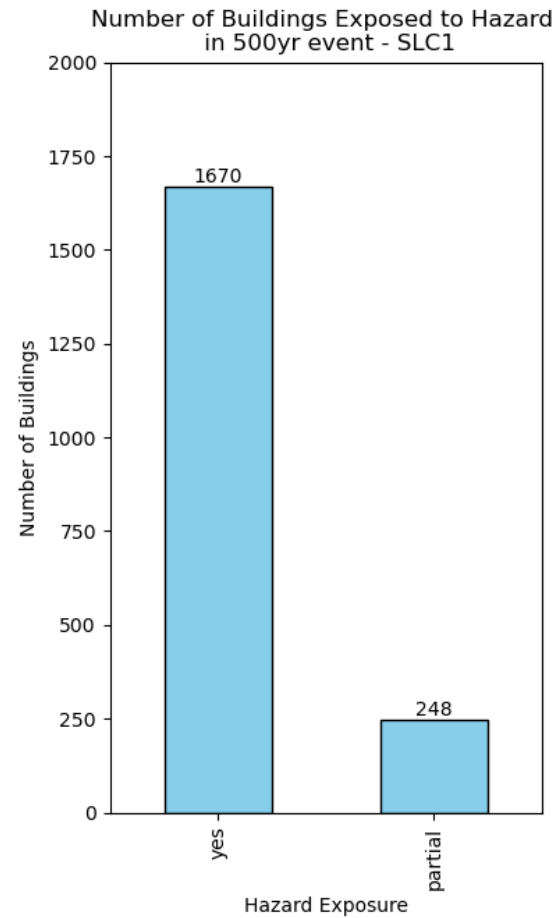
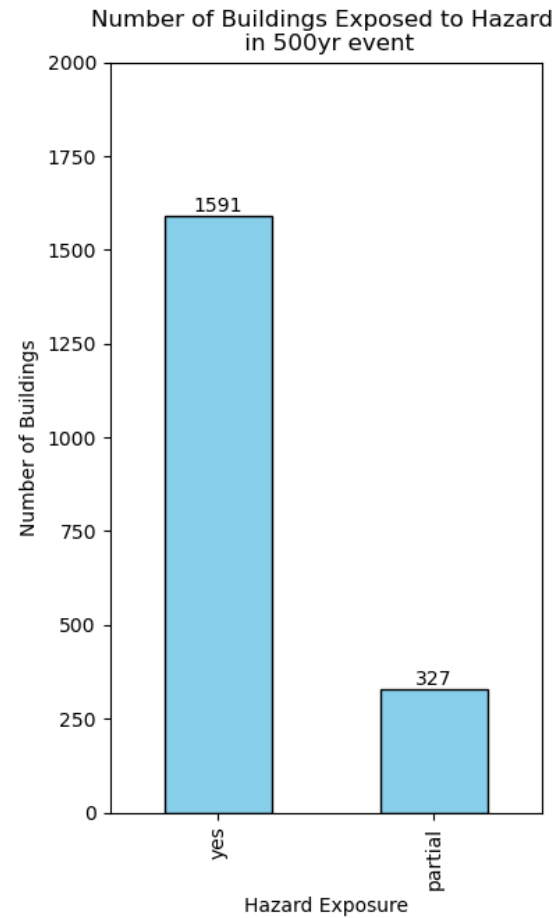
Sneak Peek – 2D Modeling

1,910 buildings
of archetype 1,
2, 20

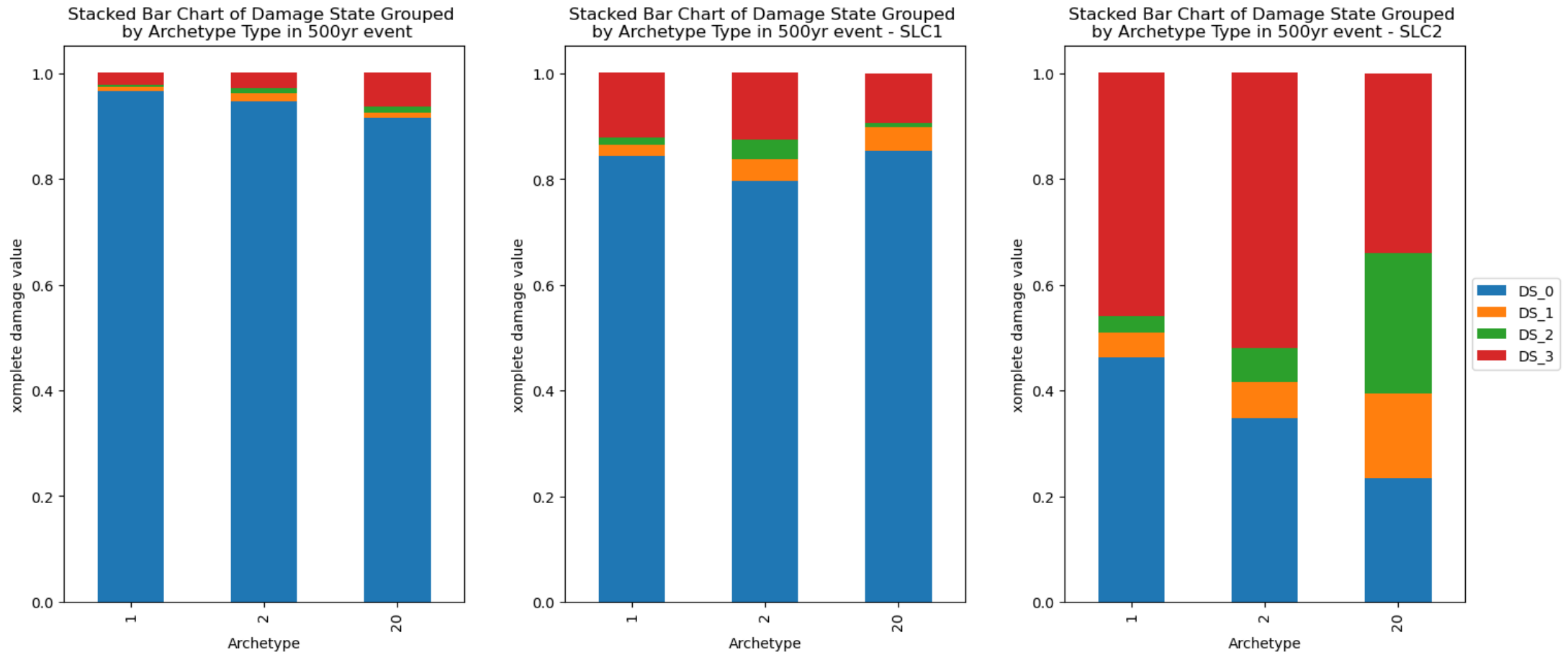


3. Preliminary Assessments

Sneak Peek – 2D Modeling



Sneak Peek – 2D Modeling



Sneak Peek – 2D Modeling



0.2% AEP

\$28M

+0.83 m SLR

\$94M

+2.24 m SLR

\$322M

*Please contact me if you are
interested in our work or would like to
be contacted with updates.*

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