Coastal Hazards & Sea-Level Rise Asset Vulnerability Assessment for Cape Cod National Seashore

Summary of Results

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ON THE COVER
Sunset at Cape Cod National Seashore
Photo credit: Program for the Study of Developed Shorelines

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Summary of Results

Executive Summary

This document presents the results of the **Coastal Hazards & Sea-Level Rise (SLR) Asset Vulnerability Assessment (VA)** completed by Western Carolina University at Cape Cod National Seashore (CACO) in 2022. In this VA, we evaluate the vulnerability (as a combination of exposure and sensitivity) of NPS buildings and transportation assets[1] to identified coastal hazards and climate change factors, approximately to the year 2050 (for full methodology, see Peek et al. 2022).

We assessed 225 buildings/structures (including visitor centers, lighthouses, houses/cottages, maintenance buildings, amphitheaters, and a dike) and 127 transportation assets (roads/road segments, parking lots, bridges, trails, and boardwalks) at CACO. Less than one-fifth (17%) of assets analyzed have high or moderate vulnerability to the evaluated coastal hazards and SLR. The majority (79%) have minimal vulnerability (are not in any of the evaluated hazard zones). Scoring details and results for all assets evaluated at CACO are reported in the provided Excel sheets.

Exposure Results

Exposure is a measure of the character, magnitude, and rate of changes a target may experience (e.g., from the impacts of climate change or a natural hazard influenced by climate change; NPS 2021). In this VA, we evaluate the exposure of each asset to the following coastal hazard indicators: flooding potential, shoreline change, SLR inundation, extreme event flooding, and reported coastal hazards (Table 1).

Table 1. Exposure indicators and hazard data sources used.

Exposure Indicator (Description)	CACO Data (Citation)
Flooding potential (1% annual-chance)	Effective FEMA VE & A zones (FEMA 2014)
Shoreline change/coastal proximity	CACO GPS shorelines (Adams 2022), USACE LiDAR (OCM Partners 2022), USGS shoreline change rates (Bartlett et al. 2021), 30-m shoreline proximity buffer (Peek et al. 2022)
SLR inundation (2050 proxy) *	NPS 2100 4.5 RCP SLR model, 0.51 m rise (Caffrey et al. 2018)
Extreme event flooding (category 3 surge)	NPS storm surge inundation model (Caffrey et al. 2018); NOAA national storm surge hazard maps (Zachry et al. 2015)
Reported coastal hazards (historic flooding)	Questionnaire results & discussions (Peek et al. 2022)

  *See Unique Considerations

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[1] The NPS Facility Management Software System (FMSS) database defines assets as "...a physical structure or grouping of structures, land features, or other tangible property that has a specific service or function, such as a farm, cemetery, campground, marina, or sewage treatment plant. The term 'asset' shall also be applied to movable items, such as vehicles and equipment."

Assets with high exposure are within at least four exposure indicator hazard zones. Assets with moderate exposure are within two or three exposure indicator hazard zones. Assets with low exposure are within only one exposure indicator hazard zone. The asset could still be seriously impacted by this hazard. Assets with minimal exposure are not in any exposure indicator hazard zone. This does not mean that the asset has no exposure to coastal hazards, but it is not within the exposure hazard data used in this study.

Forty-one assets (12%) analyzed at CACO have high exposure to the evaluated coastal hazards (Table 2). The most widespread hazard zone is flooding potential, particularly in the northern portion of the park (Figure 1). Over half of the high exposure assets are *only* within the Federal Emergency Management Agency (FEMA) VE (we automatically assign any asset within this zone a high exposure score overall); these assets are within the Herring Cove, Race Point Beach, or Dune Shack areas (Figure 2). The Nauset Bike Trail – Boardwalk/Bridge, Great Island Trail, and Nauset Marsh Trail (southwest loop) are within all evaluated exposure zones. Sixteen assets (5%) have moderate exposure, and 16 (5%) have low exposure. Over three-quarters (79%) of assets have minimal exposure, a result of the park's higher elevation areas (much of the park is 5 - 40 meters above sea level) leading to lower exposure overall to coastal flooding and SLR.

Table 2. CACO exposure results. Sum of percentages may not equal 100 due to rounding.

Assets	High Exposure		Moderate Exposure		Low Exposure		Minimal Exposure		Total
	#	%	#	%	#	%	#	%	#
Buildings	25	11%	1	<1%	8	4%	191	85%	225
Transportation	16	13%	15	12%	8	6%	88	69%	127
All Assets	41	12%	16	5%	16	5%	279	79%	352
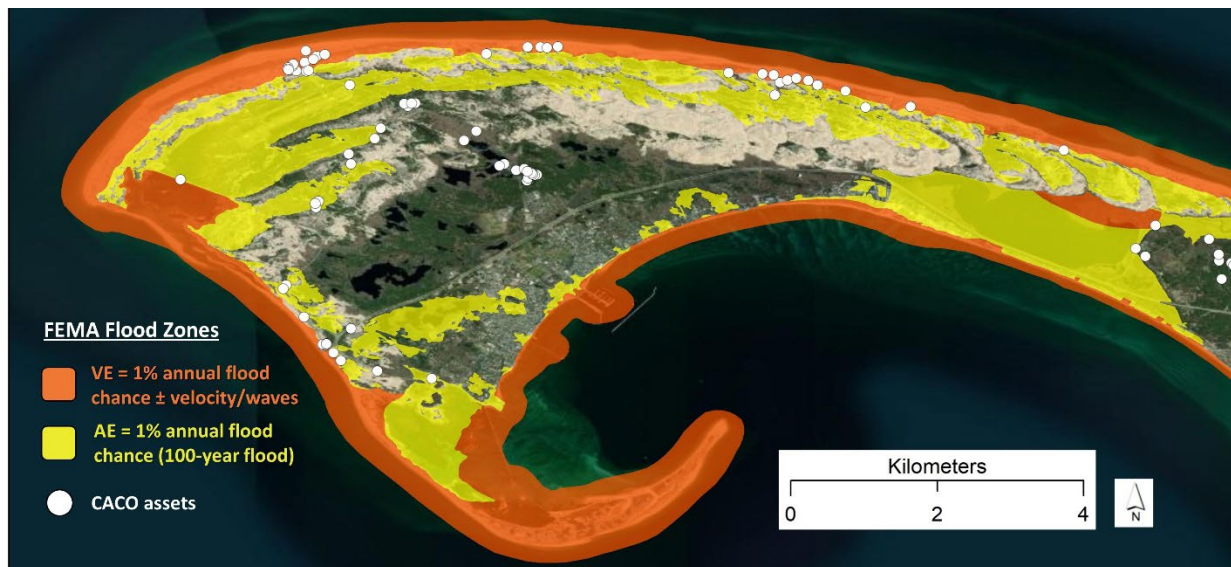
Figure 1. Effective FEMA flood zones (2014) for the Provincetown area of CACO. Background is ESRI streaming imagery.

Figure 2. CACO exposure results summary, with select areas labeled. Background map is ESRI streaming imagery.

Sensitivity Results

Sensitivity reflects the degree to which a resource is affected by exposure (NPS 2021). In this VA, we assess the following sensitivity indicators: flood damage potential/elevated, storm resistance and condition, historic damage, and protective engineering. In general, assets with high sensitivity have unfavorable determinations for 3 or 4 of these indicators, moderate-sensitivity assets have unfavorable determinations for 2 indicators, and low-sensitivity assets have unfavorable determinations for 0 or 1 indicator. Assets with minimal exposure are not analyzed for sensitivity (this is the case for 279 assets at CACO).

Seven assets (10%) analyzed at CACO have high sensitivity to coastal hazards and SLR: the Bog House, High Head Road and Parking, Hatches Harbor Parking, Buttonbush Trail, and two segments

of the Nauset Marsh Trail. The majority (82%) of assets have moderate sensitivity, and 8% have low sensitivity (Table 3). Few assets at CACO are significantly elevated above local ground level, storm resistant, or protected by effective engineering (e.g., seawalls, bulkheads). However, most evaluated assets are in good condition. High Head Road and Nauset Marsh Trail (east spur near Doane Rock) received an unfavorable rating for all sensitivity indicators.

Table 3. CACO sensitivity results. Sum of percentages may not equal 100 due to rounding.

Assets	High Sensitivity		Moderate Sensitivity		Low Sensitivity		Total Analyzed	Excluded*
	#	%	#	%	#	%	#	#
Buildings	1	3%	28	82%	5	15%	34	191
Transportation	6	15%	32	82%	1	3%	39	88
All Assets	7	10%	60	82%	6	8%	73	279

*Minimal exposure assets were excluded from the sensitivity analysis; total number analyzed is different for sensitivity.
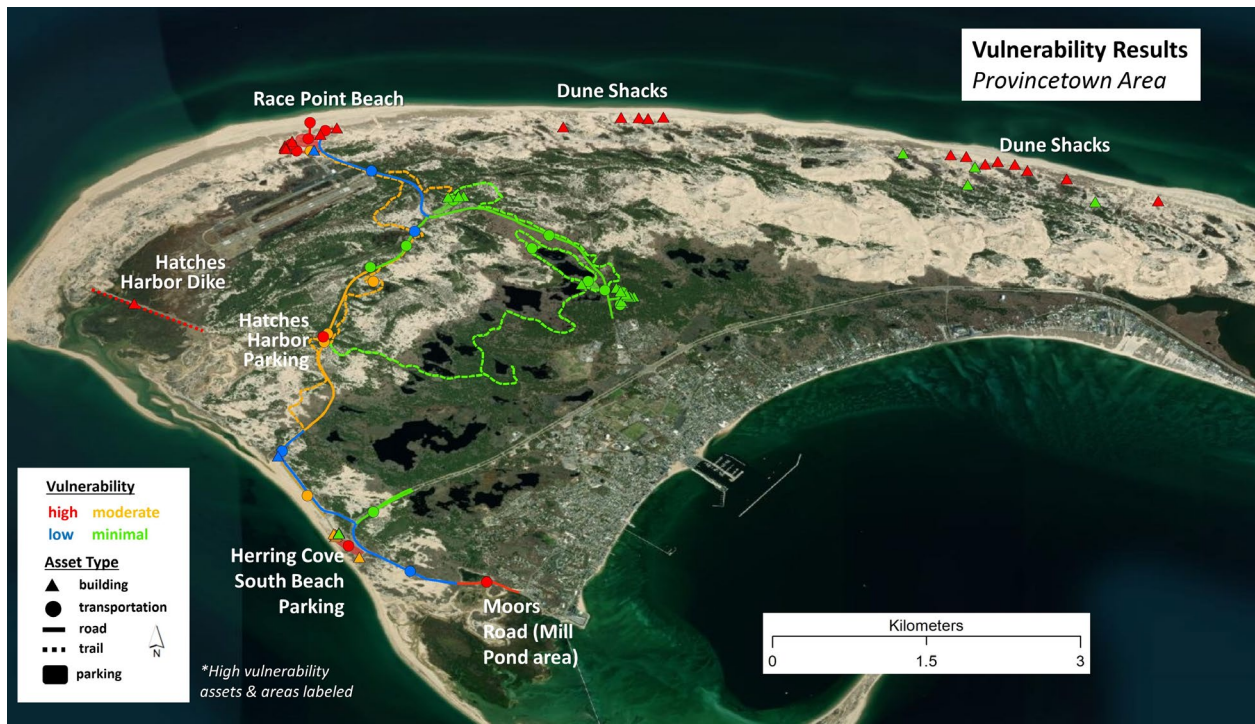
Vulnerability Results

Vulnerability is a measure of the degree to which park resources and assets are "susceptible to harm from direct and indirect effects of climate change, including variability and extremes" (NPS 2021). In this VA, we evaluate the vulnerability of infrastructure assets as a simple combination of exposure and sensitivity ratings. It should be noted that the vulnerability of any asset can change with time (e.g., due to adaptation actions or the result of geomorphic change).

Eleven percent of assets analyzed at CACO have high vulnerability to the evaluated coastal hazards, 6% have moderate vulnerability, and only 4% have low vulnerability (Table 4, and Figures 3-6). The majority (79%) of assets have minimal vulnerability. High Head Road, Hatches Harbor Parking, and Nauset Marsh Trail (southwest loop) have both high exposure and high sensitivity. Eight assets have both high vulnerability and a high asset priority index (API > 70, as reported in FMSS), including the Old Harbor Life Saving Station Museum, Hatches Harbor Dike, Hatches Harbor Parking, Coast Guard Beach Access Road Bridge, and Nauset Bike Trail – Boardwalk/Bridge.

Table 4. CACO vulnerability results. Sum of percentages may not equal 100 due to rounding.

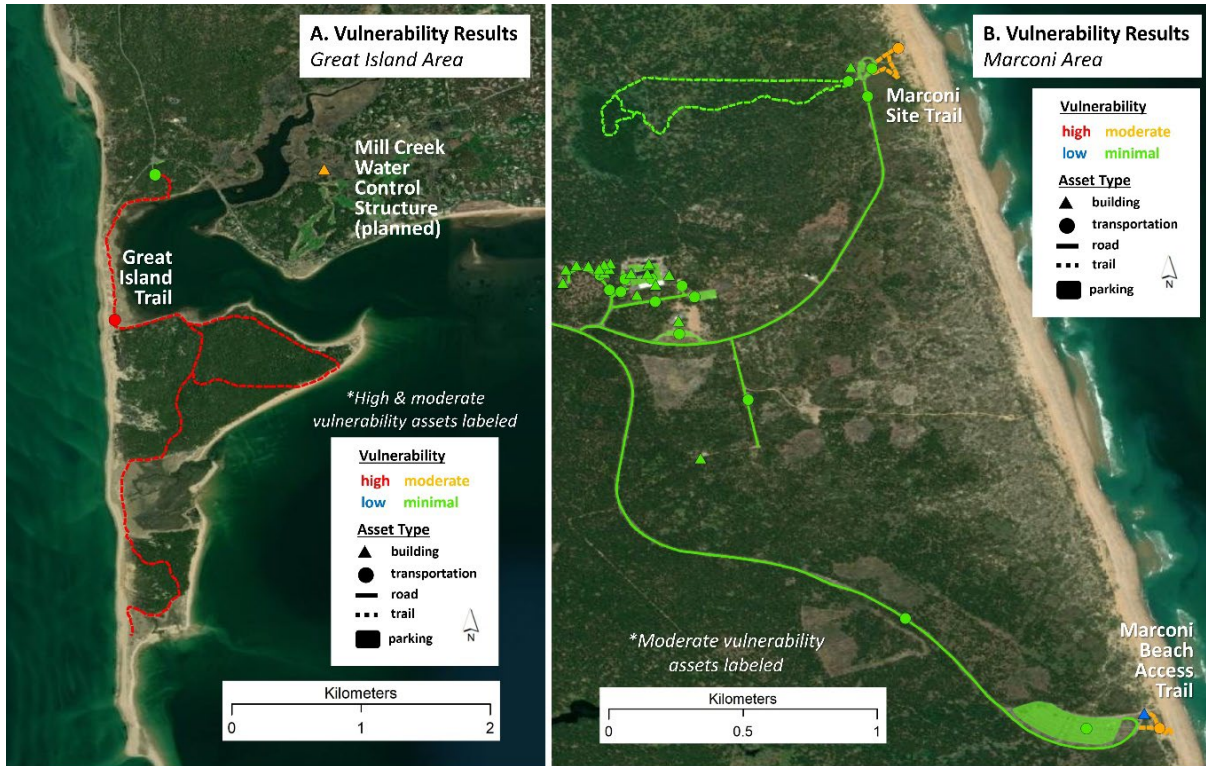| Assets	High Vulnerability		Moderate Vulnerability		Low Vulnerability		Minimal Vulnerability		Total
	#	%	#	%	#	%	#	%	#
Buildings	20	9%	7	3%	7	3%	191	85%	225
Transportation	18	14%	14	11%	7	6%	88	69%	127
All Assets	38	11%	21	6%	14	4%	279	79%	352

Figure 3. CACO vulnerability results summary for the Provincetown area. Only high vulnerability assets and areas are labeled. Background is ESRI streaming imagery.

Figure 4. CACO vulnerability results summary for the north Truro area. Only high vulnerability assets are labeled. Background is ESRI streaming imagery.

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Figure 5. CACO vulnerability results summary for the Wellfleet area. A) Great Island area results with high and moderate vulnerability assets labeled. B) Marconi area results with moderate vulnerability assets labeled. Background is ESRI streaming imagery.

Figure 6. CACO vulnerability results summary for the Salt Pond and Coast Guard Beach areas. Only high vulnerability assets are labeled. Background is ESRI streaming imagery.

The park has several ongoing adaptation projects that are intended to reduce the exposure and sensitivity of assets to coastal hazards. Herring Cove Beach eroded rapidly between 2012-2018 and, in response, the park relocated and redesigned several key assets. Transportation assets such as the Province Lands Road and North Beach Parking Lot have both been relocated, and a funding request has been made to relocate the South Parking Lot. Beach facilities at Herring Cove were also relocated and redesigned to be more storm resistant and easier to move in the future, including the Changing Room, Restroom, Concession, and Lifeguard buildings. The adaptation actions taken at Herring Cove reduce the overall vulnerability and serve as a model for the rest of CACO, and other coastal parks with similar erosion issues. Other planned projects include the reconstruction of the Mill Creek Water Control Structure as part of the Herring River Restoration project and the rehabilitation of the Hatches Harbor Dike, which will help to reduce flood impacts on assets nearby.

CACO Unique Considerations

Shoreline change data: We used a digital shoreline and 2021 United States Geological Survey shoreline change rate data (Bartlett et al. 2021) to create erosion buffer zones for the oceanfront and bayside shorelines of CACO (see Peek et al. 2022 for methodology). The digital shoreline is a combination of the 2021 GPS shoreline provided by the park (Adams 2022) and a manually digitized cliff shoreline based on the 2018 United States Army Corps of Engineers LiDAR (OCM Partners 2022).

We used a simple 30-m proximity buffer for a few locations where shoreline change data were not available. This proximity buffer accommodates an erosion rate up to 1m/year and assumes that infrastructure near the coast is likely to experience multiple coastal hazards within the 30-year (approximately 2050) timeframe of this analysis (see Peek et al. 2022).

SLR data: We used the 2100 4.5 Representative Concentration Pathway SLR projections and inundation model from Caffrey et al. (2018) developed specifically for NPS units to score exposure for this indicator (0.51 m rise for CACO). These data are used as a proxy for 2050 SLR to accommodate higher SLR projections recently released by the National Oceanic and Atmospheric Administration (NOAA; see Peek et al. 2022).

Extreme event flooding data: In most cases, we use storm surge models produced by NPS (Caffrey et al. 2018) within this protocol; however, these data are poorly mapped in some locations (Figure 7). In these areas, we also consulted the NOAA category 3 high tide inundation model (National Storm Surge Hazard Maps - Version 3; Zachry et al. 2015).
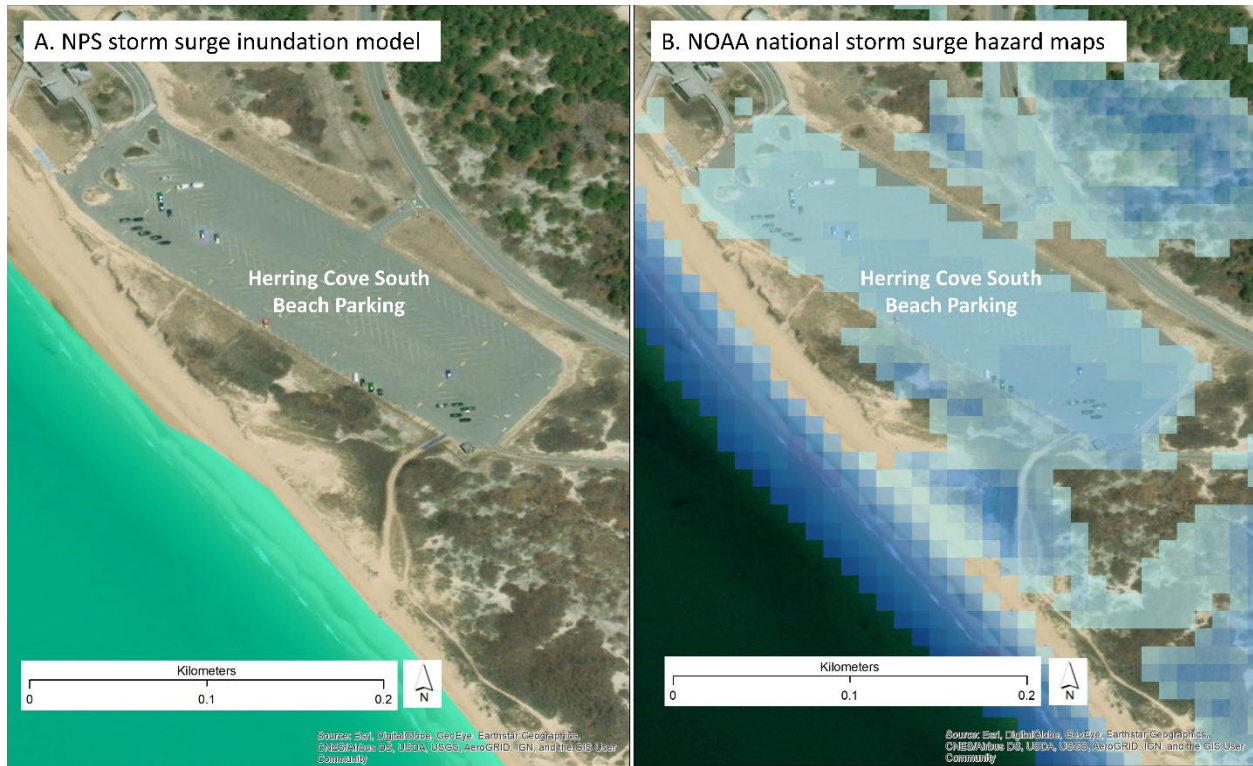
Figure 7. Storm surge model comparison near the Herring Cove South Beach Parking lot, which has been previously impacted by coastal flooding. A. NPS category 3 storm surge model inundation results (green shaded area) showing almost no inundation above the beach. B. NOAA category 3 storm surge model inundation results (shades of blue) showing extensive inundation across the parking lot. Background for both images is ESRI streaming imagery.

Linear assets: Three roads and five trails were segmented at CACO due to length and exposure variability. The following roads were segmented: Moors Road (two segments), Province Lands Road (three segments), and Race Point Road (2 segments). The following trails were segmented: Nauset Bike Trail (two segments), Fort Hill Trail (two segments), Bearberry Hill Trail (two segments), Province Lands Bike Trail (two segments), and Nauset Marsh Trail (three segments). We evaluated each segment individually for exposure, sensitivity, and vulnerability, and assigned each segment a modified location code (segments share the same FMSS attributes).

National Bridge Inventory data: The three bridges evaluated at CACO (Coast Guard Beach Access Road Bridge, Province Lands Road Bridge 1, and Province Lands Road Bridge 2) are in the National Bridge Inventory (NBI), which contains several attributes that were used as additional sensitivity indicators (clearance, scour rating, condition, and age). We use a different scoring system (see Peek et al. 2022) for bridges with additional NBI sensitivity indicators.

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