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Sustainable Operations and Climate Change Branch
Park Facility Management Division Facilities Planning Branch

Canaveral National Seashore (CANA)

Coastal Hazards & Climate Change Asset Vulnerability Assessment
December 2016

Program for the Study of Developed Shorelines
Western Carolina University
Cullowhee, NC 28723

Contents

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NPS 639/154060, December 2016

Executive Summary

The National Park Service (NPS) Sustainable Operations and Climate Change Branch, in partnership with Western Carolina University's (WCU) Program for the Study of Developed Shorelines (PSDS), has developed a ***Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol***. This protocol is meant to assess the vulnerability of infrastructure to multiple coastal hazards and climate change factors (i.e., flooding potential, extreme event flooding, shoreline change, sea-level rise, and reported costal hazards), over a 35-year planning horizon (2050). Unlike natural resource vulnerability, which combines three metrics (exposure, sensitivity, and adaptive capacity), the newly developed method for assessing infrastructure includes only exposure and sensitivity to coastal hazards and climate change factors in the vulnerability score; adaptation strategies are instead examined in the context of the vulnerability results. The overall goal of this protocol is to standardize the methodologies and data used, allowing managers to compare the vulnerability of coastal assets across local, regional, and national levels.

A total of 66 structures and 88 transportation assets (roads, parking lots, vistas, boardwalks, waterfront systems, and primary trails) are included in the vulnerability assessment of Canaveral National Seashore (CANA). Approximately half (47%) of all assets analyzed at CANA have a moderate vulnerability to coastal hazards and sea-level rise. Of the remaining assets, 27% have high vulnerability, 20% have low vulnerability, and 6% have minimal vulnerability to coastal hazards and sea-level rise.

The CANA vulnerability results are largely a function of exposure, as the majority (91%) of the analyzed assets at CANA have moderate sensitivity scores. Because the sensitivity results are relatively uniform for assets at CANA, the exposure scores most directly influence the vulnerability results. Overall, CANA has modest vulnerability, with 73% of assets having moderate, low, or minimal vulnerability. The exposure-driven vulnerability is likely due to several geologic and climatic factors, including relatively high elevations for a barrier island system and an accreting shoreline.

The high vulnerability assets at CANA have a combined replacement value (CRV) of approximately $4.1 million, which is about 10% of the total value of all assets analyzed. Overall, the high vulnerability assets are low in replacement value, as most are small-footprint assets such as boardwalks, parking lots, and comfort stations. Most of the transportation assets with high vulnerability are also of high priority to the park (API > 70). A large portion of these assets are boardwalks, which are of high priority to the park, as they provide beach access, one of the primary missions of CANA.

Vulnerability Assessment Products & Deliverables:

1) Excel datasheets - All results, as well as asset-specific scoring, are provided in tabular form. The exposure, sensitivity, and vulnerability scores are reported alongside the FMSS data for each asset, as well as the scores for each step of the analysis. Contact WCU or NPS for data.
2) GIS Maps and Layers - All GIS data, including the exposure layers, exposure results, and final vulnerability results will be sent to the park as a separate file. The GIS data will also be available to view online at the ArcGIS Online (AGOL) website. Contact WCU or NPS for data.
3) Park Specific Vulnerability Results Summary Document - This document, which explains the deliverables, results, adaptation strategies, and methodology.

Introduction & Project Description

The National Park Service Sustainable Operations and Climate Change Branch (NPS SOCC), in partnership with Western Carolina University's (WCU) Program for the Study of Developed Shorelines (PSDS), has developed a ***Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol***. This protocol establishes a standard methodology and set of best practices for conducting vulnerability assessments in the built environment. Standardizing the methodologies and data utilized in these assessments allows managers to compare the vulnerability of coastal park assets across local, regional, and national levels.

A proposed standardized approach to assessing climate change vulnerability was described in a multiple agency (NOAA, NPS, USGS, DOD, NWF, and USFS) document titled "Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment (Glick et al., 2011)." This document defines the vulnerability of natural resources to climate change as: the extent to which a species, habitat, or ecosystem is susceptible to harm from climate change impacts. Vulnerability under this approach is comprised of three equally weighted metrics or components: exposure, sensitivity, and adaptive capacity:

Vulnerability = Exposure + Sensitivity + Adaptive Capacity

- ✓ **Exposure** refers to whether a resource or system is located in an area experiencing direct impacts of climate change, such as temperature and precipitation changes, or indirect impacts, such as sea-level rise.
- ✓ **Sensitivity** refers to how a resource or system fares when exposed to an impact.
- ✓ **Adaptive Capacity** refers to a resource's or system's ability to adjust or cope with existing climate variability or future climate impacts.

While this formula has been successfully applied to natural systems, some aspects are less appropriate for application in the built environment (i.e., buildings, roads, etc.). For example, structures cannot inherently adapt to climate change or other hazards, while natural resources often can (a salt marsh can adapt to changes in sea level by migrating upland, whereas a building cannot). Therefore, the NPS and WCU have modified the methodology and formula for conducting vulnerability assessments of assets within national parks. The new modified formula for the vulnerability of the built environment (assets, infrastructure, buildings, transportation, etc.) is as follows:

Vulnerability = Exposure + Sensitivity

For this methodology, adaptive capacity of an asset is evaluated separately and is not included in the vulnerability score. This does not mean that understanding the adaptive capacity of an asset is not important. The range of adaptation strategies or options available for key vulnerable assets within a national park is the final and perhaps most important step in the overall analysis, as any adaptation actions taken for an asset will help reduce its exposure or sensitivity, which reduces vulnerability.

One goal of this protocol is to standardize methods for evaluating the exposure of NPS assets to coastal hazards and climate change. This includes the standardization of data inputs (i.e. widely available, established data) that will allow the application of a consistent methodology among units. Another goal is to create a more complete and effective set of indicators for assessing the sensitivity of assets to coastal hazards. The focus for this protocol is on structures and transportation assets in the NPS asset database (Facilities Management Software System; FMSS), but it could be adapted to other resources.

General Protocol Methodology

The **Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol** has four primary steps: 1) Exposure Analysis and Mapping, 2) Sensitivity Analysis, 3) Vulnerability Analysis, and 4) Adaptation Strategies Analysis. A detailed description of the protocol can be found in the final section of this document: "Vulnerability Assessment Methodology." Further scoring information can also be found in the Excel results sheets that accompany this report. Below is a general description of the first three steps of the protocol. Adaptation Strategies Analysis will be addressed in a separate report.

Exposure Analysis and Mapping: Standard exposure indicators have been established as part of this protocol (Table 1); these indicators represent the primary factors that should be evaluated to determine an asset's coastal hazard and climate change exposure up to the year 2050. The exposure analysis utilizes data imported into a Geographical Information System (GIS), as exposure is directly dependent on location relative to mapped hazard data. Assets located within an exposure indicator zone (e.g., the storm surge zone) are assigned a higher score than assets outside the zone. Scores for each indicator are then summed and binned to get a total exposure score. Final exposure scores fall into one of four ranking categories (based on the number of exposure zones): minimal exposure (does not lie within any mapped zone), low exposure (1 zone), moderate exposure (2-3 zones), and high exposure (4-5 zones).

Table 1. CANA specific hazards and data sources for the exposure indicators.

Exposure Indicator	CANA Specific Hazard	CANA Data Source
Flooding Potential	1% annual flood ± velocity/waves	FEMA Flood Zones (VE or AE, see page 16)
Extreme Event Flooding	Storm surge	NPS-specific SLOSH[1] model, Cat 3
Sea-Level Rise Inundation	2050 sea-level rise	NPS-specific SLR modeling
Shoreline Change	Erosion & coastal proximity	USGS erosion rate & shoreline proximity buffers
Reported Coastal Hazards	Historical flooding	Park questionnaire; storm imagery

[1]Sea, Lake, and Overland Surges from Hurricanes

Sensitivity Analysis: Sensitivity is a function of the inherent properties or characteristics of an asset. A set of primary indicators has also been determined for asset sensitivity: flood damage potential, storm resistance and condition of the asset, historical damage to the asset, and protective engineering. The main data source for much of the sensitivity analysis is an asset-specific questionnaire (completed by park staff), which contains detailed questions related to each of the sensitivity indicators. A higher score is given for an unfavorable sensitivity indicator result (e.g., an asset built at grade will get a high score for flood damage potential). The sensitivity scores for each indicator are summed to obtain a total raw score, then binned into three categories: low, moderate, and high sensitivity. Assets with minimal exposure are excluded from the sensitivity analysis, since an asset must be exposed to a hazard in order to be sensitive to it.

Vulnerability Analysis: To calculate a vulnerability score for each asset, the exposure and sensitivity scores are summed, and then binned into four vulnerability ranking categories. The vulnerability ranking categories are as follows: minimal (assets outside the mapped hazard zones), low, moderate, and high.

Unique Factors: Each park has a unique set of conditions based on the data available and the geologic setting. At CANA, the primary unique factors are: 1) incomplete FEMA data in the southern part of the park, 2) erosion rates all less than 1 meter per year, and 3) the segmentation of three park roads for analysis. A more detailed description of these factors, including how they affected the results for CANA, are presented later in the report, in the section titled: "Unique Factors & Considerations."

Results Summary & Discussion

A total of **66 structures** and **88 transportation assets** (roads, parking lots, vistas, boardwalks, waterfront systems, and primary trails) were included in the vulnerability assessment of CANA. The term "asset" will be used in this document to represent any structure or transportation infrastructure listed in FMSS, regardless of ownership. Also, the results for this vulnerability assessment represent a time frame of approximately 35 years, up to 2050. This document provides a general summary of the results for exposure, sensitivity, and vulnerability of structure and transportation assets at CANA. Specific scores for these factors are reported (alongside FMSS data) for each individual asset in the supplied Excel datasheets; final exposure and vulnerability results are also provided as GIS maps and layers.

Exposure Results:

Only one-quarter (25%) of all assets at CANA have high exposure to coastal hazards and sea-level rise, while roughly half (49%) have moderate exposure (Table 2). The majority of assets are moderate exposure (as opposed to high), primarily because they are outside of the sea-level rise zone and were reported as having no flooding history, yielding favorable scores for those indicators. Low exposure assets at CANA are all located solely within the storm surge hazard zone, thus yielding favorable scores for the other four exposure indicators.

Among the high exposure assets at CANA, there is a significant difference between structures and transportation assets. Only 8% of structures have high exposure, while over one-third of transportation assets have high exposure (38%). This difference is mainly due to the large number of beach access boardwalks (transportation), which are inherently situated near the ocean, and thus almost always within at least three of the five exposure zones (FEMA flooding, storm surge, and erosion). In fact, 22 of the 33 high exposure transportation assets are boardwalks.

Nine assets at CANA have minimal exposure (not within any of the exposure hazard zones). These assets are all in the Apollo district in the northern part of the park. Although most of the park land at CANA is on a barrier island, there are some areas of significant elevation on the island. For example, in the central portion of the Apollo district is high enough (> 15-20 feet in elevation) to be outside the storm surge zone, which is the most geographically widespread exposure zone at CANA (Figure 1).

Table 2. CANA Exposure Results Summary. Sum of percentages may not equal 100 due to rounding.

Assets	High Exposure		Moderate Exposure		Low Exposure		Minimal Exposure		Total #
	#	%	#	%	#	%	#	%	
Structures	5	8%	36	55%	20	30%	5	8%	66
Transportation	33	38%	40	45%	11	13%	4	5%	88
All CANA Assets	**38**	**25%**	**76**	**49%**	**31**	**20%**	**9**	**6%**	**154**

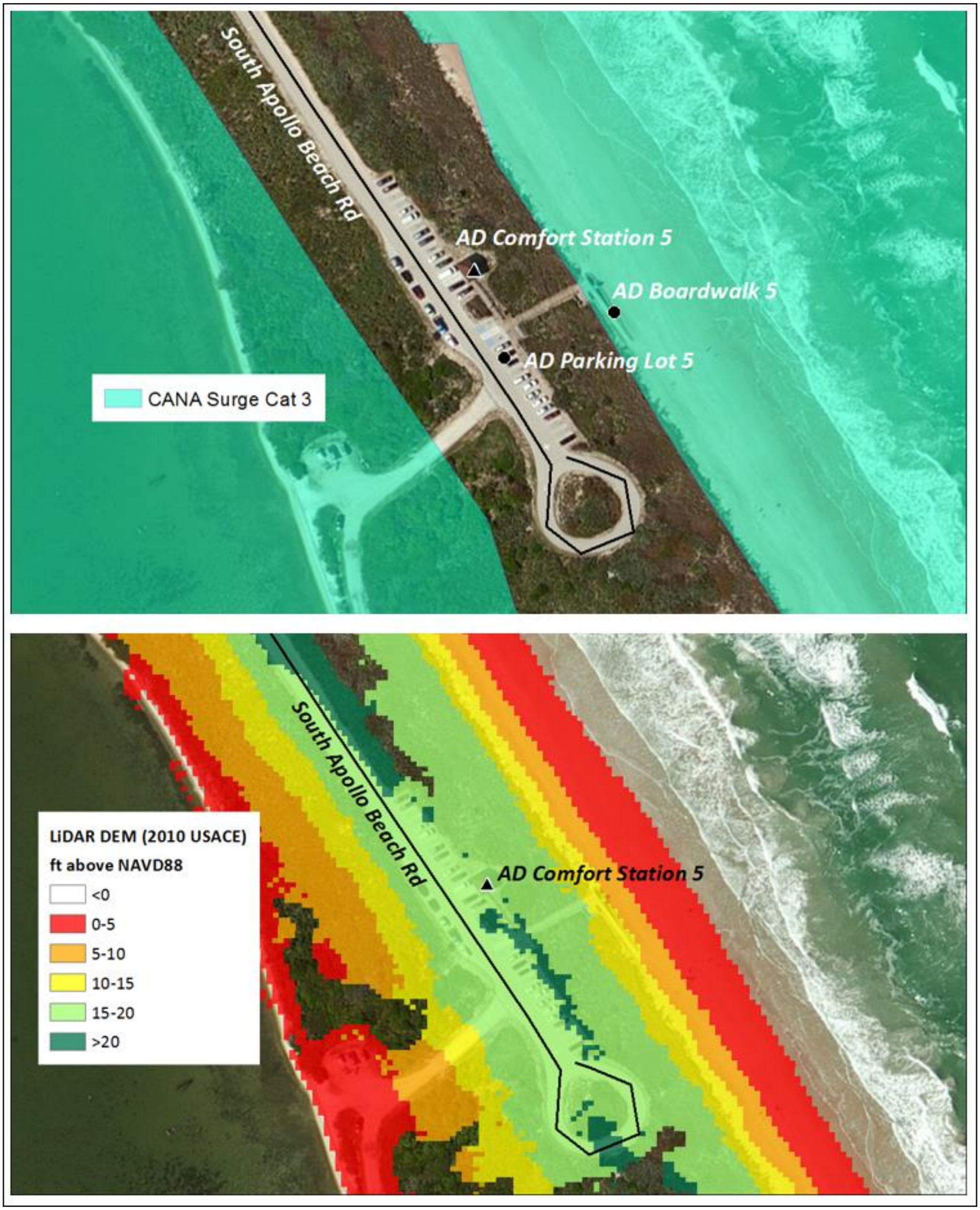


Figure 1. The north Apollo district of the park, zoomed to the southernmost beach access in this district, #5. Above: Storm surge (category 3) exposure hazard zone. Notice the Comfort Stations, Parking Lots, and South Apollo Beach Rd segment are all outside of the storm surge zone. Below: LiDAR DEM (Light Detection and Ranging Digital Elevation Model) results for this area of the park. Although the barrier island is only around 500 feet wide in this location, the elevations in the central portion of the island are between 15 and 20 feet (above the datum NAVD88).

Sensitivity Results:

The most notable result of the sensitivity analysis at CANA is the overall lack of variability in the scores. The vast majority (91%) of assets analyzed at CANA have moderate sensitivity (Table 3). Specifically, the moderate sensitivity assets have unfavorable scores for flood damage potential, storm resistance, and protective engineering, and favorable scores for condition and historical damage. In fact, all of the high sensitivity assets (9%) had higher sensitivity due to damage sustained from Hurricane Matthew in October of 2016.

One reason for the lack of variability in sensitivity is that CANA has multiple types of infrastructure with uniform design and construction, including boardwalks, parking lots, comfort stations, and road vistas. These similarities in construction led to similar results for the sensitivity indicators in this study. For example, one of the primarily goals of the park is to provide access to some of the only undeveloped barrier island beaches along the Florida coast. With this access comes the need for parking lots, boardwalks, and comfort stations for visitors. In fact, there are 18 public beach access areas in the park (5 in the Apollo district and 13 in the Playalinda district), each of which exhibit nearly identical infrastructure (Figure 2).

Table 3. CANA Sensitivity Results Summary. Sum of percentages may not equal 100 due to rounding.

Assets	High Sensitivity		Moderate Sensitivity		Low Sensitivity		Total # Analyzed	Excluded* (min. exposure)
	#	%	#	%	#	%		
Structures	3	5%	58	95%	0	0%	61	5
Transportation	10	12%	74	88%	0	0%	84	4
All CANA Assets	**13**	**9%**	**132**	**91%**	**0**	**0%**	**145**	9

*Assets with minimal exposure (in no hazard zone) were excluded from the sensitivity analysis. Total # analyzed is different for sensitivity compared to exposure and vulnerability.

Figure 2. Example of uniform infrastructure at three different beach access points at CANA. Top three images are beach access boardwalks and bottom three images are comfort stations.

Vulnerability Results:

Because the sensitivity results are mostly uniform among assets at CANA, the exposure scores most directly influence the vulnerability results (Tables 2 and 4). Overall, CANA has moderate vulnerability, which is somewhat unusual for a barrier island park, with 73% of assets having moderate, low, or minimal vulnerability.

The exposure-driven vulnerability is likely due to several geologic and climatic factors. First, the barrier islands at CANA have significant sand supply. This has allowed areas of significant elevation (> 20 feet) to build up, particularly along the vegetated coastal dune line (Figure 1). In addition, most of the CANA shoreline is accreting (Figure 3), in large part because CANA is located along an area of Florida coast that has experienced a relatively quiet hurricane history prior to Hurricane Matthew in 2016. These factors all contribute to a reduced coverage for some of the exposure hazard layers, including flooding and storm surge.

Table 4. CANA Vulnerability Results Summary. Sum of percentages may not equal 100 due to rounding.

Assets	High Vulnerability		Moderate Vulnerability		Low Vulnerability		Minimal Vulnerability		Total #
	#	%	#	%	#	%	#	%	
Structures	8	12%	33	50%	20	30%	5	8%	66
Transportation	33	38%	40	45%	11	13%	4	5%	88
All CANA Assets	**41**	**27%**	**73**	**47%**	**31**	**20%**	**9**	**6%**	**154**

The southern portion of the park (Playalinda district) has a higher percentage of assets with either moderate or high vulnerability (77%) compared to the northern portion (Apollo district; 68%). The Apollo district also contains all nine of the minimal vulnerability assets (those not in any exposure zone). Due to the widespread nature of the FEMA AE zone and the storm surge zone, all assets in the Seminole Rest district of the park have a moderate or high vulnerability. Figure 4 illustrates the vulnerability results for portions of CANA.

The high vulnerability assets at CANA have a combined CRV of approximately $4.1 million, which is about 10% of the total CRV of all assets analyzed. Most of the $4.1 million with high exposure are transportation assets, the most expensive being the waterfront systems at the Visitor Center, Eldora, and Fellers areas (CRVs from $300,000 - $500,000). Overall, the high vulnerability assets are low in value (CRV), as most of these assets have a small footprint, such as boardwalks, parking lots, and comfort stations (Figure 2). In fact, the average CRV of all high vulnerability structures and transportation assets is $98,269 and $100,858, respectively.

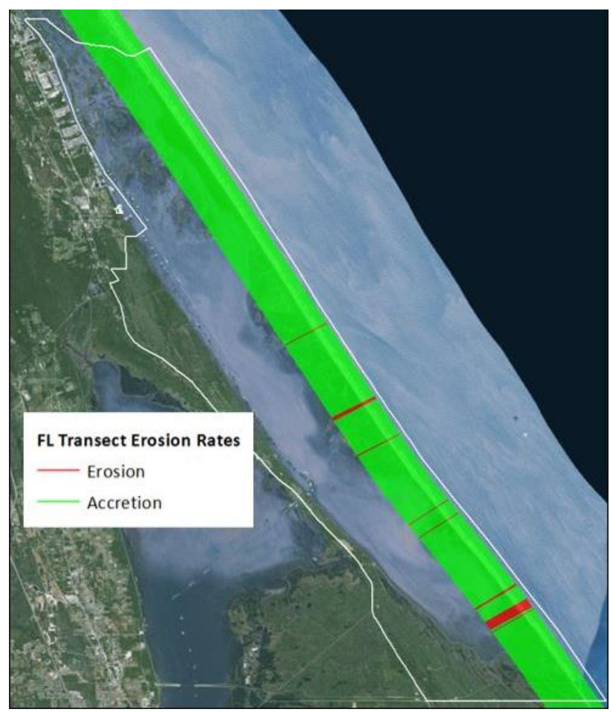
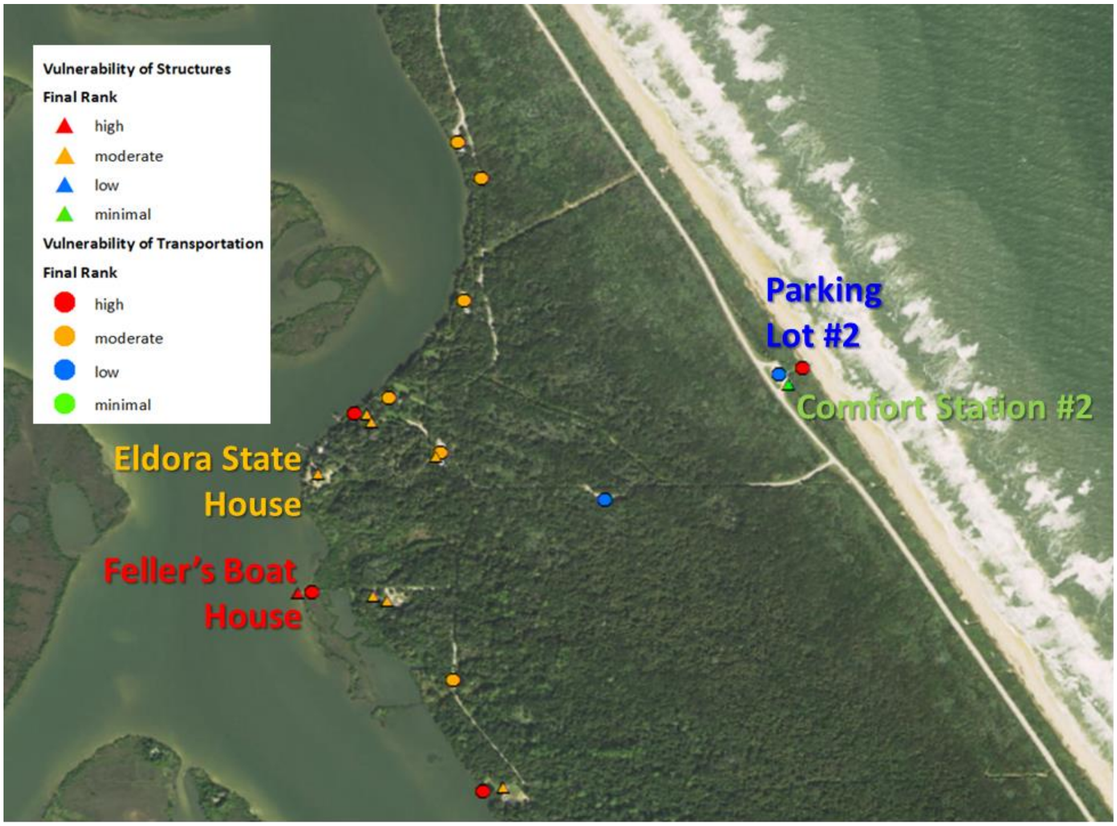


Figure 3. Erosion/accretion transects along the shoreline of CANA (boundary in white). Notice the shoreline is mostly accreting (green transects). Data from USGS (https://pubs.usgs.gov/of/2005/1326/gis-data.html).



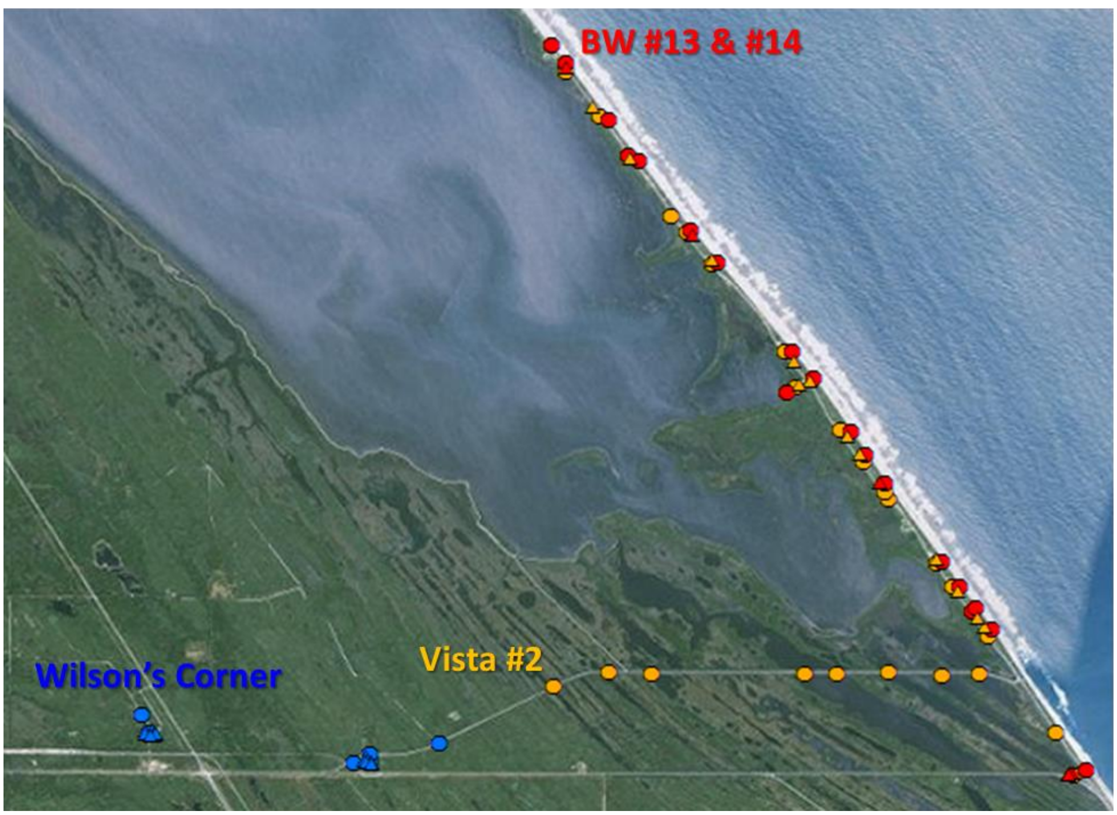


Figure 4. Example of the vulnerability results for CANA from the central Apollo district (above) and the Playalinda district (below).

Most of the transportation assets with high vulnerability are also of high priority to the park (API > 70). A large portion of these assets are boardwalks, and are significant to the park as they provide beach access, one of the primary missions of CANA. Many of these boardwalks were damaged during Hurricane Matthew (October, 2016). The park also has a few historic assets, many of which are within the Seminole Rest district of the park. This includes two structures, the Instone and Caretaker Houses, and one trail, the Seminole Rest Trail. All three of these historic assets have a moderate vulnerability to coastal hazards and climate change. However, the vulnerability of both the Instone and Caretaker houses may actually be lower than reported, as the storm surge model does not appear to incorporate the raised ground level directly beneath these assets. The ground surface beneath these structures is approximately 6-10 feet above the surrounding land elevation due to an underlying artificial shell mound (Figure 5). This extra elevation may be enough to prevent storm surge from reaching the threshold of these structures (which would reduce exposure and vulnerability). In fact, these structures were not flooded during Hurricane Matthew, while many surrounding areas experienced flooding.

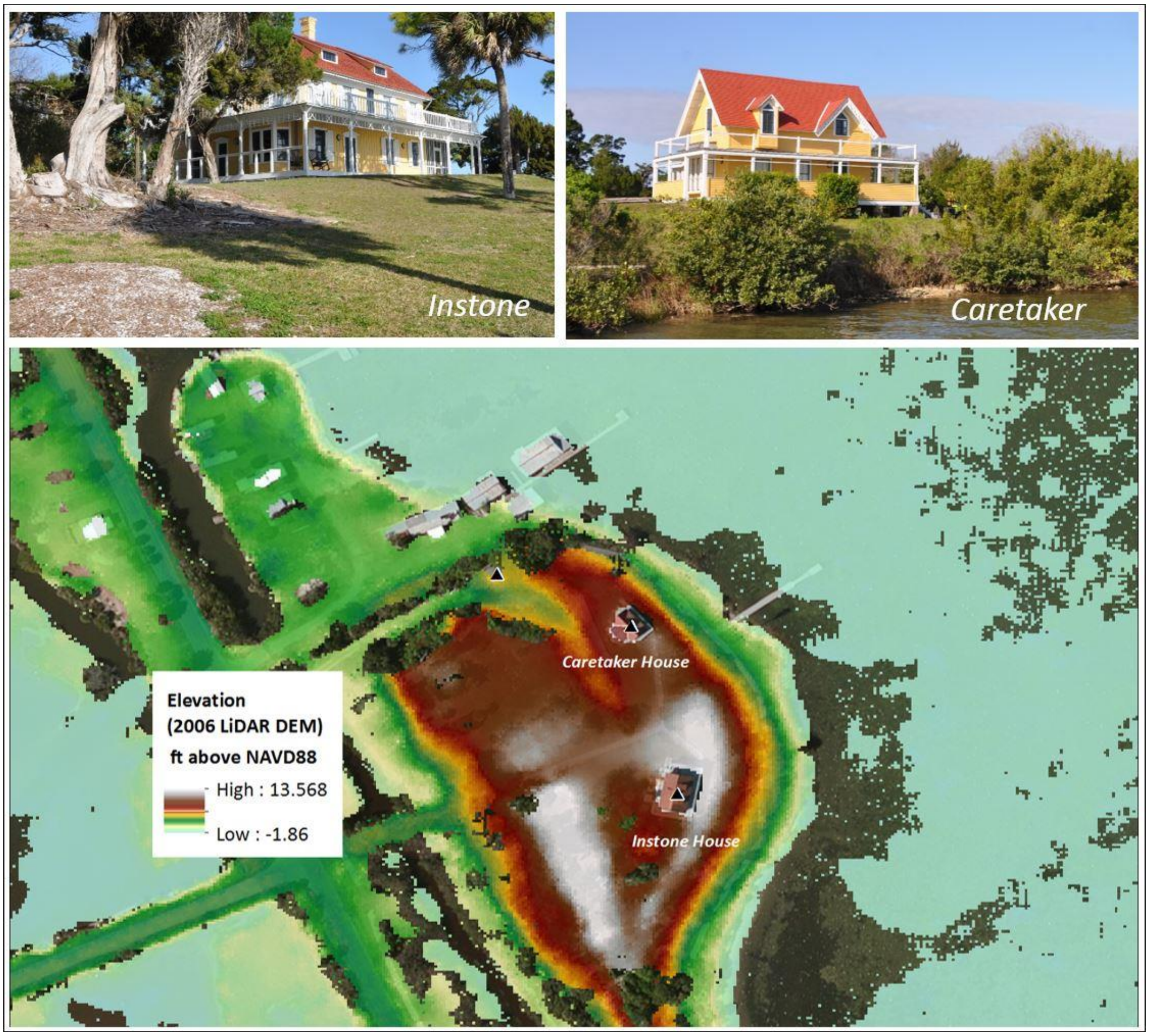


Figure 5. Historic structures within the Seminole Rest district of the park. Top: Photos of the Instone and Caretaker Houses. Bottom: LiDAR DEM for this area of the park. Notice the dark brown and white shading near the two historic houses, representing higher elevations (between 10 and 13 feet above NADV88). These structures were built upon an artificial shell mound.

Overall, almost half of all CANA assets have moderate vulnerability using this methodology (Table 3, Figure 3). However, there are several important caveats to the vulnerability assessment and results:

1) This methodology is meant to assess the vulnerability of a park to coastal hazards and climate change factors combined (i.e., erosion, flooding, storm surge, sea-level rise, and historical flooding; see indicator list in Vulnerability Assessment Methodology section). Therefore, an asset may have high vulnerability to one of these hazards but a low or moderate vulnerability to all five hazards.

2) A major goal of this methodology is to create a standard protocol for vulnerability assessments, regardless of the data utilized. As higher quality data become available for the metrics of vulnerability (exposure and sensitivity), the final rankings for these assets may change. In these cases, the same protocol will be used, incorporating the more precise data, and increasing the reliability of the vulnerability results.

3) Vehicle access to the barrier island areas of CANA depends on several transportation corridors that are not owned by NPS (e.g., South Atlantic Avenue north of the Apollo district). Some minimal, low, or moderate vulnerability assets could be safe from flooding (and sea-level rise), but rendered completely inaccessible by road. Other coastal parks have similar issues that relate to ownership or jurisdiction of the transportation leading to NPS-owned assets and resources, necessitating coordination (i.e., additional collaborative vulnerability studies) with regional stakeholders, landowners, and partners.

Unique Factors & Considerations

Erosion & Coastal Proximity:

Erosion rate data were acquired from the U.S. Geological Survey, Coastal and Marine Geology Program (http://coastal.er.usgs.gov/shoreline-change/). For CANA, all erosion rates fell within the 0 -1m/year binned category (see Figure 3).

FEMA Flooding Data:

The FEMA AE data layers were incomplete within the Playalinda district in the southern portion of the park. The AE zone artificially stops between Playalinda Beach Access Road (northern road, Figure 6) and Max Brewer Memorial Parkway (southern road, Figure 6). This creates a large gap in the data and the AE zone in this area of the park. To rectify this, the extent of the AE zone was interpreted across the data gap, in order to determine flooding exposure for the assets in the affected area. This was completed by observing the patterns in the data where it exists, and comparing to a LiDAR DEM (Light Detection and Ranging Digital Elevation Model) of the area.

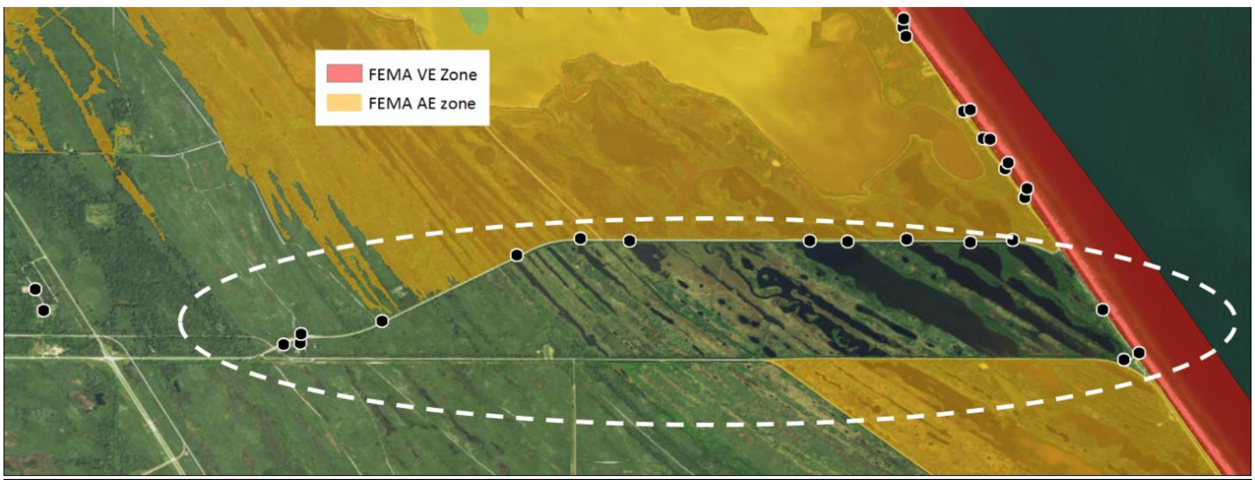


Figure 6. FEMA Zones in the Playalinda district of the park. Notice the large gap in data within the circled area (dotted white line).

Roads at CANA:

Due to the barrier island nature of the park, several of the roads at CANA are long and linear in nature. In order to acquire sensitivity data, roads were divided into smaller segments. These segments were based on several factors, primarily exposure level and connectivity/access to other park assets. Three roads were divided into segments; Apollo Beach Road, Playalinda Beach Road, and Playalinda Beach Access Road (Figure 7). Portions of some road segments are both inside and outside of an exposure zone (for example, only part of a road may intersect the FEMA VE zone). In these cases, a judgment call was made by determining whether a significant portion of the road (approximate percentage) is within the zone, or whether a critical portion is in the zone (e.g., major intersection or essential section).

Figure 7. CANA roads segmented within this assessment: Apollo Beach Road, Playalinda Beach Road, and Playalinda Beach Access Road. Colors indicate different segments of road.

Vulnerability Assessment Methodology

The **Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol** has four primary steps:

1) Exposure Analysis and Mapping
2) Sensitivity Analysis
3) Vulnerability Analysis
4) Adaptation Strategies Analysis

Step 1: Asset Exposure Analysis & Mapping

The first step in the protocol is to analyze the exposure of NPS assets to coastal hazards and climate change. Standard exposure indicators have been determined by WCU; these indicators represent the primary factors or hazards that should be evaluated to determine an asset's exposure (to the year 2050). The five general exposure indicators are: flooding potential, extreme event flooding, sea-level rise inundation, shoreline change, and reported coastal hazards. The goal of this methodology is to standardize the data sources for exposure analysis, using widely available and regularly updated sources (when possible). Table 5 summarizes these indicators, as well as common data sources for each.

Table 5. Exposure Indicators for Asset Coastal Hazards and Climate Change Vulnerability

Exposure Indicator	Common Data Sources
☑ **Flooding Potential** 1% annual flood chance ± velocity/waves	FEMA Flood Zones (VE or AE); LiDAR DEM or other elevation model
☑ **Extreme Event Flooding** storm surge, tsunami, extreme high water	NPS-specific SLOSH model; tsunami models; tide gage recorded extreme high water data
☑ **Sea-Level Rise Inundation** 2050 projection	NPS-specific SLR modeling; LiDAR DEM or elevation other model
☑ **Shoreline Change** erosion, coastal proximity, cliff retreat	State or USGS erosion rate buffers; cliff retreat rate buffers; shoreline proximity buffers
☑ **Reported Coastal Hazards** historic flooding, visible slope instability	Park surveys/questionnaire results; storm imagery & reconnaissance

The exposure analysis utilizes data imported into Geographical Information Systems (GIS) format, as exposure is directly dependent on location and mapped hazard data (whether the area experiences the hazard). Digital hazard data are gathered for each of the exposure indicators, such as the online georeferenced FEMA flood map layers. The only dataset that does not come from a widely available, well established source is the reported coastal hazards layer, which is derived from storm imagery, reconnaissance, and direct communication with park personnel. Each exposure data layer thus represents an exposure indicator hazard zone for a particular park. Assets that are located within a particular zone are assigned a higher score than assets located outside of the hazard zone.
The following sections describe the specific methods, scoring, and common data sources of each exposure indicator.

Flooding Potential:

The flooding potential indicator describes hazards related to the 1% annual flood chance, including waves and water velocity. For most parks, data for this exposure indicator comes from FEMA's digital flood maps (https://msc.fema.gov/portal/search). Two primary FEMA flood zones are utilized: the VE and AE zones (and sometimes the A, AO, or AH). According to FEMA, the VE zones are areas subject to inundation by the 1-percent-annual-chance flood event, with additional hazards due to storm-induced velocity wave action, and the AE zones are areas subject to inundation by the 1-percent-annual-chance flood event (determined by detailed methods). For a further description of the FEMA flood zones, including the other A zones, see FEMA's website: http://www.fema.gov/flood-zones.

If an asset is within the AE (or other A) zone, it receives an unfavorable score (4) for the flooding indicator. Any asset within the VE zone (the highest hazard zone) receives an unfavorable score for the flooding indicator, and is also assigned an automatic high score (4) for exposure overall. Assets in neither flood zone receive a favorable score (1) for this indicator. Within some parks the FEMA data is incomplete; in these cases, other elevation data sources (such as LiDAR DEMs) are used to supplement the FEMA data.

Extreme Event Flooding:
The extreme event flooding indicator captures flooding from major storms, tsunami, and other extreme high water events. **Storm surge** is the primary extreme event flooding that occurs within parks along the East and Gulf coasts of the U.S. The data source for storm surge is a NOAA surge inundation model: Sea, Lake, and Overland Surges from Hurricanes (SLOSH; more information: http://www.nhc.noaa.gov/surge/slosh.php). The SLOSH model uses a composite of several thousand model runs with differing storm conditions each time to predict surge. There are two products of this: the Maximum Envelope of Water (MEOW), which is a set of worst case scenarios for certain characteristics like storm category, speed, trajectory, and tide level; and the Maximum of the Maximum Envelope of Water (MOM), which is the worst of all potential scenarios modeled. The surge data included in the exposure analysis (the SLOSH MOM for a category 3 storm) represents the maximum potential surge conditions. SLOSH storm surge data for this protocol was supplied by the NPS Climate Change Response Program (CCRP).

For parks that are not subject to tropical storms and surge (primarily west coast parks), an alternative extreme event flooding hazard is evaluated, commonly either modeled **extreme high water** events or modeled **tsunami** hazard zones. Data for extreme high water events were provided by CCRP; these data map historic patterns of extreme high water events based on tide gage information. The source of the tsunami hazard data is variable, but commonly comes from state agencies or universities.

If an asset falls within the mapped category 3 storm surge zone, extreme high water zone, or the tsunami hazard zone, it receives an unfavorable score (4) for the extreme event flooding indicator. If it lies outside of these zones, it receives a favorable score (1) for this indicator.

Sea-Level Rise:
The sea-level rise indicator describes the potential rise in water within parks by the year 2050. The data source for this exposure indicator is a NPS-specific sea-level rise inundation model provided by the NPS CCRP. The estimated inundation extent was achieved by utilizing a modified bathtub approach as developed by NOAA, and attempts to account for local and regional tidal variability and hydrological connectivity. Polygon extents consist of 4 model-run scenarios using sea-level change maps produced by Colorado Center for Astrodynamics Research at the University of Colorado in Boulder. The maps are based on Representative Concentration Pathways (RCP), which are four greenhouse gas concentration trajectories. Two RCPs were modeled, a moderate RCP, 4.5, and the

most extreme RCP, 8.5. Each RCP was projected to the years 2050 (condition used for this protocol) and 2100. One caveat of these data is that the model does not incorporate local land level change (subsidence or uplift). For many parks this is not a problem, as this change is relatively small compared to the amount of predicted water level rise. However, the sea-level rise data in parks with high rates of subsidence (parks in southern Louisiana) or uplift (many Alaska parks) will require adjustment.

If an asset falls within the mapped 2050 SLR zone, it receives an unfavorable score (4) for the sea-level rise indicator. If it lies outside of the mapped sea-level rise zone, it receives a favorable score (1).

Shoreline Change:
For most parks, particularly those along the U.S. East and Gulf coasts, shoreline **erosion** buffers are created using known erosion rate data. These data are commonly acquired from the U.S. Geological Survey, Coastal and Marine Geology Program (http://coastal.er.usgs.gov/shoreline-change/) or from state coastal management programs. Short-term erosion rates (usually data ranging from the 1970s to 2004) are utilized to make buffer zones for a 35-year time frame. Rates are binned into the following categories before buffering: 1m/year, 2m/year, 4m/year, 6m/year, 8m/year, etc. (continuing increments of 2 meters).

Many national parks along the West Coast of the U.S. contain steep cliff shorelines. In some cases, these shorelines are retreating significantly due to cliff erosion; this is particularly true of areas comprised of unconsolidated materials (sands and gravels) or loosely consolidated bedrock (commonly sedimentary rock). In these cases, cliff retreat data will be utilized in place of erosion rate data (when available). Like erosion rates, the cliff retreat rates are utilized to make **cliff retreat** buffer zones for a 35-year time frame (2050). Below 1 meter, retreat rates are binned into detailed increments, with categories of: 0.25m/year, 0.5m/year, 0.75m/year, and 1m/year, and the same categories as shoreline erosion for rates above 1 meter: 1m/year, 2m/year, 4m/year, 6m/year, 8m/year, etc. (increments of 2 meters).

For shorelines without erosion or cliff retreat rate data (ocean, estuarine, or developed areas), a simple **coastal proximity** buffer is applied. The coastal proximity buffer distance used is 35 meters, which can accommodate an erosion rate up to 1m/year, and can account for the fact that infrastructure close to the shoreline is highly likely to experience a range of coastal hazards within the 35 year (to 2050) timeframe of this analysis.

If an asset falls within the erosion, cliff retreat, or coastal proximity buffer zone, it receives an unfavorable score (4) for this indicator. If an asset lies outside of these zones, it receives a favorable score (1).

Reported Coastal Hazards:
All of the other exposure indicators represent the *potential* area that could be affected by coastal hazards; the zones do not represent data from actual past events. Therefore, it is essential to have one indicator that includes actual reported coastal hazards. Understanding what has happened in the past in an area is essential to predicting what may happen in the future.

Historical flooding information for each park is commonly obtained from a questionnaire that is completed by park staff. Historical flooding information is also derived from storm imagery, reconnaissance visits, and direct communication with park personnel. For this indicator, the following question is posed to park personnel as part of the questionnaire:

> "Have any of the following assets (or lands around the asset) been FLOODED in previous storm events? * This question is referring to the lands or area around an asset. Even if the asset was not built during a particular storm, we would like to know if that location has been flooded in the past."

For high elevation parks with cliff retreat and no flooding hazards, a similar different question is asked for this indicator, and is related to **visible slope instability**. For cliff retreat, it is important to know if the landscape around an asset is currently showing signs that further retreat and erosion is imminent.

After scores are given for each exposure indicator (either 1 or 4), they are summed and binned to get a total exposure score for each asset. Final binned exposure scores fall into one of four ranking categories (based on the number of exposure zones): minimal exposure (asset does not lie within any mapped hazard zone), low exposure (1 zone only), moderate exposure (2-3 zones), and high exposure (4-5 zones). Specific scoring ranges can be found within the Excel results sheets. Any assets that obtain an exposure ranking of minimal are not further analyzed for sensitivity. Finally, all asset types (transportation and structures) are analyzed for exposure using the same general methodology.

Step 2: Asset Sensitivity Analysis

The second step in the protocol is to analyze the sensitivity of NPS assets to coastal hazards and climate change. Similar to exposure, a set of indicators was determined for asset sensitivity. Unlike exposure, however, sensitivity is evaluated independent of location (only exposure is location-dependent). Sensitivity refers to how an asset would fare when exposed to a hazard, which is a function of an asset's inherent properties or characteristics. While the sensitivity indicators for structures and transportation assets are generally the same (Table 6), how sensitivity is addressed during design and construction is very different.

Because digital sensitivity data are not generally available, the primary data source for much of the sensitivity analysis is an asset-specific questionnaire. This questionnaire contains detailed questions related to the various sensitivity indicators (e.g., is the structure elevated above base flood elevation). It is distributed to appropriate personnel within each unit— typically individuals that possess long institutional memory and familiarity with park facilities. Where appropriate, sensitivity data is also obtained from FMSS, the National Bridge Inventory, aerial imagery, and site visits.

Bridges are considered transportation assets, but have additional factors that must be considered when analyzing sensitivity to coastal hazards and climate change. Table 6 summarizes the four general sensitivity indicators (for all assets), as well as the four additional bridge indicators. The following section describes each sensitivity indicator in detail, including data sources, methodology, and scoring.

Table 6. Sensitivity Indicators for Asset Coastal Hazards and Climate Change Vulnerability

Sensitivity Indicator	Data Sources
☑ Flood Damage Potential (Elevated)	Asset questionnaire; direct measurements of threshold elevation
☑ Storm Resistance & Condition	Asset questionnaire; FMSS database
☑ Historical Damage	Asset questionnaire; discussion with park staff
☑ Protective Engineering	Asset questionnaire; field & aerial imagery analysis; WCU Engineering Inventory
Additional Bridge Indicators	
☑ Bridge Clearance	National Bridge Inventory (item 39)
☑ Scour Rating	National Bridge Inventory (item 113)
☑ Bridge Condition	National Bridge Inventory (item 59 & 60)
☑ Bridge Age	National Bridge Inventory (item 27); FMSS database

Flood Damage Potential:

The flood damage potential indicator represents how likely an asset is to be inundated if the surrounding land area is flooded. For structures, this usually means whether or not the building is constructed on elevated stilts or pilings. Alternatively, fill may be added to the surrounding land to artificially elevate the asset above local ground height. This information is commonly obtained through the park questionnaire or visual inspection during site visits. For this indicator, the following question is posed to park personnel as part of the questionnaire:

"Are any of the following assets elevated at least 5 feet above local ground level (including critical utilities)? Examples include: 1) assets on stilts or pilings, or 2) assets built on artificial fill material above local ground level. NOTE: If elevated, but not quite 5 feet, indicate in comments."

When available, threshold elevation data collected by the NPS Resource Information Services Division (RISD) are included in the sensitivity analysis. These data, which have been collected at only a handful of parks thus far, are acquired with sub-centimeter Global Positioning System (GPS) equipment in order to record accurate threshold and asset elevations. In parks that do not have these data, the questionnaire (in combination with field work) is the primary data source used to determine whether an asset is elevated. The questionnaire generally inquires whether an asset is elevated above ground level – in the case of structures, at least 5 feet. Ideally, elevation of an asset would be compared to FEMA's Base Flood Elevation (BFE), and the precise threshold elevations acquired by RISD make this comparison possible. This can aid in the determination of highly reliable elevation indicators for structures within parks. It should be noted however, that elevation is one of several indicators used to calculate the sensitivity of an asset, and availability of precise elevation data, while preferable, is not critical in gauging overall sensitivity and vulnerability.

The precise threshold elevation verifies the first metric (flood damage potential) within the sensitivity analysis. This elevation is compared to local BFE for each asset to determine if the asset's primary threshold was above or below BFE. If an asset is elevated above BFE, it will receive a favorable score for the flood damage potential sensitivity metric (only if it is within a FEMA flood zone).

If an asset is reported to be elevated on stilts, built on elevated fill, or has a threshold above FEMA BFE, it receives a favorable score (1) for the flooding potential indicator. If it is not elevated (built at grade), it receives an unfavorable score (4) for the indicator.

Storm Resistance & Condition:
This sensitivity indicator represents how well an asset will resist damage from coastal hazards based on two factors: 1) overall storm resistance and 2) condition. Assets built to storm-resistant standards, with quality construction, or in good condition are less likely to be damaged by coastal hazards. For this indicator, the following two questions are posed to park personnel:

"Are any of the following assets built to resist flood/wave storm damage? Examples include: 1) assets built to specific storm-resistant standards/engineering codes, or 2) assets particularly or inherently resistant to other forms of damage or deterioration (e.g., fortifications)."

"Are any of the assets listed below particularly vulnerable to flood/wave damage due to their condition? In other words, is the asset in poor condition due to deterioration, lack of maintenance, etc.? DO NOT consider the location of the asset (even if it is near the water or commonly flooded), only consider the physical condition of the asset itself. The condition should be considered independent of the asset's location."

This sensitivity indicator is scored as a combination of storm resistance and condition. If an asset is reported to be storm resistant, it receives a favorable score (1) for half of the total score for this indicator (and vice versa). If the asset is reported to be in poor condition, it receives an unfavorable score (4) for half of the total score for this indicator (and vice versa).

Historical Damage:
The historical damage indicator represents if an asset has been damaged by coastal hazards in the past, as assets that have been previously damaged are more likely be damaged in the future. This is similar to the reported coastal hazards exposure indicator, but instead of focusing on the site or area around an asset, this indicator is focused on damage to the asset itself. For this indicator, the following question is posed to park personnel as part of the questionnaire:

Have any of the following assets been significantly DAMAGED in previous storm/flooding events (water/wave damage only)? * This question is focused on the actual damage from an event (the prior flooding question is about the LAND near the asset being inundated; this one is about the asset itself)

If an asset is reported to have been damaged in the past, it receives an unfavorable score (4) for this indicator. If it has not been damaged in the past it receives a favorable score (1) for the indicator.

Protective Engineering:
This indicator represents if an asset is protected by engineering including hard structures (e.g., seawalls, bulkheads) or landscape modifications (e.g., significant drainage alteration, major restored landscape). This indicator assumes that assets protected with engineering are less likely to be damaged by coastal hazards. Data sources include the questionnaire, the NPS coastal engineering inventory (http://www.nature.nps.gov/geology/coastal/monitoring.cfm), and site visits. The following question is posed to park personnel as part of the questionnaire:

Are any of the following assets currently being protected by an engineered structure (e.g., seawall, bulkhead) or other major engineering (e.g. drainage, major landscape modification, major restored landscape)? Explain if needed.

If an asset is reported to be protected by engineering, it receives a favorable score (1) for this indicator; if the asset is not protected by engineering, it receives an unfavorable score (4) for the indicator.

Bridge Indicators: Clearance, Scour Rating, Condition, and Age:
For bridges within the National Bridge Inventory (NBI) database (public bridges over 20 feet in length), additional indicators are considered; the data for these indicators comes directly from the NBI database. The bridge sensitivity additional indicators include: clearance, scour rating, condition, and age. Table 10 below lists each indicator, including the description, rationale, and scoring.

Table 7. Additional Bridge Indicators

Indicator	Description & Rationale	Scoring (NBI score = sensitivity score)
Clearance	Bridges with higher clearance above the water surface are less likely to be damaged by coastal hazards.	*Amount of clearance in feet*: > 15 = 1; 9-15 = 2; 1-8 = 3; 0= 4
Scour Rating	Bridges with scour issues are more likely to be damaged by coastal hazards.	*Rating*: n/a = 1; low & stable (5-8) = 2; stable (4) = 3; critical = 4
Condition	Bridges in poor condition are more likely to be damaged by coastal hazards.	*Condition Rating*: n/a = 1; 0-3 = 2; 4-6 = 3, 7-9 = 4
Age	Bridges closer to their lifespan are more likely to be damaged by coastal hazards.	*Age (in years):* 0-25 = 1; 26-50 = 2; 51-75 = 3; > 75 = 4

To calculate a sensitivity score, each asset is first given a score for all applicable indicators. These scores are summed to obtain a total raw score for sensitivity, then binned into three categories reflective of the number of unfavorable indicators: low sensitivity, moderate sensitivity, and high sensitivity. Specific scoring ranges can be found within the Excel results sheets.

Step 3: Asset Vulnerability Analysis
To obtain a vulnerability score for each asset, the exposure and sensitivity scores are summed, and then binned into four vulnerability ranking categories. The ranking categories are as follows: minimal vulnerability (assets with minimal exposure and not included in the sensitivity analysis), low vulnerability, moderate vulnerability, and high vulnerability. Specific scoring ranges for vulnerability can be found within the Excel results sheets. A subset of the assets from the completed vulnerability analysis will be chosen by the park for development of adaptation strategies (step 4).

Step 4: Adaptation Strategies Analysis
After the vulnerability analysis is complete, adaptation strategies will be analyzed for key assets within each park. FMSS data such as Asset Priority Index (API) and Optimizer Band (OB) can help select the assets to analyze for adaptation strategies. Assets analyzed will likely include those with high vulnerability and high priority and/or high criticality (API/OB), as well as high vulnerability assets with low priority and/or criticality. This adaptation analysis begins with discussions with the park, or by way of a questionnaire. This portion of the analysis focuses on the options available to the park to reduce the overall vulnerability of key assets. An outline of potential adaptation strategies to reduce coastal hazards and climate change vulnerability has been compiled by WCU for both structures and transportation assets (Table 8).

Table 8. Adaptation Strategies to Reduce Vulnerability of Assets to Coastal Hazards and Climate Change

Adaptation Action	Effect on Vulnerability and Rationale
☑ **Elevate**	Reduces the **sensitivity** of the asset; elevating a structure (and critical utilities) or transportation asset (i.e., a road) reduces the risk of flood damage.
☑ **Relocate**	Reduces the **exposure** of the asset; relocating the asset to a lower risk area reduces the likelihood that it will experience impacts from coastal hazards/SLR.
☑ **Protect/Engineer**	Reduces the **exposure** and/or **sensitivity** of the asset; protecting the asset with an engineered structure or landscape modifications (i.e., drainage) can reduce the likelihood that the asset will experience, or obtain damage from, coastal hazards/SLR.
☑ **Decommission & Remove**	Eliminates the vulnerable asset.
☑ **Storm-Resistant Redesign**	Reduces the **sensitivity** of the asset; redesigning the asset to be more storm resistant can reduce the likelihood of damage from coastal hazards/SLR.
☑ **Engineering Downgrade** (transportation assets only)	Reduces the **sensitivity** of the asset; downgrading the amount of engineering (i.e., replacing paved parking lot with shell material lot) can reduce the cost of rebuilding after damage and gives more flexibility for replacement.

This protocol is designed solely to assess the vulnerability of physical infrastructure. However, there are other adaptation actions for vulnerable assets that would not reduce the vulnerability of the physical asset, but instead its function. For example, a park might consider moving the critical contents within a building to a higher floor to reduce potential flood damage. Similarly, parks may decide to shift an asset's function to a less vulnerable asset. These adaptation actions do not change the vulnerability of the original asset (i.e., exposure and sensitivity remain the same); instead these actions change the criticality of the asset, potentially making it less of a concern to the park.

Additional NPS Climate Change Resources

Additional efforts are being made by NPS to address climate change in the coastal zone, as well as other critical environments. A number of these studies aim to improve the understanding of overall trends in climate change stressors, while others have focused on recording the specific effects of those stressors on natural and cultural resources within parks. Using this research and the latest climate science, the NPS is guiding adaptation efforts at units nationwide. Below are some of the climate change related resources at NPS:

- General Climate Change at NPS: http://www.nps.gov/subjects/climatechange/index.htm
- Climate Change Adaptation for Cultural Resources: http://www.nps.gov/subjects/climatechange/adaptationforculturalresources.htm
- Coastal Adaptation: http://www.nps.gov/subjects/climatechange/coastaladaptation.htm
- NPS Climate Change Adaptation Plan: http://www.nps.gov/orgs/ccrp/upload/NPS_CCActionPlan.pdf