

National Park Service
U.S. Department of the Interior



Park Facility Management Division - Environmental Management Branch
Park Facility Management Division - Facilities Planning Branch

Fire Island National Seashore

Coastal Hazards & Sea-Level Rise Asset Vulnerability Assessment

April 2018



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





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Cover Photo: FIIS Lighthouse (Photo credit: Program for the Study of Developed Shorelines at Western Carolina University).

This Page: Beach at FIIS (Photo credit: Program for the Study of Developed Shorelines at Western Carolina University).

NPS 615/154058, April 2018

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Please cite this report as: Tormey, B; K. Peek; H. Thompson; R. Young; S. Norton; J. McNamee; R. Scavo. April 2018. Fire Island National Seashore Coastal Hazards & Sea-Level Rise Asset Vulnerability Assessment. NPS 615/154058. National Park Service, Washington DC.

Executive Summary

The National Park Service (NPS) and Western Carolina University's (WCU) Program for the Study of Developed Shorelines (PSDS), have developed a **Coastal Hazards and Sea-Level Rise Asset Vulnerability Assessment Protocol**. This protocol assesses the vulnerability of infrastructure to multiple coastal hazards and climate change factors over a 35-year planning horizon (to the year 2050). The overall goal is to standardize the methodologies and data used, allowing managers to compare the vulnerability of coastal assets across local, regional, and national levels. This protocol is also designed to accommodate regional differences in coastal hazards (e.g., storm surge vs. tsunami), geomorphology, evolving data sets, and scientific understanding of hazards.

Unlike natural resource vulnerability, which combines three metrics (exposure, sensitivity, and adaptive capacity), the protocol assesses infrastructure using exposure and sensitivity to coastal hazards and sea-level rise to derive a vulnerability score, with adaptation strategies discussed qualitatively in the context of that score.

A total of 98 structures and 88 transportation assets were included in the vulnerability assessment of Fire Island National Seashore. The majority of FIIS assets have either high (62%) or moderate vulnerability (21%) to coastal hazards and sea-level rise. A higher percentage of transportation assets are highly vulnerable compared to structures (83% compared to 43%). There are 19 assets at FIIS with minimal vulnerability (assets are in no exposure zone), all of which are in the William Floyd area of the park.

The high vulnerability assets at FIIS have a combined current replacement value (from the NPS facilities database) of approximately \$84.1 million, which is about 50% of the total value of all assets analyzed. When separated into structures and transportation, the statistics are quite different; high vulnerability assets account for 79% of the total value for transportation assets and only 24% of the total value for structures. Seven of the ten most valuable structures have high vulnerability to coastal hazards and sea-level rise, and two have moderate vulnerability, including the most valuable asset, the Fire Island Lighthouse (valued over \$50 million). Seven of the ten most valuable transportation assets are high vulnerability, including the Watch Hill and Sailors Haven Marinas.

No FIIS structures have both high vulnerability to coastal hazards and sea-level rise and high priority (asset priority index within the NPS facilities database) to the park. The highest priority structure with high vulnerability is the Light Station Check Station. Three structures, the Fire Island Lighthouse, Keepers Quarters, and Connector Building, have moderate vulnerability and high priority to the park. Four transportation assets have high priority and high vulnerability at FIIS, including two roads in the Seabay Beach area, and the Watch Hill and Sailors Haven bulkheads.

Vulnerability Assessment Products & Deliverables

1. **Excel datasheets**: All results are provided in tables, including asset-specific scoring. The exposure, sensitivity, and vulnerability scores are reported alongside the Facilities Management Software Systems (FMSS) data for each asset, as well intermediate scores in the analysis.
2. **Geographic Information Systems (GIS) Maps and Layers**: WCU will provide all GIS data, including the exposure layers, exposure results, and final vulnerability results to the park as a separate file. The GIS data will also be available to view online at the NPS ArcGIS Online website. Digital data sources can be found in the next section of this document. Contact WCU or NPS for further information.
3. **Park Specific Vulnerability Results Summary Document**: This summary document (herein) explains the deliverables, results, and methodology. It briefly summarizes the vulnerability assessment results in the aforementioned datasheets and maps, as well as the methodology, which has been vetted and approved by NPS. This document does not fully describe **all** results from the analysis; see provided datasheets for detailed results.

Digital Data Sources

1. **FEMA Flood Zones**: FEMA flood maps were obtained from the [FEMA's National Flood Hazard Layer \(Official\)](#) on ArcGIS.com. 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).
2. **Sea-Level Rise – Climate Change Response Program (CCRP)**: Sea-level rise data for the year 2050 were provided by the NPS CCRP. A full publication related to this product is in press (not accessible yet) and metadata is available. WCU utilized the 2050 sea-level rise inundation model (IPCC 8.5 Representative Concentration Pathway).
3. **Storm Surge (SLOSH) – Climate Change Response Program (CCRP)** – Storm surge data were provided by NPS CCRP; full publication related to this product is in press (not accessible yet); metadata is available. These data were provided to WCU as a geodatabase by CCRP, and WCU utilized the C3M_km3, which represents a category 3 mean tide surge model. The shapefile was further edited by WCU to only show area of inundation.
4. **Erosion/Coastal Proximity** - Erosion rate data were acquired from [USGS Coastal Change Hazards Portal](#). Where available, rates were utilized to make buffer zones for a 35-year time frame (2050). Rates were binned into the following categories before buffering: 1m/year, 2m/year, 4m/year, 6m/year, 8m/year, etc. (increments of 2 meters). For shorelines without erosion rate data (ocean or estuarine) a simple coastal proximity buffer was applied. The erosion rate buffers and the proximity buffers combined comprise this exposure indicator zone for FIIS. Digitized shoreline using ESRI streaming layer at scale of 1:2500.

Introduction & Project Description

The National Park Service (NPS) and Western Carolina University's (WCU) Program for the Study of Developed Shorelines (PSDS), have developed a **Coastal Hazards and Sea-Level Rise 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. 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. The term "asset" is used in this document to represent any structure, totem/memorial, or transportation infrastructure listed in FMSS, regardless of ownership.

A standardized approach to assessing climate change vulnerability was proposed in a multiple agency 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 methodology 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 sea-level rise by migrating upland, whereas a building cannot). Therefore, NPS and WCU have modified the methodology and formula for conducting vulnerability assessments of infrastructure within national parks. The modified formula for the vulnerability of the built environment (buildings, transportation assets, etc.) is:

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. Identifying the range of effective adaptations for key vulnerable assets is the final and most important step in the overall analysis. Effective adaptations will reduce exposure and/or sensitivity, which is the key to reducing vulnerability.

General Protocol Methodology

The **Coastal Hazards and Sea-Level Rise Asset Vulnerability Assessment Protocol** has four primary steps: 1) Exposure Analysis and Mapping, 2) Sensitivity Analysis, 3) Vulnerability Calculation, 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.

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 sea-level rise exposure (to the year 2050). The exposure analysis uses 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 hazard zone (e.g., tsunami hazard zone) are assigned a higher score than assets located 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 (asset does not lie within any mapped zone), low exposure (1 zone), moderate exposure (2-3 zones), and high exposure (4-5 zones).

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

Exposure Indicator	FIIS Specific Hazard	FIIS Data Source
Flooding Potential	1% annual flood ± velocity/waves	FEMA Flood Zones (VE or AE)
Extreme Event Flooding	Storm Surge	NPS-specific SLOSH* modeling
Sea-Level Rise Inundation	2050 sea-level rise	NPS-specific SLR modeling
Shoreline Change	Erosion & coastal proximity	USGS erosion rates & proximity buffers
Reported Coastal Hazards	Historical flooding	Park questionnaire; storm reports; park visit

*SLOSH - Sea, Lake, and Overland Surges from Hurricanes

Sensitivity Analysis: Sensitivity is a function of the inherent properties or characteristics of an asset. Primary indicators have also been determined for asset sensitivity: flood damage potential, storm resistance, physical condition, historical damage, 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. Because an asset must be exposed to a hazard in order to be sensitive to it, assets with minimal exposure are excluded from the sensitivity analysis.

Vulnerability Calculation: To calculate a vulnerability score for each asset, the exposure and sensitivity scores are summed, and then assigned to four vulnerability ranking categories. The vulnerability ranking categories are as follows: minimal (assets with minimal exposure), low, moderate, and high.

Unique Factors & Considerations

Each park has a unique set of considerations based on the geologic setting and the data available. At FIIS, there were two primary considerations: 1) the geomorphologic challenges of assessing vulnerability of a barrier island park and 2) the exposure analysis methodology utilized for park roads.

Geomorphologic Challenges

FIIS has a unique set of geomorphic challenges for conducting a vulnerability assessment. Most FIIS assets are located on dynamic barrier island shorelines (e.g., Light Station, Sailors Haven, Talisman/Barrett Beach, Watch Hill, Wilderness areas). Both the sea-level rise and storm surge models utilize data that represent a snapshot in time for shoreline position and elevation within the park. In some locations, the raw data sources may be several years old, and can quickly become outdated as the barrier island migrates and changes. This is especially true if the area experiences a major erosion or storm event, as these events can completely reconfigure a barrier island's shoreline and topography.

Exposure Analysis of Roads

Most of the roads in the barrier island portion of FIIS are sand roads, including the primary road across the island (Burma Road) and numerous side roads and beach access roads. In the exposure analysis, portions of some road segments were not entirely within a particular exposure zone (e.g., figure 1). In these cases, a judgment call was made using the approximate percentage of the road within the zone and the location of the hazard (e.g., if the hazard is only present at the terminus of the road, or intersects in the middle of the road).

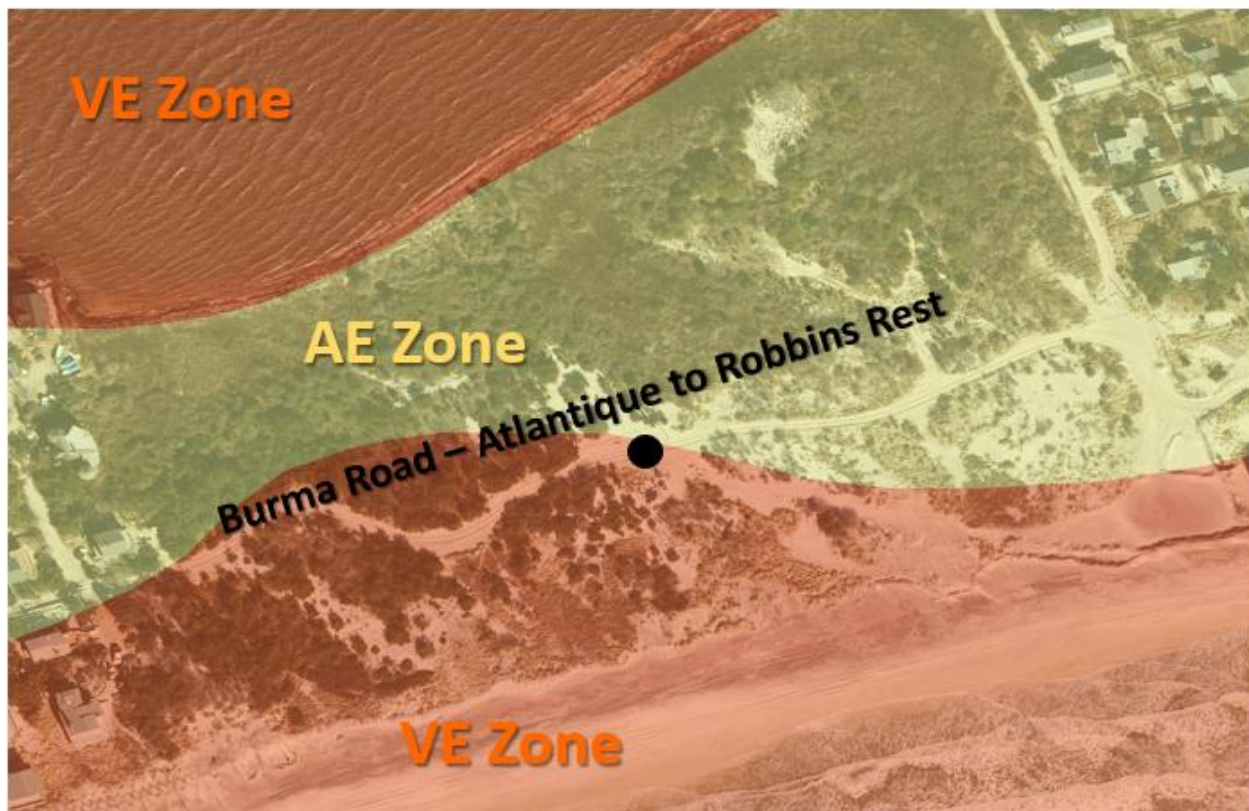


Figure 1. Example of a FIIS road partially within both the FEMA VE and AE zones. This asset was scored as within the VE because a significant and critical portion of the road is within that zone.

Results Summary & Discussion

A total of **98 structures** (buildings – houses, sheds, quarters, sun shelters, gazebos, comfort stations, and barns) and **88 transportation assets** (paved and sand roads, beach accesses/dune cuts, parking lots, boardwalks, trails, channels, marinas, docks, and bulkheads) were included in the vulnerability assessment of FIIS. Also, the results for this vulnerability assessment represent a time frame of approximately 35 years (to the year 2050). 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

A notable result of the exposure analysis of FIIS is that over 80% of all assets (both structures and transportation) have either moderate or high exposure to coastal hazards and sea-level rise, and only 7% of assets have low exposure (Table 2, Figure 2). The overall high exposure for FIIS is because most assets are situated on a low-lying barrier island, and are often close to the ocean. This places many assets within the storm surge and FEMA flood zones, and has caused many assets to be flooded in the past. A higher percentage of transportation assets have high exposure compared to structures (51% and 28%, respectively). The majority of these transportation assets are sand roads, boardwalks, and marina-related assets on the barrier island portion of the park.

Nineteen assets (10%) have minimal exposure using this protocol, which means the asset did not fall within **any** of the mapped exposure hazard zones (flooding, storm surge, erosion/coastal proximity, sea-level rise, and historical flooding - see Vulnerability Assessment Methodology section of this document). Exposure is directly dependent on location; thus, if an asset is located beyond the influence of a particular coastal hazard, its exposure is diminished. All assets with minimal exposure are in the William Floyd Estate area of the park, which is located further inland on the mainland (Figure 2).

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

ASSETS	HIGH EXPOSURE		MODERATE EXPOSURE		LOW EXPOSURE		MINIMAL EXPOSURE		TOTAL #
	#	%	#	%	#	%	#	%	
STRUCTURES	27	28%	47	48%	8	8%	16	16%	98
TRANSPORTATION	45	51%	35	40%	5	6%	3	3%	88
ALL ASSETS	72	39%	82	44%	13	7%	19	10%	186

Among structures, the highest exposure assets are the Garbage Buildings at Sailors Haven and Watch Hill. This is largely due to their close proximity to the estuarine shoreline, which placed them in all five exposure hazard zones (FEMA, erosion, sea-level rise, storm surge, and historic flooding). An additional 20 assets have high exposure at FIIS, including the Park Headquarters and the Visitors Centers at Sailors Haven, Watch Hill, and the Wilderness Area.

Forty-five transportation-related assets have high exposure to coastal hazards and sea-level rise. Almost half (20) of these assets are within all five exposure hazard zones (FEMA, erosion, sea-level rise, storm surge, and historic flooding). This includes the bulkheads at all locations, and Barrett Beach Marina, Sailors Haven Ferry Docks, and Light Station Docks.

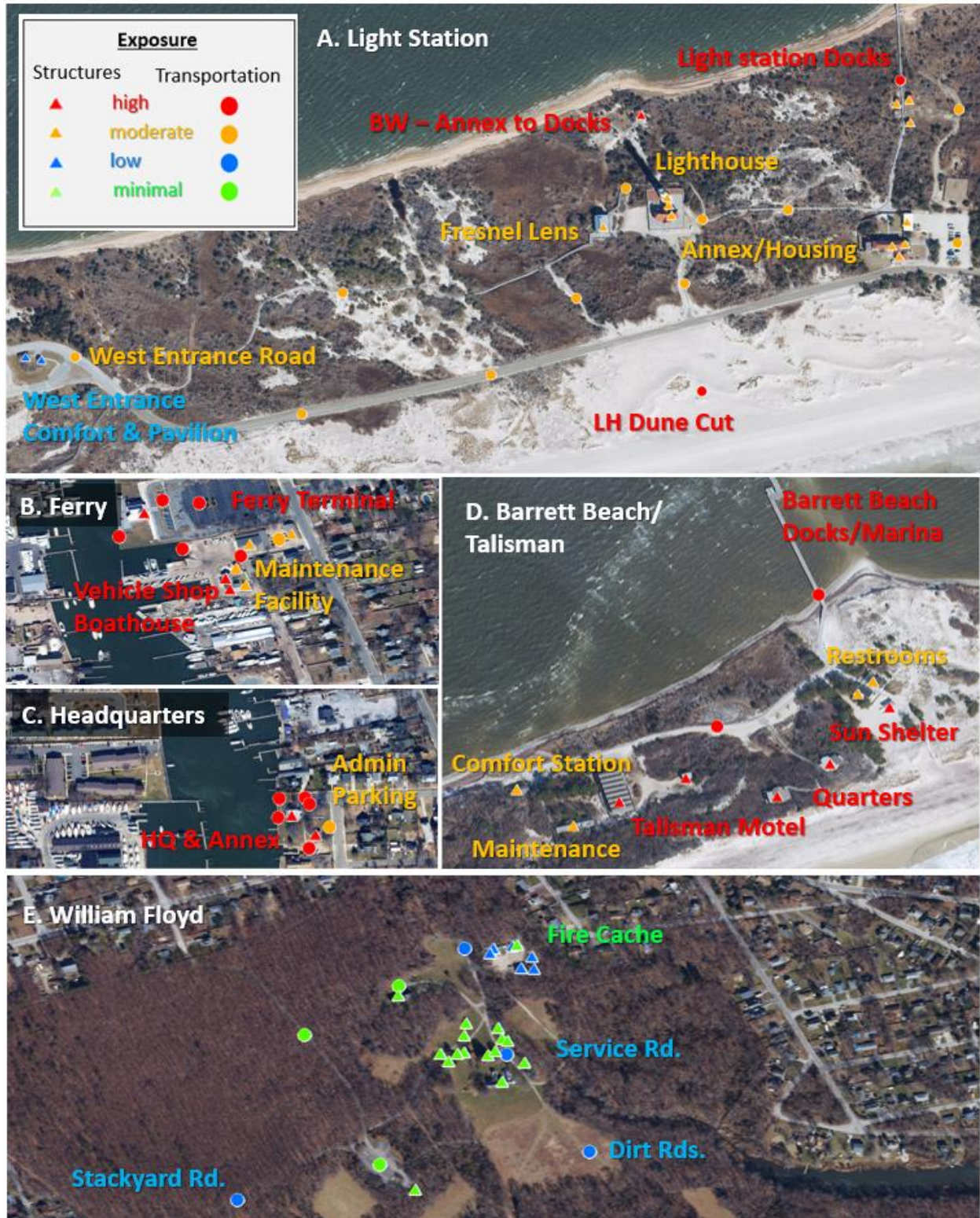


Figure 2. Mapped exposure results for select FIIS areas: A) Light Station, B) Ferry Terminal, C) Headquarters, D) Barrett Beach/Talisman, and E) William Floyd. Only select assets are labeled, see Excel sheets for the full results. Background is aerial imagery from [ESRI streaming layer](#).

Sensitivity Results

The sensitivity results for all FIIS assets (structures and transportation) show most have either high or moderate sensitivity to coastal hazards and sea-level rise (Table 3). In fact, only 5% of the assets analyzed have low sensitivity. When separated into structures and transportation, the scores are slightly different. Most structures have moderate sensitivity (66%), while the transportation assets are primarily high sensitivity (67%). The high sensitivity scores for transportation assets are primarily due to the fact that most roads are not elevated, were reported as damaged historically, and are not protected by engineering.

Table 3. FIIS 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	22	27%	54	66%	6	7%	82	16
TRANSPORTATION	57	67%	25	29%	3	4%	85	3
ALL ASSETS	79	47%	79	47%	9	5%	167	19

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

Threshold Elevation Data Collection

Threshold elevation data collected by the NPS Resource Information Services Division (RISD) were also included in the sensitivity analysis. Ideally, the elevation of all assets would be compared to the Federal Emergency Management Agency’s (FEMA) Base Flood Elevation (BFE), and the precise threshold elevations acquired by RISD make this comparison possible. This aided in the determination of more reliable sensitivity indicators for assets at FIIS.

The precise threshold elevation verifies the first indicator (flood damage potential) of the sensitivity analysis. This elevation was compared to local BFE for each asset to determine if the asset’s primary threshold was above or below BFE. In general, if an asset is above BFE and also elevated by design, it received a favorable score for the flood damage potential sensitivity metric. More specific methodology for verifying and using these data can be found in the Vulnerability Assessment Methodology section of this document.

Threshold elevation data was used to verify the flood damage potential sensitivity metric for 70 of the 98 structures analyzed at FIIS (data was not used for transportation assets). Fifteen (21%) of the structures analyzed have threshold elevations above local BFE. This comparative analysis led to revised scores for the elevation metric (as compared to the original questionnaire) for 11 structures. This included six structures in the Watch Hill area that were originally reported as elevated, which were **changed to not elevated** (Talisman Motel, Dune Station Visitor Station, Restaurant, Quarters #8, Electrical Panel Building, and the First Aid Room), and five structures originally reported as not elevated that were **changed to elevated** (Lighthouse, Single Story Connector Building, Keepers Quarters and Boat House in the Lightstation area, and the Sailors Haven Visitor Center). Figure 3 illustrates two examples of the threshold elevation verification.



Figure 3. Two FII structures that had revised scores for the flood damage potential (elevated) sensitivity indicator based on the precise threshold elevation data (collected by NPS-RISD) and BFE values. A) Sailors Haven Visitor Center was originally reported as not elevated within the questionnaire, but the threshold elevation data showed that the first floor was, in fact, **above** BFE. Therefore, this structure was modified to receive a favorable score for the flood damage potential sensitivity indicator. B) Talisman Motel was originally reported as elevated within the questionnaire, but the threshold elevation data showed that the first floor was, in fact, **below** BFE. Therefore, this structure was modified to receive an unfavorable score for the flood damage potential sensitivity indicator. Threshold elevation and BFE values are relative to the North American Vertical Datum of 1988 (NAVD88).

Vulnerability Results

The majority of FII assets have either high (62%) or moderate (21%) vulnerability to coastal hazards and sea-level rise (Table 4, Figures 4 and 5). A higher percentage of transportation assets are highly vulnerable compared to structures (83% compared to 43%). There are 19 assets at FII with minimal vulnerability (not in any exposure zone), all of which are in the William Floyd area (Figure 5C).

The high vulnerability assets at FII have a combined current replacement value (CRV within FMSS) of approximately \$84.1 million, which is about 50% of the total CRV of all assets analyzed. When separated into structures and transportation, the statistics are quite different; high vulnerability assets account for 79% of the total CRV for transportation assets and only 24% of the total CRV for structures. Seven of the ten most valuable structures have high vulnerability to coastal hazards and sea-level rise (including Patchogue Ferry Terminal and the Wilderness Visitor Center), and two have moderate vulnerability, including the most valuable asset, the Fire Island Lighthouse (CRV over \$50 million). Seven of the ten most valuable transportation assets are high vulnerability, including the Watch Hill and Sailors Haven Marinas.

No FII structures have both high vulnerability to coastal hazards and sea-level rise and high priority to the park. The term high priority within this report refers to any asset with an asset priority index (API) greater than 70 in FMSS. The highest priority structure with high vulnerability is the Light Station Check Station (API = 61). Three structures, the Fire Island Lighthouse, Keepers Quarters, and Connector Building, have moderate vulnerability and high priority to the park. Four transportation assets have high priority and high vulnerability at FII, including two roads in the Seabay Beach area, and the Watch Hill and Sailors Haven bulkheads.

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

ASSETS	HIGH VULNERABILITY		MODERATE VULNERABILITY		LOW VULNERABILITY		MINIMAL VULNERABILITY		TOTAL #
	#	%	#	%	#	%	#	%	
STRUCTURES	42	43%	31	32%	9	9%	16	16%	98
TRANSPORTATION	73	83%	8	9%	4	5%	3	3%	88
ALL ASSETS	115	62%	39	21%	13	7%	19	10%	186

More than three-quarters of all FIIS assets have moderate or high vulnerability using this methodology (Table 4, Figures 4 and 5). 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 (e.g. flooding, storm surge, erosion) and sea-level rise combined. Therefore, a park or section of park that has maximum exposure to one or more of these factors (i.e., the surge and FEMA VE/AE zones along the barrier island portion of FIIS) will inherently have a higher overall exposure, and thus, vulnerability. At the same time, some of the assets were given a low vulnerability to the analyzed coastal hazards and sea-level rise. This does not mean that these assets will not be affected by one, or more, of these hazards before the year 2050 (the time frame of this study), but instead, that the asset is not within the mapped hazard layers utilized (Table 1). **It is important to note that any coastal asset, especially on a barrier island, could be completely destroyed by a hurricane within any given year.**
- 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. The same protocol will be used to increase the reliability of the vulnerability results.
- 3) Access to much of FIIS depends on several transportation corridors that are not owned by NPS (e.g., Robert Moses Causeway and William Floyd Parkway). Some 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.

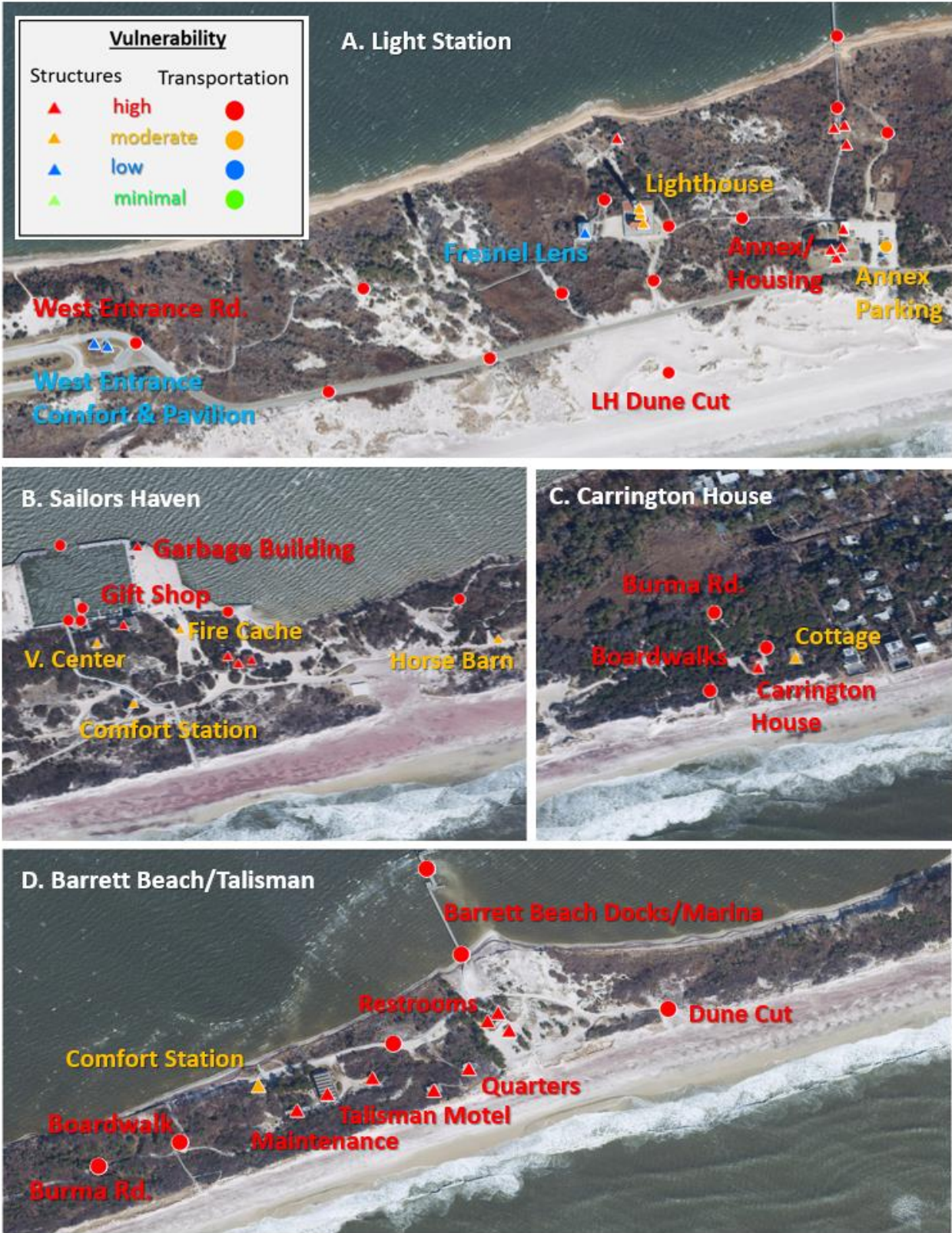


Figure 4. Mapped vulnerability results for select FIIS areas: A) Light Station, B) Sailors Haven, C) Carrington House, and D) Barrett Beach/Talisman. Only select assets are labeled, see Excel sheets for the full results. Background is aerial imagery from [ESRI streaming layer](#).



Figure 5. Mapped vulnerability results for select FIIS areas: A) Watch Hill, B) Wilderness, C) William Floyd, D) Ferry Terminal, E) and Headquarters. Only select assets are labeled, see Excel sheets for the full results. Background is aerial imagery from [ESRI streaming layer](#).

Vulnerability Assessment Methodology

The **Coastal Hazards and Sea-Level Rise Asset Vulnerability Assessment Protocol** has four primary steps:

- 1) Exposure Analysis & Mapping
- 2) Sensitivity Analysis
- 3) Vulnerability Calculation
- 4) Adaptation Strategies Analysis

Step 1: Exposure Analysis & Mapping

The first step in the protocol is to analyze the exposure of NPS assets to coastal hazards and sea-level rise. 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 Sea-Level Rise Vulnerability Protocol

Exposure Indicator	Common Data Sources
<input checked="" type="checkbox"/> Flooding Potential 1% annual flood chance ± velocity/waves	FEMA Flood Zones (VE or AE); LiDAR DEM or other elevation model
<input checked="" type="checkbox"/> Extreme Event Flooding storm surge, tsunami, extreme high water	NPS-specific SLOSH model; tsunami models; tide gage recorded extreme high water data
<input checked="" type="checkbox"/> Sea-Level Rise Inundation 2050 projection	NPS-specific SLR modeling; LiDAR DEM or elevation other model
<input checked="" type="checkbox"/> Shoreline Change erosion, coastal proximity, cliff retreat	State or USGS erosion rate buffers; cliff retreat rate buffers; shoreline proximity buffers
<input checked="" type="checkbox"/> 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](#). 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](#).

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 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, tsunamis, and other extreme high water events. **Storm surge** is the primary extreme event flooding that occurs within parks along the east and gulf coast of the U.S. The data source for storm surge is a NOAA surge inundation model: Sea, Lake, and Overland Surges from Hurricanes (SLOSH; see [NOAA](#) for more information).

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 Astrodynamic 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 SLR 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](#) 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 (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 it 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 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: Sensitivity Analysis

The second step in the protocol is to analyze the sensitivity of NPS assets to coastal hazards and sea-level rise. 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 that asset would fare when exposed to the hazard, which is a function of the inherent properties or characteristics of the asset. 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 sea-level rise. 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 Sea-Level Rise Vulnerability Protocol

Sensitivity Indicator	Data Sources
<input checked="" type="checkbox"/> Flood Damage Potential (Elevated)	Asset questionnaire; direct measurements of threshold elevation
<input checked="" type="checkbox"/> Storm Resistance & Condition	Asset questionnaire; FMSS database
<input checked="" type="checkbox"/> Historical Damage	Asset questionnaire; discussion with park staff
<input checked="" type="checkbox"/> Protective Engineering	Asset questionnaire; field & aerial imagery analysis; WCU Engineering Inventory
Additional Bridge Indicators	
<input checked="" type="checkbox"/> Bridge Clearance	National Bridge Inventory (item 39)
<input checked="" type="checkbox"/> Scour Rating	National Bridge Inventory (item 113)
<input checked="" type="checkbox"/> Bridge Condition	National Bridge Inventory (item 59 & 60)
<input checked="" type="checkbox"/> 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 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 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 to 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)

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](#), 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 7 below describes 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.	<i>Amount of clearance in feet:</i> > 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.	<i>Rating:</i> 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.	<i>Condition Rating:</i> 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.	<i>Age (in years):</i> 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: Vulnerability Calculation

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 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 sea-level rise 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 Sea-Level Rise

Adaptation Action	Effect on Vulnerability and Rationale
<input checked="" type="checkbox"/> 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.
<input checked="" type="checkbox"/> 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.
<input checked="" type="checkbox"/> 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.
<input checked="" type="checkbox"/> Decommission & Remove	Eliminates the vulnerable asset.
<input checked="" type="checkbox"/> 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.
<input checked="" type="checkbox"/> 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