National Mall and Memorial Parks

Coastal Hazards & Climate Change Asset Vulnerability Assessment
April 2017

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

Contents

Cover Photo Credit: Photo taken at NAMA by the Program for the Study of Developed Shorelines at Western Carolina University.

The National Park Service (NPS) Sustainable Operations and Climate Change Branch (SOCC) of the Park Facility Management Division (PFMD), 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., erosion, flooding, storm surge, sea-level rise, and historical flooding), 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 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 72 structures (buildings, shelters, and sheds) and 143 transportation assets (roads, parking lots, grounds/landscapes, kiosks, waterfront systems, and primary trails/walkways) are included in the vulnerability assessment of National Mall and Memorial Parks (NAMA).

The notable result of the **exposure** analysis at NAMA is that almost half (48%) of the assets have moderate exposure to coastal hazards and sea-level rise, and almost one-quarter (23%) have high exposure. Approximately 20% of all assets have minimal exposure, meaning the asset did not fall within *any* of the mapped exposure hazard zones. The majority of high exposure assets at NAMA are transportation assets, most of which are located in the Hains Point area of the park. The **sensitivity** results for all NAMA assets show the vast majority of assets (84%) have moderate sensitivity. The majority (94%) of transportation assets have moderate sensitivity, while structures are more distributed between high (33%), moderate (57%), and low sensitivity (10%).

Over one-quarter (27%) of all assets at NAMA have high **vulnerability** to coastal hazards and sea-level rise; 42% have moderate vulnerability, 11% have low vulnerability, and 20% are minimal vulnerability (not in any exposure hazard zone). Approximately the same percentage of structures and transportation assets are highly vulnerable (25% and 28%). A major portion of the high vulnerability assets are located in the Hains Point area of the park, as well as along the Tidal Basin and Potomac River waterfront. The high vulnerability scores for structures are primarily controlled by high sensitivity, whereas the high vulnerability scores for transportation assets are primarily controlled by high exposure.

The high vulnerability assets at NAMA have a combined Current Replacement Value (within the NPS Facilities Management Software System database) of approximately $388 million, which is about 16% of the total value of all assets analyzed. Only one structure and nine transportation assets (one parking lot, two roads, four bridges, and two seawalls) are both high vulnerability and high priority (Asset Priority Index within the NPS database > 70) to the park.

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.

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. Digital data sources can be found in the "Digital Data Sources" section of the document. Contact WCU or NPS for further information.

3) Park Specific Vulnerability Results Summary Document - This document, which explains the deliverables, results, and methodology.

Digital Data Sources

1. FEMA Flood Zones - FEMA's National Flood Hazard Layer (Official) on ArcGIS.com. http://fema.maps.arcgis.com/home/item.html?id=cbe088e7c8704464aa0fc34eb99e7f30. All areas of the park are covered by the official National Flood Hazard Layer.

2. Sea Level Rise – Climate Change Response Program (CCRP) - Data provided by NPS CCRP; full publication related to product in press (not accessible yet); metadata is available. Provided to WCU as geodatabase by CCRP. Utilized the NCAP_slr_85_2050 layer, which represents the 2050 sea-level rise inundation model (high scenario).

3. Surge (SLOSH) – Climate Change Response Program (CCRP) – Surge data from SLOSH (Sea, Lake, and Overland Surges from Hurricanes; http://www.nhc.noaa.gov/surge/slosh.php) provided by NPS CCRP; full publication related to product in press (not accessible yet); metadata is available. Provided to WCU as geodatabase by CCRP. Utilized the C3M_km3, which represents the category 3 mean tide surge model. Was further edited by WCU to show just area of inundation. All areas of the park are covered by the SLOSH model.

4. Erosion/Coastal Proximity - Simple shoreline buffer of 35 meters. Digitized shoreline using ESRI streaming layer at scale of 1:2500. http://server.arcgisonline.com/ArcGIS/rest/services/World_Imagery/MapServer

The National Park Service (NPS) Sustainable Operations and Climate Change Branch (SOCC) of the Park Facility Management Division (PFMD), 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, 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.

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.

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 (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 hazard zone (e.g., the storm surge 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. NAMA specific hazards and data sources for the exposure indicators.

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

[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, 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. 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 with minimal exposure), low, moderate, and high.

Unique Factors: Each park has a unique set of conditions based on the data available and the geologic setting. At NAMA, the primary unique factors affecting the analysis include: 1) the lack of erosion rate data, resulting in the use of a simple coastal proximity buffer, and 2) the highly engineered shorelines and urbanized setting, which often are not accounted for in flood maps and models.

A total of **72 structures** (buildings, shelters, and sheds) and **143 transportation assets** (roads, parking lots, grounds/landscapes, kiosks, waterfront systems, and primary trails/walkways) are included in the vulnerability assessment of National Mall and Memorial Parks (NAMA). 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 NAMA. 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 to the park as GIS maps and layers.

Exposure Analysis:
The notable result of the exposure analysis at NAMA is that almost half (48%) of the assets have moderate exposure to coastal hazards and sea-level rise, and almost one-quarter (23%) have high exposure (Table 2). In addition, one-fifth (20%) of all assets have minimal exposure. Minimal exposure within this protocol means that 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).

Roughly one-third (31%) of transportation assets at NAMA have high exposure (Table 2), most of which are located along the Hains Point, Tidal Basin, and Potomac shorelines. In contrast, only five structures (7%) have high exposure, including: NAMA Headquarters, NAMA HQ Annex, GSI Snack Bar/Paddle Boat Kiosk, NAMA HQ/Annex Two, and the Paddle Boat Rental Kiosk. The majority of structures (54%) and transportation assets (45%) have moderate exposure (Table 2), primarily because most are located outside the erosion/coastal proximity zone and the sea-level rise zone. Over one-third of the assets (both structures and transportation assets) were reported to have been historically flooded.

Table 2. NAMA 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	7%	39	54%	5	7%	23	32%	72
TRANSPORTATION	44	31%	64	45%	16	11%	19	13%	143
ALL NAMA ASSETS	49	23%	103	48%	21	10%	42	20%	215

Sensitivity Analysis:

The sensitivity results for NAMA assets (structures and transportation) show the vast majority of assets (84%) have moderate sensitivity and 9% have high sensitivity (Table 3). When divided into structures and transportation, the sensitivity scores for NAMA assets are slightly different. The vast majority (94%) of transportation assets have moderate sensitivity, while structures are more evenly split between high (33%), moderate (57%), and low sensitivity (10%). One-fifth (20%) of all assets were excluded from sensitivity analysis due to minimal exposure (assets located outside the mapped exposure hazard zones cannot be considered sensitive to that hazard; see Exposure Analysis section).

Table 3. NAMA 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	16	33%	28	57%	5	10%	49	23
TRANSPORTATION	0	0%	117	94%	7	6%	124	19
ALL NAMA ASSETS	16	9%	145	84%	12	7%	173	42

*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.

With the exception of a few assets, most structures that were analyzed for sensitivity at NAMA (i.e., those without minimal exposure) were not elevated five feet above local ground level and not built to storm-resistant standards. One-quarter of the assets have been reportedly damaged in the past by coastal storms and flooding. Most of the structures with high sensitivity were reported to be not elevated, not built to storm-resistant standards, in poor condition, and previously damaged. All transportation assets analyzed have low or moderate sensitivity. Most transportation assets have moderate sensitivity as a result of not being elevated or storm resistant.

Vulnerability Analysis:

Over one-quarter (27%) of all assets at NAMA have high vulnerability to coastal hazards and sea-level rise, while 42% have moderate vulnerability, 11% have low vulnerability, and 20% have minimal vulnerability (Table 4). Approximately the same percentage of structures and transportation assets are highly vulnerable (25% and 28%).

Almost one-half (47%) of transportation assets have moderate vulnerability, while 12% have low vulnerability, and 13% have minimal vulnerability (were not within any of the mapped exposure hazard zones). Among structures, one-third (33%) are moderate vulnerability, 10% are low, and roughly one-third (32%) are minimal (outside all exposure zones).

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

ASSETS	HIGH VULNERABILITY		MODERATE VULNERABILITY		LOW VULNERABILITY		MINIMAL VULNERABILITY		TOTAL #
	#	%	#	%	#	%	#	%	
STRUCTURES	18	25%	24	33%	7	10%	23	32%	72
TRANSPORTATION	40	28%	67	47%	17	12%	19	13%	143
ALL NAMA ASSETS	58	27%	91	42%	24	11%	42	20%	215

The majority of the high vulnerability assets at NAMA are located in the Hains Point area of the park, as well as along the Tidal Basin and Potomac River waterfront (Figure 1). The high vulnerability scores for structures are primarily controlled by high sensitivity, whereas the high vulnerability scores for transportation assets are primarily controlled by high exposure.

The high vulnerability assets at NAMA have a combined Current Replacement Value (CRV; within FMSS) of approximately $388 million, which is about 16% of the total CRV of the assets analyzed. Most of this value is comprised of transportation assets ($379 of the $388 million), as only 1% of the CRV for structures is highly vulnerable. Three of the ten most valuable structures at NAMA are moderate vulnerability, and none are high. Of the top ten most valuable transportation assets, three have high vulnerability (all are seawalls), and five have moderate vulnerability.

Only one structure has both high vulnerability and high priority to the park (Asset Priority Index in FMSS > 70), the Mini Gold Concession Building at Hains Point. Nine transportation assets are high vulnerability and high priority to the park, including three roads (Rock Creek and Potomac Parkway, Potomac Parkway, and Ohio Drive), four bridges (Kutz, Inlet, Outlet, and Watergate Plaza), and two seawalls (West Potomac Park Tidal Basin and East Potomac Park).

Overall, more than one-quarter (27%) of all NAMA assets have high vulnerability using this methodology (Table 4, Figure 1). 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, parks may be highly exposed and vulnerable to one or more of these factors, but overall have a low or moderate vulnerability.

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.
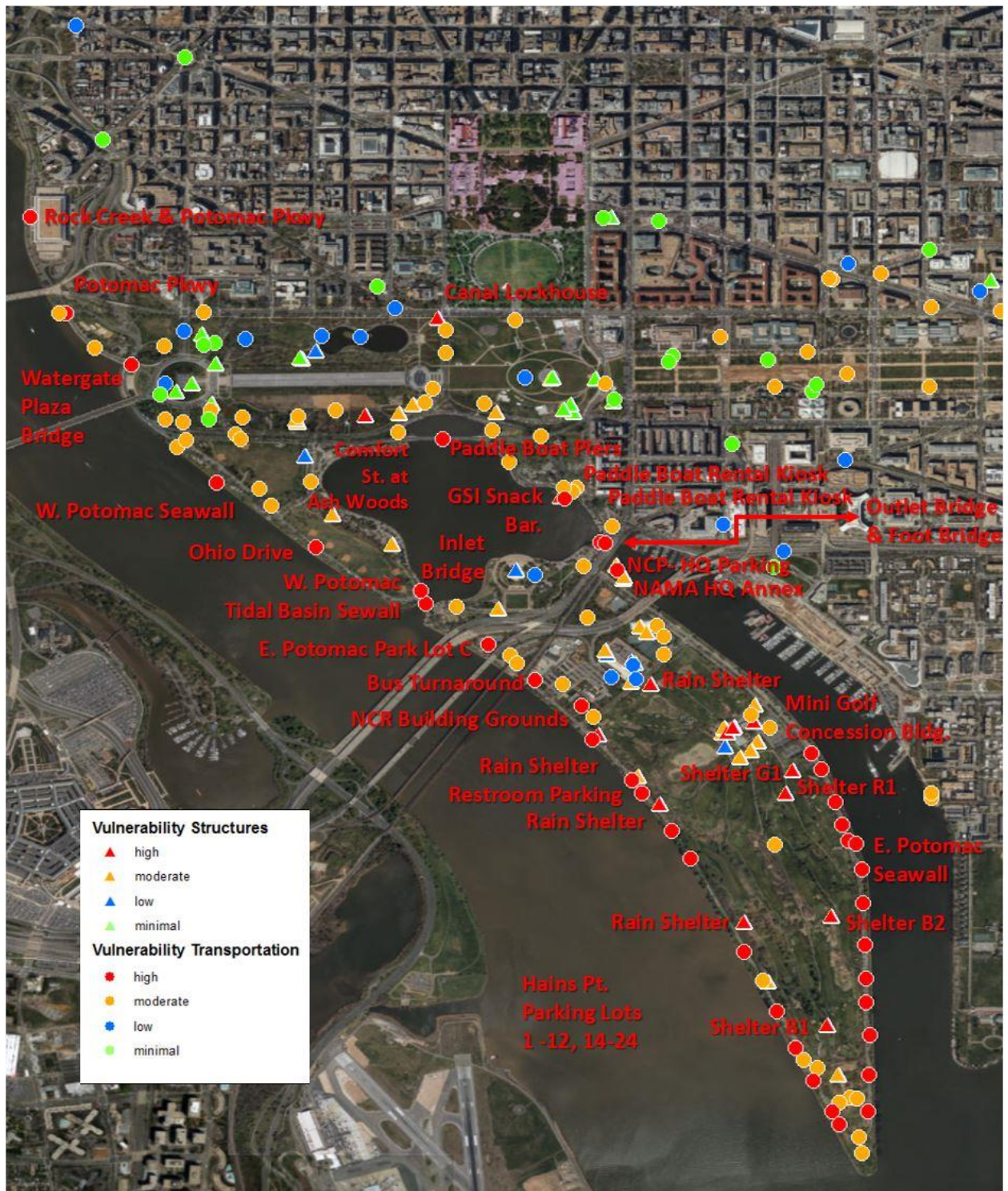
Figure 1. Mapped vulnerability results for a portion of NAMA. Only high vulnerability assets are labeled (and not all individually). Background image is aerial imagery from the ESRI streaming layer (see Digital Data Sources).

Erosion & Coastal Proximity:
For shorelines without erosion rate data (ocean, estuarine, or developed areas), a simple **coastal proximity buffer** is applied. The coastal proximity buffer distance applied 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, including erosion, within the 35 year (2050) timeframe for this analysis. Proximity buffers were used for the shorelines of NAMA, as the shoreline is within an urban area and most portions are engineered (i.e., a seawall/bulkhead). Shoreline digitizing was done using the ESRI streaming world imagery layer at a scale of 1:2500.

Sea-Level Rise Data:
The NPS-specific sea-level rise layer used for the exposure analysis in this study is an inundation model that projects sea-level rise in the park to the year 2050. 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. The extent of sea-level change polygons is derived from 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 and 2100. For NAMA, the 2050 8.5 RCP was utilized for the sea-level rise hazard zone. The CCRP model results show 0.28 meters (11 inches) of sea-level rise by 2050 for NAMA.

Flood Control System
NAMA is unique in that the park assets are located within a heavily developed urban area, surrounded by critical government infrastructure. To protect key government infrastructure, the Army Corps of Engineers has designed a series of flood control structures to minimize the flooding potential in the area surrounding the Federal Triangle (the area roughly bounded by 14th Street, Pennsylvania Avenue, and Madison Drive), which happens to lie within the 100-year flood plain (FEMA A/AE zone; Figure 2). These measures include the Reflecting Pool levee, the 17th Street barrier and levee, and a barrier at 23rd Street and Constitution Avenue.

This vulnerability assessment is based on a 35 year timeframe, approximately to the year 2050. Both the FEMA A/AE zone and category 3 surge maps show inundation of the Federal Triangle area, which would presumably be protected in most instances by the flood control system. However, one cannot assume that the flood control system will be effective in all cases through 2050, and thus it is most prudent to score exposure for the worst case (as they are currently mapped for FEMA A/AE and category 3 surge). This is the reason for the relatively high number of moderate vulnerability assets in this area.
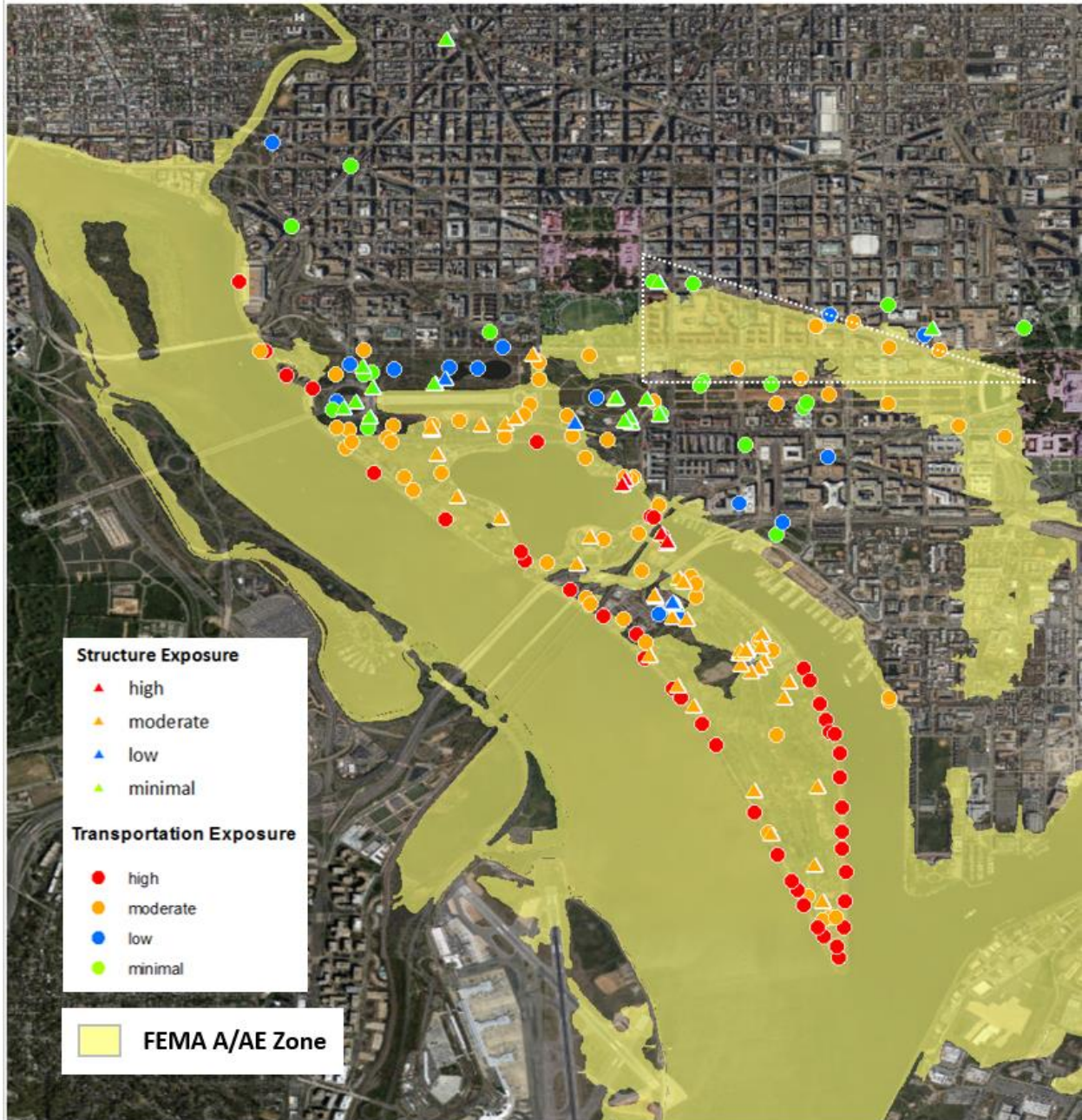
Figure 2. Exposure rankings for NAMA assets. Flood control measures installed by the U.S. Army Corps of Engineers are designed to prevent flooding in the Federal Triangle area (white dashed lines). However, in order to evaluate the "worst case," assets located in these areas were scored as exposed to both flooding (FEMA A/AE zone – yellow shading) and category 3 storm surge.

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 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 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; 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 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 (http://coastal.er.usgs.gov/shoreline-change/) or from state coastal management programs. Short-term erosion rates (usually data ranging from the 1970's 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: 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 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 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 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 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 (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 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.	*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 can 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