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Park Facility Management Division Facilities Planning Branch

Biscayne National Park (BISC)

Coastal Hazards & Climate Change Asset Vulnerability Assessment Protocol
September 2015

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

Contents

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BISC Cover Photo: Program for the Study of Developed Shorelines at Western Carolina University.

NPS 169/154055, September 2015

Executive Summary

The National Park Service (NPS) Sustainable Operations and Climate Change Branch, in partnership with Western Carolina University's (WCU) Program for the Study of Developed Shorelines (PSDS), has developed a **Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol**. This protocol is meant to assess the vulnerability of infrastructure to multiple coastal hazards and climate change factors (i.e., 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 45 structures and 15 transportation assets were included in the vulnerability assessment at Biscayne National Park (BISC). None of the assets analyzed are low exposure; the lack of low exposure assets is attributed to the fact that BISC is a low elevation, primarily island-based park, with many assets located adjacent to Biscayne Bay and the Atlantic Ocean. The majority of structures have high exposure and a significant number have moderate exposure. All of the transportation assets have high exposure. Overall, the sensitivity results for BISC assets are split between high, moderate, and low rankings. The sensitivity of structures are more evenly split between high, moderate, and low, whereas the majority of transportation assets are moderate sensitivity (60%). Threshold elevation data collected by the NPS Resource Information Services Division were also included in the sensitivity analysis; these data helped verify the flood damage potential metric within the sensitivity analysis.

A significant number of assets at BISC have high vulnerability to coastal hazards and sea-level rise (55% of structures; 87% of transportation assets). Only 13% of structures at BISC are low vulnerability and no transportation assets have low vulnerability. Many of these highly vulnerable assets are historical structures located in high exposure areas with a high sensitivity due to construction or engineering. This high vulnerability is difficult to avoid at BISC due to the high exposure of most areas within the park.

For the adaptation portion of this assessment, there was a collaboration with the NPS Integrated Park Improvement (iπ) program. This collaboration allowed the vulnerability assessment results to be integrated in discussions about asset planning and management. Further information about the collaboration with the iπ process will be documented in the BISC iπ materials and final report.

Vulnerability Assessment Products & Deliverables:

1) Excel datasheets. All results, as well as asset specific scoring, are provided in tabular form. The exposure, sensitivity, and vulnerability scores are reported alongside the FMSS data for each asset, as well as the scores for each step of the analysis. Contact WCU or NPS for access.
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. Contact WCU or NPS for access.
3) Park Specific Vulnerability Results Summary Document. This document, which explains the deliverables, results, adaptation strategies, and methodology. Contact WCU or NPS for access.

Introduction & Project Description

The National Park Service (NPS) Sustainable Operations and Climate Change Branch, in partnership with Western Carolina University's (WCU) Program for the Study of Developed Shorelines (PSDS), has developed a **Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol**. This protocol 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.

BISC Results Summary & Discussion

A total of **45 structures** (buildings and shelters) **and 15 transportation assets** (roads, parking lots, and boardwalks) were included in the vulnerability assessment at BISC. First, each asset's exposure and sensitivity was analyzed and scored, then the exposure and sensitivity scores were combined into an overall vulnerability for each asset. A general summary of the exposure, sensitivity, and vulnerability rankings of structure and transportation assets at BISC is below, and methodology for this analysis is described in the final sections of this document. Detailed exposure, sensitivity, and vulnerability scores are reported (alongside FMSS data) for each individual asset in the supplied excel datasheets; exposure and final vulnerability results are also provided as Geographic Information Systems (GIS) maps and layers. Note: the results for this vulnerability analysis represent a time frame of approximately 35 years (2050).

Exposure Analysis:

The most notable result of the exposure analysis at BISC is that none of the assets analyzed (structures and transportation assets) are low exposure. The majority of structures (69%) are high exposure and all of the transportation assets have high exposure (100%). (Table 1).

Table 1. BISC Exposure Results Summary. Due to rounding, sum of percentages may not equal 100.

Assets	High Exposure		Moderate Exposure		Low Exposure		Total #
	#	%	#	%	#	%	
Structures	31	69%	14	31%	0	0%	45
Transportation	15	100%	0	0%	0	0%	15
All BISC Assets	**46**	**77%**	**14**	**23%**	**0**	**0%**	**60**

The lack of low exposure assets can be largely attributed to the fact that BISC is an extremely low elevation park, with assets located adjacent to Biscayne Bay and the Atlantic Ocean. Exposure is directly dependent on location, and most assets are within a few hundred feet of a coastal body of water. Thus, if an asset is located within most of the exposure indicator zones, its exposure will be high. Five exposure indicators were analyzed for each asset (flooding, storm surge, sea-level rise, erosion/coastal proximity, and historical flooding). Due to the proximity to the coast, all assets are within one of the three Federal Emergency Management Agency (FEMA) high hazard flood zones (AE, VE, or Open Water), and all assets are in an area with previous flood activity. In addition, almost all BISC assets are located within the Category 3 Storm Surge Model zone. These factors combined led to all assets having at least moderate exposure at BISC. A significant portion of the assets at BISC are located within the FEMA VE Flood Zone (the highest risk zone: flood and wave energy influence), including all of the Convoy Point (CP) assets. Any asset within the VE Zone is automatically given the highest exposure rating, therefore, all of the assets at Convoy Point have a high exposure rating.

Sensitivity Analysis:

The sensitivity results for all assets (structures and transportation) at BISC are split between high (28%), moderate (45%), and low (27%). When separated into structures and transportation, the sensitivity scores of BISC assets are slightly different. The sensitivity of structures are more evenly split between high, moderate, and low, whereas the majority (60%) of transportation assets are moderate sensitivity (Table 2).

Table 2. BISC Sensitivity Results Summary. Due to rounding, sum of percentages may not equal 100.

Assets	High Sensitivity		Moderate Sensitivity		Low Sensitivity		Total #
	#	%	#	%	#	%	
Structures	13	29%	18	40%	14	31%	45
Transportation	4	27%	9	60%	2	13%	15
All BISC Assets	**17**	**28%**	**27**	**45%**	**16**	**27%**	**60**

The high sensitivity assets at BISC are primarily Stiltsville structures, which were constructed more than five miles offshore, in open water, on sandy shoals at the eastern edge of Biscayne Bay. After discussions with park staff, it was agreed that credit should be given for the elevated Stiltsville structures, however, these structures have unfavorable results for all other sensitivity indicators (not storm-resistant, poor condition, damaged in past floods, and no protective engineering). Other structures with high sensitivity include a few small storage sheds, both jetties, and the CP Diesel Fuel System. Four transportation assets have a high sensitivity at BISC (CP Entrance Road, CP Jetty Walk, CP Mainland Trail, and Boca Chita Waterfront), primarily due to poor condition and previous flood damage.

Several structures at Convoy Point, Adams Key (AK), and Elliott Key (EK) are of modern construction (1990's) built on elevated pilings to storm-resistant standards, and have not been historically damaged, resulting in low sensitivity rankings. Most structures at Boca Chita Key (BC) also have low sensitivity, in spite of the fact that most of these structures are historic assets constructed in the 1930's (except the modern comfort station). The structures at Boca Chita were built with solid construction (storm-resistant), are in good condition, and have not been historically damaged during prior flooding events, contributing to the favorable sensitivity rankings.

Threshold Elevation Data Collection at BISC

Threshold elevation data collected by the NPS Resource Information Services Division (RISD) were also 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 aided in the determination of highly reliable elevation indicators for assets at BISC. 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 was compared to local BFE for each asset to determine if the asset's primary threshold was above or below BFE (Figure 1). If an asset was elevated above BFE, it received a favorable score for the flood damage potential sensitivity metric. This comparative analysis led to revised elevation metrics for several assets, including the EK Comfort Station and Generator Building, both of which were originally reported as not elevated 5 feet above ground level (but are, in fact, above BFE).

Vulnerability Analysis:

A significant number of assets at BISC have high vulnerability to coastal hazards and sea-level rise (56% of structures; 87% of transportation assets). Only 13% of structures at BISC are low vulnerability and no transportation assets have low vulnerability (Table 3).

Two highly vulnerable assets of particular concern to BISC are the Diesel Fuel System and Entrance Road at Convoy Point. A primary component of the Diesel Fuel System is a 4,000 gallon underground storage tank. The tank, which is listed as being in serious condition (in FMSS), is located only a few feet from the waters of Biscayne Bay. The Entrance Road is less than one mile long and is also listed in serious condition. In fact, the road is experiencing erosion in multiple locations (Figure 2). This road is a critical asset for both visitors and employees, as it serves as the only land-based access to the park, including the CP Visitor Center and Park Headquarters (Figure 3A).

Location	Flood Damage Potential (Elevated) (Q1)	Threshold Elevation (m; NAVD88)	BFE (m, NAV88)	Above/ Below BFE
CP RM Storage I	4	1.720	3.80	Below
CP IN Storage	4	1.508	4.11	Below
CP FM Storage I	4	1.573	4.11	Below
CP Quay Storage	4	1.515	4.11	Below
CP Headquarters Building	4	1.646	4.40	Below
CP Maintenance Building	4	1.374	4.40	Below
CP Visitor Center	4	1.722	4.40	Below
CP Duplex Residence	1	5.330	4.11	Above
CP Hazardous Material Storage Building	4	1.345	4.11	Below
CP Fuel Pump Building	4	1.545	4.73	Below
CP Boat Maintenance Shade Structure	4	1.240	4.40	Below
CP Diesel Fuel System	4	1.297	4.73	Below
CP Jetty	4	0.456	4.73	Below
AK Water Treatment Building	4	0.787	3.20	Below
AK Temp Storage Bldg	4	0.714	3.20	Below
AK Residence West 103	1	3.323	3.20	Above
AK Residence East 102	1	3.345	3.20	Above
AK Generator Building	1	3.565	3.20	Above
AK Comfort Station	4	0.825	3.20	Below
AK Pavilion	4	0.865	2.90	Below
AK Storage Building	4	0.714	3.20	Below
BC Lighthouse	4	1.332	3.20	Below
BC Chapel	4	1.185	3.20	Below
BC Comfort Station	4	2.104	3.20	Below
BC Barn	4	1.912	3.20	Below
BC Generator Building	4	1.540	3.20	Below
BC Pavilion	4	1.145	3.20	Below
EK Generator Building	1	3.238	2.90	Above
EK Maintenance Building	4	2.334	2.90	Below
EK Storage Building	4	2.155	2.90	Below
EK Residence East 213	1	4.267	2.90	Above
EK Residence West 212	1	4.269	2.90	Above
EK Comfort Station	1	2.987	2.90	Above
EK Visitor Center	1	5.400	2.90	Above
EK WTP Building & Covered Storage	4	2.334	2.90	Below

Figure 1. Snapshot of sensitivity results for BISC, including the flood damage potential metric and threshold elevation comparative analysis.

Table 3. BISC Vulnerability Results Summary. Due to rounding, sum of percentages may not equal 100.

Assets	High Vulnerability		Moderate Vulnerability		Low Vulnerability		Total #
	#	%	#	%	#	%	
Structures	25	56%	14	31%	6	13%	45
Transportation	13	87%	2	13%	0	0%	15
All BISC Assets	**38**	**63%**	**16**	**27%**	**6**	**10%**	**60**

The areas in the park with the most high vulnerability structures include all assets at Stiltsville, several at Convoy Point and Adams Key, as well as the Black Point Jetty, Fowey Rocks Lighthouse, and Jones Property Ruins. Many of these highly vulnerable assets are historical structures that are located in high exposure areas and have high sensitivity due to construction/engineering. Several of the other highly vulnerable structures are maintenance related, which often have practical considerations that control their location (exposure) and construction (sensitivity).

Since their construction as elevated buildings in 1992, several changes have been made to the function of the ground floor of both the CP Headquarters and Visitor Center. The first floor is now enclosed space in both buildings, housing law enforcement beneath the Headquarters, and a restroom and classroom space beneath the Visitor Center. Both of these buildings also have heating, ventilating, and air conditioning (HVAC) units and other utilities located at ground level. Because the park has added significant key infrastructure to the first floor of both buildings, neither was evaluated as an elevated structure in the sensitivity analysis, and the threshold elevation reported is that of the ground level. This led to a moderate sensitivity and high vulnerability for both (Figure 3). If the park continues to add infrastructure to the ground-level space, the sensitivity (and vulnerability) will increase. Conversely, relocating this key infrastructure to a higher floor would reduce sensitivity and vulnerability

Figure 2. Erosion along the Convoy Point Entrance Road at BISC, May 2015. PSDS photo.

The low vulnerability structures (13%) at BISC include the AK Residence East, both generator buildings at Adams and Elliott keys, and the Residence East, Comfort Station, and Visitor Center at Elliott Key (Figure 3B). The main factors contributing to this low vulnerability are low exposure locations (higher and further from the shore), and low sensitivity due to elevated and storm-resistant construction. Although location often cannot be changed for assets, measures taken to lower sensitivity during planning and construction can reduce vulnerability.

Nearly all of the transportation assets at BISC have high vulnerability. This is difficult to avoid at BISC due to the high exposure of most areas within the park. However, it should be noted that the two transportation assets with a more favorable (moderate) vulnerability, CP Waterfront and EK Main Harbor Waterfront, are constructed in a manner that reduces their sensitivity (removable docks, storm resistant materials, and protective engineering), in spite of their highly exposed locations. This helps reduces the overall vulnerability of these assets (Figure 3).

This methodology is meant to assess the vulnerability of a park to multiple coastal hazards and climate change factors combined (i.e., erosion, flooding, storm surge, sea-level rise, and historical flooding; see indicator list in methodology section). Therefore, a park (like BISC) that has maximum risk with respect to the exposure indicators will inherently have a higher vulnerability. As higher quality data become available for the metrics of vulnerability (exposure and sensitivity), the final rankings for these assets may change. For example, a more accurate 2050 sea-level rise model projection is currently being developed by NPS, and could change the exposure of some assets.

UPDATE: Preliminary results from the new sea-level rise model have been incorporated into the BISC exposure and vulnerability results as of September 2015.

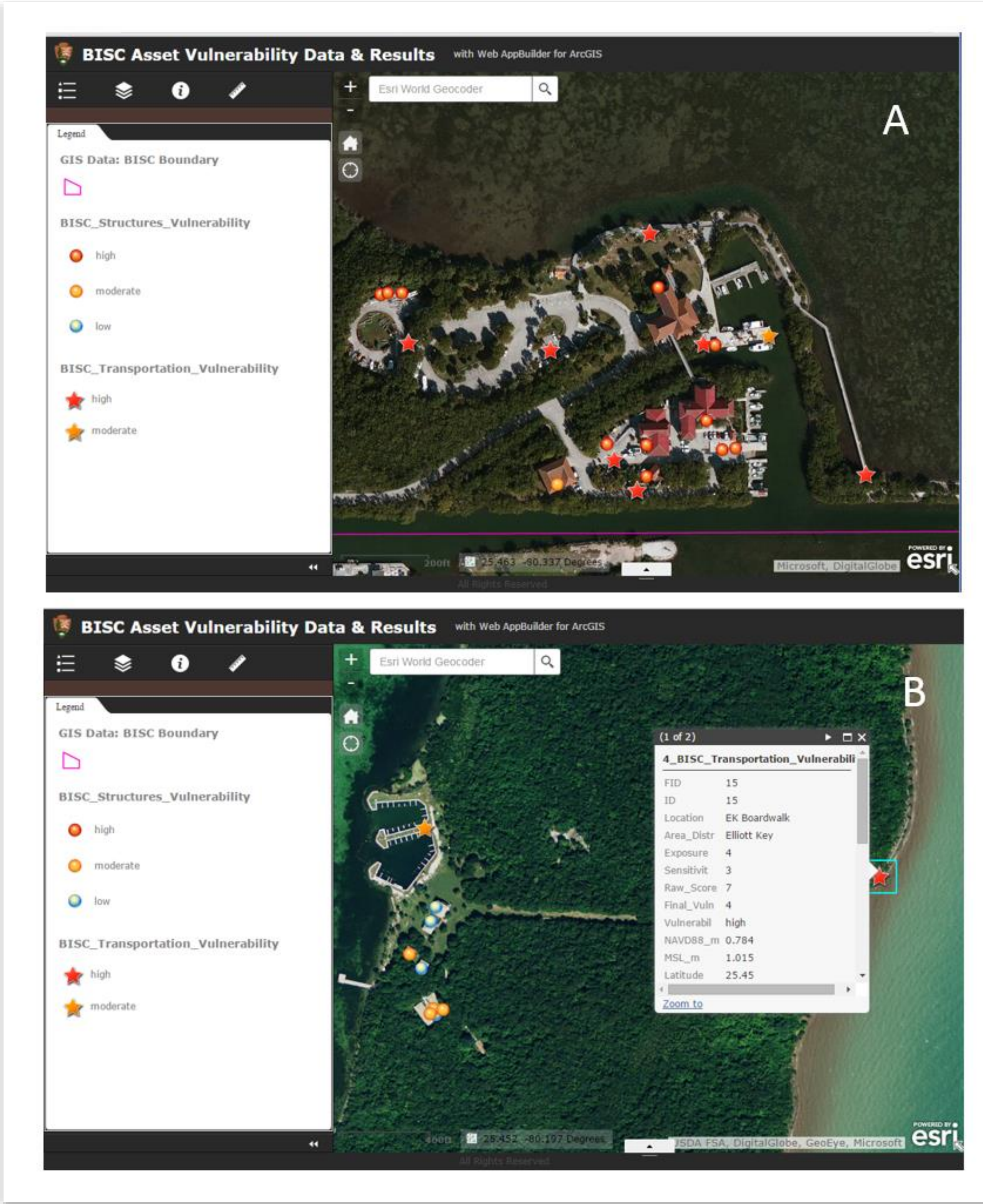

Figure 3. Examples of mapped vulnerability results for BISC assets. A) Convoy Point vulnerability results. B) Elliott Key vulnerability results. Access information for the complete data is listed at the end of the executive summary.

BISC Adaptation Strategies & Planning

Integrated Park Improvement Process:

For the adaptation portion of this assessment, WCU collaborated with the NPS Integrated Park Improvement (iπ) program. BISC has been working with the iπ team throughout 2015 to strategize and prioritize planning efforts for assets in the coming decade. The vulnerability assessment results were utilized throughout the iπ process, including the following topics:

- **Investment Level and Risk.** BISC and the iπ team assessed what levels of investment were appropriate for high vulnerability infrastructure projects, with the goal of minimizing financial risk and also maximizing results.

- **Potential Constructability Scenarios.** Given the implications of the sensitivity and vulnerability results, projects were evaluated for the type and level of "fix" that would be appropriate.

- **Benefit Margins Analysis (BMA).** For the BMA, the park evaluated each of the proposed iπ bundled projects for five criteria: 1) Cost Efficiency, 2) Funding Probability, 3) Operations and Maintenance Reduction, 4) Environmental Sustainability, Climate Change, and Cultural Stewardship, and 5) Visitor Experience. The vulnerability assessment results from this project were incorporated as part of the fourth factor, which includes both environmental sustainability and climate change considerations.

One example discussed during BMA was the potential installation of new, more efficient, HVAC systems at the CP Headquarters and Visitor Center. Although this assessment did not directly analyze the HVAC systems for vulnerability, exposure was estimated based on the metrics and data provided (same exposure as the buildings). There is not a more suitable location (lower exposure) for the HVAC units at Convoy Point. However, using the methodology of this assessment, it was determined that the park could reduce the vulnerability of these new units by reducing the **sensitivity.** While it is difficult to increase the storm-resistance or add engineering protection to the HVAC, the park could elevate the units to the second floor. Elevating the HVAC system would reduce the likelihood of flood damage to the unit, and would also reduce the sensitivity and vulnerability of the associated buildings.

Overall, this collaboration allowed the vulnerability assessment results to be integrated in park-level discussions about asset planning and management. Further information about the collaboration with the iπ process will be documented in the BISC iπ materials and final report.

Unique Factors & Considerations for BISC

Erosion & Coastal Proximity:

When available, erosion rates are used to calculate 35-year erosion hazard buffer zones. For example, many sandy barrier island parks (i.e., Cape Hatteras) have had extensive research on erosion rates over the past 50+ years; this erosion rate can be used to project **potential** erosion over the next 35 years. However, parks without a classic sandy ocean shoreline (i.e., those comprised of rock or those containing estuarine shoreline), often do not have the erosion rate data sufficient to create these buffer zones. In these cases, a standard **coastal proximity buffer zone** is created using the most current shoreline; this area does not represent where the shoreline may be in 35 years, but instead an area of **high risk** to coastal hazards. This coastal proximity buffer zone methodology was applied at BISC (Figure 4).

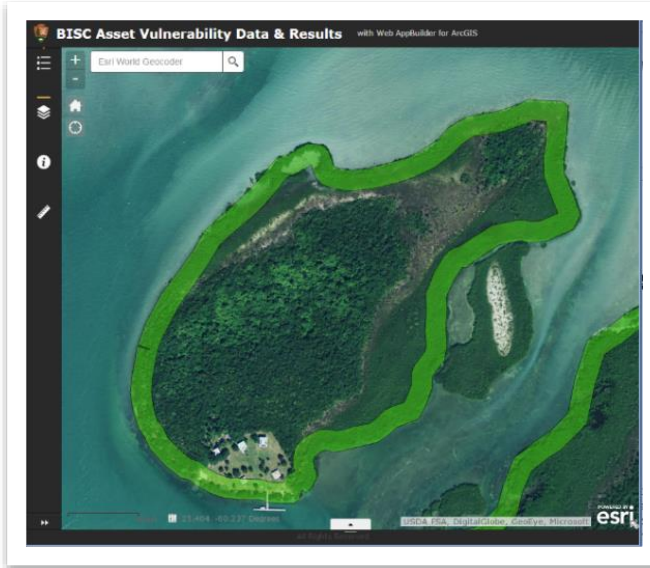

Figure 4. Coastal proximity buffer zone at Adams Key, BISC.

__Sea-Level Rise Data:__

The NPS-specific sea-level rise layer used for the exposure analysis in this study is a "bathtub" inundation model that projects sea-level rise in the park to the year 2050 (intermediate projection). It is largely derived from LIDAR elevations for the park and doesn't take into account engineered protective structures (e.g. seawalls), which could change the effects of sea-level rise. A newer and more complex model is in the final stages of development by the NPS Climate Change Response Program (CCRP), and will be available in October of 2015. This new improved dataset could potentially alter the exposure of assets at BISC to sea-level rise.

Update to Sea-Level Rise Data, September 2015: Preliminary results from a new sea-level rise model provided by the CCRP have been incorporated into the BISC exposure and vulnerability results as of September 2015. These data have been compared to the previous sea-level rise data, and changes to the results have been completed.

Methodology of Vulnerability Assessment

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 4 summarizes these indicators, as well as common data sources for each.

Table 4. 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 7), 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 5 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 5. **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 6 below describes each indicator, including the description, rationale, and scoring.

Table 6. 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 for development of adaptation strategies (step 4).

Step 4: Adaptation Strategies Analysis

After the vulnerability analysis is complete, adaptation strategies will be analyzed for key assets within each park. FMSS data such as Asset Priority Index (API) and Optimizer Band (OB) can help select the assets to analyze for adaptation strategies. Assets analyzed will likely include those with high vulnerability and high priority and/or high criticality (API/OB), as well as high vulnerability assets with low priority and/or criticality. This adaptation analysis begins with discussions with the park, or by way of a questionnaire. This portion of the analysis focuses on the options available to the park to reduce the overall vulnerability of key assets. An outline of potential adaptation strategies to reduce coastal hazards and climate change vulnerability has been compiled by WCU for both structures and transportation assets (Table 7).

Table 7. 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