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Sustainable Operations and Climate Change Branch

Park Facility Management Division Facilities Planning Branch

Big Cypress National Preserve (BICY)

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

NPS 176/154052, 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 151 structures and 80 transportation assets were included in the vulnerability analysis at Big Cypress National Preserve (BICY). Most of the structures have low vulnerability (89%), and the majority of transportation assets (65%) have moderate vulnerability. The overall low vulnerability of BICY is due (in part) to the park's exposure. BICY is located further inland and at slightly higher elevations than many coastal parks and, therefore, is less exposed to coastal hazards. In addition, the practice of elevating assets on artificial fill and storm resistant construction at BICY lowers asset sensitivity, thus reducing vulnerability.

Adaptation strategies were examined for key vulnerable assets at BICY. For high priority assets, the most appropriate adaptation action will likely include engineering (e.g., building or landscape modification to lower sensitivity). In most cases, the swamp landscape at BICY must be modified to build a structure, road, or other asset. Assets typically cannot be relocated due to a lack of suitable land (new sites would need to be created with fill), and usually cannot be removed due to priority. For low priority assets, appropriate adaptation actions can include relocation or removal. In fact, several low priority assets had strong agreement from park workshop participants for decommission and removal.

The relatively low vulnerability over this short-term horizon should not lead to complacency in adaptation planning, as this planning horizon is intended to help parks address immediate concerns for asset planning and prioritization. Over the long-term, all coastal parks, including BICY, will see the increasing effects of coastal hazards and sea-level rise. BICY should begin considering adaptation strategies for all high and moderate vulnerability assets, as well as high priority assets, in order to prepare for climate change in the coming century.

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.

BICY Results Summary & Discussion

A total of **151 structures** (buildings and shelters) **and 80 transportation assets** (roads, parking lots, airstrips, helipads, and bridges) were included in the vulnerability analysis at BICY. 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 BICY is below. 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 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 BICY was that only one of the assets analyzed (structures and transportation assets) has high exposure. The vast majority of assets (83%) have moderate exposure, and a small, but significant, number of assets (17%) have low exposure. Among transportation assets, 75% are moderate and 24% are low exposure, while structures are 87% moderate and 13% low exposure (Table 1). Only the Loop Road (unpaved section) has a high exposure.

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

Assets	High Exposure		Moderate Exposure		Low Exposure		Total #
	#	%	#	%	#	%	
Structures	0	0%	131	87%	20	13%	151
Transportation	1	1 %	60	75%	19	24%	80
All BICY Assets	**1**	**<1%**	**191**	**83%**	**39**	**17%**	**231**

The lack of high exposure assets (except one road) can be largely attributed to the fact that BICY is located further inland and at slightly higher elevations than most coastal parks and, therefore, less likely to be affected by coastal hazards and sea-level rise. Exposure is directly dependent on location; thus, if an asset is located beyond the influence of a particular coastal hazard, its exposure is diminished. Five exposure indicators were analyzed for each asset (flooding, storm surge, sea-level rise, erosion/coastal proximity, and historical flooding). Due the upland location of BICY, most of the assets are located outside the 2050 sea-level rise projection, and well outside the coastal erosion/proximity zones, which yielded more favorable exposure scores for most assets. Only the Federal Emergency Management Agency (FEMA) flood zones, storm surge model, and historical flooding indicators had a significant impact on exposure scores. BICY encompasses over 700,000 acres of swamp and, therefore, it is reasonable that storm surge and flooding are the greatest exposure risks for assets in the park. Assets with low exposure scores tended to be located in the northern portions of the park, where elevation and distance from the coast are greater.

Sensitivity Analysis:

Overall, very few assets at BICY (3%) have high sensitivity, and the remaining assets were split between moderate sensitivity (39%) and low sensitivity (58%) rankings. When separated into structures and transportation, the sensitivity scores of BICY assets are noticeably different. The majority of structures

(81%) at BICY have low sensitivity, whereas the majority of transportation assets (79%) have moderate sensitivity (Table 2).

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

Assets	High Sensitivity		Moderate Sensitivity		Low Sensitivity		Total #
	#	%	#	%	#	%	
Structures	1	< 1%	28	19%	122	81%	151
Transportation	6	8%	63	79%	11	14%	80
All BICY Assets	**7**	**3%**	**91**	**39%**	**133**	**58%**	**231**

Only one structure at BICY has high sensitivity (Schrier House). Built in 1928 and inherited by the park, the main factors contributing to the structure's sensitivity include its lack of above-grade elevation, lack of storm resistant construction, limited maintenance, and damage from prior flood events. Among transportation assets, six were highly sensitive; the unpaved sections of Loop Road and Jim Dill Road, three earth-dam bridges on Turner River Road, and a culvert bridge at Deep Lake Fire Station. The main factors contributing to the high sensitivity of these assets include construction with non-storm-resistant material and damage by prior flood events.

Vulnerability Analysis:

Relatively few assets at BICY have high vulnerability to coastal hazards and sea-level rise (<1% of structures; 8% of transportation assets). In fact, the majority of structures at BICY have low vulnerability (89%), and the majority of transportation assets (65%) have a moderate vulnerability rating (Table 3, Figure 1). The difference in the vulnerability of structures versus transportation assets was predominantly due to the sensitivity metric; transportation assets have higher sensitivity overall, primarily because structures are more commonly elevated above local ground level (compared to roads).

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

Assets	High Vulnerability		Moderate Vulnerability		Low Vulnerability		Total #
	#	%	#	%	#	%	
Structures	1	<1%	16	11%	134	89%	151
Transportation	6	8%	52	65%	22	28%	80
All BICY Assets	**7**	**3%**	**68**	**29%**	**156**	**68%**	**231**

As a whole, over two-thirds of assets at BICY have low vulnerability using this protocol. However, there are several important caveats to the vulnerability analysis and results:

1) 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 BICY) that has minimal risk to one or more of these factors will inherently have a lower overall vulnerability.

2) This protocol was developed as a means to compare vulnerability among all coastal parks, which are often environmentally distinct from one another. As previously discussed, BICY is located further inland than most coastal parks, and thus is at relatively lower risk to coastal hazards, particularly over the next 35 years (the planning horizon for this study).

3) 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, which could change the exposure of some assets. Also, many of the assets at BICY had lower sensitivity because they are built on artificial fill. With more precise threshold elevations on structures and more detailed road elevation data, the sensitivity of BICY assets could show a higher degree of variability.

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

4) While few assets have high vulnerability themselves, several roads not owned by NPS are often impassable after major storms, hindering access to BICY assets. In a sense, many low vulnerability assets could be safe from flooding (and sea-level rise), but completely inaccessible by road. Other coastal parks have similar issues that relate to ownership or jurisdiction of the transportation leading to NPS-owned assets and resources, necessitating coordination (i.e., additional collaborative vulnerability studies) with regional stakeholders, land owners, and partners.

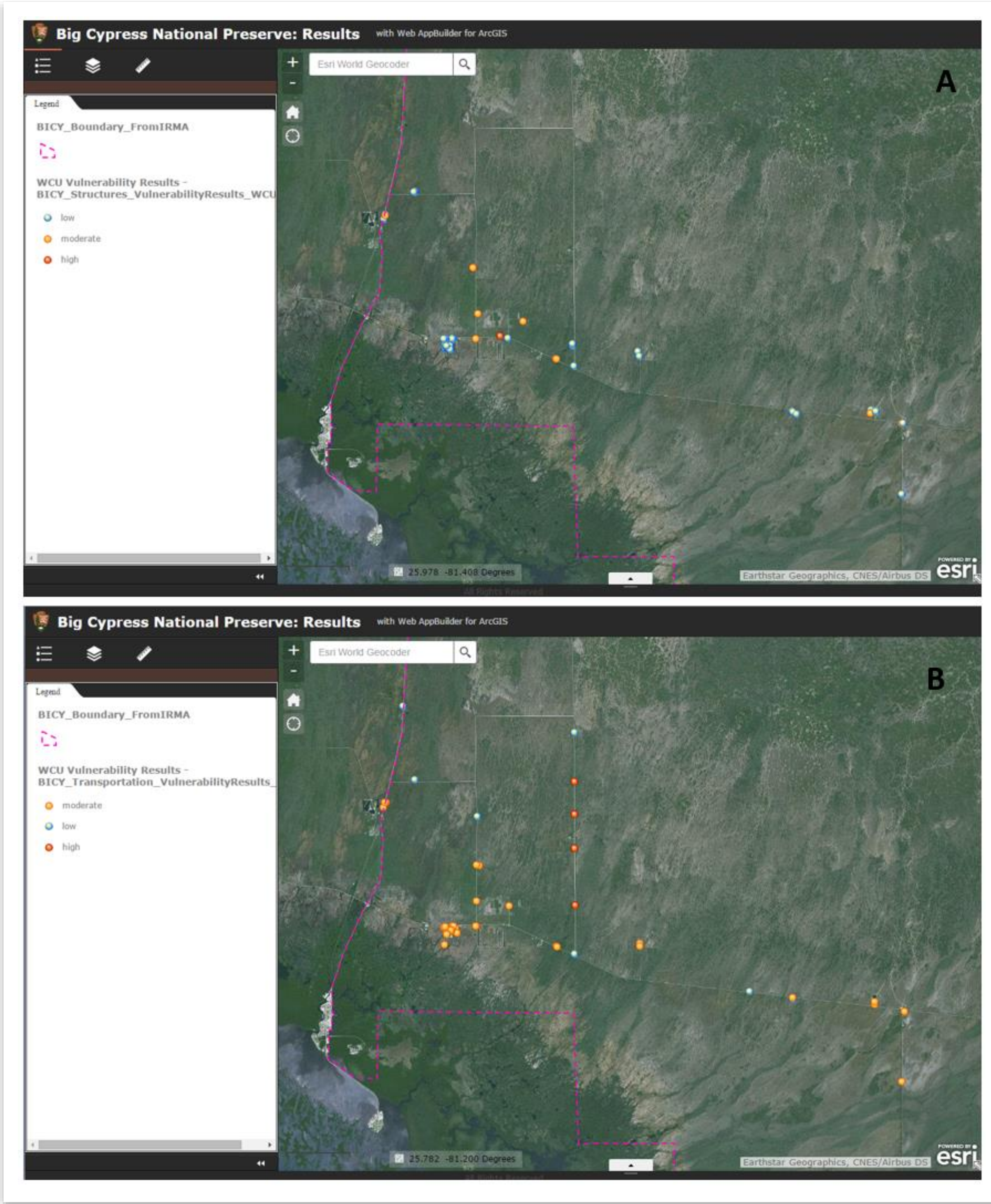

Figure 1. Example of mapped vulnerability results for BICY assets. A) Structure vulnerability results for southwest portion of BICY. B) Transportation asset vulnerability results for southwest BICY. Access information for the complete data is listed at the end of the executive summary.

BICY Adaptation Strategies & Planning

Adaptation Strategies

The potential adaptation actions for numerous key assets were discussed during an exercise at the Climate Friendly Parks (CFP) Workshop in June of 2015. This discussion included both high priority (API ≥ 70 or Optimizer Band = 1) and low priority assets (API < 20 or Optimizer Band = 4-5), as an asset's priority plays a significant role in the types of adaptation strategies a unit would likely apply to a vulnerable asset. During this discussion, BICY staff selected potential adaptation actions that would apply for each asset; these results were recorded in a questionnaire. A detailed description of the potential adaptation options considered (i.e., elevate, relocate, engineer, and remove) is provided in the methodology section of this document.

Results from the adaptation options exercise show that for the majority of high priority structures and transportation assets, the most appropriate form of adaptation would likely be engineering (building or landscape) to reduce vulnerability (Tables 4-5). Because most of BICY (especially the southern half) is swamp, the landscape must be modified in order to build a structure, road, or other asset. For example, significant drainage and fill elevation must be created to allow the asset to be positioned above the water level in the surrounding swamp. These structures, in most cases, cannot be relocated, as there is no suitable land nearby (new suitable land would need to be created with fill), and they cannot be removed as they are high priority. Therefore, the most appropriate form of adaptation will likely be to modify the engineering of the building or surrounding landscape.

Table 4. Adaptation Strategies for Structures/Buildings: Results from questionnaire at BICY.

	Assets		Potential Adaptation Actions				Total # Actions
	Name	Vuln.	Elevate	Relocate	Engineer	Remove	
High Priority	Loop Road RS Upstairs, A96	low	1	2	2		3
	Aviation Hanger, A91	low		1	4		2
	OA Visitor Center, A79	mod		1	3	1	3
	Swamp Welcome, A136	low		1	4		2
	Monroe Station, A76	mod	1		1	2	3
	Monument Pump House, A77	low	2		3		2
Low Priority	BR - Schrier house	high		1		5	2
	OA - Quarters 10	low	1			5	2
	Group: OA Storage Bldgs	low	2	2	2		3
	Group: Chickee Bldgs	low	1	1	3		3
	Group: OH Sheds	low	1	2	3		3
	EE Center Lab, A62	mod	1	2	1	2	4
	OA - VIP Laundromat	low		4	2		2
	Group - OH Sheds	mod	1	4	1		3
	OA - Maint. Storage, A52	low	1	4	1		3

Table 5. Adaptation Strategies for Transportation: Results from questionnaire at BICY.

	Assets		Potential Adaptation Actions					Total # Actions
	Name	Vuln.	Redesign	Downgrade	Relocate	Engineer	Remove	
High Priority	Loop Road, Paved	high	1	1		3		3
	Loop Rd. Ranger St. Rd	mod	1	1	1	2		4
	Oasis Road	mod	1	1		2		3
	SG Parking, Paved	mod		1		4		2
	Turner Canoe Launch Rd.	mod		1	3	2		3
Low Priority	Jim Dill Road	high	1	1		2	1	4
	Pine Oaks Road	mod					5	1
	Dona Dump St. Parking	mod		1		3	1	3
	Dona Commercial Lot	mod		1	1	3		3
	Monument Lake CG Rd.	mod		1		2	1	3
	Mount Ochopee Drive	mod		1		3	1	3
	Maint GOV Parking Co.	mod			2	2		2
	Maint POV Parking East	mod			2	2		2
	Maint GOV Parking West	mod			2	2		2
	Ranger St. POV Parking	mod			2	2		2
	Ranger St. Equip. Parking	mod			2	2		2

For BICY low priority assets, there was a wider range of responses for the most appropriate form of adaptation. Many BICY personnel still marked engineering or landscape modification as the option that should be taken. However, relocating or removing the asset entirely was considered more frequently for these lower priority assets. Three assets in particular, the Schrier House, Oasis Quarters #10, and Pine Oaks Road, had almost unanimous support from the workshop participants for decommissioning and complete removal (Tables 4-5).

Examining the number of potential adaptation actions can give insight into an asset's adaptive capacity. Assets with a higher number of options likely have a higher adaptive capacity. For example, only two of the four options were marked for the Swamp Welcome Center at Ochopee: 1) to relocate the structure or 2) to engineer the structure/landscape. Conversely, three of the four potential actions (all but relocate) were selected for the Monroe Station structure. This higher number of options likely means the Monroe Station has a higher adaptive capacity than the Swamp Welcome Center. The number of potential adaptation options may also be influenced by how practical a decision is regarding an asset. For example, only two options were recorded for the Schrier House: 1) relocate the asset or 2) remove the asset. For this asset, participants only selected two potential adaptation actions because there was clear agreement that the asset should be decommissioned and removed (due to condition and low priority). In this case, the lower number of options is a result of the fact that the decision for this asset is straightforward, and likely imminent.

The relatively low vulnerability over this short-term horizon (35 years) shouldn't lead to complacency in adaptation planning. The 2050 planning horizon is intended to help parks address immediate concerns for asset planning and prioritization. Over the long-term, all coastal parks, including BICY, will see the increasing effects of coastal hazards and sea-level rise. Nearly two-thirds of transportation assets and over 10% of structures at BICY have moderate vulnerability, which will only worsen over time. BICY should begin considering adaptation strategies for all high and moderate vulnerability assets, as well as high priority assets, in order to prepare for climate change in the coming century.

Adaptation Planning

BICY has begun the process of reflecting on ways to integrate the results of the vulnerability assessments into park planning. Below is a list of key questions from the workshop, along with the park responses and suggestions.

1. **Will this vulnerability assessment have value for the park?**
   Yes, the park staff felt they could defend their DAB and PMIS requests given they have gone through this process.

2. **Which planning processes will be impacted by these results?**
   General Management Plan: The GMP was completed in 2010. It does not include specific information about climate change impacts. The park is gaining new assets in 2015 that will have floodplain implications that will need to be addressed. BICY will develop a statement of findings for these new assets in the floodplain. There may be an opportunity to influence the lease of these buildings with this new vulnerability information.

   Foundation Documents**:** These are currently in process. The park staff will consider including the vulnerability assessment in the significance and values section of the foundation documents.

   Asset Planning: BICY will be submitting proposals to the DAB for transportation projects. These vulnerability assessment results will now allow them to finalize step 3 in the hazards checklist when they submit their project. BICY recommended that NPS add new variables into FMSS derived from this vulnerability assessment. For example, this might include an asset vulnerability rating field. Park staff suggested these results will drive investment decisions at the DAB and in PMIS, but it is also important to show that the park has evaluated highly vulnerable assets for reasonable adaptation actions.

   Engineering Studies**:** BICY can now use these results in conducting adaptation engineering studies regarding the assets that have high vulnerability and are high priority.

   Emergency Preparedness/Storm Management Plan: Park staff suggested that they could include the vulnerability results into their storm management plans.

3. **What additional adaptive capacity strategies would you suggest?**
   Accessibility issues need to be considered when examining the vulnerability of a structure or asset. For example, a building may be considered low vulnerability, but if the roads to the area are highly vulnerable, access to that low vulnerability structure may become limited or eliminated completely.

4. **What are the next steps for the park as it integrates these results into its planning processes and decision-making frameworks?**
   BICY would benefit from more precise and widespread threshold elevation data for structures and base elevation for transportation assets. This work is currently being done for other coastal parks by the Denver Services Center; park staff expressed strong interest in having this type of work completed at BICY.

Unique Factors & Considerations for BICY

Storm Surge Data:

During the exposure analysis of assets at BICY, it became apparent that there are some issues with NOAA's SLOSH (Sea, Lake, and Overland Surges from Hurricanes) model data used to determine Category 3 storm surge exposure in the park. These concerns were underscored in discussions with park staff during the CFP workshop in June of 2015. The issues are twofold: 1) park staff voiced concern that the SLOSH model predicts a degree of storm surge inundation that exceeds what has been observed in the last several decades at the park; and 2) the edge of the model's operational basin runs through the middle of the park (just north of Route 41), causing the predicted area of storm surge inundation to end abruptly at what is clearly an artificial boundary (Figure 2). To address these concerns, WCU consulted with the NPS Climate Change Response Program (who ran the model), SLOSH model researchers, and the SLOSH model documentation, and concluded the following:

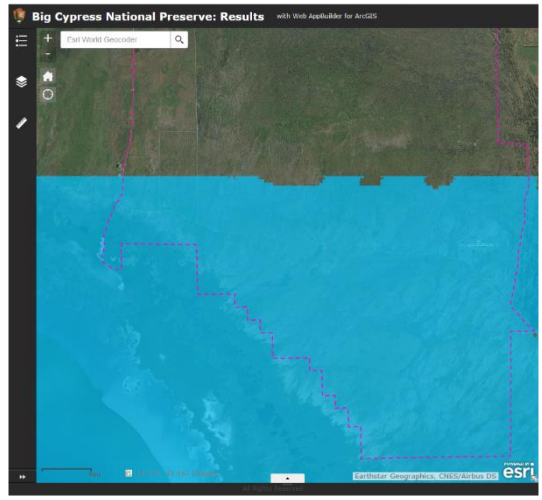

Figure 2. SLOSH storm surge model run for BICY. Note the artificial northern boundary due to the extent of the model basin.

First, 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. Therefore, the surge data included in WCU's exposure analysis (the SLOSH MOM) represents the maximum potential surge conditions of a Category 3 storm at BICY.

Second, other additional factors were considered, such as the geomorphology and hydrology of the park, as well as observations from park staff regarding past flood events in order to assess surge potential in areas beyond the limits of the model basin. Bearing in mind that the storm surge exposure is derived from the maximum modeled Category 3 scenarios, WCU determined that the assets originally reported as having storm surge exposure during the CFP workshop are indeed exposed. Furthermore, it was determined that additional assets outside the SLOSH model basin (Fire Operations Center area structures and transportation assets) would, in fact, be exposed to Category 3 surge under the maximum conditions and, therefore, should be listed among the exposed assets for storm surge.

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. Furthermore, the model does not examine the inland hydrology and engineered drainage, which at BICY plays a significant role in flooding. A newer and more complex model is in the final stages of development by the NPS Climate

Change Response Program, and will be available in October of 2015. This new improved dataset could potentially alter the exposure of assets at BICY 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 BICY 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. The sea-level rise exposure metric results were altered for three assets based on the new model. Changing this exposure metric only changed the final exposure results of one asset, Loop Road (unpaved section).

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

Table 6. 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 7 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 7. 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 8 below describes each indicator, including the description, rationale, and scoring.

Table 8. 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 9).

Table 9. 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