National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Coastal Hazards & Sea-Level Rise Asset Vulnerability Assessment Protocol

Updated Project Description & Methodology

Natural Resource Report NPS/NRSS/CCRP/NRR—2022/2427





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Coastal Hazards & Sea-Level Rise Asset Vulnerability Assessment Protocol

Updated Project Description & Methodology

Natural Resource Report NPS/NRSS/CCRP/NRR—2022/2427

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National Park Service
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Executive Summary

The National Park Service (NPS), in collaboration with the Program for the Study of Developed Shorelines at Western Carolina University, developed a standard natural hazards and climate change vulnerability assessment methodology for infrastructure in coastal national parks. The **Coastal Hazards & Sea-Level Rise Asset Vulnerability Assessment Protocol** evaluates the vulnerability of NPS buildings and transportation assets to sea-level rise, flooding, and shoreline change (note that underground utilities are not included as of this writing due to incomplete data regarding location, condition, and other attributes). The fundamental purpose of vulnerability assessments is to understand the degree to which resources and assets are "susceptible to harm from direct and indirect effects of climate change, including variability and extremes" (NPS 2021a). This document describes the developmental history of this protocol and provides a detailed description of the methodology.

Over the past decade, the **Coastal Hazards & Sea-Level Rise Asset Vulnerability Assessment Protocol** was developed and refined in phases, including 1) a review of infrastructure vulnerability assessment approaches within the NPS (2012–2013); 2) creation of a new coastal vulnerability assessment protocol for infrastructure (2014); 3) pilot application of the protocol in seven park units (2015); 4) protocol application in 12 additional parks and partnership with parallel projects (2016–2017); and 5) continued protocol implementation and collaboration (2017–present). The protocol has been used to assess more than 40 parks (as of March 2022).

Exposure is commonly evaluated when conducting vulnerability assessments for infrastructure, but sensitivity is not, particularly at the asset level (Peek et al. 2022). This vulnerability assessment protocol evaluates both the exposure and sensitivity of individual NPS assets. The protocol focuses on buildings and transportation assets listed in the NPS Facility Management Software System database and has three primary steps: 1) Exposure Analysis and Mapping, 2) Sensitivity Analysis, and 3) Vulnerability Calculations.

The first step in this vulnerability assessment protocol is to analyze the exposure of NPS assets to five exposure hazards/indicators: flooding potential, shoreline change, sea-level rise inundation, extreme event flooding, and reported coastal hazards. All exposure hazards are assessed to the year 2050, which is a reasonable timeframe for park planning. Evaluating exposure is primarily an exercise of data gathering and geospatial analysis, as exposure is directly dependent on location and site elevation. We use data from nationally available and consistent sources to facilitate direct comparison of exposure scores from one site to another.

The second step is to analyze the sensitivity of each asset. Sensitivity is not location dependent, and sensitivity analysis includes examining all features of an asset (e.g., materials, age, construction, or design elements) that will improve or degrade its performance when exposed to a hazard. The primary data source for the sensitivity analysis is an asset-specific questionnaire typically completed by knowledgeable park staff, along with additional sensitivity data obtained from the National Bridge Inventory, aerial imagery, and site visits. The final vulnerability score is a simple mathematical combination of exposure and sensitivity.

Quality control is a key component throughout this vulnerability assessment process. Expert verification of exposure data is crucial to provide accurate and meaningful results, as hazard data are often incomplete, can contain errors, and do not always accurately model dynamic coastal environments. As part of this protocol, we carefully review all exposure hazard data and employ our understanding of coastal geomorphological processes and past events to identify model errors or inaccuracies. When necessary and available, we verify hazard data by consulting various supplemental data sources (often historical aerial imagery, storm records, and other hazard maps). The sensitivity analysis process relies heavily on park institutional knowledge regarding the physical attributes of assets. We review the responses for each sensitivity indicator for consistency and verify the results as needed (e.g., through further discussion, aerial imagery, or other documentation).

Data gathered using this protocol can directly inform decision-making, be integrated into quantitative risk evaluations, and inform asset-level planning. Vulnerability is assessed at the individual park level, and results can be combined into regional or national summaries because scores are comparable from site to site, enabling the NPS to identify highly vulnerable assets across all coastal parks regardless of differences in geography or asset type. The protocol also collates the vulnerability results with input data from the Facility Management Software System and other sources. Core protocol products include these data reformatted in spreadsheets and geodatabases (e.g., ArcGIS and Google Earth files, NPS Coastal Vulnerability Data Viewer) and summarized in a final report.



Flooded boardwalk at Jean Lafitte National Historical Park and Preserve (©PROGRAM FOR THE STUDY OF DEVELOPED SHORELINES, WESTERN CAROLINA UNIVERSITY).

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Acronyms

CFP—Climate Friendly Parks
FEMA—Federal Emergency Management Agency
FIRM—Flood Insurance Rate Map
FMSS—Facility Management Software System
GIS—Geographic Information Systems
NBI—National Bridge Inventory
NOAA—National Oceanic and Atmospheric Administration
NPS—National Park Service
RCP—Representative Concentration Pathway
SFHA—Special Flood Hazard Area
SLOSH—Sea, Lake, and Overland Surges from Hurricanes
SLR—Sea-Level Rise
VA—Vulnerability Assessment
WCU—Western Carolina University

Background & Objectives

In 2013, the National Park Service (NPS) initiated a project with the Program for the Study of Developed Shorelines at Western Carolina University (WCU) to develop a climate change vulnerability assessment (VA) protocol for infrastructure in coastal national parks. The **Coastal Hazards & Sea-Level Rise Asset Vulnerability Assessment Protocol** evaluates the vulnerability of NPS buildings and transportation assets to sea-level rise (SLR), flooding, and shoreline change. Underground utilities are not included as of this writing due to incomplete data regarding location, condition, and other attributes. The overarching purpose of climate change VAs within the NPS is to better understand the degree to which park resources and assets are "susceptible to harm from direct and indirect effects of climate change, including variability and extremes" (NPS 2021a). Vulnerability assessments help identify why, where, when, and which resources may be most at risk (NPS 2021b) and help prepare managers for effective adaptation planning (Beavers et al. 2016). The purpose of this document is to provide the developmental history of this protocol and a detailed description of the methodology.

Major project goals:

- Establish a standard methodology and set of best practices for conducting VAs in the built environment to allow managers to compare the vulnerability of coastal park infrastructure assets across the NPS.
- Provide VA results that are detailed, asset specific, and integrated with other NPS asset management data.
- Evaluate asset vulnerability as a function of exposure and sensitivity.
- Use widely available, established data sources to evaluate asset exposure.
- Provide a comprehensive and objective evaluation of asset sensitivity.

Development of the Coastal Hazards & SLR Asset Vulnerability Assessment Protocol

Assessing vulnerability is the first step in climate change and hazard adaptation, as this information is critical to sensibly managing and planning for resources and assets. The NPS and WCU developed the **Coastal Hazards & SLR Asset Vulnerability Assessment Protocol**, which creates a standard VA methodology for coastal park assets.

Multiple NPS-specific studies use exposure, sensitivity, and adaptive capacity to evaluate resource vulnerability (e.g., Amberg et al. 2012; Barrows et al. 2014; Handler et al. 2020; Hansen et al. 2013; Ricci et al. 2019a; b; Stroh et al. 2016). Exposure is a measure of the character, magnitude, and rate of changes a target may experience (e.g., from the impacts of climate change or a natural hazard; NPS 2021a), while sensitivity reflects the degree to which a resource is affected by the exposure. Adaptive capacity is the ability of a resource to accommodate or cope with the impacts (Beavers et al. 2016; Glick et al. 2011; NPS 2021a).

The discussion below includes a timeline for the development of the current VA protocol including improvements in the procedure and participating NPS units that contributed to the evolution of the current product.

Review of Previous Infrastructure VA Approach (2012–2013)

The NPS Sustainable Operations and Climate Change Branch (now the Sustainable Operations and Maintenance Branch) of the Facilities Management Division (in collaboration with the NPS Climate Change Response Program) piloted an effort called "Facilities Adaptation to Climate Change Impacts in Coastal Areas" (ICF International 2012a; b). This work developed a park-level risk screening approach to assess vulnerability of park facilities to selected coastal hazards using the three metrics of vulnerability. This approach used mapped landscape and geomorphologic data to evaluate exposure, and Facility Management Software System (FMSS) data to evaluate and score sensitivity and adaptive capacity (Facility Condition Index and Current Replacement Value attributes, respectively). The NPS piloted this approach in two parks (Pu`uhonua O Hōnaunau National Historic Park and Assateague Island National Seashore) and completed final reports in 2012 (ICF International 2012a; b). In 2013, the NPS partnered with WCU to expand and improve this VA approach (ICF International 2012a; b).

Goals for next steps in the protocol development were:

- Consider additional stressors (SLR and coastal flooding).
- Explore which indicators of vulnerability are most useful and appropriate to support park planning.

Creation of a New Coastal VA Protocol for Infrastructure (2014)

We presented an updated version of this protocol (ICF International 2012a; b) during the Climate Friendly Parks (CFP) Workshop at Cape Hatteras National Seashore, Wright Brothers National Memorial, and Fort Raleigh National Historic Site in November of 2014. Participant feedback indicated that Facility Condition Index and Current Replacement Value do not accurately represent an asset's sensitivity and adaptive capacity to coastal hazards and SLR. Park staff expressed hesitation about using FMSS data to evaluate and score physical vulnerability, as FMSS attributes can be subjective (depending on current priorities and staffing) and are calculated for specific management or maintenance purposes.

Workshop participants further discussed the complexities of evaluating adaptive capacity for infrastructure, noting that indicators for this component of vulnerability are numerous, hard to quantify, and can change frequently. Infrastructure cannot inherently adapt to climate change or other hazards, while "living" resources often can (e.g., salt marsh plants can naturally adapt to SLR by migrating upland, whereas a building, on its own, cannot). Some organizations and agencies include extrinsic circumstances as part of adaptive capacity for infrastructure. These include a wide variety of organizational, social, political, or economic factors that would (or would not) enable relocation or modification of infrastructure to avoid harm from the effects of SLR, storms, and other stressors. However, the subjective, ever-changing, and often transient nature of these extrinsic factors makes them difficult to evaluate and quantify in a meaningful or consistent way.

Based on feedback from this workshop and follow-up discussions, we drafted a new VA protocol for coastal infrastructure, including these key features.

Key protocol features:

- Standardized exposure and sensitivity indicators (i.e., representative proxy factors) for evaluating the vulnerability of coastal hazards and SLR.
- Data collection that is as objective and uniform as possible.
- Exposure indicators that include multiple coastal hazards and climate change factors, and use well-established, widely available, and georeferenced data (where available). These indicators include flooding potential, shoreline change, SLR inundation, extreme event flooding, and reported coastal hazards.
- Sensitivity indicators that include inherent properties, construction types/methods, or other characteristics of the asset, and no longer use FMSS attributes. These indicators include flood damage potential, storm resistance/condition, historical damage, and protective engineering.
- Adaptive capacity is not included in an asset's vulnerability score.

Pilot of the Coastal Hazards & SLR Asset Vulnerability Assessment Protocol (2015)

In 2015, we piloted the **Coastal Hazards & SLR Asset Vulnerability Assessment Protocol** in seven park units in the NPS Southeast Region: Big Cypress National Preserve, Biscayne National Park, Fort Sumter and Fort Moultrie National Historical Park, Gulf Islands National Seashore, Cape Hatteras National Seashore, Wright Brothers National Memorial, and Fort Raleigh National Historic Site. Feedback obtained during CFP and Integrated Park Improvement workshops led to further refinement of the protocol. During this pilot period, the NPS also established additional protocol standards related to methods, data, and scoring. These standards were based on NPS planning needs and concurrent climate change and vulnerability projects.

Key protocol developments:

- Creation of the asset-level survey tool and methods for data about each sensitivity indicator, recognizing that park personnel with institutional knowledge have the most accurate and current information regarding these indicators. While facility databases may contain some data related to these indicators (e.g., condition), in most cases these data are not appropriate for this protocol.
- Incorporating precise threshold elevation data for buildings (when available) into the sensitivity analysis to increase accuracy of the indicator on flood damage potential.

Standards we adopted in the 2015 protocol revision include:

- 2050 planning horizon for the VAs as requested by the NPS.
- Scoring structure compatible with the Federal Highway Administration Vulnerability Assessment Scoring Tool (ICF 2015) as requested by the NPS.
- Use of SLR projections from the United Nations Intergovernmental Panel on Climate Change and storm surge scenarios from National Oceanic and Atmospheric Administration (NOAA) models (Caffrey et al. 2018), if available, within the exposure analysis.

VA Protocol Expansion & Collaboration (2016–2017)

Throughout 2016 and 2017, the project expanded to include additional park units across all coastal NPS regions (18 for an exposure analysis and 12 for a full VA). This required protocol modifications for areas with different geomorphology (e.g., cliffed shorelines) and areas with additional hazards (e.g., tsunami).

In addition to participating in CFP workshops at Jean Lafitte National Historical Park and Preserve and Canaveral National Seashore, we provided VA results for Colonial National Historical Park to be included in the Integrated Coastal Climate Change Vulnerability Assessment methodology piloted by the NPS Northeast Region and the University of Rhode Island (Ricci et al. 2019b). We also provided vulnerability data for incorporation into a cultural resources adaptation pilot study of historic buildings at Cape Lookout National Seashore (Fatorić and Seekamp 2017).

Key protocol developments:

- Addition of region-specific coastal hazards, such as tsunamis in the NPS Alaska Region and cliff retreat in the NPS Pacific West Region.
- Incorporation of a minimal (or no) exposure category to score assets more accurately across all coastal parks.

Continued Protocol Implementation & Collaboration (2017–present)

Over the next several years, we completed VAs at multiple parks using the **Coastal Hazards & SLR Asset Vulnerability Assessment Protocol** and assisted with the integration of these results into ongoing collaborative projects. We provided infrastructure vulnerability data for the Integrated Coastal Climate Change Vulnerability Assessment methodology at Fire Island National Seashore and George Washington Birthplace National Monument, as well as for the Facility Management Environmental Hazard Assessment, Adaptation and Resilience Planning Workshop at Fort Pulaski National Monument. We also presented vulnerability assessment results at the CFP workshop at New Bedford Whaling National Historical Park and Roger Williams National Memorial.

In 2020, the NPS Climate Change Response Program tasked WCU to complete VAs for all remaining NPS Southeast Region coastal units to provide a region-wide analysis and summary of vulnerability. The only major development to the protocol during this period was the added evaluation of a higher SLR scenario in response to updated projections in 2017 from NOAA (Sweet et al. 2017). This higher SLR scenario was included only as a comparison for these NPS Southeast Region park units.

In 2022, NOAA updated their SLR projections again (Sweet et al. 2022). These projections will determine the SLR scenario used in the protocol, and this scenario will be used to assess exposure results going forward pending additional, future SLR projection updates. The next phase of this project (which began in 2022) will complete VAs for all remaining NPS Northeast Region coastal units. To date, WCU has used the protocol to evaluate vulnerability at more than 40 park units.

Key (2022) protocol developments:

- Evaluation of a higher SLR scenario in response to updated projections from NOAA.

Protocol Methodology

The **Coastal Hazards & SLR Asset Vulnerability Assessment Protocol** evaluates the vulnerability of NPS assets to SLR, flooding, and shoreline change approximately to the year 2050, with a focus on buildings and transportation assets listed in the NPS FMSS database. This protocol has three primary steps: 1) Exposure Mapping and Analysis, 2) Sensitivity Analysis, and 3) Vulnerability Calculations. Figure 1 summarizes the key steps within this VA protocol.

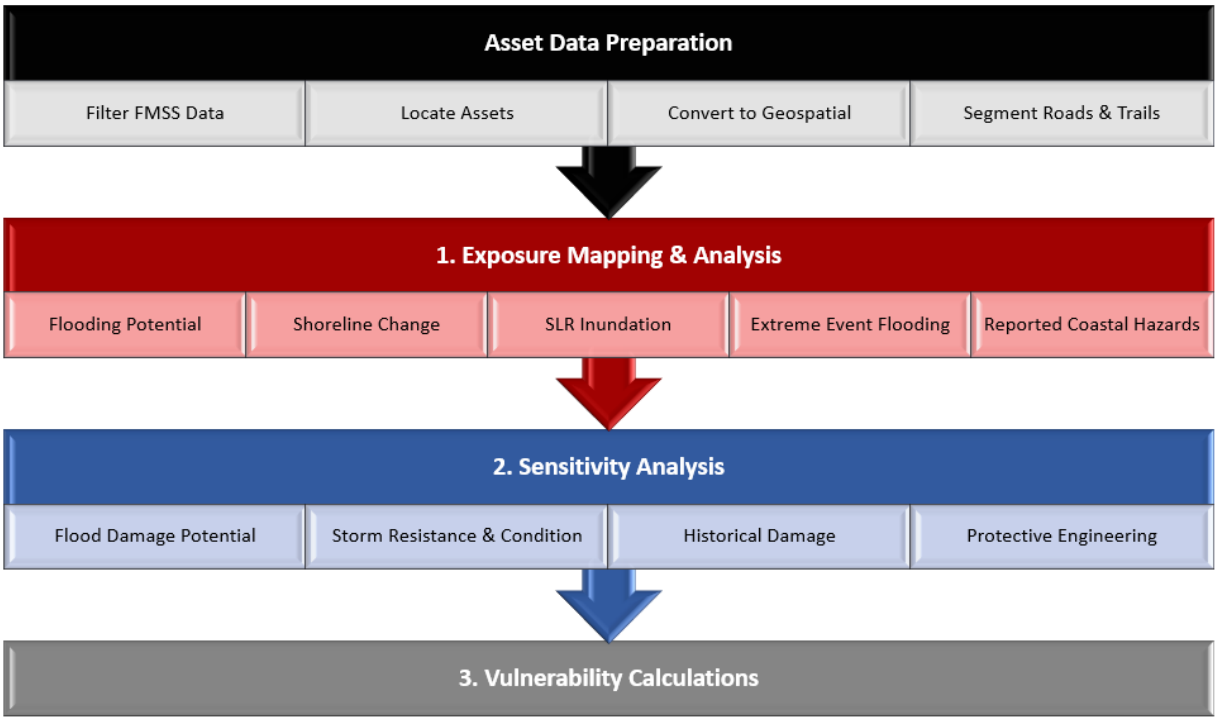


Figure 1. Flowchart of the primary steps within the Coastal Hazards & SLR Asset Vulnerability Assessment Protocol.

Asset Data Preparation

Due to the quantity of information within FMSS, we prepare the asset data by completing these initial steps.

1. **Filter park-specific FMSS Location Hierarchy Report to extract buildings (or structures) and transportation-related assets.** The most common asset types evaluated are roads, parking areas, trails, buildings, marinas, and fortifications. Asset types commonly not evaluated include maintained landscapes, major systems (e.g., water, electrical, waste, communications), archaeological sites, and interpretive media. Underground utilities are not included as of this writing due to incomplete data regarding location, condition, and other attributes. All evaluated FMSS Asset Types and Facility Types are found in Appendix A.

2. **Obtain existing asset geographic location data.** Many FMSS-listed assets lack geospatial coordinates. We request the relevant geospatial data from archives maintained at the regional and national levels (typically in a geodatabase format).
3. **Associate geospatial data with FMSS records.** As required, we associate geospatial data (provided by the NPS) with the correct FMSS records.
4. **Identify the latitude and longitude of assets without geographic location data.** We most commonly use imagery (aerial or ground), site visits, and correspondence with park staff to obtain the geographic location data of assets.
5. **Convert FMSS asset data into a geospatial format.** To prepare the FMSS asset data for exposure analysis, we initially convert location data to point shapefiles (linear and polygon features are digitized during the exposure analysis in most parks).

Road & Trail Segmentation

We represent roads and trails geospatially as continuous linear features (i.e., polylines). However, since exposure varies with location, we divide long roads and trails into smaller segments to assess vulnerability more accurately and at a finer scale. Typically, we segment these assets based on exposure variability, length, road intersections, and/or geographical features. We then evaluate and score each segment individually for exposure, sensitivity, and vulnerability (Figure 2). We also assign each segment a modified location code (e.g., 12345_1, 12345_2, 12345_3); however, all segments share the same FMSS attributes.

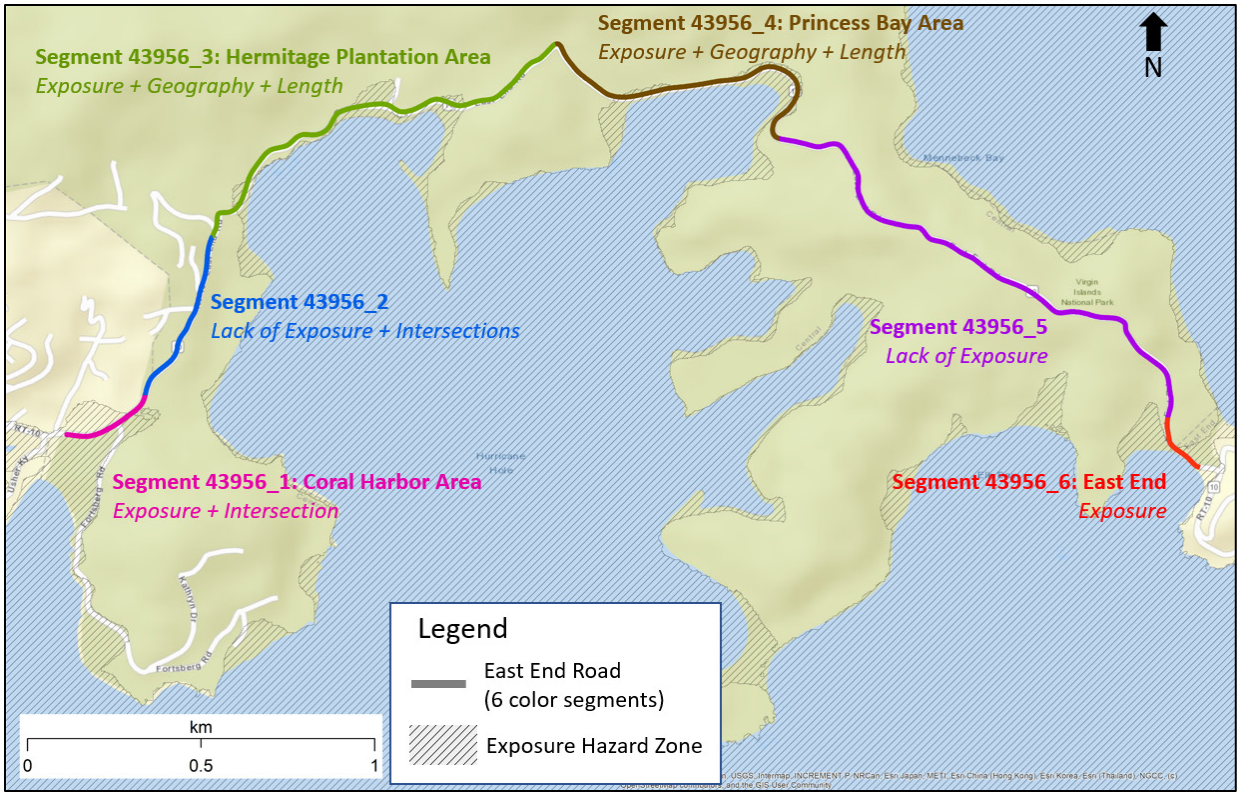


Figure 2. Example of road segmentation process for East End Road at Virgin Islands National Park. The primary segmentation factor for this road was level of exposure (the most extensive hazard zone for this area is shown by grey hatched areas). Road intersections, geography, and segment length were also used as criteria to determine break points between segments.

Exposure Mapping & Analysis

This VA protocol includes five coastal hazard and climate change exposure indicators: flooding potential, shoreline change, SLR inundation, extreme event flooding, and reported coastal hazards (Table 1). Evaluating exposure is primarily a geospatial exercise, as exposure is directly dependent on location (i.e., whether the area surrounding an asset has experienced, or has the potential to experience, a hazard). Although we complete much of the exposure analysis in Geographic Information Systems (GIS), we record all calculations and results in the Exposure Analysis Data Results Excel sheet (Figure 3). In most cases, this protocol relies on existing exposure data. Only in rare instances do we create unique exposure maps or data.

Table 1. Exposure indicators and common data sources.

Indicator	Description	Common Data Sources
Flooding Potential	1% annual flood chance ± velocity/waves	Federal Emergency Management Agency flood zones (VE or AE); digital elevation models
Shoreline Change	Erosion, coastal proximity, or cliff retreat	Shoreline buffers derived from USGS, state, or NPS shoreline change data; cliff retreat rate buffers; shoreline proximity buffers
SLR Inundation	2050 scenarios	NPS-specific SLR modeling [A]; NOAA SLR projections & inundation model [B]; digital elevation models
Extreme Event Flooding	Storm surge, tsunami, or extreme high water	NPS-specific storm surge projections & models [A]; digital elevation models; NOAA SLOSH models [C]; digital elevation models
Reported Coastal Hazards	Historic flooding, visible slope instability	Park surveys/questionnaire results; storm imagery & reconnaissance

[A] Caffrey et al. 2018

[B] Sweet et al. 2017; 2022

[C] SLOSH - Sea, Lake, and Overland Surges from Hurricanes; Zachry et al. 2015

Exposure Analysis Data Results

Definitions of WCU Columns on Next Sheet (Click Here to View)

		Step 1: Score for Exposure Indicator Zones					
ID	Location	1a. FEMA VE Zone Score	1b. FEMA A Zone Score	1c. Shoreline Change Score	1d. SLR Score	1e. Extreme Flooding Score	1f. Historic Flood Score
1	Asset Name		4	1	1	4	4
2	Asset Name		1	1	1	4	1
3	Asset Name		4	1	1	4	1
4	Asset Name		4	1	1	4	4
5	Asset Name	4		1	1	4	4
6	Asset Name		4	4	1	4	4
7	Asset Name		4	4	1	4	4
8	Asset Name	4		1	1	4	4
9	Asset Name		4	4	1	4	4
10	Asset Name		4	1	1	4	4

Figure 3. A portion of an *Exposure Analysis Data Results* Excel sheet, showing an example of scoring for each exposure indicator (columns 1a–1f). Columns 1a. and 1b. together represent the flooding potential indicator, and column 1f. Historic Flood Score is the reported coastal hazards indicator in this example. See Table B-1 for an accessible version.

In general, we assign each asset a score of 4 or 1 for each of the five exposure indicators (Table 1). We assign a score of 4 to assets located within an exposure indicator zone (or with a record of past coastal hazards), and a score of 1 to assets that are outside the indicator zone. At the outset of the protocol development, the NPS requested that our scoring structure be compatible with the Federal

Highway Administration Vulnerability Assessment Scoring Tool, which uses a 1–4 numeric scoring system. In general, the scoring structure represents a binary scoring method where 4 is unfavorable and 1 is favorable (as higher scores overall mean higher exposure). We calculate a raw total indicator score for each asset and then categorize (bin) those scores into one of four exposure rankings (based on the number of hazard zones): minimal or none (asset is not within any mapped zone), low (1 zone), moderate (2–3 zones), and high (4–5 zones). Specific methods for scoring each exposure indicator are described in the following sections.

1. Flooding Potential Indicator

The flooding potential indicator describes hazards related to the 1% annual flood chance, including waves and water velocity. The following sections describe the data sources, data preparation steps, methods, and scoring for this exposure indicator.

Data Sources & Preparation

Federal Emergency Management Agency (FEMA) Flood Insurance Rate Maps (FIRMs, also known as flood maps, see Box 1) are the most common data source for the flooding potential exposure indicator (Table 1). Relevant FEMA flood zones include those within the Special Flood Hazard Area (SFHA), most commonly the VE and AE zones (less commonly the A, AO, or AH). FEMA defines the VE zone as "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 zone as "areas subject to inundation by the 1-percent-annual-chance flood event" (determined by detailed methods; FEMA Glossary 2021). One caveat is that these data do not currently address any projections of climate change. For a further description of the FEMA flood zones, see Box 1.

Box 1. FEMA Flood Zones and Special Flood Hazard Area Definitions

Flood hazard areas identified on the Flood Insurance Rate Map are identified as a Special Flood Hazard Area (SFHA). SFHA are defined as the area that will be inundated by the flood event having a 1-percent chance of being equaled or exceeded in any given year. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood. SFHAs are labeled as Zone A, Zone AO, Zone AH, Zones A1-A30, Zone AE, Zone A99, Zone AR, Zone AR/AE, Zone AR/AO, Zone AR/A1-A30, Zone AR/A, Zone V, Zone VE, and Zones V1-V30.

Glossary Section: NFIP - National Flood Insurance Program

FEMA data preparation steps:

1. **Download digital FIRMs using FEMA's** National Flood Hazard Layer Viewer**.** Most coastal areas have digital data. For an area without digital data, we consult the PDF FIRMs.
2. **Insert digital FEMA data into a GIS software program.** Since the beginning of this project, we have used numerous versions of ESRI's ArcMap software (most recently version 10.8).
3. **Select and extract the VE and AE (or alternate A) zones.** This step reduces the overall size of the data used for the GIS analysis and is not always necessary for smaller parks.
4. **Clip the FEMA data to the extent of the park.** This step further reduces the overall size of the data used for the GIS analysis and is not always necessary.

Most parks evaluated thus far have FEMA digital flood map coverage. In the few exceptions where detailed FEMA data are lacking, we use a variety of data sources (e.g., digital elevation models, records of past flood extent, other hazard maps) and geologic expertise to make an informed decision. For example, FEMA designated a portion of Everglades National Park within a D zone, which is defined as "possible but undetermined flood hazards" (Figure 4). Based on the elevation data, other storm surge maps, adjacent flood zones, and record of past flooding, we determined that assets in this area should be scored within FEMA's A zone.

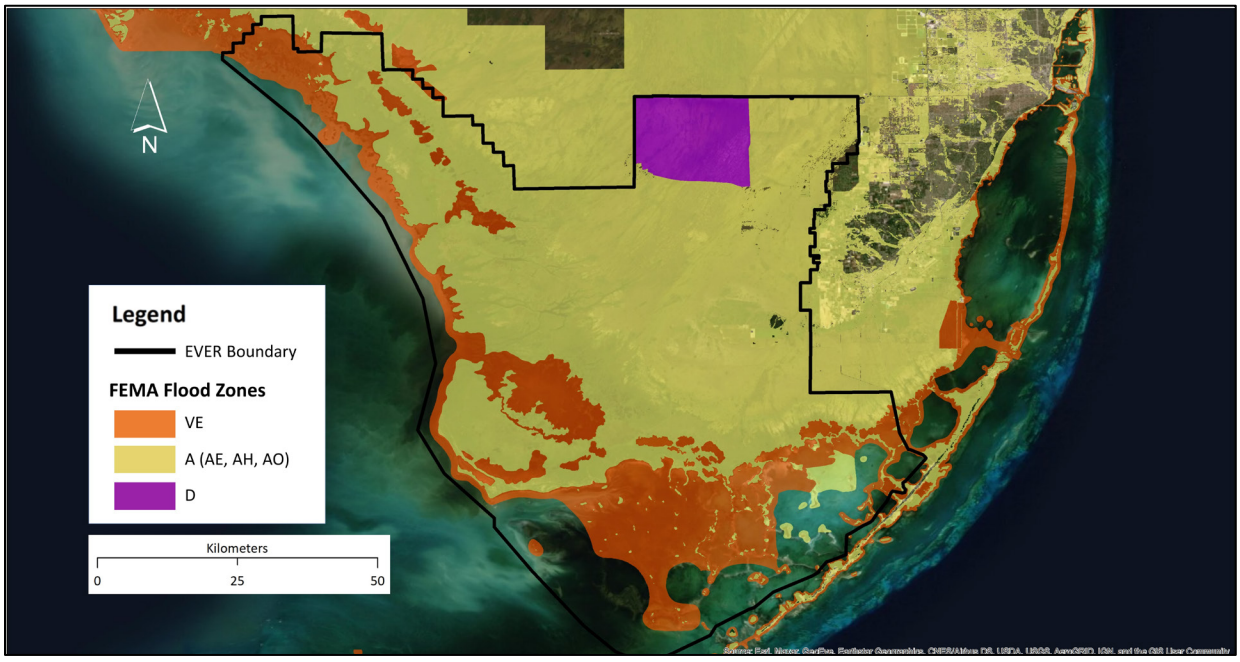


Figure 4. FEMA flood zones for Everglades National Park, showing the D zone (possible but undetermined flood hazards). In this zone, we used elevation data, storm surge maps, past flooding, and adjacent flood zones to evaluate the flooding potential indicator.

Analysis & Scoring

The following scoring methodology for the flooding potential exposure indicator applies to units with full FEMA FIRM coverage. For parks where FEMA data are lacking, we score assets directly based on alternate data sources and geologic expertise.

Flooding Potential Indicator scoring methodology:

1. **Map the location of park assets and compare to the extent of the FEMA flood zones.** Using ArcMap, we compare the location of park assets to the extent of the FEMA SFHA.
2. **Score assets within the FEMA VE flood zone.** We assign assets located within the VE zone (the highest hazard zone) a score of 4 within the *1a. FEMA VE Zone Score* column in the *Exposure Analysis Data Results* Excel sheet (Figure 3).
3. **Score assets within the FEMA AE flood zone.** We assign assets located within the AE (or other A) zone a score of 4 within the *1b. FEMA AE Zone Score* column in the *Exposure Analysis Data Results* Excel sheet (Figure 3).
4. **Score assets outside of FEMA flood zones.** We assign assets located outside of both the FEMA flood zones (VE or A) a score of 1 within the *1b. FEMA AE Zone Score* column in the *Exposure Analysis Data Results* Excel sheet (Figure 3).

2. Shoreline Change Indicator

The shoreline change exposure indicator represents hazards such as beach and dune erosion, cliff retreat, and coastal proximity. We most commonly evaluate shoreline erosion and coastal proximity hazards for this indicator. The following sections describe the data sources, data preparation steps, methods, and scoring for this exposure indicator.

Data Sources & Preparation

We commonly acquire shoreline change (erosion/accretion rate and cliff retreat) data from the U.S. Geological Survey (Coastal Change Hazards Portal), state coastal management programs (e.g., North Carolina Division of Coastal Management), or from the NPS Inventory and Monitoring Program (Table 1). In most cases, these shoreline-change data are calculated and displayed along evenly spaced transects (commonly 50 meters apart) along the oceanfront. This protocol uses the short-term shoreline change rates (calculated using data ranging from the 1970's to present day) when available. We recognize that with continuing SLR, these numbers may eventually underestimate shoreline retreat in many areas.

Using these data, we create *Shoreline Change Hazard Zones* to represent the land area potentially exposed to shoreline change to the year 2050. For parks evaluated prior to 2020, shoreline change analyses were based on a 35-year timeline. Parks evaluated after 2020 use a 30-year timeline.

Shoreline Change Hazard Zone GIS steps:

1. **Obtain or digitize a shoreline adjacent to park assets.** A digital shoreline is required as a baseline to create shoreline change hazard zones. Recent digital shorelines are sometimes available, particularly for parks with property along the oceanfront. When no shorelines are available, we manually digitize a shoreline based on the most recent aerial imagery using the wet/dry line for oceanfront or sandy shorelines (Figure 5), and the water's edge for other estuarine, soundside, and urban shorelines. We consult aerial imagery from multiple timeframes when using the water's edge for digitization, in particular in areas with a high tidal range.
2. **Group and display shoreline change data.** In most cases, we group and display (color code) shoreline-change data transects in 1- or 2-meter increment groups (Table 2, and Figure 5). In limited cases, especially shorelines with cliff retreat, it may be necessary to group transects into more detailed increments (Peek et al. 2017).
3. **Interpret shoreline segments.** We divide the digital shoreline into segments based on our interpretation of patterns in the color-coded shoreline change transects (Table 2, and Figure 5).
4. **Buffer shoreline segments with shoreline change data.** We buffer the shoreline segments based on the increment groups and corresponding buffer distance (Table 2, and Figure 5). Buffer distances are a function of the shoreline change increment and the study timeline (e.g., either 30 or 35 years).
5. **Buffer shorelines without shoreline change data.** We use a standard buffer distance for shorelines without shoreline change data (e.g., estuarine, sound, marsh, or urban; Table 2, and Figure 5). This creates a shoreline proximity buffer, which assumes areas closest to the coast generally have a higher exposure to erosion and other hazards. Final buffers represent the shoreline change hazard zones (Figure 5).

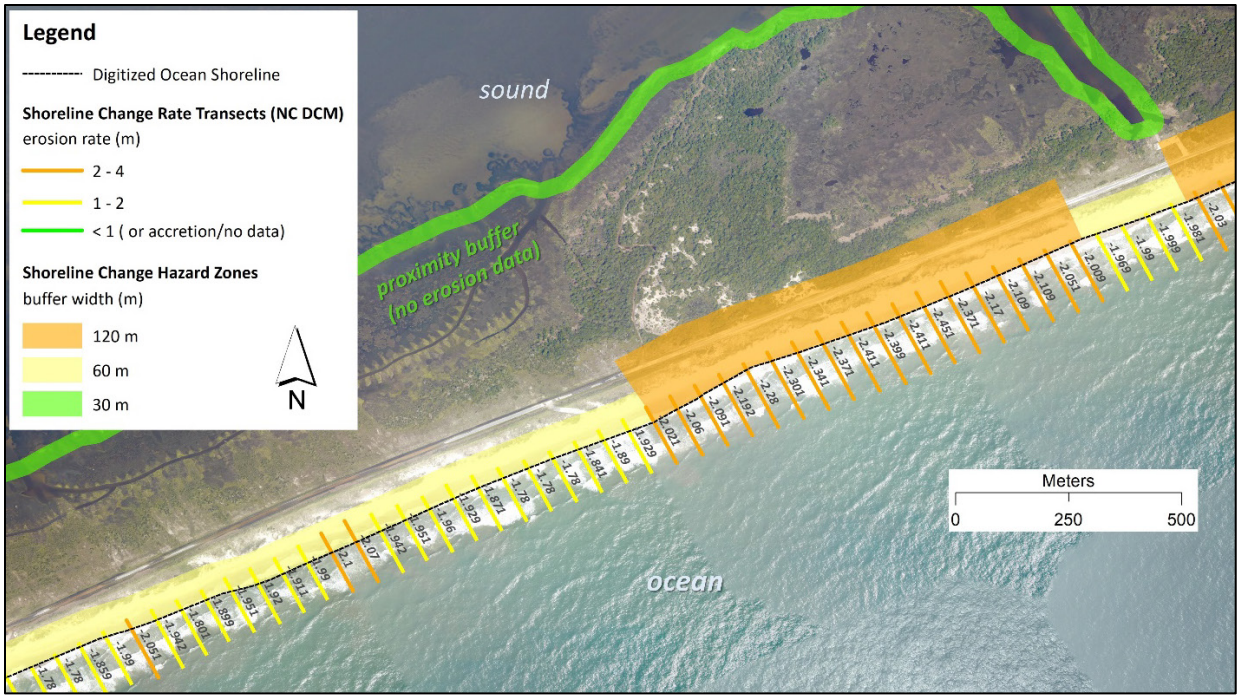


Figure 5. Example of the *Shoreline Change Hazard Zone* and associated data at Cape Hatteras National Seashore. Shoreline change rate transects are perpendicular to the shoreline and color coded by increment group (Table 2). We segmented and buffered the digitized oceanfront shoreline (dotted black line) by interpreting the general patterns in the transect rates. Note that we generalized the three 2 to 4 meters of erosion per year transects (orange) on the west portion of the shoreline to be within the 60-meter buffer zone (1 to 2 meters of erosion per year). As a rule, we only generalize up to 3 consecutive transects within another zone.

Table 2. Shoreline change increment groups and buffer distances.

Increment Groups	Description	Buffer Distance [A]
1 meter / year	<1 meters of erosion per year (accretion or no data)	30 meters
2 meter / year	1 to 2 meters of erosion per year	60 meters
4 meter / year	2 to 4 meters of erosion per year	120 meters
6 meter / year [B]	4 to 6 meters of erosion per year	180 meters

[A] Using a 30-year timeline (parks evaluated after 2020).

[B] Continued 2-meter increments as needed.

Analysis & Scoring

Using ArcMap, we compare the location of park assets to the extent of the shoreline change hazard zones. We assign assets located within any of the mapped shoreline change hazard zones a score of 4 within the 1c. *Shoreline Change Score* column in the *Exposure Analysis Data Results* Excel sheet, and those outside the zone a score of 1 (Figure 3).

3. SLR Inundation Indicator

The SLR inundation indicator describes hazards related to the potential inundation by SLR by the year 2050. The following sections describe the data sources, data preparation steps, methods, and scoring for this exposure indicator.

Data Sources & Preparation

The data for this exposure indicator are SLR projections and inundation models (Caffrey et al. 2018) developed specifically for NPS units (Table 1). This study estimated inundation extent using a modified bathtub approach developed by NOAA, which attempts to account for local and regional tidal variability and hydrological connectivity. The authors developed inundation scenarios for the years 2050 and 2100, based on the moderate (4.5) Representative Concentration Pathway (RCP) and the most extreme (8.5) RCP. 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 SLR data in parks with high rates of subsidence (parks in southern Louisiana) or uplift (many Alaska parks) will require adjustment.

In 2020, we revised the SLR data used in the protocol to reflect more closely the updated (and in most cases higher) projections from NOAA (Sweet et al. 2017). For parks with VAs initiated in 2020 or 2021 (primarily NPS Southeast Region parks), these new data were only provided for comparison and were not incorporated into the final exposure results. We will consult NOAA's most recent projections (Sweet et al. 2022) on all VAs initiated in 2022 (and later) to determine the scenario used within the protocol and will incorporate this scenario into the exposure results going forward.

Methods for incorporating higher SLR projections:

1. **Consult NOAA SLR data and projections.** We consult NOAA's Sea Level Rise Viewer to identify the closest location (to the evaluated park) with updated SLR projections. We use the 2050 intermediate and intermediate-high SLR scenarios (Figure 6).
2. **Consult SLR data tables and projections from the NPS-specific SLR study.** We consult data tables from Caffrey et al. (2018) to identify the SLR values for each year and scenario (Figure 6, inset).
3. **Select the NPS-specific projection that best matches the NOAA projections.** The selected SLR value (and associated inundation maps) serves as a proxy for the updated NOAA projections for 2050 (Figure 6).

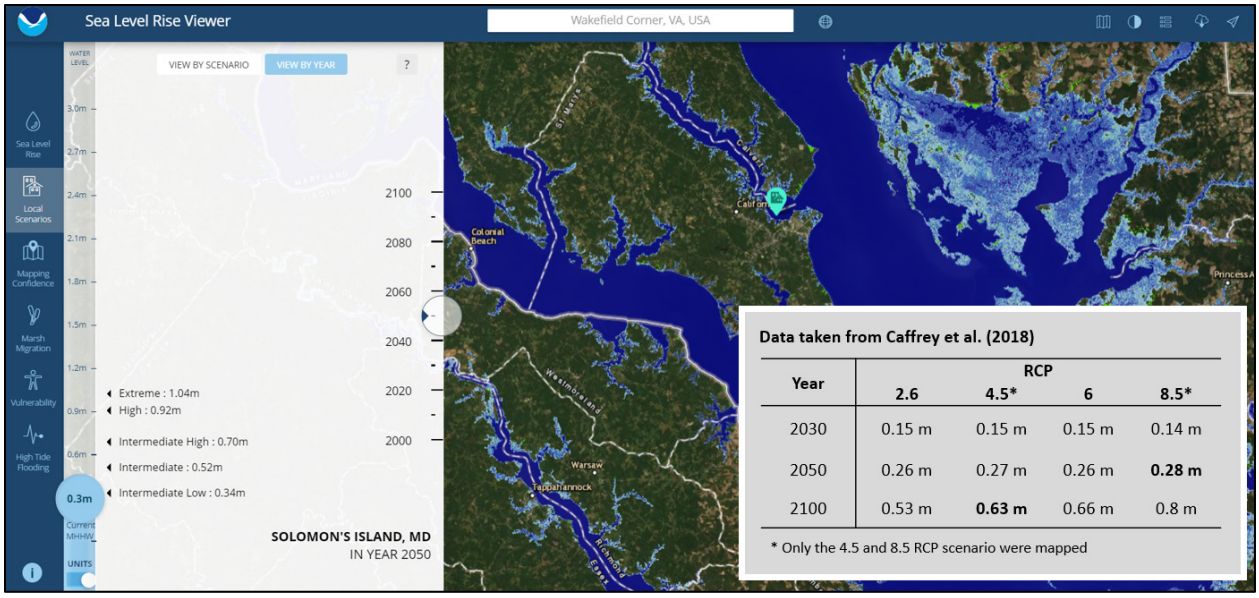


Figure 6. NOAA SLR viewer local scenario (background image) and NPS-specific SLR projections (inset table) for George Washington Birthplace National Monument. We selected the 2100 4.5 RCP SLR value (0.63 meters) because it best matches the NOAA intermediate and intermediate high scenarios (0.52 meters and 0.7 meters respectively). See Table B-2 for an accessible version of the inset.

Analysis & Scoring

Using ArcMap, we compare the location of park assets to the extent of the SLR inundation hazard zone. We assign assets located within this hazard zone a score of 4 within the *1d. SLR Score* column in the *Exposure Analysis Data Results* Excel sheet, and those outside the zone a score of 1 (Figure 3).

4. Extreme Event Flooding Indicator

The extreme event flooding indicator describes hazards related to storm surge, tsunami, or other extreme high-water events. The following sections describe the data sources, data preparation steps, methods, and scoring for this exposure indicator.

Data Sources & Preparation

Storm surge is the primary extreme flooding event that occurs within parks along the Atlantic Ocean and Gulf of Mexico coast of the U.S. The most common data source for this exposure indicator is storm surge inundation models (Caffrey et al. 2018) developed specifically for NPS units using NOAA's SLOSH (Sea, Lake, and Overland Surges from Hurricanes) methodology (see NOAA for more information). We selected the category 3 storm surge inundation maps for use within this analysis (Table 1). We also consult NOAA's National Storm Surge Hazard Maps - Version 2 (SLOSH) and/or digital elevation models as part of the analysis, primarily for comparison or when other data do not exist.

For parks not commonly impacted by tropical storms and surge (e.g., parks in the NPS Pacific West and Alaska regions), we evaluate other extreme event flooding hazards, commonly either modeled extreme high-water events (from Caffrey et al. 2018) or tsunami hazard zones. The source of the tsunami hazard data is variable, but commonly comes from state agencies or universities.

Analysis & Scoring

Using ArcMap, we compare the location of park assets to the extent of the extreme event flooding hazard zone. We assign assets located within this hazard zone a score of 4 within the *1e. Extreme Event Flooding Score* column in the *Exposure Analysis Data Results* Excel sheet, and those outside the zone a score of 1 (Figure 3). Some parks have more than one extreme event flooding dataset available (e.g., Caribbean parks often have both tsunami and storm surge inundation maps). In these cases, we assign an asset a score of 4 if located within any of the available inundation datasets.

5. Reported Coastal Hazards Indicator

The reported coastal hazards exposure indicator captures how past events (e.g., historic flooding and visible slope instability) impacted individual assets. We include this indicator to add additional weight to locations that have experienced previous flooding (primarily) and to provide some verification of the four indicators above, which are largely predictive.

Data Sources & Preparation

We commonly obtain historical flooding and visible slope instability information from park staff through a questionnaire (WCU 2022) and subsequent discussions, as well as imagery and reconnaissance visits.

Analysis & Scoring

We assign assets with reported coastal hazards a score of 4 within the *1f. Reported Coastal Hazards* column in the *Exposure Analysis Data Results* Excel sheet, and those without reported coastal hazards a score of 1 (Figure 3).

Quality Control

The exposure analysis process is primarily a geospatial exercise; however, expert verification is crucial to provide the most accurate and meaningful results. Hazard data are often incomplete within national parks, can contain errors, and do not always accurately model dynamic coastal environments. While the exposure analysis in this protocol uses the most current and reliable datasets available, extreme events often can completely reconfigure a coastal shoreline and topography in a short period of time (Figure 7). As a result, exposure data sources can quickly become inaccurate, especially inundation models, which have the potential to underestimate flooding in areas recently overwashed by hurricanes (Figure 7).

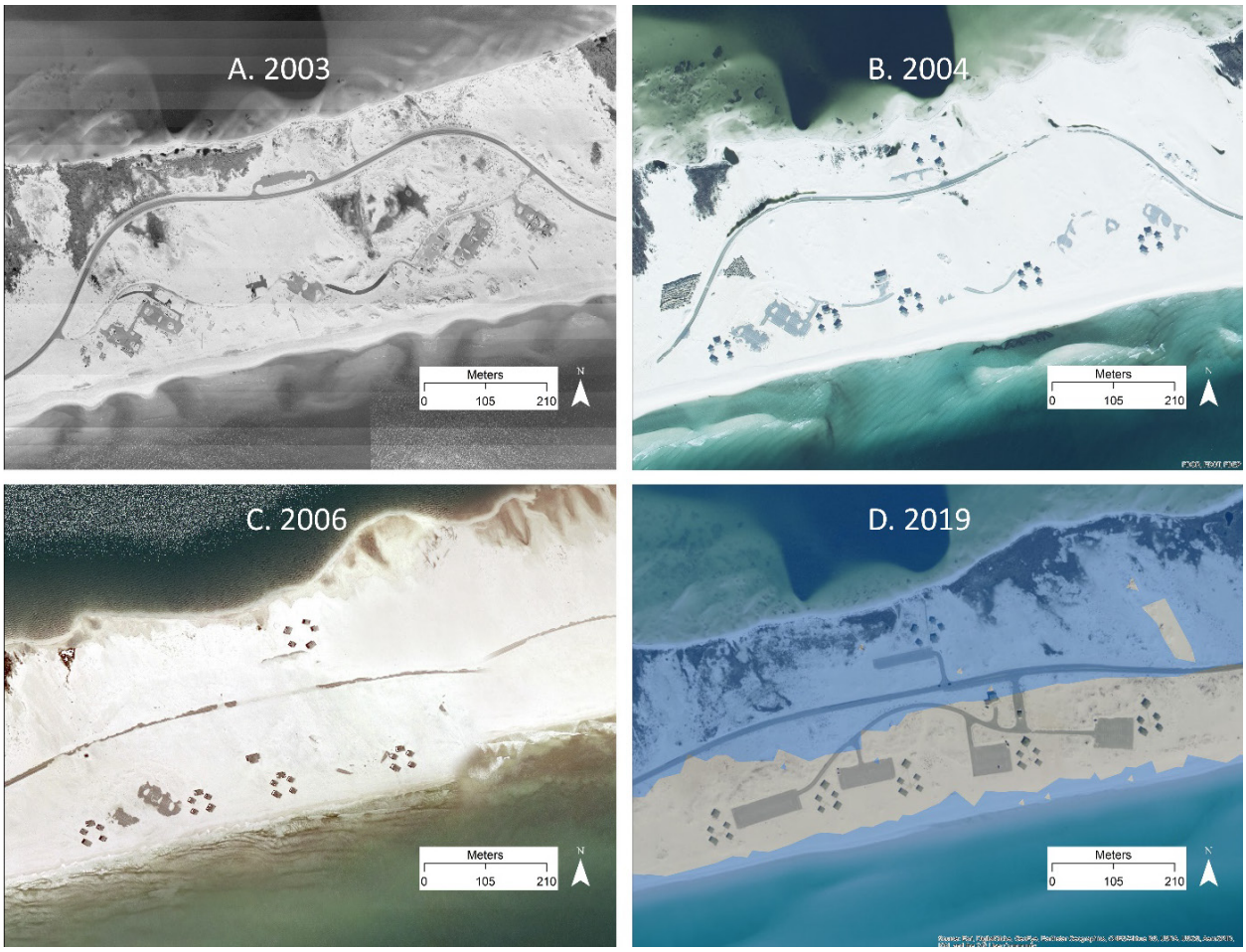


Figure 7. Aerial imagery highlighting barrier island geomorphology and infrastructure changes at Gulf Islands National Seashore. A) 2003 infrastructure configuration in the Opal Beach area. B) Overwash from storms in 2004 covering Opal Beach infrastructure. C) New infrastructure configuration at Opal Beach with overwash from storms in 2006. D) Storm surge category 3 inundation model (green shading) and recent (2019) Opal Beach infrastructure configuration. Due to the changing shoreline and topography at this location, the surge model does not show inundation of the oceanfront infrastructure, despite multiple overwash episodes.

As part of this protocol, we carefully review all exposure hazard data and use our knowledge of coastal geomorphology and past events to identify possible errors or inaccuracies. When necessary, we verify hazard data by consulting multiple other data sources (often historical aerial imagery, storm records, and other existing hazard maps). This quality control is imperative, particularly for studies that utilize hazard model datasets.

Because assets are represented in GIS by points and lines, we examine aerial imagery to observe the exact geographic footprint of each asset relative to the hazard zones. This is completed during the initial exposure analysis and scoring, and then repeated (often multiple times, by multiple personnel) as a final quality control check on the results.

Exposure Calculations & Final Scoring

After individual scores are determined for each exposure indicator (as described in the previous sections), we complete several additional steps to obtain a final, comprehensive exposure score and rank that incorporates all hazards (see Box 2). We record all exposure calculations and scoring within the *Exposure Analysis Data Results* Excel sheet (Figure 8).

Box 2. Exposure Rank Descriptions

This VA evaluates the exposure of assets to *multiple coastal hazards combined* (Table 1).

Assets with **High Exposure** are within *at least four* exposure indicator hazard zones.

Assets with **Moderate Exposure** are within *two or three* exposure indicator hazard zones.

Assets with **Low Exposure** are within *only one* exposure indicator hazard zone. The asset could still be seriously impacted by this hazard.

Assets with **Minimal Exposure** are *not in any* exposure indicator hazard zone. This does not mean that the asset has no exposure to coastal hazards, but it is not within the exposure hazard data used in this study.

Exposure Analysis Data Results														
Definitions of WCU Columns on Next Sheet (Click Here to View)														
		Step 1: Score for Exposure Indicator Zones						Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	
ID	Location	1a. FEMA VE Zone Score	1b. FEMA A Zone Score	1c. Shoreline Change Score	1d. SLR Score	1e. Extreme Flooding Score	1f. Historic Flood Score	Raw Score from Step 1	Binned Raw Score	VE Auto High	Exposure Score Unmod.	Flagged Asset	Exposure Score	Exposure Rank
1	Asset Name		4	1	1	4	4	14	3		3	see notes	3	moderate
2	Asset Name		1	1	1	4	1	8	2		2		2	low
3	Asset Name		4	1	1	4	1	11	3		3		3	moderate
4	Asset Name		4	1	1	4	4	14	3		3	see notes	3	moderate
5	Asset Name	4		1	1	4	4	14	3	4	4	see notes	4	high
6	Asset Name		4	4	1	4	4	17	4		4		4	high
7	Asset Name		4	4	1	4	4	17	4		4		4	high
8	Asset Name	4		1	1	4	4	14	3	4	4	see notes	4	high
9	Asset Name		4	4	1	4	4	17	4		4	see notes	4	high
10	Asset Name		4	1	1	4	4	14	3		3		3	moderate
11	Asset Name		4	1	4	4	1	14	3		3	see notes	3	moderate
12	Asset Name		4	1	4	4	4	17	4		4		4	high
13	Asset Name		4	1	1	4	4	14	3		3		3	moderate
14	Asset Name		4	1	4	4	4	17	4		4		4	high
15	Asset Name		4	1	4	4	4	17	4		4	see notes	4	high
16	Asset Name		4	1	4	4	4	17	4		4	see notes	4	high
17	Asset Name		4	1	4	4	4	17	4		4	see notes	4	high
18	Asset Name		4	1	1	4	4	14	3		3		3	moderate

Figure 8. Example of an *Exposure Analysis Data Results* Excel sheet, showing all scoring columns, including individual indicator scoring, intermediate calculations, and final exposure results. Data columns not shown include multiple attributes taken directly from FMSS, and any final notes related to exposure analysis and scoring. See Table B-3 for an accessible version.

Final exposure scoring steps:

1. **Calculate the raw scores.** We calculate raw scores as a sum of the exposure indicator scores (using an Excel formula) within the *Step 2: Raw Score from Step 1* column (Figure 8).
2. **Bin the raw scores.** We bin (group) the raw exposure scores into categories based on the natural breaks shown in Table 3 and record these scores within the *Step 3: Binned Raw Score* column (Figure 8).

Table 3. Exposure scoring summary.

Exposure Zones [A]	Raw Score	Exposure Score	Exposure Rank
4 or 5	17–20	4	High
2 or 3	11–14	3	Moderate
1	8	2	Low
0	5	1	Minimal [B]

[A] Number of exposure indicator zones an asset is within (assigned a 4).

[B] Minimal (or no), as some assets may not have exposure to the hazards evaluated.

3. **Record assets within the FEMA VE Zone.** Within this protocol, we automatically assign any asset within FEMA's highest hazard zone (VE) a high exposure score overall. We also assign any assets with a score of 4 in the *1a. FEMA VE Zone* column a score of 4 in the *Step 4. VE Auto High* column (Figure 8).
4. **Update the exposure score.** We assign a score of 4 within the *Step 5. Exposure Score Unmodified* column for any asset assigned a score of 4 within the previous step. Scores for all other assets are carried over directly from *Step 3: Binned Raw Score* (Figure 8).
5. **Add comments if needed.** We add any notes related to the exposure analysis or provided by park staff to the final column of the *Exposure Analysis Data Results* Excel sheet and flag these assets within the *Step 6. Flagged Asset* column (Figure 8).
6. **Assign assets a final exposure score and rank.** We carry over final exposure scores directly from the *Step 5. Exposure Score Unmodified* column into *Step 7: Exposure Score*, and we assign the corresponding exposure ranks in the *Step 7: Exposure Rank* column (Table 3, Figure 8, and Box 2).

Sensitivity Analysis

The second step in this VA protocol is to analyze the sensitivity of NPS assets to coastal hazards and SLR. We do not analyze the sensitivity of assets with minimal exposure; these assets are automatically assigned a minimal ranking for vulnerability. To be vulnerable to a hazard, an asset must first be exposed (regardless of sensitivity).

Similar to exposure, this protocol includes a set of indicators for asset sensitivity (Table 4). Sensitivity is not location dependent, and the scoring is more subjective. Sensitivity is related to how

an asset is likely to fare when exposed to a hazard, which is a function of its inherent properties, construction, and level of engineered protection. In this protocol, the sensitivity indicators for buildings and transportation assets are the same; however, the manner in which sensitivity is addressed during design and construction can be different (e.g., storm resistance of a road versus a building).

Table 4. Sensitivity indicators and common data sources.

Indicator	Common Data Sources
Flood Damage Potential	Questionnaire & discussions; threshold elevation measurements; WCU field assessments
Storm Resistance & Condition	Questionnaire & discussions; imagery; WCU field assessments
Historical Damage	Questionnaire & discussions; storm imagery
Protective Engineering	Questionnaire & discussions; imagery; NPS engineering inventory; WCU field assessments

Because digital sensitivity data are not typically available for infrastructure, the primary data source for the sensitivity analysis is an asset-specific questionnaire (Box 3; WCU 2022 and Appendix B) and feedback from park staff (Table 4). The asset questionnaire addresses each of the various sensitivity indicators (e.g., asking if a building is elevated to evaluate flood damage potential) and is distributed to appropriate personnel (typically individuals with institutional memory of park infrastructure). Where appropriate, we obtain sensitivity data from field assessments, asset databases (e.g., property records, maintenance reports, site surveys, etc.), the National Bridge Inventory (NBI), and aerial imagery.

In general, we score assets either favorably or unfavorably for each of the evaluated sensitivity indicators (Table 4). We assign assets with an unfavorable sensitivity result a score of 4 for that indicator, and assets with a favorable result a score of 1 (Figure 9). We calculate a raw total indicator score for each asset and then categorize (bin) these scores into one of three sensitivity rankings (reflective of the number of unfavorable indicators): low (0 or 1 unfavorable indicators), moderate (2 unfavorable indicators), and high (3 or 4 unfavorable indicators). Finally, we modify the scoring methodology and groupings if additional bridge indicators are necessary (see Sensitivity Calculations & Final Scoring section).

Sensitivity Analysis Data Results

Definitions of WCU Columns on Next Sheet (Click Here to View)

ID	Location	Step 1: Sensitivity Indicators Scoring								Step 2	Step 3	Step 4	
		Flood Damage Potential	BFE (m, NAVD88)	Threshold Elev (m, NAVD88)	Above or Below BFE	Storm Resistance	Condition	Historical Damage	Protective Engineering	Flagged Asset	Raw Score (sum step 1)	Sensitivity Score	Sensitivity Rank
1	Asset Name	4	1.83			4	1	1	4		11.5	3	moderate
2	Asset Name	1				4	4	1	4	see notes	10.0	3	moderate
3	Asset Name	4	1.83	1.498	Below	4	4	1	4		13.0	4	high
4	Asset Name	1				4	4	1	4	see notes	10.0	3	moderate
5	Asset Name	1	1.83			4	1	1	4	see notes	8.5	3	moderate
6	Asset Name	1	1.83			1	1	1	4	see notes	7.0	2	low
7	Asset Name	4	1.83			4	4	4	4		16.0	4	high
8	Asset Name	1	1.52			4	1	1	4		8.5	3	moderate
9	Asset Name	1	1.52	2.386	Above	4	1	1	4	see notes	8.5	3	moderate
10	Asset Name	1	1.52			4	1	1	4		8.5	3	moderate
11	Asset Name	1	1.52			4	1	1	4	see notes	8.5	3	moderate
12	Asset Name	1	1.52			4	1	1	4		8.5	3	moderate
13	Asset Name	1	1.52	2.986	Above	4	1	1	4	see notes	8.5	3	moderate
14	Asset Name	1	1.52	2.997	Above	4	1	1	4	see notes	8.5	3	moderate
15	Asset Name	4	1.52			4	1	1	4	see notes	11.5	3	moderate
16	Asset Name	4	1.52			4	1	1	4	see notes	11.5	3	moderate
17	Asset Name	1	1.52	1.737	Above	1	1	1	4	see notes	7.0	2	low

Figure 9. Example of a *Sensitivity Analysis Data Results* Excel sheet, showing all scoring columns, including individual indicator scoring, intermediate calculations, and final sensitivity results. Scoring columns with blue headers contain the threshold elevation data and analysis. Data columns not shown include multiple attributes taken directly from FMSS, and any final notes related to sensitivity analysis and scoring. See Table B-4 for an accessible version.

1. Flood Damage Potential

The flood damage potential sensitivity indicator represents how likely an asset is to be inundated if the surrounding land area is flooded. Assets constructed at least 5 feet above local ground level on elevated stilts/pilings or artificial fill material are less likely to be inundated by floods. A height of 5 feet can be easily estimated and highlights assets that were intentionally elevated higher than a typical crawlspace. We commonly obtain this information through the questionnaire (Box 3; WCU 2022), feedback from park staff, imagery, or visual inspection during field assessments (Table 4).

We assign assets elevated at least 5 feet above local ground level a score of 1 for the *Flood Damage Potential* column of the *Sensitivity Analysis Data Results* Excel sheet. If the asset is not elevated, we assign it a score of 4 (Figure 9).

Threshold Elevation Data

When available, we incorporate building threshold elevation data collected by the NPS Information System Services into analysis of the *Flood Damage Potential* sensitivity indicator. These data (collected at a handful of parks thus far) are acquired with sub-centimeter Global Positioning System equipment to record accurate threshold (first floor) elevations. For buildings within a FEMA SFHA, we compare the precise threshold elevation to the local Base Flood Elevation (level the water is anticipated to reach during a base flood). If the threshold elevation of a building is above the Base Flood Elevation, we assign it a score of 1 for the *Flood Damage Potential* indicator. If the threshold is below the Base Flood Elevation, we assign the building a score of 4 (Figure 9).

2. Storm Resistance & Condition

The storm resistance and condition sensitivity indicator represents how well an asset will resist damage from coastal hazards and SLR. Assets built to storm-resistant standards, with quality construction, or in good condition are less likely to be damaged by coastal hazards. We commonly obtain this information through the questionnaire (Box 3; WCU 2022), feedback from park staff, imagery, or field assessments (Table 4).

This sensitivity indicator is scored as a combination of storm resistance and condition. We assign assets determined to be storm resistant a score of 1 for the *Storm Resistance* column of the *Sensitivity Analysis Data Results* Excel sheet, and assets that are not storm resistant a score of 4. We assign assets determined to be in poor condition a score of 4 for the *Condition* column of the *Sensitivity Analysis Data Results* Excel sheet, and assets not in poor condition a score of 1 (Figure 9).

3. Historical Damage

The historical damage sensitivity 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 (Table 1), but instead of focusing on the site or area around an asset, this indicator is focused on wave or water damage to the asset itself. We commonly obtain this information through the questionnaire (Box 3; WCU 2022), feedback from park staff, or imagery (Table 4).

We assign assets with historical damage a score of 4 for the *Historical Damage* column of the *Sensitivity Analysis Data Results* Excel sheet, and assets with no historical damage a score of 1 (Figure 9).

4. Protective Engineering

The protective engineering sensitivity 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 assets protected with engineering are less likely to be damaged by coastal hazards. Data sources for this indicator commonly include the asset questionnaire (Box 3; WCU 2022), feedback from park staff, imagery, or the NPS Coastal Engineering Inventory (Table 4).

We assign assets protected by engineering structures a score of 1 for the *Protective Engineering* column of the *Sensitivity Analysis Data Results* Excel sheet, and assets not protected by engineering a score of 4 (Figure 9).

Box 3. Common Sensitivity Indicator Questions

Flood Damage Potential: 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.

Storm Resistance: Are any of the following assets built to specific storm-resistant standards, engineering codes, or inherently resistant to other forms of damage or deterioration (e.g., fortifications).

Condition: Are any of the following assets 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.

Historical Damage: Have any of the following assets been significantly damaged in previous storm/flooding events (water/waves only)?

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

Additional Bridge Indicators

Bridges are included as transportation infrastructure within this VA but have specific structural characteristics that we incorporate into the sensitivity analysis. Compared to other transportation assets (e.g., roads, trails, parking lots), bridges have a different design, purpose, and response to coastal hazards and SLR, highlighting the need for additional sensitivity indicators. For example, bridge clearance height can be extremely significant during flooding, as low bridge clearance can result in damage to the bridge deck, or even dislocation from its foundation. We evaluate four additional sensitivity indicators for bridges included in the NBI (Table 5). The four sensitivity indicators selected had the most consistent and widely available NBI data.

Table 5. Additional bridge sensitivity indicators and scoring.

Indicator	Data Source	Scoring
Clearance	NBI (item 39)	Feet of clearance: > 15 ft = 1; 9–15 ft = 2; 1–8 ft = 3; 0 ft = 4
Scour Rating	NBI (item 113)	Rating: n/a = 1; low (T, 9) & stable (5–8) = 2; stable (4) = 3; critical (0–3) = 4
Condition	NBI (items 58–60)	Condition Rating (average [A]): n/a = 1; 0–3 = 2; 4–6 = 3, 7–9 = 4
Age	NBI (item 27); FMSS database	Age (in years): 0–25 yrs = 1; 26–50 yrs = 2; 51–75 yrs = 3; > 75 yrs = 4

[A] Each available condition rating is first scored individually and then averaged.

Quality Control

The sensitivity analysis process relies heavily on park institutional knowledge regarding the physical attributes of assets. The level of institutional knowledge at each park varies depending on staff turnover and the asset portfolio. Although responses from the sensitivity questionnaire and discussions are relatively accurate, inaccuracies due to human error are always possible. We carefully review the responses for each sensitivity indicator for anomalies and verify the results as needed (e.g., through further discussion, aerial imagery, field assessments, or other documentation).

Sensitivity Calculations & Final Scoring

After scores are assigned for each sensitivity indicator (as described in the above sections), we complete several additional steps to obtain a final sensitivity score and rank. We record all calculations and scoring in the *Sensitivity Analysis Data Results* Excel sheet (Figure 9).

Final sensitivity scoring steps:

1. **Add comments if needed.** We add any notes related to the sensitivity analysis or provided by park staff to the final column of the *Sensitivity Analysis Data Results* Excel sheet and flag these assets within the *Step 2. Flagged Asset* column (Figure 9).
2. **Calculate the raw scores.** We calculate raw scores as a sum of the sensitivity indicator scores (as an Excel formula) within the *Step 3: Raw Score* (sum step 1) column (Figure 9). We combine the *Storm Resistance* and *Condition* indicator columns to represent one indicator (scores are summed and then divided by 2 as part of the raw score).

3. **Calculate raw scores for bridges with additional NBI indicators.** For bridges with data for the additional NBI indicators, we complete the sensitivity indicator scoring separately from the other assets. If a bridge has a NBI condition score (from Table 5), we use this score in place of the value in the *Condition* column of the *Sensitivity Analysis Data Results* Excel sheet. We sum all other indicators (as an Excel formula) within the *Step 3: Raw Score* column (Figure 9).
4. **Bin the raw scores.** We bin (group) the raw exposure scores into categories based on the breaks shown in Table 6, and we record these scores within the *Step 4: Sensitivity Score* column (Figure 9).
    a. **Bin the raw scores for bridges with additional NBI indicators.** For bridges with data for the additional NBI indicators, we bin (group) the raw exposure scores into categories based on the number of indicators and natural breaks in the values (Table 7). Because the calculated NBI condition score is used in place of the original condition value (Table 4), the number of other available NBI indicators determines the binning (grouping) of the raw scores (Table 7).
5. **Assign assets a final rank.** We assign final sensitivity ranks in the *Step 4: Sensitivity Rank* column (Table 6, Figure 9, and Box 3).

Table 6. Sensitivity scoring summary (with only 4 indicators and no NBI data).

# Indicators	Raw Score	Sensitivity Score	Sensitivity Rank
4	≥ 13	4	High
	≥ 8 and ≤ 12	3	Moderate
	≥ 4 and < 8	2	Low

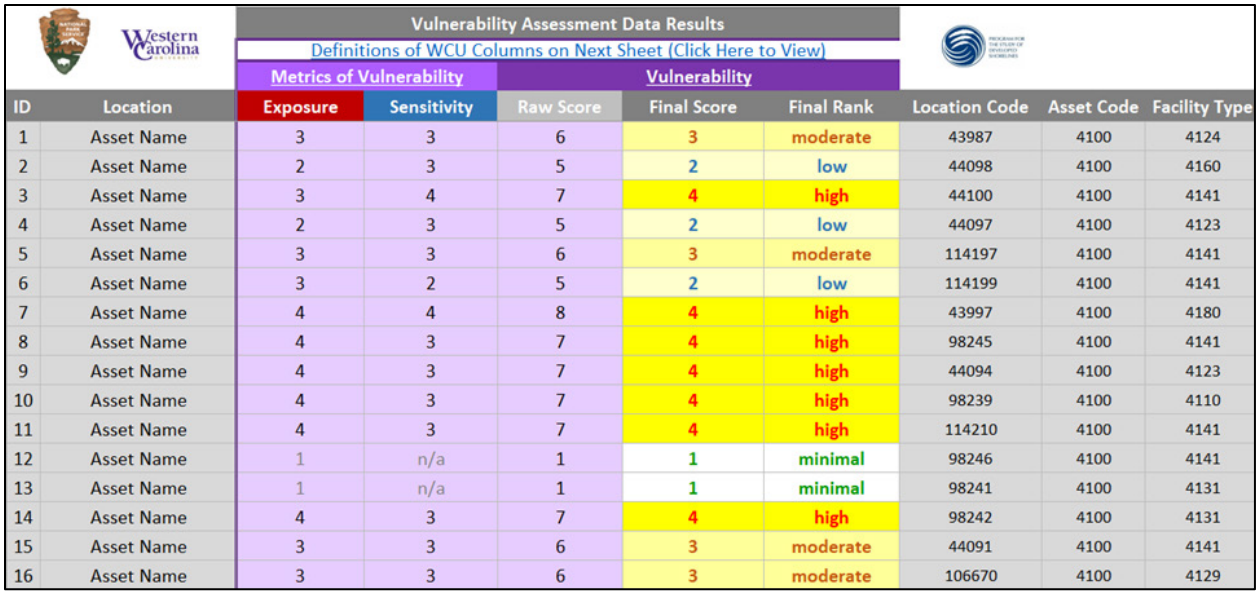
Table 7. Sensitivity scoring summary for bridges with NBI data.

Total Indicators (NBI Indicators)	Raw Score	Sensitivity Score	Sensitivity Rank
4 (bridges with only NBI condition)	≥ 13	4	High
	≥ 8 and ≤ 12	3	Moderate
	≥ 4 and < 8	2	Low
5 (bridges with one NBI indicator [A])	≥ 16	4	High
	≥ 11 and < 16	3	Moderate
	< 11	2	Low
6 (bridges with two NBI indicators [A])	≥ 18	4	High
	≥ 12 and < 18	3	Moderate
	< 12	2	Low
7 (bridges with three NBI indicators [A])	≥ 22	4	High
	≥ 14 and < 22	3	Moderate
	< 14	2	Low

[A] Number of NBI indicators (not counting NBI condition). NBI condition may or may not be present. If available, NBI condition is used in place of the original Condition score (Table 4; Figure 9).

Vulnerability Calculations

After final exposure and sensitivity scores are determined for each asset (as described in the above sections), we calculate raw scores using a simple summation formula in the Raw Score column of the *Vulnerability Assessment Data Results* Excel sheet (Figure 10). We bin (group) the raw vulnerability scores into final scores and rankings based on natural breaks (Table 8), and we report these within the *Final Score* and *Final Rank* columns of the *Vulnerability Assessment Data Results* Excel sheet (Figure 10).



Vulnerability Assessment Data Results

Definitions of WCU Columns on Next Sheet (Click Here to View)

		Metrics of Vulnerability		Vulnerability					
ID	Location	Exposure	Sensitivity	Raw Score	Final Score	Final Rank	Location Code	Asset Code	Facility Type
1	Asset Name	3	3	6	3	moderate	43987	4100	4124
2	Asset Name	2	3	5	2	low	44098	4100	4160
3	Asset Name	3	4	7	4	high	44100	4100	4141
4	Asset Name	2	3	5	2	low	44097	4100	4123
5	Asset Name	3	3	6	3	moderate	114197	4100	4141
6	Asset Name	3	2	5	2	low	114199	4100	4141
7	Asset Name	4	4	8	4	high	43997	4100	4180
8	Asset Name	4	3	7	4	high	98245	4100	4141
9	Asset Name	4	3	7	4	high	44094	4100	4123
10	Asset Name	4	3	7	4	high	98239	4100	4110
11	Asset Name	4	3	7	4	high	114210	4100	4141
12	Asset Name	1	n/a	1	1	minimal	98246	4100	4141
13	Asset Name	1	n/a	1	1	minimal	98241	4100	4131
14	Asset Name	4	3	7	4	high	98242	4100	4131
15	Asset Name	3	3	6	3	moderate	44091	4100	4141
16	Asset Name	3	3	6	3	moderate	106670	4100	4129

Figure 10. Example of a *Vulnerability Assessment Data Results* Excel sheet, showing all scoring columns, including exposure and sensitivity scoring, intermediate calculations, and final vulnerability results. Data columns after the vulnerability results are a sample of those provided and are mined directly from FMSS. See Table B-5 for accessible version.

Table 8. Vulnerability scoring summary.

Raw Score	Scoring Options	Final Score	Final Rank
7–8	high (4) exposure + high (4) sensitivity; high (4) exposure + moderate (3) sensitivity; moderate exposure (3) + high (4) sensitivity	4	High
6	high (4) exposure + low (2) sensitivity; moderate (3) exposure + moderate (3) sensitivity; low (2) exposure + high (4) sensitivity	3	Moderate
4–5	moderate (3) exposure + low (2) sensitivity; low (2) exposure + moderate (3) sensitivity; low (2) exposure + low (2) sensitivity	2	Low
1	minimal (1) exposure + null sensitivity	1	Minimal [A]

[A] Assets with a vulnerability score of 1 are those with minimal (or no) exposure.

Products & Deliverables

After completing a draft of each VA, we send all results (in Excel and/or geospatial format) to appropriate park staff. Parks review all steps and calculations and the resulting exposure, sensitivity, and vulnerability of each asset, and follow-up with any clarifications or questions. Results are final after this review period.

For each park, we deliver the final asset-specific exposure, sensitivity, and vulnerability results to the NPS in multiple formats, including 1) Excel spreadsheets, 2) ArcMap map package (.mpk) and shapefiles (.shp), and 3) Google Earth Keyhole Markup Language (.kml or .kmz). We also provide all geospatial exposure hazard data to the NPS as ArcMap shapefiles. The NPS displays the geospatial results for each park within the NPS Coastal Vulnerability Data Viewer.

Finally, we deliver a short summary of the VA results as a written report. This report includes a brief discussion of the exposure, sensitivity, and vulnerability results, as well as a list of data sources and any unique or park-specific factors (see Peek et al. 2018).

Summary & Conclusions

This report describes the developmental history and detailed methodology for the **Coastal Hazards & SLR Asset Vulnerability Assessment Protocol**. The protocol is unique in that the vulnerability of each park asset is assessed and scored individually as a combination of exposure and sensitivity. Sensitivity is not commonly evaluated within infrastructure VAs (Peek et al. 2022); this protocol creates a standardized method for evaluating and scoring the sensitivity of NPS assets. This approach began over a decade ago as a series of pilot projects in coastal parks. It has evolved to allow the NPS to integrate scientific data for exposure with the condition and characteristics of NPS buildings and transportation assets to evaluate vulnerability. Application of this methodology consistently across all coastal parks enables the NPS to identify highly vulnerable areas and assets. The exposure and sensitivity data compiled for each park can also serve as a starting point for subsequent or parallel assessment efforts. These data are being made available through web-based distribution within the NPS intranet. This is critical information to support science-based decisions for adaptation and resilience planning in parks affected by coastal hazards and SLR. Finally, the protocol is flexible in that additional hazards or updated hazard data can be easily integrated into a completed VA to refine or update the scoring as needed. The protocol can also be used to examine different time horizons if needed.

Literature Cited

Amberg, S., K. Kilkus, S. Gardner, J. E. Gross, M. Wood, and B. Drazkowski. 2012. Badlands National Park: Climate change vulnerability assessment. Natural Resource Report NPS/BADL/NRR. National Park Service, Fort Collins, Colorado.

Barrows, C. W., J. Hoines, K. D. Fleming, M. S. Vamstad, M. Murphy-Mariscal, K. Lalumiere, and M. Harding. 2014. Designing a sustainable monitoring framework for assessing impacts of climate change at Joshua Tree National Park, USA. Biodiversity and Conservation 23:3263–3285.

Beavers, R. L., A. L. Babson, and C. A. Schupp (editors). 2016. Coastal adaptation strategies handbook. NPS 999/134090. National Park Service, Washington, D.C.

Caffrey, M. A., R. L. Beavers, and C. H. Hoffman. 2018. Sea level rise and storm surge projections for the National Park Service. Natural Resource Report NPS/NRSS/NRR—2018/1648. National Park Service, Fort Collins, Colorado.

Fatorić, S., and E. Seekamp. 2017. Assessing historical significance and use potential of buildings within historic districts: An overview of a measurement framework developed for climate adaptation planning. AG-832. NC State Extension, Raleigh, North Carolina.

FEMA Glossary, 2021. Terms frequently used by FEMA website. Available at: https://www.fema.gov/about/glossary (accessed 16 February 2022).

Glick, P., B. A. Stein, and N. A. Edelson (editors). 2011. Scanning the conservation horizon: A guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

Handler, S., P. Burkman, J. Van Stappen, S. E. Johnson, E. Epstein, R. O'Connor, G. W. Schuurman, A. Prosperi, L. R. Briley, D. Cooper, M. J. Cooper, R. Croll, U. Gafvert, L. R. Iverson, B. Krumenaker, B. M. Lofgren, N. I. Montano, H. Panci, D. Panek, L. R. Parker, M. P. Peters, K. M. Schmitt, C. W. Swanston, and N. Tillison. 2020. Climate change vulnerability assessment for terrestrial ecosystems at Apostle Islands National Lakeshore. Natural Resource Report. NPS/APIS/NRR—2020/2121. National Park Service, Fort Collins, Colorado.

Hansen, A. J., N. Piekielek, C. Davis, J. Haas, D. M. Theobald, J. E. Gross, W. B. Monahan, T. Olliff, and S. W. Running. 2013. Exposure of U.S. National Parks to land use and climate change 1900–2100. Ecological Applications 24:484–502.

ICF International. 2012a. Facilities adaptation to climate change impacts in coastal areas: workshop findings for Pu`uhonua O Hōnaunau National Historic Park, September 2012. ICF International, Washington, D.C.

ICF International. 2012b. Facilities adaptation to climate change impacts in coastal areas: workshop findings for Assateague Island National Seashore, December 2012. ICF International, Washington, D.C.

ICF International. 2015. U.S. DOT Vulnerability Assessment Scoring Tool User's Guide. ICF International, Washington, D.C.

National Park Service (NPS). 2021a. Coming to terms with climate change: Working definitions. National Park Service Climate Change Response Program, Fort Collins, Colorado.

National Park Service (NPS). 2021b. Climate Change: Assess Vulnerability website. Available at: https://www.nps.gov/subjects/climatechange/vulnerability.htm (accessed 18 November 2021).

Peek, K. M., B. R. Tormey, H. L. Thompson, R. S. Young, S. Norton, and R. Scavo. 2017. Cabrillo National Monument Coastal Hazards & Climate Change Asset Exposure Analysis & Case Study: Cliff Retreat Exposure. NPS 342/154057. National Park Service, Washington, D.C.

Peek, K. M., B. R. Tormey, H. L. Thompson, R. S. Young, S. Norton, J. McNamee, and R. Scavo. 2018. Fire Island National Seashore Coastal Hazards & Sea-Level Rise Asset Vulnerability Assessment. NPS 615/154058. National Park Service, Washington, D.C.

Peek, K. M., B. R. Tormey, H. L. Thompson, R. L. Beavers, A. C. Ellsworth, and C. H. Hoffman (editors). 2022. Climate change vulnerability assessments in the National Park Service: An integrated review for infrastructure, natural resources, and cultural resources. Natural Resource Report NPS/NRSS/CCRP/NRR—2022/2404. National Park Service, Fort Collins, Colorado.

Ricci, G., D. D. Robadue Jr., P. Rubinoff, A. Casey, and A. L. Babson. 2019a. Integrated Coastal Climate Change Vulnerability Assessment: Colonial National Historical Park. Natural Resource Report NPS/COLO/NRR—2019/1945. National Park Service, Fort Collins, Colorado.

Ricci, G., D. D. Robadue Jr., P. Rubinoff, A. Casey, and A. L. Babson. 2019b. Method for Integrated Coastal Climate Change Vulnerability Assessment. Natural Resource Report NPS/NER/NRR—2019/1933. National Park Service, Fort Collins, Colorado.

Stroh, E. D., M. A. Struckhoff, D. Shaver, and K. A. Karstensen. 2016. Vulnerabilities of national parks in the American Midwest to climate and land use changes. Scientific Investigations Report 2016–5057. United Stated Geological Survey, Reston, Virginia.

Sweet, W. V., R. E. Kopp, C. P. Weaver, J. Obeysekera, R. M. Horton, E. R. Theiler, and C. Zervas. 2017. Global and Regional Sea Level Rise Scenarios for the United States. NOAA Technical Report NOS CO-OPS 083. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, Maryland.

Sweet, W. V., B. D. Hamlington, R. E. Kopp, C. P. Weaver, P. L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A. S. Genz, J. P. Krasting, E. Larour, D. Marcy, J. J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K. D. White, and C. Zuzak. 2022. Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, Maryland.

Western Carolina University (WCU). 2022. Questionnaire Templates for Coastal Hazards Protocol (2022). https://irma.nps.gov/DataStore/Reference/Profile/2293481.

Zachry, B. C., W. J. Booth, J. R. Rhome, and T. M. Sharon. 2015. A National View of Storm Surge Risk and Inundation. Weather, Climate, and Society, 7(2), 109–117. DOI: http://dx.doi.org/10.1175/WCAS–D–14–00049.1

Appendix A: FMSS Descriptions

Asset Code & Facility Type in FMSS

Table A-1. Table of Asset Code and Facility Type descriptions from FMSS (provided by NPS Information System Services).

Asset Code	Facility Type
1100 - Road	1110 - Paved
1100 - Road	1120 - Unpaved
1100 - Road	1130 - Both
1300 - Parking Area	1310 - Paved
1300 - Parking Area	1320 - Unpaved
1300 - Parking Area	1330 - Both
1700 - Road Bridge	1710 - Road Bridge
1800 - Road Tunnel	1810 - Road Tunnel
2100 - Trail	2110 - Class I
2100 - Trail	2120 - Class II
2100 - Trail	2130 - Class III
2100 - Trail	2140 - Class IV
2100 - Trail	2150 - Class V
2200 - Trail Bridge (Substantial)	2210 - Trail Bridge
2300 - Trail Tunnel (Substantial)	2310 - Trail Tunnel
3100 - Maintained Landscapes [A]	**3110 - Maintained Landscapes**
3800 - Boundary [A]	**3810 - Boundary**
4100 - Building*	4110 - Office
4100 - Building*	4114 - Post Office
4100 - Building*	4123 - School
4100 - Building*	4129 - Other Institutional Uses
4100 - Building**	4130 - Housing
4100 - Building**	4131 - Dormitories/Barracks
4100 - Building*	4141 - Warehouses
4100 - Building*	4150 - Industrial
4100 - Building*	4160 - Service

[A] Asset categories not typically evaluated with this protocol, also shown in bold text.

Table A-1 (continued). Table of Asset Code and Facility Type descriptions from FMSS (provided by NPS Information System Services).

Asset Code	Facility Type
4100 - Building*	4172 - Communications Systems
4100 - Building*	4173 - Navigation and Traffic Aids
4100 - Building*	4174 - Laboratories
4100 - Building*	4180 - All Other
5100 - Water System [A]	**5110 - Non-potable**
5100 - Water System [A]	**5120 - Potable**
5200 - Waste Water System [A]	**5210 - Municipal Wastewater**
5200 - Waste Water System [A]	**5220 - Stormwater**
5300 - Heating & Cooling Plant	5310 - Heating
5300 - Heating & Cooling Plant	5320 - Cooling
5300 - Heating & Cooling Plant	5330 - Both
5400 - Electrical System [A]	**5410 - Water (Hydro)**
5400 - Electrical System [A]	**5420 - Solar**
5400 - Electrical System [A]	**5430 - Fossil Fuel**
5400 - Electrical System [A]	**5440 - Geothermal**
5400 - Electrical System [A]	**5450 - Public**
5400 - Electrical System [A]	**5460 - Wind**
5400 - Electrical System [A]	**5470 - Fuel Cell**
5500 - Communication Systems [A]	**5510 - Phone Systems**
5500 - Communication Systems [A]	**5520 - IT Systems**
5500 - Communication Systems [A]	**5530 - Radio Systems**
5700 - Fuel System	5710 - Fuel for Transportation
5700 - Fuel System	5720 - Fuel for Utilities
5800 - Solid Waste/Recycling System	5810 - Municipal Solid Waste System
5800 - Solid Waste/Recycling System	5820 - Recycling System
5800 - Solid Waste/Recycling System	5830 - Hazardous Waste System
6100 - Dam/Levee/Dike	6110 - Dams/Levees/Dikes
6200 - Constructed Waterway	6210 - Constructed Waterways
6300 - Marina/Waterfront System	6310 - Recreational

[A] Asset categories not typically evaluated with this protocol, also shown in bold text.

Table A-1 (continued). Table of Asset Code and Facility Type descriptions from FMSS (provided by NPS Information System Services).

Asset Code	Facility Type
6300 - Marina/Waterfront System	6320 - Protection
6400 - Aviation System	6410 - Controlled
6400 - Aviation System	6420 - Uncontrolled
6500 - Railroad System	6510 - Railroad System
7100 - Monuments	7110 - Memorial Complex
7100 - Monuments	7120 - Commemorative Objects
7100 - Monuments	7130 - Headstone / Marker
7100 - Monuments	7140 - Large Interpretive Objectives
7200 - Maintained Archeological Sites [A]	**7210 - Maintained Archeological Sites**
7300 - Fortification	7310 - Earthwork
7300 - Fortification	7320 - Masonry
7300 - Fortification	7330 - Wood
7300 - Fortification	7340 - Other Construction
7400 - Towers/Missile Silos	7410 - Silo
7400 - Towers/Missile Silos	7420 - Tower
7500 - Interpretive Media [A]	**7510 - Exhibit System**
7500 - Interpretive Media [A]	**7520 - Wayside System**
7900 - Amphitheaters	7910 - Amphitheaters
8999 - Fleet [A]	**–**
9999 - No Asset Code Available [A]	**–**

[A] Asset category not typically evaluated with this protocol, also shown in bold text.

Appendix B: Accessible Figures & Tables

Table B-1. Accessible version of Figure 3. A portion of an Exposure Analysis Data Results Excel sheet, showing an example of scoring for each exposure indicator (columns 1a–1f). Columns 1a. and 1b. together represent the flooding potential indicator, and column 1f. Historic Flood Score is the reported coastal hazards indicator in this example.

ID	Location	1a. FEMA VE Zone Score	1b. FEMA A Zone Score	1c. Shoreline Change Score	1d. SLR Score	1e. Extreme Flooding Score	1f. Historic Flood Score
1	Asset Name	n/a	4	1	1	4	4
2	Asset Name	n/a	1	1	1	4	1
3	Asset Name	n/a	4	1	1	4	1
4	Asset Name	n/a	4	1	1	4	4
5	Asset Name	4	n/a	1	1	4	4
6	Asset Name	n/a	4	4	1	4	4
7	Asset Name	n/a	4	4	1	4	4
8	Asset Name	4	n/a	1	1	4	4
9	Asset Name	n/a	4	4	1	4	4

Table B-2. Accessible version of inset table in Figure 6. NPS-specific SLR projections for George Washington Birthplace National Monument from Caffrey et al. 2018. Only the 4.5 and 8.5 RCP scenario were mapped.

Year	2.6 RCP	4.5 RCP	6 RCP	8.5 RCP
2030	0.15 m	0.15 m	0.15 m	0.14 m
2050	0.26 m	0.27 m	0.26 m	0.28 m
2100	0.53 m	0.63 m	0.66 m	0.8 m

Table B-3. Accessible version of Figure 8. Example of an Exposure Analysis Data Results Excel sheet, showing all scoring columns, including individual indicator scoring, intermediate calculations, and final exposure results. Data columns not shown include multiple attributes taken directly from FMSS, and any final notes related to exposure analysis and scoring.

Location	1a. FEMA VE Zone Score	1b. FEMA A Zone Score	1c. Shoreline Change Score	1d. SLR Score	1e. Extreme Flooding Score	1f. Historic Flood Score	Step 2. Raw Score from Step 1	Step 3. Binned Raw Score	Step 4. VE Auto High	Step 5. Exposure Score Unmod.	Step 6. Flagged Asset	Step 7. Exposure Score	Step 7. Exposure Rank
Asset 1	n/a	4	1	1	4	4	14	3	n/a	3	see notes	3	moderate
Asset 2	n/a	1	1	1	4	1	8	2	n/a	2	n/a	2	low
Asset 3	n/a	4	1	1	4	1	11	3	n/a	3	n/a	3	moderate
Asset 4	n/a	4	1	1	4	4	14	3	n/a	3	see notes	3	moderate
Asset 5	4	n/a	1	1	4	4	14	3	4	4	see notes	4	high
Asset 6	n/a	4	4	1	4	4	17	4	n/a	4	n/a	4	high
Asset 7	n/a	4	4	1	4	4	17	4	n/a	4	n/a	4	high
Asset 8	4	n/a	1	1	4	4	14	3	4	4	see notes	4	high
Asset 9	n/a	4	4	1	4	4	17	4	n/a	4	see notes	4	high
Asset 10	n/a	4	1	1	4	4	14	3	n/a	3	n/a	3	moderate
Asset 11	n/a	4	1	4	4	1	14	3	n/a	3	see notes	3	moderate
Asset 12	n/a	4	1	4	4	4	17	4	n/a	4	n/a	4	high
Asset 13	n/a	4	1	1	4	4	14	3	n/a	3	n/a	3	moderate
Asset 14	n/a	4	1	4	4	4	17	4	n/a	4	n/a	4	high
Asset 15	n/a	4	1	4	4	4	17	4	n/a	4	see notes	4	high
Asset 16	n/a	4	1	4	4	4	17	4	n/a	4	see notes	4	high
Asset 17	n/a	4	1	4	4	4	17	4	n/a	4	see notes	4	high
Asset 18	n/a	4	1	1	4	4	14	3	n/a	3	n/a	3	moderate

Table B-4. Accessible version of Figure 9. Example of a Sensitivity Analysis Data Results Excel sheet, showing all scoring columns, including individual indicator scoring, intermediate calculations, and final sensitivity results. Scoring columns with blue headers contain the threshold elevation data and analysis. Data columns not shown include multiple attributes taken directly from FMSS, and any final notes related to sensitivity analysis and scoring.

Location	Flood Damage Potential	BFE (m, NAVD88)	Threshold Elev (m, NAVD88)	Above or Below BFE	Storm Resistance	Condition	Historical Damage	Protective Engineering	Step 2. Flagged Asset	Step 3. Raw Score (sum step 1)	Step 4. Sensitivity Score	Step 5. Sensitivity Rank
Asset 1	4	1.83	n/a	n/a	4	1	1	4	n/a	11.5	3	moderate
Asset 2	1	n/a	n/a	n/a	4	4	1	4	see notes	10.0	3	moderate
Asset 3	4	1.83	1.498	Below	4	4	1	4	n/a	13.0	4	high
Asset 4	1	n/a	n/a	n/a	4	4	1	4	see notes	10.0	3	moderate
Asset 5	1	1.83	n/a	n/a	4	1	1	4	see notes	8.5	3	moderate
Asset 6	1	1.83	n/a	n/a	1	1	1	4	see notes	7.0	2	low
Asset 7	4	1.83	n/a	n/a	4	4	4	4	n/a	16.0	4	high
Asset 8	1	1.52	n/a	n/a	4	1	1	4	n/a	8.5	3	moderate
Asset 9	1	1.52	2.386	Above	4	1	1	4	see notes	8.5	3	moderate
Asset 10	1	1.52	n/a	n/a	4	1	1	4	n/a	8.5	3	moderate
Asset 11	1	1.52	n/a	n/a	4	1	1	4	see notes	8.5	3	moderate
Asset 12	1	1.52	n/a	n/a	4	1	1	4	n/a	8.5	3	moderate
Asset 13	1	1.52	2.986	Above	4	1	1	4	see notes	8.5	3	moderate

Table B-4 (continued). Accessible version of Figure 9. Example of a Sensitivity Analysis Data Results Excel sheet, showing all scoring columns, including individual indicator scoring, intermediate calculations, and final sensitivity results. Scoring columns with blue headers contain the threshold elevation data and analysis. Data columns not shown include multiple attributes taken directly from FMSS, and any final notes related to sensitivity analysis and scoring.

Location	Flood Damage Potential	BFE (m, NAVD88)	Threshold Elev (m, NAVD88)	Above or Below BFE	Storm Resistance	Condition	Historical Damage	Protective Engineering	Step 2. Flagged Asset	Step 3. Raw Score (sum step 1)	Step 4. Sensitivity Score	Step 5. Sensitivity Rank
Asset 14	1	1.52	2.997	Above	4	1	1	4	see notes	8.5	3	moderate
Asset 15	4	1.52	n/a	n/a	4	1	1	4	see notes	11.5	3	moderate
Asset 16	4	1.52	n/a	n/a	4	1	1	4	see notes	11.5	3	moderate
Asset 17	1	1.52	1.737	Above	1	1	1	4	see notes	7.0	2	low

Table B-5. Accessible version of Figure 10. Example of a Vulnerability Assessment Data Results Excel sheet, showing all scoring columns, including exposure and sensitivity scoring, intermediate calculations, and final vulnerability results. Data columns after the vulnerability results are a sample of those provided and are mined directly from FMSS.

Location	Exposure	Sensitivity	Raw Score	Final Score	Final Rank	Location Code	Asset Code	Facility Type
Asset 1	3	3	6	3	moderate	43987	4100	4124
Asset 2	2	3	5	2	low	44098	4100	4160
Asset 3	3	4	7	4	high	44100	4100	4141
Asset 4	2	3	5	2	low	44097	4100	4123
Asset 5	3	3	6	3	moderate	114197	4100	4141
Asset 6	3	2	5	2	low	114199	4100	4141
Asset 7	4	4	8	4	high	43997	4100	4180
Asset 8	4	3	7	4	high	98245	4100	4141
Asset 9	4	3	7	4	high	44094	4100	4123
Asset 10	4	3	7	4	high	98239	4100	4110
Asset 11	4	3	7	4	high	114210	4100	4141
Asset 12	1	n/a	1	1	minimal	98246	4100	4141
Asset 13	1	n/a	1	1	minimal	98241	4100	4131
Asset 14	4	3	7	4	high	98242	4100	4131
Asset 15	3	3	6	3	moderate	44091	4100	4141
Asset 16	3	3	6	3	moderate	106670	4100	4129

The Department of the Interior protects and manages the nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors its special responsibilities to American Indians, Alaska Natives, and affiliated Island Communities.

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Natural Resource Stewardship and Science
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