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Sustainable Operations and Climate Change Branch
Park Facility Management Division Facilities Planning Branch

Cabrillo National Monument (CABR)

Coastal Hazards & Climate Change Asset Exposure Analysis &
Case Study: Cliff Retreat Exposure
February 2017

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

Contents

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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 34 structures (buildings, shelters, fortifications, statues, bunkers, and batteries) and 17 transportation assets (roads, parking lots, and primary trails) are included in this assessment of Cabrillo National Monument (CABR). The exposure analysis shows that the vast majority of all CABR assets (80%) have minimal exposure to coastal hazards and sea-level rise, with only 10% low exposure, and 10% moderate exposure. None of the assets have high exposure to coastal hazards and sea-level rise at CABR. The rocky coastline and generally high elevation of assets yield favorable scoring for most exposure hazards (flooding, tsunami inundation/storm surge, and sea-level rise), with cliff retreat and slope instability hazards yielding negative exposure results.

With 90% of the assets in the park at low or minimal exposure to the coastal hazards and climate change hazards evaluated in this protocol, sensitivity cannot effectively be evaluated, as an asset is only sensitive to a hazard if it is exposed to it. Therefore, vulnerability was also not calculated at CABR (as has been done at other coastal parks). Instead, this study evaluates only the exposure of CABR assets to coastal hazards and sea-level rise.

CABR is unique in that it is a coastal park experiencing shoreline change in the form of both cliff retreat and slope erosion. Cliff retreat is also the only coastal hazard that impacts CABR assets (due to the high elevation of the park), and consequently the coastal hazard and climate change exposure scores in this study are relatively low. While these results are accurate when examining all five exposure indicators as a whole, the hazards associated with cliff retreat at CABR are significant and cannot be ignored. Because of this, a case study focusing more specifically on cliff retreat exposure for structures and transportation assets was completed.

Vulnerability Assessment Products & Deliverables:

1) Excel datasheets - All results, as well as asset-specific scoring, are provided in tabular form. The exposure scores are reported alongside the FMSS data for each asset, as well as the scores for each step of the analysis.
2) GIS Maps and Layers - All GIS data, including the exposure layers, exposure results, and cliff retreat results will be sent to the park as a separate file. The GIS data will also be available to view online at the ArcGIS Online (AGOL). Please contact WCU or NPS for details.
3) Park Specific Exposure Results Summary Document - This document, which explains the deliverables, results, and methodology, will be provided.

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 resulting modified formula for the vulnerability of the built environment (assets, infrastructure, buildings, transportation, etc.) is as follows:

Vulnerability = Exposure + Sensitivity

At CABR, the vast majority of assets (90%) have low or minimal exposure to the five coastal hazards evaluated. As a result, sensitivity cannot effectively be evaluated, as an asset is only sensitive to a hazard if it is exposed to it. Instead, this study deviates from the typical coastal vulnerability analysis, and focuses solely on CABR assets' exposure to coastal hazards and sea-level rise.

A major 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. 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.

General Protocol Methodology

The **Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol** has four primary steps: 1) Exposure Analysis and Mapping, 2) Sensitivity Analysis, 3) Vulnerability Analysis, and 4) Adaptation Strategies Analysis. A detailed description of the protocol can be found in the final section of this document: Vulnerability Assessment Methodology. Further scoring information can also be found in the Excel results sheets that accompany this report.

Below is a general description of the exposure step of the protocol. Unlike other coastal parks, the vast majority of assets at CABR have either low or minimal exposure, thus the sensitivity and vulnerability of assets cannot be effectively calculated using the methodology of this protocol. Instead, this study focuses solely on assets' exposure to coastal hazards and sea-level rise, with particular focus on a park-specific hazard, coastal cliff retreat. Adaptation Strategies are also not addressed in this report.

Exposure Analysis and Mapping: Standard exposure indicators have been established as part of this protocol (Table 1); these indicators represent the primary factors that should be evaluated to determine an asset's coastal hazard and climate change exposure (to the year 2050). The exposure analysis uses data imported into a Geographical Information System (GIS), as exposure is directly dependent on location relative to mapped hazard data. Assets located within an exposure indicator hazard zone (e.g., the storm surge zone) are assigned a higher score than assets located outside the zone. Scores for each indicator are then summed and binned to get a total exposure score. Final exposure scores fall into one of four ranking categories: minimal exposure (asset does not lie within any mapped zone), low exposure (1 zone), moderate exposure (2-3 zones), and high exposure (4-5 zones).

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

Exposure Indicator	CABR Specific Hazard	CABR Data Source
Flooding Potential	1% annual flood ± velocity/waves	FEMA flood zones (VE or AE)
Extreme Event Flooding	Tsunami	MOST method, University of Southern California
Sea-Level Rise Inundation	2050 sea-level rise	NPS-specific SLR modeling
Shoreline Change	Cliff retreat	Cliff retreat rate buffers
Reported Coastal Hazards	Visible Slope Instability	Park questionnaire; park visit

Sensitivity Analysis: Sensitivity within this protocol is a function of the inherent properties or characteristics of an asset. A set of primary indicators have been determined for asset sensitivity: flood damage potential, storm resistance and condition, historical damage, and protective engineering. Typically, assets with minimal exposure are excluded from sensitivity analysis, since an asset must be exposed to a hazard in order to be sensitive to it. Because none of the assets at CABR are within the flooding exposure zones (FEMA flood, tsunami, or sea-level rise), and 80% of them are minimally exposed, the sensitivity indicators (as defined in this protocol) do not apply. Therefore, sensitivity was not calculated at CABR.

Vulnerability Analysis: At most coastal parks, the exposure and sensitivity scores are summed to calculate a vulnerability score for each asset, and then binned into four vulnerability ranking categories. Because sensitivity was not evaluated at CABR, vulnerability was also not calculated. A detailed description of the complete vulnerability methodology (including sensitivity analysis) employed at other coastal parks is in the final section of this report.

Unique Factors & Considerations for CABR

Each park has a unique set of conditions based on the data available and the geologic setting. At CABR, the primary unique factors are: 1) the use of USGS cliff retreat rates for the western shoreline, 2) the creation of cliff retreat rates on the eastern shoreline, 3) the use of the tsunami hazard zones (MOST method) created by the University of Southern California, and 4) an additional exposure analysis case study specifically focused on cliff retreat.

Erosion & Coastal Proximity:

Many national parks along the west coast of the U.S. contain steeply sloping 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 rocks). In addition, it can be extremely difficult to separate how much shoreline change is due to wave erosion and how much is triggered by precipitation. In these cases, cliff retreat data (when available) are utilized in place of erosion rate data. For CABR, cliff erosion rate data were acquired from the USGS National Assessment of Shoreline Change (A GIS Compilation of Vector Cliff Edges and Associated Cliff Erosion Data for the California Coast: http://pubs.usgs.gov/of/2007/1112/).

Sea-Level Rise Data:

The NPS-specific sea-level rise layer used for the exposure analysis in this study is an inundation model that projects sea-level rise in the park to the year 2050. The estimated inundation extent was achieved by utilizing a modified bathtub approach as developed by NOAA, and attempts to account for local and regional tidal variability and hydrological connectivity. The extent of sea-level change polygons is derived from 4 model-run scenarios using sea-level change maps produced by Colorado Center for Astrodynamics Research at the University of Colorado in Boulder. The maps are based on Representative Concentration Pathways (RCP), which are four greenhouse gas concentration trajectories. Two RCPs were modeled, a moderate RCP, 4.5 and the most extreme RCP, 8.5. Each RCP was projected to the years 2050 and 2100. For CABR, 2050 the 8.5 RCP was utilized for the sea-level rise hazard zone.

Storm Surge, Tsunami, and Extreme Flooding:

For parks subject to tropical storms, a surge model (SLOSH: Sea, Lake, and Overland Surges from Hurricanes) is used for the storm surge indicator. For parks that do not have storm surge data (primarily west coast), an alternative data source is used, commonly either modeled extreme high water events (from Climate Change Response Program, based on historic tide gage data), or modeled tsunami hazard zones (variety of sources). For CABR, both the extreme high water and tsunami models (MOST method, University of Southern California) exist. In this case, the data that extends the furthest inland was applied at CABR. However, neither of these hazard zones showed inundation near any of the structures or transportation assets at CABR.

Coastal Hazards and Climate Change Exposure Results

A total of **34 structures** (buildings, shelters, fortifications, statues, bunkers, and batteries) **and 17 transportation assets** (roads, parking lots, and primary trails) were included in the assessment of coastal hazards and climate change exposure at CABR. The term "asset" will be used in this document to represent any structure or transportation infrastructure listed in FMSS, regardless of ownership. Also, the results for this assessment represent a time frame of approximately 35 years (2050).

For this assessment, each asset's exposure to coastal hazards and sea-level rise was analyzed. This section provides a general summary of the coastal hazards and climate change exposure results at CABR. Specific scores for these factors are reported (alongside FMSS data) for each individual asset in the supplied excel datasheets; final exposure results are also provided as Geographic Information Systems (GIS) maps and layers.

Exposure Analysis:

The notable result of the coastal hazards and climate change exposure analysis of CABR assets is that 80% of all assets (both structures and transportation) have minimal exposure, and an additional 10% have low exposure (Table 2). The remaining 10% have moderate exposure. Minimal exposure within this protocol means that the asset did not fall within ***any*** of the mapped exposure hazard zones mapped (flooding, tsunami inundation, cliff retreat, sea-level rise, and visible slope instability- see Methodology section at end of document). In fact, cliff retreat proximity and visible slope instability are the only exposure indicators that affected assets at CABR, as most of the park assets are located at higher elevations, well out of the reach of flooding hazards. The generally high elevations resulted in no assets having high exposure within the park (Table 2).

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

Assets	High Exposure		Moderate Exposure		Low Exposure		Minimal Exposure		Total #
	#	%	#	%	#	%	#	%	
Structures	0	0%	1	3%	2	6%	31	91%	34
Transportation	0	0%	4	24%	3	18%	10	59%	17
All CABR Assets	**0**	**0%**	**5**	**10%**	**5**	**10%**	**41**	**80%**	**51**

The vast majority of assets at CABR have minimal exposure to coastal hazards and climate change. However, 25% of the transportation assets at CABR are exposed to the cliff retreat hazard, which resulted in moderate exposure (when coupled with visible slope instability), and low exposure rankings for these assets. This is much higher than structures, of which only 9% are situated within the cliff retreat zone (Table 2). This is primarily due to the fact that several of the parking lots and roads are located along the cliffs where they provide access to coastal trails and ocean view overlooks (Figure 1).

Transportation assets within the cliff retreat exposure zone include three trails: Bayside Trail, Coast View Parking to Tidepools Trail, and Tidepool Parking Lot to Tidepool Overlook Trail; three parking lots: Tidepool Parking, Coast View Parking, and Sea Cove Parking; and one road: Gatchell Road. The three structures that are within the cliff retreat zone include: Searchlight Shelter #15, Lower Base End Station-Billy Goat Point, and Battery Bluff - South Gun Emplacement (Figure 1).

Three assets at CABR were reported as having signs of visible slope instability, including Gatchell Road, Tidepool Parking Lot to Tidepool Overlook Trail, and Battery Bluff - South Gun Emplacement. All three of these assets are located extremely close to cliff edges, and are likely to be impacted by cliff retreat in the near future. Gatchell Road is particularly at risk between the Sea Cove and Coast View parking lots along the eastern shoreline of the park. A visit to the park in August 2016 confirmed that Gatchell Road between the Coast View and Sea Cove parking lots is as little as 6 feet from the cliff edge (Figure 2).

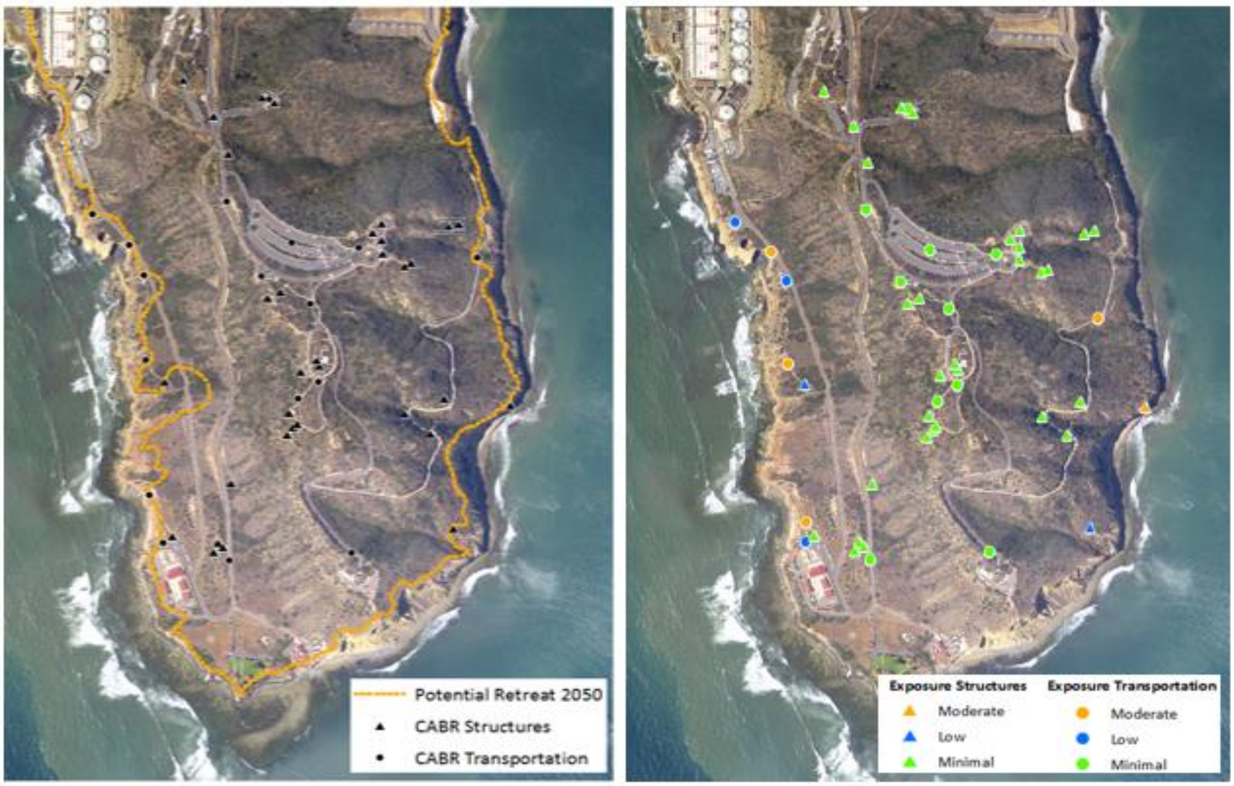

Figure 1. Left: Location of assets and potential cliff retreat (for 2050) at CABR. Note the location of many transportation assets (dots) near the cliff and shoreline. Right: Coastal hazards and climate change exposure rankings of structures and transportation assets at CABR.

Figure 2. Cliff retreat adjacent to Gatchell Road. Notice the cliff edge roughly 6 feet from the road (red box).

Case Study: Cliff Retreat at CABR

CABR is unique in that it is a coastal park experiencing shoreline change in the form of both cliff retreat and slope erosion. Cliff retreat is also the only coastal hazard that impacts CABR assets (due to the high elevation of the park), and consequently the exposure scores in this study are relatively low. While these results are accurate when examining all five exposure indicators as a whole, the hazards associated with cliff retreat at CABR are significant and cannot be ignored. Because of this, a case study was completed focusing specifically on cliff retreat exposure for structures and transportation assets.

Cliff Retreat Exposure Methodology:

For this case study on cliff retreat, the most recent (2013) cliff edge line from the USGS study was utilized where present (Figure 3), and a similar cliff edge line was created along the eastern portion of the park. The USGS study utilized a hillshade created in ArcGIS from a Digital Elevation Model (DEM) to digitize the break in slope that represented the cliff edge. A similar technique was used by WCU for the portion the coast with no USGS cliff edge data (Figure 3).

Four time periods were examined for the cliff retreat exposure case study at CABR: 2030, 2040, 2050, and 2100. Cliff retreat rates were determined by measuring the change between the USGS 1932-1934 shoreline and the 2013 shoreline. The retreat rates were then buffered to produce cliff retreat buffer zones for each of the four time frames. The buffer polygons were next used as guides to manually digitize potential retreat polylines, which were then smoothed using the ArcGIS generalization tool "Smooth Line" (Figure 4).

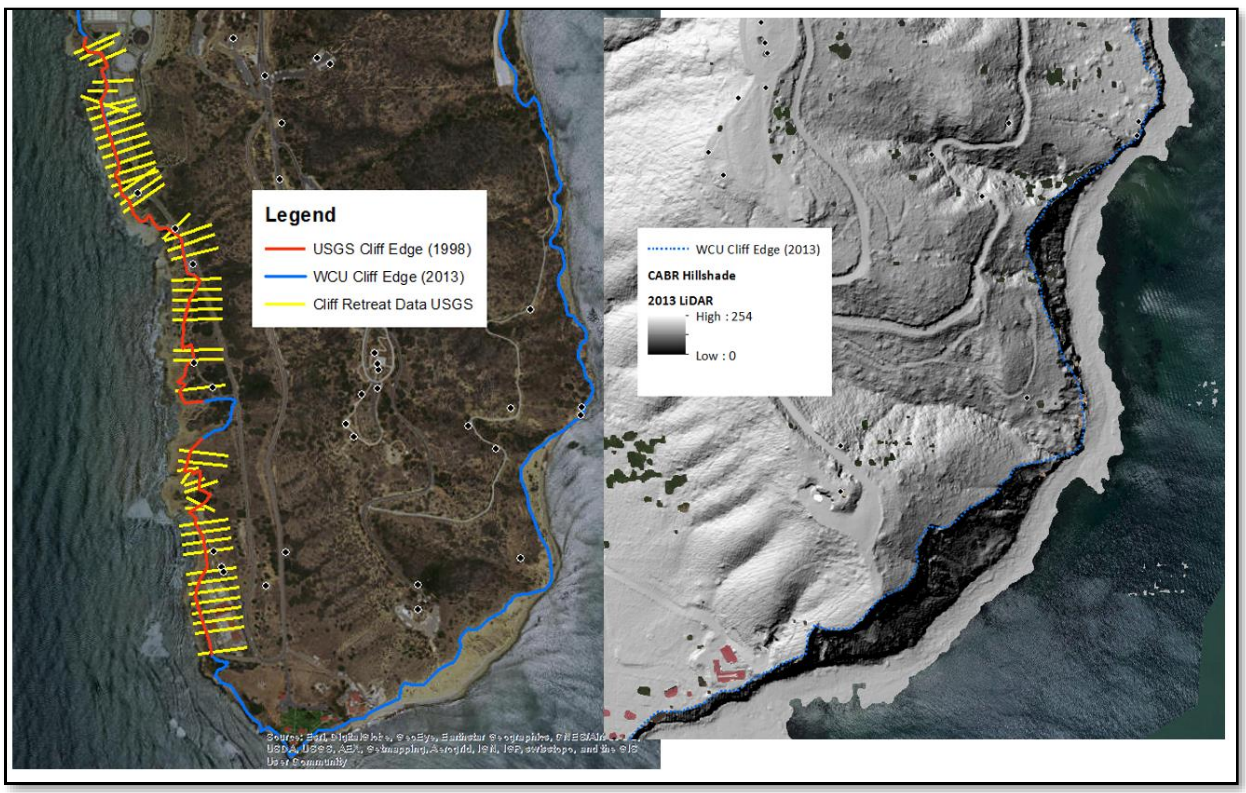

Figure 3. Left: Extent of USGS cliff erosion rate data at CABR (yellow transects). Cliff retreat buffers were created for the park using the cliff edge from the USGS study (red line) and the WCU created cliff edge (blue line) Right: Hillshade of CABR (created from a 2013 LiDAR DEM) used to create the WCU cliff edge.

Each asset that falls within a particular cliff retreat zone was assigned a higher score (4) than assets outside the hazard zone (1). After scores were given for each cliff retreat time frame (2030, 2040, 2050, and 2100), they were summed and binned to get a total exposure score for each asset. Final binned exposure scores fell into one of four ranking categories based on the number of time frames that impacted the asset: minimal exposure (asset does not lie within any of the retreat zones), low exposure (1 zone only), moderate exposure (2-3 zones), and high exposure (all 4 retreat zones). Figure 5 illustrates the cliff retreat exposure results for each time frame for transportation assets at CABR.

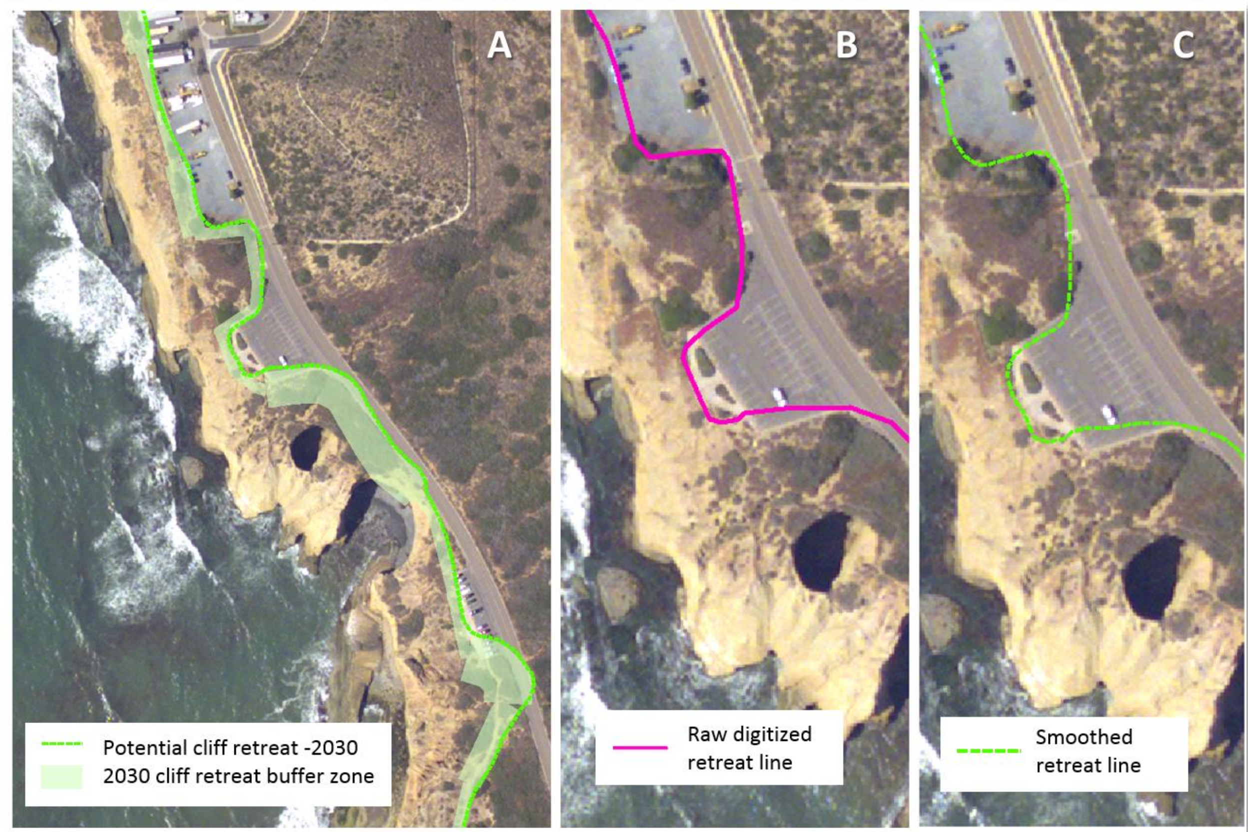

Figure 4. Creation of cliff retreat lines for CABR. A) Example of hand digitizing of the potential cliff retreat line for the 2030 timeframe using the buffer zone (light green polygons) as a guide. B) Zoomed in view of raw digitized retreat line for 2030. Notice the angularity of the line segments. C) Smoothed retreat line using the “smooth line” tool in ArcGIS for the same location.

ID	Location	Cliff Retreat Exposure 2030	2040	2050	2100	Raw Score	Step 7 Exposure Score	Exposure Rank
1	Bayside Trail	4	4	4	4	16	4	High
2	Paved Sidewalks	1	1	1	1	4	1	Minimal
3	Whale Watch Overlook Trail	1	1	1	1	4	1	Minimal
4	Visitor Center Parking	1	1	1	1	4	1	Minimal
5	Ocean View Parking	1	1	1	1	4	1	Minimal
6	Lower Maintenance Area Parking	1	1	1	1	4	1	Minimal
7	Tidepool Parking Lot	1	4	4	4	13	3	Moderate
8	Coast View Parking	4	4	4	4	16	4	High
9	Sea Cove Parking	4	4	4	4	16	4	High
10	Cabrillo Memorial Drive	1	1	1	1	4	1	Minimal
11	Lighthouse Service Road	1	1	1	1	4	1	Minimal
12	Battery Humphreys Road	1	1	1	1	4	1	Minimal
13	Cabrillo Road	1	1	1	1	4	1	Minimal
14	Gatchell Road	4	4	4	4	16	4	High
15	Coast View Parking to Tidepools Trail	4	4	4	4	16	4	High
16	Tidepool Parking Lot to Tidepool Overlook Trail	4	4	4	4	16	4	High
17	Lighthouse Parking Area	1	1	1	1	4	1	Minimal

Cliff Retreat Exposure Results

Name of Column	Description of Each Column Cliff Exposure
2030	This column represents if an asset is within the 2030 Cliff Retreat Zone.
2040	This column represents if an asset is within the 2040 Cliff Retreat Zone.
2050	This column represents if an asset is within the 2050 Cliff Retreat Zone.
2100	This column represents if an asset is within the 2100 Cliff Retreat Zone.
Raw Score	Sum of scores for all time frames.
Exposure Score	The final exposure score (1-4), binned, including any interpretations by WCU.
Exposure Rank	Final binned exposure rank (low, moderate, high). If ranked "minimal" it means that the asset was is NONE of the exposure zones.

Figure 5. Example of cliff retreat exposure scoring for transportation assets at CABR. Notice the scoring for each time frame (4 or 1).

Cliff Retreat Exposure Results:

The potential cliff edge lines for the years 2030, 2040, 2050 and 2100 are shown in Figures 6 and 7 and tabular results are shown in Table 3. The cliff edge lines (Figures 6 and 7) assume constant rates of cliff retreat, which are calculated based on the past 80 years of retreat. The maps are meant to highlight assets that have the greatest potential to be impacted by cliff retreat in the coming decades.

Because cliff retreat rates vary over time, the retreat lines on the maps do not represent a definitive prediction of where the cliff edge will be at that time. Instead, these lines represent the average retreat over 80 years projected into the future. It is important to note that the cliff retreat that has occurred over the past 80 years has happened both gradually and episodically; the same will be true for any future cliff retreat.

While 80% of all assets at CABR have minimal exposure to cliff retreat, 14% are highly exposed to cliff retreat (in all four retreat zones) and 6% are moderately exposed (in three retreat zones) over the timeframes analyzed. Assuming constant rates of retreat, the assets with high exposure have the highest potential to experience the effects of cliff retreat by 2030, while the moderate exposure assets could potentially begin experiencing the effects of cliff retreat by 2040. Among transportation assets, 35% have high exposure and 6% have moderate exposure to cliff retreat. Structures fare a little better, with 3% high exposure and 6% moderate exposure.

The only structure with high exposure to cliff retreat is the Battery Bluff - South Gun Emplacement (Figure 8). This asset is located close to the former North Gun Emplacement, which fell into the ocean in 2006. A total of six transportation assets (35%) have high exposure to cliff retreat: Bayside Trail, Coast View Parking, Sea Cove Parking, Gatchell Road, Coast View Parking to Tidepools Trail, and Tidepool Parking Lot to Tidepool Overlook Trail (Figure 8). Each of these high exposure assets is likely to be affected by cliff retreat by 2030 (Figures 6 and 7), if retreat continues at its current rate.

The moderate cliff retreat exposure assets include: Searchlight Shelter #15, Lower Base End Station - Billy Goat Point, and Tidepool Parking Lot (Figure 8). Each of these assets will likely begin to experience the effects of cliff retreat by 2040 (Figures 6 and 7), if retreat continues at its current rate.

Table 3. CABR Cliff Retreat Exposure Results. Sum of percentages may not equal 100 due to rounding.

Assets	High Exposure		Moderate Exposure		Low Exposure		Minimal Exposure		Total #
	#	%	#	%	#	%	#	%	
Structures	1	3%	2	6%	0	0%	31	91%	34
Transportation	6	35%	1	6%	0	0%	10	59%	17
All CABR Assets	**7**	**14%**	**3**	**6%**	**0**	**0%**	**41**	**80%**	**51**

Figure 6. CABR assets and cliff retreat timelines based on 80-year erosion rates.

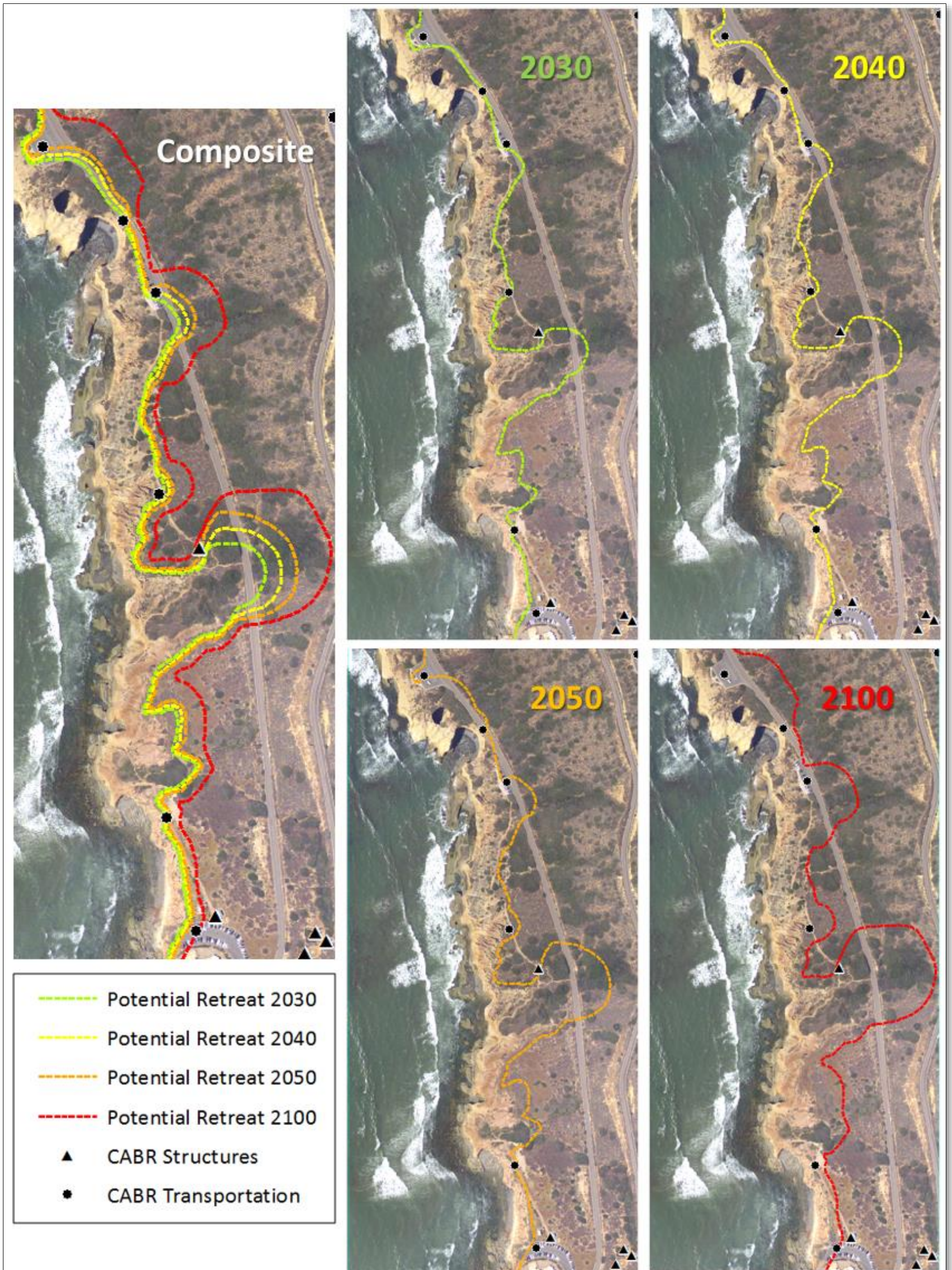

Figure 7. Expanded view of CABR assets most threatened by cliff retreat timelines.

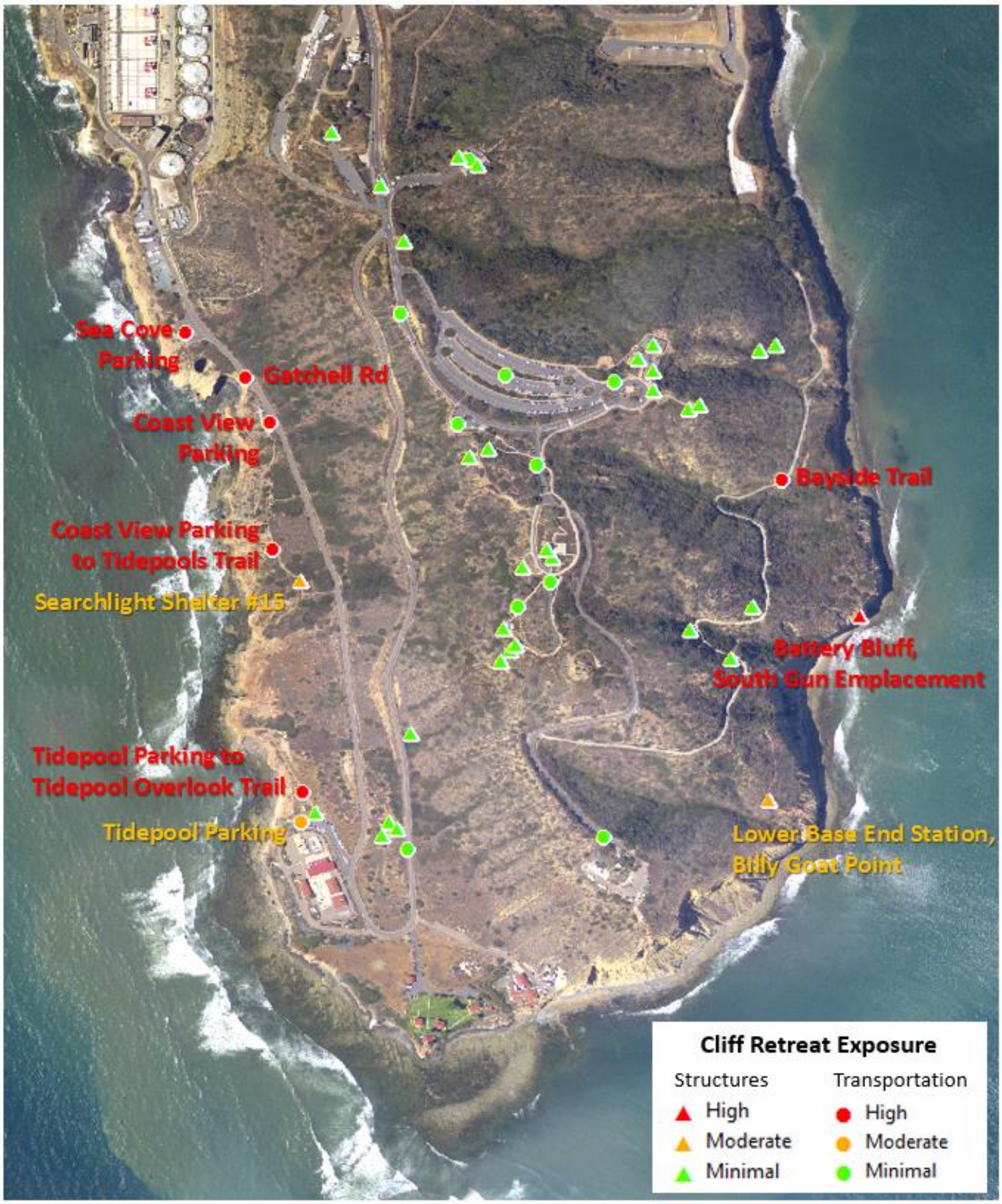

Figure 8. CABR assets most threatened by cliff retreat. One structure, Battery Bluff - South Gun Emplacement, has high exposure to cliff retreat. Six transportation assets have high exposure to cliff retreat: Bayside Trail, Coast View Parking, Sea Cove Parking, Gatchell Road, Coast View Parking to Tidepools Trail, and Tidepool Parking Lot to Tidepool Overlook Trail. Moderate cliff retreat exposure assets include: Searchlight Shelter #15, Lower Base End Station - Billy Goat Point, and Tidepool Parking Lot

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

Table 7. 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). In some cases, a more detailed park-specific analysis may be necessary.

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 8 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 8. **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 9 below describes each indicator, including the description, rationale, and scoring.

Table 9. Additional Bridge Indicators

Indicator	Description & Rationale	Scoring (NBI score = sensitivity score)
Clearance	Bridges with higher clearance above the water surface are less likely to be damaged by coastal hazards.	*Amount of clearance in feet*: > 15 = 1; 9-15 = 2; 1-8 = 3; 0= 4
Scour Rating	Bridges with scour issues are more likely to be damaged by coastal hazards.	*Rating*: n/a = 1; low & stable (5-8) = 2; stable (4) = 3; critical = 4
Condition	Bridges in poor condition are more likely to be damaged by coastal hazards.	*Condition Rating*: n/a = 1; 0-3 = 2; 4-6 = 3, 7-9 = 4
Age	Bridges closer to their lifespan are more likely to be damaged by coastal hazards.	*Age (in years):* 0-25 = 1; 26-50 = 2; 51-75 = 3; > 75 = 4

To calculate a sensitivity score, each asset is first given a score for all applicable indicators. These scores are summed to obtain a total raw score for sensitivity, then binned into three categories reflective of the number of unfavorable indicators: low sensitivity, moderate sensitivity, and high sensitivity. Specific scoring ranges can be found within the Excel results sheets.

Step 3: Asset Vulnerability Analysis
To obtain a vulnerability score for each asset, the exposure and sensitivity scores are summed, and then binned into four vulnerability ranking categories. The ranking categories are as follows: minimal vulnerability (assets with minimal exposure and not included in the sensitivity analysis), low vulnerability, moderate vulnerability, and high vulnerability. Specific scoring ranges for vulnerability can be found within the Excel results sheets. A subset of the assets from the completed vulnerability analysis will be chosen by the park for development of adaptation strategies (step 4).

Step 4: Adaptation Strategies Analysis
After the vulnerability analysis is complete, adaptation strategies 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 10).

Table 10. 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