NATIONAL PARK SERVICE • U.S. DEPARTMENT OF THE INTERIOR

Coastal Adaptation Strategies Handbook

2016

ON THIS PAGE
Hurricane Sandy created a breach at Fire Island National Seashore. Photograph by Diane Abell, NPS.

ON THE COVER
Point Reyes Historic Lighthouse at Point Reyes National Seashore, California. Photograph by Don Weeks, NPS.

Coastal Adaptation Strategies Handbook

National Park Service Report 2016

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While publicly available content was the focus of this handbook for National Park Service employees and our partners, some information and resources in this report are only available to internal National Park Service and Department of Interior staff. Where there is a restriction on access, a disclaimer similar to "*NPS/DOI internal access only*" is used.

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Executive Summary

The National Park Service has an agency-wide responsibility to address climate change impacts on vulnerable park resources. This handbook provides guidance for National Park Service (NPS) managers, partners, and other practitioners in exploring and implementing climate change adaptation strategies in estuarine and coastal areas, including the Great Lakes. This handbook captures the National Park Service's current understanding of a rapidly developing field as it relates to coastal parks; identifies tools and strategies; provides examples of approaches that the National Park Service as an agency and individual parks are using to address coastal vulnerabilities and climate change impacts; and provides policy and decision-making guidelines. Online resources will be updated to supplement this document and can be found at https://www.nps.gov/subjects/climatechange/coastalhandbook.htm.

The National Park Service protects natural resources, cultural resources, and facilities in over 120 parks that are vulnerable to changes in sea and lake levels, saltwater intrusion, ocean acidification, inundation during coastal storms, and the impacts of changing temperature and precipitation regimes. These parks compose a network of protected areas that are critical to maintaining threatened coastal resources and values and preserving coastal heritage. The National Park Service must prepare for and adapt to coastal climate change impacts in order to protect irreplaceable resources where possible, and to connect visitors to the resources and the potential impacts of climate change.

The nine chapters in the handbook expand upon the following take-home messages.

Introduction

- Climate change will continue to impact coastal resources and assets in the national parks at various rates. To address the current and anticipated impacts, parks can work proactively and cooperatively with others to implement adaptation strategies for resources at various levels of exposure and vulnerability. Adaptation is a process, not a single action.
- Adaptation includes a range of potential responses, including resisting change, accommodating change, and directing change towards a specific desired new future.
- Adaptation decisions should be made using the best available science; however, uncertainty should not prohibit adaptation action. There are numerous information systems and tools available to support climate change adaptation planning.
- Responding to climate change impacts on coastal parks is most effective when diverse adaptation strategies on a variety of temporal and spatial scales are considered.
- Vulnerability assessments can help prioritize among resources or better target an adaptation strategy.

Policy

- Park managers have substantial flexibility and discretion when selecting coastal adaptation strategies. Yet this flexibility and discretion are not unconstrained; various policy and guidance documents contain additional considerations that should be incorporated into park managers' decisions about adaptation alternatives.
- Park adaptation decisions must be well documented.

Planning

- Adaptation is most effective when it is intentionally and deliberately designed as a response to anticipated effects associated with climate change.
- Climate change adaptation is not a stand-alone plan, but should be addressed in ongoing, routine planning processes such as foundation documents, general management plans, resource stewardship strategies, and preparedness planning.
- Adaptation strategies may require a series of decisions and actions that will change over time.
- Preparing for natural disasters includes planning for uncertainty and allows for adaptation opportunities post-incident.

Natural Resources

- Parks can choose from a range of potential adaptation strategies developed for climate-sensitive ecosystems. Applying strategies to coastal systems is park- and resource-specific. There is not yet a clear way forward to know which adaptation options will be most effective, and implementation is an active research field. The scientific resources to support adaptation are varied and growing.
- Uncertainty or the lack of locally specific information should not stop adaptation action. Strategies that are able to incorporate additional information at later steps, such as adaptive management, are well suited to coastal climate adaptation challenges.
- Managing for change may require working at a larger landscape scale than a single park and, thus, working with partners.

- NPS policies to maintain natural processes are consistent with consideration of natural resource adaptation strategies because change is part of natural processes, and natural processes can be highly resilient. Yet climate change functions outside bounds of natural variability and thresholds will be exceeded. Strategies to manage for change, especially where natural systems are more vulnerable, or where thresholds can be anticipated, are a growing challenge.

Cultural Resources

- Cultural resources are unique and nonrenewable resources.
- The capacity of cultural resources to move or change is limited because they are in large part non-living and have strong ties to place, part of which can be ties to a dynamic coastal landscape.
- Cultural resource adaptation strategies can be applied to coastal systems.
- Managers need NPS-level guidance for adaptation of archeological and ethnographic resources to climate change. Upcoming reports and guidance for museum collections, cultural landscapes, and built environments will include coastal-relevant adaptation strategies.

Facility Management

- The National Park Service has the responsibility to invest wisely in facilities for the long term. Unquestionably, climate change and natural hazards pose a significant threat to our investment in current and future facilities.
- Vulnerability to climate change impacts needs to be understood at the asset level for parks to plan for these impacts. This includes an understanding of the risk of exposure and sensitivity of the asset to these impacts.
- Park asset management plans and five-year project plans should be evaluated to include elements of climate change vulnerability and coastal adaptation strategies.
- Climate Friendly Park workshops are opportunities to integrate climate change mitigation planning with coastal adaptation.

Communication and Education

- At the heart of the variety of products covered in this section lies communication itself. These products merely serve as the vehicle to provide audiences with effective communication of the efforts made in coastal adaptation. The communication of success stories, both with other parks and with partners, will help build support for the implementation of adaptation strategies.
- Support of local communities, parks, partners, stakeholders, and the general public is necessary for the effective implementation of any adaptation strategy. Many times the efficacy of adaptation programs relies on the cooperation of a variety of interested parties. Communication is necessary to include stakeholder involvement, which is crucial for planning and managing for change.

Protecting Infrastructure: Costs and Impacts

- Shoreline stabilization mechanisms can protect resources in place but are not long-term solutions and have trade-offs, including disruption of natural processes.
- Beach nourishment can be a costly short-term effort. There are ecological and physical consequences of dredging sand from other locations and placement of sediment on intertidal and nearshore habitats.
- The effectiveness of natural and nature-based features for shoreline protection is site-specific. Their suitability as a long-term alternative depends on ability to adapt to climate change, design, and compatibility with local conditions.
- Consider opportunities to redesign and relocate facilities, and to replace facilities with portable structures. Evaluate the maintenance costs and non-standard costs associated with these alternatives.

Lessons Learned from Hurricane Sandy

- Hurricane Sandy presented opportunities for adaptation and for testing adaptation elements in existing plans.
- Natural resources were found to be more resilient than many cultural resources and facilities.
- Historic structures have resilient design features. If buildings are well maintained, they may have a better chance of surviving a major storm.
- National seashores can provide other parks with good examples of preparation for and learning from experience about storm impacts on dynamic landscapes.
- After an event, there is an immediate and strong push to return park assets to pre-storm conditions, which can leave resources vulnerable to similar impacts in the future.
- Baseline monitoring and resource assessments are essential data to evaluate impacts and plan for recovery.
- Post-storm recovery is a critical opportunity to adapt to climate change.

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Acronyms

ABFE	Advisory Base Flood Elevation
ADA	Americans with Disabilities Act
API	Asset Priority Index
ASIS	Assateague Island National Seashore
ASMIS	Archeological Sites Management Information System
BELA	Bering Land Bridge National Preserve
CAKE	Climate Adaptation Knowledge Exchange
CAKR	Cape Krusenstern National Monument
CBA	Choosing By Advantages
CC	Climate Change
CCRP	Climate Change Response Program
CEI	Coastal Engineering Inventory
CFP	Climate Friendly Parks
CFR	Code of Federal Regulations
CLIP	Climate Leadership in Parks
CO2	Carbon dioxide
CRAVe	Climate Registry for the Assessment of Vulnerability
DAB	Development Advisory Board
DEM	Digital Elevation Model
DOI	Department of the Interior
EA	Environmental Assessment
EMS	Environmental Management Systems
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FIIS	Fire Island National Seashore
FIRM	Flood Insurance Rate Map
FMSS	Facility Management Software System
FY	Fiscal Year
GATE	Gateway National Recreation Area
GHG	Greenhouse Gas
GIS	Geographic Information System
GPS	Global Positioning System
GRD	Geologic Resources Division
GMP	General Management Plan
GNSS	Global Navigation Satellite System
HAB	Harmful Algal Bloom
HABS	Historic American Building Survey
HAER	Historic American Engineering Record
HALS	Historic American Landscape Survey
I&M	Inventory and Monitoring
IMT	Incident Management Teams
IPCC	Intergovernmental Panel on Climate Change
LCC	Landscape Conservation Cooperatives
LiDAR	Light Detection and Ranging
MsCIP	Mississippi Coastal Improvements Program
NAVD	North American Vertical Datum
NCTC	National Conservation Training Center
NED	National Elevation Dataset
NEPA	National Environmental Policy Act
NER	Northeast Region
NGS	National Geodetic Survey
NGO	Non-governmental Organization
NHL	National Historic Landmark
NHPA	National Historic Preservation Act

NNBF	Natural and Nature-Based Features
NOAA	National Oceanic and Atmospheric Administration
NPS	National Park Service
NRSS	Natural Resource Stewardship and Science Directorate
NWP	Nationwide Permit
OB	Optimizer Band
OPUS	Online Positioning User System
PM	Policy Memo
PMIS	Project Management Information System
RRT	Rapid Review Team
RTK	Real Time Kinematic
SAGE	Systems Approach to Geomorphic Engineering
SCAPE	Scottish Coastal Archaeology and the Problem of Erosion
SLAMM	Sea Level Affecting Marshes Model
SLOSH	Sea, Lake, and Overland Surges from Hurricanes
SLR	Sea Level Rise
SOCC	Sustainable Operations and Climate Change (Branch)
USACE	United States Army Corps of Engineers
USC	United States Code
USFWS	United States Fish and Wildlife Service
USGS	United States Geological Survey
VA	Value Analysis
WASO	Washington Support Office
WRD	Water Resources Division

Chapter 1 Introduction

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The National Park Service manages 88 ocean, coastal, and Great Lakes parks with more than 11,200 mi (18,000 km) of shoreline (Curdts 2011).[1] An additional 35 parks are subject to coastal influence from sea level change, though some do not manage a shoreline (Caffrey and Beavers 2013). As a network of protected areas important to maintaining threatened coastal resources and values, these parks serve as sentinels of coastal change and examples to the world of stewardship for irreplaceable natural and cultural resources and visitor experiences. They are also vulnerable to threats from climate change effects such as sea level rise, lower lake levels, salt water intrusion, and inundation during coastal storms. Thus, more than one-third of the 413 National Park Service (NPS) park units must prepare to adapt to coastal climate change impacts.

Purpose

This handbook provides guidance for NPS managers, partners, and other practitioners in exploring and implementing climate change adaptation in coastal settings, including Great Lakes areas but excluding nearshore and open-ocean issues such as oceanographic changes to marine ecosystems, and impacts to threatened and endangered species habitats such as offshore shoals, and fisheries. Climate change adaptation is a broad, interdisciplinary, and rapidly developing field. This handbook is not a comprehensive manual with a single decision framework or a complete listing of the best tools for a particular resource or asset. Instead, it summarizes key approaches currently in practice or considered for climate change adaptation in coastal areas to guide adaptation planning in coastal parks. The level of detail varies by topic depending on the state of research and practice in that field. Some topics are well researched in coastal areas, while others are emerging issues for which there may be no specific adaptation strategies to recommend or results available. Numerous information systems and tools support climate change adaptation planning (Stein et al. 2014), and the field of climate change adaptation is rapidly developing. Thus, the handbook also directs readers to other excellent sources on adaptation. Online resources supplement this document and are available at https://www.nps.gov/subjects/climatechange/coastalhandbook.htm.

[1]park-specific statistics are available at https://www.nps.gov/orgs/1439/upload/NPS_OceanCoastal_Stats.pdf

Provision of this guidance is a further step in implementing the NPS Climate Change Response Strategy (NPS 2010), which includes four major components: science, communication, adaptation, and mitigation. While this handbook primarily focuses on adaptation, it also addresses science, communication, and mitigation where these intersect with adaptation.

Terminology

Many coastal parks have dynamic features such as barrier islands, marshes, estuaries, bluffs, glaciers, or volcanic features; others have fixed coastline types (e.g., rocky, coral reef, built, armored) that may respond differently to climate change. The vulnerability of each of these features varies; climate change will affect them in distinct ways. Vulnerability is the extent to which a target (resource, asset, or process) is susceptible to harm from climate change and other stressors.

A vulnerability assessment (Glick, Stein, and Edelson 2011) can help to understand relative impacts from climate change, thus informing priorities for response. The National Park Service provides guidance on what to include in a robust vulnerability assessment analysis (NPS 2014a). While initially developed to assess the potential impact of climate change on natural resources, vulnerability assessments are being applied in other interdisciplinary contexts. For example, the National Park Service is developing methods to conduct vulnerability assessments for cultural resources and facilities.

> **Vulnerability:** The degree to which a resource, asset or process is susceptible to adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed; its sensitivity; and its adaptive capacity (IPCC 2014).

Given the variety of coastal types and the diversity of resources and assets managed by the National Park Service, multiple climate change adaptation strategies may apply to a given situation (Beavers et al. 2014; Schupp, Beavers, and Caffrey 2015). This handbook uses the term "adaptation" as defined in Executive Order 13653, "Preparing the United States for the Impacts of Climate Change" (78 FR 66819, 6 November 2013).

Adaptation: An adjustment in natural or human systems in anticipation of or in response to a changing environment in a way that effectively uses beneficial opportunities or reduces negative effects.

Within the adaptation field and this handbook, "resilience" is a common term used differently between disciplines. This handbook uses two definitions, one more broadly applied in a community context and another in an ecological context, as defined in the Glossary (see also Fisichelli, Schuurman, and Hawkins Hoffman 2016).

Resilience (community context): The capability to anticipate, prepare for, respond to, and recover from significant multi-hazard threats with minimum damage to social well-being, the economy, and the environment. It is not a synonym for adaptation.

Resilience (ecological context): The ability to return to a previous state after disturbance.

Fundamental Concepts

Adaptation is an ongoing process, not a single action completed "once and forever." Planning for adaptation does not require a stand-alone effort but is best incorporated into ongoing planning processes such as general management plans, resource stewardship strategies, and storm response and recovery plans. Strategic, advanced planning for adaptation prepares parks for action when opportunities to adapt arise through response to storm events and other rapid changes in the coastal zone. Rapid changes in the coastal zone will mean that managers may have limited time and opportunities to make decisions. A hurricane, budget realities, or abrupt changes in the physical landscape will define the timeline for some decisions. However, even these limited windows of time offer opportunities in which to act, especially when the park has determined appropriate responses through advanced planning.

Adaptation can occur as a series of actions that have different foci. For example, stewardship of a historic structure (Caffrey and Beavers 2008) may involve multiple adaptation actions:

- cultural: document the structure (Historic American Buildings Survey [HABS] standards)
- interpretation: interpret the change to create opportunities for visitors to connect with the significance of the structure (see "Chapter 5 Cultural Resources")
- facility management: elevate the structure above flood hazards, following best practices that are outlined in *The Secretary of the Interior's Standards* for the Treatment of Historic Properties (36 CFR 68) and Federal Flood Risk Management Standard (E.O. 13690) (see "Chapter 6 Facility Management")

There may be inherent trade-offs in effective adaptation; for example, protecting cultural resources or facilities through shoreline stabilization mechanisms may protect resources in place but disrupt natural processes. On the other hand, adaptation approaches used for infrastructure may be consistent with cultural resource goals (e.g., for a cultural landscape) while also helping to protect opportunities for habitat and species migration.

Adaptation Continuum: Resist, Accommodate, and Direct Change

Observed and anticipated ecological responses suggest that many current management goals and strategies may become ineffective under accelerated rates of climate change, sea level rise, and associated impacts (NPSABSC 2012). Adaptation includes a range of potential management responses, including resisting change, accommodating change, and directing change towards a specific desired new future (figure 1.1; Fisichelli, Schuurman, and Hawkins Hoffman 2016): *resist change* to maintain current or past conditions, *direct change* towards specific desired new conditions, and *accommodate change* by supporting a resource's capacity to respond to changes without steering it towards past conditions or a strictly-defined desired future state. The intensity of management intervention required to achieve a particular adaptation goal depends on many variables, such as the focal resource's vulnerability to climate change, and may vary with management time horizons and rates of climate change. These concepts are described further in "Chapter 4 Natural Resources." Many of the case studies in Schupp, Beavers, and Caffrey (2015) focus on resisting and accommodating change.

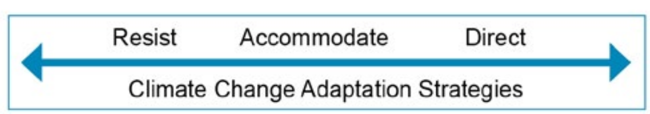

Figure 1.1. Climate Change Adaptation Continuum (adapted from Fisichelli, Schuurman, and Hawkins Hoffman 2016).

Decision Tools

Parks should use the best available science to inform management decisions, but high uncertainty or lack of local science should not preclude adaptation action (NPS 2016). Hoffman et al. (2014) describes five strategies for exploring uncertainty and making decisions. Scenario-based planning is a structured, "what if" exercise that uses qualitative and quantitative information to envision multiple possible futures. Robust decision-making identifies decisions that maximize the likelihood of some acceptable outcome across a range of scenarios rather than seeking the best possible outcome for one scenario. Expert elicitation helps to identify and characterize uncertainty and fill data gaps with local expertise and contextual knowledge. Structured decision-making begins with a solid understanding and framing of the problem to be solved, and evaluation and prioritization are formal and quantitative. In adaptive management, decisions are made while simultaneously pursuing additional knowledge, which is incorporated into subsequent re-evaluation of management decisions. NPS climate change scenario planning, which is described in "Chapter 3 Planning," incorporates at least four of these strategies: scenario-based planning, robust decision-making, expert elicitation, and adaptive management; structured decision-making may also be used within the scenario planning framework. An example of value-based decision-making from Liberty and Ellis Islands is provided in "Chapter 9 Lessons Learned from Hurricane Sandy." NPS examples of adaptive management are provided in "Chapter 3 Planning" and "Chapter 5 Cultural Resources."

Impacts of Climate Change on Coastal Resources and Assets

The coastal zone is a dynamic environment subject to the effects of wind, waves, tidal processes, freshwater and sediment inputs, and other processes with rates and magnitudes affected by climate change. Coastal resources and assets are affected by changes in sea level, temperature of both air and water resources (i.e., lakes and oceans), precipitation, storminess, and ocean acidification. Changes to the physical environment may be gradual and subtle or rapid and easily noticeable.

Changes in Sea Level and Lake Level

Global sea level is increasing and expected to continue to increase into the future (Tebaldi, Strauss, and Zervas 2012). However, location and magnitude of sea level change will vary along United States (US) coasts (figure 1.2); causes include changes in North Atlantic circulation that will affect the mid-Atlantic coast (Sallenger, Doran, and Howd 2012), land subsidence along the Gulf Coast (Parris et al. 2012), and isostatic rebound causing relative sea level to fall along the southeast coast of Alaska, including Glacier Bay National Park and Preserve (Motyka et al. 2007). Higher relative sea level causes accelerated coastal erosion, landward migration of shorelines, and saltwater intrusion into aquifers and estuaries, and amplifies the more frequent flooding caused by higher storm surges (Field et al. 2007). Impacts of sea level rise on coastal ecosystems are amplified by submergence and where landward migration is impeded by built structures or steep topography and where vertical growth is slower than sea level rise (Field et al. 2007). Along Alaska's northwestern coast, sea level rise combines with other forces, including thawing permafrost, loss of coastal sea ice, and more intense extreme weather events to increase erosion and flooding (Maldonado et al. 2013).

Along the Great Lakes, shoreline water levels will decrease as a result of climate change (Schramm and Loehman 2010). Many parks have already experienced changes in lake level due to recent changes in climate coupled with ongoing tectonic conditions (Hartmann 1990; Lofgren, Hunter, and Wilbarger 2011). Lake level fluctuations in the Great Lakes prior to 1980 were predominantly driven by changes in precipitation, but evaporation has begun to significantly contribute to lake level decreases for the first time on record, including on Lake Superior in Apostle Islands National Lakeshore (Hanrahan, Kravtsov, and Roebber 2010). There are significant data gaps in the geographic extent of lake level data. The lake level as recorded by tide gauges is further complicated by local tectonics that have caused decreasing relative lake level in some areas and increasing lake level in others (Gronewald et al. 2013).

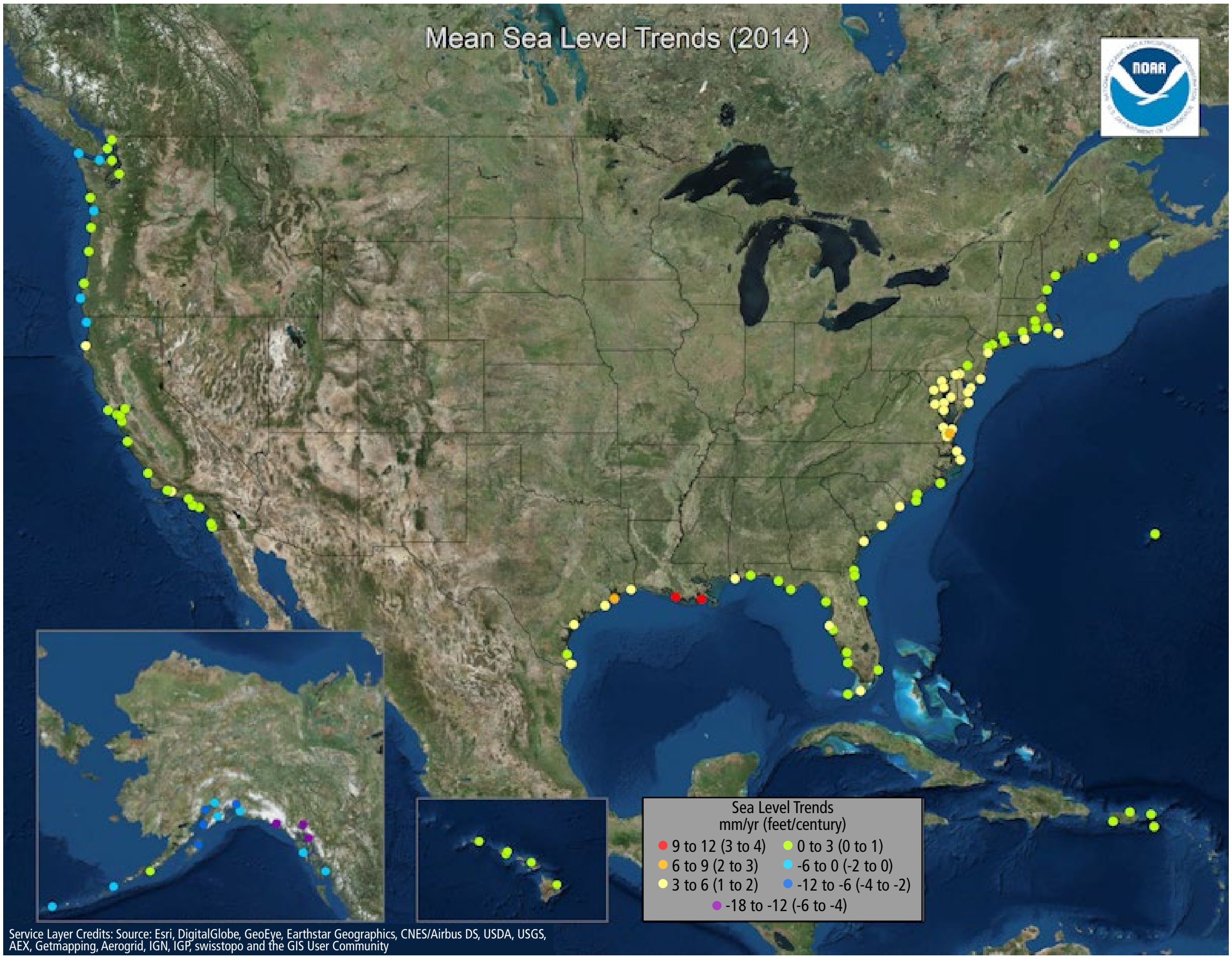

Figure 1.2. Map of regional mean sea level trends in the United States. The rates of relative local mean sea level observed at long-term tide stations (based on a minimum of 30 years of data) vary due to differences in rates and sources of vertical land motion. Areas experiencing little-to-no change in mean sea level are illustrated in green, including stations consistent with average global sea level rise rate of 0.7 in/yr (1.7-1.8 mm/yr). Stations illustrated with positive sea level trends (yellow-to-red) are experiencing both global sea level rise, and lowering or sinking of the local land, causing an apparently exaggerated rate of relative sea level rise. Stations illustrated with negative trends (blue-to-purple) are experiencing global sea level rise and a greater vertical rise in the local land, causing an apparent decrease in relative sea level. Figure from NOAA available at http://tidesandcurrents.noaa.gov/sltrends/slrmap.htm (accessed 20 April 2016).

Temperature Increases

Temperatures continue to increase in most parks, including coastal areas. For the United States, the last decade is the warmest on record, and as of April 2016, 2015 is the warmest year on record since modern record-keeping began in 1880 (NASA 2016). A recent study (Monahan and Fisichelli 2014) identified parks with climate variables that had "extreme" values recently (in the last 10–30 years) relative to the 1901–2012 historical range of variability; "extreme" conditions were those that exceeded 95% of the historical range of conditions. An overwhelming majority of national parks are already at the extreme warm end of their historical range of conditions (figure 1.3). Of 289 parks included in the study, 81% (235 parks) have recent "extreme" warm average air temperatures. This study included 80 coastal and Great Lakes parks, of which 74% (59 parks) were extreme warm, one park was extreme cold, one park was both extreme warm and cold, and 19 parks (24%) did not have any recent extreme temperature variables.

Models project that by 2071–2100, annual water temperature may increase in all of the Great Lakes, with the most change in Lake Superior and the least in Lake Erie (Trumpickas, Shuter, and Minns 2009). Summer surface water temperatures are expected to increase by up to 6°C (10.8°F) on average (Trumpickas, Shuter, and Minns 2009). The combination of long-term warming and increasing wind speeds on Lake Superior may lengthen the season of stratification and cause the surface mixed layer to become shallower, which has significant implications for the biogeochemical cycles of large lakes, atmospheric circulation along lake shores, and the transport of airborne pollutants in regions with many lakes (Desai et al. 2009).

Sea surface temperature is rising at an average rate of 0.13°F (0.23°C) per decade (figure 1.4). Some areas have experienced cooling, such as in the North Atlantic, though not including coastal park areas. Increases in sea surface temperature have fueled weather systems such as heavy rain and snow, and can shift storm tracks, potentially contributing to droughts in some areas (IPCC 2013). Changes in sea surface temperature can also affect marine ecosystems by controlling which species are present, altering migration and breeding patterns. Over the long term, increases in sea surface temperature will change water circulation patterns. Resultant changes in habitats and nutrient supply could dramatically alter ocean ecosystems and lead to declines in fish populations and the commercial and subsistence fisheries that depend on them.

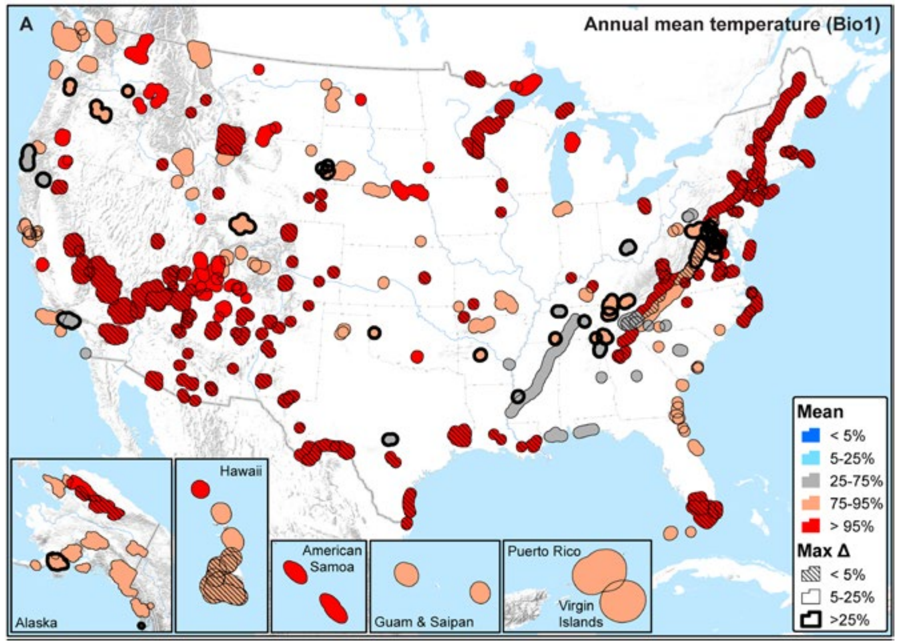

Figure 1.3. Recent mean air temperature relative to the historical range of variability (1901–2012) in 289 US national parks (park plus 30 km buffer). Park temperature is considered extreme if one or more of seven temperature variables examined is <5th percentile ("cold") or >95th percentile ("warm") of the historical distribution. Figure from Monahan and Fisichelli (2014).

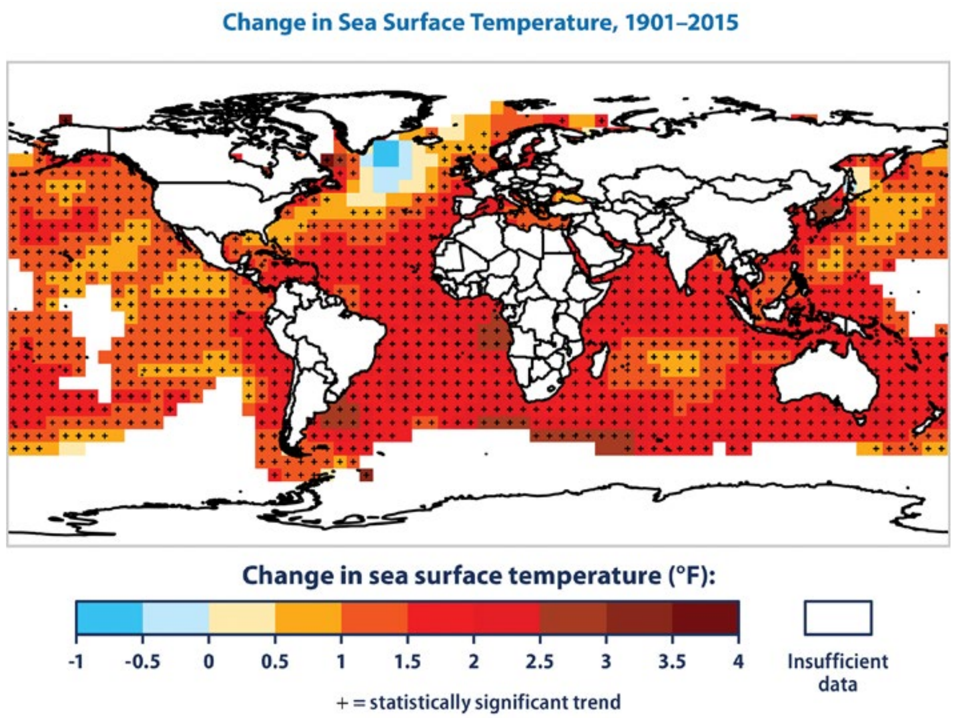

Figure 1.4. Map showing the change in global average sea surface temperatures between 1901 and 2014. It is based on a combination of direct measurements and satellite measurements. A black "+" symbol in the middle of a square on the map means the trend shown is statistically significant. White areas did not have enough data to calculate reliable long-term trends. Figure from U.S. Environmental Protection Agency. 2016. Climate change indicators in the United States, 2016. Fourth edition. EPA 430-R-16-004. https://www.epa.gov/climate-indicators/climate-change-indicators-sea-surface-temperature

Ocean Acidification

Ocean acidification has implications for coastal resources; it is enhanced by coastal processes, affects coastal species such as coral, and may affect some coastal adaptation efforts, such as oyster reefs emplaced as living shorelines.

Ocean acidification occurs when atmospheric carbon dioxide gas dissolves in the ocean where it reacts with seawater to form carbonic acid, raising the acidity of the seawater and decreasing pH (NOAA 2016) (figure 1.5). The current rate of ocean acidification is unprecedented in the past 300 million years (Hönisch et al. 2012). Over the past 200 years, the ocean's acidity has increased by 30% (a decrease of 0.1 pH units) due to increased uptake of carbon dioxide (CO_2), primarily as a physical response to rising atmospheric CO_2 concentrations. Acidification affects growth rate in fish and inhibits shell growth in coastal and marine animals, including corals, oysters, clams, shrimp, lobster sea urchins, and calcareous plankton. This in turn affects significant segments of the marine food web and habitat-forming species such as coral reefs, along with commercial fisheries based on these species.

Ocean acidification processes are more complex near the coast than in the open ocean. In addition to ocean acidification due to increased atmospheric carbon dioxide, nearshore pH is affected by nutrient and freshwater inputs, as well as upwelling, and is much more variable than open-ocean pH (Duarte 2013; Gledhill et al. 2015; Barton et al. 2015). Along the Alaskan coast, where average temperatures over the last 60 years have risen twice as quickly as the US average (Chapin et al. 2014), freshwater inputs from melting glaciers, snow, and ice exacerbate the problem because glacial melt water has low concentrations of carbonate ion, which marine animals need to build shells, and because when freshwater enters the marine environment, it quickly absorbs atmospheric CO_2 to reach equilibrium (NOAA 2014). Along the Pacific coast, oyster aquaculture is affected by anthropogenic CO_2 that contributes to seasonally low pH, which exacerbates the effects of acidic water rising due to natural upwelling. Nutrient pollution from runoff advances acidification by changing water chemistry, and controlling nutrient inputs is a potential adaptation action in the Pacific Northwest, Gulf of Mexico, and Atlantic Coast (Ekstrom et al. 2015). To explore the dimensions of ocean acidification in various coastal hotspots, see the interactive website (NRDC 2015).

Precipitation

As average temperatures rise, evaporation increases, which, in turn, increases overall precipitation. Climate change is also shifting the wind patterns and ocean currents that drive the world's climate system, so some areas will have less precipitation than in the past (figure 1.6) (EPA 2015b). Precipitation change is highly variable and seasonally dependent. Rainfall, snowfall, and the timing of snowmelt can all affect the amount of fresh water entering estuaries and oceans. Increased precipitation causes heavier runoff from inland areas and associated changes in sediment and nutrient transport. Lower precipitation and drought reduce freshwater inflows to the coast (Moser et al. 2014). This, in turn, can affect estuarine communities, estuarine circulation, and fish migration. Changes in precipitation patterns can also affect what types of animals and plants can survive in a particular place, particularly if they cannot adapt to the pace of change or the variability in precipitation (EPA 2015b).

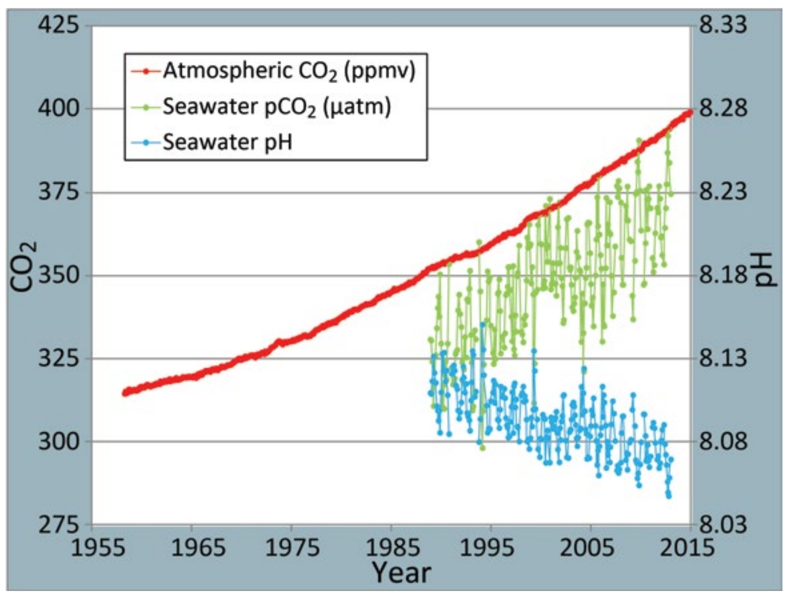

Figure 1.5. Correlation of atmospheric and dissolved carbon dioxide levels. Figure from NOAA Pacific Marine Environmental Lab at http://pmel.noaa.gov/co2/files/co2_time_series_12-17-2014_with_text.jpg (accessed 21 April 2015).

Change in Precipitation in the United States, 1901-2015

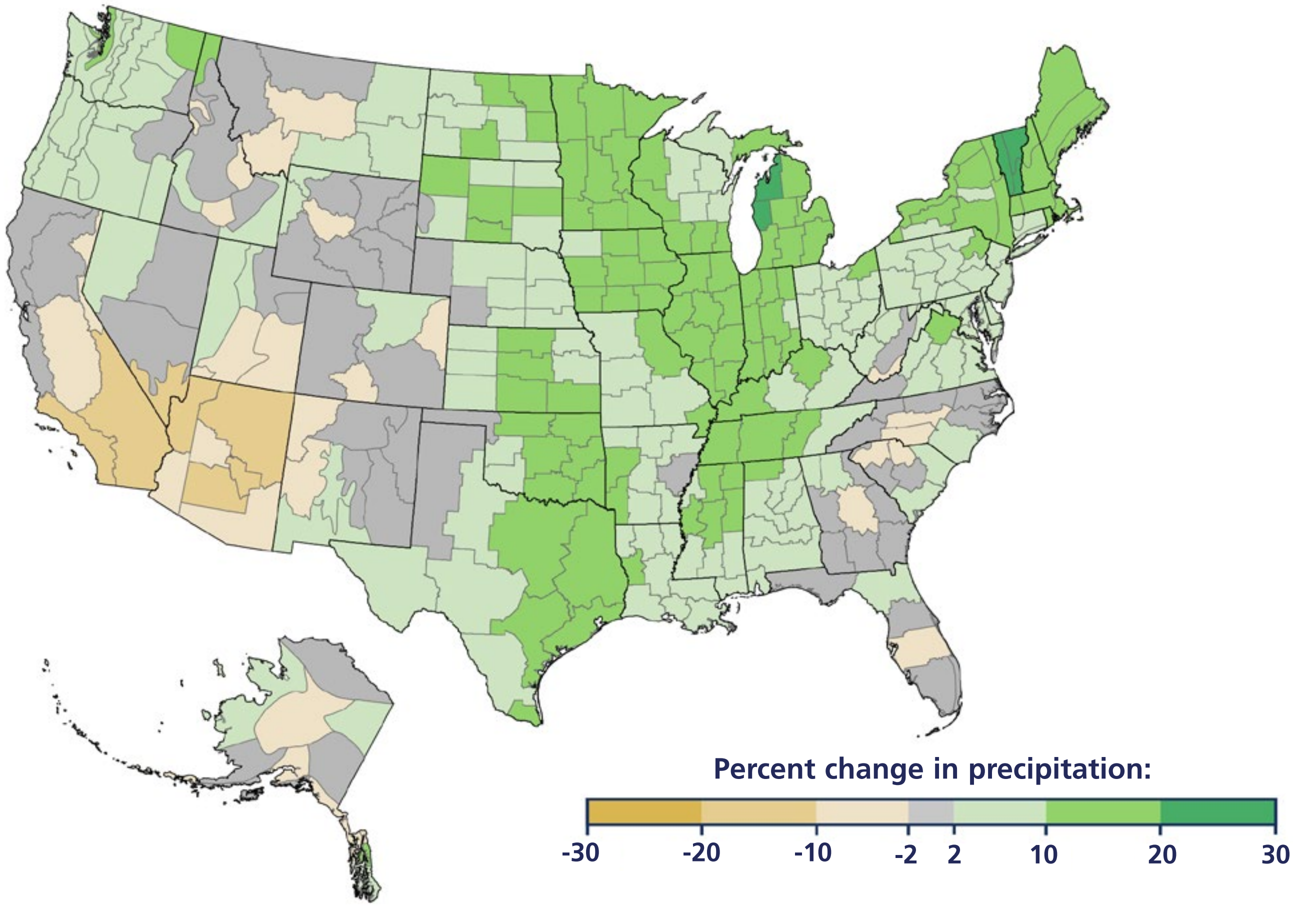

Figure 1.6. Map of changes in total annual precipitation for the United States since the early 20th century. Data show changes since 1901 for the contiguous 48 states and 1925 for Alaska. Figure from U.S. Environmental Protection Agency. 2016. Climate change indicators in the United States, 2016. Fourth edition. EPA 430-R-16-004. https://www.epa.gov/climate-indicators/climate-change-indicators-us-and-global-precipitation

Storms

Storms, which often cause pronounced changes, are projected to become more intense with climate change. Projections suggest a decrease in the annual number of hurricanes in the Atlantic but an increase in the number of the strongest (Category 4 and 5) hurricanes, and increases in associated rainfall (Walsh et al. 2014). In the North Atlantic, the average storm track may shift northward, causing more frequent impacts to northern areas (IPCC 2007). There is low confidence of large-scale trends in storminess over the last century and low confidence in near-term projections for increased tropical cyclone intensity in the Atlantic and in region-specific projections (IPCC 2013). Even if storm characteristics do not change, at higher sea level, storm surge will travel farther inland, affecting a larger area and having greater impacts. The Great Lakes areas are projected to have increasing frequency and intensity of severe storms and increased wind speeds (Schramm and Loehman 2010).

Climate Change Information Resources

There are numerous sources of information (several highlighted here) and ongoing efforts to meet data needs to support coastal adaptation planning. The NPS Climate Change Response webpage for Resources includes several adaptation resources for park managers, such as briefs on climate exposure (summarizing the magnitude and direction of changes in temperature and precipitation), visitation trends related to climate change, and a summary of species adaptive capacity. Climate summaries developed for each park's foundation document workshop include an analysis of historical and projected climate trends downscaled for each park for temperature and precipitation, and provide annual, seasonal, and monthly averages (e.g., Gonzalez 2015). These reports are available via the NRSS Sharepoint (*NPS internal access only*) or Integrated Resource Management Applications Portal (IRMA). The Sea Ice Atlas has been compiled by a number of partners in the Alaska region.

The field of inundation modeling is ever growing. Errors in tidal datum calculation, vertical landform position accuracy, and biases in oceanographic and atmospheric models can alter calculations of location and magnitude of storm surge across landscapes at the scale of coastal properties contained within park boundaries. A recent study (see summary in Schupp, Beavers, and Caffrey 2015, "Case Study 24: Storm Surge and Sea Level Change Data Support Planning") projects sea level rise and storm surge trends for individual parks using downscaled data from the Intergovernmental Panel on Climate Change (IPCC) and the US Army Corps of Engineers sea level calculator. Gauges measuring river flow, which is very important to estuaries, sediment and nutrient transport, and fish migration, are available through USGS. The Water Resources Division continues to deploy tide gauges in locations where water level information is needed to fill in gaps (Curdts 2014) in the data available through NOAA's National Water Level Observation Network. In addition to providing valuable synoptic data, these instruments can also provide valuable information regarding system evolution on management-timescales to individual parks.

NPS Offices Supporting Climate Change Adaptation Efforts

Adaptation is not the responsibility of certain individuals; rather it is an NPS agency-wide responsibility conducted in coordination with partners and stakeholders. Staff from all divisions can contribute meaningfully to adaptation: from maintenance staff identifying vulnerable infrastructure resources and processes; to interpretation staff communicating to visitors why beach access may be changing; to resource managers identifying and monitoring at-risk natural and cultural resources; to management teams planning for visitor access when roads and bridges may be undermined.

Indeed, the National Park Service is engaged on multiple levels in addressing climate change impacts. Climate change adaptation is done at the Department level all the way to individual parks and individual staff members and visitors that incorporate climate change into their daily work including, but not limited to, interpretation, maintenance, education, resource protection, and research. Some NPS servicewide programs are described below.

- The NPS Directorates of Natural Resource Stewardship and Science (NRSS), Cultural Resources, Partnerships and Science (CRPS), Park Planning, Facilities, and Lands (PPFL), Information Resources, and Partnerships and Visitor Experience provide technical expertise, science, and assistance to coastal parks, and include several programs and divisions that also play important roles in NPS adaptation efforts.
- The Climate Change Response Program (CCRP) leads the NPS climate adaptation response, providing services and guidance on climate change science and modeling, interpretation and education, planning, coastal hazards, cultural resources, and renewable and efficient energy use.
- The Geologic Resources Division works to guide and plan for coastal adaptation. Efforts have addressed a variety of hazard concerns and contributed to planning efforts in coastal parks.
- The NPS Inventory and Monitoring (I&M) program, including 32 regional networks, collects, organizes, analyzes, and synthesizes natural resource data and information, including climate data, and provides the results in a variety of formats.
- The Ocean and Coastal Resources Branch, part of the NRSS Water Resources Division, is developing partnerships with NOAA and providing technical assistance to gain accurate observations of water levels in parks with the goal of providing monitoring coverage for parks to evaluate coastal change, sea level rise, and lake level change.
- The Sustainable Operations and Climate Change (SOCC) branch, a part of the Washington Support Office (WASO) Park Facility Management Division, oversees NPS progress under the Green Parks Plan assisting parks in implementing sustainable best practices throughout NPS operations.
- The NPS Information Resources Directorate, regional offices, and individual parks and regional offices work to collect data, develop geospatial products, collaborate with research partners, and write funding proposals.
- The National Geospatial Program is working through the GIS Council to develop infrastructure capable of providing more robust mapping information services to analysts, decision-makers and policy makers.
- The Denver Service Center is leading the development of Park Atlases (*NPS internal access only*), an interactive web mapping viewer created to support access and visualization of park resources for planning, management, and operations. The geospatial products include resource elevations and can be used for pre-storm planning, incident response, and post-storm recovery, as described in "Chapter 3 Planning."

- The National Park Service also participates in and supports landscape conservation cooperatives (LCCs), which consist of federal, state, tribal, local, nonprofit, and private stakeholders working with existing partnerships and programs, and establishing new partnerships, to facilitate communication, share the results of research, and strategically target and implement additional research and actions to meet shared conservation goals. The LCC and CCRP programs work to connect parks to larger landscapes; help parks predict the effects of climate change and other large-scale stressors; understand and promote climate change adaptation; and collaborate with other programs to create a regional strategy for landscape conservation.
- The coastal Cooperative Ecosystem Studies Units and Research Learning Centers connect parks and NPS programs with academic and research partners to develop the science and outreach tools needed to advance the Climate Change Response Strategy.

What to Expect in this Document

This document is intended to be a starting point and to direct users to many other resources when they need more depth, while capturing key points for those users who do not have the time to consult the original references.

The National Park Service has an opportunity to take a leadership role in adaptation to climate change and demonstrate many strategies for coastal adaptation. Chapters 3–6 in this handbook conclude with opportunities to prepare for and adapt to climate change.

Coastal adaptation extends beyond relocating lighthouses from eroding shores, restoring wetlands, and finding ways to work with the combination of the built and natural environments found in cultural landscapes. Coastal adaptation includes working with partners and gateway communities to address the topics of change, loss, and championing the role of documentation and museum collections.

"Chapter 2 Policy" tackles the challenging questions on when the National Park Service can intervene. The National Park Service now has four policy memos (PM) for climate change on natural resources (PM 12-02, NPS 2012), cultural resources (PM 14-02, NPS 2014b), facilities (PM 15-01, NPS 2015), and resource stewardship (PM 16-01, NPS 2016), which are described in more detail in "Chapter 4 Natural Resources," "Chapter 5 Cultural Resources," and "Chapter 6 Facility Management" respectively, as well as discussed together in "Chapter 2 Policy."

Elevated water levels during major events such as Hurricanes Sandy and Katrina reinforce the need for the National Park Service to plan for and be prepared to respond to coastal impacts. "Chapter 3 Planning" outlines the NPS planning framework and emerging work with scenario planning and climate-smart strategies. Further information on lessons learned from incident response and recovery is included in "Chapter 9 Lessons Learned from Hurricane Sandy."

"Chapter 4 Natural Resources" focuses on the natural resources of the dynamic coastal zone. It includes an overview of science and tools to support adaptation (many of which are applicable to other resources) and a discussion of how to handle uncertainty. This chapter provides examples of vulnerable habitats and discusses application of seven natural resource adaptation strategies to the coastal zone. Future guidance will address additional climate change forcings, such as elevated water temperatures, changes in ocean currents, ocean acidification, changes in freshwater flows, sediment and nutrient fluxes in coastal water bodies, and degradation of coastal water quality, and will describe possible adaptation approaches at relevant geographic scales.

"Chapter 5 Cultural Resources" focuses on cultural resources. The National Park Service preserves many elements of the nation's heritage in archeological sites, historic and prehistoric buildings and structures, cultural landscapes, museum collections, and the environments and places that support traditional and indigenous lifeways (ethnographic resources). Some cultural resources are threatened by changes in the low-lying coastal landscape. In many places, park infrastructure is also a cultural resource, such as the Sleeping Bear Point Life-Saving Station that now serves as the Maritime Museum at Sleeping Bear Dunes National Lakeshore in Michigan, and the Russian Bishop's House at Sitka National Historical Park in Alaska. Cultural resources along with the geologic record can help to tell the story of climate change. The use of historical records can increase understanding of how prior cultures and landscapes have responded to drivers such as rapid environmental change. Adaptation for cultural resources brings together approaches to address impacts on cultural resources from climate change and engage with the information they contain.

"Chapter 6 Facility Management" covers the work of the Sustainable Operations and Climate Change Program along with facility management and transportation programs that are challenged with managing assets in low-lying areas exposed to coastal hazards.

The National Park Service has an opportunity to communicate about coastal adaptation to climate change and educate the visiting public in person and via online and print resources. "Chapter 7 Communication and Education" provides examples of interpretive products, training, and communication strategies.

The adverse and beneficial impacts of coastal engineering structures are detailed in "Chapter 8 Protecting Infrastructure: Costs and Impacts." The National Park Service recognizes that there is a history of inherited and recently constructed coastal engineering structures, and that in the future park managers will have to consider the potential placement of additional structures to protect coastal resources and assets at risk. The decision to construct a new structure along the shoreline should be part of a careful process that includes consultation with other entities through feasibility studies, compliance processes, funding requests, and more. The options outlined in this chapter include strategies for shoreline stabilization, coastal restoration, living shorelines, and other coastal engineering options. Sample construction costs are included to help inform initial project statements for technical assistance or initial funding.

Accompanying this handbook is a compilation of many adaptation strategies that have been recommended, tried, and even dismissed at some units in the "Coastal Adaptation Strategies: Case Studies" (Schupp, Beavers, and Caffrey 2015). In addition, an expanded Hurricane Sandy case study is included in "Chapter 9 Lessons Learned from Hurricane Sandy." Each chapter concludes with Take Home Messages.

Take Home Messages

- Climate change will continue to impact coastal resources and assets in the national parks at various rates. To address the current and anticipated impacts, parks can work proactively and cooperatively with others to implement adaptation strategies for resources at various levels of exposure and vulnerability. Adaptation is a process, not a single action.
- Adaptation includes a range of potential responses, including resisting change, accommodating change, and directing change towards a specific desired new future.
- Adaptation decisions should be made using the best available science; however, uncertainty should not prohibit adaptation action. There are numerous information systems and tools available to support climate change adaptation planning.
- Responding to climate change impacts on coastal parks is most effective when diverse adaptation strategies on a variety of temporal and spatial scales are considered.
- Vulnerability assessments can help prioritize among resources or better target an adaptation strategy.

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Chapter 2 Policy

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Introduction

This chapter describes the policies that guide National Park Service (NPS) consideration and selection of adaptation strategies in response to climate change in coastal parks and ecosystems. As presented in the other chapters in this handbook, there are many potential coastal area adaptation strategies that the National Park Service is already considering and implementing over time. This chapter addresses questions that may arise regarding the compatibility of these strategies with NPS policy. Online resources to supplement this document are available at http://www.nps.gov/subjects/climatechange/coastalhandbook.htm.

General NPS Policies

NPS policy for cultural resource management provides NPS managers with direction to actively manage those resources based on research, planning, and stewardship principles (see “Chapter 5 Cultural Resources”). This is an urgent and targeted task as the effects of climate change on cultural resources become more evident, leading to specific policy direction (PM 14-02) relevant to the adaptation strategies in this handbook.

NPS policy for natural resource management, however, provides NPS managers with the flexibility to take various management actions, including restoration, mitigation, and other intervention, with respect to natural resources and processes in these four circumstances:

- when directed by Congress;
- in emergencies in which human life and property are at stake;
- to restore natural ecosystem functioning that has been disrupted by past or ongoing human activities; or
- when a park plan has identified the intervention as necessary to protect other park resources, human health and safety, or facilities (NPS Management Policies 2006 § 4.1).

While all of the above bullets are relevant at various times, the third circumstance is discussed here. It means that where natural resources or processes have been disrupted by human activities, NPS policy permits park managers to take action as necessary and feasible to protect, restore, or otherwise conserve the disrupted resources or processes.

While this policy is stated in slightly different ways throughout Chapter 4 of the NPS Management Policies, the intention is evident and applies across biological and physical resources (see NPS Management Policies § 4.1 (general management concepts), § 4.1.5 (restoration of natural systems), § 4.4.1 (biological resources), § 4.4.2 (native plants and animals), § 4.4.2.2 (restoration of native plants and animals), § 4.4.2.2 (landscapes and vegetation), § 4.6.3 (protection and restoration of water quality), § 4.6.5 (wetlands), and § 4.8.1.1 (shorelines and barrier islands).

Note that the *Management Policies* do not require active NPS management in human-disturbed resources or processes. The National Park Service may investigate various alternatives, and based on scientific, technical, financial reasons, and/or stakeholder input, decide to act or not to act to address the impacts of the human disturbance. If the National Park Service does take action, it must be kept to the minimum necessary to achieve the stated management objectives (NPS *Management Policies* 2006 § 4.1).

The questions when evaluating potential natural resource adaptation strategies for consistency with *Management Policies*, then, are whether the current impacts resulting from climate change are a human-caused disruption, and whether the proposed adaptation strategy would conserve, restore, or otherwise protect park resources or processes from the impacts of the human disruption.

To answer the first question, the majority of scientific information indicates that current climate change is largely a result of human activities (IPCC 2014). These activities and the resulting changes to Earth’s climate are changing the pace, magnitude, timing, and other aspects of natural ecosystem resources and processes. Where natural processes in parks have been impacted in pace, magnitude, and timing by human-caused climate change, it is consistent with NPS policy, for the National Park Service—at the appropriate time and in the appropriate circumstances—to consider management actions to mitigate, reduce, compensate for, or adapt to the effects, based on best available information, of the human-caused impacts at coastal parks. While climate change effects may seem ubiquitous, attribution of effects remains an important step in determining the appropriate management response. As explained elsewhere in this handbook (see figure 1.1, table 4.2, and table 5.4), adaptation strategies may range from resist change, accommodate change (which might include specific management actions such as reducing stressors or restoring human-disturbed resources), to direct change toward a new future (which might include specific management actions such as relocating certain resources). Again, such actions are not necessarily required but should be evaluated based on science, technical, financial, and societal factors, rather than ignored without any investigation.

Management actions to mitigate, restore, or otherwise address human-caused climate change impacts may likewise be considered at NPS coastal or ocean areas that are designated or suitable for wilderness status but must be conducted in accordance with the concept of minimum requirement management to be consistent with other NPS wilderness policies (see Director's Order #41, Wilderness Stewardship).

To answer the second question, the potential adaptation strategy should be evaluated for whether it addresses the result of the human disruption, in which case it would be consistent with the general NPS policy, or whether it goes beyond or is unrelated to the result of the human disruption, in which case it would not be consistent and should be modified or dismissed from further evaluation.

Additional Policies That Apply to NPS Coastal Adaptation Strategies

In addition to complying with the general *Management Policies* considerations discussed above, potential adaptation strategies should be evaluated for consistency with the policies listed below. These additional policies are compiled and distilled from multiple documents, including several executive and secretarial orders, the Department of the Interior Manual, and four NPS policy memos (table 2.1) (See References).

Table 2.1. Handbook chapters with further discussion of NPS Policy Memoranda

Chapter 4 Natural Resources	PM 12-02: Applying National Park Service Management Policies in the Context of Climate Change; PM 16-01: Resource Stewardship for the 21st Century – Interim Policy
Chapter 5 Cultural Resources	PM 14-02: Climate Change and Stewardship of Cultural Resources; PM 16-01: Resource Stewardship for the 21st Century – Interim Policy
Chapter 6 Facility Management	PM 15-01: Addressing Climate Change and Natural Hazards for Facilities

Based on those documents, when evaluating coastal climate change adaptation strategies, it is consistent with policies of the National Park Service, to:

- gather and maintain baseline climatological data for reference.
- use best available information and science to inform NPS understanding of climate change risks, impacts, vulnerabilities, and adaptation options.
- incorporate climate change considerations and adaptation strategies into NPS planning, programs, and operations.
- maintain partnerships and information flow with other entities and stakeholders to develop adaptation strategies and coordinate adaptation strategies with those entities.
- select adaptation strategies and investments that
    - integrate climate risk-management considerations into resource management and infrastructure decisions;
    - use, where feasible, landscape and seascape-scale, ecosystem-based, and nature-based management approaches;
    - protect natural and cultural resources, including diversity and key ecosystem benefits and/or services;
    - preserve and restore unfragmented or undisturbed habitat areas and key habitat linkages between them;
    - prevent or slow the spread of invasive species that would cause environmental or human harm;
    - focus development in disturbed areas, away from ecologically sensitive landscapes, culturally sensitive areas, and wildlife corridors; and
    - promote carbon sequestration or otherwise reduce the sources of anthropogenic climate change.
- do not select adaptation strategies and investments that
    - contribute to climate change impacts; or
    - increase vulnerability of resources or infrastructure within or outside park units to climate change impacts and risks.

Implementation of the Above Policies: Document All Adaptation/ Intervention Decisions

The final policy relevant to the selection of adaptation strategies is that park managers must document the reasons for choosing particular adaptation and intervention strategies. Selected strategies must be consistent with laws, regulations, policies, other existing guidance (see references), and available scientific and technical information. Costs and benefits, and the assumptions underlying those costs and benefits, should likewise be considered. Documentation will demonstrate how selected strategies were reached and how they are consistent with these factors. Because of the importance of flexibility over time, a selected strategy does not have precedential value at any other park unit or at the same park in a different situation. The National Park Service should revisit adaptation decisions regularly. If a selected strategy turns out to be problematic for any reason, then the National Park Service should consider modifying that strategy as necessary and appropriate.

Take Home Messages

- Park managers have substantial flexibility and discretion when selecting coastal adaptation strategies. Yet this flexibility and discretion are not unconstrained; various policy and guidance documents contain additional considerations that should be incorporated into park managers' decisions about adaptation alternatives.
- Park adaptation decisions must be well documented.

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Chapter 3 Planning

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Considering climate change in park planning and management is required (Secretarial Order 3289; Executive Order 13653). Planning for climate change is especially important for coastal parks because sea level rise and increased flooding risks are likely to present tradeoffs between park resources and assets. Without planning and prioritization, responses will be reactive and potentially maladaptive. For example, "Chapter 9 Lessons Learned from Hurricane Sandy" describes potential barriers to adaptation such as the pressure to rebuild facilities and reopen storm-damaged areas quickly, instead of taking the additional time and funding to design new sustainable infrastructure, which may also entail considering more optimal locations. Advance planning can improve post-storm responses, such as anticipating and allowing a natural breach in a wilderness area to remain open (see other examples in "Chapter 9 Lessons Learned from Hurricane Sandy").

Some links in this chapter refer to internally available NPS documents. Externally available resources can be accessed at https://www.nps.gov/subjects/climatechange/coastalhandbook.htm.

Planning Framework

The new National Park Service (NPS) planning framework (figure 3.1) accommodates the flexibility needed for adaptive park planning and management within the context of a changing climate.

This planning framework introduces the concept of a dynamic park planning portfolio, which is the assemblage of the individual plans, studies, and inventories needed to guide park decision-making. The portfolio can be visualized as a loose-leaf binder, in which particular planning elements can be removed and updated, and new elements added, without revising the entire body of work. This flexibility is well suited to the needs of climate change adaptation as a rapidly evolving field with a growing list of processes and frameworks.

Foundation Document

The NPS planning framework begins with the Foundation Document (figure 3.1), identifying the park purpose, significance, and fundamental resources and values a park is committed to preserving and maintaining based on park legislation. The document includes an assessment and prioritization of park planning and data needs to provide direction for developing the overall park planning portfolio that guides park, regional, and national planning and information priorities. Over time, continued monitoring of the effectiveness of management decisions and incorporation of new information (e.g., new climate change projections, ecological responses) feeds back into the assessment and prioritization of park planning and/or data needs, informing adjustments in the park planning portfolio, as needed. Foundation documents have acknowledged climate change as a threat to important resources and values, a data need, and as a planning need (for example, see NPS 2012).

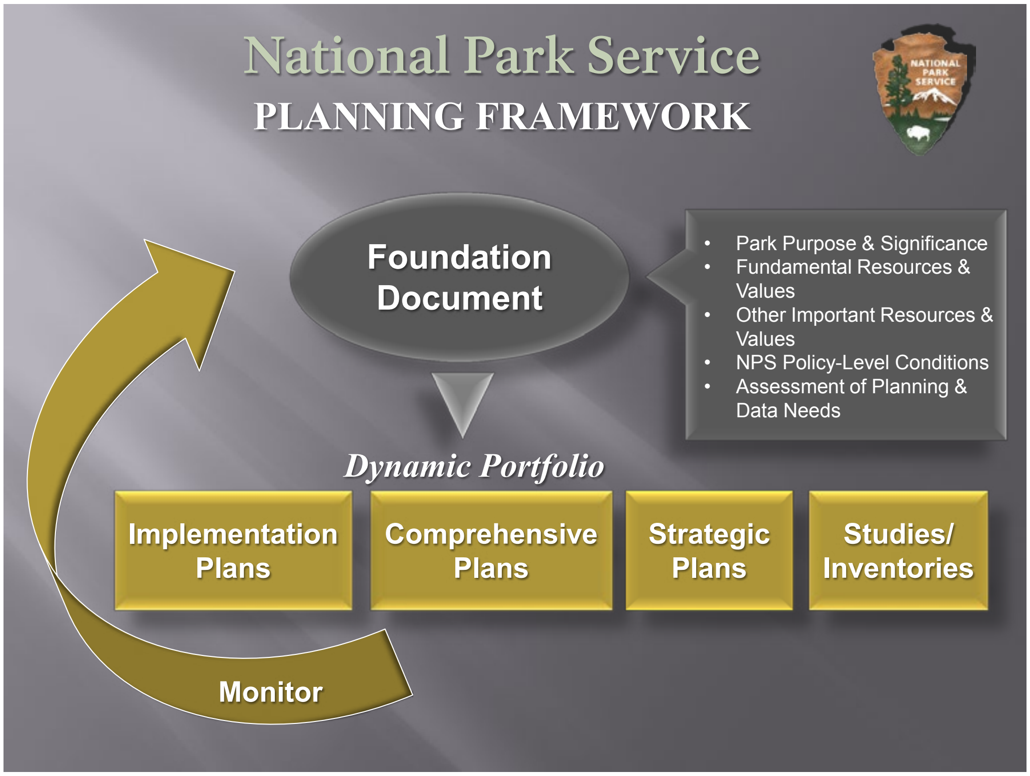

Figure 3.1. National Park Service Planning Framework.

The NPS Climate Change Response Program (CCRP) provides relevant climate change information to inform development of all park foundation documents; such information includes sea level change and storm surge observations and projections for coastal NPS units. Guidance for addressing climate change in foundation documents (*NPS internal access only*), (NPS 2014a) is available.

A component of the Foundation planning process is the Park Atlas (*NPS internal access only)*, a compilation of baseline GIS data for each park presented in an interactive web mapping site. Accurate spatial data, especially elevations for coastal resources vulnerable to sea level rise and flooding, are essential for many adaptation decisions. The park atlases and the underlying geodatabase provide valuable resources for pre-storm planning, incident response, and post-storm recovery.

General Management Plan

The General Management Plan (GMP) builds from the Foundation Document and is required for all park units under statute (National Parks and Recreation Act of 1978) and 2006 NPS Management Policies (§2.3.1). These plans address four legislated requirements:

- Management actions to preserve park resources
- Intensities of development
- Visitor capacity
- Boundary modification, if needed

The 2014 memo, *Guidance for Addressing Climate Change in ongoing General Management Plans* (NPS 2014b), outlines how and where climate change considerations should be incorporated into ongoing general management plans. When preparing a GMP, it is important for coastal parks to consider the implications of ongoing and projected sea level rise and lake level changes (coupled with storm effects, melting permafrost, and other coastal changes) on park infrastructure, resources, and visitor use, and anticipate decisions that may be required in the future. Examples of the needed flexibility for coastal climate change adaptation can be found in some of the more recent park GMPs (figure 3.2). A case study on "Incorporating Climate Change into a General Management Plan" is available at Schupp, Beavers, and Caffrey (2015; Case Study 23).

Resource Stewardship Strategy

The Resource Stewardship Strategy (RSS), (*NPS internal access only*) is the bridge between a park's Foundation Document and the everyday management of natural and cultural resources. A Resource Stewardship Strategy evaluates the major components of the park's priority resources (defined in the *Foundation Document*) that must be protected into the future; establishes science- and scholarship-based methods to evaluate success in protecting these priority resources and values; determines measurable targets for success; and includes prioritized strategies for achieving and maintaining those targets over time. Inclusion of current climate projections, plausible climate futures, and the associated range of effects in an RSS enables parks to develop flexible adaptation strategies that anticipate and can best respond to evolving conditions.

Assateague Island National Seashore

2014 Draft General Management Plan

Preferred Alternative: "Climate change adaptation would play an increasingly important role in seashore management. Over time, the effects of natural coastal processes and climate change/sea level rise are expected to become the dominant force shaping the character of the island developed area. To minimize or avoid the damaging effects of natural coastal processes and climate change/sea level rise, visitor use infrastructure would evolve to more sustainable designs and likely shift to new, more stable locations."

Fire Island National Seashore

2013 Draft General Management Plan

One of the listed goals for responding to the impacts of a changing climate is to "proactively plan for and adapt to the effects that may be realized from climate change including: a changing shoreline, altered terrestrial and marine ecosystems, threatened cultural resources, loss of recreation sites, and Seashore facilities, and disruption of visitor use. Existing facility operations would be re-evaluated to ensure that they are appropriately designed and outfitted to respond to changing conditions and that they minimize their impacts on the environment."

Figure 3.2. Excerpts from Draft General Management Plans from Two Parks Addressing Climate Change.

Tools for Climate Change Adaptation of Coastal Resources and Assets

This section summarizes some of the applied processes and available resources for climate change adaptation at coastal parks.

Processes

Vulnerability Assessment

A climate change vulnerability assessment is a crucial tool for understanding the effects of climate change on natural systems, cultural resources, and park assets, and is a critical element of setting the stage for effective adaptation planning. For this reason, a climate change vulnerability assessment is typically conducted early in the adaptation planning process (Stein et al. 2014).

Vulnerability to climate change refers to the "degree to which as system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes." (IPCC 2007, 2014). Vulnerability has three principal components: *sensitivity, exposure,* and *adaptive capacity* (figure 3.3). *Sensitivity* generally refers to innate characteristics of a specific resource, system, or asset and considers tolerance to changes in such things as temperature, precipitation, sea level rise, and storm frequency. Exposure in contrast, refers to extrinsic factors, focusing on the character, magnitude, and rate of change that the specific resource, system, or asset is likely to experience. *Adaptive capacity* addresses the ability of a specific resource, system, or asset to accommodate or cope with climate change impacts with minimal disruption (Glick, Stein, and Edelson 2011). Note that adaptive capacity may not be relevant to all types of resources or systems; for example, some cultural resources, and many types of infrastructure do not have inherent adaptive capacity.

Climate change vulnerability assessments provide two essential types of information needed for adaptation planning (Stein et al. 2014):

- Identifying which species, systems, or assets are likely to be vulnerable
- Understanding why they are vulnerable

An overview on climate change vulnerability is provided in Chapter 6 of Stein et al. (2014), with more comprehensive guidance provided in Glick, Stein, and Edelson (2011). A description of a vulnerability assessment approach specific to infrastructure in coastal park units is available in the *Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol* report (NPS 2016).

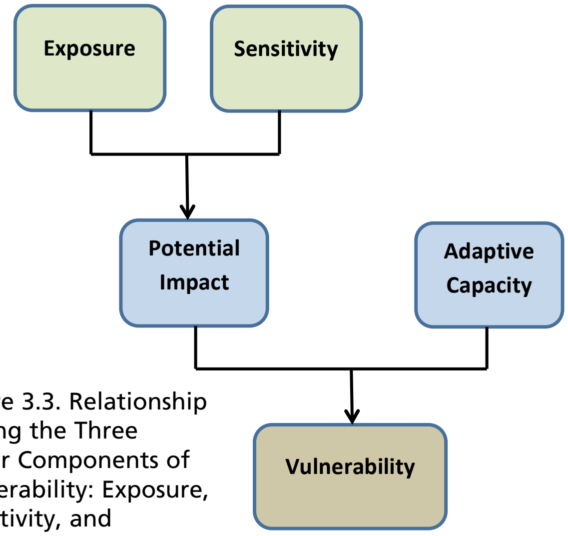

Figure 3.3. Relationship among the Three Major Components of Vulnerability: Exposure, Sensitivity, and Adaptive Capacity.

One example is the "Relative Coastal Vulnerability Assessment of National Park Units to Sea-Level Rise" project, created in partnership between the National Park Service and the US Geological Survey (USGS), which assessed and mapped hazards posed by future sea level change to NPS units. The result from this effort was the coastal vulnerability index assessment for many national park units, highlighting areas that are likely to be most affected by future sea level rise. This index was developed at a large, coarse scale and is useful as a screening tool. If a park is in a highly vulnerable location, more detailed analysis will be needed.

Outcomes from climate change vulnerability assessments logically feed into other planning and management processes. The National Park Service has made significant investment towards developing, training, and applying two processes that assist parks with planning and managing in uncertain climate futures: climate change scenario planning and climate-smart conservation.

Scenario Planning

Planning in the National Park Service has been based on experiences in the past and projecting that understanding into the future, resulting in a range of "desired conditions" for priority park resources and assets. This is often referred to as "forecast planning" (figure 3.4). When considering a changing climate in park planning and management, the forecast approach is limited by incomplete knowledge of highly consequential factors that are largely unpredictable and outside of management control, but that influence future park conditions. The far-reaching effects of climate change, coupled with high uncertainty about local impacts (e.g., population growth, economic conditions), produce a range of plausible futures that park managers may encounter (figure 3.4).

Scenario planning is a continuous and adaptive process for developing a science-based decision making framework in the face of futures with high uncertainty and lack of control (figure 3.5). This continuous process helps parks and local stakeholders prepare for climate change and other relevant uncertainties by exploring and tracking several plausible scenarios that represent a range of relevant and challenging futures for a park or region. The resulting scenarios help managers assess relative risk, test important decisions, develop strategies or contingency actions (figure 3.6), and identify key indicators to monitor that validate the scenarios over time, making adjustments as needed.

Multiple methods exist to facilitate scenario development. The NPS handbook, *Using Scenarios to Explore Climate Change: A Handbook for Practitioners* describes a five-step scenario building process with detailed instructions on how to accomplish each step using the "matrix approach" (NPS 2013). An accompanying Addendum I was released in 2014 that introduces an alternative technique that requires less time to facilitate the five-step scenario building process (NPS 2014c). More information on the NPS approach to climate change scenario planning is available at http://www1.nrintra.nps.gov/climatechange/planscenarios.cfm (*NPS internal access only*). Further synthesis of additional scenario planning methods case studies is in *Considering Multiple Futures: Scenario Planning to Address Uncertainty in Natural Resource Conservation* (Rowland, Cross, and Hartmann (2014).

Climate change vulnerability assessments and climate change scenario planning integrate with the climate-smart process. The plausible climate change futures created through a scenario planning effort, along with climate-related vulnerabilities for select systems, resources, or assets, logically feed into the climate-smart step that assesses climate impacts and vulnerabilities. Table 3.1 provides a quick summary and reference link on these three processes.

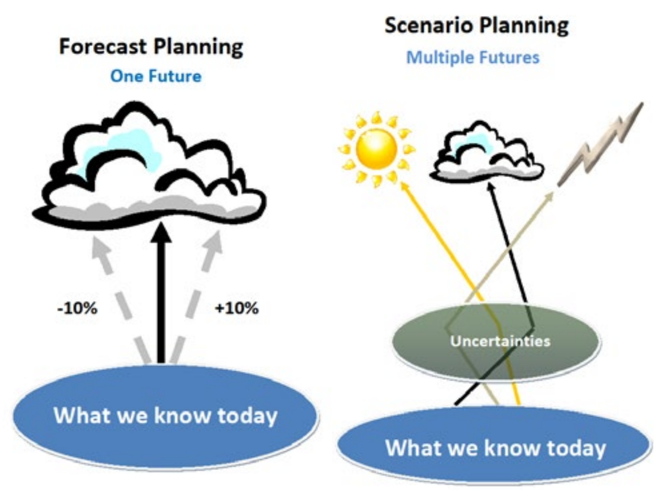

Figure 3.4. Forecast Planning differs from Scenario Planning. Figure 2 from Weeks, Malone, and Welling (2011).

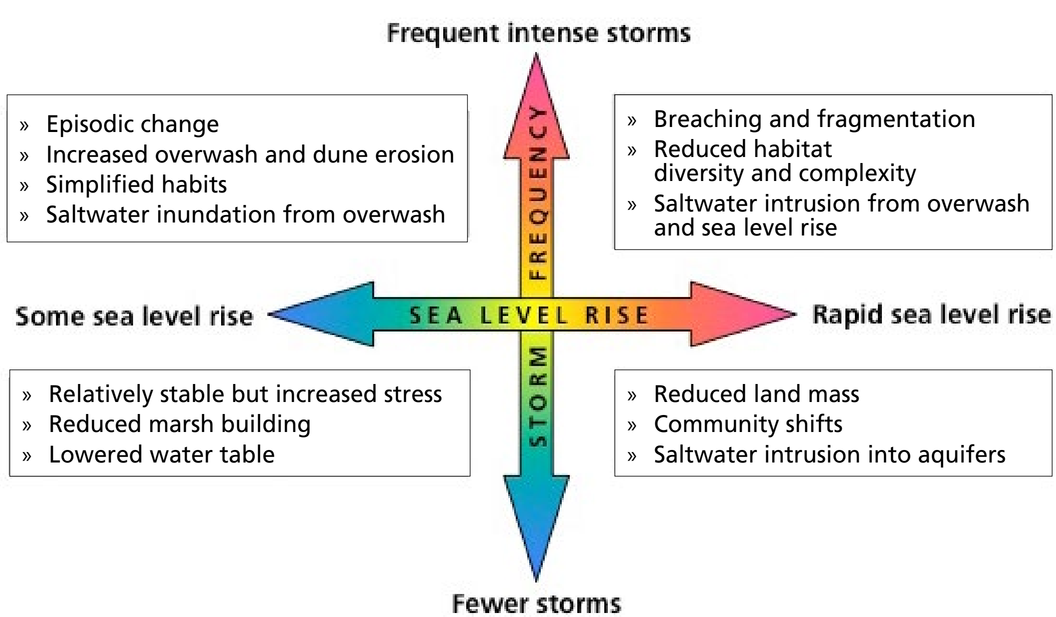

Figure 3.5. Scenario planning example from Assateague Island National Seashore.

Figure 3.6. Through climate change scenario planning at Assateague Island National Seashore, the increased vulnerability of the shallow freshwater aquifer on the barrier island due to sea level rise and salt water intrusion was identified. This freshwater supply is important in sustaining the wild horses on the island that visitors come to see. The park is working with the USGS to characterize this shallow aquifer to better assist with management decisions and future planning. Photograph by NPS.

Climate-Smart Conservation

Completed in 2014, the guidance document *Climate-Smart Conservation: Putting Adaptation Principles into Practice* describes a seven-step, iterative process for integrating concepts and tools of climate-smart conservation into existing work (Stein et al. 2014). The guidance is the product of an expert workgroup that included participants from the National Wildlife Federation, USGS, US Forest Service, National Oceanic and Atmospheric Administration, The Nature Conservancy, the National Park Service, US Fish and Wildlife Service, US Environmental Protection Agency, and others. While developed specifically for natural resources, the approach and principles included in the guidance are relevant for adaptation planning across the breadth of NPS stewardship responsibilities.

The principles of "climate-smart conservation" help to answer the question, "What should be done differently in light of climate change, and what actions continue to make sense?" This thinking helps to develop goals and strategies that are forward-looking, intentionally consider climate change, and manage for change, not just persistence (Stein et al. 2014). An important goal of climate-smart conservation is to help practitioners and policy makers understand what constitutes "good" climate adaptation, how to recognize those characteristics in existing work, and how to design new interventions when necessary.

The guidance highlights nine characteristics of climate-smart conservation:

- Link actions to climate impacts
- Embrace forward-looking goals
- Consider broader landscape context
- Adopt strategies robust to uncertainty
- Employ agile, informed management
- Minimize carbon footprint
- Account for climate influence
- Safeguard people and nature
- Avoid maladaptation

Table 3.1. Tools for Climate Change Adaptation of Coastal Resources and Assets

Tool	Climate Change Vulnerability Assessment	Scenario Planning	Climate-Smart Conservation
Summary	Offers guidance on the key components of vulnerability—sensitivity, exposure, and adaptive capacity—to identify which resources, systems, or assets are likely vulnerable and why they are vulnerable.	Offers a structured process designed for managing into futures with high uncertainty and lack of control (e.g., climate change). Rehearsing for multiple futures strengthens NPS and stakeholder ability to recognize, adapt to, and take advantage of changes over time.	Offers a structured process for linking climate adaptation actions to climate change impacts. Emphasis is placed on acting with intentionality while being transparent (show your work) in adaptation planning and implementation processes.
Link	http://www.nwf.org/pdf/-Climate-Smart-Conservation/-NWFScanningtheConservationHorizonFINAL92311.pdf	http://www1.nrintra.nps.gov/climatechange/planscenarios.cfm *(NPS internal access only)* https://www.fws.gov/home/climatechange/pdf/Scenario-Planning-Report.pdf	http://www.nwf.org/pdf/Climate-Smart-Conservation/NWF-Climate-Smart-Conservation_5-08-14.pdf

Resources

The CCRP provides climate change information specific to parks and assists in adaptive planning and management that incorporate this information. Adaptation is most effective when it is both (1) intentionally and deliberately designed and implemented, and (2) "mainstreamed" into an existing overall management approach alongside actions that address other issues (Stein et al. 2014). Guidance on mainstreaming climate adaptation into foundation documents (NPS 2014a), general management plans (NPS 2014b), and resource stewardship strategies needs to be flexible and periodically revisited and updated. Within the NPS planning framework, climate adaptation also needs to be incorporated into other park plans such as wilderness stewardship plans, invasive plant management, cultural landscape reports, and commercial services planning. The forthcoming NPS guide, *Planning for a Changing Climate*, builds on climate-smart principles, and provides a standard approach for incorporating climate change adaptation as a routine part of all park planning, including the variety of planning needs in coastal parks.

Lastly, revisions to the DO-12 Handbook and supplemental guidance (NPS in prep; CEQ 2016) for considering project contributions to greenhouse gases, as well as influences from climate change on project success, support parks in addressing climate change as part of National Environmental Policy Act (NEPA) analyses. Additional planning resources are available at http://www.nps.gov/subjects/climatechange/coastaladaptation.htm.

Disaster Planning and Preparing for Opportunities for Adaptation

Unfortunately natural disasters happen, and coastal zones are vulnerable because of coastal flooding, wave action, and high winds. It is more important now than ever for parks to plan ahead because climate change is increasing the risks of natural disasters (Field 2012; Smit and Wandel 2006; Smit et al. 2000). The National Park Service is steward to a variety of built resources that are vulnerable to climate change and natural disasters such as the storm surge, wave action, ice push, and high winds associated with coastal storm systems (e.g., hurricanes, typhoons, Northeasters), tsunami, and other sources of inundation. Some coastal storms could increase in intensity due to warmer ocean temperatures (Melillo, Richmond, and Yohe 2014). When a park is highly vulnerable to natural disasters, pre-incident planning can create post-incident adaptation opportunities, and the tools and resources described above can be applied to pre-planning efforts.

Parks in locations that are susceptible to natural disasters and include vulnerable infrastructure such as visitor centers, comfort stations, and historic buildings must plan for the risk associated with development in these locations. Where the risk is high, it may benefit a park to pre-plan for potential damage by identifying opportunities to restore infrastructure in a more sustainable manner and location.

The idea of pre-incident planning is compatible with Director's Order 80: PM 15-01 Addressing Climate Change and Natural Hazards for Facilities, (NPS 2015; see "Chapter 6 Facility Management"). The memorandum provides guidance to managers and their teams to proactively identify and document facility vulnerabilities to climate change and other natural hazards, which are most easily managed by planning for avoidance, resilience, or adaptation before events occur.

When developing new facilities, it is prudent to do so in lower risk locations. For facilities already located in a highly vulnerable place, pre-incident planning can facilitate post-incident adaptation actions. For example, if a park has a fixed boat dock that is destroyed by a hurricane, restoring the dock as a floating or removable dock may make it less vulnerable to sea or lake level change and destruction by storm surge.

A major component of adaptation planning focuses on disaster response and recovery. In order to understand adaptation and find plausible opportunities to adapt to upcoming changes, we need to study the disaster recovery timeline and look into each stage as a unique opportunity for adaptation. England (2005) developed a six-phase disaster recovery life cycle framework shown in figure 3.7. Each of these phases gives rise to distinctive priorities and goals as a context for decision making and can be evaluated as an opportunity for adaptation.

Disaster preparedness requires regular review and adjustment of existing plans to meet ever-changing situations. A good place to start is with analysis and assessment because it provides opportunities to identify vulnerabilities in systems, processes, and preparations. As a part of this stage, the current state of preparedness and the ability to respond effectively is assessed. Analysis is followed by remediation planning, which sets preparedness measures that help managers anticipate the response needs of a disaster. Prevention measures set in this stage help to avoid hazards and lessen the effects of events.

Once analysis and remediation has been completed, adaptation (referred to as mitigation in the emergency response community, such as in figure 3.7) can be used to take steps to lessen the impact of disasters and reduce loss of life. Effective adaptation requires that local risks are understood and addressed and often includes making hard choices and investing in the long-term well-being of park assets and resources. After the disaster hits, the extent of damage is evaluated at the impact assessment stage and reports to acquire funds used for recovery are developed. Reporting is followed by immediate steps to respond to the event and use recovery procedures to help restore visitor access to facilities and natural and cultural resources.

Throughout the disaster timeline cycle, the analysis and assessment stage is the stage where the most return can be made on an investment of time and money. Data collection, analyses, and assessment are the most important actions that can be taken today to adapt to future changes. For example, breach management plans must be prepared in advance of storm impacts, as was done for Fire Island National Seashore (see "Chapter 9 Lessons Learned from Hurricane Sandy"). Storm Response Plans are specific plans for coastal parks to implement strategies to prepare for adaptation opportunities by acknowledging that particular window as a time for change.

Figure 3.7. Phases of the Disaster Recovery Life Cycle. Figure from England (2005).

Opportunities for Adaptation

Being aware of pre- and post-event opportunities for adaptation and deliberately identifying opportunities can support adaptation of facilities and historic buildings. As discussed in "Chapter 9 Lessons Learned from Hurricane Sandy," disasters can be drivers of adaptation. Grannis et al. (2014) acknowledge that ideally, climate change adaptation actions are proactive and vulnerable communities anticipate and prepare for risks, but that in reality, adaptation actions are usually reactive, following a disaster. This highlights the importance of building in locations with lower vulnerability. Reactive adaptation is appropriate under some circumstances, considering that replacement of functional systems before a storm hits may incur as much damage and cost as much as post-storm replacement would. Ideally, plans for replacement or adaptation strategies are developed before a disaster, so that planners are better prepared to seize post-disaster opportunities to rebuild sustainably. It is also necessary to build support for adaptation strategies through stakeholder involvement in pre-event planning, so that there is less likely to be post-event resistance to implementation, as discussed in "Chapter 7 Communication and Education."

Leveraging opportunities to rebuild sustainably after disruptive events like hurricanes benefits from advance planning and stakeholder engagement. Examining the emergency response timeline and applying a selection of the planning tools and methods described above at the appropriate stages can identify potential future opportunities and position the park to leverage them for adaptation after a disruptive event takes place. See "Chapter 9 Lessons Learned from Hurricane Sandy," which describes how much of the planning and stakeholder engagement happened post-storm and continues through the recovery. In short, managers should try to prevent damage to resources but be prepared to rebuild or restore sustainably if those efforts fail.

Take Home Messages

- Adaptation is most effective when it is intentionally and deliberately designed as a response to anticipated effects associated with climate change.
- Climate change adaptation is not a stand-alone plan, but should be addressed in ongoing, routine planning processes such as foundation documents, general management plans, resource stewardship strategies, and preparedness planning.
- Adaptation strategies may require a series of decisions and actions that will change over time.
- Preparing for natural disasters includes planning for uncertainty and allows for adaptation opportunities post-incident.

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Chapter 4 Natural Resources

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Coastal natural resource managers are active leaders in the field of climate change adaptation, in part because climate change impacts to coastal natural resources are already apparent. Impacts from climate change are producing fundamental changes in ecosystem character, distribution, and function (Doney et al. 2012). These changes are exacerbated by stressors such as habitat destruction, pollution, and invasive species, further limiting the ability of coastal ecosystems to adapt. This chapter is not comprehensive on impacts and interacting stressors; rather, it focuses on the information and strategies necessary for getting started with adaptation for coastal natural resources. As our understanding of the breadth of coastal vulnerability develops and more examples of National Park Service (NPS) implementation of adaptation across a range of ecosystems and impacts become available, this guidance will be revised. Additional resources are available at http://www.nps.gov/subjects/climatechange/coastalhandbook.htm.

Expected Climate Change Impacts on Natural Resources

The major climate change impacts on coastal natural resources are changes in sea and lake level, air and water temperature, precipitation, storminess, and ocean acidification (see "Chapter 1 Introduction" for more information on each impact). Together and individually, these affect other ecological and geophysical processes and can have impacts to resources that can be cumulative and direct or indirect. Each habitat type may have differing susceptibility to particular impacts (table 4.1). Sea level rise is an often cited impact, but it does not act alone. Scientists and managers are working to better understand the combined impacts of multiple stressors on park resources. Combined impacts of sea level rise and storm surge, as they affect erosion both gradually and episodically, are beginning to be addressed together. Synergistic effects between sea level rise and nutrients, which influence eutrophication and thus hypoxia, have been found (Crain, Kroeker, and Halpern 2008). Hypoxia (low oxygen) can be exacerbated by warming water temperatures and increased stratification. Stratification is one of several factors influencing water quality that can be exacerbated by changes in precipitation patterns.

Changes in water level and air temperature can define which stretches of lakeshore are affected by ice cover and protect or expose stretches of lakeshore to coastal erosion. Warmer air temperatures are melting permafrost and causing an increase in erosion at northern latitudes when sea ice is not present along shores to prevent storm waves and currents from eroding the shores (see Schupp, Beavers, and Caffrey 2015, "Case Study 4: Cultural Resources Inventory and Vulnerability Assessment" and "Case Study 9: Collecting Baseline Biological and Geologic Data to Understand Coastal Change").

Ocean acidification is a result of rising atmospheric carbon dioxide absorbed into the ocean, which decreases pH. This change is harmful to calcifying species such as corals, oysters, mollusks, and calcareous plankton (Doney et al. 2009). In coastal areas (in contrast to open ocean areas), biological processes, nutrient loading, and freshwater inputs also influence acidity; the signal from these can be much larger and more variable than the open ocean signal of global changes in ocean pH driven by increased anthropogenic carbon dioxide alone (Wallace et al. 2014; Gledhill et al. 2015). Because of this variability and due to complexities of ocean carbonate chemistry, measuring pH and the associated variables (e.g., the partial pressure of CO_2 in seawater, total alkalinity, and dissolved inorganic carbon) is not a straightforward endeavor for parks, but it remains important to monitor and understand (Gledhill et al. 2015). Ocean acidification and increased hypoxia are being studied for their synergistic effects (Doney et al. 2009). Table 4.1 describes some of the ways in which coastal habitats are vulnerable to climate change.

Table 4.1. Climate Change Vulnerabilities of Coastal Habitats. Photographs by Tim Carruthers (seagrass & coral reef); NPS (all others).

Habitat Type	Description
Beach 	Beaches are dynamic in nature, shaped by wind and waves. They accrete, erode, and develop dunes. Inlets open, migrate, and close. Both seasonal and long-term changes occur along beaches (Riggs and Ames 2007). Higher sea level causes increased coastal erosion and accelerates landward migration of barrier shorelines (Field et al. 2007). Impacts from sea level rise are amplified where sediment supply is disrupted or landward migration is impeded by built structures or steep topography (Field et al. 2007). Beaches provide vital nesting and feeding grounds for birds and sea turtles, as well as sunbathing and fishing spots for visitors. Lower lake levels allow vegetation encroachment on bare sand or sparsely vegetated beach areas that provide nesting habitat for birds.
Sand Dunes 	Sand dunes protect interior habitat from wind and wave damage. They protect the middle and inland facing sides of islands. While dunes are dynamic features, sea level rise and increased storm surge can lead to more frequent overwash events and increased erosion that will give less time for dune recovery and ecosystem recovery and subsequent restabilization. Dune grasses such as sea oats in the southeast Atlantic and American beach grass in the northeast Atlantic are essential to island health because they trap and hold sand, allowing the dunes to build. They are frequently used in coastal restoration programs following storm damage because they can stabilize dunes and reduce damage arising from erosion and wave action (Hodel and Gonzales 2013). On the Pacific mainland coast, non-native species that were historically used to stabilize dunes (e.g., iceplant and European beach grass) have led to monocultures. A number of federally and state protected species including shorebirds and beach mice use interdunal areas (overwash fans) for nesting, relying on the adjacent beaches for foraging.
Grasslands 	Grasslands are relatively flat sections of barrier islands. They make up the leeward side of the primary and secondary dunes. Although grasslands are somewhat protected by the dunes, large storms or heavy rains often bring salt water to this area, limiting the survival of woody vegetation. Terrestrial mammals, small birds, and reptiles inhabit the grasslands. If rainfall decreases and/or evaporative moisture loss increases with climate change, the likelihood of wildfires will increase (Twilley et al. 2001). While wildfires are an essential part of grassland ecosystems, in some sections of the United States (US), such as the Gulf Coast, increases in wildfires could threaten the ecosystem.
Salt Marsh 	Salt marshes are incredibly important nursery habitats for many estuarine fish and invertebrate species. They generally lie on the landward side of islands or in sheltered areas of a coastal system. Marsh grasses and dead plant material provide food for insects, crabs, shrimp, fish, and other bottom-dwelling organisms. Salt marshes also provide cover for offspring of many species of fish and crustaceans. Many species of birds feed on the insects, crabs, and other invertebrates that live in marshes and some nest in the high marsh. Salt marshes respond to sea level rise by landward marsh migration or conversion to mudflat if a marsh is not able to keep pace vertically. Warmer temperatures cause faster peat decomposition, which makes it harder for salt marshes to keep pace with sea level rise. Increases in storm frequency or intensity increase marsh edge erosion. Changes in seasonal freshwater input and drought will impact vegetation health and composition (Craft et al. 2009; Thorne, Takekawa, and Elliot-Fisk 2012). Peat bank erosion and conversion to mudflat releases sequestered carbon. Salt marshes are also susceptible to invasive species.

Table 4.1. Continued

Habitat Type	Description
Mangroves 	Mangrove forests grow in tropical and subtropical intertidal zones, are highly adaptable to variability and disturbance, have historically kept pace with sea level by building elevation and have been expanding their range northward in Florida with warming. In addition to their important habitat functions, mangroves offer storm protection and carbon sequestration benefits. Mangroves may be vulnerable to increasing air temperatures, to changes in precipitation affecting salinity, and in some areas to high rates of sea level rise depending on sediment sources (Lugo, Medina, and McGinley 2014). Estimates of 10-15% future mangrove loss due to climate change, especially in areas with low-relief islands or carbonate settings with low sediment supply and upland migration potential, are secondary compared to the current rates of loss due to deforestation (Alongi 2008).
Maritime Forest 	Maritime forests are coastal wooded habitat found on higher ground than dune areas within range of salt spray. They are found along the Atlantic, Gulf of Mexico, and Pacific Northwest coasts and are composed of deciduous, coniferous, and broadleaf evergreen tree species. The composition and structure of these forests are likely to change with changes in air temperature, precipitation, and sea level. For example, 36% of tree species are projected to undergo major change in habitat suitability at Cumberland Island National Seashore and surrounding areas by 2100, based on changes in air temperature and precipitation (Fisichelli et al. 2014). At Fire Island National Seashore, one of the few remaining occurrences of maritime holly forest, 74% of tree species are projected to undergo major change in habitat suitability by 2100 (Fisichelli et al. 2014). Saltwater intrusion into the freshwater aquifer and increased incidence of overwash will also impact vegetation. Invasive species may cause further stress as milder winters reduce pest mortality and temperature changes increase the range of invasive species.
Seagrass 	Seagrasses are vitally important nursery habitat for many marine species, several of which are important economically and socially. Potential threats to seagrass from climate change include rising sea level, which can affect light availability; increases in sedimentation and turbidity due to increases in heavy precipitation events; sediment hypoxia and anoxia due to warmer water temperatures; and increased storm damage (Bjork et al. 2008). The ability of seagrasses to buffer against local acidification through uptake of carbon dioxide through photosynthesis and sequestration in their roots and rhizomes is an active research topic (Bjork et al. 2008; Manzello et al. 2012). Interactions with non-climate stressors including eutrophication may increase hypoxia and reduce light availability, further stressing seagrasses.
Freshwater / Great Lakes Coastal Wetlands 	Climate change impacts on Great Lakes wetlands include earlier spring runoff, larger floods, higher nutrient loading, and hotter summers. Changes in biodiversity and wetland structure could lead to a reduction of services provided by wetlands including flood storage, breeding habitats for birds and amphibians, and reduced water filtering and clean-up capacity. Wetlands exposed to lower Great Lakes water levels are likely to be under intense pressure for alteration through "beach grooming" (wetland removal) activities undertaken by lakeshore owners. Forested wetlands may be affected by more frequent droughts and fires, and the introduction of new forest pests in response to warmer temperatures and shifts in species composition as the forest biomes shifts northward (Christie and Bostwick 2012). Coastal freshwater wetlands are vulnerable to saltwater intrusion and migration of saltwater wetlands.

Table 4.1. Continued

Habitat Type	Description
Tundra 	Tundra is high latitude, generally treeless landscapes with low growth vegetation underlain by frozen subsurface soils (permafrost). This frozen layer contributes to the low growth characteristics of the habitat. Tundra includes numerous plant, lichen, and fungus genera and is found ranging from low coastal plains into mountainous areas. Tundra is susceptible to climate change impacts through the melting of the permafrost layer, leading to coastal erosion rates in the Arctic that are among the highest in the world (Jones, Mieszkowska and Wethey 2009). As permafrost melts, tundra elevation decreases, melt ponds form (thermokarst lakes), and rapid runoff can occur (Callaghan et. al 2005). Tundra elevation decreases can lead to tundra submergence into thermokarst lakes or through oceanic inundation, drowning the tundra. Rapid runoff on steep slopes can slough tundra into adjacent water bodies (thaw slumps) (Burn and Lewkowicz 1990). Uneven melting of coastal tundra cliffs causes catastrophic structural failure of the underlying soils, leading to cliff collapse and wave erosion (Mars and Houseknecht 2007).
Coral Reefs 	Coral reefs are extremely vulnerable to climate change, with projected loss globally between 30% and 90% depending on our ability to limit warming and coral thermal tolerances (Frieler et al. 2013). Warming increases bleaching events, leading to degradation and mortality. Ocean acidification reduces (and potentially reverses) coral calcification and growth (Hoegh-Guldberg et al. 2007). Identifying species resilient to bleaching and refugia from warming events is a growing research focus to better protect these species and places.
Coastal Waters 	Warming of coastal waters from the sub-tropics through the Great Lakes to Alaskan waters is affecting fisheries and nearshore and pelagic ecosystems. In Alaska, air and ocean warming and decreased sea ice cover is causing northward shifts in Alaskan fisheries and ecosystem reorganization (Grebmeier et al. 2006). While effects of warming are already becoming evident on Arctic coastal waters and marine ecosystems, the research documenting changes is limited (Wassmann et al. 2011). Tropical and subtropical sea surface temperatures increased by an average of 0.5°F between the 1950s and 1990s, and this trend is projected to continue (Florida Oceans and Coastal Council 2009). Several commercially important species now present off the New England coast, such as cod, haddock, winter flounder, and yellowtail flounder, are particularly vulnerable to temperature increases at the southern end of their ranges (Staudinger et al. 2013). Great Lakes nearshore waters are warming faster than air temperatures due to declining ice cover and changes in stratification; this influences the growth and distribution of a variety of aquatic species (Austin and Colman 2007; Dobiesz and Lester 2009).

Adaptation of Coastal Natural Resources

Effective adaptation strategies require an understanding of the effects of climate change on parks and a deliberate consideration of climate change within planning and management processes. Understanding ecosystem responses to those adaptation actions will require new research and monitoring that will provide an understanding of how resources are expected to change over time. Uncertainty of climate change effects and rapid development of climate change science make it imperative that we employ new, more flexible planning approaches. Science and management responses to ongoing and rapid changes must be developed concurrently, iteratively, and collaboratively in inclusive partnerships.

Adaptation options will be park- and resource-specific and are likely to evolve over time, but general strategies can be chosen from adaptation approaches for ecosystem management strategies that were outlined in Climate-Smart Conservation and the 2nd National Climate Assessment (Kareiva et al. 2008; West et al. 2009; West and Julius 2014). Definitions, applications, and issues for these seven strategies are highlighted in table 4.2 and parallel strategies for cultural resources are detailed in “Chapter 5 Cultural Resources.”

Table 4.2. General adaptation strategies for ecosystem management (West and Julius 2014; Kareiva et al. 2008; West et al. 2009)

Strategy	Description
Reduce Non-climate Stresses	By reducing non-climate anthropogenic stressors (e.g., excess nutrient inputs, introduction of invasive species, overfishing), an ecosystem is thought to be more resilient to stressful climatic events. For coastal parks, this includes options working with state and local water management agencies to reduce land-based sources of nutrient pollution or removing hard structures (e.g., bulkheads, seawalls) that disrupt sediment transport and are impediments to shoreline migration. This approach has many benefits in the case of high uncertainty about climate impacts because it should be part of management goals without climate considerations. Marine reserves that reduce anthropogenic stressors such as fishing pressure can increase the resilience of coastal ecosystems to impacts of climate change such as increased harmful algal blooms or disease, when marine reserves are established within park boundaries (McLeod et al. 2009). Climate change may also indirectly increase risks from non-climate stressors, such as melting sea ice increasing shipping and the potential for oil drilling in new areas of the Arctic, which increase potential spill risk. Incident response plans need to be updated to protect ecosystems from increasing risks.
Protect Key Ecosystem Features	Keystone species such as ecosystem engineers (e.g., oysters, which build reefs or kelp forests that provide a physical substrate) have a disproportionate effect on the ecosystem and thus merit additional protection. Where key ecosystem features have already been identified as park fundamental resources, this is another approach that is an easy choice in the case of high uncertainty because it is already part of park goals. In cases such as historical parks where key ecosystem features may not be defined as fundamental resources, it will be important to identify the landscape characteristics (e.g., dunes), species, or areas that are key to other resources' resilience and then to protect those features.
Ensure Connectivity	Protecting and restoring landscape corridors and connections facilitates the movement of species that are able to respond to changing conditions. It also increases ecological resilience of species in their current ranges through increased gene flow across isolated populations. Coordination on a larger landscape scale by partnering with entities outside the park to maintain connectivity across park boundaries provides more diverse combinations of biological communities and environments.
Restore Structure and Function	A healthy functioning ecosystem is better able to adapt to climate change impacts. By restoring degraded ecosystems now, it is thought they will be better able to persist in future conditions. For example, by removing tidal restrictions to salt marshes and thus restoring hydrology, the marsh will be better able to keep pace with accelerated sea level rise by vertical accretion through sediment trapping and adding belowground biomass (Burdick and Roman 2012). See Schupp, Beavers, and Caffrey (2015), "Case Study 11: Restoring the Jamaica Bay Wetlands" and "Case Study 12: Restoring the Giacomini Wetlands from Agricultural Lands."
Support Evolutionary Potential Strategy	By protecting a diversity of species, populations, and ecosystems in multiple locations, we can support ecological adaptive capacity. The idea that biodiversity improves resilience (Worm et al. 2006; SCBD 2009) is the basis for this approach, and it applies to physical environments as well (Lenihan et al. 2001). When it is uncertain how systems will adapt, maintaining diversity and a representation of a range of system characteristics, such as depths of oyster reefs, keeps more options available for systems or populations and increases the chances of protecting resilient resources or sources for recovery. Maintaining multiple locations of habitats or populations of species reduces risk in the case of disturbance. Maintaining larger population sizes of individual species may ensure sufficient genetic diversity to allow for natural selection under climate change and for possible adaptation to ocean acidification (Pespeni et al. 2013). As climate changes, managers will need to look beyond park boundaries. For marine systems, replication can provide larval sources for recovery of impacted areas. As with representation, coordinating on a larger landscape scale expands replication opportunities. The Pacific Ocean Parks Strategic Plan calls for a seamless network of ocean parks, sanctuaries, refuges and reserves across the Pacific West and Alaska regions.
Protect Refugia	Once resistant and resilient areas have been identified, they need to be provided with additional protections to maintain their refuge status. Marine reserves are coastal examples that have been shown to be more resilient and could be designed within coastal parks as resilience research areas to compare inside and outside areas of additional protections (Bengtsson, Angelstam, and Elmqvist 2003; Roman and Babson 2013). For many parks, resources such as fisheries may reside primarily outside of their boundaries or the scale of an effective marine reserve extends well beyond an individual park; for refugia to be effective adaptation strategies, managers need to work beyond park boundaries and collaborate with partners to manage ecosystems at larger scale. See Schupp, Beavers, and Caffrey (2015), "Case Study 10: Recognizing Coral Adaptations to Environmental Stressors."
Relocate Organisms	The concept of human-facilitated transplantation of species outside of their historical range or to bypass a barrier is less applicable to marine systems without barriers to transport but could be applied to select marine habitats and species and terrestrial coastal habitats. Currently seed banking for environmental restoration efforts have focused on using native, locally adapted, genetically diverse seedlings, but future planning efforts could consider shifting climate envelopes for sourcing seedlings. See also Schwartz et al. (2012) for a discussion of managed relocation, which remains a controversial strategy due to risks, uncertainties, and ethical questions. While marine barriers to migration are not as tangible as for terrestrial species, they do exist and can cause populations to become small and isolated. An example of marine translocation is the sea otter population in southern California by the US Fish and Wildlife Service.

Most strategies in table 4.2 focus on resisting change or increasing resilience, but such strategies may not be successful as conditions continue to change (Millar, Stephenson, and Stephens 2007) and it will be necessary to manage for change (Kareiva et al. 2008; Stein et al. 2014). As thresholds of resilience are passed, planning methods that address uncertainty, such as scenario planning and adaptive management and accompanying monitoring will become increasingly important (Baron et al. 2009). Other adaptation approaches and frameworks are outlined in table 5.1 of Stein et al. (2014). Choosing between approaches, especially whether to manage for change, will depend on the ecosystem, timing, and magnitude of expected impacts and how well understood or effective the adaptation approach is for the park-specific conditions. Management criteria that will influence the decision include landscape context (e.g., regional or national significance of the resource), threatened or endangered species status, cost, stakeholder support, and feasibility. Since the options based on resisting change and increasing resilience may only be effective in the near term through the next couple of decades, flexibility to change between adaptation options needs to be part of the planning process (Baron et al. 2008).

The Adaptation Continuum

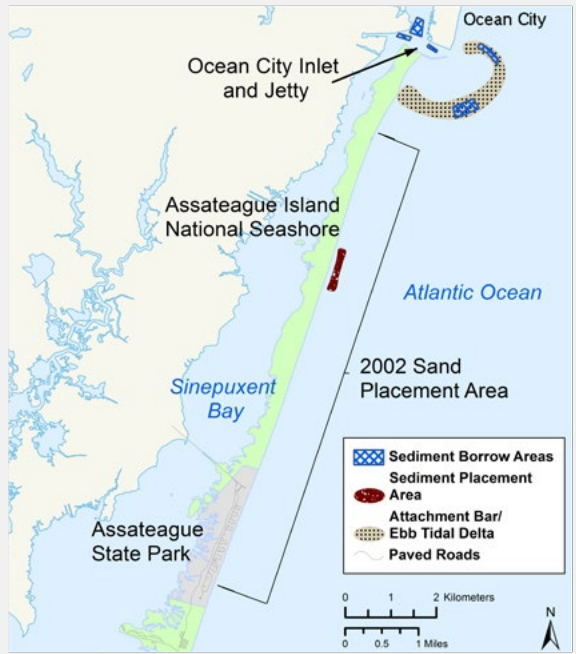
The continuum of adaptation responses of resist, accommodate, and direct change is introduced in "Chapter 1 Introduction" and is illustrated in box 4.1 with an example from Assateague Island National Seashore. A *resist change* approach seeks to preserve existing ecological conditions in spite of the stressors and climate change impacts affecting the ecosystem (Stein et al. 2014). This approach often works to prevent systems from crossing major change thresholds by promoting resistance, enhancing ecological resilience, protecting ecosystems from stress, and supporting recovery after major disturbances. Reducing other stressors (e.g., reducing runoff/pollutants, restoring degraded habitat, controlling competing nonnative species) can be considered a resist change response if it is done with climate change adaptation intentionality such that it explicitly and deliberately addresses climate change impacts.

An *accommodate change* response that allows ecological processes to proceed unimpeded and ecosystems to adapt on their own (i.e., autonomy of nature) may be chosen if other responses are undesirable, impossible, economically infeasible, or likely ineffectual (see NPS Policy Memo [PM] 12-02, "Applying National Park Service Management Policies in the Context of Climate Change" [NPS 2012]), or if those strategies would risk impairment of other park resources and values (NPS Management Policies 2006 Section 1.4.4 "The Prohibition on Impairment of Park Resources and Values"). Accommodating change may also be chosen under an adaptive management approach as a control treatment to monitor the unmitigated effects of climate change and evaluate adaptation interventions in similar areas (Fisichelli, Schuurman, and Hawkins Hoffman 2016). An accommodating change response allows conditions to shift with climate and makes no particular effort to reverse, resist, or direct climate-driven changes. Parks are uniquely suited to provide places where the stories of our legacy of climate change can best be told. In places where we choose an accommodate change response, documenting and interpreting that change will be an important role for the National Park Service.

A *direct change* approach accepts change and attempts, where feasible, to steer towards desired future conditions. An example is assessing where unavoidable threshold changes in ecological systems may be about to happen, such as from freshwater to brackish wetlands, and planning the management towards these future conditions (Stein et al. 2014). These concepts in the adaptation continuum are relatively new and are evolving as they are tested, so this handbook cannot yet provide the guidance for choosing between these responses.

Climate-smart conservation is an approach that helps managers both to develop adaptation strategies and to reconsider overarching goals (desired conditions) in light of climate change, as described in "Chapter 3 Planning" and has the potential as a process to guide parks through these decisions. This new climate-smart conservation process has not yet resulted in a completed coastal park case study; the Climate Change Response Program (CCRP) is supporting the application of the approach to NPS planning in "*Planning for a Changing Climate: NPS Climate Change Adaptation Planning Guidance*" further described in "Chapter 3 Planning". Similarly to the rapidly developing information on adaptation, new information related to climate change impacts is emerging, as described in box 4.2, and the National Park Service is working with partners to stay on top of what these emerging topics mean for coastal adaptation but does not yet have the guidance on these topics to include in this handbook. As the adaptation strategies to address these complex issues develop and park examples of implementation are completed, new and iterative NPS guidance will be necessary.

BOX 4.1. EXAMPLE OF THE ADAPTATION CONTINUUM FROM ASSATEAGUE ISLAND NATIONAL SEASHORE



Management of Assateague Island National Seashore and development of a new general management plan (GMP), which will guide management of the park for the next twenty years, incorporates all three adaptation responses: resist, accommodate, and direct change. The park's preferred alternative **accommodates change** and allows natural processes such as beach erosion and overwash to continue unimpeded and addresses the possibility of alternative transportation, such as a ferry service to access the island if bridges and roads can no longer be maintained. The accommodation approach to natural resources (acceptance of the ongoing beach erosion) requires a **direct change** approach to visitor experience (accessing the park by ferry instead of by personal vehicle).

An example of **resist change** is along the north end of the island where the Ocean City Inlet has caused island narrowing and retreat. In 2002, beach nourishment occurred along the northern 8.08 mi (13 km); beginning in 2004, sand has been mechanically bypassed from the inlet shoals to the shallow nearshore area twice each year (see inset figure 4.1 from Schupp and Coburn 2015). The park plans to continue bypassing sediment to the north end of the island to prevent further degradation of the habitat and geologic integrity and to prevent that vulnerable area from crossing a major change threshold such as submergence, recognizing that increased storm intensity and sea level rise will continue to weaken this area of the island.

For additional information on the new GMP, see Schupp, Beavers, and Caffrey (2015), "Case Study 23: Incorporating Climate Change Response into a General Management Plan." The draft GMP and Environmental Impact Statement were available for public comment from January through May 2016.

BOX 4.2. EMERGING COASTAL CLIMATE CHANGE ISSUES

OCEAN ACIDIFICATION

The breadth of ecosystem impacts of ocean acidification and methods for monitoring it are the focus of most research on this topic, but following close behind is research into adaptation options. Because other factors influence coastal acidification, strategies based on reducing non-climate stresses like reducing nutrient inputs can have a buffering effect. Identifying resilient corals for added protection or active management is described in Schupp, Beavers, and Caffrey (2015), "Case Study 10: Recognizing Coral Adaptations to Environmental Stressors, National Park of American Samoa." Seagrasses have the potential to benefit from increased seawater CO_2, and their carbon uptake capacity and associated influence on seawater chemistry could thereby effectively buffer against acidification (Hendriks et al. 2015).This emerging research field may demonstrate seagrass restoration, or other habitats, as an adaptation strategy, providing multiple ecosystem services as refugia to counter ocean acidification, and has added carbon sequestration benefits.

BLUE CARBON

Blue Carbon is a term for carbon stored in coastal wetlands including salt marshes, mangroves, and seagrass meadows, which store carbon at much higher rates than tropical forests (Murray et al. 2011). Methods and research to quantify carbon sequestration of wetlands is expanding and development of a model for marketing carbon credits for these coastal systems (after forest sequestration protocols) has the possibility of providing financial incentives for restoration. The proposed Herring River Estuary restoration at Cape Cod National Seashore is part of a feasibility assessment to see if Blue Carbon credits could be applicable to this project and, thus, be the first Blue Carbon restoration project with credits marketed.

HARMFUL ALGAL BLOOMS (HABS)

Climate change may influence the frequency, duration, or geographic range of HABs (algal blooms that produce toxins or other negative effects on ecosystems or human health), though currently the link is poorly studied (Moore et al. 2008). Potential mechanisms include warming waters favoring harmful species or stratification intensifying blooms; changes in salinity expanding ranges for HABs species into freshwater systems; and changes in precipitation patterns increasing nutrient inputs or increases in carbon dioxide favoring rapid growth. The complexity of these processes, limited understanding of HAB physiology and ecology, and the limited long term datasets at time scales that capture HAB events mean that this is a research area to follow more than a current adaptation field (Moore et al. 2008).

WATER QUALITY

Climate change is adding new hurdles as parks work to address water quality issues, as Great Lakes phosphorus loading, Gulf Coast hypoxia, and Combined Sewer Overflows are all exacerbated by increases in heavy precipitation events. Saltwater intrusion, driven by groundwater pumping in some areas, is emerging as an issue for many more coastal parks because it is driven by sea level rise.

PHENOLOGY

Phenological (the timing of life events of plants and animals) responses of marine and coastal species are more difficult to study than terrestrial species, so the climate related changes are much less well documented, with the exception of migratory birds. Visualizations of phenological changes, including for migratory raptors at Acadia National Park, are part of the Whenology project. The National Ocean Policy Implementation Plan (National Ocean Council 2013) calls for actions to "develop and begin to implement a plan for incorporating species phenology information…from coastal and ocean ecosystems in the National Phenology Network" so a Marine and Coastal Phenology Project is underway.

Climate Adaptation Issues for Designated Wilderness Areas

Change is inherent in natural processes, especially in the case of dynamic coastal landforms. Designated wilderness areas, where natural resources have the least interference from human activity, provide excellent sites to study the ecological resilience or other responses of natural processes and natural resources to climate change. As climate change pushes natural processes outside the bounds of natural variability, these places will teach us what happens when thresholds are crossed. Wilderness area designation limits some active management adaptation actions and relies primarily on accommodate change responses but applies the strategy of removing non-climate stresses. While the restraints of the Wilderness Act limit some active adaptation strategies, where there is certainty that such actions will be effective, there is flexibility to implement provided procedural processes to justify the actions are followed (Long and Biber 2014).

One example, described in more detail in "Chapter 9 Lessons Learned from Hurricane Sandy," occurred at Fire Island National Seashore. There, Hurricane Sandy caused two breaches that didn't close immediately. One occurred in the Otis Pike Fire Island High Dune Wilderness, where policy disallows artificially closing the breach, allowing the natural processes of the barrier island to continue. In contrast, the second breach occurred outside of the wilderness area and was artificially closed. Intensive study of the open breach continues, allowing documentation of the continuing changes to the landforms and the water quality benefits to the adjacent Great South Bay (see "Chapter 9 Lessons Learned from Hurricane Sandy"). The breach that was artificially closed has remained closed.

Coastal wilderness areas are a portion of a much larger coastal ecosystem and are affected by anthropogenic actions taken outside of designated wilderness areas. For example, at Gulf Islands National Seashore, the wilderness area of the Mississippi barrier islands migrates westward with shoreline changes until it reaches the adjacent shipping channel, where it is no longer considered wilderness. Regular dredging of the major shipping channel shaves off the western tip of the wilderness area at a higher rate than accretion is occurring at the eastern tip. Human actions occurring outside of wilderness boundaries may compromise the area's ecological resilience. In "Case Study 13: Consideration of Shackleford Banks Renourishment" (Schupp, Beavers, and Caffrey 2015), Cape Lookout National Seashore decided against placement of dredged material on a barrier island, a proposed wilderness area, until more information on the potential impacts was known.

When choosing climate adaptation strategies in wilderness areas, the tradeoffs between short- and long-term impacts on wilderness character must be evaluated. A comprehensive assessment is needed to understand how action or inaction may impact the qualities of wilderness character. Designation of new wilderness areas may be a feasible climate adaptation strategy for some parks. Additional guidance on adaptation actions related to wilderness policy is provided in "Chapter 2 NPS Policies Applicable to Coastal Adaptation."

Science to Support Climate Adaptation for Natural Resources

Adaptation strategies will depend on the articulated goals, magnitude of climate change, rate of change with respect to identified thresholds, and availability of management resources. Vulnerability assessments inform managers of the magnitude of climate change and potential impacts on the resources articulated within goals, as well as the adaptive capacity of resources. There is a variety of scientific resources to inform these vulnerability assessments and adaptation strategy development.

Parks are encouraged to use best available science, which can bring up questions about which tools to use in the crowded field of sea level rise, storm surge, and inundation modeling. Models, projections, and scenarios developed from broader data sets such as the National Oceanic and Atmospheric Administration (NOAA) Digital Coast, the Landscape Conservation Cooperatives (LCC), and sea level rise and storm surge maps for all coastal NPS units (see Schupp, Beavers, and Caffrey 2015, "Case Study 24: Storm Surge and Sea Level Data Support Planning") use the best available science at a larger regional or national scale, but this may not be best available at a local scale. The need for data consistency for regional or national tools often means that locally specific data of higher quality is not incorporated. Parks have the flexibility to choose from locally specific information when it is available or from regional or servicewide-scaled products. Since there are many sources of uncertainty in each of these tools, for most purposes, it is more important to develop a flexible and iterative adaptation process than to invest in the most complex, locally detailed model.

Managing for an Uncertain Future

It is important to incorporate information on uncertainty into the decision-making process. A chapter on "Managing Under Uncertainty" within Climate-Smart Conservation offers guidance on how to understand and work with uncertainty, instead of delaying decisions while awaiting additional information (Hoffman et al. 2014). Sources of uncertainty are not limited to future climate and sea level rise projections; they include how ecosystems will respond, how managers will respond, the effectiveness of adaptation actions, and randomness (Hoffman et al. 2014).

Multiple planning strategies and resources are available to help make management decisions for an uncertain future. Scenario planning is one approach for decision-making under uncertain conditions that the National Park Service has explored more than other methods; it is described in "Chapter 3 Planning." The uncertainty estimates provided in the park-scale climate resource briefs (see Monahan and Fisichelli 2014; e.g., Gonzalez 2015) and trend reports are well constrained for these physical variables, but many ecological variables have limited information on uncertainty and require more qualitative estimates. An example of qualitative treatment of uncertainty is estimating levels of confidence, such as high/low for the amount of evidence and high/low for the amount of agreement between them (Kareiva et al. 2008). This method was applied to evaluating the efficacy of the adaptation approaches in table 4.2 as applied to the National Park Service; three approaches were high in both categories and the remainder was low in both categories (Kareiva et al. 2008).

Incorporating Uncertainty into Inundation Models

When considering the uncertainty in inundation models, it is important to weigh the vertical accuracy of the elevation data (both land and bathymetry) relative to the sea level rise scenarios (Murdukhayeva et al. 2013). Figure 4.2 compares the minimum vertical accuracy of the US Geological Survey (USGS) National Elevation Dataset (NED) (available for the study sites described Schupp, Beavers, and Caffrey 2015, "Case Study 24: Storm Surge and Sea Level Data Support Planning"), Light Detection and Ranging (LiDAR) data (not available everywhere), and high-accuracy elevation data (e.g., Real Time Kinematic-Global Positioning System [RTK-GPS] data), relative to a sea level rise scenario of 3.28 ft (1 m). Often the planning horizon will be within a few decades, in which case sea level rise projections are of smaller magnitude than the vertical accuracy of USGS NED values and many LiDAR products, most of which have a maximum accuracy of + 5.9 in (15 cm) depending on the system and processing. The application of the models (e.g., planning site level restoration vs communication tools) will influence the accuracy needed and how much to invest in higher accuracy data or more complex models.

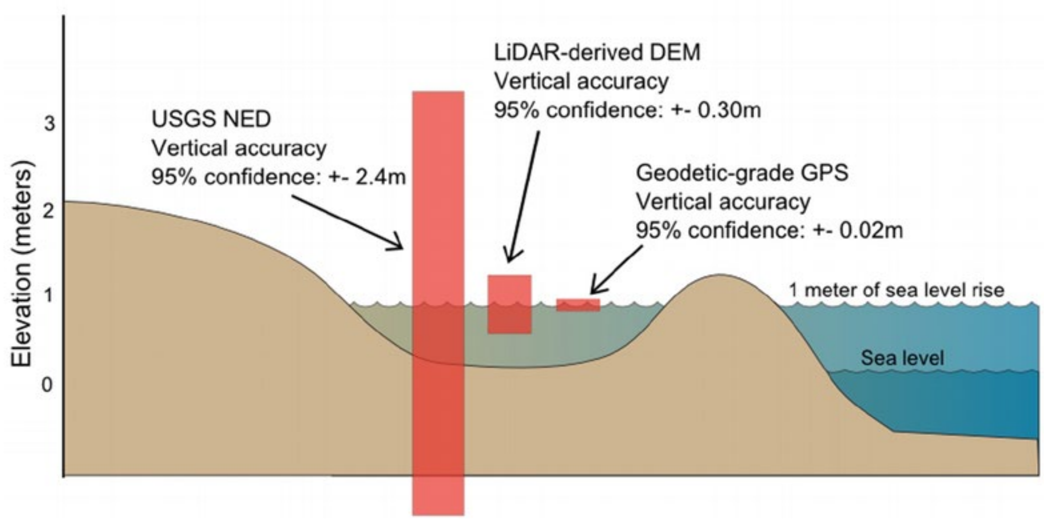


Figure 4.2. Vertical accuracy estimates of Digital Elevation Models.
Note: Figure from Murdukhayeva (2012), mapping 3.28 ft (1 m) of sea level rise on land, adapted from Gesch (2009). Digital elevation models with different vertical root-mean-square errors result in inundation zones with different 95% confidence intervals and estimates of uncertainty.

The field of inundation modeling is ever growing, and it can be challenging to determine which tool to use to better understand the coastal system response to sea level rise and storm surge. NOAA has a "low-tech" guidance document Incorporating Sea Level Change Scenarios at the Local Level intended for community planners to support the application of modeling results to mapping (NOAA 2012). USGS has a Sea-level rise modeling handbook—Resource guide for coastal land managers, engineers, and scientists for those wanting to dig into more technical detail (Doyle et al. 2015). Errors in tidal datum calculation, vertical landform position accuracy, and biases in oceanographic and atmospheric models can lead to challenges in accurately representing exact location and magnitude of storm surge across landscapes at the scale of coastal properties contained within park boundaries. To provide guidance in managing changing coastal systems in the national park system, the National Park Service is currently supporting partnering efforts with universities and other government agencies such as NOAA and the USGS to continue to support parks in utilizing this expertise.

Another consideration for inundation modeling is when and where it is appropriate to use static models (often referred to as "bathtub models") instead of dynamic models. The type of model needed will depend on the resources at risk and the particular park. Static inundation models do not account for sediment budget variation, sediment redistribution, and biological processes. Static models also do not capture water level changes in narrow water bodies or complex shorelines. Dynamic coastal landforms such as dunes and salt marshes respond to sea level rise in ways that are locally specific, so local models may be necessary. Lentz et al. (2015) developed a framework for categorizing which coastal response needs to be dynamically modeled, and applied it using a Bayesian model to the northeastern United States. Static inundation models were used for exposure assessments of park assets in 40 coastal parks (Peek et al. 2015) and will be available for all coastal park units by 2016 (see Schupp, Beavers, and Caffrey 2015 "Case Study 24: Storm Surge and Sea Level Data Support Planning"); other methods have been done by individual parks and regions (Nielsen and Dudley 2013; Shaw and Bradley 2014; URI and NPS 2014).

There is a range of dynamic models in development that are being applied to coastal parks. These models include different geomorphic and biologic processes and have varying degrees of complexity and data requirements (Fuller et al. 2011; Roman and Babson 2013). While this discussion has primarily focused on inundation modeling, related questions about static vs dynamic models apply to other types of models, such as species climate envelope modeling or groundwater modeling. Other Bayesian models build on sea level rise models and have been applied to barrier island groundwater modeling or shorebird nesting habitat suitability (Gutierrez, Plant, and Thieler 2011; Masterson et al. 2013; Gieder et al. 2014).

Additional Resources for Data and Collaboration

The National Park Service is engaged in many efforts and with many organizations to develop datasets and partnerships that will improve resource management. Several of these resources are described below as they relate to coastal climate adaptation.

NPS Inventory and Monitoring Program

The NPS Inventory and Monitoring (I&M) program provides valuable resource specific information and data that can be used to understand climate change effects and to support adaptation planning. The I&M program is enhancing monitoring to support climate change in several ways, including expanded coverage of Surface Elevation Tables to monitor tidal marsh surface elevation and monitor salt marsh breeding birds (Stevens et al. 2010). Other vital signs important to coastal adaptation include shoreline position, seagrass condition, and water quality including nutrient enrichment. Standard and park-specific monitoring protocols are available at http://science.nature.nps.gov/im/monitor/.

A climate inventory of stations and data sources adjacent to NPS units is compiled by the I&M program in an NPS Climate Database. There is a need for additional science communication products; guidance for developing these is provided in "Chapter 7 Communication and Education."

Landscape Conservation Cooperatives

LCCs can provide applied science, tools and resources for parks to address conservation challenges at a larger, landscape and seascape-level, trans-boundary scale, and the longer time scale needed to address climate change. These cooperatives are groups of conservation professionals who partner to work collaboratively to identify best practices, connect efforts, identify science gaps, and avoid duplication through conservation planning and design. In some places, a park may be one of a handful of protected areas and conservation organizations, and identifying and engaging partners could be fairly straightforward. In more fragmented landscapes like along the Atlantic coast of the United States, the Great Lakes, and the mainland Pacific coast of the United States, protected areas tend to be smaller while the number of conservation organizations working on the landscape is larger, making the development of collaborative partnerships more time-consuming. Although cooperatives do not have the capacity to take on every issue, they usually attempt to address broad issues that most conservation professionals are facing in that general ecosystem.

For example, sea level rise is affecting many places in the southeastern United States. Most coastal managers are dealing with saltwater intrusion, loss of marsh, narrowing beaches, and increased and more frequent storm surge. To prepare for these changes, the South Atlantic LCC, the Gulf Coast Plains and Ozarks LCC, the NPS Southeast Regional Office, and the National Oceanic and Atmospheric Administration collaborated on a Gulf Coast Vulnerability Assessment. The report identifies exposure, sensitivity, and adaptive capacity of 4 key ecosystems and 11 associated species to the effects of climate change, sea level rise, and land use change across the US portion of the Gulf of Mexico.

Climate Change Vulnerability Assessment

Climate change vulnerability assessment is a tool for examining the "extent to which a species, habitat, ecosystem, place, or project is susceptible to harm from climate change impacts" (Stein et al. 2014). Climate change vulnerability assessments, as described in "Chapter 3 Planning," are intended to support decision-making; thus, it is vital to involve decision makers from design through completion of the assessment. It is also important to consider that the process of a vulnerability assessment is just as important as the conclusion. Furthermore, an assessment can be quantitative or qualitative depending on management needs and availability of data, funding, and capacity. There is no single approach that applies to all situations. Information from an assessment is primarily intended for guidance and analysis purposes; it does not outline a management response.

There are four key steps for assessing vulnerability to climate change (Glick, Stein, and Edelson 2011):

1. Determine objectives and scope.
2. Gather relevant data and expertise.
3. Assess components of vulnerability.
4. Apply assessment in adaptation planning.

A marine vulnerability assessment methodology that qualitatively categorizes sensitivity, exposure, and adaptive capacity for four climate stressors (sea level rise, temperature change, salinity change, and ocean acidification) on nine marine habitats is being developed and piloted for Cumberland Island National Seashore (Peek et al. 2016). Understanding relative vulnerability between habitats and the contributions between stressors will inform the development and implementation of strategies for adapting these resources to climate change.

Tools

An array of tools that specifically relate to coastal climate change have been developed, many of which are focused on natural resources. Table 4.3 highlights some of the tools available and their various applications.

Table 4.3. Examples of Tools and Resources for Climate Change Adaptation of Coastal Natural Resources.

Tool	Agency/ Organization	Summary	Website	Models	Case Studies	Plans	Data	Tools	Training and Collaboration
Surging Seas	Climate Central	Offers plans, actions, and resources for preparing for sea level rise. Highlights national and state-specific tools such as the NOAA Coastal Inundation Toolkit and California's Cal-Adapt.	http://sealevel.climatecentral.org/responses/plans	X	-	X	-	-	-
Digital Coast	NOAA	Offers data, tools, training, and stories from the field on coastal issues and climate change.	http://coast.noaa.gov/digitalcoast/	X	X	X	X	X	X

Table 4.3. Continued

Tool	Agency/ Organization	Summary	Website	Models	Case Studies	Plans	Data	Tools	Training and Collaboration
Sea, Lake, and Overland Surges from Hurricanes (SLOSH)	NOAA	The SLOSH model estimates storm surge heights resulting from historical, hypothetical, or predicted hurricanes. The National Park Service is providing all coastal parks SLOSH inundation maps as part of coastal climate briefs (see Schupp, Beavers and Caffrey 2015 case study 24).	http://www.nhc.noaa.gov/surge/slosh.php	X	-	-	-	-	-
Sea Level Change Calculator	US Army Corps of Engineers	This on-line sea level change calculator provides sea level change curves from 1992 to 2100 adjusted for NOAA tide gauge stations.	http://corpsclimate.us/ccaceslcurves.cfm	-	-	-	X	X	-
Climate Ready Estuaries Adaptation Planning Workbook	EPA	Includes case studies, Climate Ready Estuaries, examples, and related links to illustrate what is being done in coastal communities to protect people and property.	http://www2.epa.gov/cre/risk-based-adaptation	-	X	-	-	X	-
Climate Adaptation Knowledge Exchange (CAKE)	EcoAdapt	One-stop shopping for adaptation information: case studies, tools, vulnerability assessments, virtual library, etc.	www.cakex.org	-	X	-	-	X	X
Climate Registry for the Assessment of Vulnerability (CRAVe)	USGS	Clearinghouse of climate change vulnerability assessments, compatible with CAKE.	https://nccwsc.usgs.gov/crave/	-	X	-	-	-	-
Collaboratory for Adaptation	Hosted by Notre Dame University	Website hosted by Notre Dame. Similar to CAKE—one-stop shopping for adaptation information: resources, climate tools and models, workflows, case studies, etc.	https://adapt.nd.edu/	X	X	-	X	X	X
National Climate Assessment	US Global Change Research Program	Provides an integrated assessment of observed and projected climate changes and key impacts on the regions of the US Northeast, Southeast and Caribbean, Midwest, Great Plains, Southwest, Northwest, Alaska and the Arctic, and Hawai'i and the Pacific Islands, as well as coastal areas, oceans, and marine resources. This report is revised every four years.	http://ncadac.globalchange.gov/	-	X	-	X	-	-
National Fish, Wildlife, and Plants Climate Adaptation Strategy	Multiple	Authoritative guidebook on adaptation written by large number of government and nongovernment entities.	http://www.wildlifeadaptationstrategy.gov	-	-	X	-	-	-
National Climate Change Viewer	USGS	Historical and future projected changes for temperature and precipitation variables at the county, regional, state, and watershed levels.	http://www.usgs.gov/climate_landuse/clu_rd/nccv.asp	X	-	-	X	X	-

Table 4.3. Continued

Tool	Agency/ Organization	Summary	Website	Models	Case Studies	Plans	Data	Tools	Training and Collaboration
FedCenter.gov	FedCenter	Provides links to numerous tools and agency sites for climate change adaptation.	https://www.fedcenter.gov/programs/climate/	-	X	X	-	X	-
Great Lakes Climate	The Ohio State University	Includes education, ecosystems, infrastructure, public health, public policy, water, and webinars.	http://www.climategreatlakes.com	-	-	-	-	-	X
Great Lakes Coastal Resilience Planning Guide	NOAA and partners	Shows how coastal communities are using science-based information to address coastal hazards such as flooding, shore erosion, and lake-level fluctuations.	http://greatlakesresilience.org/	-	X	-	-	-	-
Coastal Resilience	The Nature Conservancy	A network, mapping tool and apps to view flood and sea level rise risk, alongside coastal habitat, social and economic information.	http://coastalresilience.org/	X	X	-	X	X	X
Community Resilience Building	The Nature Conservancy	Workshop guide process, where participants identify top hazards, current challenges, strengths, and priority actions to improve community resilience to all natural and climate-related hazards today, and in the future.	http://www.community-resiliencebuilding.com/	-	X	X	-	X	X
Climate Change Vulnerability Assessment Tool for Coastal Habitats	NOAA National Estuarine Research Reserves	Spreadsheet based decision support tool for land managers, decision makers, and researchers to identify habitats that are likely to be affected by climate change and the ways in which they will be affected.	http://www.northinlet.sc.edu/stewardship/CCVATCH/Overview.html	-	-	-	-	X	-
Guide for Considering Climate Change in Coastal Conservation	NOAA	Step by step guide to including climate change in conservation plans for coastal environments.	https://coast.noaa.gov/data/digitalcoast/pdf/considering-climate-change.pdf	-	-	X	-	X	-

The number and wide range of complexity of tools for coastal climate adaptation can be overwhelming. Table 4.3 provides an overview of examples of the wide array of available tools. The climate-smart conservation scoping steps within the first step of identify planning purpose and scope of: articulate planning purpose; clarify existing goals and objectives; specify geographic scope and time frame; and determine data needs and acceptable levels of uncertainty, can be useful to work through before choosing a tool (Stein et al. 2014). The climate-smart conservation scoping process actions within the first step,"Identify planning purpose and scope" (articulating the planning purpose, clarifying existing goals, specifying geographic scope and timeframe, and determining data needs and acceptable levels of uncertainty) can be useful to work through before choosing a tool (Stein et al. 2014).

Once a tool is chosen, parks may need technical assistance on using tools and finding the necessary data to run and validate them. Technical assistance resources described in "Chapter 1 Introduction" are available through CCRP, NRSS, and collaboration with partners such as LCCs or cooperative ecosystem studies units.

Opportunities for Adaptation

Revisiting Leopold

Because change is a part of natural processes, there is an opportunity to embrace innate adaptive capacity while managing the trajectory of change. With natural resources for which the pace of change is larger than the resource's ability to adapt on its own, park managers will need to prioritize action early and often. The report Revisiting Leopold: Resource Stewardship in the National Parks (NPSABSC 2012) provides an opportunity to reconsider what is "natural" in a time of change, and how parks make decisions under accelerated, changing conditions. According to the report, "the overarching goal of NPS resource management should be to steward NPS resources for continuous change that is not yet fully understood, in order to preserve ecological integrity and cultural and historical authenticity, provide visitors with transformative experiences, and form the core of a national conservation land- and seascape." The new Director's Order #100 will be a way to implement the ideas in the report to update *Resource Stewardship for the 21st Century*, the guiding principles and policies of resource management and stewardship in the National Park System. Policy Memo 16-01, setting the framework for the new director's order, calls for integrating the precautionary principle into resource stewardship decision making, which in the context of climate change, will be a powerful impetus to address climate adaptation (NPS 2016).

Implement National Fish, Wildlife and Plants Climate Adaptation Strategy

The National Park Service has an integral role in implementing this national strategy for natural resource climate adaptation. All of the goals in the strategy are applicable to coastal park resources, and they are as follows:

- Conserve habitat to support healthy fish, wildlife, and plant populations and ecosystem functions in a changing climate.
- Manage species and habitats to protect ecosystem functions and provide subsistence, recreational, and commercial use in a changing climate.
- Enhance capacity for effective management in a changing climate.
- Support adaptive management in a changing climate through integrated observation and monitoring and use of decision support tools.
- Increase knowledge and information on impacts and responses of fish, wildlife, and plants to a changing climate.
- Increase awareness and motivate action to safeguard fish, wildlife, and plants in a changing climate.
- Reduce non-climate stressors to help fish, wildlife, plants, and ecosystems adapt to a changing climate (NFWPCAP 2012).

As parks implement the strategies described in this chapter, there is an opportunity to share successes and lessons nationally with others working toward achieving these goals as part of a collective effort to adapt.

Expansion of Submerged Resources

Sea level rise may result in additional submerged resources in some ocean and coastal parks. If the park's boundary is based on a static location, such as latitude and longitude or the Intracoastal Waterway, then the boundary will remain fixed, and those parks will begin to manage a larger percentage of submerged resources within their boundaries. However, the majority of ocean and coastal parks have boundaries that are tied to the mean high water line, mean low water line, or some other tidal measure. For these parks, sea level rise will cause the water line and the park's boundary to move landward, resulting in changing park acreage. For more information on park boundaries and jurisdiction, please see NPS 39-1 Ocean and Coastal Jurisdiction Reference Manual (*NPS internal access only*).

Managing at the Landscape Scale

The threat of climate change is prompting organizations including the National Park Service to look across borders and missions to collaborate on responses at a landscape scale, such as through LCCs. Many current management goals will be increasingly difficult to achieve without regional cooperation. Issues such as migratory bird habitats, marine invasive species, and sediment budgets all have landscape-scale management questions exacerbated by climate change impacts. To be good stewards of natural resources within park boundaries, it is important, where possible, to act in concert with other stewards to serve as part of a network of professionals, each doing their part to support habitats and species broadly so that parks are not the last refuge, but part of a functioning landscape that sustains these important resources for future generations.

Review Documentation, Data Integration, and Prioritization (See more in the "Opportunities for Adaptation" section in "Chapter 6 Facility Management.")

Documenting resource condition and change is important to understanding vulnerability and planning for adaptation; the science and monitoring in support of adaptation will be useful to other aspects of natural resource management. There is a growing amount of and accessibility to data related to climate change impacts on natural resources, providing new opportunities for the National Park Service to gather compatible baseline data and to synthesize trends. In addition, CCRP maintains an adaptation database complete with case studies of adaptation from various parks. Parks can either query other parks or input their case studies into the database.

Prioritization of resources is more challenging under climate change. PM 12-02, (NPS 2102) helps to inform prioritization activities. As our adaptation experience grows and servicewide understanding of vulnerability develops, the opportunity to prioritize at regional and national scales will help with allocating resources. Working at a large landscape scale and collaborating with partners, the National Park Service will set priorities to support evolutionary potential of habitats and species.

Inform Natural Resource Decision Making with other Decision-Making Processes

Because climate change affects all resources, adaptation is an opportunity to integrate decision-making processes across cultural resources, facilities, and natural resources. The needs and vulnerabilities of various park functions can inform assessment, selection, and implementation of management actions across a park. An adaptation strategy that works for a facility, for example, (e.g., reducing runoff from stormwater) can also have benefits for natural resources (e.g., less nutrient pollution from stormwater). Another example is the opportunity to examine coastal engineering inventories (see "Chapter 6 Facility Management" and "Chapter 9 Lessons Learned from Hurricane Sandy") and to consider building restrictions and removal of structures to protect and enable migration of beaches, dunes, estuarine shorelines, and wetlands (Nordstrom and Jackson 2016).

Take Home Messages

- Parks can choose from a range of potential adaptation strategies developed for climate-sensitive ecosystems. Applying strategies to coastal systems is park- and resource-specific. There is not yet a clear way forward to know which adaptation options will be most effective, and implementation is an active research field. The scientific resources to support adaptation are varied and growing.
- Uncertainty or the lack of locally specific information should not stop adaptation action. Strategies that are able to incorporate additional information at later steps, such as adaptive management, are well suited to coastal climate adaptation challenges.
- NPS policies to maintain natural processes are consistent with consideration of natural resource adaptation strategies because change is part of natural processes, and natural processes can be highly resilient. Yet climate change functions outside bounds of natural variability and thresholds will be exceeded. Strategies to manage for change, especially where natural systems are more vulnerable, or where thresholds can be anticipated, are a growing challenge.
- Managing for change may require working at a larger landscape scale than a single park and, thus, working with partners.

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Chapter 5 Cultural Resources

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Introduction

This chapter describes threats to cultural resources in the coastal zone, identifies multiple adaptation strategies to address these threats, and outlines policies and decision-making processes to assist with adaptation. Online resources will be updated to supplement this document and can be found at https://www.nps.gov/subjects/climatechange/coastalhandbook.htm.

The National Park Service manages five types of cultural resources: archeological resources, cultural landscapes, ethnographic resources, museum collections, and historic and prehistoric buildings and structures (NPS 2006), all of which are found in the coastal zone. Underwater or submerged resources, which include shipwrecks, other submerged buildings or structures, and inundated archeological sites and cultural landscapes, also occur in and are accessed from the coastal zone.

This diversity of cultural resources anchors the history of human interactions with water. While humans have lived in nearly every environment on the planet, coasts – through the access they have provided to plants and animals for food and manufacturing; to means of transportation, commerce, communication, and defense; and to areas of beauty and recreation – have high concentrations of cultural resources. These in turn hold a wide array of meanings and livelihoods for many different communities. Combined, this abundance of resources and their diverse associations create substantial challenges for the management of cultural resources in the coastal zone, particularly in regard to climate change.

Figure 5.1. The Cockspur Lighthouse at Fort Pulaski National Monument, Georgia, needs to be stabilized with a structure that can withstand ongoing erosion around the revetment, sea level rise over the next 20 years, and related impacts such as increased wave heights. Photograph by Paul Brennan.

Because cultural resources hold significance from both place and the past, they are unique and nonrenewable. Once they are lost, they are gone forever, along with their value for research and discovery, provoking public introspection, keeping and reawakening cultural memories, connecting individuals to their ancestors, and maintaining ties from generation to generation. For these reasons, National Park Service (NPS) Director Jarvis stated in NPS Policy Memorandum 14-02 "Climate Change and Stewardship of Cultural Resources" (PM 14-02, NPS 2014a) that cultural resource management "must keep in mind that (1) cultural resources are primary sources of data regarding human interactions with environmental change; and (2) a changing climate affects the preservation and maintenance of cultural resources." This chapter provides an overview of the current state of the art for understanding the threats of climate change for cultural resources in the coastal zone (see phrase 2 above), and for integrating unique and significance aspects of cultural resources into adaptation in the coastal zone (see phrase 1 above).

Climate Change Threats to Cultural Resources in the Coastal Zone

Environmental forces have always affected cultural resources. Climate change, however, is accelerating, intensifying, recombining, and adding to these forces. Evidence of a wide range of climate change impacts on different types and forms of cultural resources are accumulating throughout different coastal environments of the National Park System. The potential and observed impacts of the many dimensions of climate change on the five categories of NPS cultural resources are outlined briefly in table 5.1 and table 5.2 (Rockman 2015; for more detailed descriptions, see Morgan et al. 2016 and Graphic 2 in the *NPS Cultural Resources Climate Change Strategy* [Rockman et al. in review]). This chapter focuses on the impacts of climate change specific to cultural resources in the coastal zone.

Table 5.1. Synthesis of diverse climate change impacts across the five categories of cultural resources (CR) managed by the National Park Service: archeological sites (AS), historic and prehistoric buildings and structures (B/S), cultural landscapes (CL), ethnographic resources (E), and museum collections (MC). Table from Rockman (2015).

Impact	Environmental Forces	CR Affected	Rate
Submersion	Sea Level Rise (SLR)	AS, B/S, CL, E	Trend
Erosion	SLR, Storm surges	AS, B/S, CL, E	Event, Trend
Inundation	Storm surges, Flooding	All	Event
Saturation	SLR (rising water tables)	1st: AS, B/S, CL, E 2nd: MC	Trend
Deterioration	Precipitation variation Temperature variation Wind variation	AS, B/S, CL, E AS, B/S, CL, E AS, B/S, CL, E	Trend/event Trend/event Event/trend
Dissolution	Temperature increase (permafrost) Ocean acidification	AS, B/S, CL, E AS (terrestrial, underwater)	Trend Trend
Destruction	Flooding Storm (rain/wind)	All All	Event Event
Oxidation	Increased atmospheric moisture	B/S	Trend
Depletion	Ecosystem changes due to human development	AS, B/S, CL, E	Event, Trend
Conflagration	Fire (Drought) (Temperature extremes +/- insect effects)	All	Event
Dessication	Temperature extremes Drought	AS, B/S, CL, E AS, B/S, CL, E	Event (trend?) Long event
Invasion	Invasive species Mold	AS, BS, CL, E, MC BS, MC	Trend Event
Disruption	Loss of species Loss of access Looting	E E AS	Trend/event Event/trend Event

Table 5.2. Climate change related impacts on cultural resources in the coastal zone. Excerpted from Morgan et al. (2016).

Climate Indicator	Climate Change Risk	Impact on Cultural Resource
Increased global temperature	• Extreme weather events • Permafrost melt • Increased freeze-thaw cycle • Higher relative humidity • Stronger wind patterns • Species shift	• Accelerated rusting in submerged and littoral archeological resources • More rapid decay of organic materials • Faster deterioration of newly exposed artifacts and sites • Increased rate of chemical decay of collections • Increased crystallization of efflorescent salts due to increased evaporation rates, leading to increased rates of structural cracking, deterioration • Damage to foundations • Reduced access to marine hunting grounds due to shifting sea ice • Changes in historic/ culturally significant vegetation patterns
Precipitation Change	• Saturated soils • Flooding • Drought	• Increased exposure from vegetation loss and erosion • Destabilization of wetland or waterlogged sites • Exposure of submerged sites due to lower water levels in lakes • Erosion of supporting ground around structure • Increased pressure to relocate or elevate structures and/or surrounding structures • Loss of landscape features • Damage to structures • Increased risk of post-flood subsidence • Impacts from post-flood mitigation
Sea level rise	• Inundation and flooding • Increased storm surge height • Increased coastal erosion • Higher water table • Salt water intrusion	• Submersion of coastal sites • Increased post-flood cracking due to associated ground heave and subsidence • Increased pressure to relocate or elevate structures • Loss of coastal sites and artifacts • Loss of culturally significant symbols, plants, and animals • Loss of or limited access to culturally important sites • Increased rusting, corrosion, and salt deposits

The changing climate will affect cultural resources in the coastal zone through discrete events such as hurricanes and through ongoing changes such as changing sea and lake levels (both vertical rise or fall and rate of change), ocean acidification, and water temperature change. The abilities of cultural resources to withstand these and other effects without substantial change are related to the condition of the specific resource. A well-protected resource such as a shipwreck with a healthy covering of seagrass, or a resource in good condition such as a recently painted wooden building, will be better able to withstand particular destructive pressures of climate change, and for a longer period of time.

Coastal impacts of climate change are, at times, dramatically visible, such as heightened storm surge impacts. Other impacts may be more subtle or may result from the intersection of several forces. For example, where sea ice is diminishing and permafrost is melting, coastal archeological and ethnographic resources are eroding, changing, deteriorating, and becoming harder to access. These resources may not be well documented, making assessment of resource significance and vulnerability and prioritization of management response difficult (see Schupp, Beavers, and Caffrey 2015, "Case Study 4: Cultural Resources Inventory and Vulnerability Assessment"). For other resources, increased temperatures and humidity are affecting buildings and structures as heat accelerates the rusting of iron, and swelling and fungal decay of wood.

PM 14-02 emphasizes adding to the understanding of the range and diversity of climate change impacts on cultural resources, and directs management priorities to resources that are both significant and most at risk, because human-caused stressors will exacerbate climate impacts. For example, deeper navigation channels and increased size and frequency of associated large vessel boat wake impacts will increase the vulnerability of coastal places such as Fort Sumter National Monument, Fort Caroline National Memorial, and the Cockspur Lighthouse at Fort Pulaski National Monument by accelerating erosion of the shorelines and exposure of their foundations to storms of increased magnitude (see figure 5.1 and Schupp, Beavers, and Caffrey 2015, "Case Study 7: Lighthouse Stabilization Design Incorporates Sea Level Rise").

Threats to Archeological Resources

Archeological resources are physical evidence of past human occupation or activity across the span of human existence. Archeological sites may be located anywhere there has been previous human occupation on the current ground surface or buried. The resources are incredibly diverse; examples include a small scatter of prehistoric stone or bone tools or historic metal cans, town sites, heiau (Hawaiian temples), fish ponds, road system complexes, shell middens, and buried evidence of coastal occupation.

Climate change threats to coastal archeological resources can take many forms, including erosion, inundation, and chemical alteration. Erosion can be exacerbated by changes in water supply, such as increases in rainfall overall or the intensity of individual rainfall events; by drought (see Schupp, Beavers, and Caffrey 2015, "Case Study 1: Reservoir Water Level Change Impacts on Cultural Resources"); and by additional stresses affecting shoreline sediments, such as loss of soil structure due to melting permafrost. Unless quickly covered with sediments, sites in the intertidal zone may lose stratigraphic integrity as a result of water level rise or may be subject to physical degradation resulting from wave impacts.

A vulnerability assessment for coastal archeological sites and traditional cultural properties at Point Reyes National Seashore (Newland 2013) provides detailed analyses of climate impacts across different ecosystems within a single park, such as ocean acidification effects on cliff areas, sea level rise in tidal marshes, and wildfire along cliff tops. This report also provides a list of questions developed by the culturally associated tribe (the Federated Indians of Graton Rancheria) to help guide development of policies to manage archeological and ethnographic resources that may be increasingly exposed to weathering and unauthorized collection when exposed by storms and erosion.

Threats to Cultural Landscapes

Cultural landscapes are geographic areas, including both cultural and natural resources and the wildlife or domestic animals therein, associated with a historic event, activity, or person or that exhibit other cultural or aesthetic values. Cultural landscapes may be historic sites, historic designed landscapes, historic vernacular landscapes, and ethnographic landscapes (Birnbaum 1994).

Climate-related impacts on coastal cultural landscapes include both ecosystem impacts and impacts on the built environment (when it is part of the landscape). Changing water levels may exacerbate erosion of cultural landscapes along a shoreline. Changes in temperature and precipitation patterns may stress building materials or favor different vegetation species or patterns of historic or culturally significant vegetation species. Climate change also may lead to the introduction of new pests, and may change soil fertility or water table level that affects gardens and other vegetation that are character-defining features.

For cultural landscapes, character-defining features are key foci for assessing impacts. Natural and cultural components of the landscape and the relationships between them convey different aspects of the significance of the landscape and will interact in different ways with climate change impacts.

Dyke Marsh, on the western shore of the tidal Potomac River south of Washington, DC, and part of the George Washington Memorial Parkway, is an example of a cultural landscape that will be affected by rising sea level. The marsh was formed over thousands of years from the sediment load discharged by upstream Hunting Creek. Portions of the then-650 acres were diked in the early 1800s for pasturage (Melnick, Burry-Trice, and Malinay in prep.). After abandonment of the area for grazing, shallow waters were dredged for sand and gravel. Rising sea level is affecting tidal heights in the Potomac estuary and is increasing wave impact on the south side of the marsh where a remnant dike is still visible, eroding that portion of the cultural landscape (Palinkas 2016).

Threats to Ethnographic Resources

Ethnographic resources are basic expressions of human culture and the basis for continuity of both tangible and intangible components of cultural systems, including traditional arts, native languages, religious beliefs, and subsistence activities (NPS 1998a). Ethnographic resources include tangible places such as sites, structures, and landscapes, as well as natural resources needed for cultural expression, such as salmon, sweet grass, or species of predatory birds.

Coastal climate change impacts to ethnographic resources damage tangible resources and/or disrupt or otherwise disconnect people from their arts, language, beliefs, and activities and associations with the places in which they have performed them. Impacts include permafrost melt, which can accelerate coastal erosion that in turn may force relocation of communities, separating people from subsistence resources. Changes in sea ice due to increased temperatures and changing winds may limit access to traditional hunting areas and are expected to shift migratory patterns of significant marine prey. Warming temperatures also may affect the distribution and phenology of key terrestrial and coastal plant and animal species.

Wild rice is an ethnographic resource used by the Bad River Band of the Lake Superior Tribe of Chippewa Indians that is being affected by climate change. The rice grows in ephemeral wetlands on the shore of Lake Superior in Apostle Island National Lakeshore. For centuries Anishinaabe people have harvested the rice for subsistence and trade. Climate change projections for the Great Lakes estimate that lake levels will continue to fall, depriving wetlands and the rice beds of the moisture needed to survive (Krumenaker 2014).

Threats to Historic and Prehistoric Buildings and Structures

A historic or prehistoric building or structure is "a constructed work . . . consciously created to serve some human activity" (NPS 1998b). They are usually immovable although some have been relocated and some are mobile by design. Examples include buildings and monuments, dams, millraces and canals, nautical vessels, bridges, tunnels and roads, railroad locomotives, rolling stock and track, stockades and fences, defensive works, temple mounds, ruins of all structural types, and outdoor sculptures. Preservation approaches for prehistoric structures are often similar to those for historic structures. Prehistoric structures also may be considered archeological resources, and some are ethnographic resources as well (NPS 1998a).

Climate change drivers interact variably with structural materials, architecture, and location (Sabbioni, Brimblecombe, and Cassar 2012). For example, increased rainfall may lead to accelerated rates of mortar and masonry decay, while associated ground heave and subsidence can lead to destabilization of foundations and pipes (Moss 2010; Morgan et al. 2016). Warmer, longer summers will enable new threats to wood structures as termites and other pests expand territory, and increased temperatures may increase growth of destructive mold and algae (Morgan et al. 2016).

Lighthouses and forts are iconic examples of coastal historic buildings. Facilities may include the lighthouse, the lighthouse keeper's residence, outbuildings, and docks, as well as cultural landscapes that can encompass gardens and walkways. All of these buildings and structures are impacted in different ways by dimensions of climate change depending on material composition and condition of structure. For examples of impacts and NPS adaptation strategies for Fort Jefferson and for the Cockspur and Cape Hatteras Lighthouses, see figures 5.1, 5.2, and 5.3, and Schupp, Beavers, and Caffrey (2015), "Case Study 5: Strategic Planning and Responsible Investments for Threatened Historic Structures," "Case Study 7: Lighthouse Stabilization Design Incorporates Sea Level Rise," and "Case Study 8: Relocating the Lighthouse."

Figure 5.2. Sea level rise and increased tropical storm intensity pose a serious risk to the long-term sustainability of historic Fort Jefferson at Dry Tortugas National Park, Florida. Photograph by Kelly Clark, NPS.

Figure 5.3. After multiple hard stabilization protection efforts proved unsuccessful, the Cape Hatteras lighthouse at Cape Hatteras National Seashore, North Carolina, was moved inland from the eroding beach using a railway in 1999. Photograph by NPS.

One historic district that is particularly vulnerable to maritime effects of climate change is Portsmouth Village, which is part of Cape Lookout National Seashore and is located on a barrier island (Melnick, Burry-Trice, and Malinay in prep.). The village was first established in the 1700s; extant historic buildings date to the 19th and early 20th century. As the barrier islands move westward in response to the complex interactions between sea level rise and ocean currents, the sea moves closer and closer to the village. Shifting of the low mobile sand dunes on which the village stands will impact the integrity of design, materials, and workmanship of any buildings that survive high winds and the direct impact of storm surges.

Threats to Museums and Collections

Museums will play increasingly important roles in future cultural resource preservation. The National Park Service is the steward of the largest network of museums in the United States and is responsible for the welfare of more than 44.5 million museum objects and 74,000 linear feet of archives (NPS Museum Management Program 2014). In addition to ongoing work to address backlogs in cataloguing and accessioning new collections (Wilson 2015), additional facilities and funds will be needed for monitoring and mitigation programs.

A review by the NPS Museum Management Program in 2014 found that 233 parks have museum facilities in high-risk flood zones (NPS Museum Management Program 2014), including facilities in the interior and along the coast. Other types of impacts can affect the museum facility building itself, such as through rising damp from changes in local ground water level and increased tree fall (Sonderman 2016). Additional impacts can affect collections, such as through loss of climate controls or exposure to new species of insect pests. Museums and collections are clearly vulnerable to floods and storm surges.

Impacts from hurricanes provide opportunities to implement adaptation strategies to meet the challenges of climate change. For example, in 2003, Hurricane Isabel (National Hurricane Center 2016) inundated the Colonial National Historical Park museum facility located in the basement of the visitor center within the flood zone of the James River. The water inundated the building to a height of 5 feet (1.5m) and damaged archeological collections and records from excavations at Jamestowne. Restoration of these collections and records took four years. In another example, Hurricane Sandy caused the loss of electrical power and mechanical systems in the Ellis Island museum collection. See "Chapter 9 Lessons Learned from Hurricane Sandy."

Threats to Underwater Resources

Consideration of cultural resources within coastal adaptation planning does not stop at the water's edge. Submerged cultural resources can comprise or contribute to archeological and ethnographic resources, cultural landscapes, and structures. Many coastal cultural resources managed by NPS units are littoral or submerged resources. Submerged historic structures, shipwrecks, submerged maritime landscapes, and other underwater cultural sites are equally as vulnerable as terrestrial sites to the effects of climate change, and perhaps are more vulnerable because they can be difficult to recognize and their threats can be easily overlooked (figure 5.4).

Figure 5.4. Dry Tortugas National Park protects submerged resources in south Florida. Photograph by NPS.

Submerged cultural resources can have different vulnerabilities than their terrestrial counterparts (Wright 2016). While inundation concerns may be diminished, mechanical damage from storm surge and changing wind and current patterns can scatter, disrupt, erode, or destroy submerged sites. The depth changes associated with sea level rise can affect the retreat of protective seagrass beds and corals, water chemistry changes associated with water depth, sediment coverage and mobility, and changes in anoxic environments conducive to preservation. Temperature rise and ocean acidification can destabilize wreck structures, increasing corrosion rates and weakening protection provided by adhering layers of calcium carbonate-based organisms.

One example of an underwater cultural resource at risk from climate change is the 100-year old steamboat *Charles H. Spencer*, which lies at the edge of the Colorado River at Glen Canyon National Recreation Area. Deficits in water supply for the entire Colorado River system have lowered the average volume of the river, exposing *Spencer*. While coastal threats from climate change are often framed in terms of sea level rise, decrease in water supply also can be destructive. Uncontrolled drying of waterlogged remains damages archeological materials, particularly wooden remains such as components of *Spencer*.

Important management steps to support adaptation strategies for submerged resources include inventory and monitoring plans. The Submerged Resources Center is available to assist parks with stewardship of submerged cultural sites. Additionally, for information on park boundaries and jurisdiction (which can be particularly challenging to determine in coastal areas), see NPS 39-1 Ocean and Coastal Jurisdiction Reference Manual.

Management of Cultural Resources in the Coastal Zone under Climate Change

NPS Policy Memorandum 16-01 "Resource Stewardship for the 21st Century – Interim Policy" (PM 16-01, NPS 2016) calls for integrating natural and cultural resources management, and for using the precautionary principle when making decisions related to resource stewardship; in the context of climate change, this means that the National Park Service must address climate adaptation as part of its cultural resources management strategy.

The NPS adaptation strategy for cultural resources recognizes that, because many cultural resources are nonliving and so have no or limited capacity to absorb climate change impacts, the focus for cultural resource adaptation should be flexible and responsive human management. The framework for adaptation for cultural resource management set out in PM 14-02 addresses what adaptation means for cultural resources management, how to approach decision-making for cultural resources in light of climate change, and the important role of cultural resources in climate change communication (NPS 2014a, 2014b, 2015; Morgan et al. 2016).

Specific topics developed in PM 14-02 include the following:

Adaptation

- Recognize that the primary focus for adaptation for cultural resources lies in research, planning, and stewardship activities.
- Integrate natural and cultural resources. Examples include addressing shared natural and cultural resource data needs in climate modeling and environmental monitoring, and incorporating relevant information into planning, such as Resource Stewardship Strategies.

- Use innovative actions to address emergent threats. For example, reallocate funds where appropriate when budgetary cycles do not accommodate the urgency of actions.
- Incorporate cultural resources into sustainability actions. For example, adaptively reuse historic buildings.
- Evaluate siting of museum facilities and collections, starting with a vulnerability study and a plan to improve stewardship of museum facilities and collections.

Decision Making

- Refocus inventory responsibilities onto lands that have not been investigated in areas that are most vulnerable to climate change impacts.
- Direct management decisions and funding to resources that are both significant and most at risk.
- Identify, develop means to address, and communicate to the public the range of climate change effects on cultural resources, including subtle and inland effects such as the impacts of more freeze/thaw cycles on stone walls.
- Consult a broad array of stakeholders to inform the assessment of resource significance.
- Value information from the past and incorporate the capacity of cultural resources to provide unique information about human adaptation to climatic and environmental variability through time into assessments of resource significance.
- Recognize the potential for loss in management options, work to balance sustainability with preservation, and coordinate decisions on management options servicewide.

Communication

Every place has a climate story. Cultural resources embody:

- climate change impacts at human scales that can be seen and touched;
- traditional ecological knowledge and changes in experience and lifeways;
- past human successes and failures of adaptation; and
- origins of modern climate situations.

In response to this directive, an assessment of the vulnerability of NPS museum facilities to climate change is being developed and will inform the upcoming servicewide revision of the collections storage plan (NPS Museum Management Program 2014).

Building on PM 14-02, the NPS Preserving Coastal Heritage workshop identified additional opportunities to improve the development of viable management alternatives for threatened coastal cultural resources (NPS 2014b):

- Engage interdisciplinary expertise.
- Establish short- and long-term goals before the inventory begins, and identify where goals may conflict. Revisit the goals throughout the planning process.
- Establish thresholds for monitoring and reassessment that allow change over time. Assume that new data and documentation will influence the planning process.
- Engage the public every step of the way.
- Establish vulnerability metrics so that resources can be evaluated and compared. Assess the risk of saving one resource at the expense of another.
- Update collections management plans to include an emergency plan that donors, owners, and the public can agree on in advance.
- Use the planning process as an opportunity to enhance public awareness about climate change.

Broad approaches and tools for addressing the impacts of climate change to cultural resources are being incorporated into the NPS *Cultural Resources Climate Change Strategy* (Rockman et al. in review). The following sections discuss some of these management approaches directed toward resources and impacts in the coastal zone.

Two-fold Approach to Cultural Resources and Climate Change

Management of cultural resources in the coastal zone must balance response to the effects of climate change on cultural resources with the significance that those resources hold for the communities that use and value them. The NPS *Cultural Resources Climate Change Strategy* (Rockman et al. in review) sets out a concept framework that applies these two areas of responsibility (i.e. "Impacts" and "Information") across the four pillars of NPS climate change response (NPS 2010): science, adaptation, mitigation, and communication (table 5.3). This concept framework is designed to support resource management decision-making across cultural and natural resources and facilities management by setting out the diversity of cultural resource impacts and information topics in relation to climate change, many of which overlap with natural resource, science, and facilities management topics.

Such overlap may be particularly useful in developing and selecting adaptation options, in which an option for a given resource is likely to have implications across multiple other resources.

While the cultural resources in the coastal zone can contribute generally to the topics in the Information columns, they have particular capacity to provide information in the areas of coastal science and coastal adaptation. For example, coastal archeological sites, cultural landscapes, and associated museum collections can hold paleoclimatic data, information about past fluctuations in shorelines, and evidence of past human and other plant and animal responses to those fluctuations. A recent report about Shackleford Banks, part of Cape Lookout National Seashore, used archeological sites to refine our understanding of the island's geomorphological evolution (Riggs, Ames, and Mallinson 2015). Traditional ecological knowledge can describe both long-term patterns in use and settlement in coastal environments and ways of matching human activity to those patterns. PM 16-01 specifically calls for an increase in our understanding and use of traditional ecological knowledge to strengthen stewardship of cultural and natural resources (NPS 2016).

Table 5.3. Concept framework for cultural resources in relation to climate change. This framework applies needs of resource managers to address the impacts of climate change on cultural resources (Impacts) and the capacity to learn about long-term human interactions with environmental and climatic change (Information) across the four pillars of NPS climate change response: science, adaptation, mitigation, and communication (NPS 2010). Table from Rockman et al. (in review).

Science		**Mitigation**	
Impacts	**Information**	**Impacts**	**Information**
• Climate science at cultural heritage-relevant scales • Cultural resource (CR) vulnerability assessments • CR inventory/monitoring techniques and protocols • Integrated CR databases-GIS • Preservation science • Documentation science	• Paleoclimate • Traditional ecological knowledge • Social climatic thresholds • Shifting baselines • Past land use and human impacts on environments • Paleogenetics	• Integration of historic buildings into energy efficiency plans • Resource conservation through historic or native landscapes • Reduce carbon footprint of CR management practices	• Past architectural and landscape techniques suited to local environments • Cultural heritage to conserve/reestablish sense of place and community stewardship
Adaptation		**Communication**	
Impacts	**Information**	**Impacts**	**Information**
• Scenario planning • Adaptation options • Decision frameworks • Disaster risk reduction/response connections • Policies and standards • Contexts/theme studies to support decision frameworks	• Past social adaptability per environmental change • Traditional ecological knowledge • Relating past adaptability to current issues, methods, and decisions	• Cultural resources climate change (CR-CC) literacy • Dialogue between impacts and information in all pillars • Links between CR-CC managers (local-international) • CR-CC links to public	Every Place has a Climate Story: • Change in material culture • Change in experience and lifeways • Insights on change from past societies • Origins of the modern climate situation

Vulnerability and Prioritization

As set out in "Chapter 1 Introduction," vulnerability is the degree to which a system is susceptible to adverse effects of climate change. Within natural resource management, vulnerability with respect to climate change is often expressed in the following formula:

> Vulnerability = Exposure + Sensitivity – Adaptive Capacity

As noted previously, cultural resources themselves are largely non-living and, as such, have limited or no capacity to adapt to changing conditions. As a result, climate change adaptation for cultural resources lies in our use and management of them. Further, adaptive use and management can draw from a wide range of options (see below). Therefore, for cultural resources, a variation of the vulnerability formula that separates adaptive capacity from exposure and sensitivity is more appropriate:

> Vulnerability = Exposure + Sensitivity

This same formula has been developed and adopted for park infrastructure and facilities, as discussed in "Chapter 6 Facility Management."

Building out these terms, "exposure," as a measure of the amount of climatic and environmental change that a geographic region or given resource is likely to experience, is an equivalent concept across resources. "Sensitivity" for cultural resources incorporates the adverse effects of climate change on the material components of a resource, and how those adverse effects may affect integrity and significance of the resource.

As noted above, exposure to essentially all climate change phenomena can occur in the coastal zone. Exposures specific to the coastal zone include sea level rise (causing inundation, increased severity of storm surges, and increased rates of erosion) and changes in water table (causing soil saturation, expansions of wetlands, and salt water intrusion). Sensitivity of cultural resources to these exposures is also diverse; several examples are listed for each resource type in the sections above, and detailed sensitivity lists are included in table 5.1 and in *Climate Change Impacts on Cultural Resources* (Morgan et al. 2016).

PM 14-02 states that management decisions and funding should be directed to resources that are both significant and most at risk. Currently, several projects are underway to assess vulnerability of cultural resources and to convey identified vulnerabilities in such a way that they can be readily displayed and compared. Projects include work in the Cultural Landscapes program (Melnick, Burry-Trice, and Malinay in prep.) to develop a vulnerability assessment system for all cultural landscapes in the Pacific West Region, and two projects addressing vulnerability of National Historic Landmarks (NHL). The NHL projects include a process and assessment of six NHLs in Alaska (Anderson 2014) and for NHLs across the Pacific West Region (Stein Espaniola in prep.). To date, a consistent method of merging vulnerability assessments with resource significance has not yet been developed. One potential model of doing so has been implemented by international colleagues in Scotland through the work of the Scottish Coastal Archaeology and the Problem of Erosion Trust (SCAPE) (see discussion below).

Cultural Resources Adaptation Strategies

Adaptation strategies should seek to preserve not just an object or structure itself but also the components of the resource that convey its significance. To be significant, a cultural resource must have important historical, cultural, scientific, or technological associations, and it must manifest those associations in its physical substance (NPS 2002). A character-defining feature of a historic property is a prominent or distinctive aspect, quality, or characteristic that contributes significantly to its physical character. Structures, objects, vegetation, spatial relationships, views, furnishings, decorative details, and materials may be such features (NPS 2002). For example, at Fort Jefferson at Dry Tortugas National Monument, the moat wall, which forms a distinctive ring around the main structure of the fort, is a character-defining feature. It was designed to keep enemy ships away from the fort walls and now functions as a breakwater (see figure 5.2, and Schupp, Beavers, and Caffrey 2015, "Case Study 5: Reconsidering Investment Strategies for Threatened Historic Structures"). All cultural resources have connection to place, and the integrity and significance of cultural resources may change as those places change. However, decisions to make such changes are difficult, such as raising the moat wall to improve its current function as a breakwater, which would alter its historic form and use.

Cultural resources adaptation options were presented and further developed during the [Preserving Coastal Heritage] workshop (NPS 2014a, also described in "Chapter 9 Lessons Learned from Hurricane Sandy"). The current set of adaptation options is described in table 5.4. The current draft of the cultural landscapes climate change adaptation report (Melnick, Burry-Trice, and Malinay in prep.) develops examples of these options specifically for cultural landscapes. These cultural resources adaptation management options roughly parallel natural resource management adaptation strategies (figure 5.5 and table 4.2). However, they do not fit easily within the adaptation continuum set out in "Chapter 1 Introduction": resist change, accommodate change, and direct change, which has its roots in natural resource adaptation. The objective of cultural resources management is the preservation of as much or as many cultural resources as possible; this objective aligns most closely with the concept of "resist change." Aspects of the "accommodate change" approach are also important because the aspects of cultural resources that anchor their significance are in large part non-living and non-renewable, so their adaptation depends on the selection and implementation of management actions by resource managers. Management actions for cultural resources range from no active intervention (when necessary) to active preservation measures. Different measures will be appropriate for different resources depending on the nature of the resource and the nature and severity of the observed or assessed risk from periodic and long-term climate change impacts (figure 5.6).

Each of these options can be used in combination with others. Status of the resources and actions taken should be documented throughout the process. The final option on the list, interpret the change, addresses not only preservation of the history of the resource, but also the interactions between climate change and the story of that place. The underlying premise of this option is that climate change is the heritage of the future. As with the other options, the interpret the change option may be used on its own or in combination with other actions.

Table 5.4. Seven Climate Change Adaptation Options for Cultural Resources. Table from Rockman et al. (in review).

Adaptation	Description
No active intervention	Taking no action is a decision. This may be an appropriate decision in situations of low vulnerability (no action warranted) or when, due to one or more of a range of constraints, including lack of technological or economic feasibility, no action can be taken. This decision may include assessment of the need for monitoring of resource condition, with a plan to revisit a no action decision at a future point in time.
Offset stress	Removing or deflecting a stress is one or more actions taken away from the resource or a component of the resource to reduce or remove the environmental or other force(s) acting on the resource or component. The goal of this option is to enhance survival of a resource while minimizing changes to the physical materials and setting of the resource. Constraints on this option are likely to include impacts of actions to surrounding resources, such as natural habitat or infrastructure. Examples include temporary measures such as sandbags or levee plugs; an offsite retaining structure or living shoreline to reduce shore erosion; upstream re-vegetation to reduce flood hazards; and changes in adjacent forest management to reduce wildfire risk.
Improve resilience	Improving resilience consists of one or more actions that change the nature of a resource and/or the immediate setting of a resource and that are designed to make a resource more resistant or resilient to environmental or other forces. The goal of this option is survival of the resource despite possible impacts of actions on integrity of the resource, although this option does not necessarily mean the resource will be impaired. Examples include treatment of structural materials to better withstand increased moisture, wind, or an invasive species; elevation of a building to raise it above projected flood level; addition of a cap over an archeological site; changes in landscape plantings or soil treatments; and alternate storage arrangement of museum materials.
Manage change	Managing change is an action or set of actions that incorporate change into the form of the resource and/or into its management plan. The goal of this option is to maintain character-defining features of a resource, even if original specific materials or individual species are no longer part of the resource. An example is changing tree species on cultural landscapes by removing the original species that has died and replacing it with a species that is healthy in that environment and will provide similar shade and foliage conditions.

Table 5.4. Continued

Adaptation	Description
Relocate/ facilitate movement	Relocating/facilitating movement includes two types of actions: (1) moving a resource, and (2) allowing movement to happen. The strategy of moving a resource is an action or set of actions that move all or a portion of a resource that cannot move on its own to a less vulnerable location. The iconic example of this option is the moving of the Cape Hatteras Lighthouse inland from the coast (see Schupp, Beavers, and Caffrey 2015, "Case Study 8: Relocating the Lighthouse"). Another example is temporary relocation of the museum collections from Ellis Island to a facility in Maryland following Hurricane Sandy (see "Chapter 9 Lessons Learned from Hurricane Sandy"). Assisting with relocation of a human community to a safer location and assisted migration of a culturally important species to a refugium that it would not have been able to reach on its own (for instance, moving salmon species to a new watershed) are also examples of this strategy. The strategy of allowing movement to happen is an action or a set of actions that enable movement of living portions of resources to less vulnerable or more stable locations, or halting actions that would otherwise impede movement of living portions of resources to less vulnerable or more stable locations. Examples include allowing ecosystems such as a marsh or barrier island with cultural significance or which contains culturally significant species to migrate landward, or allowing species with cultural significance to shift ranges. Such shifts may move all or components of a resource outside of documented resource or park boundaries. Movement is not feasible for a whole cultural landscape but may be appropriate for character-defining features of a landscape once the whole cannot be saved.
Document and release	This strategy is a set of actions to record a resource and then subsequently allow the geographic location of the resource to undergo full effects of environmental or other forces that are likely to destroy or remove all or portions of the resource. Documentation may be exhaustive, such as data recovery (full excavation) of an archeological site or detailed recording of a building or structure or cultural landscape (such as a Historic American Building Survey [HABS], Historic American Engineering Record [HAER], Historic American Landscape Survey [HALS]), or a cultural landscape inventory, possibly in combination with laser scanning documentation techniques. Documentation may also be done at a less-than exhaustive level. This approach may be appropriate when exhaustive approaches are infeasible (due to limitations in access, time, human capacity, or financial constraints), not warranted (due to nature and scale of impacts), or there is merit in not recovering or preserving the whole of the resource (such as an archeological site that may become inaccessible because of submersion but is not anticipated to be fully destroyed). This option further differs from the data recovery option in that it requires consideration and documentation of the resource sampling and preservation approach. Other examples of documentation techniques that may be used in either approach include collection of pollen, seeds, or plant cuttings, and oral histories and video.
Interpret the change	Interpreting the change is an action or set of actions that preserves and then serves to engage people in the future with the effects of climate change on a resource. This option may be used on its own or in combination with any of the other options. A dramatic example would be preservation of a coastal resource such that its location and form remain either intact or otherwise visible from the coast once it is offshore or partially submerged (e.g., construction of a cover or large buoy at the former location of a lighthouse or archeological site). Other examples include interpretation signage of changing ecosystems and photo series of changes in garden phenology or vegetation across a landscape. While interpretation may be developed across any of the adaptation options on this list, for this option, interpretation addresses not only preservation and history of the resource, but also climate change itself, and seeks to tell the story of the place and climate change and how they are interacting.

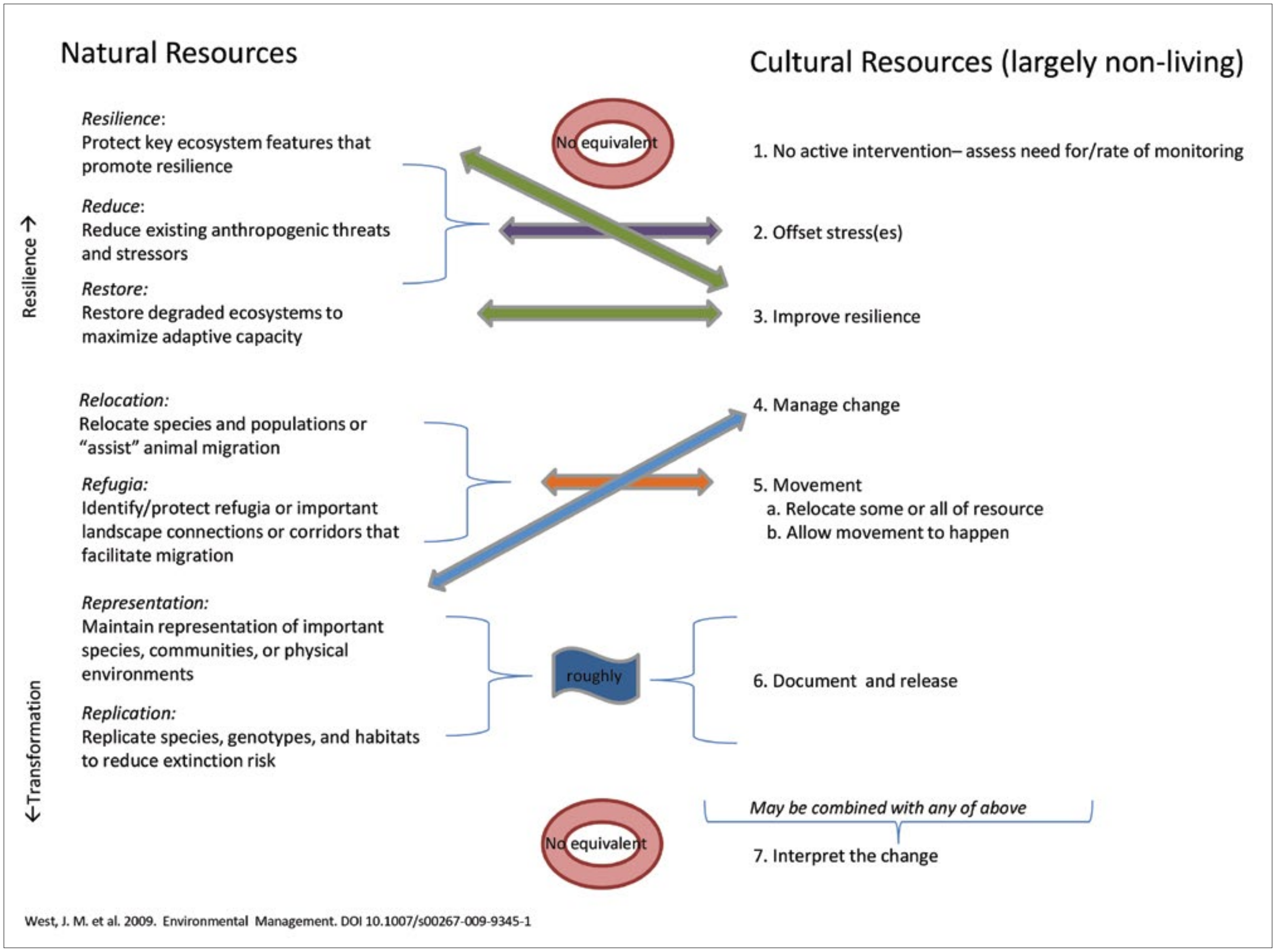

Figure 5.5. Cultural Resources Adaptation Strategies Parallel Management Strategies Used in Natural Resource Management. Graphic by M. Rockman, NPS.

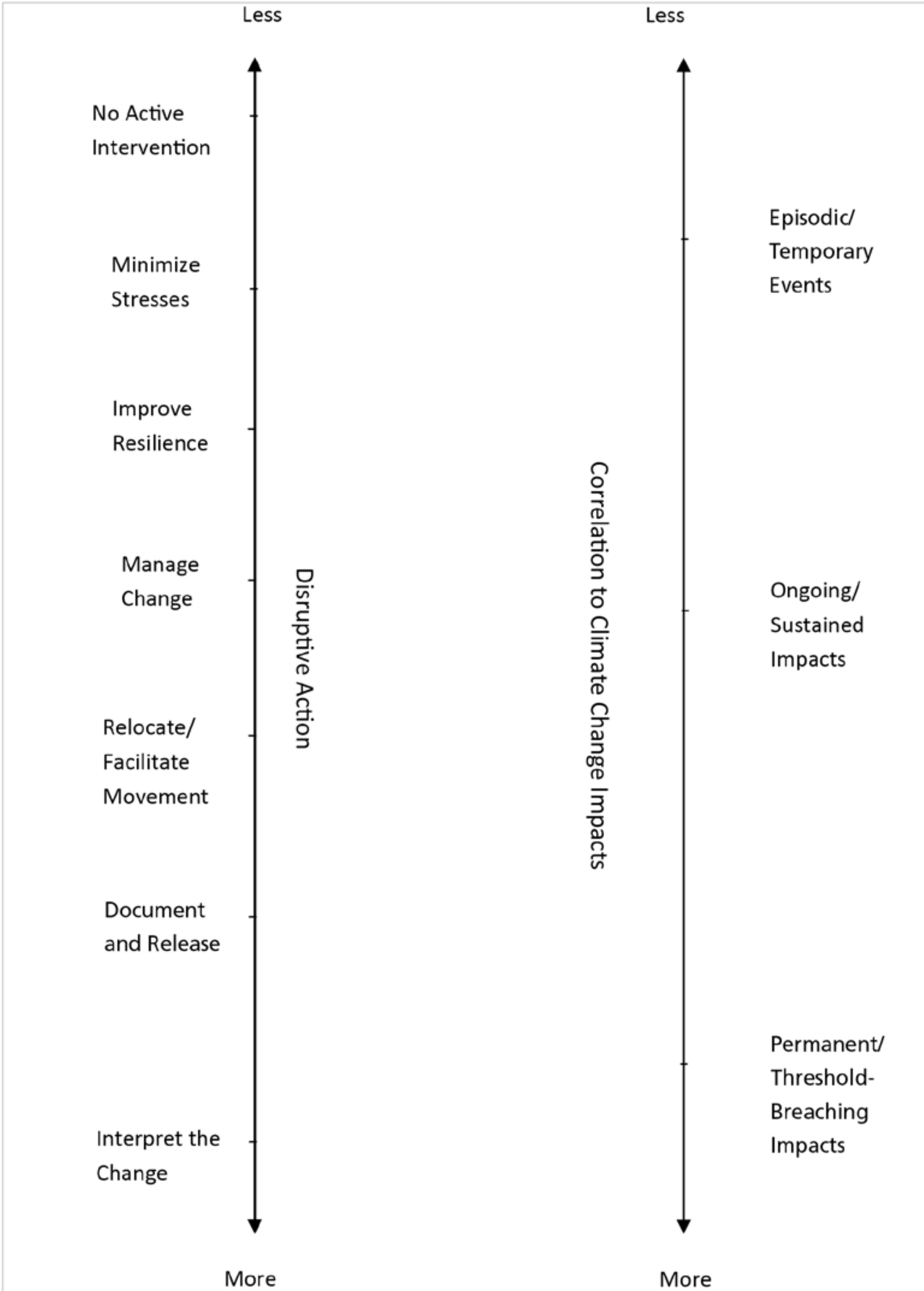

Figure 5.6. Cultural Resources Adaptation Strategies vary with Respect to the Disruptive Nature of each Strategy and the Temporal Nature of each Climate Change Impact. Graphic by M. Morgan, NPS.

Any work done on cultural landscapes, historic properties, or historic structures must consider The Secretary of the Interior's Standards for the Treatment of Historic Properties (36 CFR 68). The standards are a series of concepts about maintaining, repairing, and replacing historic materials, as well as designing new additions or making alterations. They are written in nontechnical language to promote historic preservation best practices. The standards offer four distinct approaches to the treatment of historic properties: preservation, rehabilitation, restoration, and reconstruction, with guidelines for each. The guidelines, which are advisory rather than regulatory, offer general design and technical recommendations on applying the standards to a specific property. Together, they provide a framework and guidance for decision-making about work on or changes to a historic property. The choice of treatment of historic properties depends on a variety of factors, including the property's historical significance, physical condition, proposed use, intended interpretation, and mandated code requirements. Together with Section 106 of the National Historic Preservation Act of 1966 (Public Law 102-575), "Protection of Historic Properties" (36 CFR 800), these documents guide the National Park Service in planning and executing actions to minimize harm to cultural resources. More information is available on the NPS cultural resource management website at http://www.nps.gov/history/howto/PAToolkit/parkcrm.htm.

When choosing an adaptation option, managers must recognize that addressing vulnerability may change the resource and therefore may be considered an adverse impact. Implementing an adaptation strategy that causes an adverse impact on natural resources or other cultural resources may be feasible and may be the best option in some cases. There are a variety of resources to help managers ensure that adaptation strategies align with NPS policies; checklists and guidelines are described in "Chapter 2 Policy."

Guidance for developing and selecting adaptation actions in national parks is currently in development, including *Planning for a Changing Climate* (in progress) (see "Chapter 3 Planning" for additional information). At the Preserving Coastal Heritage workshop it was determined that more guidance is needed to integrate climate change into existing cultural resource planning processes. An integrating framework for cultural resources and climate change that addresses inventory, significance assessment, and prioritization will be included in the NPS *Cultural Resources Climate Change Strategy* (Rockman et al. in review).

In-progress or completed adaptation projects for coastal cultural resources are discussed in the following sections.

Archeology

At Canaveral National Seashore in Florida, impacts from sea level rise and increased storm activities are predicted to accelerate erosion and cause the loss of shell mounds and the archeological and ecological data within them (see figure 5.7, and Schupp, Beavers, and Caffrey 2015, "Case Study 3: Shell Mound Sites Threatened by Sea Level Rise and Erosion"). The park is reducing shoreline erosion by planting vegetation and deploying oyster shell as recruitment substrate (Walters et al. 2013).

Parks are also addressing diverse impacts with a variety of solutions that are highlighted in Schupp, Beavers, and Caffrey (2015):

- Amistad National Recreation Area in Texas (see figure 5.8, and "Case Study 1: Reservoir Water Level Change Impacts on Cultural Resources"),
- Olympic National Park in Washington (see "Case Study 2: Preparing for Impacts to Archeological Sites and Traditional Resources"), and
- Bering Land Bridge National Preserve and Cape Krusenstern National Monument in Alaska (see "Case Study 4: Cultural Resources Inventory and Vulnerability Assessment").

Other organizations have also initiated inventory efforts in recognition of climate vulnerabilities, including the Society for California Archaeology, which has developed a standard methodology for use by volunteers to survey the condition of known archeological sites (Newland 2014).

Figure 5.7. Prehistoric shell mound sites are threatened by sea level rise and erosion at Canaveral National Seashore, Florida. In this image, volunteers are building a living shoreline at Castle Windy mound site. Photograph by Margo Schwadron, NPS.

Figure 5.8. At Amistad National Recreation Area, Texas, Panther Cave contains extensive pictographs, which are threatened by fluctuating water level tied to storm events and (indirectly) to siltation. Photograph by Randy Rosales, Texas Parks and Wildlife Department.

Cultural Landscapes

A cultural landscapes climate change adaptation project is developing a series of 12 case studies, including multiple coastal examples. The current draft report, *Climate Change and Cultural Landscapes: Research, Planning, and Stewardship* (Melnick, Burry-Trice, and Malinay in prep.) includes three coastal parks in the eastern United States: Portsmouth Village at Cape Lookout National Seashore, Dyke Marsh at George Washington Memorial Parkway, and Jacob Riis Park at Gateway National Recreation Area. Additional case studies being developed about the Pacific West include coastal cultural landscapes in Redwood National Park and Pu'ukoholā Heiau National Historic Site. This project and its reports are linking climate projections to impacts on character-defining features and potential adaptation actions. To address deterioration and inundation impacts on Portsmouth Village, for example, the current draft report explores three of the adaptation options described in table 5.4: No Active Intervention, Manage Change, and Document and Release.

Ethnographic Resources

Olympic National Park is working with eight associated tribes to prepare for future effects on archeological sites, traditional burial locations, and nearshore traditional resources; the park also recognizes the need to incorporate traditional knowledge into management efforts and to recognize that people have traditions that document major events (see Schupp, Beavers, and Caffrey 2015, "Case Study 2: Preparing for Impacts to Archeological Sites and Traditional Resources"). In southern Louisiana, the US Department of Housing and Urban Development (HUD) has awarded $48 million in the National Disaster Resilience Competition to move an entire community. The Isle de Jean Charles Band of Biloxi-Chitimacha-Choctaw Indians will relocate from their subsiding island, which is 55 km (34 mi) southwest of Jean Lafitte National Park and Preserve, to "a resilient and historically-contextual community" (Louisiana Disaster Recovery Unit 2016; US HUD 2016).

Museums and Collections

In direct response to PM 14-02, the NPS Museum Management Program assessed its facilities' vulnerability to climate change (NPS Museum Management Program 2014). Currently, 331 NPS units have museum facilities, and more than 60% of these have identified mitigation actions needed to reduce their risks related to climate change. Many parks have some existing background risk and also face new and future risks due to climate change. Seventy percent of these units have reported flood risks, 38% have drought risks, and other units face additional climate-related risks related to wind, permafrost, biology, and heating, ventilation, and cooling systems (NPS Museum Management Program 2014). For examples of post-storm care of impacted collections, see "Chapter 9 Lessons Learned from Hurricane Sandy."

Buildings and Structures

Parks are using various strategies to protect historical structures, as described in the following, companion case studies (Schupp, Beavers, and Caffrey 2015):

- Revetments at Fort Pulaski National Monument (figure 5.1, "Case Study 7: Lighthouse Stabilization Design Incorporates Sea Level Rise");
- Relocation at Cape Hatteras National Seashore (figure 5.3, "Case Study 8: Relocating the Lighthouse");
- Restoration at Dry Tortugas National Park (figure 5.2, "Case Study 5: Reconsidering Investment Strategies for Threatened Historic Structures");
- Identifying options at Yellowstone National Park (figure 5.9, "Case Study 6: Eroding Shoreline Threatens Historic Peale Island Cabin"); and
- Rehabilitation at Acadia National Park ("Case Study 15: Rehabilitating Stream Crossings on Historic Roads").

Figure 5.9. Coastal impacts affect inland lakes as well as ocean shorelines. The historic Peale Island Cabin in Yellowstone National Park, Wyoming, is threatened by shoreline change that may be accelerated by tectonic uplift, tree death, and longer ice-free periods. Photograph by Yellowstone National Park.

Underwater Resources

To date, there are few documented examples of climate change adaptation undertaken for underwater resources. One example is recent research and stabilization of HMS *Fowey*. *Fowey* is an 18th century shipwreck in Biscayne National Park that has been damaged in recent years by looting, Hurricane Andrew, and Hurricane Sandy. Studies of sediments surrounding *Fowey* have established baseline information important for developing stabilization methods for the wreck and understanding sediment mobility at the site (Keller et al. 2014, Wright 2016).

Opportunities for Adaptation of Cultural Resources in the Coastal Zone

Because cultural resources in the coastal zone are increasingly vulnerable with little chance of condition improvement and high potential for permanent loss due to storm impacts and other climate change impacts, the following opportunities should be prioritized:

- Conduct inventory in the most vulnerable areas that have not yet been inventoried.
- Determine significance and vulnerability of known resources to determine the most significant at-risk resources.
- Prioritize documentation of the most vulnerable undocumented resources.
- Assess the vulnerability of museum collection locations and create a plan to reduce vulnerability, such as through modifications to a curation facility or by moving collections to less vulnerable locations.
- Recognize cultural resources as opportunities to learn and engage with the information and stories they hold.

In Scotland, the Scottish Coastal Archaeology and the Problem of Erosion (SCAPE) Trust has developed a citizen science approach to vulnerable coastal heritage (SCAPE Trust 2015). The program began with detailed analysis of site records and prioritization based on site vulnerability and significance. These results are now displayed in a mobile application through which individuals can monitor sites and contribute observations. The program has also added a community engagement initiative that enables collective decision making and community projects for heritage that cannot be saved. The philosophy of this project is that "eroding coastal heritage provides opportunities for anyone to enjoy and benefit from taking part in archeological and historical exploration and discovery."

The concepts shown under the “Information” columns in table 5.3 share this hope. Cultural resources can contribute to climate science through topics such as paleo-environmental and shifting baseline information; to adaptation planning through examples of resilience and social change; to mitigation through reuse of historic buildings and examples they provide of lower-energy practices; and to communication through interpretation of all of these considerations and stories developed under the “Every Place has a Climate Story” framework (Rockman 2015).

Take Home Messages

- Cultural resources are unique and nonrenewable resources.
- The capacity of cultural resources to move or change is limited because they are in large part non-living and have strong ties to place, part of which can be ties to a dynamic coastal landscape.
- Cultural resource adaptation strategies can be applied to coastal systems.
- Managers need NPS-level guidance for adaptation of archeological and ethnographic resources to climate change. Upcoming reports and guidance for museum collections, cultural landscapes, and built environments will include coastal-relevant adaptation strategies.

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Chapter 6 Facility Management

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Introduction

Over the next century, warming global temperatures will present many challenges for the National Park Service and public land managers. Rising sea level will be one of the most obvious and most challenging impacts of this warming. Even a minor increase in sea level will have significa t effects on coastal hazards, natural resources, cultural resources, and assets within national parks (figu e 6.1). While sea level change and storm impacts are likely to occur in the future in most coastal parks, the timing of those impacts is not well-defi ed. However, it is certain that over time, facilities that are iconic and irreplaceable cultural resources and key roads and bridges that provide access will be lost. Park managers should approach development in areas vulnerable to climate change and/or other natural hazards conservatively, understanding that current estimates of changes and impacts may well underestimate future risk. This chapter describes the regulatory, program, and technical framework that the National Park Service will use to respond to climate change impacts to facilities in coastal parks. Updated resources can be found at https://www.nps.gov/subjects/climatechange/coastalhandbook.htm.

Figure 6.1. Built facilities, also known as assets, including roads, parking lots, and buildings, such as these pictured before and after Hurricane Sandy at Sandy Hook unit of Gateway National Recreation Area in New Jersey, are vulnerable to rising water level. In the post Sandy image, sand covered the parking lots.

Guiding Policies, Regulations and Plans

There are a number of governmental guiding policies, regulations, and plans that require the National Park Service to address the impacts of climate change on assets, including the president's Executive Order (EO) 13653 Preparing the United States for the Impacts of Climate Change (2013) and EO 13690 on Federal Flood Risk Management (2015). Additionally, the Council on Environmental Quality's Guiding Principles for Sustainable Federal Buildings and Associated Instructions was updated in 2016 and is required by EO 13693 *Planning for Federal Sustainability in the Next Decade* (2015). EO 13693 requires federal agencies to assess impacts from climate change in designing new facilities and modernizing existing facilities.

From the Department of the Interior (DOI), the Climate Change Adaptation Plan (DOI 2014) incorporates "Guiding Principles," which requires the National Park Service to consider climate change impacts on infrastructure and equipment. Lastly, the National Park Service (NPS) Climate Action Plan (2012a) and Green Parks Plan (2012b) both have climate change adaptation as key emphasis areas and require the agency to evaluate parks for vulnerability to climate change stressors and to develop guidance for adapting these vulnerable structures.

Executive Order 13690 – Federal Flood Risk Management

Impacts like rising sea level, intensified torms, and heavy downpours are contributing to an increased risk of floodi g. In January 2015, the president signed EO 13690, establishing a flood tandard that will reduce the risk and cost of future flood disa ters by requiring all federal investments in and affecting flood lains to meet higher floo -risk standards. These standards are higher than the 1% annual chance (100-year) flood le el. By requiring that federally funded buildings, roads, and other infrastructure are constructed to better withstand the impacts of floodi g, the new standard will help ensure federal projects last as long as intended. Implementation guidance will be forthcoming from the National Park Service and will build upon Reference Manual (RM) 77-2.

EO 13690 modified he flood esilience standard that had been required by EO 11988 since 1977 for federally funded structures and facilities. Another requirement is that federal agencies shall use, where possible, natural systems, ecosystem processes, and nature-based approaches in federal actions and alternatives. This policy change is highly supportive of NPS Management Policies (2006) that promote preservation of natural resources and use of natural approaches.

In 2013, the Hurricane Sandy Rebuilding Task Force adopted a higher flood tandard for the Hurricane Sandy affected region to ensure that federally funded buildings, roads, and other projects were rebuilt to reduce vulnerability to future storms (see “Chapter 9 Lessons Learned from Hurricane Sandy”). While the new Federal Flood Risk Management Standard (FFRMS) gives agencies the flexi ility to select one of three approaches for establishing the flood levation and hazard area they use in siting, design, and construction, the Climate-Informed Science Approach (fir t option) is preferred where data are available:

1. Use data and methods informed by best-available, actionable climate science.
2. Build 2 ft (0.6 m) above the 100-year (1%-annual-chance) flood levation for standard projects, and 3 ft (0.9 m) above for critical buildings like hospitals and evacuation centers.
3. Build to the 500-year (0.2%-annual-chance) flood levation.

Note that the return periods determining the 1% annual-chance and 0.2% annual-chance flood zo es are based on historical flood ri ks; exceeding this elevation is intended to account for potential increases where best-available, actionable climate science is not currently available.

Executive Order 13653 – Preparing the United States for the Impacts of Climate Change

In support of EO 13653 and in preparation for the impacts of climate change, the National Park Service needs to develop plans that integrate consideration of climate change into agency operations and overall mission objectives, including:

- identificat on and assessment of climate change related impacts on and risks to the agency’s ability to accomplish its missions, operations, and programs;
- a description of how any identified cli ate change related risk impairs NPS statutory mission or operation;
- a description of how the National Park Service will improve resilience, including capital equipment purchases such as updating agency policies for leasing, building upgrades, relocation of existing facilities and equipment, and construction of new facilities; and
- a description of how the National Park Service will contribute to coordinated interagency efforts to support climate preparedness and resilience at all levels of government, including collaborative work across agencies.

The National Park Service is developing a number of policy and program initiatives to meet the mandates found above and assess, plan for, and implement projects that enhance climate preparedness and resilience. Additionally, the National Park Service has developed a Facilities Adaptation Roadmap that will guide its response to climate change.

NPS Policy Memorandum 15-01

In response to federal mandates, the National Park Service issued Policy Memorandum (PM) 15-01 (NPS 2015). This provides guidance on the design of facilities to incorporate impacts of climate change adaptation and natural hazards when making decisions in national parks. It is the third "policy pillar" of the NPS climate change response (table 2.1). It complements PM 12-02, "Applying NPS Management Policies in the Context of Climate Change" (NPS 2012c) and PM 14-02 "Climate Change and Stewardship of Cultural Resources" (NPS 2014a). PM 15-01 (NPS 2015) states:

> *"Facilities play a critical role in the mission of the Service: they house our employees, protect and store equipment and materials, demonstrate sustainable design to our visitors, provide context for periods significant to our history, and connect the Service with the public. The Service has the responsibility to invest wisely in these facilities for the long term. Unquestionably, climate change and natural hazards pose a significant threat to our investment in current and future NPS facilities."*

> *"This Policy Memorandum, in conjunction with the Level 3 guidance, Addressing Climate Change and Natural Hazards Handbook, will help park personnel in planning and designing facilities that are responsive to the existing and projected climate change and other natural hazards. Managers must apply the guidance in the Handbook. The Associate Director for Park Planning, Facilities and Lands has the authority to update the Handbook periodically as necessary."*

The Level 3 Handbook (*NPS internal access only*) that accompanies PM 15-01 (NPS 2015) "will help provide information and context so that park decision-making appropriately addresses risks associated with natural hazards and climate change. It will ensure that the National Park Service reduces those risks to facilities and fulfills ts mission to conserve natural and cultural resources established by Congress in the Organic Act of 1916." The Handbook and Natural Hazards Checklist are designed to support parks in planning and designing facilities that evaluate and respond to existing and projected climate change impacts and natural hazards.

Specific azard Assessments include answering direct questions designed to guide decision makers through the range of alternatives that project teams could employ to maximize resiliency against certain risks. For example, coastal floodi g can be a significa t risk to park assets and functions, and climate change potentially amplifies his risk. To plan/design for a floodi g risk, decision makers need resources to quantify the hazard now (baseline) and for the future, including resilient/adaptable construction alternatives (figu e 6.2). One strategy is to elevate a building above the expected height of sea level rise and wave effects (figu e 6.3). This strategy was used at Flamingo for visitor use facilities in Everglades National Park (see Schupp, Beavers, and Caff ey 2015, "Case Study 18: Developing Sustainable Visitor Facilities").

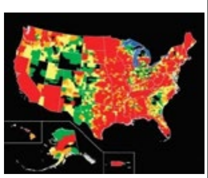
Potential Natural Hazard	Risk or Secondary Hazard	Sources of General Non-Site Specific Data	Sources for Site Specific Data	Best Professional Judgment
Coastal Storm Surge	• Rising Sea Levels • Rising Water – Wind Driven (i.e. hurricane, nor'easter)		• FEMA Map Service Center • NPS Technical Support	Potential Hazard ☐ Not applicable ☐
Tsunami	• Coastal area inundation associated with earthquakes or undersea landslides.		• State Tsunami Inundation Mapping e.g. OR Tsunami Clearinghouse • National Tsunami Watch Center	Potential Hazard ☐ Not applicable ☐

Figure 6.2. Excerpt from NPS Natural Hazards Checklist.

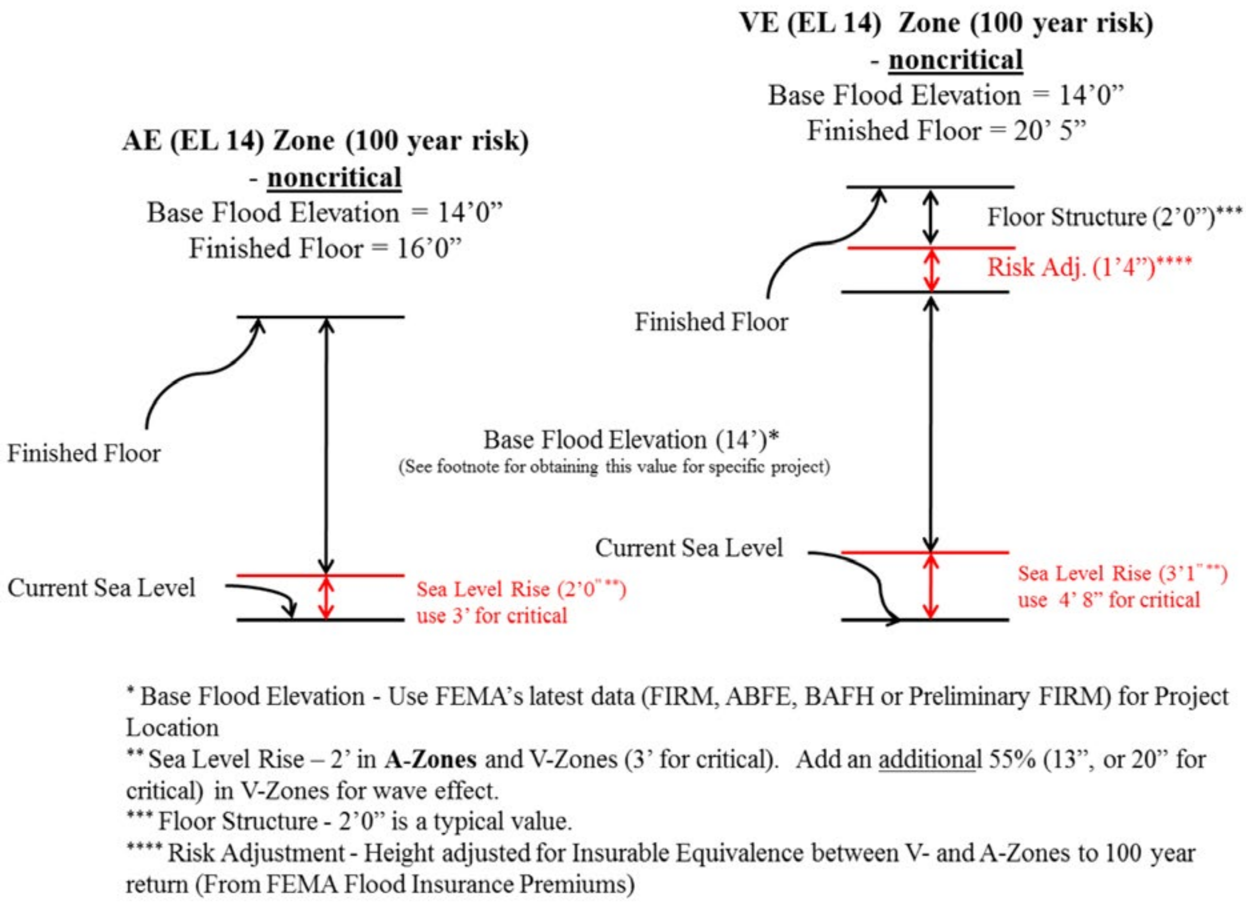


Figure 6.3. Illustration of flood zones relative to floor elevations. The illustration provides a process used to develop the finished floor elevation for projects within the floodplain for the case where the BFE is 14'. It incorporates adjustments to the finished floor elevation for both the A-Zone and the V-Zone. These adjustments account for sea level rise (A and V-Zones), and wave effects of sea level rise, floor structure depth, and insurance risk adjustment (V-Zone only). These adjustments will vary based on location and must be consistent with the requirements of EO 13960. Figure from NPS (2015).

Road Map for Planning for Climate Change Resilience and Sustainability of NPS Assets

The NPS Facilities Management community is working to implement an overarching process or "Road Map" to respond to the challenges of climate change and its impact on park facilities and assets. The Road Map will be used to guide the high level program actions that need to occur to meet both federal mandates and comprehensively track agency actions. The process will require all NPS stakeholder groups to collaborate on a wide-ranging set of actions across multiple components. Each of these Road Map components will have a series of milestones associated with them that will allow for a successful implementation of the Road Map.

The Road Map components are as follows:

- Policy/Guidance – Establish all necessary policies to focus investment in climate change facility adaptation. This may involve general management plans, risk management for facilities management, and cultural resources. Implement PM 15-01.
- Business Standards/Practices – Establish the framework for decision making. This may involve data elevation protocols (box 6.1) and the coastal hazards and climate change asset vulnerability assessment protocol. Apply *Addressing Climate Change and Natural Hazards for Facilities Handbook*.
- Stakeholder Engagement/Communication – Develop a process to involve and communicate with all stakeholders. Create communication materials and host stakeholder forums.

- Data Integration and Management – Develop systems for managing and storing integrated data. Identify systems of records, standardize data sources and protocols, and implement enterprise solutions. Identify key assets using flood apping.
- Park Adaptation/Resiliency Management – Conduct vulnerability screenings and assessments and incorporate climate change adaptation in plans.
- Project Funding/Prioritization – Develop regional prioritization process and criteria for funding projects. Identify funding sources.
- Reporting and Evaluation – Monitor and evaluate performance of Road Map and projects. Track projects. Complete mandatory reporting.

Table 6.1. Overarching Climate Change Facility Adaptation Planning Framework

Step	Status	Planning
Step 1: Climate Change Adaptation Scoping (Business Standards/Practices; Data Integration & Management)	The Sustainable Operations and Climate Change (SOCC) Branch and the CCRP completed an inventory and assessment of parks vulnerable to 3.3 ft (1 m) of sea level rise. Top 100 parks identified.	SOCC and CCRP review other climate impact areas and identify affected parks.
Step 2: Vulnerability Assessments (Business Standards/Practices; Park Adaptation/ Resiliency Management)	SOCC is developing and piloting a vulnerability assessment protocol for park assets (structures and transportation) focused on sea level rise, storm surge, and coastal erosion.	SOCC, CCRP, and DOI to review the need for building out the protocol to address other climate stressors.
Step 3: Plan for Resilience and Sustainability in Capital Investments and Operations (Policy/Guidance; Project Funding/ Prioritization)	SOCC will pilot a climate change resiliency planning approach for sea level rise, storm surge, and coastal erosion during upcoming Climate Friendly Park workshops, webinars, and other training programs including collaborating with the Integrated Park Investment program.	SOCC to provide planning support to parks to address other climate impact areas through future Climate Friendly Park workshops, webinars, and other training programs.
Step 4: Implement and Monitor (Project funding/Prioritization; Reporting & Evaluation)	Parks, regions, and headquarters to assist with implementation and monitoring of project implementation as it relates to coastal hazards.	Parks, regions, and headquarters to assist with implementation and monitoring of other climate stressors.
Step 5: Communicate and Educate (Stakeholder engagement /Communication)	SOCC will prepare general communication materials (focused on sea level rise, storm surge, and coastal erosion) for parks to modify that communicate risks and adaptive strategies to park staff, visitors, and gateway communities.	SOCC will prepare general communication materials on other climate impact areas for parks to modify to communicate risks and adaptive strategies to park staff, visitors, and gateway communities.

In addition to the Facilities Management Climate Change Roadmap, the facilities management community has identified an verarching Climate Change Facility Adaptation Planning and Implementation Framework that will be used to guide NPS response to climate change in coastal parks. This process, which includes the key steps in planning for climate change impacts at facilities in coastal parks, is summarized in table 6.1. Additionally, we have developed a *Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol*, which is described below.

Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol

The Sustainable Operations and Climate Change Branch (SOCC) of the Park Facility Management Division (PFMD) is providing various levels of support to parks to assist them in planning for park adaptation, including evaluating park assets for climate change vulnerability, assisting in the development of adaptation options, and training park staff on this topic. The National Park Service has partnered with the Program for the Study of Developed Shorelines (PSDS) at Western Carolina University (WCU) to create a C*oastal*

Hazards and Climate Change Asset Vulnerability Assessment Protocol. This protocol (NPS 2016) establishes a standard methodology and set of best practices for conducting vulnerability assessments in the built environment. Standardizing the methodologies and data used in these assessments allows managers to compare the vulnerability of coastal park assets across local, regional, and national levels. Additionally, the fi dings from these assessments can then be integrated into future decision-making and planning efforts (e.g., Choosing By Advantages [CBA]).

The assessments are currently focused on assets at risk to coastal hazards and sea level rise within coastal parks. Coastal vulnerability was chosen as a starting point in the development of vulnerability assessments because of digital data availability and a good understanding of the trends in the major climate stressors (e.g., sea level). Ultimately, the general methodology can be applied to additional natural hazards and climate stressors in non-coastal parks, as long as georeferenced hazard data exist or can be mapped.

A proposed standardized approach to assessing climate change vulnerability was described in a multiple agency – National Oceanic and Atmospheric Administration (NOAA), National Park Service, United States Geological Survey (USGS), Department of Defense (DOD), National Wildlife Federation (NWF), and United States Forest Service (USFS) – document titled "Scanning the Conservation Horizon: A Guide to Climate Change Vulnerability Assessment" (Glick, Stein, and Edelson 2011). This document defi es 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 the Glick, Stein, and Edelson (2011) approach is composed of three equally weighted metrics or components: exposure, sensitivity, and adaptive capacity. However, for this infrastructure-specific rotocol, vulnerability is comprised of only the fir t two metrics: Exposure and Sensitivity.

The adaptive capacity of an asset is evaluated separately and is not included in the vulnerability score. Note that this is different than how vulnerability is defi ed in "Chapter 3 Planning," "Chapter 4 Natural Resources," and the Glossary. This does not mean that understanding the adaptive capacity of an asset is not important. The range of adaptation strategies or options available for key vulnerable assets within a national park is the fi al and perhaps most important step in the overall analysis because any adaptation actions taken for an asset will help reduce its exposure or sensitivity, and, in turn, its vulnerability.

Vulnerability =
Exposure + Sensitivity

- ✓ **Exposure**—magnitude of change in climate and other stressors that a resource, asset, or process has already or may experience in the future.
- ✓ **Sensitivity**—degree to which a resource, asset, or process is or could be affected, either adversely or beneficially, by climate variability or change.

One of the primary goals of this protocol is to standardize methods for evaluating the exposure of NPS assets to coastal hazards and climate change. This includes the standardization of data inputs (i.e., widely available, established data) that will allow the application of a consistent methodology among units. Another goal is to create a complete and effective set of factors or indicators for assessing the sensitivity of assets to coastal hazards. The current focus for this methodology is on structures and transportation assets within the NPS asset database (Facilities Management Software System [FMSS]); however, other resources will likely be included in future work.

The protocol will benefit y having significa tly more high accuracy building elevation data (see "Chapter 4 Natural Resources" for a discussion on accuracy of elevation data). The National Park Service has begun a process for collecting building elevation data (box 6.1). Once elevations (which will be related to the area's local tidal datum) are associated to the threshold of each structure, investment decisions can be based on location vulnerability (Smith and Gallagher 2011).

The Coastal Hazards and Climate Change Asset Vulnerability Assessment Protocol comprises four primary steps:

1. Exposure Analysis and Mapping
2. Sensitivity Analysis
3. Vulnerability Analysis
4. Adaptation Strategies Analysis

STEP 1 ASSET EXPOSURE ANALYSIS AND MAPPING

The first step in the protocol is to analyze the exposure of NPS assets to coastal hazards and climate change. The goal of this methodology is to standardize the data sources for exposure analysis, using widely available and regularly updated sources (when possible). Standard exposure indicators have also been determined; these indicators represent the primary factors or hazards that should be evaluated to assess an asset's exposure (over the short-term to the year 2050). The five factors are storm surge, sea level rise, erosion/coastal proximity, and historical flooding. The following is a summary of these indicators (as well as likely data sources for each):

- **Flooding** (Federal Emergency Management Agency (FEMA) Flood Maps; Light Detection and Ranging (LiDAR) Digital Elevation Model (DEM) or other elevation model)
- **Storm Surge, Extreme Flooding, and Tsunamis** (NPS-specific Sea, Lake and Overland Surges from Hurricanes (SLOSH) model results; Tsunami models, LiDAR DEM or other elevation model)
- **Sea Level Rise** (NPS-specific sea level rise (SLR) modeling; LiDAR DEM or other elevation model)
- **Erosion, Coastal Proximity, and Cliff Retreat** (State/USGS erosion rate buffers; shoreline proximity buffers)
- **Historical Flooding** (Park surveys/interviews/questionnaire results; storm imagery/reconnaissance)

The exposure analysis utilizes data imported into Geographical Information Systems (GIS) format because exposure is directly dependent on location (whether the area experiences the hazard) and mapped hazard data. 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 historical flooding layer, which is derived from storm imagery, reconnaissance, and direct communication with park personnel. Thus, each of these exposure data layers represents an exposure indicator hazard zone for a particular park. Each asset that falls within a particular zone (exposed) is assigned a higher score than assets outside the hazard zone (unexposed).

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, 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 (see list below), how sensitivity is addressed during design and construction is very different. Below is a list of the sensitivity indicators (with data sources) on the following page:

Examples of Sensitivity Analysis

1. **Headquarters Building: Low Sensitivity**
   (1 of 4 "high" sensitivity indicators)
   - ✓ Low Flood Damage Potential (elevated)
   - ✓ Storm Resistant/Good Condition
   - ✓ No Historical Damage
   - **X No Protective Engineering**
2. **Comfort Station: Moderate Sensitivity**
   (2 of 4 "high" sensitivity indicators)
   - **X High Flood Damage Potential (at grade)**
   - ✓ Storm Resistant/Good Condition
   - ✓ No Historical Damage
   - **X No Protective Engineering**
3. **Entrance Road: High Sensitivity**
   (3 of 4 "high" sensitivity indicators)
   - **X High Flood Damage Potential (at grade)**
   - **X Not Storm Resistant/Poor Condition**
   - **X Historical Damage**
   - ✓ Protective Engineering

- **Flood Damage Potential/Elevated** (asset questionnaire; direct measurements of threshold elevation)
- **Storm Resistance and Condition** (asset questionnaire; FMSS database)
- **Historical Damage** (asset questionnaire; discussion with park staff)
- **Protective Engineering** (asset questionnaire; field and aerial imagery analysis; Coastal Engineering Inventory)

Bridges are considered transportation assets but have additional factors that must be considered when analyzing sensitivity to coastal hazards and climate change. Additional bridge sensitivity indicators are listed below (with data sources):

- **Bridge Clearance** (National Bridge Inventory, item 39)
- **Scour Rating** (National Bridge Inventory, item 113)
- **Bridge Condition** (National Bridge Inventory, items 59 and 60)
- **Bridge Age** (National Bridge Inventory, item 27; FMSS database)

Because digital data are not generally available, the primary data source for much of the sensitivity analysis is an asset 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 are also obtained from FMSS, the National Bridge Inventory, aerial imagery, and site visits.

STEP 3

STEP 3: ASSET VULNERABILITY ANALYSIS

Upon completion of step 3, each asset will have been given a rating (and score) of low, moderate, or high vulnerability to coastal hazards and climate change (calculated as the sum of exposure and sensitivity). A subset of the assets from the completed vulnerability analysis will be chosen for development of adaptation strategies (step 4).

STEP 4

ADAPTATION STRATEGIES ANALYSIS

After the vulnerability assessment 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 prioritize the assets to analyze for adaptation strategies. These assets 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. If an asset is a historic asset, then its historic character should be considered in selecting and designing adaptation options (see "Chapter 5 Cultural Resources"). 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 for both structures and transportation assets (NPS 2016). Below is a list of these strategies, including the potential effect on vulnerability.

- Elevate the asset: 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. Conversely, planning for submersion of assets such as roadways may also provide added protection during storm inundation. See additional discussion in "Chapter 9 Lessons Learned from Hurricane Sandy."
- Relocate the asset: reduces the exposure of the asset; relocating the asset to a lower risk area reduces the likelihood it will experience impacts from coastal hazards/SLR.
- Protect/Engineer: 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. This reduces the exposure and/or sensitivity of the asset.
- Decommission and 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. An example from Assateague Island National Seashore is described in "Case Study 16: Relocating Visitor Facilities Threatened by Erosion" in Schupp, Beavers, and Caffrey (2015).

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 damages. 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.

BOX 6.1. PROCESS FOR COLLECTING ELEVATIONS ON VULNERABLE ASSETS

Note: Locations of Vulnerable Asset Elevations procedure documentation https://www.nps.gov/orgs/socc/mitigation-and-adaptation.htm

PRE-FIELD:

1. Verify quality of Facility Management Software System (FMSS) data.
2. Coordinate with Regional and Washington Support Office staff so there will not be duplication of efforts. Your project may support existing efforts.
3. Asset data should be mapped in a GIS format (Shapefile or GeoDatabase) with FMSS Location IDs (FMSS primary key for assets) associated to the features. FMSS data can be accessed through Asset Management Record System. Location Hierarchy reports are recommended to be run to assist in attribution of spatial data.
4. Inventory, evaluate, and compile a list of existing local survey monumentation infrastructure as described in Accurate Elevation in Coastal National Parks (Smith and Gallagher 2011). Of particular interest are tidal benchmarks with published benchmark data sheets. If deep rod monumentation needs to be installed, this should be completed at least 30 days before data collection field work.
5. Determine the location of current and historic tide stations in the study area using the NOAA Tides and Currents website: http://tidesandcurrents.noaa.gov/stations.html?type=Water+Levels.

FIELD:

6. Set up geodetic receiver on a backbone monument that will be tied to all of the survey points that you collect in a given area. If conventional surveying techniques are required, all points should be tied back to the backbone monumentation with traditional Real Time Kinematic (RTK) or static Global Navigation Satellite System (GNSS) surveying techniques.
7. Best approach is to have a 3-person field crew: two people using RTK rover devices and one person capturing photos and providing Locations ID's to be used as the RTK point name and photo names. This is done to later associate the photos to the survey horizontal and vertical data (figures 6.4 and 6.5).
8. For buildings, collect first floor elevations at the threshold of primary entrance if possible. Collect multiple points for linear transportation assets and parking lots.

POST-FIELD:

9. Process project static base control files through National Geodetic Survey OPUS (Online Positioning User Service) using the precise ephemeris. It can take up to 21 days for the precise ephemeris to be available, so static files should be first processed using the rapid ephemeris to confirm their quality before final processing when the precise ephemeris is available. After the base control files are processed with the precise ephemeris, all RTK and conventional surveyed points can be adjusted and processed for North American Vertical Datum of 1988 (NAVD88) heights using current geoid.

10. Relate the NAVD88 orthometric heights of the assets to the local tidal datums. These tidal datums are mean lower low, mean low, mean sea level, mean high, and mean higher high water. Tidal datums are determined by recording tidal observations at a tide station over a period of months or years and deriving the relevant statistics. NPS staff and partners should request assistance with this step, especially in areas with relative land movement (subsidence, isostatic rebound, etc.).
11. Relate horizontal and vertical positions to photos.
12. Post results to NPS Focus/FMSS, and produce data-sharing products such as CSV and File GeoDatabase files (figure 6.6).

LESSONS LEARNED:

1. Data quality in FMSS is important.
2. NPS staff with park knowledge is crucial.
3. Park-specific tidal data and permanent survey monumentation (backbone) are often lacking.
4. Proper planning and coordination with park and/or program staff prior to field work are critical.
5. Experience in surveying techniques, tidal datums, FMSS, and GeoJot is essential.
6. Where proper GNSS signal is obstructed, conventional survey methods will be necessary.
7. Specialized equipment and knowledge of how to use it is required for this type of data collection.

Stakeholder Involvement and Outreach

The success of the facilities management climate change adaptation response will require the involvement of many stakeholder groups. It will also require the development of communication materials that can be used by parks and programs to reach out to these core groups. Workgroups will need to be established to develop components of the road map that require subject matter expertise such as GIS. These will be identified a d integrated as needed.

One of SOCC's main programmatic responsibilities is the Climate Friendly Parks (CFP) Program. The principle output of this program is a park climate change action plan. Through the NPS Green Parks Plan (GPP; NPS 2012b) the Director has required that, where feasible, all parks become CFP and develop a climate change action plan. These plans currently focus mostly on greenhouse gas mitigation in the energy, transportation, and waste areas as well as planning around climate change communications at the park (see "Chapter 7 Communication and Education"). CFP workshops now include adaptation discussions, and SOCC will modify the CFP initiative to add a climate change facility adaptation component (focused on assets) to the CFP plan as appropriate. This process is shown in box 6.2.

Strategies for Adapting Coastal Facilities and Operations

Visitor use areas in coastal environments are vulnerable to storm surges and future changes in sea level and lake level. With the projected changes in storm frequency and intensity, there are no "easy" answers to the design elements for coastal infrastructure. Certain engineering standards based on historic conditions are no longer accurate guides of future asset performance. More detailed examination of climate change impacts will be critical as actions envisioned in the general management plan and other planning documents are analyzed and implemented at site-specific levels. Factoring in changes in sea level and lake level, these analyses will influe ce the type, design, location, and ultimate feasibility of coastal facilities and developments.

When parks engage in development employing site-specific esign, outstanding opportunities are created to demonstrate forward thinking, innovative designs, flexi ility, and readiness for change in response to changes in sea level and lake level. Coastal resiliency will be incorporated into any new developed areas and adaptively reused structures and facilities. Multiple strategies and associated costs for protection and adaptation of infrastructure in the coastal zone are described in "Chapter 8 Protecting Infrastructure: Costs and Impacts."

These strategies propose a range of facility additions and renovations to expand recreational opportunities. Proposed facility investments will be evaluated using the following climate change overarching approach prior to project approvals to ensure the long-term sustainability of these investments. Future plans and studies will provide technical data and resource information to support the strategies. Creative solutions will be identified o limit impacts from future floodi g, storm surge, and other impacts on existing visitor and operations facilities. When these facilities are no longer viable to retain and use, a transition to portable facilities or other means to continue to offer visitor services, as feasible, should be considered. This could include the following on page 82:

BOX 6.2. OVERARCHING PROCESS FOR FACILITIES CLIMATE CHANGE RESPONSE AND ADAPTATION

STEP 1 — PARK CLIMATE CHANGE SCOPING
(STEP 1 FROM ADDRESSING CLIMATE CHANGE AND NATURAL HAZARDS HANDBOOK)

- Review climate change impacts including
  - » sea level rise, storm surge, coastal hazards.
  - » blizzards, extreme cold, extreme heat.
  - » hurricanes, heavy rains.
  - » wildfires, drought, lightning, tornadoes.
  - » permafrost depletion.
- Build working group and subcommittees.
- Characterize critical assets.

STEP 2 — VULNERABILITY ASSESSMENT
(STEP 2 FROM ADDRESSING CLIMATE CHANGE AND NATURAL HAZARDS HANDBOOK)

- Refine impacts assessment and conduct asset inventory.
- Conduct vulnerability assessment.
- Use Sustainable Buildings Checklist, Natural Hazards Checklist (figure 6.2), and other new standards.
- Establish vision and resiliency goals.
- Prioritize planning issues.

STEP 3 — PLAN FOR RESILIENCE AND SUSTAINABILITY IN CAPITAL INVESTMENTS AND OPERATIONS
(STEP 3 FROM ADDRESSING CLIMATE CHANGE AND NATURAL HAZARDS HANDBOOK)

- Identify, evaluate, and prioritize adaptation strategies.
  - » Identify options that could reduce vulnerability; suggestions for eliciting additional options include:
    - ▫ Analyze past climate events that led to disaster; working backwards from a negative impact, at what points in the process could an intervention have improved the outcome?
    - ▫ Could existing or outdated technologies or resources be repurposed in ways that would reduce vulnerability or enhance resilience?
    - ▫ What newly available technologies have potential to improve resilience?
    - ▫ Review various levers for affecting change such as land use planning, codes and standards, inspection and enforcement, operations, maintenance and repair, and renewal and renovation.
- Create response plan or integrate strategies into other plans; plan and invest for resilience and sustainability at all scales including operations and capital investments.
- Develop and submit a funding request (PMIS).
  - » Use Sustainable Buildings Checklist and other new standards and criteria to assess assets.
  - » Use rating scores as they become available from the National Park Service.

STEP 4 — IMPLEMENT AND MONITOR

- Implement high-priority actions.
- Track progress and evaluate effectiveness.
- Assess new impacts information and conduct adaptive management.
- Revise strategies and priorities as needed.

STEP 5 — COMMUNICATE AND EDUCATE
(SEE "CHAPTER 7 COMMUNICATION AND EDUCATION")

- Share success stories.
- Develop a robust resource center.
- Provide user-friendly communication materials to parks and stakeholders.

- Removing existing facilities and discontinuing recreational uses where continued use is unsafe, infeasible, or undesirable because of changing environmental conditions.
- Avoiding or minimizing additions of new infrastructure, construction of high value assets, or major investments in facility renovations within coastal hazard or storm surge zones.
- Reflecti g EO 13690's amendments to EO 11988 for substantial facility investments within the coastal zone, including an adjustment for projected sea level rise by year 2100; these investments should be avoided to the extent possible. Essential improvements within these floo -prone areas, such as rehabilitation of historic structures or provision of necessary facilities for beach access and recreation, will be carefully evaluated to determine whether facilities should be elevated, made portable, hardened, or otherwise made resilient to potential floodi g. Any decision to proceed with substantial improvements within the flood zo e as adjusted for sea level rise will be documented in a flood lain statement of fi dings according to DO-77 per EO 13690's amendments to EO 11988.
- Transitioning to systems and facilities that are more resistant to the effects of natural hazards and climate change effects on those hazards.
- Keeping susceptible elements of utilities, critical systems, and infrastructure out of flood zo es (and away from the effects of other natural hazards) to the extent possible.

Visitor Experience, Transportation, and Access

Sea level rise and storm surge impacts will change the way that visitors experience park assets and resources. Perhaps one of the most notable of these changes will be the way visitors access the parks. Many park transportation assets have the highest exposure to SLR and coastal floodi g making them the most vulnerable assets. For example, future visitors to Gulf Islands National Seashore may need to access the Fort Pickens unit via a ferry instead of driving in on the asphalt road, which is vulnerable to storm overwash (see Schupp, Beavers, and Caff ey 2015, "Case Study 19: Establishing Alternative Transportation to Fort Pickens to Supplement Vulnerable Road Access"). Alternate forms of transportation and access can benefit atural resources by reducing impacts to habitats of rare species such as the dune habitat used by the Santa Rosa beach mouse (Jackson et al. 2001). Although the park has implemented several strategies to maintain the road, including lowering road elevation, the value analysis should also consider the alternative of elevated causeways, which were once viewed as cost prohibitive. Existing roads may need to have larger culverts to address climate change impacts on drainage and local watershed precipitation (see Schupp, Beavers, and Caff ey 2015, "Case Study 15: Rehabilitating Stream Crossings on Historic Roads").

Some parks have already embraced more resilient design of parking lots. For example, Assateague Island National Seashore incorporates native materials so that asphalt debris will not litter the beach after storms (see Schupp, Beavers, and Caff ey 2015, "Case Study 16: Relocating Visitor Facilities Threatened by Erosion"). Other parks have considered the extent to which facilities should be replaced and elevated (see Schupp, Beavers, and Caff ey 2015, "Case Study 18: Developing Sustainable Visitor Facilities"). In the future, certain decisions and adaptation strategies may become more or less viable. It is important that parks document their process for planning and the rationale for which adaptation strategies are chosen.

While the loss of access can be a true loss, in some cases it will only be a change in traditional access to resources and assets. Although it may change the way that visitors experience a resource, the resource can persist. Some parks may have to consider acquiring land at higher or inland locations to properly provide for the safety of visitors and park staff. For example, Assateague Island National Seashore's general management plan (see Schupp, Beavers, and Caff ey 2015, "Case Study 23: Incorporating Climate Change Response into a General Management Plan") includes the potential for obtaining additional lands on the mainland for visitor contact stations, staff housing, maintenance, and headquarters. Recognizing these needs will help the park prioritize and plan for obtaining these lands even if the acquisition is many years into the future. A storm impact may accelerate the timeline for implementing such strategies.

Coastal landscapes that are allowed to evolve naturally can become more resilient and better able to withstand changes (see "Chapter 9 Lessons Learned from Hurricane Sandy"). At Cape Hatteras National Seashore on Hatteras Island, a breach during Hurricane Isabel in 2003 was artific ally closed with dredged sediment. The inlet closure allowed State Highway 12 to be reestablished close to its pre-storm location, but that stretch of barrier island continues to be narrow and vulnerable to future breaches. The balance between the natural environment and the built environment must be considered when planning future actions. After later hurricanes (Hurricane Irene in 2011 and Hurricane Sandy in 2012) breached the same highway, some breaches were allowed to persist with temporary bridges put in place to allow access to communities without impeding natural coastal processes of overwash, breach closure, and wetland building.

Figure 6.4. Image of base station set up for RTK-GPS elevation data collection at Fort Sumter National Monument as part of the vulnerable asset elevation project in 2015.

Asset Management Plans and Incident Response

The goal of coastal adaptation is to implement strategies as soon as they can be acted upon and to prepare for opportunities. Without consideration and planning for a variety of strategies, parks may fi d it is easiest in the short-term to return to business as usual, such as conditions that existed prior to a storm (see "Chapter 3 Planning" for a discussion of pre-disaster planning). When vulnerable locations are identified hrough processes described earlier in this chapter, funding to relocate assets and resources away from vulnerable locations should be pursued.

Parks are required to maintain asset management plans that describe the condition and priority of investments at the park. Park asset management plans should include elements of climate change vulnerability assessment and coastal adaptation. For example, plans for assets in the maintenance backlog must align with park adaptation strategies. If a certain structure is no longer serving its intended function, the future of that asset should be reconsidered (see "Chapter 9 Lessons Learned from Hurricane Sandy" for additional discussion of deferred maintenance and prioritization of cultural resources).

The NPS Southeast Region has recognized the need to prepare for storms, and to have plans in place for post-storm recovery/adaptation. The Cape Lookout National Seashore Storm Recovery Plan sets an excellent example of preparing for post-storm assessments (see Schupp, Beavers, and Caff ey 2015, "Case Study 20: The Need for Storm Recovery Plans"). The plan lists the most important resources in several categories. These priority resource listings assist ordering of recovery efforts; provide justificat ons for the expertise recommended on each assessment team; and inform incident responders of the resources that drive visitation, operations, and the overall character of the park. Detailed checklists of major resources are included in the plan's appendix so that teams can assess their status such as presence/absence and immediate threats. These assessments help the incident command to assemble and dispatch resource assessment teams. For the purpose of resource damage assessment, the park is divided into multiple areas and the expertise and number of specialists needed in each of those assessment areas are specified. The park storm recovery plan also explains the need for immediate aerial photo overfl ghts and specifies hotograph needs (e.g., resolution and vantage points) and provides contact information for appropriate pilots.

Figure 6.5. Image of rover GPS data collection at the Sally Port of Fort Pickens at Gulf Islands National Seashore as part of the vulnerable asset elevation project in 2015.

For staff living in and near coastal parks, the realities of living in a changing environment can affect both participation at work and their ability to participate in incident response activities. When a major storm impacts a park, many of the park staff may be involved in addressing human health and safety concerns for themselves, their friends and family, and the local community, and may not be able to fully participate in park incident management activities. Therefore, it is very important that information about resources and facilities be stored in systems that can be easily accessed by incident management teams (IMT) deployed to or working remotely for the impacted site. The systems, such as park atlases and off-site web mapping services, should be accessible and understandable, and should use standard protocols. Backup copies of the systems must be maintained offsite to enable the IMT staff to work at that remote location or on-site at the park.

Figure 6.6. Coastal asset at Elliot Key in Biscayne National Park was documented as part of the vulnerable asset elevation project in 2015.

Coastal Fortifications and Lighthouses

Coastal fortificat ons and lighthouses are unique sets of cultural resources that are also assets. With a few exceptions (see Schupp, Beavers, and Caff ey 2015, "Case Study 8: Relocating the Lighthouse"), these structures are so large that they cannot or will not likely be relocated. Strategies to address these assets will have to consider the place-based nature of these cultural resources. Some assets may be protected in place for a limited period of time with coastal engineering methods such as seawalls or beach nourishment (see Schupp, Beavers, and Caff ey 2015, "Case Study 5: Strategic Planning and Responsible Investments for Threatened Historic Structures"). Data have shown that many forts and lighthouses along the southeast coast of the United States have high exposure to 3.3 ft (1 m) of sea level rise (Peek et al. 2015). Prioritizing funding of repairs, maintenance, and even improvements at the sites may be critical in deciding how to distribute limited funds (see Schupp, Beavers, and Caff ey 2015, "Case Study 5: Strategic Planning and Responsible Investments for Threatened Historic Structures"). It is important to place each of these assets in context of the system of cultural and historical resources managed along the coast (figu e 6.7). Even when access is limited and structures are partially submerged, it is still possible to provide a visitor experience related to these resources. As "Chapter 5 Cultural Resources" discusses, unique compliance requirements and more complex decision-making processes are required for these irreplaceable cultural resources.

Opportunities for Adaptation

Mitigate Impacts of Coastal Engineering

When human actions impact natural coastal processes, such as when coastal engineering structures disrupt sediment supply and affect the evolution of a coastal landscape, the National Park Service can take actions to mitigate for those human-caused alterations (see "Chapter 2 Policy"). For a discussion of pre-disaster planning, see "Chapter 3 Planning." Some impacts are caused by actions that occur outside of NPS boundaries, such as an updrift jetty affecting sediment transport to a down-drift park. The National Park Service has begun a series of coastal engineering inventories (CEIs) (e.g., Coburn, Griffith, and Young 2010; Dallas, Ruggiero, and Berry 2013; Schupp and Coburn 2015; and other coastal engineering inventories available at http://www.nature.nps.gov/geology/coastal/monitoring.cfm that identify the locations and impacts of historic and current coastal engineering projects that affect coastal parks. These data exist for only 19 parks, so this work must be expanded to all coastal parks. The Northeast Region recognized that many coastal engineering structures are not comprehensively documented in FMSS, so post-Hurricane Sandy work has included incorporating data from available coastal engineering inventories into that database.

Remove, Restrict, and Redesign Structures

Aging coastal protection structures will become less effective as they deteriorate with age or their design elevations are exceeded. Building restrictions and structure removal can protect and promote open marine and estuarine shorelines and habitats such as wetlands (Nordstrom, Jackson, and Roman 2016). Coastlines respond differently to storm impacts and rising water level associated with coastal change depending on whether they are fi ed or dynamic. Nature-based and hybrid infrastructure strategies can be an important component of coastal adaptation (see "Chapter 8 Protecting Infrastructure: Costs and Impacts"). Following the publication of the CEI reports and creation of the associated GIS datasets, projects by the US Naval Academy at Fort Raleigh National Historic Site have helped the park to consider the elements related to implementation of a living shoreline. "Chapter 9 Lessons Learned from Hurricane Sandy" identifies a ditional opportunities related to facilities and infrastructure, such as including architectural, engineering, and project management expertise on the post-storm assessment teams so that FMSS rebuilding estimates will consider the cost of newly designed sustainable buildings in addition or instead of the cost of rebuilding the damaged structure as it was.

Funding Opportunities

Funding opportunities for adaptation will vary depending on location, park resources, and temporal conditions, such as storm events. Parks with fi e-year project plans should review these plans in conjunction with climate change vulnerability information to determine how the use of any project funding can be used to reduce exposure or sensitivity using strategies and actions noted above. Many project specificat ons and plans can be modified o increase the overall resiliency of the asset. The opportunity to adapt following a large-scale incident such as Hurricane Sandy may also bring needed funds for implementation of recovery objectives. It is important to conceive and perhaps even design projects to be implemented on dynamic post-storm landscapes. While the funding process for the National Park Service may not currently be designed to intentionally incorporate these “adaptive” actions, the concept of incorporating adaptive designs and other adaptive planning efforts will be very useful to effect changes for asset management in coastal parks. Examples of how the Value Analysis (VA), CBA, Rapid Review Team, and Development Advisory Board processes and procedures were used to incorporate adaptive element of project design are discussed for Hurricane Sandy recovery in “Chapter 9 Lessons Learned from Hurricane Sandy.”

Documentation

As the consequences of climate change increase, parks will need to evaluate and document vulnerable assets and resources. Adaptation strategies may include Historic American Buildings Survey (HABS), Historic American Engineering Record (HAER), or Historic American Landscapes Survey (HALS) documentation, 3D laser scanning surveys, digitizing hard copies of documents and artifacts, and interpretation. Parks should also recognize that loss of resources and assets will be part of this process, as recognized in the *Preserving Coastal Heritage Workshop Report* (NPS 2014b) and PM 14-02, and discussed further in “Chapter 5 Cultural Resources.”

Storm Recovery Planning

The storm recovery plan for Cape Lookout National Seashore (CALO 2011; see Schupp, Beavers, and Caff ey 2015, “Case Study 20: The Need for Storm Recovery Plans”) uses existing databases such as FMSS and the Archeological Sites Management Information System (ASMIS) for cultural resources. It is important that the incident management team has the ability to easily access this information and to know the intentions of the park management team for recovery. Incidents provide opportunities for climate change adaptation. Without prior planning, including consultation and coordination with National Historic Preservation Act section 106, it can be challenging to implement changes during the recovery process. Use of storm recovery plans for Fire Island and Assateague Island National Seashores are discussed in “Chapter 9 Lessons Learned from Hurricane Sandy.”

Figure 6.7. Panorama of waterfront of Salem Maritime National Historic Site in Massachusetts. Photograph by Marcy Rockman, NPS.

Emerging Topics

In addition to managing and adapting to potential impacts to NPS facilities from climate change, the National Park Service must address potential impacts from non-NPS infrastructure development near and through its coastal parks. In particular, there is increasing pressure for rapid deployment of energy development projects and related infrastructure, including offshore wind, offshore oil and gas drilling, marine hydropower, marine electric transmission related onshore substations, and petroleum product pipelines and related onshore compressor stations.

Regarding renewable energy, the current administration has committed to a national, non-hydro renewable energy generation of 20% by 2030, with efforts to streamline and expedite permitting of offshore wind and related transmission infrastructure. In 2011, the Department of Energy and DOI formed a strategic partnership and issued a National Offshore Wind Strategy aimed at deploying generation projects. Likewise, DOI launched its "Smart from the Start" initiative to facilitate siting, leasing, and construction of new projects. In addition, a number of coastal states have Renewable Portfolio Standards requiring that a certain percentage of energy either used or produced in that state is from renewable energy sources. Generally, these efforts seek to reduce carbon emissions and reliance on fossil fuels, increase energy efficiency, and to use more renewable energy to generate electricity, pointing to the growing importance of these technologies.

Large-scale development projects have the potential to cause adverse, cross-boundary impacts to NPS units. Examples include: direct mortality of avian species; potential disruption to physiology and behavior of nocturnal species from night lighting of facilities such as wind turbines; interference with sand and gravel transport from submerged facilities and construction activities; destruction of submerged archaeological resources; and others. Many of these resources are already vulnerable to the stressors of sea level rise and climate change. As such, it is imperative that the National Park Service engage on such activities occurring near its boundaries to ensure protection of park resources and values.

Increasingly, coastal parks are called upon to permit third-party infrastructure development within and through park units or to provide access to near shore facilities through seashores and park coastal waters. For example, the formerly named Atlantic Wind Connection electric transmission project was designed to connect offshore wind facilities to the onshore grid and had proposed a route through Assateague Island National Seashore that would have required directionally drilling the marine transmission cable under the barrier island. NPS staff identified a number of potential resource impacts, including the possibility of piercing the freshwater lens under the island, interfering with sand transport along the seafloor, and creating a vulnerability point for a future island breach. Moreover, NPS staff raised concerns about the ongoing management and safety of such facilities in an area constantly in flux. Clearly, such facilities have the potential to compound adaptation and management needs for coastal parks.

Take Home Messages

- The National Park Service has the responsibility to invest wisely in facilities for the long term. Unquestionably, climate change and natural hazards pose a significa t threat to our investment in current and future facilities.
- Vulnerability to climate change impacts needs to be understood at the asset level for parks to plan for these impacts. This includes an understanding of the risk of exposure and sensitivity of the asset to these impacts.
- Park asset management plans and fi e-year project plans should be evaluated to include elements of climate change vulnerability and coastal adaptation strategies.
- Climate Friendly Park workshops are opportunities to integrate climate change mitigation planning with coastal adaptation.

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Chapter 7 Communication and Education

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Communication

This chapter describes tools, goals, and media for communicating information about climate change adaptation to multiple audiences. The communication of coastal adaptation efforts is paramount to fostering a basic understanding of ways in which to adapt, restore, and protect coastal environments from the effects of climate change.

Given the number of ways in which climate change is currently affecting our coastal environments—sea level rise, ocean acidificat on, shoreline erosion, and increased storminess—the need for adaptation will only continue to grow. The National Park Service (NPS) has the responsibility to protect not only the habitats found along the coastlines, but also coastal processes, biodiversity, visitor facilities and opportunities, and archeological sites. Innovative, cost-effective ways to adapt to the ever-changing conditions are necessary to minimize these negative effects.

Communication about existing coastal adaptation efforts will encourage successful proactive adaptation by providing the following: the necessary framework for managers to apply to decision making for other areas being affected by climate change; an opportunity to promote and build stakeholder support for the steps taken to protect resources; ways to foster collaboration between parks and park partners; an examination of vulnerability pertaining to various areas; education to the general public about climate change and the ways of combating its effects; and an opportunity to publicize success stories regarding coastal adaptation efforts.

A variety of products can effectively communicate coastal adaptation efforts. Many of these products can be used broadly, for multiple uses and audiences. Most NPS sites already have trained communication experts in-house as part of their interpretive staff. It is highly recommended that resource managers work with interpretive staff to create the most appropriate and effective communication possible. In the event that a park does not have in-house interpretive capacity, the regional office or he NPS Harpers Ferry Center would be next options for the creation of these products.

Effective communication is best achieved by using the NPS graphic identity guidelines to ensure uniformity. The NPS brand is widely recognized and trusted, and, as such, adherence to these principles will help to embolden the message parks are looking to convey. These standards include guidance on the correct usage of the arrowhead, the correct fonts to be used, and the formats to use to achieve the greatest level of success. These guidelines used in conjunction with this handbook serve as a starting point for the creation of successful communications. The standards and templates can be found at http://www.nps.gov/hfc/services/identity/.

Site Bulletins

Site bulletins are materials that are created and produced in-house and are intended for short-term use. These site bulletins allow for the rapid transmission of information, can be used by a wide range of audiences, and are usually produced in black and white. The template brings uniformity to the presentation of information. This type of product is ideal for disseminating success stories on a small scale, highlighting a specific   roject or action taken, providing general understanding of impacts and solutions, conveying management philosophies regarding specific   abitats, and providing updates on the implementation of post-storm recovery actions.

An example of a site bulletin from Assateague Island (figu e 7.1) can be found at: http://ian.umces.edu/pdfs/ian_newsletter_380.pdf.

Figure 7.1. Example of a site bulletin from Assateague Island.

Rack Cards

Whereas site bulletins are designed for in-house production and use, rack cards are used for off-site promotional efforts. Typically, these are distributed to the local community and to other partners. Similar to site bulletins, rack cards are designed for the transmission of simple and easy-to-understand information. These publications are ideal for fostering collaboration with partners, promoting success stories, highlighting upcoming projects, and educating the general public about issues and proposed actions.

Figure 7.2. Example of a rack card from Assateague Island.

A template for this type of publication can be found on the graphic identity website. It is highly recommended that parks use this template to ensure uniformity.

An example of a rack card from Assateague Island (figu e 7.2) can be found at: http://ian.umces.edu/pdfs/ian_brochure_391.pdf.

Waysides

Waysides are a fantastic tool to use for longer-term dissemination of information to the public. They are site-specific, o tdoor interpretive exhibits designed to be simple in form and function. There are two types of waysides that can be used: (1) a low-profile e hibit, used for aspects that are readily visible to the visitor, or (2) an upright exhibit, designed to provide information about an entire area, trail, or habitat type. Keeping in line with the tenets of the site bulletin and the rack card, waysides are designed to convey simple and easy-to-understand information. Complex issues or processes should be included in other types of media.

Examples of climate related waysides from Dry Tortugas National Park and Gulf Islands National Seashore are shown in figu e 7.3.

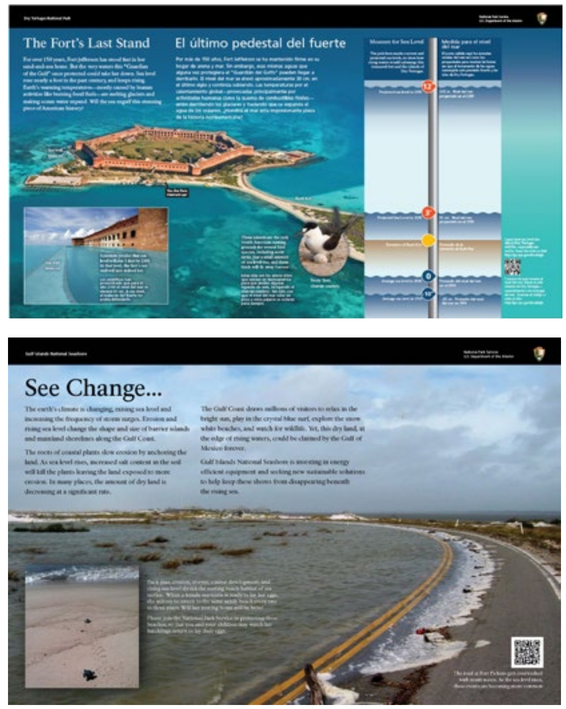

Figure 7.3. Example waysides from: a) Dry Tortugas National Park, and b) Gulf Islands National Seashore

Audio/Visual Arts

A different way to communicate the work being done at park sites is through web videos or audio/visual products. Videos give an opportunity to transmit information not just with written words, but with images as well. This tool can be incorporated either through the park's webpage, or through an offi al YouTube page. This type of media allows for more complex and technical information to be conveyed and can be used when site bulletins or waysides are not the appropriate choice for information sharing.

The Climate Change Response Program (CCRP) has a YouTube account with many videos that highlight what these products may be used for, including examples specific to sea level rise and coastal park adaptation projects. It is recommended that park managers frequently check this site for updated videos and that parks share their climate change videos here as they develop their own.

Although there are no established standards regarding content in audio/visual products, there are standards that apply to the fi al product. These standards will help to unify the brand of NPS videos. You may view this standardized process by following this link: http://www.nps.gov/hfc/acquisition/pdf/standard-specs-av-production.pdf.

Newspapers/Newsletters

Coastal adaptation projects may take several months or even years to complete. Newsletters are a great way to communicate about the status of these ongoing projects. Newspapers, newsletters, and e-newsletters can provide more in-depth examinations of the project that consider the issues surrounding the project and the steps being taken to mitigate those issues. These newsletters can be a one-time use product, or can be part of an on-going series to match the pace of the project.

An example of a climate-focused park newspaper (figu e 7.4) can be found at the following link: http://www.nps.gov/hfc/services/identity/downloads/templates/2013/NPS_Newspaper25x17.zip


The Maritime News

The Greening of the Park

Steam Tug *Hercules* Turns 100

Volunteers Enrich Park Programs

Music, Tours, Events, Living History and Films

Fun and Education for Younger Sailors

Of Flying Fish and Sailing Cats

Sign Aboard at the Park Association

Figure 7.4. An example of a park newspaper from San Francisco Maritime National Historical Park.

Another example of a newsletter is from the NPS Southeast Region Newsletter (figu e 7.5), which can be found at [http://api.ning.com/files YIi6je0KpJOsrnbBJB7WKvgiFhpF-vhoL5RzBvNMieuq6ZQYuFFmiVGGXYspnMONKmFE*Xfo*1fhN6yA04IAmS8NashMbcU2*/SoutheastRegionClimateChangeNewsletter_Winter2014_2015_Final.pdf](http://api.ning.com/files/YIi6je0KpJOsrnbBJB7WKvgiFhpF-vhoL5RzBvNMieuq6ZQYuFFmiVGGXYspnMONKmFE*Xfo*1fhN6yA04IAmS8NashMbcU2*/SoutheastRegionClimateChangeNewsletter_Winter2014_2015_Final.pdf).


Winter 2014/2015

HOT Topics

Built Fort Tough

How sensitivity plays a role in vulnerability

Figure 7.5. NPS Southeast Regional Newsletter.

Twitter/Facebook and Social Media

One of the newest and highly utilized forms of communication is social media. The speed at which information can be relayed and the general acceptance of that information makes it an indispensable tool. Coastal change is a certainty, and social media provides an opportunity to react to ever-changing conditions in real time.

Currently, there are four approved social media sites for the NPS: Facebook, Twitter, YouTube, and Flickr. These four sites have vastly different uses and each can provide a tailored product for the intended audience:

- **Facebook** – an online community where people anywhere in the world go to stay connected with family, friends, colleagues, and organizations. The main use of this site is to provide subscribers with news updates, information, events, and announcements. The NPS Ocean and Coastal Facebook page is a closed group to which you can request to be added.
- **Twitter** – a "microblogging" site that is a shorter form of a blog. Twitter allows the use of only 140 characters per statement (tweet), so precise choice in words is essential for an effective tweet.

- **YouTube** – the world's largest video sharing website. It should be the "second stop" when posting videos after the site's main webpage.
- **Flickr** – one of the world's largest photo sharing communities. This site allows only still images to be posted and does not have a video posting option. Several King Tides Flickr photo sharing groups provide a way for volunteers to help visualize what sea level rise may look like in the future by sharing photos taken during the highest tides each year (e.g., Washington State https://www.fl ckr.com/groups/1611274@N22/.

Some guidelines to keep in mind when using social media include:

- Only post information, images, and videos that are publicly available. Do not post anything that is related to a pending lawsuit, contains personally identifia le information, or is classified
- Be aware that the entire notion of social media is for the interaction of groups, and, as such, comments from the audience are a part of that interaction. These comments can be both positive and negative. Please use tact and caution when replying to negative comments, as these are still part of the conversation. If in doubt on how to respond, refer to the NPS policy on social media relations: https://www.nps.gov/policy/Socialmedia.pdf.
- Be sure that no commercial advertising appears on the site.

For more in-depth guidance on how to effectively use social media please see "Social Media: A Guide to Tools and Strategies" http://share.inside.nps.gov/sites/Web/Documents/Social%20Media/NPS_SocialMediaGuideforToolsStrategies.pdf (*NPS internal access only)*.

Case Study Review

Communication is different from interpretation. Communication is the transmission of information, whereas interpretation ensures that the audience makes a connection. Not all communication needs to be interpretive. Many of the strategies described in this chapter have strong interpretive opportunities. One method that focuses more on communication than on interpretation is a case study review, which can disseminate high-priority, current natural resource management information with managerial application.

A case study is an explanatory analysis of a person, group, or event. Case studies use scientific anguage to describe issues and the steps taken to address those issues. This allows decision makers to frame their decision in terms of the successes and failures of similar issues. When the audience is composed mostly of resource managers, this type of communication is among the best choices; however, it is probably not the best selection for the general public.

When putting a case study review together, there are a few guidelines to help ensure the product is as effective as possible:

1. Read and examine the cases thoroughly.
2. Focus on the analysis.
    A. What were the major issues?
    B. What caused these issues?
    C. How did they impact the area?
3. Uncover the solutions.
4. Identify the best solution and transmit supporting evidence, pros and cons, and the possibilities of success elsewhere.

Case study analyses bring together a number of different case studies for comparison to one another. Typically, case studies included in the analysis are of a similar focus to highlight similar problems with different solutions. Collaboration is key when crafting a case study analysis; contact other sites to ensure that information presented is verified a d that the most robust analysis possible is attained.

In addition to the case studies in the "Coastal Adaptation Strategies: Case Studies," (Schupp, Beavers, and Caff ey 2015) a few examples of climate related case studies can be found at the following links:

http://ncptt.nps.gov/blog/climate-change-strategy-for-cultural-landscapes/

http://ncptt.nps.gov/blog/climate-change-at-el-morro/

http://ncptt.nps.gov/blog/climate-change-at-dry-tortugas/

General Recommendations

It is worth noting that not all communication will focus on outcomes. Climate adaptation work often hinges on the unknown. There is no way of telling how a storm will alter a coastal environment, or how far-reaching storm surge effects will be. As a result, the communication of the unknown is valuable, and in many ways can have the same impact as the communication of observed results.

Here are fi e tips for effective communication about adaptation:

1. Balance urgency with hope.
2. Tailor communication to your audience.
3. Emphasize preparedness, risk reduction, and a healthy future.
4. Avoid jargon.
5. Make it personal, local, and timely.

Education

The communication of previous efforts is not the only way to share the success stories of coastal adaptation. When projects have a modicum of success, there is a unique opportunity to be able to share those successes in an educational setting. The great American psychiatrist William Glasser once said, "95% of what we learn is what we teach others." The sharing of success through education not only helps to teach others, but also helps to embolden the efforts parks have already undertaken.

The National Park Service holds a unique position as one of the world's leading organizations for informal learning. Park visitors, partners, stakeholders, and the general public all look to the National Park Service for leadership in professionalism, education, and connections to these special places. This puts the organization in a position to educate a diverse grouping of audiences through an array of media. These educational opportunities will help to strengthen coastal communities by freely sharing information, lessons learned, and success stories.

There are a variety of products that can be used effectively to teach the stories of coastal adaptation. Keep in mind that not all education opportunities need to focus on a specific project. Sharing the processes, science, possible actions to be taken, and general understanding of climate change are possible ways to educate those who are interested. The following sections will highlight several ways to incorporate educational opportunities in park communication efforts.

Webinars

A webinar is similar to a seminar with the exception that it uses computers and the internet to make the connection instead of bringing the participants together physically. As a seminar is essentially a group of people coming together to discuss and learn, a webinar is a much more cost-effective and time-effective way to have a similar experience. Webinars are also convenient and easy to use, and reduce greenhouse gas (GHG) emissions by reducing travel.

For examples of how a webinar could work, check the NPS website, which links to completed webinars. Additionally, the CCRP currently has a monthly webinar series related to climate news and scientists.

Websites

Similar to how a newsletter can provide greater and more in-depth information about a topic, a website allows you to provide additional information about a topic. A dedicated website allows close work with partners and stakeholders to create a resource from which the audience can learn based on individual speed and interest. One of the main benefits o a dedicated website is that it allows for a broad range of resources to be brought together in one area for ease of access. It also allows for a great diversity of collaborators to provide the framework necessary to convey the desired messages.

For an example of a dedicated website, see the Teach Ocean Science website (figu e 7.6) that Assateague Island National Seashore, National Science Foundation, and the Integration & Application Network at the University of Maryland Center for Environmental Science partnered together to create. It is available at the following link: http://www.teachoceanscience.net/teaching_resources/education_modules/barrier_islands_and_sea_level_rise/get_started#

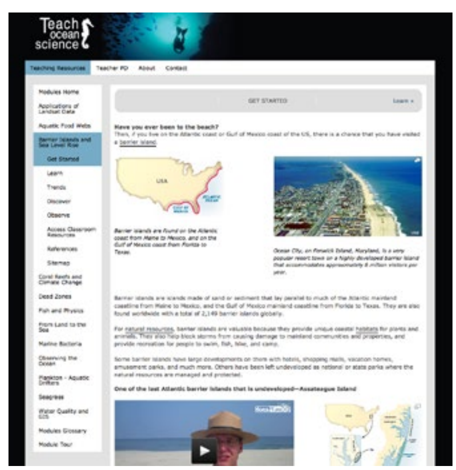

Figure 7.6. An example of a website: Teach Ocean Science.

Online Courses

Online courses are a fantastic way to teach and train others about coastal adaptation efforts. These courses provide more information than a webinar and allow for more interaction between the participants and the instructors/presenters. They also provide the ability to check the audience's comprehension of the topics covered. Online classes operate in a way similar to in-person classes, with a great deal more flexi ility and cost savings and the added benefit o GHG emissions saving. Once these courses have been created, they can be used over and over until updating is needed or the information becomes irrelevant. There is also a greater deal of flexi ility with online courses as participants can take these courses at their leisure. These attributes afford online classes more depth in the information being presented, and tend to produce more attrition from the participants than a webinar.

Online courses, however, do require more planning and effort to create than a webinar and potentially more than planning an in-person course, and this should be taken into account when creating online courses. Planning is essential when creating an online course. Planning should not be limited to the content but also on the way information retention is tested. Having a solid plan of what the goals are for any online course is a necessity.

Climate Friendly Parks Workshops

In 2000, the Climate Friendly Parks (CFP) plan was created to hold workshops to discuss sustainability options for individual NPS sites. Each workshop includes staff training, carbon management inventory, action planning, technical assistance, national recognition, and education and outreach products. These workshops have detailed content, akin to that included in webinars and online courses, and they focus on the specific pa k setting. While these workshops primarily provide parks with management tools and resources to address the mitigation aspect of climate change, communication has always been a major focus, and more recent efforts to integrate adaptation have shown this venue is an ideal entrée for developing coastal adaptation efforts. Cape Hatteras National Seashore is an example of one of the fir t CFP Action Plans that include adaptation actions (figu e 7.7).

The dedicated CFP staff can assist in planning and hosting a workshop, which requires approximately four months of planning. There are several areas in which the CFP staff can help:

- Inventory support. The technical experts help guide parks through conducting a GHG emissions inventory using the Climate Leadership in Parks (CLIP) tool.
- Action planning support. Technical experts can help to develop a strategic plan to address climate and sustainability issues. This section is ideal for coastal adaptation as it allows action items to be included in environmental management systems (EMS).
- Education and outreach support. The team and regional partners can help create outreach strategies to promote climate change efforts and educate visitors about their contributions to sustainability goals.

At the end of a CFP process, it is possible to have the site named a Climate Friendly Park. This national recognition can help embolden the efforts of implementing the park plan and combating climate change.

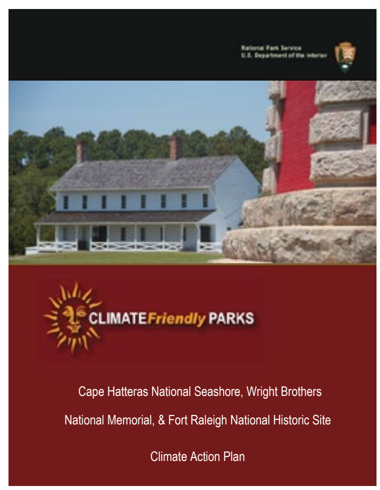

Figure 7.7. Cape Hatteras Climate Friendly Parks Action Plan.

Climate Smart Training

Climate-smart conservation (see chapters 3 and 4) is the intentional and deliberate consideration of climate change in natural resource management, realized through adopting forward-looking goals and explicitly linking strategies to key climate impacts and vulnerabilities.

The Climate-Smart Conservation trainings based on the guidance document *Climate-Smart Conservation: Putting Adaptation Principles into Practice* (Stein et al. 2014) are being offered through the National Conservation Training Center several times a year. This training helps to serve natural resource managers with the following objectives:

Design adaptation planning processes that are relevant at multiple scales to:

- Evaluate conservation goals from a climate change perspective.
- Explain how climate change vulnerability assessments, scenario planning, and downscaled climate models inform adaptation.
- Describe the process for identifying possible adaptation options based on vulnerability information.
- Integrate climate adaptation into existing planning and decision-making processes and policies.

Take Home Messages

- At the heart of the variety of products covered in this section lies communication itself. These products merely serve as the vehicle to provide audiences with effective communication of the efforts made in coastal adaptation. The communication of success stories, both with other parks and with partners, will help build support for the implementation of adaptation strategies.
- Support of local communities, parks, partners, stakeholders, and the general public is necessary for the effective implementation of any adaptation strategy. Many times the effica of adaptation programs relies on the cooperation of a variety of interested parties. Communication is necessary to include stakeholder involvement, which is crucial for planning and managing for change.

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Chapter 8 Protecting Infrastructure: Costs and Impacts

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Infrastructure Adaptation

This chapter identifies ultiple strategies and associated costs for protection and adaptation of infrastructure in the coastal zone. While this chapter focuses specificall on infrastructure, many of these adaptation strategies can also be applied to archeological resources and other cultural resources; for a more detailed discussion of relevant issues, see "Chapter 5 Cultural Resources."

Infrastructure comprises the physical assets and components of a region that provide service to the public, and includes buildings, roads, water and wastewater systems, bridges, and electrical grids. Some of these park assets are also protected cultural resources. The National Park Service manages numerous types of coastal infrastructure that will be affected by climate change and is investigating coastal infrastructure adaptation options at park, regional, and servicewide levels. As coastal vulnerability increases with changes in the climate, public pressure will also increase to armor the coastline.

Climate change adaptation is important for National Park Service (NPS) assets in terms of both planning new construction, such as ensuring that the location is not along an eroding shoreline or within a flood zone, and managing existing assets through engineered protection, relocation, or abandonment. Adaptation efforts must consider the NPS mission and the balance of natural, historic, and cultural resources, as well as recreational access, budget constraints, and public and political pressure.

This chapter describes different climate change adaptation options for infrastructure within coastal parks, with emphasis on sea level rise and storms. Options include hard stabilization structures, relocation and retreat, redesign, abandonment, and creation of nature-based features (Bridges et al. 2015), such as beach nourishment and living shorelines. A continuum of these options from hard to soft or nature-based options is described by SAGE, NOAA, and USACE (2014) and illustrated in figu e 8.1; their costs, benefits, a d impacts are summarized in table 8.1. Online resources will be updated to supplement this document and can be found at http://www.nps.gov/subjects/climatechange/coastalhandbook.htm.

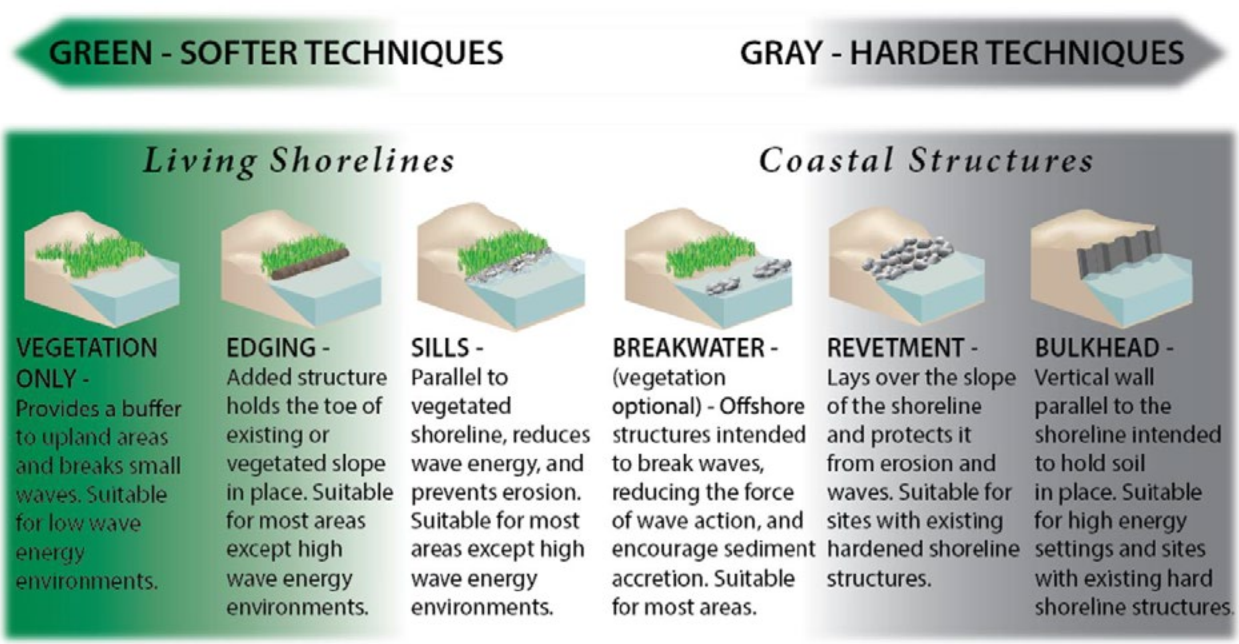


Figure 8.1. A continuum of green (soft) to gray (hard) shoreline stabilization techniques. Figure 1 from NOAA (2015) based on SAGE, NOAA, and USACE (2014).

Table 8.1. Summary of adaptation options and their costs, benefits, and impacts.

Adaptation Option	General Cost	Benefits	Disadvantages/Impacts
Onshore, Shore-Parallel Structures	$2,000 – $3,000/ft ($6562-$9843/m)	Reduce upland erosion	Disrupts natural processes; causes erosion; impacts habitat
Shore-Perpendicular Structures	Groins: $250 – $6,500/ft ($820-$21,325/m) Jetties: $16,000/ft ($52,493/m)	Groins: Widen beach Jetties: Limit sediment flow and wave energy in inlet	Disrupt natural processes (longshore transport); cause downdrift erosion; cascading effect of installation (groins); hinder inlet migration (jetties)
Breakwaters	Initial: $16,000/ft ($52,493/m) Annual maintenance: over $500/ft ($1640/m)	Reduce force and height of waves; allow accretion landward of structure	Navigation hazard; disrupt natural processes; cause downdrift erosion; no high water protection
Beach Nourishment	$300 – $1,000 ft ($984-$3,281/m) per linear foot or between $5 and $30 ($3.80 and $23 per cubic meter) per cubic yard of sand	Increase beach sand volume/ width; reduce wave energy near infrastructure; protection from moderate water rise; can promote tourism, rapid visible change	Temporary solution; does not reduce or eliminate erosion; sand compatibility limitations; impacts on wildlife on beach and at borrow sites; disrupts natural beach processes; can encourage increased development in high-risk areas
Sand Fencing	Inexpensive	Support natural vegetation growth (and sand accumulation); reduce wind stress and salt spray	Can create debris and safety hazards when destroyed
Living Shorelines	Initial: $1,000 ft ($3,281/m) Annual maintenance: $100/ft ($328/m)	Provide habitat; dissipate wave energy; slow inland water transfer	No upland flood protection; vegetation survival can be limited; hybrid techniques that include hard structures disrupt sediment processes
Redesign the Structure	May be lower than complete removal or relocation; adaptive maintenance costs can increase with redesign	Prolong accessibility; postpone need to find new site for structure; allow historical structure to remain in associated landscape	Pilings can be undermined by erosion or affected by groundwater; means of access may change
Relocate	$800 – $40,000/ft ($2625-$131,234/m)	Long-term solution, reduced maintenance needs; allow natural processes	Lack of appropriate relocation site; loss of historical context; size limitations
Abandon in Place	Reduced short-term maintenance costs	Reduced maintenance needs; can eliminate need for protective structures	Deterioration over time; attractive nuisance; loss of historical value; potential for introduction of hazardous materials

Protect in Place: Costs, Benefits, and Impacts of Infrastructure Adaptation Options

Many adaptation efforts have focused on protecting infrastructure in place by stabilizing the shoreline using seawalls, groins, bulkheads, and soft stabilization techniques, such as beach nourishment. These are strategies to resist change that are often not long-term solutions because climate change and sea level rise will continue to threaten the assets, and the stabilizing structures will require ongoing maintenance and repair.

Hard stabilization structures can have adverse impacts, which are described within each section below; there are also impacts common to all of them. By changing natural shoreline processes in the project area, the structures may reduce sediment transport to downdrift areas, which may also have natural and cultural resources to be considered. If downdrift erosion needs to be mitigated, there will be additional costs for stabilization or nourishment. As sea level rises and erosion continues, the shoreline may migrate away from the fi ed structure, requiring rehabilitation and extension to re-attach the structure to land. Also, hard stabilization and beach nourishment can give the false sense of security and reduced risk in an area. Although well intentioned, these projects could induce more risk by encouraging development within these vulnerable areas.

Hard stabilization often impacts wildlife habitat and ecosystem services and may also limit the extent of or seriously degrade seagrass, salt marsh, and coral reefs, all of which in themselves attenuate waves and provide a level of coastal protection and other ecosystem services, and all of which must be protected under NPS policies and regulations. Some studies have found that adding hard structures increases species diversity, particularly if the surface is complex (rough and pitted instead of smooth) (Moschella et al. 2005; Chapman and Underwood 2011). Structures diversify habitat through new substrate types and differences in wave energy levels seaward and landward of structures (Martin et al. 2005). Compared to hard bottom habitat, breakwaters can show lower overall species richness than rocky shores because they are less established, and they have less habitat complexity and spatial extent (Moschella et al. 2005) although some studies have shown no significa t difference (Pister 2009). Some studies indicate that anthropogenic structures favor invasive or exotic species over native ones (Wasson, Fenn, and Pearse 2005; Glasby et al. 2007; Tyrrell and Byers 2007). These changes to the local coastal ecosystem are substantial and may not be desirable in the context of conservation and park values.

As detailed in "Chapter 2 Policy," NPS policy has been to allow natural shoreline processes to continue and to investigate mitigation options for the effects of human alterations to shoreline processes (NPS Management Policies 2006 § 4.8.1.1). Any such intervention must be kept to the minimum necessary to achieve the stated management objectives (NPS Management Policies 2006 § 4.1 and § 4.8.1.1). A thorough decision-making process related to emplacing new structures will include evaluations of what happens when decisions must be made to repair, replace, or remove the structures (Nordstrom 2014).

The following section describes the costs, benefits, and impacts of protecting assets in place using various coastal engineering approaches. A review of many coastal stabilization structures can be found in Nordstrom (2014).

Onshore, Shore-Parallel Structures: Seawalls, Revetments, and Bulkheads

Seawalls (figu e 8.2) are onshore, shore-parallel structures built along open coasts with the primary purpose of protecting the resource behind the seawall from wave action. They are commonly constructed with a vertical, stepped, or curved face using stone, steel, concrete, or wood (Benoit et al. 2007).

Revetments are placed directly on an existing slope, embankment, or dike to protect the upslope area from waves and strong currents, sometimes at the expense of the downslope area. They are commonly built to preserve the existing uses of the shoreline and to protect the slope. Like seawalls, revetments armor and protect the land and structure behind them. Revetments are commonly constructed using armorstone (in high wave energy environments), articulated concrete mattress (on riverbanks and in low and intermediate wave environments) (Leidersdorf, Gadd, and McDougal 1989), or rip-rap stone (in lower wave energy environments) in combination with smaller stone and geotextile fabrics. Other construction materials include gabions, placed concrete (usually in stepped fashion), pre-cast concrete blocks, and grout-filled bags

Figure 8.2. A seawall protects Fort Warren on Georges Island at Boston Harbor Islands National Recreation Area. Photograph by NPS.

Bulkheads (figu e 8.3) are vertical structures or partitions, usually running parallel to the shoreline on sheltered coasts, for the purpose of retaining upland soils while providing protection from wave action and erosion. Bulkheads are commonly rock-filled timber cribs a d gabions, steel/composite sheet pile, concrete blocks, or armorstone units (Coburn, Griffith, and Young 2010). They can be freestanding or can have a series of tiebacks for stability (Benoit et al. 2007).

Sea level rise and increased wave heights may necessitate increased maintenance or elevation of the hard structures to maintain their effica . Increased wave heights and scour at the base of the structure are likely to reduce structure stability (NRC 2014). Seawalls are effective against coastal floodi g only if they prevent tides from fi tering up through the ground and can compound problems when they prevent rainwater from draining out (Spanger-Siegfried, Fitzpatrick, and Dahl 2014). As sea level rises, the beach in front of the structures will be submerged, resulting in a loss of recreation opportunities and habitat (Heberger et al. 2009).

Costs

The construction costs for shore-parallel engineering structures vary widely depending on factors such as material, height, land characteristics, and location. Total planning and installation is commonly around $2,000 to $3,000 per linear ft ($6,500 to $9,800 per m) but has topped $10,000 per linear ft ($32,800 per m) in several projects. Repair and replacement of deteriorating seawalls, revetments, and bulkheads can be more expensive than new construction. Examples from within and outside the National Park Service are compiled here.

1. **Montauk Lighthouse, New York: Seawall and Stone Revetment Construction (2006)**
   The US Army Corps of Engineers (USACE) constructed a stone seawall and revetment in 2006 around a portion of the Montauk Lighthouse, part of the Montauk Point State Park in New York. The project was labeled as a "hurricane and storm damage reduction project" and total construction costs were estimated by the USACE as $13,720,000 for 840 linear ft (256 m) at 40 ft [12 m] wide, and 25 ft [7.6 m] above National Geodetic Vertical Datum of 1929). This seawall and revetment replaced a deteriorated seawall installed in the 1940s (USACE 2005).
   Approximate cost: $16,665/ft ($54,675/m)
2. **Harkers Island, Cape Lookout National Seashore: Bulkhead Repairs and Replacement (2007)**
   The bulkhead at the headquarters of Cape Lookout National Seashore on Harkers Island was repaired and replaced starting in 2007. The work included the construction of a vinyl sheet pile bulkhead along more than 740 ft (225 m) of shoreline and boat ramp repair, with an award value of $2,042,372 (USACE 2007).
   Approximate cost: $2,759/ft ($9,052/m)
3. **Ellis Island, New York: Seawall Repair (2010)**
   Major repair of the Ellis Island seawall began in 2010. Ellis Island is situated within the Hudson River in New York and is part of the Statue of Liberty National Monument. Approximately 5,550 linear ft (1,690 m) of deteriorating seawall was repaired at an estimated cost of $20.9 million (US DOI 2010).
   Approximate cost: $3,800/ft ($12,470/m)

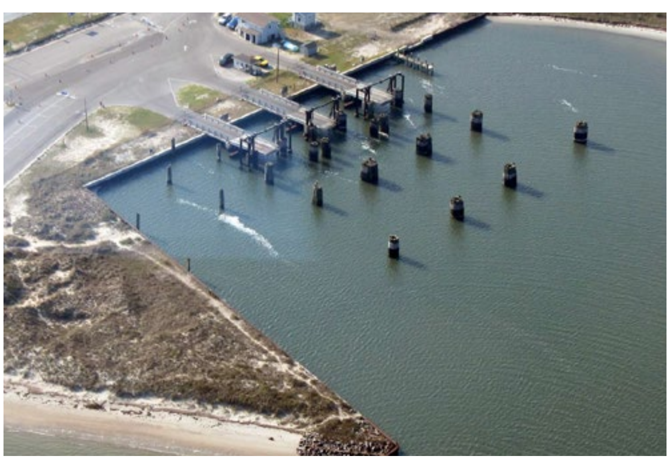


Figure 8.3A. Bulkheads at the Hatteras Island ferry landing on Ocracoke Island, NC. Photograph by NPS.

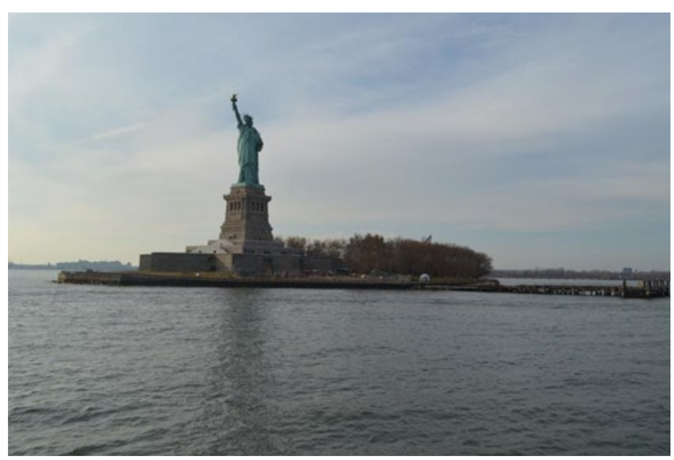


Figure 8.3B. Bulkheads protect Liberty Island. Photograph by NPS.

4. **Thomas Jefferson Memorial, Washington, DC: Seawall Repair and Replacement (2011)**
   A replacement of the seawall along the Potomac River at the Thomas Jefferson Memorial in Washington DC was completed in 2011. The work was done by Clark Construction for the National Park Service at a cost of approximately $13 million. This project required the removal of 500 linear ft (152 m) of old seawall and complete replacement with new piling and seawall (NPS 2014b).
   Approximate cost: $26,000/ft ($85,526/m)
5. **Scituate Lighthouse, Massachusetts: Rock Revetment Improvement and Repair (2014)**
   Repairs to the granite revetment around Scituate Lighthouse in Massachusetts included replacing around 400 linear ft (122 m) of the revetment with new granite boulders at a cost of $800,000 (Shields 2013).
   Approximate cost: $2,000/ft ($6,562/m)
6. **Marshfield, Massachusetts: Seawall Replacement (2013)**
   The oceanfront seawall in Marshfi ld, Massachusetts, was reconstructed in 2013 at a cost of $3.2 million to repair 1,131 linear ft (345 m) of the concrete and stone seawall with a height increase of 2 ft (0.6 m) (Trufant 2013). In January 2014, winter storms destroyed sections of the seawall, and a 1,000 ft (305 m) section, which is less than half of the damaged length, was reconstructed with a 2 ft (0.6 m) height increase in the fall of 2015 at a cost of $4 million (Conti 2015).
   Approximate cost: $3,379/ft ($11,076/m)
7. **Elliot Bay, Seattle, Washington: Seawall Replacement (2013)**
   The Elliot Bay seawall is currently being replaced in Seattle, Washington, from South Washington Street to Broad Street (approximately 4,000 ft [1,220 m]). The cost of the replacement has been estimated at $300 million (Thompson 2012).
   Approximate cost: $75,000/ft ($246,063/m)
8. **Mantoloking and Brick Township, New Jersey: Stone Seawall Construction (planned)**
   A new steel seawall is being planned along the oceanfront in the communities of Mantoloking and Brick Township. It will extend for 10,636 ft (3,242 m) and has a cost estimate of $78,905,000, including purchase of easements and property (USACE 2015).
   Approximate cost: $7,418/ft ($24,338/m)
9. **Riis Landing, Gateway National Recreation Area: Bulkhead Repair (2013)**
   An award was made with a construction company to make repairs to the bulkhead at Riis Landing in the Jamaica Bay unit of the Gateway National Recreation Area at a cost of $1.1 million; the bulkhead is approximately 500 ft (152 m) in total length (NPS 2012).
   Approximate cost: $2,200/ft ($7,217/m)

Benefits

Seawalls, revetments, and bulkheads reduce the impact of wave energy and associated erosion on coastal assets directly behind them along vulnerable shorelines. These structures may be a good choice for protecting assets that are not feasible to relocate, such as cultural landscapes and associated sensitive cultural and historic assets.

Impacts and Disadvantages

These structures are expensive and disturb the natural sediment transport processes that allow a beach to maintain itself. They cause both active and passive erosion of the beach in front of the structure. When waves hit a seawall or bulkhead, they are reflec ed downward, increasing scouring at the toe of the wall (active erosion). This impedes the natural landward migration of beaches in response to sea level rise (passive erosion). The reflec ed wave energy also degrades seagrass, submerged habitat, and marsh areas that might otherwise grow on the bay side of structures (Titus and Strange 2008). If a bulkhead is constructed at the shoreline, the area landward of a bulkhead is typically filled, co verting existing marsh or beach to uplands (Benoit et al. 2007); this can be considered an impact to existing habitat but a benefit to uplands. Structures made of rip-rap stone have an additional disadvantage: they are very diffi lt to clean following an oil spill, because oil becomes entrained within the structure and is then slowly released over a much longer time scale than it might otherwise be.

All three structure types provide only a temporary solution to a threatened asset. The beach that is seaward of the structure will narrow and steepen as soon as the structure is constructed. Stone or riprap is often placed at the toe of a bulkhead to absorb some of the wave energy (Benoit et al. 2007). Over time the scouring at the toe of the structure will cause destruction of the beach ecosystem, including turtle and bird habitat, and can remove the public recreational beach. Recurring beach nourishment is often needed when seawalls are placed on the oceanfront to replace the beach that will eventually be lost seaward of the structure. It is generally recognized that seawalls, revetments, and bulkheads can also cause “end effect” erosion, which occurs when the structure causes erosion on the down-drift side of the structure. The structures need to be maintained and repaired (at a high cost) and are often overtopped and damaged by water during storms. It is possible to design seawalls to withstand some overtopping so that following a storm, they can return to service quickly.

An additional limitation of seawalls is the incorrect perception that they are designed to prevent floodi g, even when their height is insuffi ent and their intended purpose is to prevent erosion. This is a kind of induced risk, in that the risk reduction measure can lead to increased overall risk, such as residents’ failure to evacuate during dangerous conditions or leaving resources vulnerable to floodi g due to a misperception that the structure can protect them.

Shore-Perpendicular Structures: Jetties and Groins

Jetties (figu e 8.4) are hard structures that extend perpendicularly or at nearly right angles from the shore and are commonly used to limit the volume of sediment deposited in inlet channels, prevent inlet migration, and decrease wave energy around inlets.

Groins (figu e 8.5) are structures that extend perpendicularly or at nearly right angles from the shore and are shorter than jetties (Coburn, Griffith, and Young 2010). Often constructed in groups called groin fi lds, their primary purpose is to trap and retain sand that is being transported alongshore to build the beach on the updrift side of the structure. Jetties and groins can be constructed from a wide range of materials, including armorstone, pre-cast concrete units or blocks, rock-filled timber cribs a d gabions, steel sheet pile, timber sheet pile, and grout filled bags and tubes.

Sea level rise increases the possibility of flan ing or submergence of these structures (Heberger et al. 2009). Flanking may occur during high tides, because landward retreat of the beach and dune line leave the structure’s landward attachment point exposed. Submergence of the structure can lead to overtopping by the longshore current (Heberger et al. 2009).

Costs

The cost of groin construction, repair, and replacement generally ranges from $250 to $6,500 per linear ft ($820 to $21,325 per m) depending on the material used (NCCRC 2010). Jetties tend to be more expensive, reaching up to $16,000 per linear ft ($52,495 per m). Jetties require maintenance, such as elevating the jetty height and extending the downdrift jetty inland

Figure 8.4. Ocean City Inlet jetty and breakwaters on the north end of Assateague Island National Seashore in 2011. Photograph by NPS.

as the shoreline retreats to extend the lifespan of the structure. Maintenance frequency may vary depending on erosion rate of the land to which it is tied, water level including storm surges, and height and integrity of the initially-built structure. Costs of maintenance depend on the level of maintenance (e.g., minor modificat on vs. complete rebuild), material used, labor used, diffi lty of accessing the site, time frame of modificat on, and regulatory and public notice requirements, among other considerations (USACE 2008).

Examples of jetty and groin projects are summarized below with cost estimates and project details. Both NPS and non-NPS examples are included.

Figure 8.5. Steel sheet-pile groin at the former location of the Cape Hatteras Lighthouse. Photograph by NPS.

1. **Columbia River Inlet, Lewis and Clark National Historic Park: Jetty Repair (2007)**
   The south jetty at the mouth of the Columbia River in Lewis and Clark National Historic Park was repaired in 2006–2007 at a cost of $1.9 million for 5,300 ft (1,615 m). The jetty is constructed of stone (USACE 2012).
   Approximate Cost: $3,585/ft ($11,176/m)
2. **Ponce de Leon Inlet, Florida: Jetty Extension (2010)**
   The south jetty at Ponce de Leon Inlet in Florida was extended by 900 ft (274 m) for $14.8 million in 2010. The extension was constructed out of light-weight stone from a Florida quarry and was a straight jetty design (Florida Department Environmental Protection 2010).
   Approximate cost: $16,444/ft ($53,950/m)
3. **Matagorda, Texas: Jetty Replacement (2010)**
   The east jetty on the mouth of the Colorado River in Matagorda, Texas, was replaced in 2010 by the US Army Corps of Engineers. The jetty was 2,780 ft (847 m) in length and constructed of 170,000 tons of rock, at a price of $25 million (MCEDC 2011).
   Approximate cost: $8,992/ft ($29,500/m)
4. **North Carolina Terminal Groin Study (2010)**
   The North Carolina legislature directed the North Carolina Coastal Resources Commission to initiate this project for the consideration of terminal groin construction in North Carolina. A study (NCCRC 2010) was conducted on the costs, benefits, a d impacts of terminal groins. Table 8.2 summarizes the results of this study and the costs for the installation and repair of terminal groins.

Table 8.2. Construction costs by material.

Construction Material	Price Per Linear Foot	Price Per Linear Meter
Rock and Stone	$1,200–$6,500	$3,937–$21,325
Concrete and Steel Sheet Pile	$4,000–$5,000	$13,123–$16,404
Timber	$3,000–$4,000	$9,843–$13,123
Geotextile	$250–1,000	$820–$3,281

Two specific e amples from the 2010 North Carolina terminal groin study are summarized below:

a. **Fort Macon, North Carolina: Terminal Groin Construction (1961–1970)**
   The terminal groin at Fort Macon was constructed between 1961 and 1970 and is a 1,530-ft (466-m) stone structure. The crest width of the groin is around 10 ft (3 m) and the base width around 60 ft (18 m). According to the authors of the study, the groin cost $2.9 million in 2009 dollars (NCCRC 2010).
   Approximate cost (2009 dollars): $1,900/ft ($6,234/m)

b. **Oregon Inlet, North Carolina: Terminal Groin Construction (1991)**
   Oregon Inlet impacts Cape Hatteras National Seashore. The terminal groin on the south side of Oregon Inlet was built in 1991 at a cost of $13.4 million. It is a stone structure 3,125 ft (952 m) long and includes a revetment on the shoreline. An estimated (2009 dollars) cost of $26.3 million for the structure was made in this study (NCCRC 2010).
   Approximate cost (2009 dollars): $8,410/ft ($27,592/m)

Benefits

Groins can create a temporary wide beach on the updrift side of the structure. Jetties limit sediment flow i to the adjacent inlet, reducing the frequency of maintenance dredging to maintain a navigable depth. Jetties also reduce the wave energy within the inlet and can widen the beach just up-drift of the structure.

Impacts and Disadvantages

Shore-perpendicular structures, such as groins and jetties, disrupt natural beach processes and alongshore sediment transport pathways. By design, these structures are meant to capture sand transported by the longshore current; this depletes the sand supply to the beach area immediately down-drift of the structure. In response, down-drift property managers often install groins on adjacent properties to counteract the increased erosion, leading to a cascading effect of groin installation. Groins may be notched to increase their permeability, allowing some sediment to pass over the groin. This strategy is used with beach nourishment projects to limit overall sediment loss and to reduce renourishment frequency.

Jetties can also hinder inlet migration and delta processes, which are natural and important parts of the stability of coastal systems that allow sediment to build marsh platforms and add sediment to the bay side of an island. Large jetties and groins can alter physical processes significa tly, which in turn can create new and different habitat. For example, a jetty can trap large quantities of sand on the updrift side, which can create beach, sand dune, or other upland coastal habitat that replace the nearshore or intertidal environment. This might be considered a benefit or the habitat type created and an impact to the pre-existing habitats and associated resources that are lost.

Breakwaters

A breakwater (figu e 8.4) is an offshore shore-parallel structure that breaks waves, reducing the wave energy reaching the beach and fostering sediment accretion between the beach and the breakwater. It is made of rock, concrete, or oyster shell (if in a low-wave environment). It can be floati g or fi ed on the ocean floor a d can be continuous or segmented or as a series of spheres (reef balls). It can be high-crested to act as wave barriers, low-crested to allow overtopping, or submerged to lessen its physical and visual impact (Nordstrom 2014). Breakwaters are often used in marinas or other areas without high wave energy (SAGE, NOAA, and USACE 2014).

Breakwaters within protected harbors are not expected to be impacted by sea level rise over a 50-year project life span (HR Wallingford 2015), although that review only considered the lowest sea level rise scenario. If sea level rises to the point that the breakwater is submerged at high tide, the breakwater would be a navigation hazard. Breakwaters exposed to increased wave height associated with sea level rise may be weakened by wave impact; extreme significa t wave heights are expected to increase by about 55% of the increase in relative sea levels, for a total increase of 155% (HR Wallingford 2015). The increased frequency of wave overtopping will reduce the ability of the breakwater to shelter the shoreline from wave energy (Heberger et al. 2009). Additionally, rising water levels will effectively move the shoreline farther from the breakwater, increasing the ability of the waves to diff act behind the structure and reducing the breakwater's effica (Heberger et al. 2009).

Costs

Initial construction costs are up to $10,000 per linear ft ($32,808/m) and an annual maintenance cost of over $500 per linear ft ($1,640/m), assuming a 50-year project life (SAGE, NOAA, and USACE 2014).

Benefits

Breakwaters reduce the force and height of waves reaching the shoreline. Sediment accretes landward of the breakwater, and in the case of high-crested breakwaters, can even create salients that connect the beach to the structure.

Breakwaters can stabilize wetlands and provide shelter for new intertidal marsh habitat to form landward of the structure (Nordstrom 2014). The rocky habitat can provide some reef function (SAGE, NOAA, and USACE 2014). Along estuarine shorelines, bagged oyster breakwaters were found to support much higher densities of live ribbed mussels than reef ball breakwaters, but both configu ations supported increased species richness of juvenile and small fi hes compared to controls (Scyphers, Powers, and Heck 2014).

Impacts and Disadvantages

Breakwaters are expensive to install in deep water, can create a navigational hazard, and can reduce water circulation. Sediment that accumulates landward of the breakwater may reduce alongshore transport, leading to downdrift erosion; this sediment can be silty and rich in organic matter. Intertidal marsh that forms landward of the breakwater may not be appropriate in that location and may replace a natural sandy beach habitat (Nordstrom 2014). Breakwaters do not provide high water protection (SAGE, NOAA, and USACE 2014).

Beach Nourishment

Beach nourishment, also referred to as renourishment or replenishment, is the placement of sand onto beaches or within the nearshore (figu e 8.6). Sand is obtained from an outside source; it is commonly dredged from an offshore location and pumped via pipelines directly onto the beach or dumped from a hopper dredge into the nearshore, or in some cases it is trucked from an inland source and dumped onto the lower beach. Nourishment replaces sand that is lost because of coastal erosion and can temporarily widen a narrow beach. Many times this process is used to mitigate erosion caused by hard structures such as groins and seawalls. The placement of sand on the beach increases the distance between vulnerable infrastructure and wave energy, which in some cases can help mitigate and postpone damage to infrastructure and property from coastal hazards. Berms may also be built when sand is added to replace dune function; they absorb wave energy before the water reaches infrastructure behind the dunes, and they serve as a sand source to nourish the beach. Dunes may be stabilized by planting vegetation and erecting sand fencing, which is described in the following section. The NPS Reference Manual 39-2: Beach Nourishment Guidance provides guidelines and best management practices for implementing beach nourishment projects where they have been deemed necessary and consistent with NPS management policies (Dallas, Eshleman, and Beavers 2012).

Figure 8.6. Beach nourishment at Assateague Island National Seashore in 2002 added sediment and widened the beach. Photograph by NPS.

Nourished beaches are subject to the same erosional forces as natural beaches (NRC 2014), and increased renourishment frequency is expected with increased sea level rise and storm impacts.

The US Fish and Wildlife Service (USFWS) has published a set of best management practices (Rice 2009) to avoid adverse impacts to biological resources including macro-invertebrates upon which fi h and birds prey, and which can be buried by sand placement. Important considerations include the timing of any sand placement relative to reproductive seasons; the quality and match of sand grains to the existing habitat; and maintaining the appropriate beach slope.

Costs

The cost of beach nourishment, like other types of coastal protection measures, varies depending on the method, location, and distance to the source sand. However, it is widely acknowledged that this method of protection can be extremely expensive, especially given that the process must be repeated frequently (commonly every few years). The cost of nourishment, including the transport and placement of the material, is commonly between \$300 and \$1,000/ft (\$984 to \$3,281/m) or between \$5 and \$30/yd^3 (\$3.80 to \$23/m^3) of sand. Below are eight beach nourishment projects in recent years within and outside of NPS coastal park units.

1. **Assateague Island, Maryland (2002)**
   A one-time beach nourishment event widened the beach by 100 ft (30 m) in the area between 1.2 and 7.5 mi (2 and 12.5 km) south of the Ocean City Inlet (figu e 8.6). The sediment was dredged from Great Gull Bank, in offshore Maryland State waters, and placed just seaward of the mean high water line to replace about 15% of the sand captured by the Ocean City Inlet since 1934 (USACE 1998). This effort cost \$13.2 million.
   Total Volume: 1,832,000 yd^3 (1.4 million m^3)
   Approximate cost: \$7/yd^3 (\$9.42/m^3)
2. **Assateague Island, Maryland (2004–present)**
   The North End Restoration project is a 25-year effort that began in 2004 to restore sediment transport to the North End, which has been eroding since the Ocean City Inlet was stabilized in 1934. Twice each year, a dredge vessel takes sand from the inlet ebb and flood t dal deltas and deposits it approximately 1.5 to 3.1 mi (2.5 to 5 km) south of the inlet, placing a volume approximately equal to the natural pre-inlet longshore transport rate. The bypassed borrow material is deposited on the crest and just seaward of the nearshore bar. The project

moved 1,990,956 yd³ (1,522,195 m³) between 2004 and 2010. The estimated cost for dredging and placing sediment, and for monitoring and administering the project, is $2 million annually (Schupp et al. 2013).
Total Volume: 188,345 yd³/year (144,000 m³/year)
Approximate project cost: $10.62/yd³ ($13.89/m³)
Approximate cost, not including monitoring program: $6 to $7/yd³ ($7.85 to $9.15 m³)

3. **Cape May Point, New Jersey (2005–ongoing)**
Cape May had been negatively affected by the dredging of a 3-mi (5-km) canal during World War II, as well as the installation of jetties in 1911, resulting in significa t beach erosion. In 2005, USACE began a four-year renourishment cycle. Initial nourishment in 2005 consisted of 1.5 million yd³ (1,146,832 m³) at Meadows and Cape May Point as well as nourishment of the Cape May Inlet (Fox 2007; USACE 2013). Nourishment occurring through 2014 brought the total to 3.9 million yd³ (3 million m3) placed at a cost of $40.9 million (PSDS 2016).
Total Volume (2005-2014): 3.9 million yd³ (3 million m³)
Approximate cost: $10.45/yd³ ($13.70/m³)

4. **Harrison County, Mississippi (2007)**
Development along the coast of Harrison County, Mississippi, has compromised the natural shoreline. Beginning in the 1950s, a seawall and human-made beach were constructed to protect the shoreline. The latest renourishment along the 24.5 mi (39 km) of beach took place in 2007, pumping 1.1 million yd³ (841,010 m³) of sand and costing about $6 million (Melby 2007; Brown, Mitchell & Alexander, Inc. 2011; PSDS 2015).
Total Volume: 1.1 million yd³ (841,010 m³)
Approximate cost: $5.40/yd³ ($7.13/m³)

5. **Bald Head Island, North Carolina (2010)**
More than 150 ft (46 m) of beach had been lost on the west and south beach areas on Bald Head Island, North Carolina, by the time nourishment began in early November 2009. The dredged Cape Fear River contributed about 1.8 million yd³ (1,376,200 m³), which was pumped onto the shoreline over a four-month period at a cost of about $17 million (McGrath 2009; PSDS 2015).
Total Volume: 1.8 million yd³ (1,376,200 m³)
Approximate cost: $9/yd³ ($12.35/m³)

6. **West Ship Island, Mississippi (2011)**
Ship Island, part of the Gulf Islands National Seashore, was initially divided by Hurricane Camille in 1969 and the inlet significa tly widened during Hurricane Katrina in 2005. Therefore, a three-phase project was implemented to rejoin the East and West Ship Islands (Schupp, Beavers, and Caff ey 2015, "Case Study 14: Large-Scale Restoration of Barrier Island Systems and Cultural Resource Protection through Sediment Placement"). By 2011, more than 0.5 million yd³ (almost 432,000 m³) of sand had been pumped along 10,350 ft of the West Ship Island shoreline to complete the $6 million north shore portion of the project that will protect the historic Fort Massachusetts (NPS 2011a; Kirgan 2011; USACE 2014; PSDS 2015).
Total Volume: 565,000 yd³ (431,942 m³)
Approximate cost: $10.61/yd³ ($13.89/m³)

Additional renourishment and sand bypassing is planned as part of the Mississippi Coastal Improvements Program project and will affect other areas of the park. Filling in Camille Cut to rejoin East and West Ship Islands is estimated to require approximately 13.5 million yd³ (10.3 million m³) of sediment. As part of the Ship Island restoration, the southern (Gulf) shoreline of East Ship Island will also be renourished with 5.5 million yd³ (4.2 million m³) of sediment. The Ship Island restoration will be accomplished in 5 phases over a 2.5-year period beginning in early to mid-2016. Natural regional sediment transport volumes will be restored by modifying future placement locations to better place material dredged from Horn Island Pass into the active littoral drift zone. The estimated cost for sand placement in Camille Cut and nourishment of East Ship Island is dependent on borrow site combinations used and is estimated at $368 million, not including monitoring costs (USACE 2014).

7. **Perdido Key, Florida (2011)**
A sand renourishment project took place in 2011 on the south shore of Perdido Key, Florida, part of Gulf Islands National Seashore. The area had been heavily affected by Hurricane Ivan in 2004 and was considered "critically eroded." Three million yd³ (2.3 million m³) of sand from Pensacola Pass was used to restore 2 mi (3.2 km) of shoreline located between Johnson Beach and Perdido Key State Park, costing about $14.5 million (NPS 2011b; My Escambia n.d.).
Total Volume: 3 million yd³ (2,293,664 m³)
Approximate cost: $4.80/yd³ ($6.32/m³)

8. **Ocean City Beach, New Jersey (2013)**
The USACE beach nourishment project at Ocean City Beach, New Jersey, in 2013 was part of a series of beach maintenance projects for the area following Hurricane Sandy. This three month renourishment began in February 2013 when 1.8 million yd³ (almost 1.4 million m³) were placed along 2.3 mi (3.7 km) of the beach. The initial $11 million project raised its cost to about $18 million, which included supplemental funds from the

Sandy disaster fund (Bergen 2013).
Total Volume: 1.8 million yd^3 *(1,376,200* m^3*)*
*Approximate cost: $10/*$yd^3$ *($13.07/*$m^3$*)*

Benefits

Beach nourishment can provide protection from coastal hazards, such as storms, by increasing beach sand volume and beach width and reducing wave energy near at-risk infrastructure. The addition of sand to the beach profile (w dth and height) can also provide protection from moderate water level rise, up to the height of the constructed beach. Nourishment is often preferred to other types of coastal protection because many consider it a “soft” approach to beach engineering, which may attract less community resistance than hard structures such as groins, revetments, seawalls, or bulkheads. Some municipalities and states (e.g., North Carolina) restrict hard structures but allow soft stabilization. The additional beach width created by nourishment can help to promote beach tourism and recreational activities. Nourishment also creates a rapid visible change in the beach, in comparison to breakwaters or groins that trap sand over a longer period of time. Constructed dunes add sand to nourish the beach, with or without structural control, and provide a foundation for additional dune growth that may be enhanced by vegetation planting or sand fencing (Benoit et al. 2007). Newly constructed dunes provide new types of upland habitat, but it is not known if they provide the same ecosystem services, including wave energy dissipation, as naturally built dunes.

Impacts and Disadvantages

Beach nourishment can have ecological, physical, and fi cal consequences. Beaches have a natural process of migration, which can accelerate during storm events. Beach migration does not end after nourishment, and continued erosion results in the need for subsequent nourishment projects within the same area, typically every few years. This short-term approach is very costly and can shut down a beach area for several months during each nourishment project. Predictions related to the durability of a nourishment project (i.e., how long the sand will last) are commonly overestimates and cost predictions are commonly underestimates (Pilkey et al. 1998). Research has also shown that nourished beaches disappear more quickly and recover more slowly from storms than natural beaches do (Pilkey et al. 1998). The cost and scale of renourishment episodes are highly likely to increase with sea level rise and with any increase in storm frequency or intensity.

Compatible sand sources for nourishment projects can be limited. Where possible, sand is often dredged from local sites for the purpose of introducing similar and compatible sediment into the beach areas of nourishment, but appropriate sources are not always available nearby. Sediment taken from nearby areas may have different proportions or ranges of grain sizes that are incompatible with existing habitat, impacting shorebird foraging, sea turtle nesting, shallow marine life, and the aesthetic quality of the beach (e.g., mudballs on previously sandy beaches). Dredging from local offshore sources may provide sediment with similar characteristics, but the dredging can disrupt the sediment transport pathway and reduce the ongoing natural sand supply to that location or other portions of the coast. Also, sediment borrow areas may become depleted as nourishment increases, thus requiring sediment to be borrowed from a greater distance or potentially from a less compatible source.

There are ecological impacts in the areas where sand is dredged and placed. Borrow pits can fill w th fi e-grained sediment that is resuspended during storm events; this in turn can impact adjacent resources (e.g., coral reefs). Borrow pits with fi e-grained sediment also typically host a different ecological community from that which would occur naturally. Sand placement may cause burial of intertidal invertebrate communities (ASMFC 2002) and sedimentation of hardbottom reef structure (Lindeman and Snyder 2002) either by direct placement on reefs or as sediment is transported by nearshore waves and currents. Nourished beaches tend to have pronounced vertical scarps, especially soon after they are placed. This scarp can impact use by animals (e.g., shorebirds, turtles), and people (e.g., safety of oversand vehicles).

Physical processes can also be impacted by beach nourishment and associated dredging. For example, dredging inlet or delta sands, or placing sediment updrift of an inlet, can alter natural inlet and delta dynamics including inlet bypassing processes and flood t dal delta sedimentation. These dynamics and processes are vital for maintaining barrier island systems; the natural maintenance that is provided by these systems promotes resilience to storms and sea level rise. Any interruption or alteration of inlet or delta processes can hinder these benefits. For e ample, tidal delta deposits are often a major source of sand for nearby beaches; taking sand from these deposits may increase shoreline retreat downdrift.

Nourishment also can encourage increased development in high-risk areas. A nourishment project can give future land owners, land developers, and real estate personnel the erroneous impression that since the beach is wider, it is stable and low risk for damage and erosion. However, beach nourishment only postpones the danger by shifting the current shoreline seaward and does not reduce or eliminate erosion. For more information on park boundaries and jurisdiction that might be impacted by beach nourishment, see NPS 39-1 Ocean and Coastal Jurisdiction Reference Manual.

Sand Fencing

A sand fence can be constructed on a beach or dune to build a new foredune or to fill gaps in une ridges by reducing wind speed or trapping sand. Fences can be made of wooden slats, plastic, or fabric attached to fence posts. Fences that run parallel to the shore can build a protective dune ridge. Two parallel lines of fencing create a wide foredune with a round crest and allow for planting dune grasses. Zig-zag configu ations can create wider dunes with lower slopes that appear more natural. Fence configu ations that maximize height of the dune are best for infrastructure protection; configu ations that create multiple crests on lower and wider dunes are best for enhancing ecological value (Nordstrom 2014). Fences have been used at many national seashores, including Assateague Island National Seashore (Schupp and Coburn 2014) and Cape Hatteras National Seashore (Schupp 2015).

Costs

Sand fences are relatively inexpensive, are easy to install, and do not often require permits.

Benefits

Sand fences can support increased vegetation growth and species richness by reducing wind stress and salt spray (Nordstrom 2014). Sand fencing can provide co-benefits by directing visitor pathways away from delicate dune and beach habitats.

Impacts

Sand fences are usually placed at a highly dynamic boundary between the beach and dune, which is important habitat for sea turtles and nesting shorebirds (Nordstrom 2014). Effective sand fences are buried as the sand is trapped, so they are not removed. When exposed by erosion events, the relict fencing material may create unwanted debris and safety hazards on the beach.

Natural and Nature-based Features (NNBF)

Shorelines can be protected by natural features, nature-based built features, other built features, and hybrids of these feature types. Nature-based features may mimic characteristics of natural features but are human constructions to provide specific se vices such as coastal risk reduction. The combination of both natural and nature-based features is referred to collectively as NNBF. The relationships and interactions among the natural and built features in the coastal system influe ce coastal vulnerability, reliability, risk, and resilience (Bridges et al. 2015).

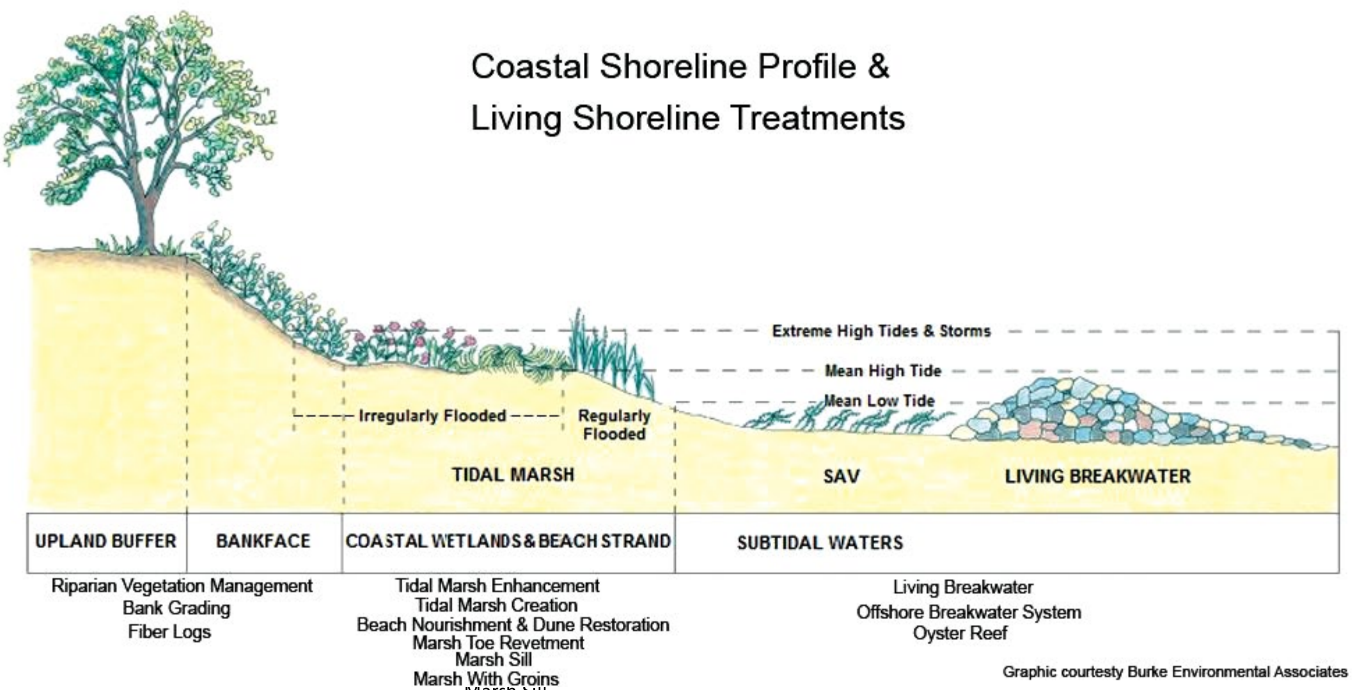
Living shorelines use natural elements, such as vegetation, to stabilize sheltered coastlines such as along estuaries. They maintain continuity of the natural land–water interface and reduce erosion while providing habitat value (NOAA 2015). For example, along low-energy estuarine shorelines, native plants can be planted so that their roots hold soil in place to reduce erosion. The plants provide a wave buffer to upland areas.

Nature-based features, also known as hybrid techniques (figu e 8.7), incorporate both nonstructural components and structural approaches (e.g., rock sill, breakwater). They have sometimes been referred to as "living shorelines," a misnomer because the living component can be used as a façade to build what is functionally a hardened shoreline. An example is the combination of plantings with edging (e.g., geotextile tubes, oyster reef) or rock sills to hold the toe of the existing slope in place (see Schupp, Beavers, and Caff ey 2015, "Case Study 3: Shell Mound Sites Threatened by Sea Level Rise and Erosion"). Sills are low edges that protect marsh grass fringe by breaking approaching waves. Breaks in the sills allow fauna to cross through the barrier. Building a sill system requires encroachment beyond the shoreline. Sand may be added with marsh grass plantings to provide stability and will be necessary at sites with a wind fetch that exceeds 0.5 mi (0.8 km). Creating this system changes existing habitat; the eroding bank, narrow beach and nearshore are converted to a stable bank, marsh and stone sill (Benoit et al. 2007).

It is important to have ongoing maintenance of the living shoreline, including replanting vegetation as needed, trimming tree branches, removing debris, and removing any interfering invasive species (NOAA 2015). The natural feature, if not maintained correctly, may damage the hard structure; an example would be when trees colonize the shoreline and then fall in a storm, causing their roots to unseat the hard structure. Conversely, the structural components can interrupt natural processes or the non-structural components can fail.

Figure 8.7. Examples of hybrid approaches to living shorelines. ***Notes: (a) This hybrid approach to a living shoreline uses natural and nature-based features by combining a planted marsh with a rock sill. Photograph from Bilcovic and Mitchell (2011). (b) The vegetation component of this hybrid approach at GATE was unsuccessful, leaving only shoreline armoring. Photograph by NPS.***

NOAA Fisheries Office Habitat Conservation provides [guidance for living shoreline planning and implementation](), including a diagram (figu e 8.8) showing a continuum of treatment options (NOAA 2016); other good sources are Benoit et al. (2007) and the Maryland Chesapeake Bay experience over the past decades (Maryland Department of Environment 2008). In general, nonstructural approaches are better suited to low wave energy environs, while hybrid techniques are typically applied in areas of medium to high wave energy (Bilcovic and Mitchell 2011). The non-structural component should be appropriately designed for the environment.



Marsh Sill
Marsh With Groins
Graphic courtesy Burke Environmental Associates

Figure 8.8. Living shoreline options for stabilizing estuarine shorelines. Figure by Burke Environmental Associates available via National Geographic, http://nationalgeographic.org/encyclopedia/living-shoreline/ (accessed 9 September 2016).

A hybrid engineering approach known as Systems Approach to Geomorphic Engineering (SAGE) is being advocated by a Community of Practice of numerous of agencies and organizations, including state and federal government (USACE and NOAA), academic institutions, NGOs, and private sector. The goals are to stabilize the shoreline, reduce current rates of shoreline erosion and storm damage, provide ecosystem services (such as habitat for fi h and other aquatic species), increase flood torage capacity, and maintain connections between land and water ecosystems to enhance ecosystem resilience (SAGE, NOAA, and USACE 2014). SAGE considers the landscape view of how multiple site management strategies work (or do not work) together, such as a protected area with no shoreline structures next to a levee or living shoreline or seawall. SAGE leverages partnerships across entities and jursidictions making these decisions, and provides expertise and information needed to make them.

Recent research suggests that the biggest cause of salt marsh erosion is waves driven by moderate storms, not occasional major events such as hurricanes and other strong storms, which contribute less than one percent of deterioration (Leonardi, Ganju, and Fagherazzi 2016). Storm impacts on wetlands often include erosion, stripped vegetation, and salinity burn, all of which can decrease long-term productivity; storms may also introduce new sediment that increases long-term sustainability of wetlands with respect to sea level rise (Bridges et al. 2015). Long-term consequences for wetland systems depends on many factors, including the size of the wetland, proximity of the wetland to a storm track, and post-storm conditions (for example, high post-storm precipitation will reduce the effects of salinity burn) (Bridges et al. 2015). Salt marsh elevation may not be able to keep pace with the rate of sea level rise (Bridges et al. 2015). Many components of natural infrastructure, including vegetation and oyster reefs, may be increasingly vulnerable to climate-related changes, such as warmer water, disease, invasive species, and changes in salinity, water temperature, and air temperature (Melillo, Richmond, and Yohe 2014). Planning for hybrid projects must consider the lifespan of the living component and the possibility that the living component will fail and the hard structure will remain.

The draft proposed 2017 Nationwide Permits issued by the USACE includes a new Nationwide Permit (NWP B) for the construction and maintenance of living shorelines, which would be separate from NWP 13, which authorizes bank stabilization activities (USACE 2016). Doing a project under a NWP decreases the processing times and permit application costs associated with obtaining authorization under Section 404 of the Clean Water Act and Section 10 of the Rivers and Harbors Act of 1899.

Costs

Estuarine vegetation planting has an initial construction cost of up to $1,000 per linear ft ($3,280/m) and an annual maintenance cost of up to $100 per linear ft ($328/m), assuming a 50-year project life. Construction of edging or sill in combination with vegetation planting has an initial construction cost of up to $2,000 per linear ft ($6,562/m) and an annual maintenance cost of up to $100 per linear ft ($328/m), assuming a 50-year project life (SAGE, NOAA, and USACE 2014).

Costs will vary depending on the materials used. Installation may require professionals. Long-term maintenance is required, such as post-storm replanting.

Benefits

Living shorelines are increasingly promoted as a way to protect estuarine shorelines, as an alternative to armoring, which can result in habitat fragmentation or loss, reduced capacity to fi ter pollutants, reduced biotic integrity, increases in invasive species, and disturbance of sediment budgets sustaining adjacent properties (Bilcovic and Mitchell 2011). Vegetation alone or planted in combination with the edging or sill structures will dissipate wave energy, provide habitat and ecosystem services, and slow inland water transfer. Planting submerged aquatic vegetation such as seagrass stabilizes sediment and may contribute to wave attenuation at low tide (Koch 2001). Seagrass beds are most effective at attenuating waves (and thus protecting the shoreline) when seagrass height reaches the water surface (Fonseca and Cahalan 1992).

Impacts and Disadvantages

Estuarine vegetation planting may increase or decrease storm surge water levels (and therefore wave energy) depending on the storm and the water level relative to the planted elevation. They may be misperceived as protecting uplands from high water, which they are not intended to do. Vegetation survival may be limited or unsuccessful (figure 8.7b) and may depend on competition with invasive species (SAGE, NOAA, and USACE 2014).

The value of seagrass beds for shore protection is limited by their seasonality. During the winter months, seagrasses in temperate areas become less dense or may even disappear.

Hybrid techniques can be more effective at reducing erosion, but the structural component will disrupt sediment processes and many of the benefits as alternatives to traditional armoring are lost. When a hybrid approach is planned, there needs to be a contingency plan for removing the structures or restoring the vegetation if the initial vegetation does not survive. Permitting processes may be complicated because the existing regulatory process is centered on traditional hard stabilization techniques.

Redesign the Structure

Adapting the design of a structure is another way to protect a structure, or the function of a structure, in place (figure 8.9). Design options for existing infrastructure include elevating the structure, elevating systems within the structure, or waterproofing mechanical systems (as described in "Chapter 9 Lessons Learned from Hurricane Sandy"). New construction design may include elements such as sacrificial construction that is expected to be destroyed during an event, but will minimize clean up or hazards. Historic infrastructure may now be insufficient for modern conditions, such as stream culverts in places experiencing increased high flow events. Enlarging or re-engineering culverts (see Schupp, Beavers, and Caffrey 2015, "Case Study 15: Rehabilitating Stream Crossings on Historic Roads") can prevent erosion and road damage and may provide additional benefits (e.g., improving fish passage).

Costs

Costs may be lower than complete removal or relocation of the structure. Adaptive maintenance costs and requirements may be higher than for typical infrastructure; for example, adapting the electrical panels to withstand future inundation at Ellis Island required innovation and upgrades to standard electrical panels (see "Chapter 9 Lessons Learned from Hurricane Sandy").

Benefits

Elevating a structure can prolong its accessibility and functionality for many years and may allow use of the structure until the end of its expected serviceable years. This option postpones or eliminates the need to find and impact a new site. It also allows historical structures to remain within an associated historic or cultural landscape.

Impacts and Disadvantages

Pilings used to elevate a structure may be undermined by continued shoreline erosion and changes in groundwater elevation. Means of accessing the structure may change, for example, if roads are undermined by continued erosion. Utility systems for elevated structures can be problematic, especially if buried, as they are vulnerable where they come up to the structure. This approach is likely not feasible as a permanent solution, and additional measures such as relocation or removal may need to be considered as shoreline vulnerability increases.

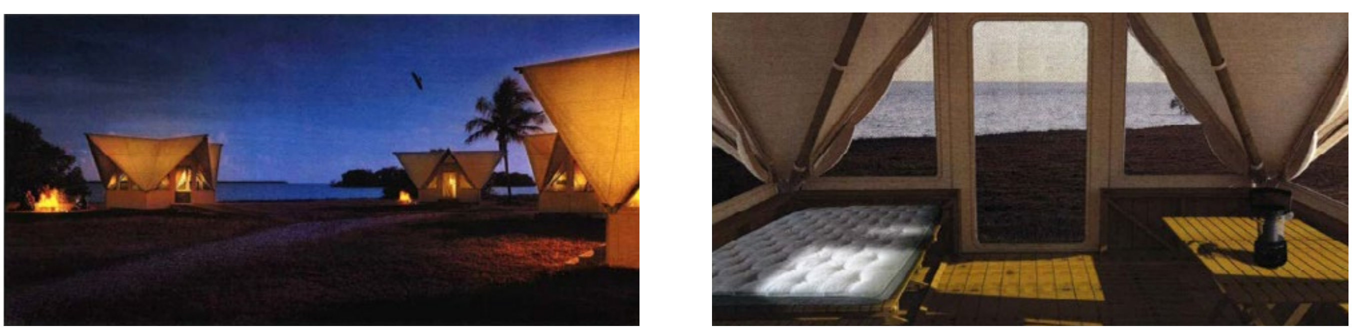


Figure 8.9. Visitor facilities have been redesigned at Everglades National Park; the new eco-tents are designed to be portable and can be moved in advance of storms. Images by NPS.

Figure 8.10. In this example of relocation and retreat, the Cape Hatteras lighthouse was moved inland using a railway. Photograph by NPS.

Relocate

Structure relocation is the strategy of transporting a structure from a vulnerable area and placing it in a more stable location (figu e 8.10). This can reduce structure vulnerability to threats, such as undermining caused by shoreline erosion, damage from wave impact, boring by marine organisms, and sea level rise. A structure can be moved as a whole or in parts using a flat-bed tr ck or temporary rails. The transport distance can vary, but most examples of relocation have been less than 500 feet inland from the original location. Infrastructure can also be replaced by structures that are designed to be moved landward to a new site, usually once or twice away from an eroding shoreline, or by portable structures that are moved off site seasonally or ahead of a storm and then returned (see Schupp, Beavers, and Caff ey 2015, "Case Study 16 Relocating Visitor Facilities Threatened by Accelerated Erosion"). Relocation should also consider the vulnerability of the new site to climate change.

Costs

The cost of structure relocation ranges from $800 to $40,000 per linear ft ($2,625 to $131,234/m) of movement depending on the size of the structure and method of relocation. Various projects within this range are described below.

1. **Hunting Island, South Carolina: Lighthouse Relocation (1889)**
   The second Hunting Island Lighthouse, fir t lit on July 1, 1875, was an iron building capable of being relocated. It was thought to be protected by a jetty constructed in 1886, until one year later a storm resulted in the shoreline being only 152 ft (46 m) from the lighthouse. In 1889, the relocation of Hunting Island Lighthouse, 6,600 ft (2,012 m) inland from the original site, lasted six months and cost $51,000 ($1.3 million in 2013 dollars) (Lighthouse Friends 2001b).
   Approximate cost of relocation (2013 dollars): $197/ft ($646/m)
2. **Block Island Southeast, Rhode Island: Lighthouse Relocation (1993)**
   Block Island Southeast Lighthouse, built in 1874, stood only 75 ft (23 m) from the edge of a bluff formed by substantial erosion. It was moved 300 ft (91 m) farther inland in August 1993 over a period of 19 days at a cost of approximately $2 million (Lighthouse Friends 2001c).
   Approximate cost of relocation: $6,666/ft ($21,870/m)
3. **Highland, Cape Cod, Massachusetts: Lighthouse Relocation (1996)**
   The relocation of Cape Cod's Highland Lighthouse, which is within Cape Cod National Seashore, occurred over a two-week period in July 1996. The Coast Guard Light was transported 450 ft (137 m) westward to escape the ongoing erosion occurring on the Highlands of Truro. The cost of this relocation was about $1.54 million (Lighthouse Friends 2001a; NPS 2014a).
   Approximate cost of relocation: $3,422/ft ($11,227/m)
4. **Cape Cod, Massachusetts: Lighthouse Relocation (1996)**
   Nauset Lighthouse was only 36 ft (11 m) from a cliff in Eastham, Massachusetts, when it was relocated in 1996. The privately owned lighthouse, which is within Cape Cod National Seashore, was built to be moved, and had already been moved to Eastham from Chatham in the 1870s. Nauset Lighthouse was relocated 300 ft (91 m) inland in three days at a cost of $253,000 (Nauset Light Preservation Society 1996; NPS 2014a).
   Approximate cost of relocation: $843/ft ($2766/m)
5. **Herring Cove Beach, Cape Cod, Massachusetts: Structure Relocation (2013–ongoing)**
   A retreat and mitigation plan began in 2013 to relocate structures on Herring Cove Beach, part of Cape Cod National Seashore in Provincetown, Massachusetts, (see Schupp, Beavers, and Caff ey 2015, "Case Study: 17 Reducing Vulnerability of Coastal Visitor Facilities"). This included relocation of the north parking lot, a bath house and concession stand, and removal of a revetment constructed in the 1950s. The plan intended a one-time retreat to protect the structures for 50 years. The relocation included moving the north parking lot 125 ft (38 m) inland to an elevation of 15 ft (4.6 m) above sea level. The bathhouse and concession stand were replaced with a moveable, elevated structure

approximately 100 ft (30 m) landward of the former location. The cost of the retreat strategy was estimated at $4.5 million with an $825,000, 25-year maintenance plan (NPS 2013).
Approximate cost of relocation: $36,000/ft ($118,421/m)

Benefits

Structure relocation or "managed retreat" can be a long-term solution for infrastructure as sea level rise, erosion, and storms affect coastal national parks now and in the future. Relocation can have long-term fi cal benefits because removing the structure from the hazardous area can significa tly reduce the need for repair and maintenance, and by reducing interest in expensive hard stabilization structures (e.g., seawalls, groins, and bulkheads) and beach nourishment, which offer only temporary protection. Natural resources may also benefit from a managed retreat strategy because the shoreline can be allowed to migrate and function naturally.

Impacts and Disadvantages

The repeated cost and maintenance requirements of moving portable structures ahead of storms can be significa t although likely lower than replacing the structures or mitigating damages and cleanup from structures that the storm moves into sensitive areas (e.g., removing damaged structures from the marsh). It may be diffi lt to locate an appropriate site for relocation due to construction impacts on resources at a new undeveloped site or a lack of open sites within highly developed urban areas. In the case of historical structures, relocation will cause the loss of historical context. Resistance within local communities and from other stakeholders can also arise. Some infrastructure may be particularly diffi lt to move, such as large complex structures including power plants, water treatment facilities, and major roads.

Abandon in Place

The National Park Service will not always be able to maintain infrastructure in place. Certain types of nonessential infrastructure become obsolete over time, particularly within the National Park Service. Many units have structures, buildings, and roads that are never used by the public, that no longer provide their original intended service, or that have a historic value that is not essential to the interpretive themes of the park (Nordstrom and Jackson 2016). Other structures may be significa t but become prohibitively expensive to maintain and repair, and the park may lack staff and funding to carry out this maintenance. In these cases, parks may want to consider the adaptation option of letting the structure deteriorate and abandoning it in place. For cultural resources, the related strategy of Document and Release (table 5.4 in "Chapter 5 Cultural Resources") requires documentation of the resource, its condition, and the decision.

Costs

Abandoning in place reduces maintenance needs but creates new costs including preparing a structure for abandonment, including the NEPA and the NHPA compliance processes; securing the structure, removal of potentially hazardous materials; and documentation or data recovery where appropriate. This action may create an attractive nuisance where people are attracted to explore a structure that is unsafe. Continued deterioration may necessitate the eventual demolition and removal of the structure.

Benefits

Abandoning in place can have long-term fi cal benefits y reducing the need for ongoing repair and maintenance of the structure. This strategy may also eliminate the need for protective engineering structures and associated impacts to adjacent resources. Allowing no longer effective shoreline protection structures to deteriorate in place may allow the re-establishment of coastal landforms when the structure has deteriorated to a degree that is no longer interfering with natural processes (Nordstrom and Jackson 2016). The abandoned structure provides interpretive opportunities related to climate change including sea level rise impacts and the different conditions when the structure was built.

Impacts and Disadvantages

Impacts of abandoning in place include the deterioration and, over time, the demolition of infrastructure that may have historical or other functional value to the public. There also may be negative impacts on the local environment, such as introduction of hazardous materials or unsecured items that may be displaced during a storm if regular inspections to the infrastructure are not completed or if there is not funding for removal of the structures before they become hazardous. "Chapter 9 Lessons Learned from Hurricane Sandy" for a discussion of infrastructure that has deteriorated and been abandoned in place, especially the groins at Fort Tilden and numerous buildings at GATE.

Take Home Messages

- Shoreline stabilization mechanisms can protect resources in place but are not long-term solutions and have trade-offs, including disruption of natural processes.
- Beach nourishment can be a costly short-term effort. There are ecological and physical consequences of dredging sand from other locations and placement of sediment on intertidal and nearshore habitats.
- The effectiveness of natural and nature-based features for shoreline protection is site-specific. Their suitability as a long-term alternative depends on ability to adapt to climate change, design, and compatibility with local conditions.
- Consider opportunities to redesign and relocate facilities, and to replace facilities with portable structures. Evaluate the maintenance costs and non-standard costs associated with these alternatives.

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Chapter 9 Lessons Learned from Hurricane Sandy

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This case study highlights a few of the adaptation lessons learned from parks' efforts to prepare for and recover from Hurricane Sandy. It also evaluates the success of various adaptation strategies and identifies oppo tunities to improve those strategies. The magnitude of this storm provides insight into a future with projected higher intensity storms, though the science of changing storm patterns remains an active research fi ld.

Currently, the National Park Service is developing a range of storm recovery, response, and long-term planning efforts that integrate climate change adaptation, anticipating higher sea levels and storm surge. The lessons learned from Hurricane Sandy directly benefit he management of each of the affected parks, and similarly can improve adaptation planning at other parks facing increased impacts of future storms due to sea level rise. Hurricane Sandy preparedness, response, and recovery has been a complex partner coordination effort at all levels of government, and we can learn from the lessons of other agencies and our partners and communities (e.g., FEMA 2013; NOAA 2013) in addition to reflecti g on National Park Service (NPS) specific lessons described in this chapter.

Hurricane Sandy made landfall along the New Jersey coast on October 29, 2012. It was the largest diameter Atlantic hurricane on record, causing $50 billion in property damages and bringing very high storm surges (Blake 2013) (figu es 9.1, 9.2). Although its wind speed was relatively low (category 1 on the Saffir-Simpson scale), its westward direction was abnormal (most hurricanes in this area head northeastward). The storm surge coincided with peak high tide at Sandy Hook and at the southern tip of Manhattan in New York City (Sweet et al. 2013). Flood analysis yielded a return interval of between 559 and 650 years for the storm surge alone and 993 years for the surge plus tide at Manhattan (Shrestha et al. 2014).

The storm caused substantial damage to infrastructure in coastal national parks, including Ellis Island, which is part of the Statue of Liberty National Monument, New York, where mechanical systems were floo ed and destroyed. The Statue of Liberty National Monument; Castle Clinton National Monument, New York; Gateway National Recreation Area (GATE), New Jersey and New York; and other sites in the region experienced floodi g, significa t damage to mechanical systems, destruction of employee facilities, and considerable landscape changes. The storm inundated Sandy Hook in GATE, where storm surge exceeded 8.5 feet (2.6 meters) above normal tide levels (figu e 9.2) (Blake 2013), and breached Fire Island National Seashore (FIIS), New York, in two places in addition to eroding the barrier island's shoreline.

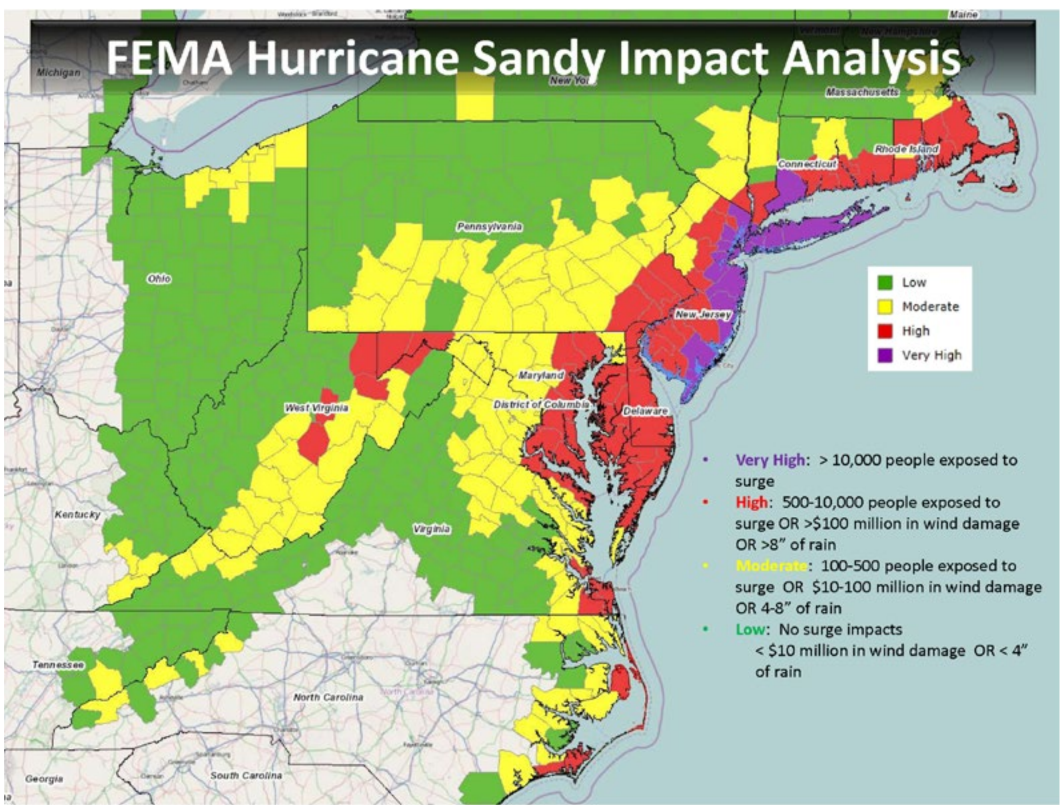

Figure 9.1. FEMA Impact Analysis of Hurricane Sandy. Slide 22 from Blake (2013).

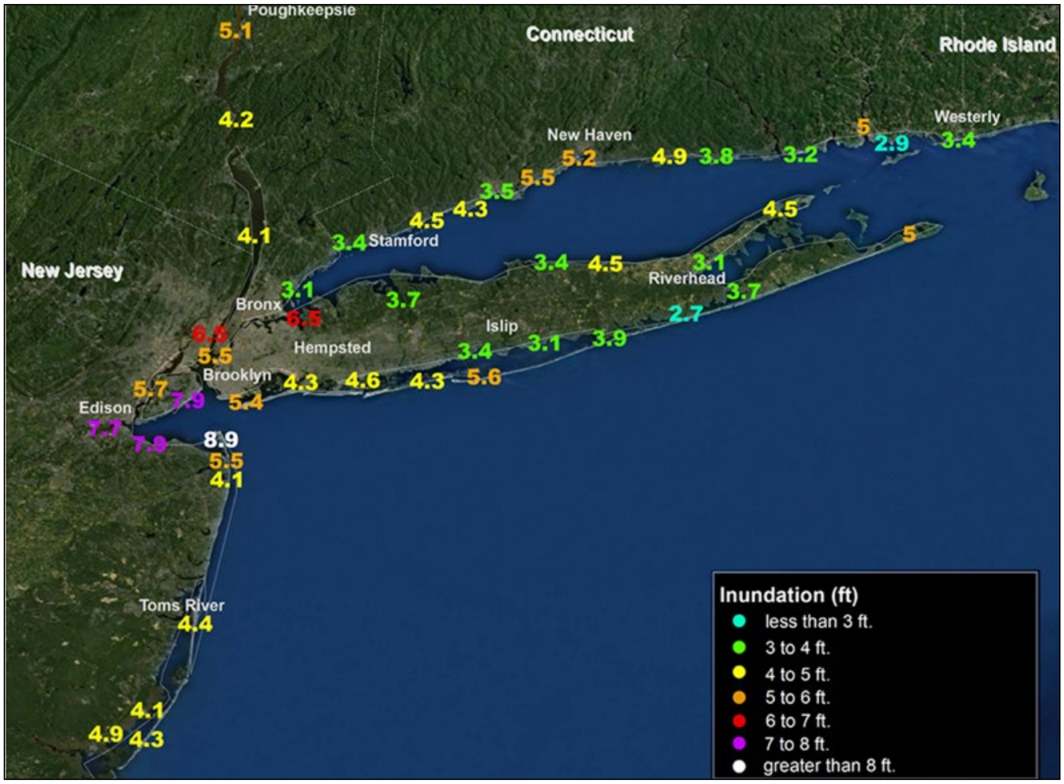

Figure 9.2. Estimated inundation (feet above ground level) was calculated from USGS high-water marks and NOS tide gauges in New Jersey, New York, and Connecticut from Hurricane Sandy. Figure 25 from Blake et al. (2013).

Disaster as a Driver of Adaptation

As discussed in “Chapter 3 Planning,” disasters can drive adaptation. Grannis et al. (2014) acknowledges that ideally, climate change adaptation actions are proactive where vulnerable communities anticipate and prepare for risks. In reality, adaptation actions are usually reactive, following a disaster. This highlights the importance of building in locations with lower vulnerability. Deliberately choosing reactive adaptation may be appropriate under some circumstances. For example, it does not make sense to undertake proactive adaptation measures if the costs and impacts of these adaptive measures are greater than the costs and impacts of recovery or replacement after a disaster. In such cases, plans for replacement or adaptive structures are ideally developed before a disaster, so that planners are better prepared to seize post-disaster opportunities to rebuild resiliently. To accompany such plans, continued awareness and monitoring will be benefic al to catch if costs and conditions change so that reactive adaptation may no longer have lower costs and impacts than proactive options.

Hurricane Sandy and funding provided to agencies through the Sandy Recovery Improvement Act (part of Public Law [PL] 113-2) provided an opportunity to incorporate climate change adaptation features in recovery projects. As the National Park Service worked to restore parks and park facilities during the Hurricane Sandy recovery phase (NPS 2013), there was high-level support to incorporate adaptation strategies where possible. The magnitude of damage and volume of recovery projects required a process to provide consistency and expanded capacity and project review.

The National Park Service created the Rapid Review Team (RRT) to review recovery projects quickly and to ensure that adaptation measures were included to the extent possible and practical. The team reviewed projects at the predesign stage to ensure appropriate consideration of projected future climate change impacts and that repaired or relocated facilities would be sound, sustainable, and resilient. The NPS Development Advisory Board (a board of NPS executives and external advisors who review all NPS construction projects valued greater than $500,000) delegated review authority for immediate repairs to the RRT and required RRT review for subsequent Hurricane Sandy projects before they were reviewed by the Development Advisory Board (DAB). The RRT has a national and a regional component depending primarily on project cost. During the fir t review phase, relevant to facilities reopening for the 2013 summer season, a set of standard questions evolved to guide design teams in considering construction and long-term resiliency. An RRT subcommittee composed of NPS subject matter experts used those questions to develop a document for the remainder of recovery project reviews. This chapter describes some of the adaptation examples that emerged from that process. The siting and design considerations that emerged from this RRT process informed the development of Level 3 guidance *Addressing Climate Change and Natural Hazards Facility Planning and Design Considerations (Handbook)* released in January 2015, to support Policy Memorandum (PM) 15-01, see “Chapter 6 Facility Management”).

Because of safety concerns, Fort Tilden Beach was closed to the public after Hurricane Sandy. One example of a recovery project included in the RRT process was removal of all concrete rubble from the demolished section of Shore Road, removal of exposed rusting steel cable at the deteriorating wooden bulkhead, and beach cleanup along Fort Tilden shoreline. This project enabled the re-opening of the beach to public use. The Fort Tilden Shoreline Resiliency Project / Environmental Assessment (EA) was underway at the time. As part of data collection activities pertinent to the EA, a Shoreline Structure Condition Assessment was completed for the historic wooden bulkhead and associated wooden groin system (groin fi ld is yellow in lower left of figu e 9.7). A full range of alternatives was developed and evaluated in a Value Analysis (a structured team process to achieve essential functions at the lowest life-cycle cost with required performance, reliability, quality, consistency, and safety factors.) The evaluation for the range of alternatives included assessment of resiliency and sustainability. This process assessed risk across a range of potential alternatives, and incorporated values including desired conditions for resources based on the management zones designated in the General Management Plan (GMP; NPS 2014a). The resulting preferred alternative recommends replacing the destroyed portion of Shore Road with an alternative surface (e.g., clay/shell) for pedestrian access and improving Range Road for accessibility and emergency egress and access for the adjacent community. It includes removal of the wooden bulkhead, associated wooden groins, and fi e damaged buildings/structures. Implementation is contingent on compliance and agency coordination, which is underway.

Assessing Impacts and Resilience

Natural Resources

After Hurricane Sandy, the National Park Service assessed the condition of natural and cultural resources and the built environment. In natural areas such as the Jamaica Bay salt marsh islands at GATE, the natural resource impacts were subtle and the recovery was rapid. The storm's effect on wetland restoration projects (see Schupp, Beavers, and 2015, "Case Study: 11 Restoring the Jamaica Bay Wetlands with Sediment and Plantings"), especially for the sites where sediment addition (with and without replanting) was completed just prior to the storm, was insightful; other than loss of the perimeter fence in some places, there was little immediate damage, and two years of post-storm data confirm hat wetland impact was minimal (NPS, Patricia Rafferty, coastal ecologist, Northeast Region, pers. comm. with Amanda Babson, 27 October 2014). At the tip of Breezy Point in the park, overwash fla tened rolling dunes and created extensive new shorebird habitat for piping plover, and by August 2013, there was substantial recovery of the beach grasses.

At FIIS, a comparison of pre-and post-Hurricane Sandy US Geological Survey (USGS) beach profiles howed substantial changes in beach volume due to the hurricane, but that as of September 2014, the beach was growing steadily and approaching pre-Hurricane Sandy conditions in some locations, likely because the sand remained within the littoral system in the nearshore area (Hapke et al. 2014) (figu e 9.3). Significa t impacts to natural resources resulted from debris floati g onto beaches and salt marsh habitat.

Built Environment

The greater resilience of the natural environment compared to that of the built environment was instructive. In many parks, facility managers had considered climate adaptation as primarily a natural resource issue since the science to support adaptation often comes from the natural resource realm. While vulnerability concepts such as sensitivity originated around biological systems, these ideas can be applied to infrastructure as well. In comparison to the effects on natural areas, the impacts on the built environment and cultural resources were extensive and required expensive repairs. It was necessary to transfer research on vulnerability and inundation from natural resources to facilities. Throughout the national parks of New York Harbor, wind and floodi g (storm surge and standing water) caused substantial damage to historic structures and assets contained within areas that had not been impacted by past storms and in places not previously thought to be vulnerable.

Cultural Landscapes

In addition, cultural landscapes sustained storm impacts that were not previously considered by facility and park managers. Similar to historic buildings, the most obvious impacts on cultural landscapes included damage to historic materials (e.g., railings, chain link fence, light posts, and brick courtyard fence at Jacob Riis Park), as well as changes to the natural resources and systems (e.g., changes in vegetation, topography, and sand dunes at Jacob Riis Park and Fort Tilden), which are character-defini g features of historic landscapes.

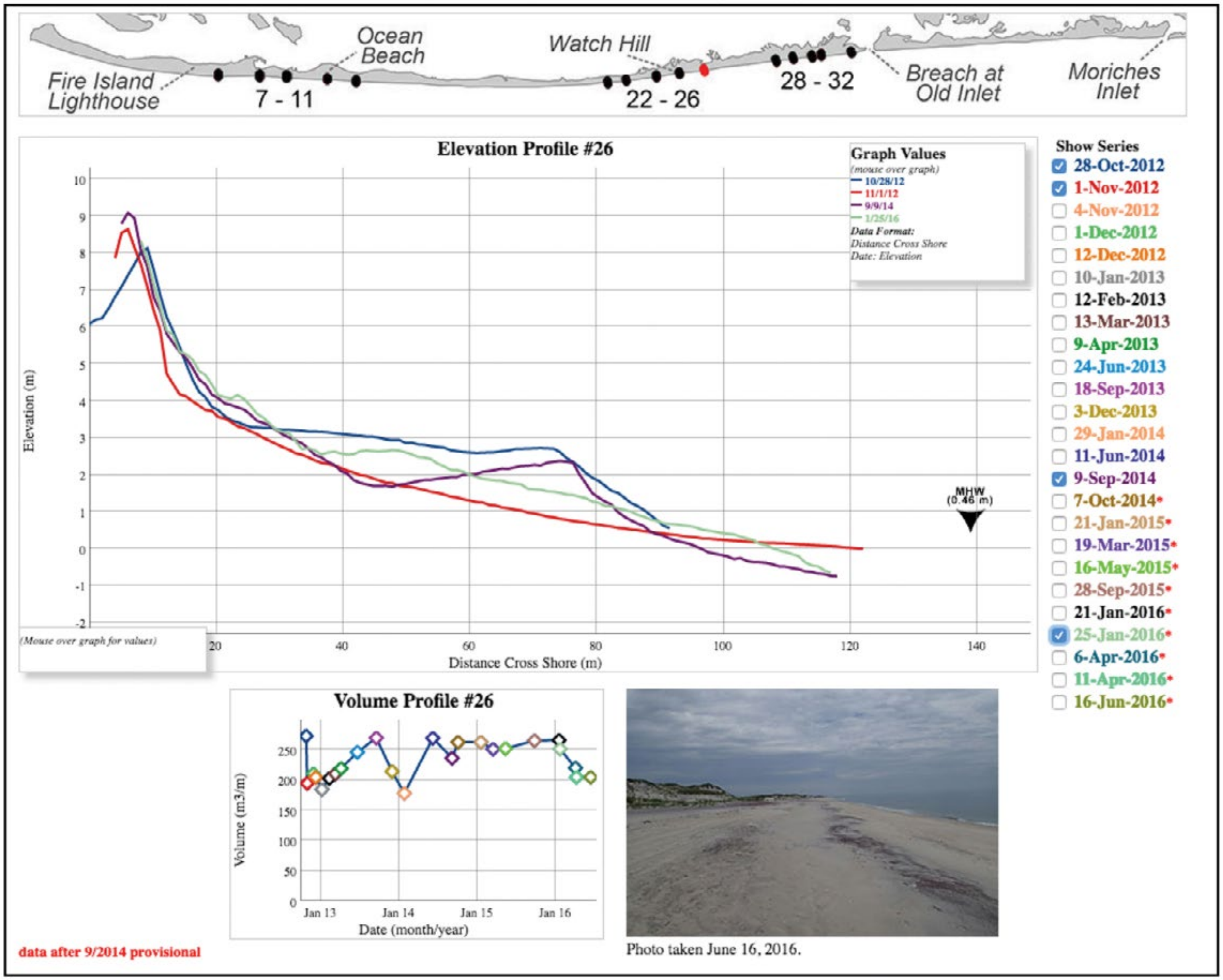

Figure 9.3. Beach profiles at FIIS before and after Hurricane Sandy. *Note: Shore-perpendicular elevation profiles of Fire Island, New York, capture the initial impact of Hurricane Sandy and the ongoing recovery of the beach system. Surveys were performed one day prior to Hurricane Sandy landfall in October 2012, within three days after the storm (in November 2012), in September 2014 and in January 2016. Profile elevation data were collected at 0.5 second intervals using an Ashtech Z-Xtreme GPS surveying instrument and post-processed using positional data from a base receiver to achieve sub-decimeter accuracies. This figure and additional data are available from* http://coastal.er.usgs.gov/fire-island/research/sandy/beach-profiles.html. Figure from Hapke (2014).

Cultural landscapes also sustained some additional impacts from the immediate clean-up efforts as open areas were used as staging grounds, parking areas, and other aspects of operational support for the NPS Incident Management Team and the adjacent community. In particular, Miller Field at GATE was heavily used as a parking area for surrounding neighborhood recovery efforts, which resulted in muddy and compacted soil conditions; while the listed features of this cultural landscape were not affected, the surrounding area was heavily used. Unlike other cultural resources, cultural landscapes offer an opportunity to accommodate such staging and parking areas during disaster clean-up and recovery, though designated areas for such functions should be clearly marked and boundaries should be defi ed. Such activities should also be located away from sensitive, subsurface resources.

Completed cultural landscape inventories and cultural landscape reports at GATE greatly contributed to making informed decisions about appropriate staging areas and decisions about character-defini g features of landscapes that needed to be preserved to maintain landscape integrity. Having baseline studies available for the Incident Management Team and park managers is essential for assessing impacts. A lesson from Sandy is storm response would benefit f om involving facility management staff in future inventories and assessments to ensure necessary data get collected to improve Facility Management Software System (FMSS) data quality. Moving forward, cultural landscapes and their inherent characteristics offer an opportunity for improved resiliency and adaptation against climate change.

Museum Collections

The loss of electrical power and mechanical systems affected historic structures and collections, both those that were damaged by direct storm effects and those that were not. Without climate control, collections that were not damaged by the storm because they were stored at high locations within the buildings were at risk from extremes of temperature and humidity and resulting mold. A month after Hurricane Sandy hit, many of the climate control systems on Ellis Island were still not functioning, so the Ellis Island Museum Collection and exhibits were temporarily moved offsite to the NPS Museum Resources Center in Landover, Maryland, where they remain in a stable, climate-controlled environment until resilient repairs on Ellis Island are completed. In addition to building resiliently in place, GATE is permanently relocating some collections to less vulnerable locations. The park has permanently relocated its museum collections off of Sandy Hook with the expectation that Sandy Hook facilities will be impacted again by future storms. The experiences of these parks following Hurricane Sandy influe ced the development of a servicewide assessment of NPS museum facility vulnerability to climate change report (NPS Park Museum Management Program 2014) which was already underway at the time (see “Chapter 5 Cultural Resources”). That assessment will be used to initiate scoping of an updated park museum collection storage plan.

Climate Adaptation for Cultural Resources

The many cultural resource vulnerabilities illuminated by Hurricane Sandy impacts and recovery efforts inspired the National Park Service to convene a workshop called “Preserving Coastal Heritage” in April 2014 (see “Chapter 5 Cultural Resources”). The purpose of this session was to inform development of NPS decision-making frameworks for cultural resources that are vulnerable to climate change. The workshop explored decision-making criteria and planning processes through case studies of Hurricane Sandy impacts including north Ellis Island, Spermaceti Cove life-saving station, and Jacob Riis Park. The summary report from this session identified a d described seven climate change adaptation strategies for cultural resources: do nothing; offsite action; improve resiliency; relocate or allow movement; data recovery, then let go; record, then let go; and interpret the change, which are further developed into the seven strategies in table 5.4 (NPS 2014b) The report also identified oppo tunities to improve the development of viable management alternatives for threatened cultural resources (NPS 2014b), as enumerated in “Chapter 5 Cultural Resources.”

Success Stories of Planning, Preparation, and Experience

Some NPS units with barrier island seashores have designed or adapted their infrastructure to minimize vulnerability to the frequent storms that impact those parks. At FIIS and Assateague Island National Seashore (ASIS), Maryland and Virginia, the staff reviews storm response plans after each hurricane and northeaster that affects the park in order to incorporate lessons learned. While storms with the impact of Hurricane Sandy are infrequent, the historic experiences with large storms coupled with preparation for smaller storms minimized storm damage to park buildings at FIIS and ASIS. Such examples of successful designs and plans from national seashores can be adapted for other coastal parks facing increased storm impacts.

Adaptation strategies may vary by site, because they need to be compatible with site-specific eatures. Successful adaptation strategies post-Hurricane Sandy include (1) relocation to higher and less floo -prone locations, (2) portable construction, and (3) resilient construction or (4) sacrific al construction. At FIIS, where boardwalks were impacted by Hurricane Sandy, staff members are developing options to replace traditional boardwalks with alternatives using multiple adaptive techniques. Boardwalks were relocated to higher and less floo -prone locations, and were also anchored into the ground so they will not float a ay when future floods each those heights or locations. At ASIS, assets in the Virginia district have been adapted over time to minimize damage from repeated storms (see Schupp, Beavers and Caff ey 2015 "Case Study 16: Relocating Visitor Facilities Threatened by Erosion"). For example, traditional visitor facilities such as beachside bathhouses have been replaced with portable structures that are secured off-island in advance of storms, and beach parking lots have been resurfaced with native materials (clay and clam shell) that can be reused and that do not leave asphalt debris on the beach when overwashed. ASIS is now implementing these successful adaptations in the Maryland district, where visitor facilities had not experienced significa t storm damages until Hurricane Sandy significa tly impacted infrastructure on both the ocean and bay sides of the park.

Reducing infrastructure vulnerability by locating or relocating permanent facilities to lower-vulnerability locations is not without potential impacts on other resources. For example, when two visitor parking lots at ASIS were damaged by Hurricane Sandy, the park proposed relocating these assets to inland areas of the barrier island that would not be as vulnerable to ongoing shoreline change and future storm impacts. Through the environmental assessment process, the park discovered that this adaptation action was not as straightforward as expected because it could have undesirable aspects, such as impacts on inland resources and visitor experience. The birding community was opposed to the proposed location for one of those parking areas, which is located on the bay side of the island, because it would have disturbed a shrub/scrub vegetation community that migratory birds used as a stopover. Birders were also dissatisfied hat only one alternative parking site was being considered. The NEPA public scoping process identified ju t how important this portion of the bayside peninsula currently is to recreational use and the birding community as a whole (NPS, Bill Hulslander, ASIS Resources Management Chief, email, 30 October 2014). As a result, the park developed a new, separate environmental assessment (NPS 2015b) focused solely on the bayside parking lot to identify alternative locations for a parking lot, so that after the next storm event, there is a plan in place to relocate this asset. In the meantime, the bayside parking lot will be resurfaced with clay and clamshell rather than with asphalt. As illustrated by this ASIS example, as resource conditions change, and new adaptation strategies are developed, the value and use of park habitats will also likely change. This will make traditional planning processes more complex. Planning processes that are nimble and flexi le will allow decisions to be made today despite it becoming increasingly diffi lt to evaluate specific esource impacts in the face of a changing environment.

Another strategy to reduce vulnerability is to develop contingency plans for responding to possible or probable future scenarios. FIIS provides one successful model, where the potential for a barrier island breach is of concern to multiple stakeholders. An existing plan, known as the Fire Island to Montauk Point Reformulation Plan, Long Island, New York (USACE 2016), included a Breach Contingency Plan to guide decisions related to breach closure. This plan called for the closure of all breaches on Fire Island with the exception of the wilderness area, where any breach would be monitored to determine whether it would close under natural conditions. The plan was implemented after Hurricane Sandy created three breaches on Fire Island within the national seashore: one in the Otis Pike Wilderness and two within the Smith Point County Park. One breach in Smith Point County Park was closed immediately following the storm, and the other breach closed naturally.

Monitoring data have been important in responding to public concerns about the open breach and understanding breach influe ce on Great South Bay located inland of FIIS. NPS scientists immediately began monitoring the morphology of the wilderness breach location, monitoring and mapping the east and west locations of the breach on a near daily basis. Subsequent monitoring efforts measured water velocity through the breach, the morphology of the depth of the breach, water quality (temperature and salinity), and changes in water level in the Great South Bay. Pre-storm baseline monitoring and post-storm data analyses enabled Stony Brook University (Flagg and Flood 2013) and USGS (Aretxabaleta, Butman, and Ganju 2014) to show that the increased floodi g during the winter following the breach was regional, occurred both inside and outside Great South Bay, and was due to subsequent storms and unrelated to the breach. Data also show that the breach has improved water quality near the inlet due to increased local flu hing, which has reduced brown tide in the vicinity of the breach. There is little impact beyond the vicinity of the breach due to the limited reach of the inlet flo , which has a small volume relative to the total volume of Great South Bay (Flagg, Flood, and Wilson 2013). Additional studies focus on the ecological response to the breach open condition, including potential changes in phytoplankton, clams, submerged aquatic vegetation, and other ecologically important organisms (Gobler and Thickman 2016).

Allowing the natural coastal processes of overwash and island migration to continue enables barrier islands to keep up with moderate rates of sea level rise. The breach monitoring program will improve future science-based management decision making. An environmental impact statement and associated technical reports supporting breach management planning for FIIS are currently in development as part of the Sandy Recovery Improvement Act of 2013.

Common Barriers to Adaptation

There are several common barriers to the development and implementation of appropriate climate change adaptation strategies. A primary barrier to post-storm adaptation is the pressure to return the park and its facilities to pre-storm conditions quickly (Grannis et al. 2014). This expectation may be generated by policy, funding requirements, park culture, political pressure, or the desire to restore access quickly. The quickest solution is often to replace damaged structures "in kind," thereby avoiding the lengthy process needed for new design work; additionally, cost estimates (often generated during the incident response process to quantify damage) for NPS funding though Project Management Information System (PMIS) are based on direct replacement of existing structures, and some federal funding has been tied to "in kind" replacement.

In contrast, the Hurricane Sandy Rebuilding Task Force (2013) initially required that federal facilities receiving Hurricane Sandy recovery funding must rebuild critical infrastructure to Federal Emergency Management Agency (FEMA) Advisory Base Flood Elevations (ABFE) standards plus 1 foot or plus 2 feet instead of to pre-storm elevations. This evolved as other data sets became available (e.g., FEMA's Best Available Flood Hazard data and Preliminary Flood Insurance Rate Maps) and has now been modified o plus 2 feet or plus 3 feet. The Hurricane Sandy Rebuilding Strategy (2013) deals with this as follows:

> *"The Task Force previously advised use of FEMA ABFEs plus 1 foot for rebuilding in the region. In the July–October time frame, the Federal Emergency Management Agency will release most of the Preliminary Digital Flood Insurance Rate Maps for coastal areas in both states, which will replace the ABFEs and refine the 1%-annual-chance (100-year) coastal flood elevations based on improved modeling."*

The ABFEs for the New York and New Jersey coastlines were developed in 2012 using updated coastal study methodologies and topographic data. These were interim coverages. Existing FEMA Flood Insurance Rate Maps (FIRMs) were developed as long as 25 years ago in some locations along the New York and New Jersey coastlines. In most locations, the Advisory Base Flood Elevations reflect higher flood levations than the current regulatory Flood Insurance Rate Maps, and are believed to represent a more likely scenario for the 1% annual flood risk in a given location (FEMA 2012). However, the link between recovery funds and elevation presented a challenge to parks with incomplete elevation data for facilities; the resulting efforts and protocols for GATE are described in the next section.

This expectation that resources must be restored to their pre-storm state primarily applies to infrastructure and cultural resources; for the most part, park visitors understand that natural resources are dynamic. The feasibility of adapting some types of coastal infrastructure depends on location. For example, docks, bathing facilities, and boardwalks will continue to be located close to the shoreline and therefore likely within the flood zo e, but they can be adaptively redesigned. Political pressure, timeliness, and stakeholder interest in maintaining existing public amenities in places like the beach parking lot at ASIS or the marina at Great Kills in GATE can limit adaptation efforts to small, short-term changes in design. For example, although ASIS has reduced infrastructure vulnerability by investing in bathhouses that are moved off-island ahead of storms and resurfacing parking lots with native materials, more significa t changes to the location of the recreational beach and associated parking lots have been met with strong resistance from the neighboring communities that are dependent on the tourism economy (see Schupp, Beavers, and Caff ey 2015, "Case Study: 16 Relocating Visitor Facilities Threatened by Accelerated Erosion"). In another popular NPS unit, political pressure to quickly restore dock access to Liberty Island at the Statue of Liberty National Monument resulted in minimal time to incorporate design features to accommodate rising water levels. The design changes that were incorporated included design-to-fail connection points between the dock sections to isolate damage and improved connections where the docks are fi ed to the piles to improve survival (figu e 9.4).

Figure 9.4. Photo from Liberty Island of damaged dock access. Photograph by Rebecca Beavers, NPS.

Many cultural resources must be protected in place and restored with appropriate materials to maintain their historic characteristics; this requirement also maintains their vulnerabilities. Resources listed in the National Register of Historic Places and resources covered by the The Secretary of the Interior's Standards for the Treatment of Historic Properties (36 CFR 68) needed additional review and oversight of recovery decisions. Structures such as the Jacob Riis bathhouse and the surrounding cultural landscape were heavily damaged by storm surge and the overwash of sand. Plans for adaptive reuse of this structure include roll-up doors or openings on both sides so that water can pass through, elevated electrical systems, resilient wall fini hes (subway tiles) at ground level, and portable food service such as vendors with mobile carts or units.

Impacts on historic structures were often greatest for those with deferred maintenance.

If buildings are well maintained, they have a better chance of surviving a major storm; the porches of the Officers ow at Fort Hancock on Sandy Hook are an illustrative example. There were two buildings that had been rehabilitated and maintained, including the building at the lowest elevation—these were the only buildings that had porches without major storm damage.

The need to prioritize cultural resources is described in "Chapter 5 Cultural Resources." At GATE, many cultural resources were in poor condition before Hurricane Sandy due to deferred maintenance and the lack of capacity to assess maintenance needs. GATE had been working on a banding method to prioritize cultural resources with the awareness that they had never been able to fully address the maintenance needs or even a complete assessment of GATE's extensive cultural resource assets. After the storm, capacity was strained to evaluate which resources could be rehabilitated and which to document and let go. Hurricane Sandy recovery brought home the realization that you cannot protect every resource and spurred staff to fi alize the banding process and include storm vulnerability. The resulting prioritized list of resources was included as an appendix in the General Management Plan (GMP) update, for which the Hurricane Sandy impacts became a proxy for vulnerability to future storm events (NPS 2014a). With the combination of recovery funding and the cultural resource prioritization, GATE has an updated strategy for maintenance of cultural resources.

The expectations of other agencies, partners, and adjacent communities can also be a barrier to adaptation. The Breezy Point Cooperative, a private community located within GATE and adjacent to Fort Tilden, previously removed the dune system fronting the community to allow for easier beach access, and experienced substantial storm damage. The established dune system protecting Fort Tilden was overwashed during the storm, but the beach volume eroded during Hurricane Sandy is recovering and dune building is occurring by natural processes. The Breezy Point Cooperative has constructed a dune system to protect residences from future storms and has tied this feature to the dunes in the park at the east and west ends of the community.

Funding availability, constraints, and timelines can also be barriers to adaptation. Once the Sandy Recovery Improvement Act of 2013 was passed, the funding process and timing determined which adaptation strategies could be included in recovery projects. The proposals had to be developed quickly in the midst of ongoing storm response efforts. Where storm recovery plans were in place, teams were able to evaluate the extent of damage, estimate costs of repair, and prioritize what was needed to get the park operational again. Infrastructure repairs to prevent further damage were a focus of the Incident Management Team (NPS 2013). While initial repairs were underway, the initial recovery funding call requested projects with design features to make infrastructure more resilient. The NPS RRT ensured that Hurricane Sandy funded facility projects dealt with resiliency and not just replacement in-kind. In later funding decisions, the DOI eventually did provide substantial funding for projects intended to improve ecological resilience. The initial project timeline was that all projects must be completed by November 2016. This timeline is incompatible with the need for continued monitoring to evaluate resilience, because it will be a challenge to complete the planning, design, and implementation in that time. While some projects are being given extensions, it is to complete work, not to address the continued monitoring needs.

To better address rapid timelines of future storm response and recovery funding requests, efforts would benefit f om having PMIS estimates come from an interdisciplinary project management team rather than only from estimators of damage. Current condition assessments would make it easier to determine storm damage from previous condition. Preapproved flexi ility to design future structures differently (smarter) rather than replace in-kind and boilerplate text to include in storm recovery funding proposals would improve the response and recovery process. Hurricane Sandy construction projects were able to work around the initial challenges related to the above points by having a high degree of flexi ility in managing projects as a whole body of work; within infrastructure projects there was flexi ility for changes without having to redo the entire PMIS statement, including changing dollar amounts and moving funds between projects.

Servicewide Coastal Adaptation Strategies and Challenges

Several of the recovery and adaptation issues highlighted by Hurricane Sandy are common to other coastal parks and are addressed in previous chapters of this handbook. One issue is how to consider tradeoffs in adaptation options across natural resources, cultural resources, and facilities. For example, overwashed roads and parking lots at GATE represent infrastructure in need of repair (figu e 6.1), but are also new habitat for shorebirds. In that case, the park removed the sand burden from the road and parking surfaces, and placed the sand within the infrastructure zones, on the seaward side of buildings and parking lots, to create protective berms. The park made an effort to limit the intrusion of those berms into overwash areas to avoid habitat fragmentation. Resource advisors on the Incident Management Team discussed a backshore placement alternative, but necessary wetland and New Jersey and New York Coastal Zone Management permits had not been secured. Plans for future post-storm recovery should include back barrier shoreline placement alternatives in areas prone to overwash.

With limited capacity to evaluate which resources to document and let go, parks needed guidance on whether degraded shore protection structures (e.g., remnant seawalls) are historic. The Sandy Recovery Improvement Act of 2013 provided additional funding to the New York and New Jersey State Historic Preservation Offices o comply with the NHPA (PL 89-665; 16 USC 470 et seq.) Section 106, which requires federal agencies to consider the effects of projects they carry out, approve, or fund on historic properties. It would be benefic al to have response team members, and budgets to support them, with expertise in design and in cultural resources to help guide assumptions and decisions on post-storm recovery.

Hurricane Sandy recovery has presented educational and outreach opportunities on coastal climate adaptation, such as the October 2014 climate science education workshop, focused on the Sandy Hook area of GATE, titled Communities and Sandy Hook Workshop: Partnering to Build Resilience to Climate Change. The workshop engaged diverse local communities to discuss a possible vision for the future of the Sandy Hook Unit of GATE and the surrounding region. Several of the potential projects identified o advance climate adaptation project planning, funding, and implementation were based around education and climate literacy (NPCA 2014).

Parks must also develop ways to implement climate change adaptation strategies in cooperation with concessions partners, who often have both the expectation to return to previous conditions and pressure to reopen quickly. Responses differed based on functional needs, contracts, concessioner insurance, and level of impact. In some places, there were multiple occupants, and the responsibilities for common space and utilities were unclear. Systems such as electricity and climate control were moved out of basements, but large freezers were more challenging to make more sustainable in places where they were incompatible with the cultural landscape. The Great Kills Marina was rebuilt to more resilient standards with higher piles and materials better able to withstand future storms through a combination of insurance and federal funding. The Silver Gull Beach Club was able to use insurance money to replace in-kind without improvements in resilience. The Sandy Hook Beach Centers were under-insured and no longer has a concession operator, so the National Park Service could make recovery decisions without contract issues.

Implementation of Lessons Learned from Hurricane Sandy

Hurricane Sandy created opportunities to replace damaged structures with resilient alternatives, rather than rebuilding damaged structures back to their pre-storm state. At Liberty and Ellis Islands, below grade-level electrical and mechanical equipment was damaged. The decisions on how and where to replace the equipment were made through a value-based decision-making process (e.g., Value Analysis or Choosing by Advantages). At Ellis Island, the park decided to relocate some of the equipment within an existing Power House building. Chillers and boilers were located on a new elevated steel frame platform, and electric switchgear was moved to the second floo . Similar, but less complicated, solutions for Liberty Island, where there had been less damage, also include an elevated steel platform to support equipment above flood zo es within an existing maintenance building (figu e 9.5). At the Sandy Hook unit of GATE, grade-level electrical equipment serving below grade sewage lift stations was damaged. The initially popular idea to install electrical panels that could be detached from the stand and moved inland was untenable because removal would have required unprotected flexi le cord and a 220V outlet exposed to the public, which would violate code. As an alternative, a risk assessment helped prioritize the few key vulnerable lift stations and equipment to protect with water proof enclosures. These are larger or multiple enclosures that were ultimately able to fit i to the historic district, with only minor items left unprotected that can easily be bypassed in the short term. An important lesson learned from this process was to consider all options fully without focusing a preference on existing methods or locations. The concept of risk management in making decisions is also exemplifie in this example. The concept of risk comes into play in many decisions when there is usually no obvious solution, so risk management becomes a key component of making informed decisions.

The storm recovery effort identified lanning needs that can be addressed in preparation for future storms. One immediate need was data for each building's floor levation relative to the flood lain. The NPS Northeast Region (NER) and the NPS GPS Program (WASO) already had several elevation inventory efforts underway prior to the storm. At GATE in June 2013, a "GPS Swat Team" that included park employees used protocols (Smith and Gallagher 2011) from previous NPS asset elevation inventories and surveyed accurate elevations of fir t-floor hresholds for all buildings in GATE and Statue of Liberty National Monument, including Ellis Island (see box 6.1 "Chapter 6 Facility Management" for details). The success at GATE and previous efforts in Cape Lookout and Cape Hatteras National Seashores (North Carolina) is being expanded to an NPS-wide project; FIIS building elevations were surveyed in summer 2014, and surveys have been completed in 2015 of Biscayne National Park (Florida), Gulf Islands National Seashore (Florida and Mississippi) and Fort Sumter National Monument (South Carolina). Colonial National Historical Park (Virginia) including the historic Jamestown site and Fort Monroe National Monument (Virginia) were completed in 2016. Planned future projects are dependent on future funding and include Cumberland Island National Seashore (Georgia), Fort Frederica National Monument (Georgia), Boston National Historical Park (Massachusetts), Boston Harbor Islands National Recreation Area (Massachusetts), and Jean Lafi te National Historical Park and Preserve (Louisiana) (NPS, Tim Smith, National GPS Program Coordinator, email, 11 May 2016; updated 10 August 2016).

Figure 9.5. Photo of elevated platform in maintenance building on Liberty Island.

Executive Order 13690 sets a new, post-Sandy federal floo risk management standard (see discussion in "Chapter 6 Facility Management"), a minimum elevation relative to floo zones that accounts for sea level rise for all major federal investments to better avoid riverine and coastal flood lain risks. It is important to consider that facilities at risk from future sea level rise may be different from facilities susceptible to storm surge and coastal floodi g alone. A recent risk analysis of coastal assets at GATE examined the vulnerability of assets identified y the National Park Service as having high exposure to long-term sea level rise because of their elevation (Peek et al. 2015). The locations of these highly exposed assets were then compared to assets within FEMA-designated high flood ri k and coastal high hazard areas (the AE and VE zones, respectively) (Peek et al. 2015). Overall,

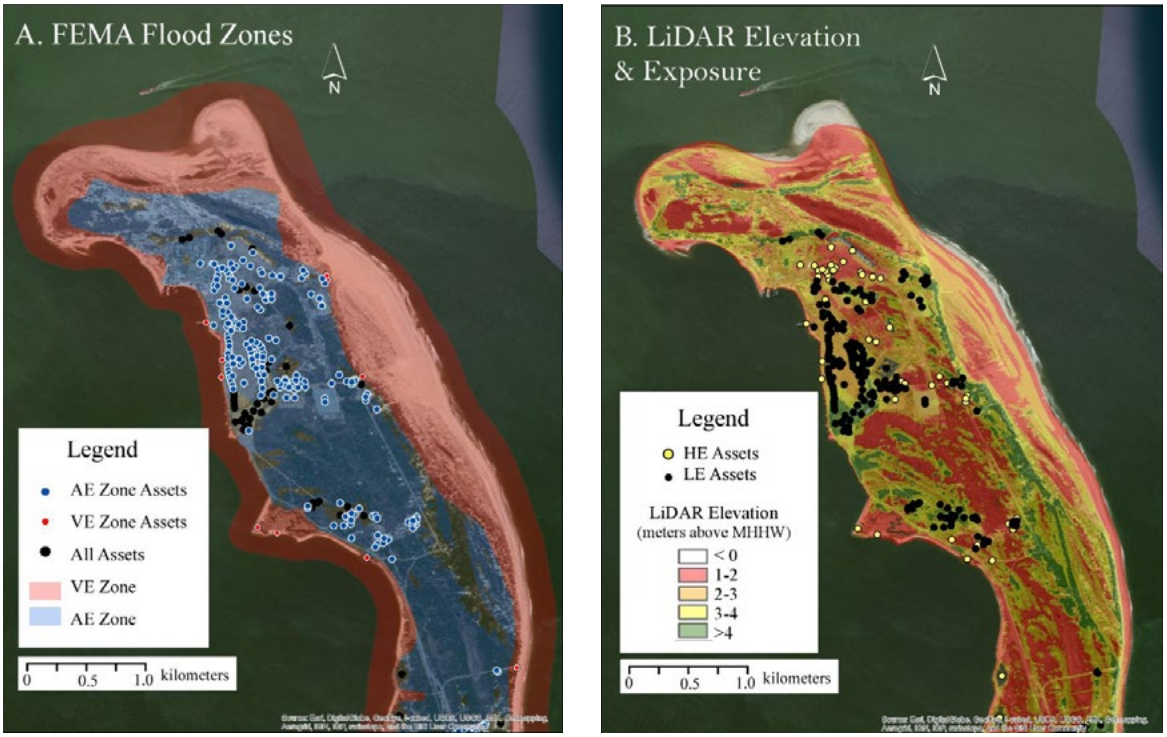

Figure 9.6. Comparison map of the results from the Sandy Hook portion of GATE, including the FEMA flood zone analysis (A) and the SLR exposure analysis (B) for assets within the area based on first-floor elevations (HE = high exposure, LE = limited exposure). Figure from Peek et al. (2015).

57% of all assets within GATE are in FEMA high coastal risk zones, with variability between areas (for example, 82% of the assets on Sandy Hook are in FEMA high coastal risk zones), but only 30% of all park assets were considered to have high exposure to long-term sea level rise (Peek et al. 2015). The risk analysis did not incorporate storm surge and floodi g, which can increase coastal vulnerability; for example, surge floodi g during Hurricane Sandy exceeded 10 ft (3 m) in the GATE region (Peek et al. 2015) (figu e 9.6).

Availability of inventories or baseline data improved the ability of response teams to evaluate impacts and monitor recovery. Hurricane Sandy exposed shortcomings in data availability describing the vulnerability of resources and understanding their resilience to extreme events. For example, documentation supporting response and recovery for facilities relies heavily upon FMSS. Many coastal engineering structures (e.g., bulkheads and seawalls) were damaged in the storm, but are not consistently listed in FMSS (figu e 9.7). Recognizing this need, the NER Facilities Management funded a partner to input FMSS data based on recent inventories of coastal engineering actions in coastal parks (e.g., Dallas, Ruggiero and Berry 2013; Coburn, Griffith, and Young 2010; and other coastal engineering inventories available at http://www.nature.nps.gov/geology/coastal/monitoring.cfm).

Research funded by the NER begun prior to Hurricane Sandy assessed potential coastal engineering structures for removal within coastal NER units to allow for shoreline habitats such as wetlands to exist and migrate (Nordstrom and Jackson 2016, also discussed in "Chapter 6 Facility Management"). At GATE, a sheetpile bulkhead along the Jamaica Bay shoreline near Aviation Road was assessed for its current function and impacts. A section of the sheetpile bulkhead was cut off approximately two feet below fini h grade to allow for safe recreational access to a popular fi hing location and plans to remove a more extensive section of the structure and the damaged parking area behind it to allow for migration of the beach habitat were recommended through a value analysis. Implementation was complicated by learning that the bulkhead is under US Marine Corps (USMC) jurisdiction; it was delayed until an agreement with USMC was reached, and this project is now proceeding (figu e 9.8). The relocation of the upland parking lot and associated RV housing loop road pavement is still moving forward.

The response and recovery phase of incident management are recognized as adaptation opportunities. One lesson learned from Hurricane Sandy was that pre-storm planning for the after-effects of a storm is crucial to effective and thoughtful recovery (see "Chapter 2 Planning" and "Chapter 6 Facility Management").

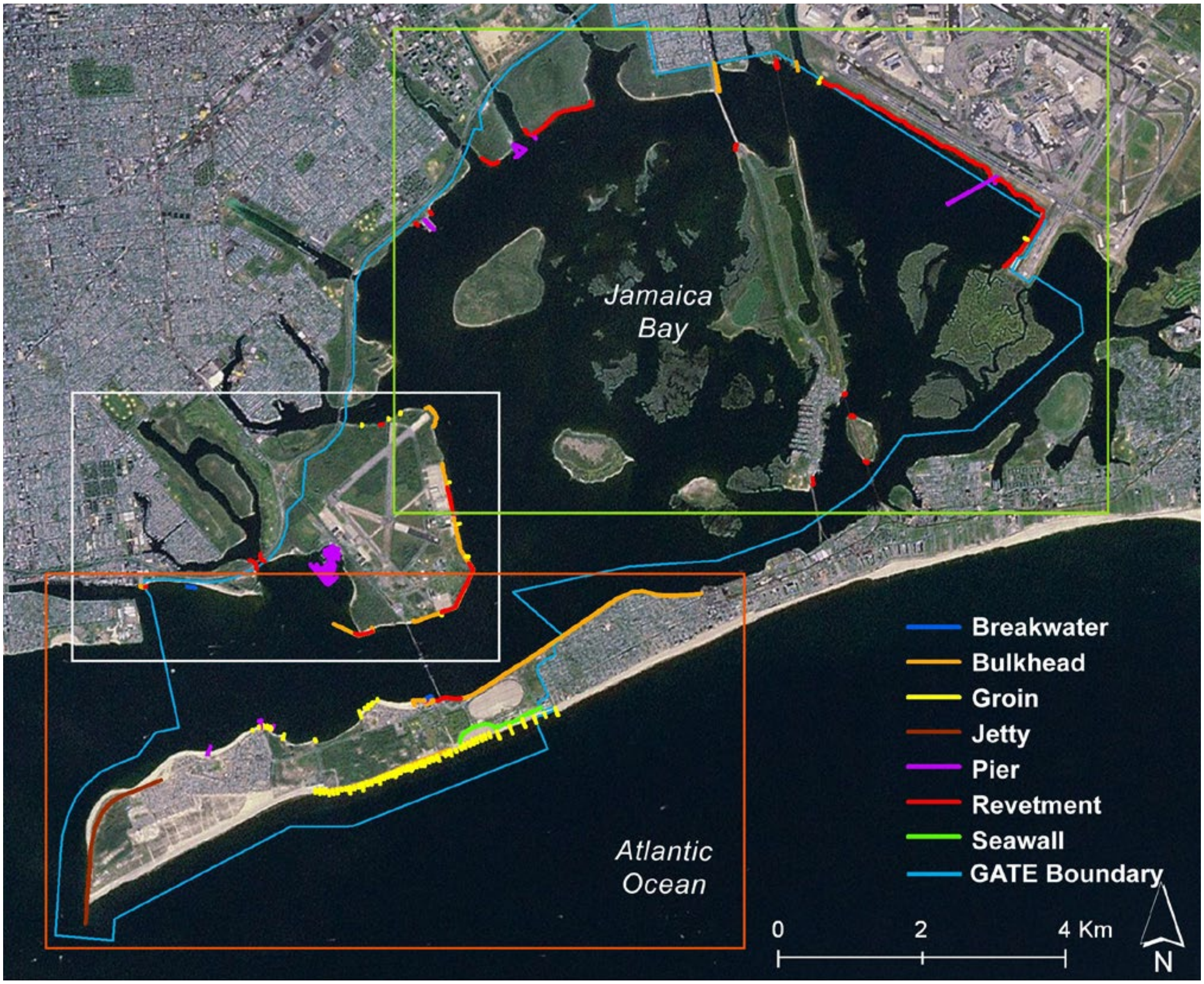

Figure 9.7. GATE Coastal Engineering Inventory of Jamaica Bay. Figure from Dallas, Ruggiero and Berry (2013).

The concept of resilience has taken a central role in Hurricane Sandy recovery, yet it is a challenge to measure or defi e. Some of the funding from the Sandy Recovery Improvement Act of 2013 was designated for mitigation and resilience studies to help National Park Service better understand the resilience of natural resources. Department of the Interior's Hurricane Sandy Mitigation Funding awarded $21 million dollars to study coastal marshes, wetlands and shorelines, measure the effects of Hurricane Sandy on park natural resources and provide natural resource monitoring information and necessary scientific data to park managers. Part of that funding went to the Science and Resilience Institute at Jamaica Bay to lead 10 studies that advance knowledge of resilience in urban coastal ecosystems. The projects will examine the health and resilience of Jamaica Bay salt marshes, including water quality and shoreline position; monitor and evaluate current ecosystem restoration efforts; and assess barriers to future projects and community visions of resilience (CUNY 2014). Study results will improve the design and implementation of restoration practices and other strategies that enhance the resilience and long-term sustainability of Jamaica Bay. This funding also supported a wide variety of resilience studies and actions by other federal agencies and partners. One example that can help provide the larger landscape context for NPS efforts is a series of reports inventorying modificat ons to beaches and tidal inlets prior to, immediately after, and several years post- Hurricane Sandy (Rice 2015; Rice 2012a; Rice 2012b).

Figure 9.8. Photos of Aviation road bulkhead (left) and area where section was removed (right). *Note: Planned removal of the Aviation road bulkhead to allow shoreline migration was delayed and only a section was removed initially for safe access. Removal of the bulkhead is now proceeding.*

Recommendations for Park Actions based on Hurricane Sandy Lessons Learned

The impacts of Hurricane Sandy on NPS areas and assets, and NPS response following the storm, provided opportunities to identify lessons learned and to prepare for future storms.

Pre-Storm

Several pre-storm preparations would improve park response and recovery:

- **Create and Update Storm Response Plans:** Create checklists for park recovery, in addition to existing storm response plans, to guide response team to evaluate park resource impacts (e.g., check on a particular species in a particular location), similar to those found in the appendix of the Cape Lookout National Seashore Storm Recovery Plan (CALO 2011).
- **Update geodatabases:** Prepare a Park Atlas (*NPS internal access only*), or a GIS Toolbox. Create and update GIS coverages. Update and georeference FMSS assets. Add cultural resources and Coastal Engineering Inventory data to FMSS. Add first floor threshold elevations of buildings and resources to FMSS and the GIS toolbox. Create ready to print PDF showing the locations of key cultural resources, sensitive habitats and species, and the FMSS numbers of all facilities.
- **Reduce facility vulnerability:** Incorporate design features to address new guidance from Facility Management PM 15–01 on climate change and natural hazards (NPS 2015a). The guidance includes a checklist and guidance to identify potential risks associated with climate change and strategies to reduce that risk for facilities.
- **Plan for sediment movement:** Plan in advance for alternatives to moving all sediment overwashed on built assets (e.g., asphalt parking lots) back onto the beach (e.g., landward or to bayside feeder beaches).
- **Allow natural processes:** Allow the natural coastal processes of overwash and island migration to continue, to enable barrier islands to keep up with moderate rates of sea level rise.
- **Create a monitoring plan:** Plan to collect monitoring data to understand storm impacts and respond to public concerns about allowing natural processes to continue.

- **Develop a long-term landscape plan:** Develop a landscape-scale plan for future habitat, migration corridors, habitat for threatened and endangered species, working strategically with partners where appropriate to capture a range of habitat.
- **Build stakeholder support:** Before a disaster, develop plans, and build stakeholder support so that parks are better prepared to seize post-disaster opportunities to rebuild resiliently with replacement or adaptive structures. Identify educational and outreach opportunities related to coastal climate adaptation, to improve stakeholder understanding and support of post-storm recovery efforts.
- **Consider removing vulnerable facilities:** Do an analysis of entire areas and determine the risks and needs of each facility. Those that are not resilient and not able to be maintained should be considered for documentation and removal before the next storm.
- **Tailor site solutions:** A number of resilient solutions need to be evaluated site by site; there is no one silver bullet.

Post-Storm

Post-storm response strategies could be improved with the following actions:

- **Develop integrated teams:** Develop integrated project management teams that consider natural and cultural resources, sustainability, and facilities design/planning, to supplement individual FMSS estimators. For example, Museum Emergency Response Teams in Northeast, Southeast, and National Capital Regions and Cultural Resource Emergency Response Teams in Pacific West and Alaska Regions use project statements from resource advisors/professionals.
- **Include wide expertise:** Include team members with expertise in design, project management, and cultural and natural resources to help guide assumptions and decisions on post-storm recovery, such as which resources should be rehabilitated or protected and which might be let go after a more deliberative process in the recovery/mitigation processes. Continue to support the training and integration of Resource Advisors on Incident Management Teams.
- **Increase funding flexibility:** Increase funding flexibility to design replacement structures differently and to incorporate new smart designs instead of replacing in-kind.
- **Use value-based decision-making:** Use a process that considers all the factors that might be affected by a change in infrastructure and rebuilding; accept that some ideas will ultimately be rejected.

Recovery and Mitigation

The recovery and mitigation processes would benefit from the following actions:

- **Lay the ground work for funding applications:** Develop or copy boilerplate text to include in storm recovery project statements.
- **Recognize changing values:** Recognize that as resource conditions change, and new adaptation strategies are developed, the value and use of park habitats and resources will also likely change. This will make traditional planning processes more complex.
- **Recognize limitations of relocation:** Recognize that relocating permanent facilities inland can have undesirable aspects, such as impacts on inland resources and visitor experience.
- **Consider infrastructure alternatives:** Consider replacing traditional infrastructure with
    - portable structures that can be moved in advance out of the path of a storm.
    - structures that are elevated above predicted storm surge heights.
- **Adapt infrastructure:** Incorporate design elements within traditional infrastructure such as
    - flow-through elements that will accommodate storm surge and limit standing water.

- non-mold growing materials that will withstand intermittent water.
- impact resistant materials that can replace the need for hurricane shutters, etc.
- elevated utilities (e.g., first floor, attic spaces, additional elevated platforms).

- **Learn from cultural resource management strategies:** Consider the seven climate change adaptation strategies for cultural resources: no active intervention, offset stress(ors), improve resilience, manage change, relocate/facilitate movement, document and release, and interpret the change.

Take Home Messages

- Hurricane Sandy presented opportunities for adaptation and for testing adaptation elements in existing plans.
- Natural resources were found to be more resilient than many cultural resources and facilities.
- Historic structures have resilient design features. If buildings are well maintained, they may have a better chance of surviving a major storm.
- National seashores can provide other parks with good examples of preparation for and learning from experience about storm impacts on dynamic landscapes.
- After an event, there is an immediate and strong push to return park assets to pre-storm conditions, which can leave resources vulnerable to similar impacts in the future.
- Baseline monitoring and resource assessments are essential data to evaluate impacts and plan for recovery.
- Post-storm recovery is a critical opportunity to adapt to climate change.

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Glossary

Accommodate change – a class of adaptation response (alongside resist change and direct change) in which the target (resource, asset, system, or process) responds to climate change, and management may support its capacity to do so but does not aim to steer the target back towards past conditions or move it towards a strictly-defi ed desired future state.

Adaptation – adjustment in natural or human systems in anticipation of or response to a changing environment in a way that effectively reduces negative effects or uses opportunities.

Adaptive capacity – the ability of a resource, asset or process to adjust to climate change (including climate variability and extremes), i.e. to moderate potential damages, to take advantage of opportunities, or to cope with the consequences.

Adaptive management – a systematic approach for improving management by learning from management outcomes. The approach involves exploring alternative ways to meet management objectives, predicting the outcomes of alternatives based on current state of knowledge, implementing one or more of these alternatives, monitoring to learn about the impacts of management actions, and then using the results to update knowledge and adjust management actions.

Anthropogenic – made by people or resulting from human activities. Usually used in the context of emissions that are produced as a result of human activities.

Carbon sequestration – terrestrial, or biologic, carbon sequestration is the process by which trees and plants absorb carbon dioxide, release the oxygen, and store the carbon.

Climate – climate in a narrow sense is usually defi ed as the "average weather," or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands of years. The classical period is 3 decades, as defi ed by the World Meteorological Organization (WMO). These quantities are most often surface variables such as temperature, precipitation, and wind. Climate in a wider sense is the state, including a statistical description, of the climate system.

Climate change – climate change refers to any significa t change in the measures of climate lasting for an extended period of time. In other words, climate change includes major changes in temperature, precipitation, or wind patterns, among others, that occur over several decades or longer.

Climate model – a quantitative way of representing the interactions of the atmosphere, oceans, land surface, and ice. Models can range from relatively simple to quite comprehensive.

Coral bleaching – the process in which a coral colony under environmental stress expels the microscopic algae (zooxanthellae) that live in symbiosis with their host organisms (polyps). The affected coral colony appears whitened.

Direct change – the focus of a class of adaptation response (alongside resist change and accommodate change) in which the target (resource, asset, system, or process) is actively managed towards a specific esired new condition.

Ecosystem services – the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill uman life.

Exposure – magnitude of change in climate and other stressors that a resource, asset, or process has already or may experience in the future.

Inundation – the submergence of land by water, particularly in a coastal setting.

Isostatic rebound – the movement of land masses in response to the massive weight of continental glaciers. As glaciers melt, the land rises slightly, unburdened by the ice load.

Mitigation (climate change context) – human intervention to reduce the human impact on the climate system; it includes strategies to reduce greenhouse gas sources and emissions and enhancing greenhouse gas sinks.

Mitigation (emergency response context) – the effort to reduce loss of life and property by lessening the impact of disasters.

Monumentation – a control station and its coordinates established by geodetic methods and permanently marked with a brass disk, metal rod driven to refusal (or 80 ft), cement or stone platform, or other permanent structure with the purpose of making consistent relative measurements and tying these measurements to the most recent horizontal and vertical datum.

Nature-based features – features that mimic characteristics of natural features but are created by human design, engineering, and construction to provide specific se vices such as coastal risk reduction.

Ocean acidification – increased concentrations of dissolved carbon dioxide gas in sea water causing a measurable increase in acidity (i.e., a reduction in ocean pH). This may lead to reduced calcificat on rates of calcifying organisms such as corals, mollusks, algae, and crustaceans.

Permafrost – perennially (continually) frozen ground that occurs where the temperature remains below freezing for several years.

Persistence – current/past target (resource, asset, system, or process) conditions continue to exist, either because the target is inherently resistant to change or because of adaptation efforts to resist change.

Phenology – the timing of natural events, such as flo er blooms and animal migration, which is influe ced by changes in climate. Phenology is the study of such important seasonal events. Phenological events are influe ced by a combination of climate factors, including light, temperature, rainfall, and humidity.

Recovery (Incident Command System context) – a set of policies and procedures to enable continuation of vital park management following a natural or human-induced disaster.

Relative sea level rise – the increase in ocean water levels at a specific locat on, taking into account both global sea level rise and local factors, such as local subsidence and uplift. Relative sea level rise is measured with respect to a specified ertical datum relative to the land, which may also be changing elevation over time.

Resilience (community context) – capability to anticipate, prepare for, respond to, and recover from significa t multi-hazard threats with minimum damage to social well-being, the economy, and the environment. Note that this term has been misused as a synonym for adaptation in some contexts, but is used in this document with this specific efin tion.

Resilience (ecological context) – the ability to return to a previous state after disturbance.

Resistance – the ability to withstand perturbations without significa t loss of structure or function.

Resist change – the focus of a class of adaptation response (alongside accommodate change and direct change) in which current/past target (resource, asset, system, or process) conditions are maintained.

Response (Incident Command System context) – organized approach to addressing and managing the aftermath of an incident. The goal is to handle the situation in a way that limits damage and reduces recovery time and costs.

Salt water intrusion – displacement of fresh or ground water by the advance of salt water due to its greater density, usually in coastal and estuarine areas.

Scenario planning – scenarios are plausible, internally consistent stories about the future that help us incorporate scientific u certainty into our thinking; scenario planning is a tool to challenge us to consider how we would operate under novel conditions.

Sensitivity – degree to which a resource, asset, or process is or could be affected, either adversely or benefic ally, by climate variability or change.

Storm surge – a rise of water level generated by a storm, over and above the predicted astronomical tide.

Subsidence – the downward shift of the land surface relative to its surroundings.

Sustainability – the conditions under which humans and nature can exist in productive harmony, that permit fulfilli g the social, economic, and other requirements of present and future generations.

Vulnerability – the degree to which a resource, asset or process is susceptible to adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed; its sensitivity; and its adaptive capacity.

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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On the Back Cover

Left: Thunder Hole viewing platform, at Acadia National Park, Maine. Photograph by Rebecca Cole-Will, NPS.
Center: The *America* shipwreck in Lake Superior at Isle Royale National Park, Michigan. Photograph by Brett Seymour, NPS.
Right: Waterfront at Boca Chita Key at Biscayne National Park, Florida. Photograph courtesy of Program for the Study of Developed Shorelines at Western Carolina University.

http://www.nps.gov/subjects/climatechange/coastalhandbook.htm

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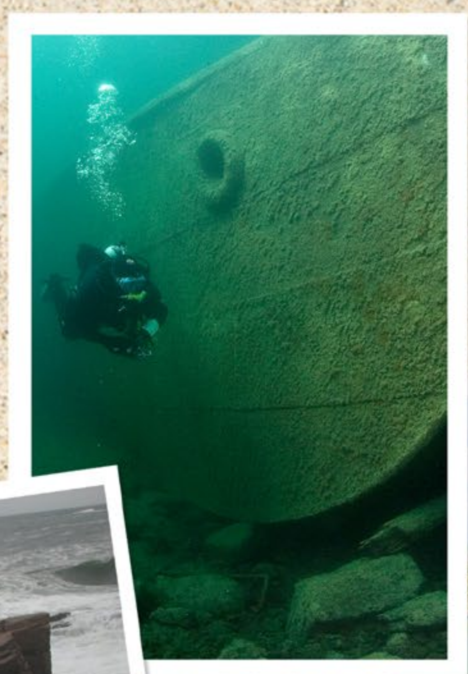

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