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 opportunities 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 field.

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 the 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 reflecting 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) (figures 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 flooded 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 flooding, significant 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 (figure 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.

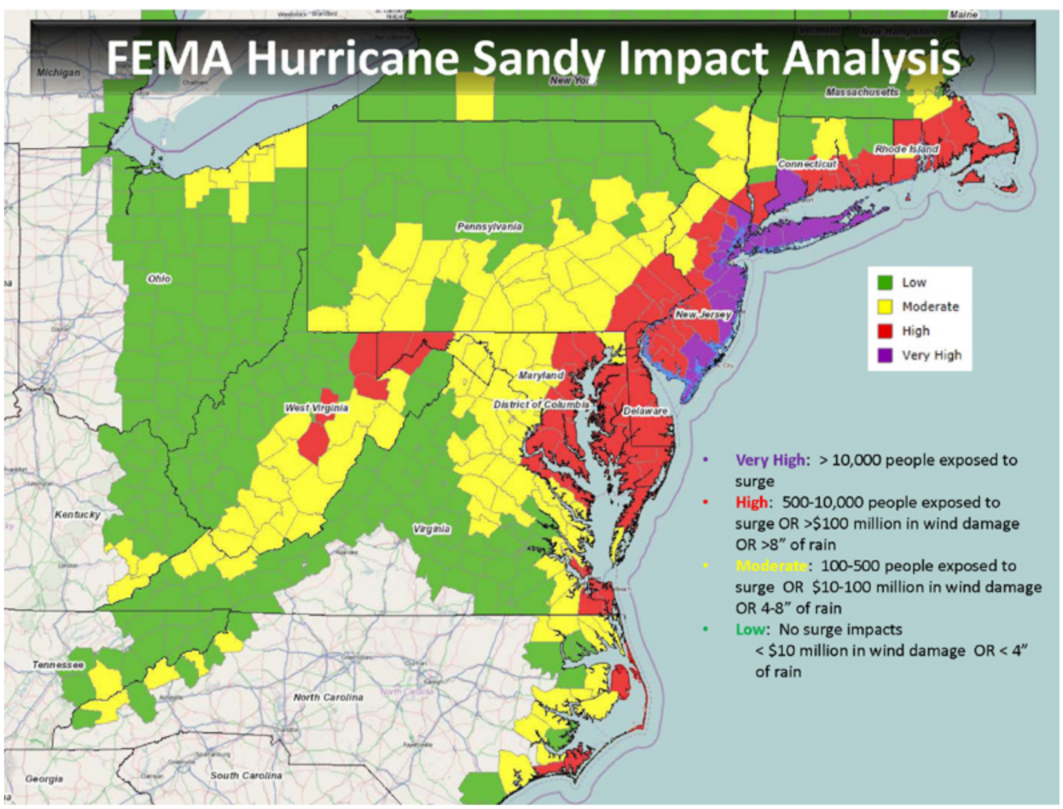

Figure 9.1. FEMA Impact Analysis of Hurricane Sandy. Slide 22 from Blake (2013).

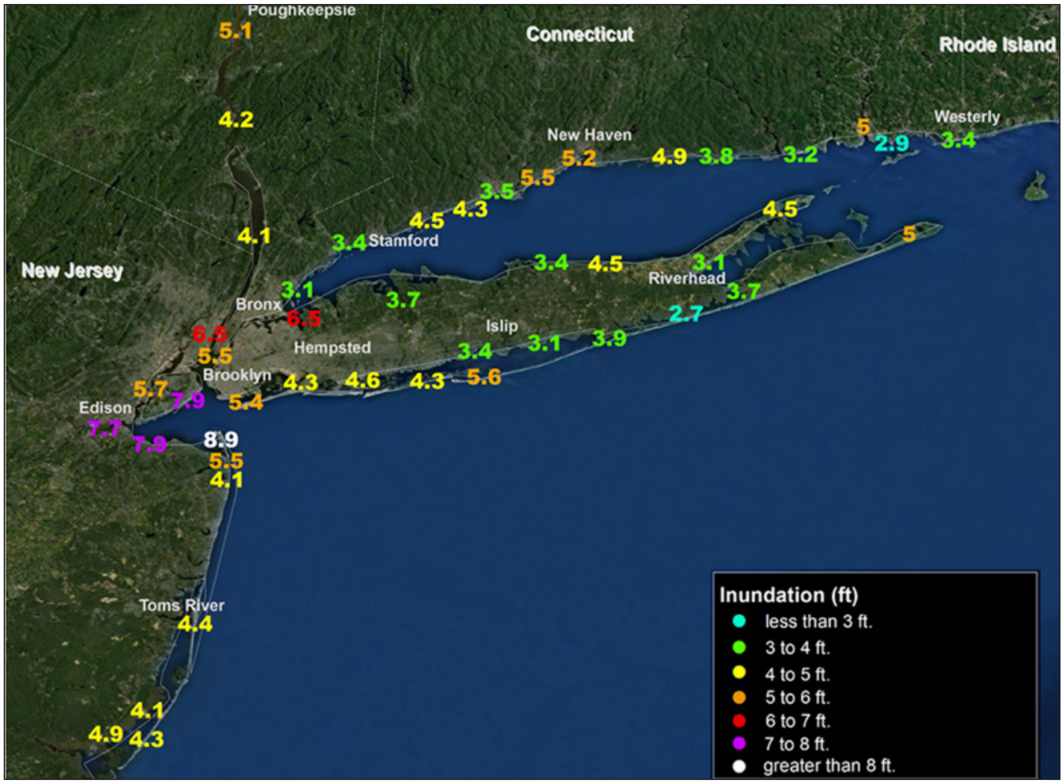

Figure 9.2. Estimated inundation (feet above ground level) was calculated from USGS high-water marks and NOS tide gauges in New Jersey, New York, and Connecticut from Hurricane Sandy. Figure 25 from Blake et al. (2013).

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 beneficial 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 first 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 field is yellow in lower left of figure 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 five 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 that 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 flattened 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 showed 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) (figure 9.3). Significant impacts to natural resources resulted from debris floating 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 flooding (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-defining features of historic landscapes.

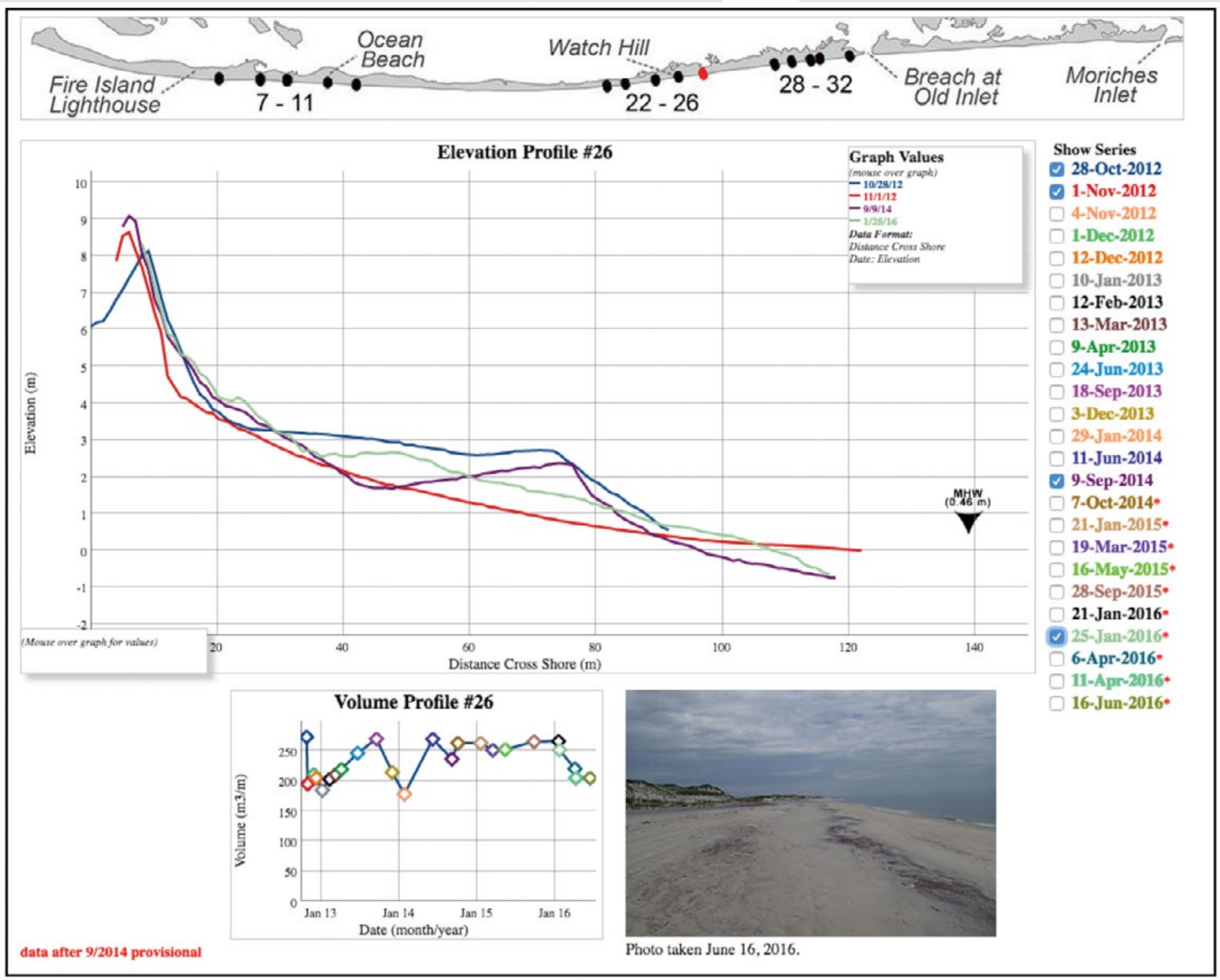

Figure 9.3. Beach profiles at FIIS before and after Hurricane Sandy. *Note: Shore-perpendicular elevation profiles of Fire Island, New York, capture the initial impact of Hurricane Sandy and the ongoing recovery of the beach system. Surveys were performed one day prior to Hurricane Sandy landfall in 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 defined. 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-defining 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 from 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 influenced 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 and 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 opportunities 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 features. Successful adaptation strategies post-Hurricane Sandy include (1) relocation to higher and less flood-prone locations, (2) portable construction, and (3) resilient construction or (4) sacrificial 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 flood-prone locations, and were also anchored into the ground so they will not float away when future floods reach 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 Caffrey 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 significant storm damages until Hurricane Sandy significantly 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 that only one alternative parking site was being considered. The NEPA public scoping process identified just 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 flexible will allow decisions to be made today despite it becoming increasingly difficult to evaluate specific resource 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 influence 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 flooding 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 flushing, 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 flow, 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 to 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 elevations 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 zone, 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 significant 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 Caffrey 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 fixed to the piles to improve survival (figure 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 finishes (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 Row 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 finalize 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 from 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 flexibility 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 flexibility in managing projects as a whole body of work; within infrastructure projects there was flexibility 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 (figure 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 to 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 beneficial 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 to 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 floor. 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 zones within an existing maintenance building (figure 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 flexible 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 into 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 exemplified 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 planning needs that can be addressed in preparation for future storms. One immediate need was data for each building's floor elevation relative to the floodplain. 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 first-floor thresholds 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 Lafitte 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 flood risk management standard (see discussion in "Chapter 6 Facility Management"), a minimum elevation relative to flood zones that accounts for sea level rise for all major federal investments to better avoid riverine and coastal floodplain 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 flooding alone. A recent risk analysis of coastal assets at GATE examined the vulnerability of assets identified by 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 risk and coastal high hazard areas (the AE and VE zones, respectively) (Peek et al. 2015). Overall,

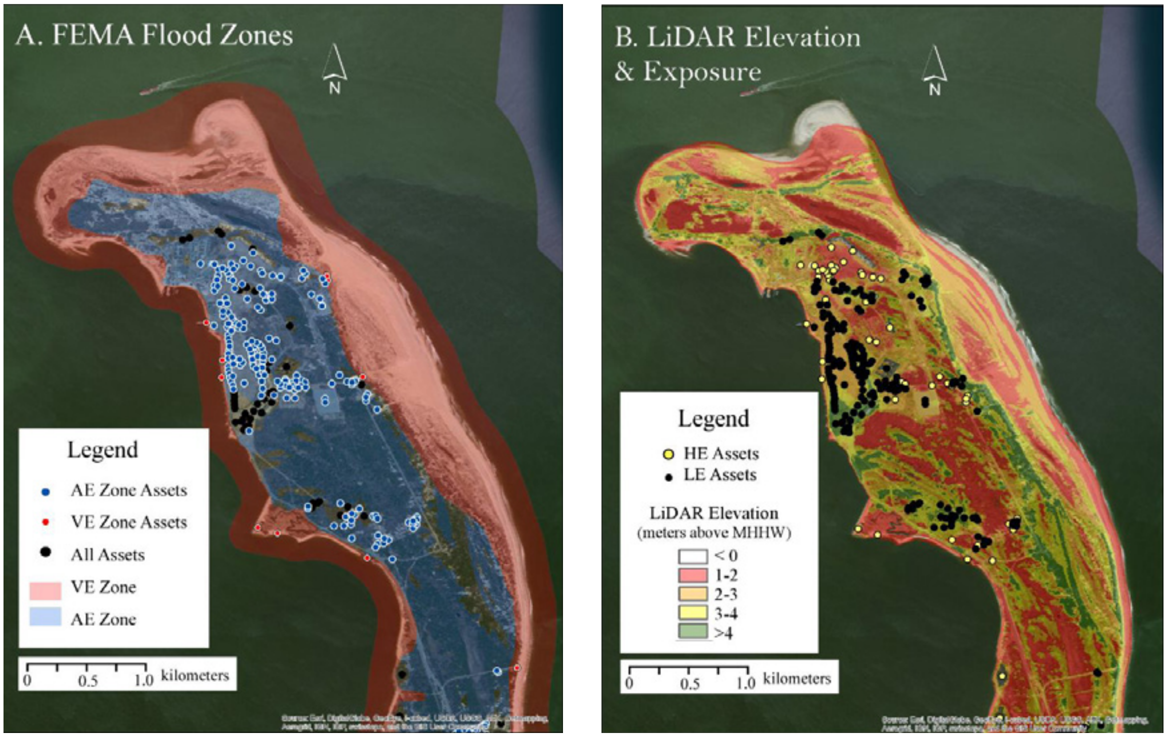

Figure 9.6. Comparison map of the results from the Sandy Hook portion of GATE, including the FEMA flood zone analysis (A) and the SLR exposure analysis (B) for assets within the area based on first-floor elevations (HE = high exposure, LE = limited exposure). Figure from Peek et al. (2015).

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 flooding, which can increase coastal vulnerability; for example, surge flooding during Hurricane Sandy exceeded 10 ft (3 m) in the GATE region (Peek et al. 2015) (figure 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 (figure 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 finish grade to allow for safe recreational access to a popular fishing 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 (figure 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").

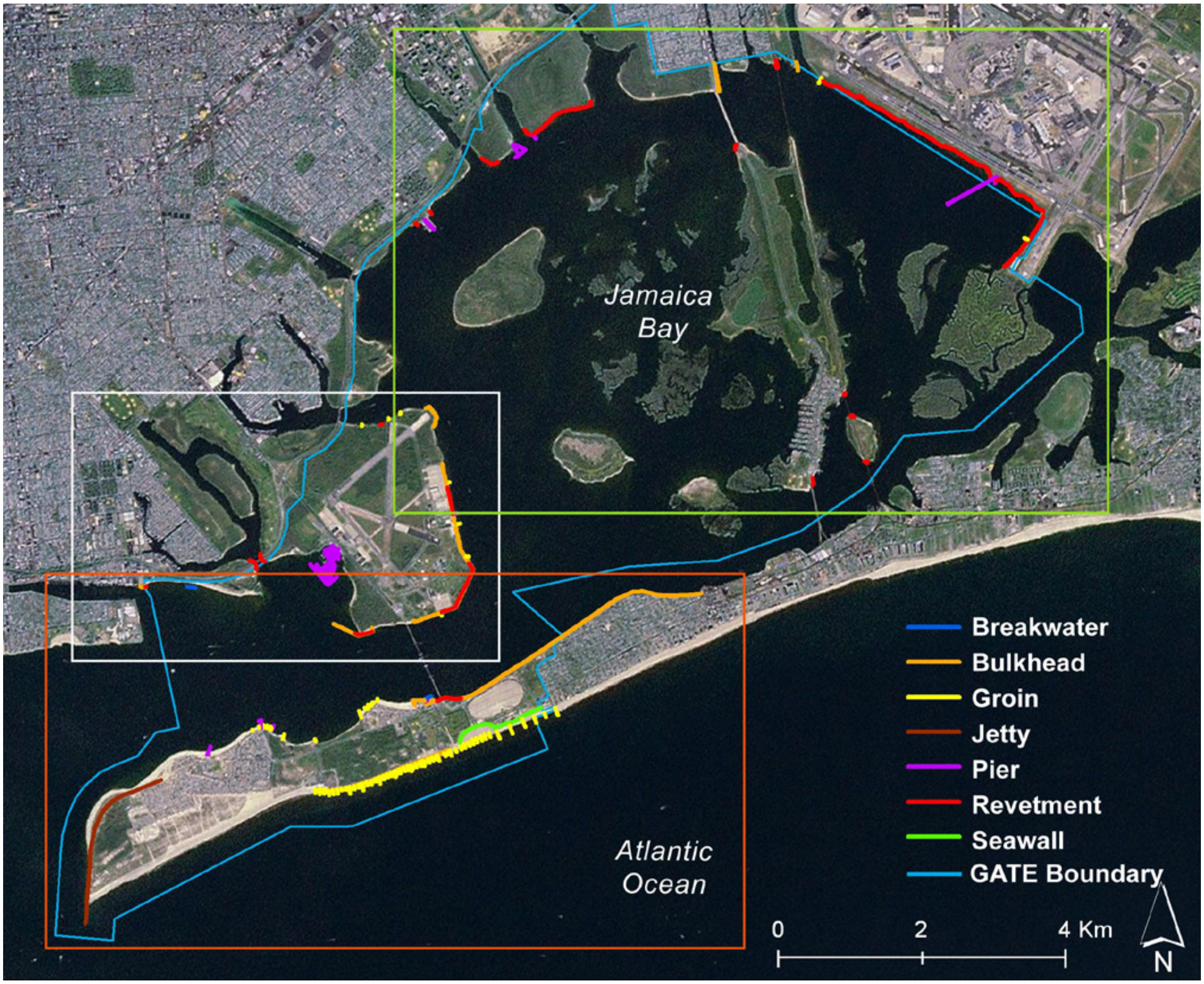

Figure 9.7. GATE Coastal Engineering Inventory of Jamaica Bay. Figure from Dallas, Ruggiero and Berry (2013).

The concept of resilience has taken a central role in Hurricane Sandy recovery, yet it is a challenge to measure or define. 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 modifications 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.

References

Aretxabaleta, A. L., B. Butman, and N. K. Ganju. 2014. Water level response in back-barrier bays unchanged following Hurricane Sandy. Geophysical Research Letters 41(9): 3163–3171. doi:10.1002/2014GL059957. http://woodshole.er.usgs.gov/project-pages/estuarine-physical-response/pdf/aretxabaleta_et_al_Sandy.pdf (accessed 3 December 2014).

Blake, E. S. 2013. Hurricane Sandy. Powerpoint presentation. National Hurricane Center, Miami, FL. http://www.nhc.noaa.gov/outreach/presentations/Sandy2012.pdf (accessed 7 October 2014).

Blake, E. S., T. B. Kimberlain, R. J. Berg, J. P. Cangialosi, and J. L. Beven II. 2013. Tropical Cyclone Report: Hurricane Sandy (AL182012) 22 – 29 October 2012. National Hurricane Center Report. 12 February 2013. National Hurricane Center, Miami, FL. http://www.nhc.noaa.gov/data/tcr/AL182012_Sandy.pdf (accessed 7 October 2014).

Cape Lookout National Seashore (CALO). 2011. Cape Lookout National Seashore Storm Recovery Plan 2011. Cape Lookout National Seashore, Harkers Island, NC. http://www.nature.nps.gov/geology/coastal/documents/CALO_Final_Storm_Recovery_Plan_2011.pdf (accessed 5 December 2014).

Coburn, A. S., A. D. Griffith, and R. S. Young. 2010. Inventory of Coastal Engineering Projects in Coastal National Parks. Natural Resource Technical Report. NPS/NRPC/GRD/NRTR—2010/373. NPS Natural Resource Program Center. Fort Collins, CO. https://irma.nps.gov/DataStore/Reference/Profile/2195056 (accessed 15 October 2014).

The City University of New York (CUNY). 2014. “Science and Resilience Institute at Jamaica Bay Awarded $3.6 Million to Support Research on Resilience in Urban Coastal Ecosystems.” Press release. 21 July 2014. http://www1.cuny.edu/mu/forum/2014/07/21/science-and-resilience-institute-at-jamaica-bay-awarded-3-6-million-to-support-research-on-resilience-in-urban-coastal-ecosystems/ (accessed 9 August 2016).

Dallas, K., P. Ruggiero, and M. Berry. 2013. Inventory of coastal engineering projects in Gateway National Recreation Area. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2013/738. National Park Service, Fort Collins, CO. https://irma.nps.gov/DataStore/Reference/Profile/2195204, (accessed 9 August 2016).

Executive Order 13690, “Establishing a Federal Flood Risk Management Standard and a Process for Further Soliciting and Considering Stakeholder Input.” 30 January 2015. https://www.whitehouse.gov/the-press-office/2015/01/30/executive-order-establishing-federal-flood-risk-management-standard-and- (accessed 23 June 2016).

Federal Emergency Management Agency (FEMA). 2012. Hurricane Sandy Advisory Base Flood Elevations – NJ and NY Frequently Asked Questions. Fact Sheet. Federal Emergency Management Agency, Washington, DC. http://www.nfipiservice.com/pdf/Storm%20Sandy/Hurricane%20Sandy%20ABFE_FAQ.pdf (accessed 14 October 2014).

FEMA. 2013. Hurricane Sandy FEMA After-Action Report (July 1, 2013). Federal Emergency Management Agency. Washington, DC. https://www.fema.gov/media-library-data/20130726-1923-25045-7442/sandy_fema_aar.pdf (accessed 8 April 2016).

Flagg, C. N. and R. Flood. 2013. The Impact on Great South Bay of the Breach at Old Inlet March 10, 2013. Report 8. School of Marine and Atmospheric Sciences, Stony Brook University, Stony Brook, NY. http://www.somassbu.org/research/storm/sandy/reports/FLAGG_Inlet_Report_8.pdf (accessed 11 September 2016).

Flagg, C. N., R. Flood, and R. Wilson. 2013. The Continuing Evolution of the New Inlet. Report 10. School of Marine and Atmospheric Sciences, Stony Brook University, Stony Brook, NY. http://www.bellport.com/vnews/seenheard/2013/Dec15_Inlet_Report.pdf (accessed 11 September 2016).

Gobler, A. B., and J. Thickman. 2016. Response of indicator bacteria in Great South Bay, Long Island to the breach at Old Inlet: An analysis of coliform bacteria post Hurricane Sandy. Natural Resource Report NPS/NER/NRR—2016/1261. National Park Service, Fort Collins, CO.

Grannis, J., V. Arroyo, S. Hoverter, and R. Stumberg. 2014. Preparing for Climate Impacts: Lessons from the Front Lines. A Synthesis Report to The Kresge Foundation. Georgetown Climate Center, Washington, DC. http://kresge.org/sites/default/files/Preparing%20for%20Climate%20Impacts%20-%20Georgetown%20Climate%20Center.pdf (accessed 31 August 2016).

Hapke, C. J., O. Brenner, R. Here, and B. J. Reynolds. 2013. Coastal Change from Hurricane Sandy and the 2012-2013 Winter Storm Season: Fire Island, New York. USGS Open-File Report 2013-1231. http://pubs.usgs.gov/of/2013/1231/ (accessed 13 March 2015).

Hapke, C. 2014. Fire Island Coastal Change. Online datasets and project status. USGS St. Petersburg Coastal and Marine Science Center, St. Petersburg, FL. http://coastal.er.usgs.gov/fire-island/research/sandy/beach-profiles.html (accessed 18 November 2014).

Hurricane Sandy Rebuilding Task Force. 2013. Hurricane Sandy Rebuilding Strategy. http://portal.hud.gov/hudportal/documents/huddoc?id=hsrebuildingstrategy.pdf (accessed 13 March 2015).

National Oceanic and Atmospheric Administration (NOAA). 2013. Service assessment: Hurricane/Post-Tropical Cyclone Sandy October 22–29, 2012. NOAA, Washington, DC.

National Parks Conservation Association (NPCA). 2014. Communities and Sandy Hook: Partnering to Build Resilience to Climate Change. Workshop Summary. https://sites.google.com/site/resilientparksandcommunities/home (accessed 9 August 2016).

National Park Service (NPS). 2013. Hurricane Sandy After Action Report. 14pp. National Park Service, Washington, DC.

NPS. 2014a. A New Vision for a Great Urban National Park Gateway National Recreation Area: Final General Management Plan Environmental Impact Statement. National Park Service, Washington, DC. https://parkplanning.nps.gov/document.cfm?parkID=237&projectID=16091&documentID=59051 (accessed 9 August 2016).

NPS. 2014b. Preserving Coastal Heritage. Summary Report. April 3-4, 2014. Federal Hall, New York City, NY. Available at http://www.achp.gov/docs/preserve-coastal-heritage.pdf (accessed 7 October 2014).

NPS. 2015a. Addressing Climate Change and Natural Hazards: Facility Planning and Design Considerations. US DOI National Park Service Policy Memorandum 15-01. http://www.nps.gov/policy/PolMemos/PM_15-01.htm (accessed 28 April 2015).

NPS. 2015b. Bayside Picnic and Parking Area Environmental Assessment. National Park Service, Washington, DC. https://parkplanning.nps.gov/document.cfm?parkID=207&projectID=52476&documentID=68176 (accessed 9 August 2016).

NPS Museum Management Program. 2014. Assessment of National Park Service Museum Facilities' Vulnerability to Climate Change. National Park Service, Washington, DC.

Nordstrom, K. F., and N. L. Jackson. 2016. Facilitating migration of coastal landforms and habitats by removing shore protection structures: An adaptation strategy for Northeast Region units of the National Park Service. Natural Resource Report NPS/NER/NRR—2016/1240. National Park Service, Fort Collins, CO. https://irma.nps.gov/DataStore/Reference/Profile/2230271 (accessed 9 August 2016).

Peek, K. M., R. S. Young, R. L. Beavers, C. H. Hoffman, B. T. Diethorn and S. Norton. 2015. Adapting to climate change in coastal national parks: Estimating the exposure of FMSS-listed park assets to 1 m of sea-level rise. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2015/961. National Park Service, Fort Collins, CO. https://www.nature.nps.gov/geology/coastal/coastal_assets_report/2015_916_NPS_NRR_Coastal_Assets_Exposed_to_1m_of_Sea_Level_Rise_Peek_et_al.pdf (accessed 9 August 2016).

Rice, T. M. 2012a. The Status of Sandy, Oceanfront Beach Habitat in the Continental U.S. Coastal Migration and Wintering Range of the Piping Plover (Charadrius melodus). Appendix 1c in US Fish and Wildlife Service. Comprehensive Conservation Strategy for the Piping Plover (Charadrius melodus) in its Coastal Migration and Wintering Range in the Continental United States. US Fish and Wildlife Service, East Lansing, MI. https://www.fws.gov/midwest/endangered/pipingplover/pdf/CCSpiplNoApp2012.pdf (accessed 9 August 2016).

Rice, T. M. 2012b. Inventory of Habitat Modifications to Tidal Inlets in the Continental U.S. Coastal Migration and Wintering Range of the Piping Plover (Charadrius melodus). Appendix 1b in US Fish and Wildlife Service. Comprehensive Conservation Strategy for the Piping Plover (*Charadrius melodus*) in its Coastal Migration and Wintering Range in the Continental United States. US Fish and Wildlife Service, East Lansing, MI. https://www.fws.gov/midwest/endangered/pipingplover/pdf/CCSpiplNoApp2012.pdf (accessed 9 August 2016).

Rice, T. M. 2015. Inventory of Habitat Modifications to Sandy Oceanfront Beaches in the U.S. Atlantic Coast Breeding Range of the Piping Plover (*Charadrius melodus*) prior to Hurricane Sandy: South Shore of Long Island to Virginia. Report submitted to the US Fish and Wildlife Service, Hadley, MA, 47 p.

Schupp, C. A., R. L. Beavers, and M. Caffrey [eds.]. 2015. Coastal Adaptation Strategies: Case Studies. NPS 999/129700. National Park Service, Fort Collins, CO. https://www.nps.gov/subjects/climatechange/coastalhandbook.htm (accessed 10 August 2014).

Shrestha, P., S. James, P. Shaller, M. Doroudian, D. Peraza, and T. Morgan. 2014. Estimating the Storm Surge Recurrence Interval for Hurricane Sandy. Pages 1906-1915 in W. Huber [ed.]. World Environmental and Water Resources Congress 2014: Water without Borders. American Society of Civil Engineers, Reston, VA. http://dx.doi.org/10.1061/9780784413548.191 (accessed 9 August 2016).

Smith, T. G. and C. Gallagher. 2011. Accurate Elevations in Coastal National Parks. 999/107779 National Park Service. National Park Service, Lakewood, CO.

Sweet, W., C. Zervas, S. Gill, and J. Park. 2013. Hurricane Sandy Inundation Probabilities Today and Tomorrow. Bulletin of the American Meteorological Society 94.9: S17-S20. http://www1.ncdc.noaa.gov/pub/data/cmb/bams-sotc/extreme-events/2012/BAMS-Extremes-of-2012-Section-06.pdf (accessed 3 December 2014).

US Army Corps of Engineers (USACE). 2016. Fire Island to Montauk Point. Fact Sheet. http://www.nan.usace.army.mil/Media/Fact-Sheets/Fact-Sheet-Article-View/Article/487483/fact-sheet-fire-island-to-montauk-point/ (accessed 9 August 2016).