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Evaluation of Hurricane Sandy Coastal Resilience Program

Contract # 5359

PREPARED FOR:

National Fish and Wildlife Foundation
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Washington, DC 20005

U.S. Department of the Interior
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Washington, DC 20240

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IN PARTNERSHIP WITH:
Virginia Institute of Marine Science,
Center for Coastal Resources Management
Crucial Economics Group, LLC

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2019

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Final Version

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The U.S. Department of the Interior and the National Fish and Wildlife Foundation commissioned Abt Associates to conduct an initial external evaluation of the Hurricane Sandy Coastal Resilience Program projects funded between 2013 and 2016.

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List of Acronyms and Abbreviations

Abt	Abt Associates
Act	Hurricane Sandy Disaster Relief Appropriations Act
CBRS	Coastal Barrier Resources System
DOI	U.S. Department of the Interior
Hurricane Sandy Program	Hurricane Sandy Coastal Resilience Program
ID	identification
NAACC	North Atlantic Aquatic Connectivity Collaborative
NFWF	National Fish and Wildlife Foundation
NWR	National Wildlife Refuge
TNC	The Nature Conservancy
USFWS	U.S. Fish and Wildlife Service
USGS	U.S. Geological Survey
VIMS	Virginia Institute of Marine Science

Executive Summary

Hurricane Sandy made landfall on October 29, 2012, wreaking havoc on communities along the U.S. Atlantic Coast, impacting 12 states and the District of Columbia. The U.S. Department of the Interior's (DOI's) Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program) was implemented to help ecosystems and communities affected by Hurricane Sandy become more resilient to the impacts of future coastal storms, environmental changes, and sea level rise. ***Resilience*** is defined here as the ability to anticipate, prepare for, and adapt to changing conditions; and withstand, respond to, and recover rapidly from disruptions.

Between 2013 and 2016, the Hurricane Sandy Program, administered through both DOI and the National Fish and Wildlife Foundation (NFWF), invested more than $302 million to support 160 projects designed to improve the resilience of ecosystems and communities to coastal storms and sea level rise. The three specific overarching goals of the Hurricane Sandy Program were to:

- Reduce the impacts of coastal storm surge, wave velocity, sea level rise, and flooding on coastal and inland communities;
- Strengthen the ecological integrity and functionality of coastal/inland ecosystems to protect communities and to enhance fish and wildlife and their associated habitats; and
- Enhance our understanding of the impacts of storm events and identify cost-effective resilience tools that help mitigate the effects of future storms, rising temperatures, and sea level rise.

DOI and NFWF commissioned Abt Associates to conduct an initial external evaluation of the 160 Hurricane Sandy Program projects funded between 2013 and 2016. For this evaluation, we categorized projects according to seven major activity categories under two general groups ("on-the-ground" and "science and planning"; Box ES.1). Locations of on-the-ground projects are displayed in Figure ES.1.

> The Hurricane Sandy Program is aiming to improve **resilience** through:
>
> - Restoring coastal habitats or improving aquatic connectivity to reduce storm-related flooding and erosion in nearby communities
> - Increasing the extent, physical integrity, accessibility, and quality of wildlife habitat, making species better able to withstand and recover from storm-related disturbances
> - Identifying or improving tools and approaches for reducing coastal storm impacts
> - Improving human safety.

Box ES.1. Categories of on-the-ground restoration, and science and planning projects.

On-the-Ground Projects
Marsh restoration. Projects that enhance the ecological resilience of marsh sites and protect human communities and infrastructure from storm surge through restoration of marsh vegetation and improved hydrological connections.
Living shorelines. Projects that install natural habitats and structures on the coastline, as opposed to hard shoreline structures, to protect shoreline communities and habitats.
Aquatic connectivity. Projects that re-establish connected waterways and mitigate storm-related flooding and safety risks primarily by removing dams, improving or replacing culverts or bridges, and improving riverine habitat for diadromous fish and other migratory and non-migratory species.

Box ES.1. Categories of on-the-ground restoration, and science and planning projects.

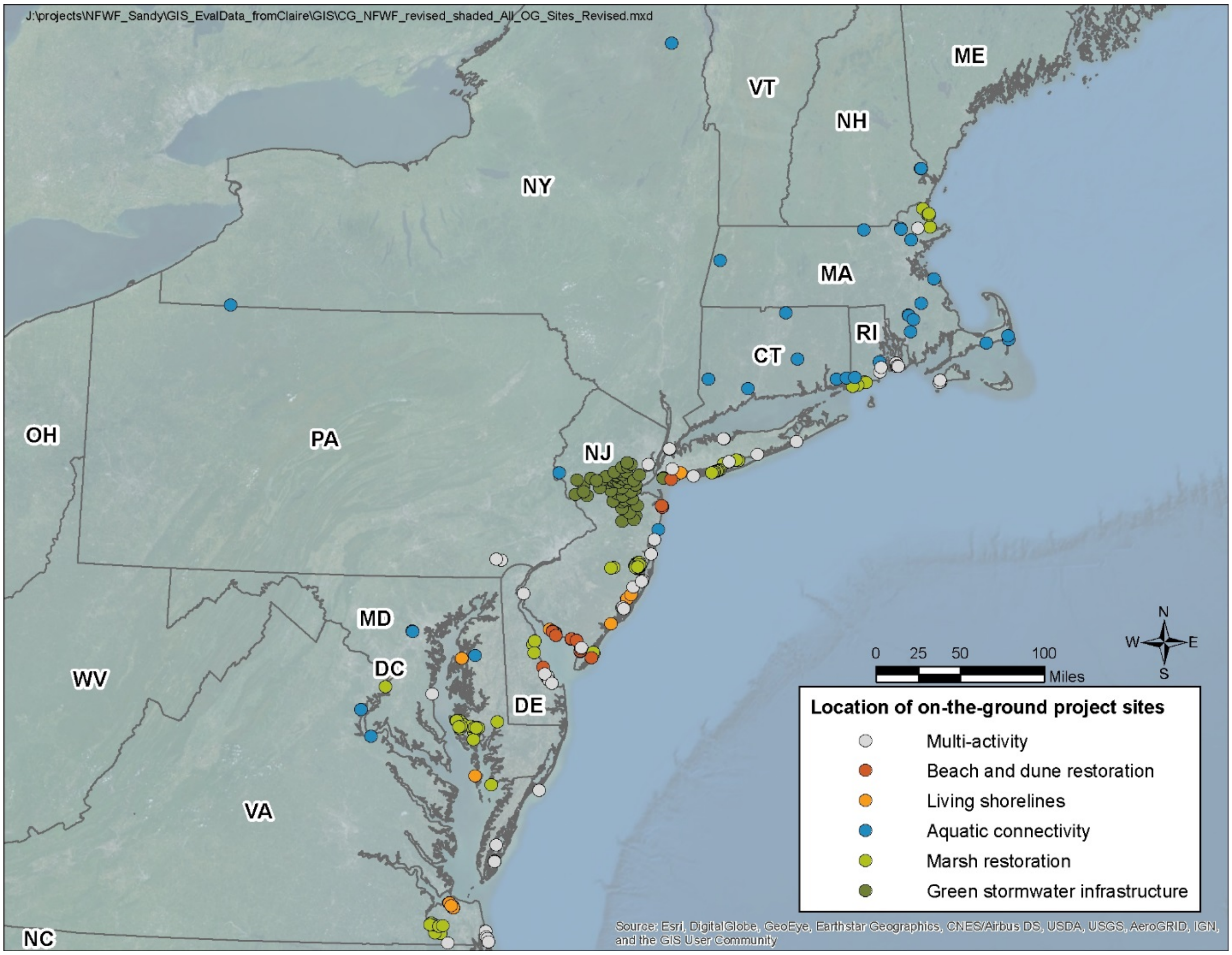
	Beach and dune restoration. Projects that restore beach and dune habitats to improve wildlife habitat; and protect and sustain nearby coastal communities, natural resources, and recreational activities.
	Green stormwater infrastructure. Projects that install green stormwater infrastructure to improve stormwater management and reduce flood risk by using vegetation, soils, and other practices to restore natural processes required to manage water.
Science and Planning Projects	
	Coastal resilience science. Projects that produce scientific knowledge that can be used to identify key risks and vulnerabilities to coastal storms, and to inform resilience-related decision-making in the region.
	Community resilience planning. Projects that produce plans, strategies, and recommendations to enable rapid implementation of planned projects and improve decision-making related to enhancing resilience.

To assess the impact of these projects, NFWF and DOI have also funded long-term monitoring and evaluation of the Hurricane Sandy Program portfolio to more fully understand ecological and economic benefits of the resilience projects (Box ES.2).

Box ES.2. Monitoring and evaluation projects.

Monitoring and Evaluation	
	Long-term monitoring. A subset of 38 of the Hurricane Sandy projects will be monitored from 2018 to 2023 to assess the trajectory of their project activities against a suite of metrics related to these activities. This monitoring includes both ecological and socioeconomic metrics.
	Program evaluation. The evaluation of the Hurricane Sandy portfolio will occur in two phases. This report encompasses the first phase of the evaluation; the second phase of the evaluation will occur following the long-term monitoring, which is planned to conclude in 2023.

Figure ES.1. Location of on-the-ground projects funded by the Hurricane Sandy Program. Because many projects conducted restoration activities in multiple sites, the number of sites (dots) in the figure exceeds 160 (the total number of projects included in the evaluation). In addition, many projects were combined projects, which included multiple activities at a site. Projects without an on-the-ground component, such as some science and planning projects, are not shown here.



Through archival research, surveys, interviews, literature reviews, and quantitative analyses, we addressed the five evaluation questions developed by DOI and NFWF to serve as the focus of this evaluation (Table ES.1).

Table ES.1. Summary of evaluation questions and findings[a]

Question 1:	To what extent did projects **implement activities** as intended? What factors facilitated or hindered project success?
Finding PI.1	Overall, approximately 80% of the evaluated projects had successfully completed their proposed activities at the time of the evaluation, with the remainder of projects slated for completion by the end of 2019. Projects with activities in multiple categories were least likely to be complete (48%). The average duration for a project was approximately three years.
Finding PI.2	Nearly half of the projects (73 out of 160) experienced some type of project modification, including changes in schedule, scope, or budget. These modifications facilitated project completion.
Finding PI.3	A variety of factors caused implementation delays for on-the-ground projects, including permitting, seasonal limitations, the need for additional data collection or project design work, and contracting or procurement issues.
Finding PI.4	Completed on-the-ground projects have generally met their design goals, with the majority of projects exceeding targets for area or length restored.
Question 2:	What **key outcomes** were realized for habitat, fish and wildlife, and human communities?
Finding PO.1	Projects have reduced flood risk and improved human safety through the removal of dams, including dams categorized as hazardous; culvert improvements; restoring and protecting coastal habitats that reduce storm surge; and better management of stormwater.
Finding PO.2	Overall, the portfolio of Hurricane Sandy Program on-the-ground restoration projects restored or created more than 190,000 acres of coastal marshes, freshwater wetlands, beaches and dunes, oyster reefs, and associated habitats; improved fish access to nearly 370 miles of streams; and protected approximately 300 acres of marsh and beach habitats behind living shorelines, providing critical support to fish and wildlife in the region.
Finding PO.3	Early improvements in fish passage, water quality, habitat conditions, and wildlife use have already been reported by a subset (64%) of on-the-ground projects.
Finding PO.4	Generally projects are maturing as expected after restoration, compared to reference conditions. Early observations of recovery for restoration projects are consistent with expected timelines of recovery after restoration for each of the different focus areas (aquatic connectivity, marsh, living shorelines, and beach and dune). However, initial project budgets and timelines did not include substantial pre- or post-project monitoring; more monitoring is needed to understand the long-term outcomes.
Question 3:	Is there evidence that investments in green stormwater infrastructure are **cost-effective** compared to gray infrastructure?
Finding CE.1	Living shorelines were typically more cost-effective than stone revetments for erosion protection, especially when the additional benefits of habitat creation were considered, averaging five to eight times greater cost-effectiveness to achieve the same erosion control benefits. (Note that because of data limitations, this was the only quantitative cost-effectiveness analysis undertaken.)

Table ES.1. Summary of evaluation questions and findings[a]

Question 4:	Did investments in tools and knowledge related to resilience **improve decision-making**?
Finding ID.1	Science-focused and community planning projects developed products to benefit resilience across the region, including datasets, maps, models, management plans, and resilience planning tools.
Finding ID.2	Coastal resilience science efforts have directly improved resilience-related decision-making, while 54% of planning projects have directly led to project implementation and adoption of resilience activities beyond the original project areas.
Question 5:	What **information is needed** to better understand the long-term impacts of investments in resilience?
Finding IG.1	Subsequent funding from NFWF and DOI will support the long-term monitoring needed to assess the impact of restoration on coastal ecosystem resilience, though some data gaps will likely remain.
Finding IG.2	More time is needed to observe how and to what extent science and planning products are used to improve decision-making and promote coastal resilience.

a. Findings are organized by question, where PI = Project Implementation, PO = Project Outcomes, CE = Cost-Effectiveness, ID = Improved Decision-Making, and IG = Information Gaps.

The evaluation also includes six in-depth case studies, each of which focuses on understanding the impacts and effectiveness of projects within a specific resilience activity category. The case studies analyzed projects in the following resilience categories[1]:

- Marsh restoration
- Living shorelines
- Aquatic connectivity
- Beach and dune restoration
- Community resilience planning
- Coastal resilience science.

Key findings from the case studies are summarized in Boxes ES.3 and ES.4.

[1] Note: We included green stormwater infrastructure activities within the community resilience planning case study instead of preparing a separate case study for it.

Box ES.3. Key findings for on-the-ground restoration projects. These findings include socioeconomic benefits of reducing flooding and coastal erosion risks for communities and ecological benefits of increasing ecological resilience through improving habitat accessibility, integrity, and extent, which can allow populations and ecosystems to recover more quickly from storm-related disturbances.

	Marsh restoration projects are restoring approximately 190,000 acres of marsh – equivalent to approximately 300 square miles. • *Socioeconomic benefit*: Improved resilience to future storms by absorbing waves, and reducing storm surge and related flooding and coastal erosion. • *Ecological benefit*: Provide important nursery, foraging, and refuge habitats for many commercially and recreationally important species of fish and crustaceans, building the capacity of these systems to persist into the future. Early project results include enhancements in marsh vegetation cover and growth, reduced invasive cover, and improved hydrological dynamics, improving the ability of marshes to provide habitat for birds, fish, and other wildlife.
	Nearly 53,000 linear feet of living shorelines have protected adjacent habitats and reduced coastal erosion on up to 440 acres of land. • *Socioeconomic benefit*: Reduced coastal erosion, while being at least as cost-effective as traditional gray infrastructure approaches for coastal protection, such as stone revetments. • *Ecological benefit*: Protection of adjacent habitat and benefits to wildlife by providing approximately 40 acres of newly restored habitat, including marshes, beaches, oyster reefs, and submerged aquatic vegetation.
	Removal of 23 dams and improvements to 10 culverts. • *Socioeconomic benefit*: Reduced flood risk during storms by lowering surface-water elevations by an average of 5 feet at modeled sites, improving the downstream conveyance of water and increasing floodplain storage. Additionally, dam removal, including the removal of 11 dams categorized as "hazardous," prevented potential loss of human life and infrastructure damage from catastrophic dam failure. • *Ecological benefit*: Nearly 370 miles of stream habitat are newly accessible to fish – ending more than a century of blockages by dams and other structures. Improved fish access supports representative species in the region such as river herring, American shad, and American eel, increasing population sizes and thus increasing the likelihood that these populations will persist into the future.
	Beach and dune restoration for community protection and ecological resilience. • *Socioeconomic benefit*: Protected inland communities from recent storm damage by preventing flooding of infrastructure behind the protective dune. These community-focused projects restored 4 linear miles and 75 acres of beach and dune habitats. Preliminary observations of four projects found that the restored dunes were stable and resilient to recent coastal storms. • *Ecological benefit*: Nearly 11 linear miles and 140 acres of restored beaches and dunes, including the community-focused projects described above, are providing important habitat for beach-dependent wildlife, including two threatened birds (red knot and piping plover).

Box ES.4. Key findings for science and planning projects.

One hundred twenty-six management plans or assessments, 85 site-specific designs, and 65 resilience tools are being created to identify, describe, or prioritize future actions that would improve community resilience. More than 50% of the projects have already led to on-the-ground actions that are directly increasing resilience, with a rapid progression from planning to implementation.
More than 700 data information products are being created, including presentations, reports, manuscripts, datasets, maps, and models. The information provided by these projects has filled key knowledge gaps and, in some cases, directly improved resilience-related decision-making.

Overall, key insights and lessons learned from this evaluation include:

- Program Structure
  - By supporting **multiple activity categories**, the program is effective in enhancing coastal resilience to **multiple risks**, including sea level rise, storm surge, erosion, and inland flooding.
  - Hurricane Sandy Program projects fall into two overarching types, depending on the type of activities they perform: **"on-the-ground" and "science and planning." These activity types have complemented each other** – people leading on-the-ground projects have noted data gaps and the lack of plans and permits as constraints on implementation. Science and planning projects aim to fill those needs – leading to more efficient and effective implementation of future projects.
- Project Implementation
  - On-the-ground resilience activities experienced extensive delays, especially from **challenges associated with the design and permitting** of projects. These challenges were exacerbated when staff leading projects were inexperienced with the requirements of large-scale restoration work and when initial project deadlines were unrealistic.
  - Development of a system to **track scope changes and time extensions** allowed for clear communication about project changes.
  - Investments in site-specific designs have allowed projects to move rapidly from the planning to implementation stages. For example, **more than 50% of the planning projects have resulted in on-the-ground projects being implemented**.
- Project Results
  - **Early observations** of results for completed projects suggest that **on-the-ground projects generally are on track** to improve ecological and community resilience, with observed results being consistent with expected trajectories of recovery.
  - Science and planning projects that **incorporated stakeholders and end users into project teams moved rapidly to uptake**, without delays resulting from the need to perform additional outreach.
  - **Investments made by DOI and NFWF in metrics development and long-term monitoring will enable a robust understanding** of the full spectrum of benefits from resilience projects. Over the long-term, this information is intended to inform best practices, guide future enhancements to projects, address knowledge gaps, and sustain improvements in coastal resilience.

The evaluation team also developed a set of recommendations for future coastal resilience funding programs and for practitioners who implement coastal resilience projects (Table ES.2).

Table ES.2. Recommendations for future coastal resilience funding programs and practitioners

Category	Recommendation
On-the-ground projects	Funders and practitioners for coastal resilience projects should anticipate and accommodate changes in schedule, scope, and budget as data are collected and project designs are developed, particularly for projects that do not already have detailed plans in place. Project leads should not be pressured to submit overly optimistic schedules and budgets in proposals as a condition of funding.
	Permitting agencies are encouraged to proactively improve inter- and intra-agency coordination for permitting and compliance of coastal restoration projects. Project leads are encouraged to involve permitting agencies early in the design process.
	Investments in site-specific designs and permitting for coastal resilience projects are encouraged, even if implementation funding is not yet available.
Science and planning projects	Science and planning project teams should be encouraged or required to include stakeholders and end users, where possible, and to invest in outreach and engagement to stakeholders as a critical part of the success of science and planning projects.
Monitoring and evaluation	Support for long-term, systematic monitoring of coastal resilience projects is encouraged. This funding is required for understanding the long-term economic and ecological benefits of coastal resilience projects. Investments in this site-specific monitoring will enable future projects to be more effective and cost-efficient.
Overarching and administrative functions	For emergency funding packages, a combination of on-the-ground and science and planning projects are recommended as this combination of projects provides benefits to specific communities, while also enabling broader regional gains in resilience through the longer-term uptake of science and planning products.
	Establishment of an Executive Council and an Implementation Team provides an effective management framework, with the Executive Council providing high-level oversight on funding allocation and program progress, and the Implementation Team having management responsibility for implementation progress and cross-project coordination.
	Providing sufficient agency funding for program-wide activities enables important functions to occur such as external communication, administration, and oversight.

The Hurricane Sandy Program has improved ecological and human community resilience in the region affected by Hurricane Sandy. The program has successfully moved through the stages of project planning and implementation – funding a wide range of projects that have provided direct on-the-ground benefits as well as catalyzed future resilience activities through better science and planning. Recognizing the need for long-term, systematic data collection to assess restoration success, NFWF and DOI are supporting additional, future long-term monitoring at 38 projects. This next phase of the program will provide the ability to measure and evaluate the additional ecosystem services or benefits that can be realized through implementing natural and green stormwater infrastructure approaches, such as habitat restoration and living shorelines, to improve coastal resilience. This monitoring work is intended to further advance and inform decision-making regarding how best to achieve sustainable coastal resilience at local, state, and national levels.

1. Introduction

The U.S. Department of the Interior's (DOI's) Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program) was implemented to help ecosystems and communities affected by Hurricane Sandy in 2012 become more resilient to the impacts of future coastal storms and sea level rise. Between 2013 and 2016, the Hurricane Sandy Program, administered through both DOI and the National Fish and Wildlife Foundation (NFWF), invested more than $302 million to support 160 projects designed to improve the resilience of ecosystems and communities to coastal storms and sea level rise. [Additional projects and evaluation activities have been funded since 2016]. The program supported a wide array of activities including aquatic connectivity restoration, marsh restoration, beach and dune restoration, living shoreline creation, community resilience planning, and coastal resilience science to inform resilience-related decision-making. Each of these activities has a distinct impact on ecosystem and community resilience. ***Resilience*** is defined here as the ability to anticipate, prepare for, and adapt to changing conditions; and withstand, respond to, and recover rapidly from disruptions.

This report presents the findings of an external evaluation of the 160 Hurricane Sandy Program projects funded between 2013 and 2016. In this first introductory section, we provide background information on the history and goals of the Hurricane Sandy Program and its key partners. This provides important context for understanding our methodology and our evaluation findings in subsequent sections. In Section 2, we describe the purpose, questions, and methods of the evaluation. In Section 3, we present our evaluation findings, organized by the questions that guided the evaluation. In Section 4, we present conclusions of the evaluation and provide recommendations for those working to improve community and ecosystem resilience. The appendices provide additional technical detail on the projects funded (Appendix A), our evaluation methodology (Appendix B), and the metrics for long-term socioeconomic monitoring (Appendix C).

The Hurricane Sandy program is aiming to improve **resilience** through:

- Restoring coastal habitats or improving aquatic connectivity to reduce storm-related flooding and erosion in nearby communities
- Increasing the extent, physical integrity, accessibility, and quality of wildlife habitat, making species better able to withstand and recover from storm-related disturbances
- Identifying or improving tools and approaches for reducing coastal storm impacts
- Improving human safety.

1.1 Funding History

Hurricane Sandy made landfall on October 29, 2012, wreaking havoc on communities along the U.S. Atlantic Coast, impacting 12 states and the District of Columbia. In response to this disaster, Congress passed the Hurricane Sandy Disaster Relief Appropriations Act (the Act) to provide supplemental funding to improve and streamline disaster assistance for Hurricane Sandy, including $829.2 million (which was reduced by $42.5 million to $786.7 million due to sequestration) for DOI and its bureaus to respond to and recover from Hurricane Sandy's impacts. The Act also supported establishing a more-resilient Atlantic Coast (Public Law 113-2-Jan. 29, 2013). In addition to the more traditional stream of financial support associated with disaster relief, directed toward clean-up and rebuilding based on damages caused by the storm, $360 million (which was reduced by $18.1 million to $341.9 million due to sequestration) was appropriated to the Office of the Secretary of the DOI for projects to support resilience (referred to as "mitigation" in the Act). Public Law 113-2-Jan. 29, 2013 provides explicit direction to use resilience funds to restore and rebuild national parks, national wildlife refuges, and other federal public assets with the goal of increasing the resilience and capacity of coastal habitat and infrastructure to withstand and reduce damage from storms.

Of the $341.9 million, DOI invested approximately $221 million to support over 106 projects led by DOI bureaus that were designed to improve the resilience of ecosystems and communities to coastal storms and sea level rise by strengthening natural ecosystems in the region. These DOI-funded projects also included investments in resilience planning, and scientific data and studies to inform recovery in the region. In addition, DOI partnered with NFWF to administer an external funding competition to support similar projects led by state and local governments, universities, nonprofits, community groups, tribes, and other non-federal entities. Through this process, an additional $120.6 million in DOI funding from the Act was awarded to NFWF and invested in over 54 projects, as well as program evaluation and long-term monitoring. This evaluation covers the 160 projects funded with over $302 million between 2013 and 2016.

1.2 Hurricane Sandy Program Goals

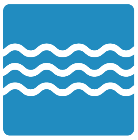
The three specific overarching goals of the Hurricane Sandy Program were to:

- Reduce the impacts of coastal storm surge, wave velocity, sea level rise, and associated natural threats on coastal and inland communities;
- Strengthen the ecological integrity and functionality of coastal/inland ecosystems to protect communities and to enhance fish and wildlife and their associated habitats; and
- Enhance our understanding of the impacts of storm events and identify cost-effective resilience tools that help mitigate the effects of future storms, rising temperatures, and sea level rise.

1.3 Projects Funded

Projects funded by the Hurricane Sandy Program undertook a wide array of activities, each with different pathways for achieving resilience improvements. We categorized projects according to seven major activity categories under two general groups ("on-the-ground" and "science and planning"; Box 1).

Box 1. On-the-ground restoration, and science and planning projects.

On-the-Ground Projects	
	**Marsh restoration.** Projects that enhance the ecological resilience of marsh sites and protect human communities and infrastructure from storm surge through restoration of marsh vegetation and improved hydrological connections.
	**Living shorelines.** Projects that install natural habitats and structures on the coastline, as opposed to hard shoreline structures, to protect shoreline communities and habitats.
	**Aquatic connectivity.** Projects that re-establish connected waterways and mitigate storm-related flooding and safety risks primarily by removing dams, improving or replacing culverts or bridges, and improving riverine habitat for diadromous fish and other migratory and non-migratory species.
	**Beach and dune restoration.** Projects that restore beach and dune habitats to improve wildlife habitat; and protect and sustain nearby coastal communities, natural resources, and recreational activities.

Box 1. On-the-ground restoration, and science and planning projects.

	Green stormwater infrastructure. Projects that install green infrastructure to improve stormwater management and reduce flood risk by using vegetation, soils, and other practices to restore natural processes required to manage water.
Science and Planning Projects	
	Coastal resilience science. Projects that produce scientific knowledge that can be used to identify key risks and vulnerabilities to coastal storms, and to inform resilience-related decision-making in the region.
	Community resilience planning. Projects that produce plans, strategies, and recommendations to enable rapid implementation of planned projects and improve decision-making related to enhancing resilience.

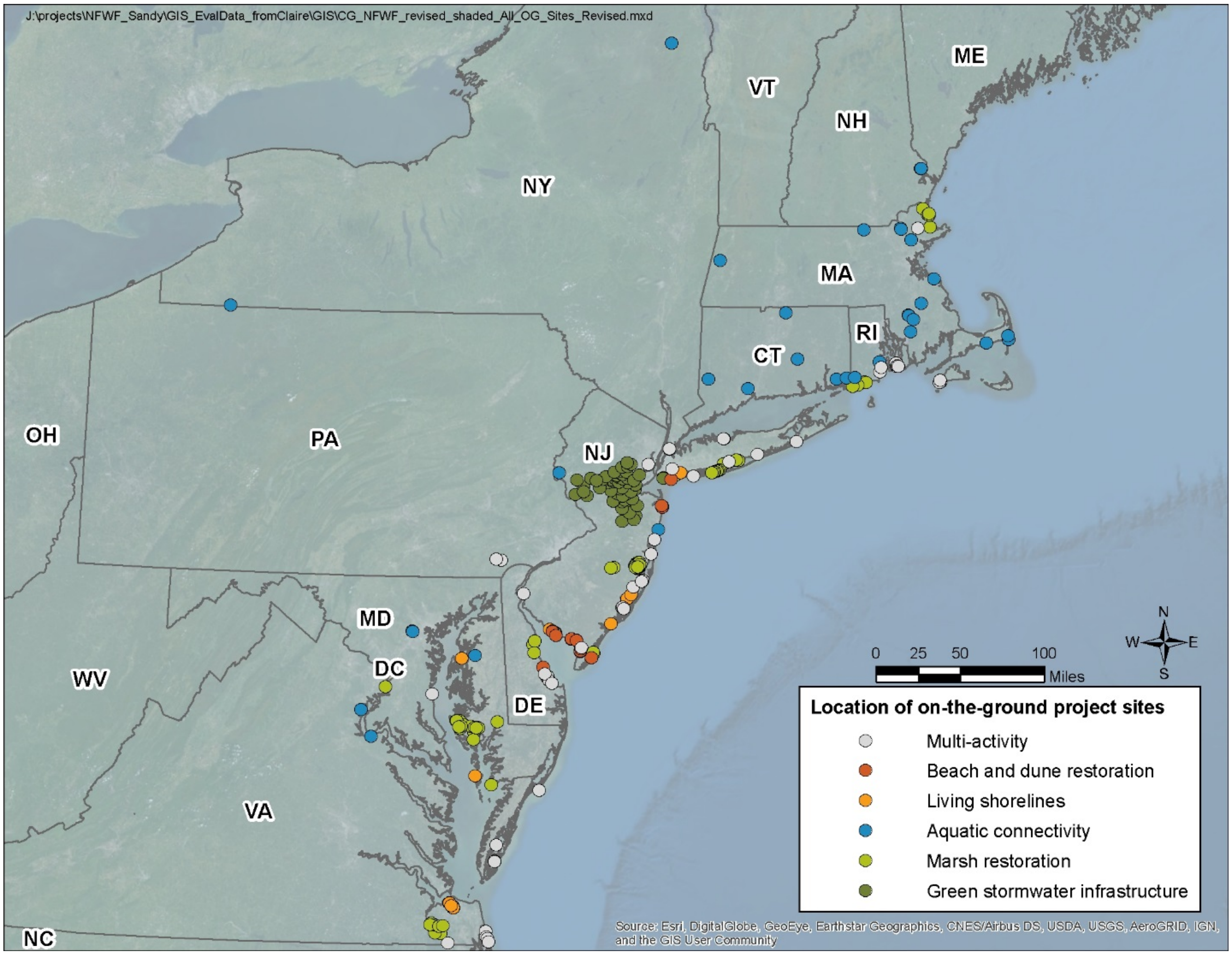
To assess the impact of these projects, NFWF and DOI have also funded long-term monitoring and evaluation of the Hurricane Sandy portfolio to more fully understand the ecological and economic benefits of the resilience projects (Box 2).

Box 2. Monitoring and evaluation projects.

Monitoring and Evaluation	
	Long-term monitoring. A subset of 38 of the Hurricane Sandy projects will be monitored from 2017 to 2023 to assess the trajectory of their project activities against a suite of metrics related to these activities. This monitoring includes both ecological and socioeconomic metrics.
	Program evaluation. The evaluation of the Hurricane Sandy portfolio will occur in two phases. This report encompasses the first phase of the evaluation; the second phase of the evaluation will occur following the long-term monitoring concluding in 2023.

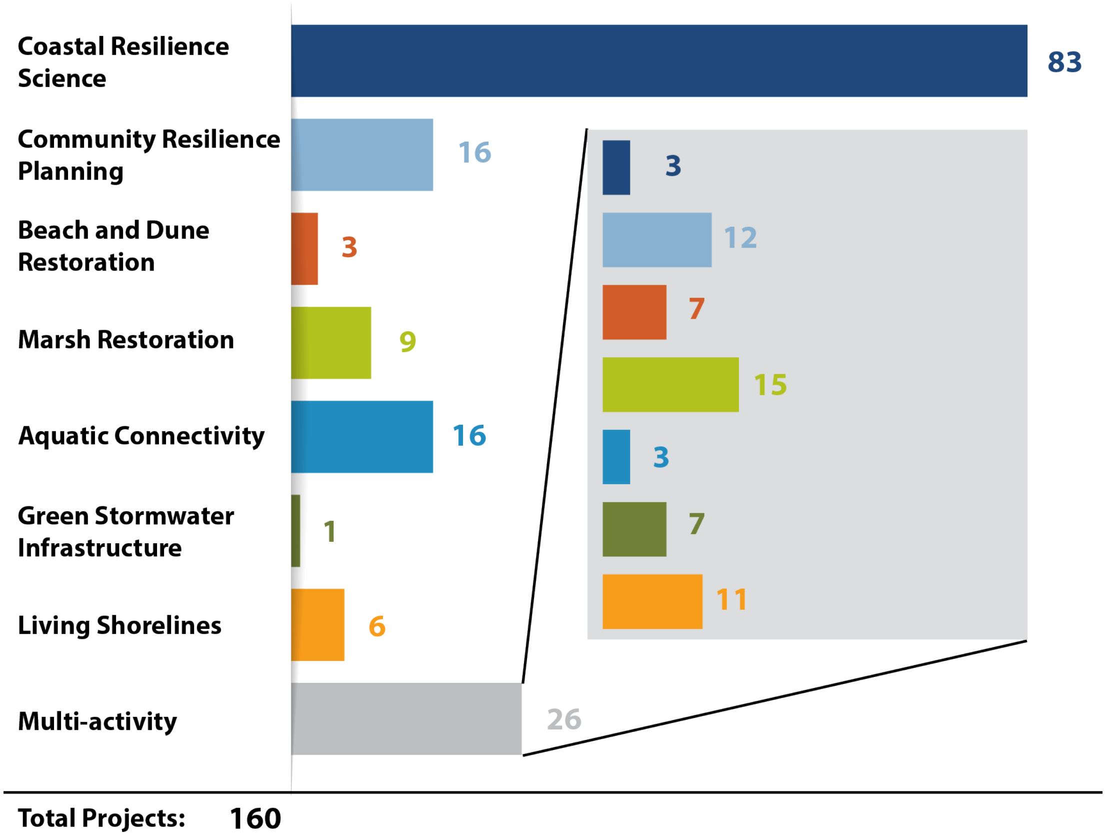
On-the-ground projects supported through DOI and NFWF were located in 10 states and the District of Columbia: Connecticut, Delaware, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Virginia (Figure 1).

Figure 1. Location of on-the-ground projects funded by the Hurricane Sandy Program. Because many projects conducted restoration activities in multiple sites, the number of sites (dots) in the figure exceeds 160 (the total number of projects included in the evaluation). In addition, many projects were combined projects, which included multiple activities at a site. Projects without an on-the-ground component, such as some science and planning projects, are not shown here.



Of the 160 evaluated projects,[2] the category of coastal resilience science included the largest number of projects, while green stormwater infrastructure accounted for the smallest number of projects (Figure 2). To avoid double-counting funding, we also included a "multi-activity" category; this category included 26 projects that integrated multiple activities. Projects in the multi-activity category most commonly included the marsh restoration, community resilience planning, and living shorelines categories, with 20 projects in 2 activity categories and 6 projects in 3 categories (Figure 2).

Figure 2. Distribution of projects by activity category. Projects categorized as "multi-activity" included more than one activity.



[2] This evaluation covers the 160 resilience-focused projects funded through the Disaster Relief Appropriations Act of 2013 that were awarded between 2013 and 2016 through either DOI or NFWF. Additional projects funded by the Hurricane Sandy Program since December 2016 are not included in this evaluation.

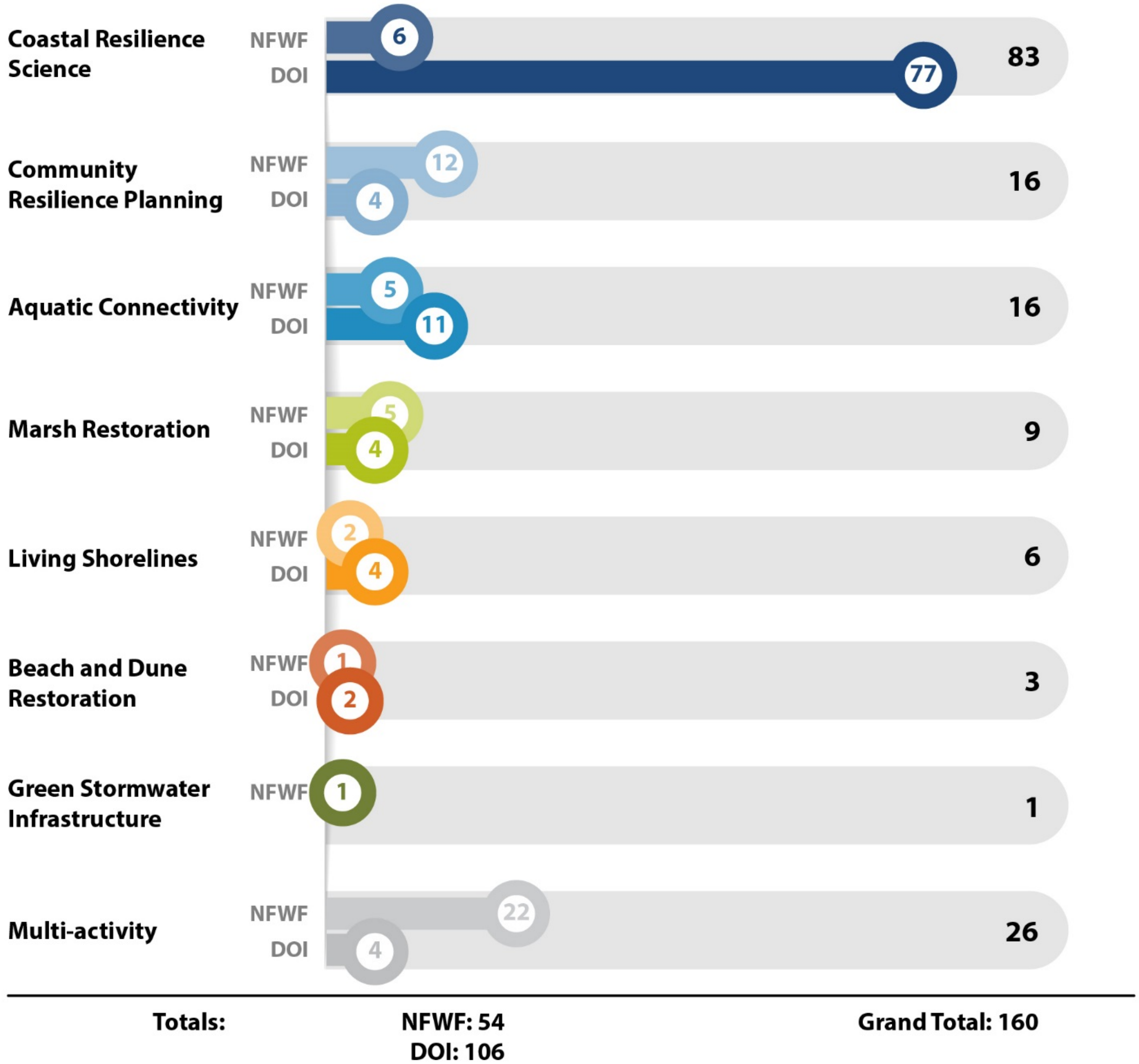
The Hurricane Sandy Program invested more than $302 million in resilience activities. Funding allocated to each project activity ranged from $92.6 million (marsh restoration) to $8.4 million (green stormwater infrastructure). Marsh restoration had the highest average project award size ($3.9 million), while community resilience planning had the lowest average project award size ($0.8 million). Coastal resilience science projects received a total of $82.5 million; however, due to the large number of projects in this activity category, the average award per project was relatively low at less than $1 million (Table 1).

Table 1. Hurricane Sandy Program funding by project categorization. For this analysis, project funding was allocated across each activity category; therefore, the total number of projects is greater than 160. This analysis does not include additional matching or leveraged funding obtained by project leads. All costs are rounded to the nearest hundred.

Activity category	Total number of projects (including multi-activity projects)	Total funding	Average funding per project
Coastal Resilience Science	86	$82,526,200	$959,600
Community Resilience Planning	28	$22,873,000	$816,900
Marsh Restoration	24	$92,559,300	$3,856,600
Aquatic Connectivity	19	$30,550,300	$1,607,900
Living Shorelines	17	$37,647,300	$2,214,500
Beach and Dune Restoration	10	$27,760,800	$2,776,100
Green Stormwater Infrastructure	8	$8,438,000	$1,054,800

As noted above, DOI directly funded 106 of the evaluated projects, while NFWF administered the funding for 54 projects. The distribution of projects by category differed for DOI- and NFWF-funded projects (Figure 3). DOI had the largest number of projects in the coastal resilience science category; while NFWF had the largest number of multi-activity projects.

Figure 3. Project categorizations for DOI- and NFWF-administered projects.



Many organizations that received funding also obtained matching or "leveraged" funding that enabled projects to include larger or additional activities. This leveraged funding, which was not a program requirement, included both cash and in-kind contributions. On average, project leads obtained approximately 30% more funding for their projects through leveraged funds. The greatest amount of leveraged funding (compared to the Hurricane Sandy Program funding) was in the marsh restoration category.

2. Evaluation Purpose and Scope, Questions, and Methods

2.1 Purpose and Scope of the 2018 Evaluation

The purpose of this evaluation was to conduct a broad assessment of the outcomes and resilience benefits resulting from the projects funded by the Hurricane Sandy Program.

The evaluation covers the 160 resilience-focused projects funded through the Disaster Relief Appropriations Act of 2013 that were awarded between 2013 and 2016 through either DOI or NFWF. In some cases, NFWF and DOI reinvested funds into new, additional projects after 2016; these projects, which are not included in this evaluation, are listed in Table A.2 in Appendix A. Except where noted, our conclusions are based on information available through December 2018.

2.2 Evaluation Questions

DOI and NFWF drafted the following questions to serve as the focus of the evaluation:

1. To what extent did projects **implement activities** as intended? What factors facilitated or hindered project success?
2. What **key outcomes** were realized for habitat, fish and wildlife, and human communities?
3. Is there evidence that investments in green infrastructure are **cost-effective** compared to gray infrastructure?
4. Did investments in tools and knowledge related to resilience **improve decision-making**?
5. What **information is needed** to better understand the long-term impacts of investments in resilience?

Evaluation findings are organized according to these five question topics.

2.3 Methodology Overview

The methodology for the evaluation included both qualitative and quantitative approaches to assess the effectiveness and impact of the Hurricane Sandy Program investments. Our methodological approach, described in detail in Appendix A, included the following activities:

- Review of archival materials from Hurricane Sandy Program project files (e.g., proposals, interim and final reports)
- A survey of project leads via a web-based instrument (across 136 projects; 85% response rate)
- Interviews with 44 project leads who led resilience projects
- Interviews with two NFWF staff and four DOI staff
- Quantitative information provided by project leads in their reports (e.g., acres of coastal habitat restored, miles of upstream river habitat newly accessible to fish)
- Literature searches addressing specific contextual issues relevant to different activities, or to provide important context and/or background for the main report.

During the analytical integration phase of our analysis, we examined the information provided through all of the methods used above. Where appropriate, we note where a finding is based on a subset of the data sources.

The evaluation includes six in-depth case studies, each of which focuses on understanding the impacts and effectiveness of projects within a specific resilience activity category (Abt Associates, 2019a–f). The case studies analyzed projects in the following resilience categories[3]:

- Marsh restoration
- Living shorelines
- Aquatic connectivity
- Beach and dune restoration
- Community resilience planning
- Coastal resilience science.

Projects that fall into the multi-activity category were considered and analyzed within all of the case studies where those projects belong (e.g., a project that fell into the two resilience categories of marsh restoration and living shoreline restoration was included in both case studies).

This report includes key findings from the case studies but does not repeat all of the analyses in the individual case studies. Instead, it focuses on drawing conclusions and integrating information across the activity categories.

[3] Note: We included green stormwater infrastructure activities within the community resilience planning case study instead of preparing a separate case study for it.

3. Findings

The report is organized by the overall topic of each evaluation question (i.e., project implementation, project outcomes, cost-effectiveness, improved decision-making, and information gaps). Below, we present our overarching findings for each topic and discuss the sources of evidence that support our findings.

3.1 Project Implementation (PI)

Finding PI.1: Overall, approximately 80% of the evaluated projects had successfully completed their proposed activities at the time of the evaluation, with the remainder of projects slated for completion by the end of 2019. Projects with activities in multiple categories were least likely to be complete (48%). The average duration for a project was approximately three years.

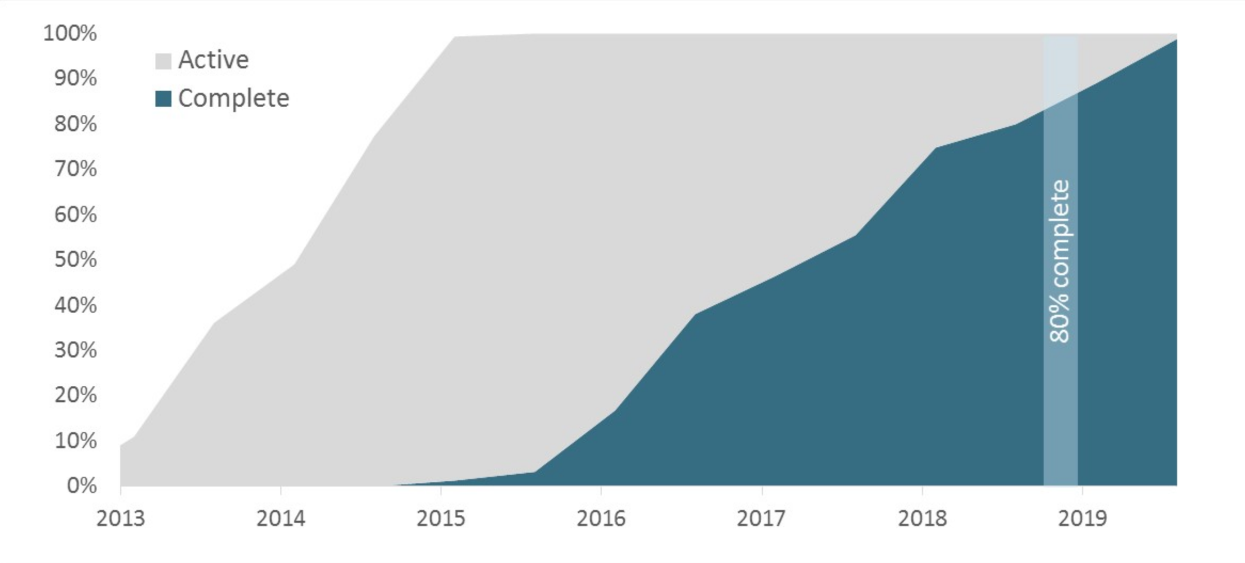
Archival and web-based materials show that over 80% of the projects have been completed (133 out of 160); 27 projects are still considered active.[4] In addition to these 160 projects, 1 additional project originally approved for funding was completely canceled following community opposition, with the funding reallocated for a future marsh creation project. Projects that included activities in multiple categories were most likely to still be active (only 48% complete), while science-based projects were nearly all complete (98% complete).

The average duration of a Hurricane Sandy Program project was approximately three years. The shortest project was a rapid five-month project by the National Park Service to replace beach fill at Jacob Riis Beach along the Rockaway Peninsula in Brooklyn, NY. The longest projects are two ongoing six-year mapping efforts by the U.S. Fish and Wildlife Service (USFWS), with projected end dates of December 2019: one project is mapping the strengths and vulnerabilities of over 70 miles of shoreline habitat at coastal refuges, while the other project is updating the official Coastal Barrier Resource System maps along the North Atlantic Coast.

Hurricane Sandy Program projects in this evaluation began in May 2013. The first project completed was in December 2014 – the final projects are scheduled for completion by December 2019 (Figure 4). Because the majority of projects have only been completed since 2017, the full ecological and community resilience benefits associated with these projects have not yet been realized (see Project Outcomes, Section 3.2).

[4] Project status information reflects information we gathered through April 2019. These active projects were initially expected to be completed in 2018 but have experienced delays.

Figure 4. Percentage of projects active and completed from 2013 through 2019. This figure shows the completion timeline for 155 projects with confirmed start and end dates (archival information confirming start and end dates was not available for 5 projects). By the time of this evaluation (in December 2018), over 80% of the projects were complete. For end dates after April 2019, we use projected end dates provided by the project leads.



Finding PI.2: Nearly half of the projects (73 out of 160) experienced some type of project modification, including changes in schedule, scope, or budget. These modifications facilitated project completion.

Overall, project leads modified nearly half of their projects (73 out of 160) by requesting timeline extensions, changes to their project scope, or changes in budget. Project leads could submit multiple amendment requests for a single project. Almost all of the multi-activity projects requested amendments, while fewer than 15% of the coastal resilience science projects requested amendments (Table 2). For the purpose of this evaluation, we have assumed that all projects requesting amendments were granted these changes by their funding agency as reported.

Table 2. Percentage of projects requesting amendments by project categorization. This analysis includes timeline, scope, and budget amendments. Projects are only counted once, even if they submitted multiple amendments.

Activity category	Total number of projects	Projects requesting amendments	Percentage requesting amendments
Coastal Resilience Science	83	12	14%
Community Resilience Planning	16	10	63%
Aquatic Connectivity	16	12	75%
Marsh Restoration	9	8	89%
Living Shorelines	6	4	67%
Beach and Dune Restoration	3	1	33%
Green Stormwater Infrastructure	1	1	100%
Multi-activity	26	25	96%
Total	**160**	**73**	**46%**

Of the 73 projects that submitted amendments, 71 requested timeline extensions, 19 requested scope changes, and 8 requested changes to their budget in order to complete their project activities.

Both on-the-ground restoration projects as well as science and planning projects experienced delays, most commonly due to permitting, weather and seasonal issues, additional data collection needs, or changes to project designs (see Finding PI.3). Projects were delayed between three months and three-and-a-quarter years. Forty-five projects experienced a confirmed delay of more than 9 months compared to their original completion estimates, and 11 of these projects experienced delays of more than 2 years.

NFWF and DOI have an internal approval process to document changes in project scope that requires some level of approval. Requested changes to project scope included changes in the extent of the restoration, the location of the restoration, and activities to be performed. These changes often occurred after on-the-ground data collection or permitting were complete. The majority of the project scope changes were minor (e.g., adjustments to existing project components), with only a few involving major changes (e.g., total addition or removal of project components).

Finding PI.3: A variety of factors caused implementation delays for on-the-ground projects, including permitting, seasonal limitations, the need for additional data collection or project design work, and contracting or procurement issues.

On-the-ground projects funded by the Hurricane Sandy Program were not required to have all permits and clearances in place prior to receiving funding. NFWF's Hurricane Sandy Program Request for Proposal required applicants to provide documentation that the project expected to receive or did receive all necessary permits and clearances to comply with all federal, state, or local requirements. Where appropriate, applicants were also encouraged to conduct a permit pre-application meeting with the Army Corps of Engineers prior to submitting their proposal for funding. Despite these requirements, project leads often found that the many sequential steps required for project implementation could serve as potential sources of delay (Figure 5).

Figure 5. Steps for implementing on-the-ground resilience projects.

For the Hurricane Sandy Program on-the-ground projects, permitting issues were noted in contract amendments as the most common cause of project delays (37% of projects with amendments), followed by weather- or seasonal-related effects on restoration activities (33%), additional data collection or design work (30%), and contracting or procurement (22%; Box 3).

Box 3. Examples of most common factors that contributed to schedule delays for on-the-ground projects. Information is from project reports and archival materials.

 ***Permitting delays***	Permitting issues were the most common cause of project delays. Project leads often described challenges with the permitting process as being a source of delays, including describing permitting as a cumbersome and somewhat unpredictable process. For novel or complex restoration approaches, such as some marsh restoration work, project leads noted that existing permitting systems were often not well-equipped to handle the projects, often due to the novel and multifaceted nature of the restoration work.
 ***Seasonal limitations***	Many project leads noted that the weather- and seasonal-dependent nature of restoration activities contributed to delays. For example, weather events and growing seasons can limit the time available to perform on-the ground restoration, and restoration work was sometimes delayed for months by waiting for appropriate working conditions to return. In addition, construction, including constructing living shorelines or dredging or nourishment for beach and dune restoration, was often restricted to specific times of the year to avoid harming wildlife (e.g., during migration or breeding seasons).
 ***Additional data collection or project design work***	Many project leads noted that they needed to gather additional data or adjust their project designs given onsite conditions, which caused unexpected project delays. For example, one beach and dune restoration project noted that because sand resources were obtained for less than originally budgeted amounts, beach restoration activities were expanded; this required additional time to design and implement those additional activities. In another example, a marsh restoration project utilized thin-layer deposition in a novel context (e.g., wetlands in a micro-tidal environment, where marsh loss is not due to coastal erosion but to gradual sea level rise, and where sediment accretion is minimal). Because of this approach, project leads needed to ensure that the proper approach was used to increase marsh height while also maintaining natural vegetation.
 ***Contracting or procurement***	Some project leads reported difficulties in contracting or procurement. Some delays were due to the contractor bidding process (e.g., one marsh restoration project noted that it was difficult to secure contractors because of the complex nature of the work and the narrow timeframes involved).

Science and planning projects also experienced delays. However, these delays were often minor or related to on-the-ground activities associated with multi-activity projects. In planning projects, delays occurred at different stages in the planning cycle, most commonly from additional data collection or changes to the project design prior to creation, time to effectively coordinate project activities with other partners, and difficulties in completing outreach to key audiences.

Finding PI.4: Completed on-the-ground projects have generally met their design goals, with the majority of projects exceeding targets for area or length restored.

Projects that are complete have generally met their key design goals. As reported in the **marsh restoration** case study, completed projects that were evaluated in-depth reported reaching target elevations, restoring tidal regimes, or removing invasives as designed. Across all of these marsh restoration projects, approximately 1,600 more acres were restored than proposed, and approximately 90% of the marsh projects met or exceeded the proposed marsh acreage restored. The majority of completed **living shoreline** projects reported either reaching or exceeding project design goals in terms of linear feet of living shorelines constructed. Only one completed project constructed a living shoreline that was smaller than proposed due to conflicting activities occurring at the site that prevented construction activities. The majority of **aquatic connectivity** projects proposed dam removal (12 of 19 projects). All dam removal projects removed at least one of their proposed dams. The non-dam removal projects generally met their restoration design goals. One project intended to replace a culvert, but ended up restoring the stream bank above the culvert to improve sediment transport, water flow, and fish habitat; and reduce flooding risk. Results for completed **beach and dune restoration** projects were mixed: approximately 55% of the projects met or exceeded their proposed linear miles restored; whereas approximately 45% of the projects fell short, ranging between a modest amount (only 0.15 linear miles short) and a significant amount (nearly 3 linear miles short of a 5.7-linear-mile project).

Projects also required some modifications to meet design goals for elevation, hydrology, and vegetation cover. For example, in marsh thin-layer deposition projects, the deposition of sediment was sometimes uneven and project leads moved dredge sediment or added more sediment to some locations. For hydrologic reconnection projects, typically some adjustments to the site needed to be conducted to increase flow and reduce ponding (e.g., cleaning out channels). Project leads noted the need to replant some vegetation due to mortality from coastal storms damaging newly planted vegetation, as well as wildlife grazing, sediment compaction, hypersaline waters, and other causes. Engaging in these adaptive management activities was important for the projects' success. One beach and dune restoration project location was hit by a winter storm and the restored areas experienced serious damage from overwash and losses in elevation, although the project was successful in protecting infrastructure behind the dune.

3.2 Project Outcomes (PO)

3.2.1 Human Community Outcomes

Finding PO.1: Projects have reduced flood risk and improved human safety through the removal of dams, including dams categorized as hazardous; culvert improvements; restoring and protecting coastal habitats that reduce storm surge; and better management of stormwater.

The Hurricane Sandy Program provided a suite of resilience benefits to human communities (Box 4). The program's on-the-ground projects undertook dam removal, restoration of coastal habitats, and green stormwater infrastructure improvements to improve safety, protect property and infrastructure, and increase resilience to natural hazards. In particular, a major focus of the projects involved reducing inundation risk, which results in economic benefits to communities by avoiding flooding that would have otherwise occurred.

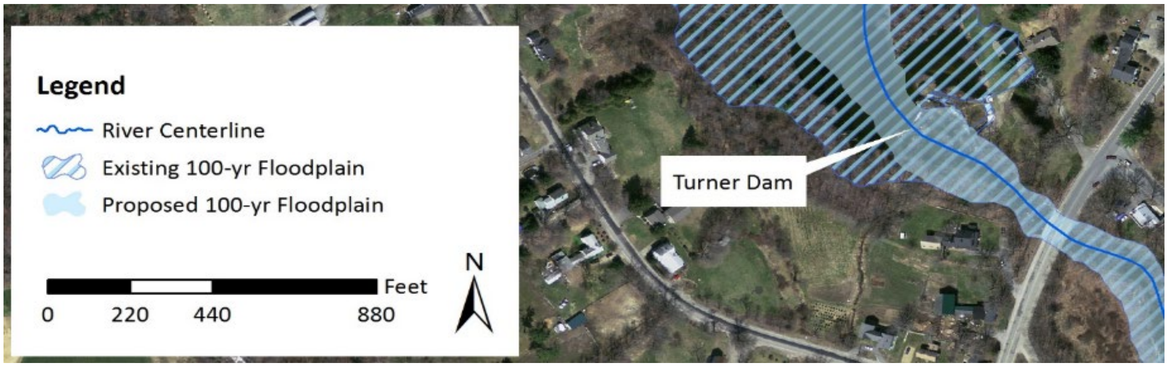
Dam removal and culvert replacement and improvement projects lowered water elevations in project areas upstream of the former dam, thereby reducing flood risk. Modeling at 16 different Hurricane Sandy Program dam removal sites estimated a median reduction in water elevations of 5 feet across all locations, even during a modeled 100-year flood. Flood risk was lowered in sites where culvert improvements or replacements increased river spans and improved the conveyance of water downstream. Shoreline stabilization and vegetation development through **living shorelines**, **beach and dune restoration**, and **marsh restoration** help protect inland resources, such as coastal infrastructure and communities, by absorbing waves and reducing storm surge and related flooding and erosion.

Green stormwater infrastructure projects used natural and nature-based designs – such as rain basins, rain gardens, permeable paving, and green streets – to manage stormwater, reduce localized flooding, and improve water quality in urban communities. By capturing stormwater, these projects delay the discharge of water to surrounding areas, which reduces the likelihood of persistent runoff and flooding following a storm.

Box 4. Examples of on-the-ground restoration projects providing resilience benefits to human communities.

Aquatic connectivity – reduced flood risk

Removal of the Millie Turner Dam on the Nissitissit River, a tributary of the Nashua River in Massachusetts, is expected to decrease the area in the 100-year floodplain and the number of properties potentially exposed to flooding events (below).



Source: Millie Turner Dam Preliminary Design for Removal, Final Report, Appendix A.

Replacing narrow culverts with a wider bridge improved water conveyance and minimized the risk of flooding. One project performed replacements at six sites; one culvert replacement at New Bridge Brook in Wilmington, NY (below) opened the river span from 4 feet to 22 feet. The project noted resulting improvements in tidal hydrology, water quality, and vegetation.

Replacement of a culvert with a new bridge in Wilmington, NY (project final report).

Box 4. Examples of on-the-ground restoration projects providing resilience benefits to human communities.

Beach and dune restoration – shoreline stabilization

A New Jersey project created a dune to protect a nearby coastal community from potential storm-related flooding and erosion. Following two major storms, the project reported that the dune held.

Project area and nearby community at Seven Mile Island, NJ (project final report).

Living shorelines – shoreline stabilization

A living shoreline project in Back Bay National Wildlife Refuge provides long-term protection of public use facilities that have historically experienced accelerated rates of erosion from storm events, such as Hurricane Sandy.

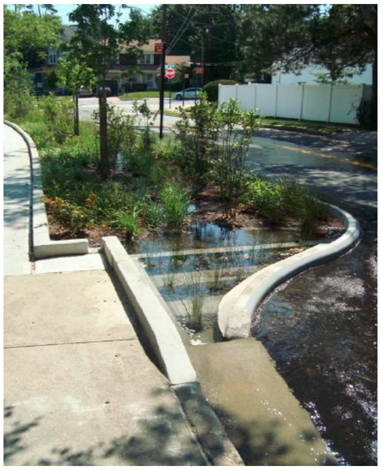
Back Bay National Wildlife Refuge completed living shoreline construction (project final report).

Green stormwater infrastructure – reduced risks of runoff and flooding from storms

At New Jersey's Governor Livingston High School, two installed rain gardens capture, treat, and infiltrate stormwater runoff generated by the school's parking lot. Some schools, including Livingston High, began to use rain gardens as teaching tools and learning opportunities.

Rain gardens at Governor Livingston High School, Berkeley Heights, NJ (project final report).

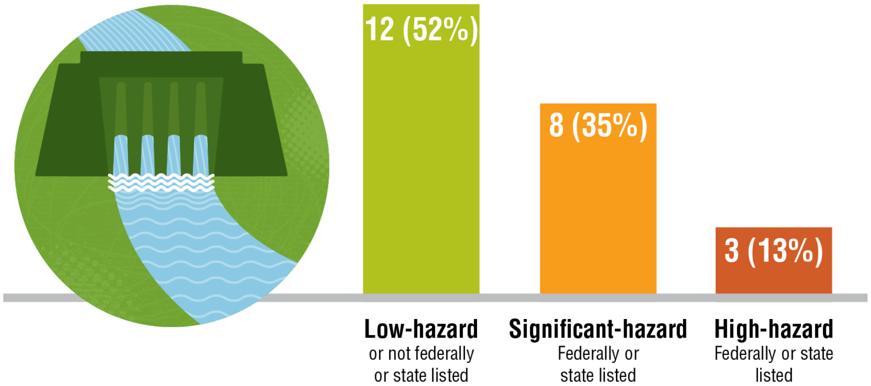
A project in New York **installed four green streets in New York City**, which will help mitigate flooding and filter more than 860,000 gallons of stormwater runoff for over 4,700 square feet. This project will serve as a model for other communities as New York City expands its green infrastructure initiatives.



Green street design precedent (project proposal).

Many dams removed through the Hurricane Sandy Program were disused and deteriorating dams, which could fail during storms, posing significant hazards to the safety and well-being of downstream communities and businesses. Three of the dam sites in the Hurricane Sandy Program were listed as high hazard by either federal or state authorities, and 8 were listed as moderate hazard (Figure 6).[5] Thus, the removal of these 11 dams improved human safety for those who live, work, or recreate close to these sites. Furthermore, removing dams of any hazard and condition rating can reduce direct, life-threatening hazards to swimmers and others who recreate near them (Kobell, 2015).

Figure 6. Number and percent of dams removed that were listed as low-, significant-, or high-hazard on federal or state dam inventories.



Sources: MA ODS, 2012; Ipswich River Water Association, 2014; USFWS, 2015a, 2015b, 2017; RI DEM, 2017; CT DEEP, 2019; MD DE, 2019; USACE, 2019.

3.2.2 Habitat, Fish, and Wildlife Outcomes

Finding PO.2: Overall, the portfolio of Hurricane Sandy Program on-the-ground restoration projects restored or created more than 190,000 acres of coastal marsh, freshwater wetlands, beaches and dunes, oyster reefs, and associated habitats; improved fish access to nearly 370 miles of streams; and protected approximately 300 acres of marsh and beach habitats behind living shorelines, providing critical support to fish and wildlife in the region.

Hurricane Sandy Program projects focused on restoring aquatic connectivity for waterways that had been blocked by dams or other obstructions, improving fish passage, particularly for diadromous fish that migrate between the ocean and inland waterways. Hurricane Sandy Program projects also benefited a large range of coastal habitats, including coastal low marsh and high marsh; adjacent freshwater wetland, beach, and dune habitats; and oyster reefs that help protect the shoreline (Table 3).

[5] Hazard classifications vary between federal and state dam inventories. In general, a high-hazard potential indicates that dam failure would result in probable loss of life and extensive property damage, a significant-hazard potential indicates that dam failure would result in no probable loss of human life but could result in property damage, and a low-hazard potential indicates that dam failure would cause no loss of human life and minimal property damage.

Table 3. Amount of restored and protected coastal and urban habitats expected from the Hurricane Sandy Program. This table includes restoration or protection resulting from on-the-ground projects, plus the extent of confirmed implementation resulting from community resilience planning projects.

Benefit type	Amount restored or protected
Marsh	190,379 acres
Stream	368.8 linear miles
Beach and dune	12 linear miles, 165 acres
Shoreline	10.3 linear miles
Green stormwater infrastructure[a]	828.7 acres; 38,376,970 gallons per year
Oyster reef	5.3 acres
Submerged aquatic vegetation	1.7 acres

a. Eight green stormwater infrastructure projects reported drainage area acreage; only six reported capture capacity of gallons per year.

Habitats restored through the Hurricane Sandy Program benefit key coastal species, including migratory and resident bird species, species of conservation concern either at the federal or state level, as well as fish and other wildlife (Box 5). For example, coastal marsh provides important nursery, foraging, and refuge habitats for many commercially and recreationally important species of fish and crustaceans found along the Atlantic Coast, including blue crab (*Callinectes sapidus*), striped mullet (*Mugil cephalus*), Atlantic croaker (*Micropogonias undulatus*), and black drum (*Pogonias cromis*). Freshwater instream habitat provides feeding, reproduction, resting, or migrating grounds for several diadromous fish species, enhancing commercial and recreational fishing. Beaches and dunes provide high-quality habitat to support breeding horseshoe crabs (*Limulus polyphemus*), which then become a critical food source for the federally threatened red knot during their spring migration, when they rely on horseshoe crab eggs during stopovers on the Atlantic Coast.

Box 5. Examples of representative species noted by project leads as likely to benefit from, or that are already benefiting from, on-the-ground restoration projects.*

Marsh restoration

Seaside sparrow* depend on salt marsh habitat for breeding and foraging. Multiple subspecies are along the Atlantic Coast, most of which are of conservation concern (photo: Wikipedia).

Red knot are migratory shorebirds that depend on mid-Atlantic marsh and beach habitats for foraging during migration. Red knot are protected as a threatened species under the Endangered Species Act (photo: Gregory Breese, USFWS).

Black skimmer use marsh-adjacent areas to forage, including tidal areas, estuaries, ditches, and rivers. The North American Waterbird Conservation Plan lists the black skimmer as a species of high concern (photo: Andreas Trepte/Wikimedia).

Saltmarsh sparrow live solely in salt marshes, where their nests are threatened by sea level rise. Approximately 80% of the population has disappeared over the last 15 years and it is currently being considered for listing under the Endangered Species Act (photo: Evan Lipton, Macaulay Library).

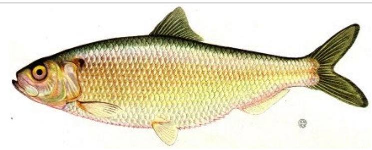
Sources: NYSDEC (Undated), Atlantic Coast Joint Venture (2014), Audubon (Undated, 2014), USFWS (2018, 2019b), Cornell Lab of Ornithology (2019).

Box 5. Examples of representative species noted by project leads as likely to benefit from, or that are already benefiting from, on-the-ground restoration projects.*

Aquatic Connectivity

Alewife* is a common species that migrate from the ocean to upstream rivers and lakes to spawn. It is a crucial component of the marine and freshwater food chains, serving as prey for larger commercial fish. Both alewife and blueback herring (collectively referred to as river herring) are at near historic lows coast-wide. Alewife and other migratory fish populations are depleted due to historical overfishing, habitat fragmentation and loss, and other factors.

Blueback herring* migrate from saltwater to freshwater to spawn, and serve as prey for bass and other large recreational and commercial species. As noted above, river herring stocks are at near historic lows coast-wide.



American shad,* a staple food for pre-colonial Native Americans, were historically over-harvested in the mid-Atlantic region and serve as an important forage fish for larger fish. Stocks are currently at all-time lows and there is no current indication of recovery.

American eel are an important prey species for commercial fish. A catadromous species that lives in freshwater and migrates to saltwater to spawn, they have the largest range of any fish species in North America. American eel stocks are depleted due to historical overfishing, habitat loss, and other factors.

Drawings not to scale.

Sources: ASMFC-1 through ASMFC-4 (Undated), USFWS (2015c), State of Maine Department of Marine Resources (2016), ASMFC-A (2019), ASMFC-B (2019), Chesapeake Bay Program (2019).

Beach and Dune Restoration

Red knot,* a federally threatened species, use the Delaware Bay as an important stopover habitat on their migration between South America and the Arctic.

Piping plover,* a federally threatened species with approximately 2,000 breeding pairs in the Atlantic region, depend on beach habitat for feeding and nesting; habitat loss is a key factor contributing to their decline.

American oystercatcher* is a shorebird species that roost in beach, dune, and marsh areas. After being hunted to near-extinction in the 19th century, the species is rebounding due to a variety of efforts focused on promoting successful nesting.

Horseshoe crab* live in shallow waters and are known to nest on mid-Atlantic beaches. Their eggs are an important food source for migrating birds such as red knots.

Sources: USFWS (2007, 2015d, 2019a, 2019c); University of Michigan Museum of Zoology (2019). Image credits: birds (Gregory Breese, USFWS; USFWS, 2017, 2019a); horseshoe crab (Wetlands Institute, 2013).

* Asterisks note species for which direct improvements in abundance, nesting success, or desired movement patterns have been observed in relevant restoration projects. See Box 4 and associated case studies for more details (Abt Associates, 2019a–f).

3.2.3 Trajectories of Outcome Achievement

Finding PO.3: Early ecological improvements in fish passage, water quality, habitat conditions, and wildlife use have already been reported by a subset of on-the-ground projects.

Observations made through project reports, archival materials, and project lead interviews indicate that on-the-ground restoration efforts have resulted in early observations of positive ecological improvements and benefits for wildlife (Box 6). For example, marsh projects that focused on hydrologic reconnection observed improvements in tidal flow and the re-establishment of appropriate flood durations, with relatively quick transitioning to native salt marsh species. Marsh projects that included thin-layer deposition to reach a target elevation found vegetation cover and productivity are generally increasing in all projects. However, some specific areas within projects are underperforming with respect to elevation, percent cover of vegetation, or vegetation growth, requiring adaptive management such as redistribution of sediment or replanting.

For ecologically focused beach and dune projects, projects observed increases in horseshoe crab breeding activity, bird utilization of beach habitat, bird breeding activity, and bird weight gains on restored beaches. As vegetation establishes and dunes stabilize, these coastal habitats provide increased storm protection for infrastructure behind the dunes. Multiple living shoreline projects reported initial improvements in oyster reef recruitment, and anecdotal observations of increases in bird and fish numbers at restored sites. As shoreline stabilization increases, this can lead to stabilized or increased shoreline elevation, providing increased resilience to erosion. Similarly, while most aquatic connectivity projects were only recently completed at the time of our evaluation, some have already achieved improvements in fish passage, in-stream habitat, water quality, and fish use of upstream habitat. For example, American shad and river herring were quickly observed in habitats upstream of dam removals in New Jersey and Massachusetts. As noted previously, dam removal projects also provide an immediate resilience benefit by reducing downstream inundation risks.

Box 6. On-the-ground restoration projects: Early observations of resilience improvements through improved habitat integrity, extent, and access to wildlife.

Marsh restoration

Hydrologic reconnection: A Delaware project observed **reduced water levels** post-restoration in much of the marsh interior. Tidal wetland grasses and other **vegetation had begun to recolonize** many of the exposed mud flat areas. Based on remote sensing, there has been an observed reduction of 700 acres of open water and an increase of over 500 acres of vegetated marsh in the 2 years post-project.

A small channel dug on Prime Hook National Wildlife Refuge (NWR) to reconnect the flow of water (Cape Gazette).

Thin-layer deposition: A Maryland project **reached target elevations** and **vegetation came back strongly** within the first year. Additional plantings were done in the second year, increasing vegetative cover. Project leads also **observed seaside sparrows** onsite following restoration.

Seaside sparrow nesting in the salt marsh at Blackwater NWR, MD (USFWS).

Beach and dune restoration

A New York project reported **increased horseshoe crab spawning and egg density, and greater increases in red knot weights during stopovers** on restored beaches compared to non-restored beaches.

The project team captures knots, turnstones, and sandpipers in the Delaware Bay (Stephanie Feigin, Conserve Wildlife NJ).

Aquatic connectivity

The Hughesville Dam was a disused, river-spanning, 15-foot high safety hazard and impediment to fish passage on the Musconetcong River in New Jersey. **Following the removal of the dam in 2016, American shad were reported upstream for the first time since upstream passage was blocked in 1768.**

Source: NJ DEP Press Release, June 15, 2017.

Box 6. On-the-ground restoration projects: Early observations of resilience improvements through improved habitat integrity, extent, and access to wildlife.

Living shoreline

As part of a living shoreline, shell bags have successfully **protected vegetation from scouring erosion and improved sediment accretion** at the northern end of Gandy's Beach, New Jersey.

Source: NJ DEP Press Release, June 15, 2017.

Green stormwater Infrastructure

Sunken Meadow State Park in New York is retrofitting a 12-acre parking lot with green infrastructure improvements to reduce stormwater runoff pollution to Sunken Meadow Creek and Long Island Sound. **Improvements in stormwater management will benefit the ecological services of the estuary, including alewife and American eel**. As water quality improves, marsh and eelgrass habitats are likely to become healthier, and the site may be used by wading birds and waterfowl.

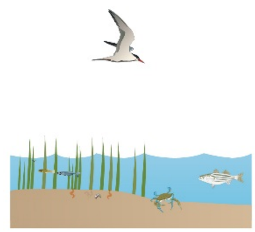
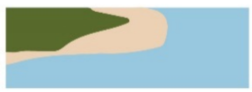
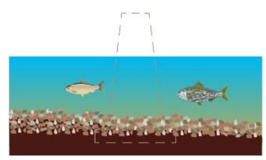
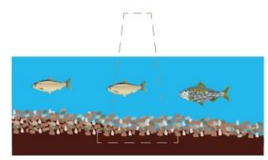
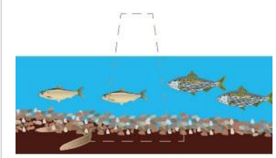
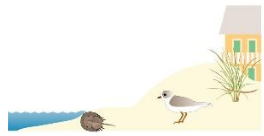
Twelve acres of impervious surface (project proposal).

Finding PO.4: Generally projects are maturing as expected after restoration, compared to reference conditions. Early observations of recovery for restoration projects are consistent with expected timelines of recovery after restoration for each of the different focus areas (aquatic connectivity, marsh, living shorelines, and beach and dune). More monitoring is needed to understand the long-term outcomes.

The ecological and socioeconomic benefits of many projects funded through the Hurricane Sandy Program will take time to materialize after restoration activities are completed. Long-term monitoring for a subset of projects is proceeding through 2023 to track the progression of project outcomes. To better understand and convey the potential timing of the achievement of key outcomes, the Abt Associates (Abt) evaluation team developed conceptual timelines of recovery after restoration using information from key peer-reviewed articles in combination with professional judgment from our team's subject matter experts (Figure 7). Each of the individual Hurricane Sandy Program evaluation case studies contains additional details about the expected recovery trajectory, relevant citations, and methodological details (Abt Associates, 2019a–f). A summary of key benefits can be found in Figure 7.

Overall, we found that each type of restored habitat has a unique restoration trajectory, depending on the types of physical and biological processes that need to be restored. For example, after a dam is removed, flood risk is immediately reduced, but channel morphology, flow, and sediment dynamics all take time to recover to reference conditions. For marsh restoration projects, hydrologic properties and appropriate elevations need to be restored before native vegetation and biota will thrive. For beach and dune habitats, stabilization of dunes with vegetation over time helps to reduce storm risk. For living shoreline projects, shoreline stabilization allows marsh and seagrass vegetation to develop, while oysters and mussels recruit onto the living shoreline structure.

Figure 7. Comparison of expected trajectories of short-, medium-, and long-term outcomes related to each of the on-the-ground activity categories.[a]

	Year 0 (Pre-project)	Short-term (1–2 years) outcomes	Mid-term (3–7 years) outcomes[b]	Long-term (10+ years) outcomes
Marsh				
	• No to sparse native vegetation • No to little storm protection • Few or no key species • Hydrologic functions compromised.	• Marsh elevation increases, vegetation establishes and matures over time, similar to reference by 15–30 years • Storm protection improves over time; native biota increase • Hydrologic features restored, similar to reference after 20 years • Water quality improves over time.		
Living shoreline				
	• No to sparse native vegetation • Minimal support to key wildlife • Habitat prone to erosion.	• Vegetation and seagrass establish over time, similar to reference by 15–30 years • Seagrass, oysters, and mussels recruit; native biota increases • Shoreline stabilization increases, leading to stabilized or increased shoreline elevation.		
Aquatic connectivity				
	• Barrier alters hydraulics, traps sediment • Few or no diadromous fish • Flooding risk.	• After barrier is removed, risk of structure failure is immediately eliminated, and upstream inundation risk reduced • Channel morphology and sediment dynamics improve over time • Diadromous fish and other aquatic species recolonize available habitat • Water flows approach reference conditions.		
Beach and dune				
	• No to sparse native vegetation • No to little storm protection • Few or no key species.	• Vegetation establishes and matures over time, until next storm disturbance; if undisturbed, similar to reference by 24+ years • Beach and dunes stabilize over time (without disturbance), leading to improved storm protection • Invertebrates recolonize (without disturbance), providing food to birds/wildlife that increases over time.		

a. Trajectory highlights are presented here; full details can be found in the individual habitat case studies.
b. For aquatic connectivity, the mid-term time period represents 3–5 years instead of 3–7 years.

There are also significant commonalities across the different habitats. All habitats go through a process of ecological development, from short- to long-term outcomes. Typically, vegetation helps stabilize the habitat and contributes to storm protection. Recruitment of biota occurs in stages, as habitats mature and prey species become more available. For example, beach restoration can provide suitable habitat for horseshoe crab reproduction, and the eggs of horseshoe crabs are an important food source for migrating birds such as red knots. Similarly, as marsh productivity increases, more native biota utilize those habitats.

Although projects generally look to be on track for achieving expected long-term outcomes, more monitoring is required over a longer time period to understand ecological and socioeconomic benefits of the Hurricane Sandy Program resilience projects. The long-term monitoring funded by the DOI on a subset of projects is described more fully in Finding IG.1.

3.3 Cost-Effectiveness (CE)

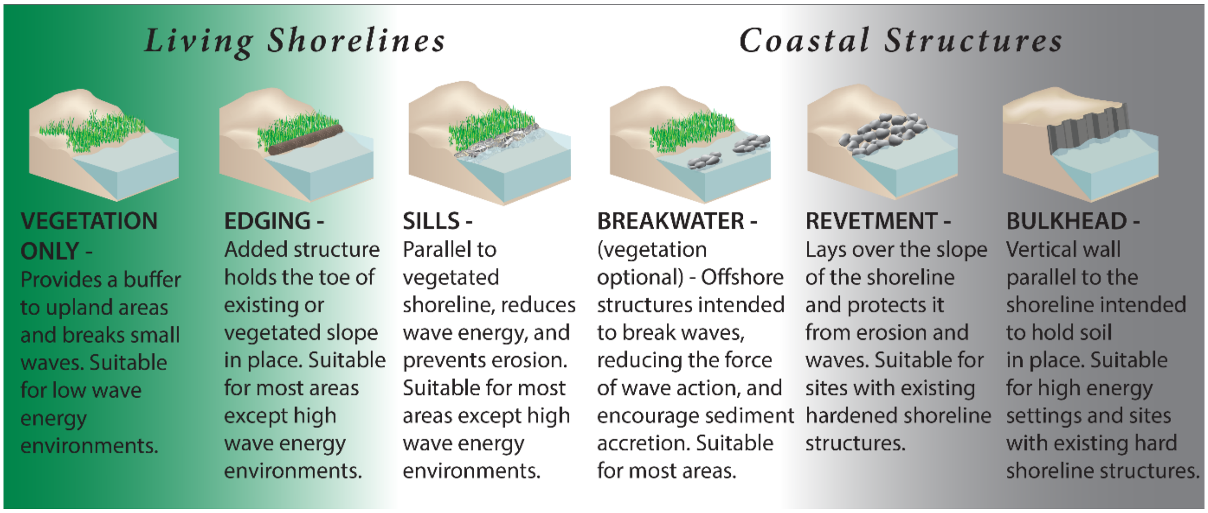
Cost-effectiveness compares the relative costs and projected outcomes, or effects, of different courses of action. This type of analysis estimates the costs per unit of benefit using a consistent metric, such as the number of acres protected or the value of damages avoided. By using consistent metrics across activities, decision-makers can determine the most efficient approach to achieving a set of goals. In this evaluation, we applied a cost-effectiveness analysis to determine if Hurricane Sandy Program investments in living shorelines are cost-effective compared to stone revetments (a typical "gray infrastructure" approach). Data were not available for a robust cost-effectiveness analysis of other resilience activities.

Finding CE.1: Living shorelines were typically more cost-effective than stone revetments for erosion protection, especially when the additional benefits of habitat creation were considered, averaging five to eight times greater cost-effectiveness to achieve the same erosion control benefits.

The Hurricane Sandy Program invested in natural infrastructure that can provide community benefits, such as coastal protection, water purification, and reduced flood damages. Living shorelines, for example, use plants and natural elements – sometimes in combination with harder structures – to protect and stabilize the coastline, as opposed to hard shoreline structures like revetments or bulkheads (Figure 8; NOAA, 2015). Unlike hard shoreline structures, living shorelines connect the land and water to stabilize the shoreline, reduce erosion, and provide ecosystem services – all of which enhance coastal resilience (NOAA, 2015).

We selected living shoreline projects for the cost-effectiveness analysis because we could disaggregate costs of the living shoreline activity from total project costs (many projects included multiple types of resilience interventions, such as marsh or beach and dune restoration), and we could develop a cost-effectiveness estimate of a comparable alternative project (i.e., stone revetment project).

Figure 8. Shoreline stabilization techniques, where objects on the left side of this continuum represent green, living shoreline techniques; and projects on the right represent gray, harder shoreline stabilization techniques.



Source: Figure 1 in NOAA, 2015.

Under the Hurricane Sandy Program, projects are creating nearly 53,000 linear feet (approximately 10 miles) of living shorelines.[6] These projects stabilize shorelines and avoid coastal erosion. While coastal erosion is a natural process, it can lead to the degradation or loss of valuable coastal resources and is considered a critical threat to coastal communities and ecosystems along the Atlantic Coast. Based on coastal erosion rates provided by project leads and federal and state data, we estimate these projects will reduce coastal erosion on approximately 300 to 440 acres of land over the 30-year project lifespan (approximately 30–44 acres protected per mile of living shorelines).

For a subset of projects,[7] we compared living shorelines to stone revetments of equivalent length, assuming a low-erosion rate. We found that living shoreline costs per acre protected were generally lower than comparable stone revetment costs.[8] The average difference in costs per acre protected across these living shoreline sites was approximately $84,800. The difference between stone revetment and living shoreline costs over 30 years (the assumed project lifetime) ranged from approximately a negative $2.2 million, meaning the stone revetment was less expensive, to a positive $1.1 million, meaning the living shoreline was less expensive (Figure 9). Negative values, which indicate that the living shoreline was less cost-effective than the stone revetment, were seen at only 5 of the 22 sites (as shown by the gray shaded areas in Figure 9).

[6] These data include projects that have not yet been completed, and thus the final number of linear feet created may change.

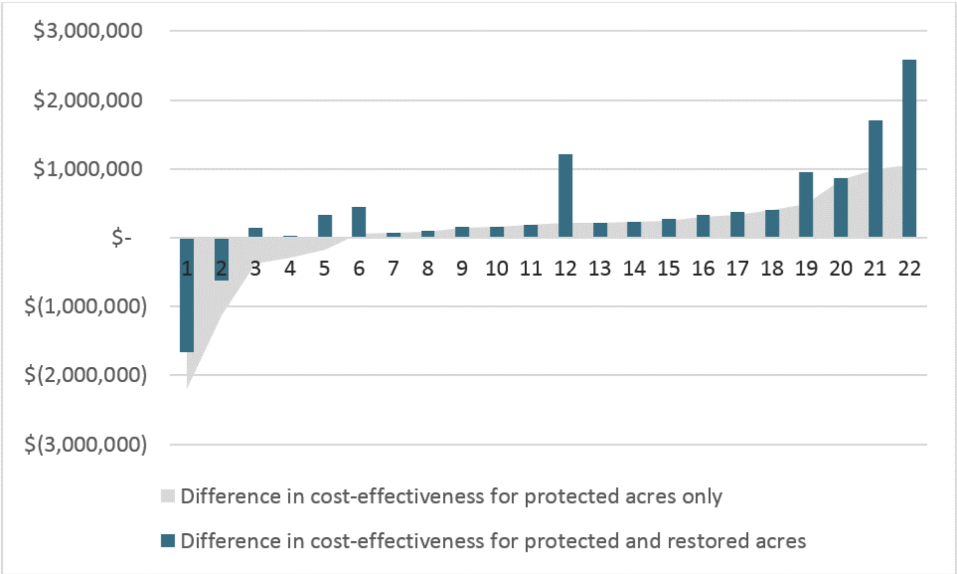
[7] Eleven of the total 17 living shoreline projects were selected for the in-depth, cost-effectiveness analysis because the costs of the living shoreline activity could be disaggregated from total project costs. These 11 projects encompassed 22 project sites.

[8] For additional information about cost-effectiveness methods, see Appendix B.

In addition to protecting natural habitat and infrastructure, these projects also restore or create habitat behind the living shoreline; data provided by project leads indicate these projects are restoring nearly 40 acres of wildlife habitat. While, on average, each living shoreline project only directly protects and restores a modest amount of habitat, these habitats can play an important role in providing foraging, resting, and reproductive habitats for key bird, fish, and other wildlife in the region.

When we incorporated the acres restored for the subset of the living shoreline projects, the cost-effectiveness increased markedly. Using this modified benefit metric, the cost-effectiveness of living shorelines compared to stone revetments increased by roughly 5- to 8-fold, and only two living shoreline sites had lower cost-effectiveness than comparable stone revetment projects (Figure 9). Living shorelines with the highest cost-effectiveness compared to equivalent stone revetments were those that added the most habitat.

Figure 9. Differences in cost-effectiveness for living shorelines versus stone revetments across 22 project sites. Compares differences in cost-effectiveness using two benefit metrics: acres protected by the projects (gray shaded areas) and acres protected and restored by the projects (blue bars).



We find that Hurricane Sandy Program investments in natural infrastructure, namely living shorelines, are a cost-effective and ecologically sound approach for reducing coastal erosion and improving resilience. Data were not available for a robust cost-effectiveness analysis of other project activities.

3.4 Improved Decision-Making (ID)

Finding ID.1: Science-focused and community planning projects developed products to benefit resilience across the region, including datasets, maps, models, management plans, and resilience planning tools.

For community resilience planning projects, 28 projects developed planning products that provided site-specific designs for future projects, identified key assets and vulnerabilities, recommended actions for improving resiliency, and shared knowledge and outreach on potential strategies. These plans also increased the visibility of natural and nature-based solutions to coastal hazards, and promoted the uptake and implementation of such solutions in communities. Community resilience planning projects created 126 management plans or assessments, 85 site-specific designs, and 65 resilience tools to identify, describe, or prioritize future actions that would improve community resilience.

For coastal resilience science projects, 87 projects produced scientific knowledge that can be used to identify key risks and vulnerabilities to coastal storms, and to inform resilience-related decision-making in the region. The scientific activities included in this case study were not conducted to support the implementation of a specific on-the-ground restoration project. Instead, the results were intended to help guide future storm response, restoration, and resilience actions. Coastal resilience science projects resulted in the creation of more than 700 deliverables, including presentations, reports, manuscripts, datasets, maps, and models.

Finding ID.2: Coastal resilience science efforts have directly improved resilience-related decision-making, while 54% of planning projects have directly led to project implementation and adoption of resilience activities beyond the original project areas.

Observations made through a combination of project reports, archival materials, and project lead interviews indicate that coastal resilience science efforts have directly improved resilience-related decision-making (Box 7). For example, projects have generated information that was used by other agencies and programs to create or improve decision-support tools, refine existing models, and update maps. Projects have also improved the availability and accessibility of data and information (e.g., protocols) to managers to help them make better-informed decisions.

Community resilience planning projects have directly led to project implementation and adoption of resilience activities (Box 8). For example, projects have developed site-specific designs for restoration activities, which were later used in the implementation of on-the-ground resilience efforts. Projects also developed planning documents that provide guidance in the implementation and adoption of resilience activities.

Box 7. Coastal resilience science projects: Examples of project-generated information used to improve resilience.

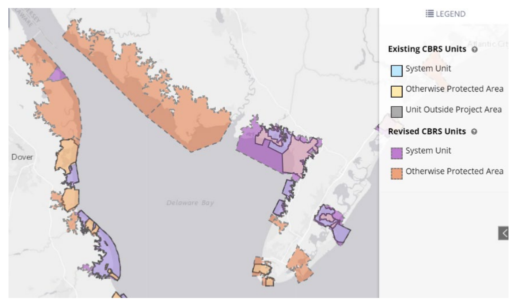
Coastal resilience science – data-focused project activities

USFWS supported the creation of the North Atlantic Aquatic Connectivity Collaborative (NAACC) – a network of partners in 13 states working to improve road-stream crossings. The NAACC provides a central database of road-stream crossing infrastructure, protocols, and training sessions for infrastructure assessments; and web-based tools for prioritizing upgrades. The creation of the NAACC led to a collaborative effort among Essex County, The Nature Conservancy (TNC), and USFWS to replace a problematic culvert with a design that would reduce onsite flooding and improve fish passage.

Culvert restoration in North Elba, NY. Source: TNC.

Coastal resilience science – mapping-focused project activities

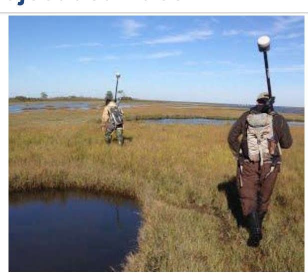
The official maps of the Coastal Barrier Resources System (CBRS) were first created more than 35 years ago, having used what are now outdated base maps and cartographic techniques. The Hurricane Sandy Program supported USFWS in revising these maps to fix technical mapping errors, add missing areas, and make the data more accessible and user-friendly. As of February 15, 2019, the Federal Emergency Management Agency has updated its flood insurance rate maps to use the new, dynamically updated digital CBRS boundaries. The revised boundaries have gone through a period of public review and are being prepared for consideration by Congress to be adopted into law.



Example of CBRS map from Delaware Bay. Source: USFWS. Resilience Tool.

Coastal resilience science – modeling-focused project activities

Three U.S. Geological Survey (USGS) projects supported the development of the Coastal National Elevation Database Topographic and Bathymetric Digital Elevation Model. Data from this model improved a coastal resilience tool developed by the TNC for New Jersey, enabling the state to support critical decision-making regarding coastal habitat restoration.



Staff collect high-resolution elevation data. Source: University of Rhode Island.

Box 8. Community resilience planning projects: Examples of developing plans to expedite future resilience projects.

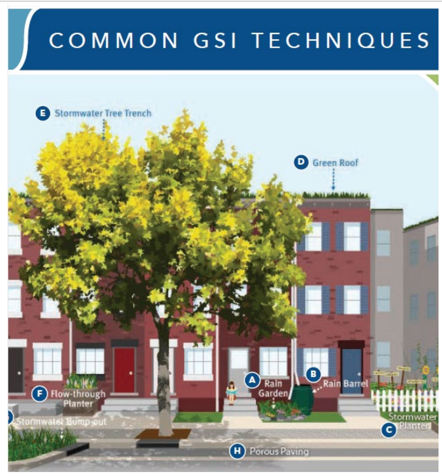
Community resilience planning – site-specific designs

A Massachusetts project created site-specific designs for removing three dams at risk for causing flood damage. After the plans were created, the project secured additional funding to move ahead with the removal of all three dams. The project also developed conceptual plans and cost estimates for an additional 10 new dam removals based on a statewide public safety and ecological benefit prioritization process. With the conceptual plans in place, 1 of the 10 sites already is moving forward to implementation.

Ipswich Mills Dam, funded for a removal feasibility study, is scheduled to be removed in summer 2019. Source: Ipswich River Watershed Association.

Community resilience planning – management plans and assessments

A project developed a framework document describing actions to expand the use of green stormwater infrastructure to enhance stormwater management, reduce water volume and flooding, and protect water quality in a Pennsylvania community. The plan defines green infrastructure approaches, describes the applicability of different approaches within the community, outlines relevant regulatory requirements, and offers potential first steps toward implementation. At the time of publication of the plan, the city announced a community-based public-private partnership to invest $50 million in the design, construction, and maintenance of green infrastructure within the community over the next two decades.



A screenshot of the City of Chester Green Stormwater Infrastructure Plan.

3.5 Information Gaps (IG)

Finding IG.1: Subsequent funding from NFWF and DOI will support the long-term monitoring needed to assess the impact of restoration on coastal ecosystem resilience, though some data gaps will likely remain.

Recognizing the need for long-term, systematic data collection to assess restoration success, NFWF and DOI are supporting additional, long-term monitoring for 38 of the 160 projects through 2023 (see Table A.1). To identify the most appropriate ecological metrics for these projects to measure over the long-term, NFWF and DOI leveraged work done by a multi-agency expert group, which developed a suite of standardized performance metrics for different types of Hurricane Sandy Program resilience projects (DOI, 2015). Grantees selecting projects for long-term monitoring had to propose a specific subset of these metrics for their projects (Box 9).

Box 9. Long-term ecological monitoring for project activities.

	Most of the **marsh restoration** projects included in the long-term monitoring are assessing the ecological effectiveness of their restoration actions by measuring changes in habitat use by marsh birds (i.e., abundance, distribution, breeding productivity), salt marsh vegetation (i.e., cover and community composition), and elevation (e.g., real-time kinematic measurements) over time. A smaller subset of projects are evaluating other metrics, including nekton abundance and diversity, water quality, and accretion. All of the ecological metrics included are consistent with those identified in the DOI (2015) report, but have been adapted in some cases to meet project-specific needs.
	Living shoreline projects included in long-term monitoring are collecting data for metrics such as wave height and velocity, sediment deposition and transport, vegetation cover, and oyster and nekton (fish and crustacean) abundance. These data will help assess the long-term benefits of these projects.
	Aquatic connectivity projects will be undertaking field measurements of fish abundance, assemblage, and migration patterns. Additional data will help improve understanding of how riverine and adjacent systems can rebound after restoration and the long-term benefits of aquatic connectivity projects. In addition, NFWF and DOI are supporting inundation modeling in a subset of sites to better characterize and quantify flood risk reduction in project sites over the long-term. More specifically, a joint USFWS- and USGS-led effort is performing HEC-RAS modeling for 9 of the 23 dam removal sites. The output from these models will be used to create detailed inundation maps of nearby communities and to compare inundation patterns before and after dam removal. This will offer clear, quantifiable insights regarding the flood risk benefits provided through dam removal under different flow scenarios. NFWF and DOI are also supporting long-term monitoring to understand the ecological recovery of restored areas, and the impacts of project-related flooding reduction on human health and well-being, transportation, critical facilities, and recreation.
	Beach and dune restoration projects will be tracking beach and dune dimensions (e.g., height, width), vegetative cover, and avian habitat use (e.g., abundance, distribution, breeding productivity). Socioeconomic monitoring will also assess how beach and dune restoration affects human well-being, primarily by evaluating any reductions in hazardous flooding. Data will improve understanding of the quality and longevity of the habitat, and protection provided by the beaches and dunes restored through the Hurricane Sandy Program.

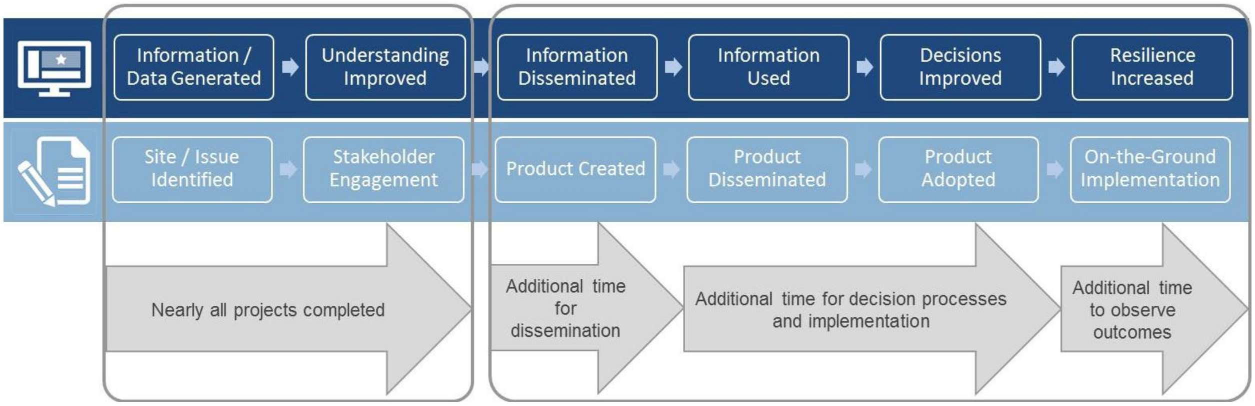
In addition to these ecologically focused metrics, NFWF and DOI are also supporting long-term monitoring to understand the impacts of on-the-ground restoration on human well-being, primarily through the benefits gained by reducing flooding-related impacts on human health, transportation, critical facilities, and recreation (see the socioeconomic metrics in Appendix C). As with the ecological monitoring, the socioeconomic metrics being monitored were previously identified as potential standardized performance metrics for Hurricane Sandy Program resilience projects (Abt Associates, 2015).

Finding IG.2: More time is needed to observe how and to what extent science and planning products are used to improve decision-making and promote coastal resilience.

As with on-the-ground interventions (e.g., marsh, beach, or dune restoration), the direct resilience benefits of coastal resilience science may take time to fully materialize. For example, it may take time for decision-makers to become aware of relevant new scientific knowledge, particularly when direct outreach is limited. It may take even longer for an opportunity to apply that information to policies or specific decisions. For example, information products that enhance the ability to detect and predict storm surge impacts may be utilized very soon after they are created, but products that are designed to inform decisions about long-term investments in coastal restoration may take longer to be applied. Projects noted that outreach efforts such as follow-up workshops and guidance training sessions were a success factor in gaining engagement and buy-in from decision-makers. Furthermore, depending on the specific decision informed (e.g., climate change adaptation plan, restoration of a marsh), more time may be required before the resilience impacts of the decision are realized. Therefore, longer-term assessments of the application of coastal resilience science project information are needed to fully understand their resilience-related impacts.

Similar to coastal resilience science projects, the direct resilience benefits of planning efforts take time to fully materialize. Following the creation of a planning document or tool, key steps can include the (1) promotion and dissemination of the planning product, (2) adoption of the planning product by relevant decision-makers, and (3) further prioritization and funding acquisition to implement on-the-ground interventions. As described in the on-the-ground restoration case studies (Abt Associates, 2019a–d), there is also a time lag between project implementation and full realization of the resilience benefits of those activities as the project matures. Although some projects moved quickly from the planning to implementation stages, we expect that longer-term assessments are needed to fully understand how and to what extent these recently completed planning products have led to resilience benefits such as improving habitats or reducing flood risk for communities. Figure 10 shows the additional time needed in the context of a logic model.

Figure 10. Additional time is typically needed to observe impacts of coastal resilience science project results.



4. Conclusion and Recommendations

4.1 Summary

The Hurricane Sandy Program invested approximately $302 million in 160 projects to improve the resilience of ecosystems and human communities in the region impacted by Hurricane Sandy. Multiple DOI bureaus and NFWF were able to initiate projects rapidly; these projects generally met or exceeded their design goals. Although nearly half of the projects experienced some form of delay compared to their original schedules, projects moved successfully to completion, with only a few projects still scheduled for completion by December 2019. These projects reduced flooding and coastal erosion risks to communities, improved ecological resilience through habitat improvements, and helped communities better prepare for future storms. Early monitoring results appear positive and demonstrate improved ecological functioning and decreased flooding risk, consistent with the early stages of project development. Long-term monitoring of ecological and socioeconomic metrics is in place at a subset of the projects to better validate project benefits. Monitoring results will be used for the second phase of the evaluation, which will occur following the long-term monitoring concluding in 2023.

The Hurricane Sandy Program has supported a wide variety of projects and approaches to achieve its resilience goals, which include making communities and ecosystems more resilient to sea level rise, storm events, and rising temperatures. For example, dam removal and culvert improvements reduce flood risk during future storms by lowering water-surface elevations and eliminating the risk of catastrophic dam or culvert failure. Restored beaches, dunes, marshes, and shorelines reduce the risk of coastal erosion and storm surge by absorbing wave energy during storms, which helps protect the infrastructure behind these coastal habitats. Green stormwater infrastructure projects reduce inland flooding risk by improving stormwater management. See Sections 3.2.1 and Box 4 for more detail on human community outcomes and Section 3.2.2 and Box 5 for more detail on ecological outcomes of Hurricane Sandy Program projects. These on-the-ground projects also have improved ecological resilience by providing habitats for birds, fish, and other wildlife, including representative species of conservation concern (Box 10). When birds, fish, and wildlife are able to access larger areas of high-quality habitats, these species are better able to withstand and recover rapidly from storm-related disruptions.

In addition, the Hurricane Sandy Program invested in science and planning projects to help communities better prepare for future storms and improve the effectiveness of future investments in resilience projects. These science and planning projects have filled key knowledge gaps, catalyzed investments in on-the-ground resilience projects, and led to improved resilience-related decision-making (Box 11).

The Hurricane Sandy Program also has prioritized long-term ecological and socioeconomic monitoring to more fully assess project outcomes and improve future resilience investments. Initially, DOI and NFWF led efforts to develop metrics to measure the ecological and socioeconomic outcomes of resilience projects. Subsequently, DOI and NFWF have funded long-term ecological and socioeconomic monitoring (2017–2023) for 38 of the Hurricane Sandy Program resilience projects. This long-term monitoring is intended to provide insights to the public and to decision-makers on multiple dimensions of project performance, including the recreational and economic benefits of projects.

Box 10. Key findings for on-the-ground restoration projects. These findings include socioeconomic benefits of reducing flooding and coastal erosion risks for communities; and ecological benefits of increasing ecological resilience through improving habitat accessibility, integrity, and extent, which can allow populations and ecosystems to recover more quickly from storm-related disturbances**.**

	Marsh restoration projects are restoring approximately 190,000 acres of marsh – equivalent to approximately 300 square miles. • Socioeconomic benefit: Improved resilience to future storms by absorbing waves and reducing storm surge and related flooding and coastal erosion. • Ecological benefit: Provide important nursery, foraging, and refuge habitats for many commercially and recreationally important species of fish and crustaceans, building the capacity of these systems to persist into the future. Early project results include enhancements in marsh vegetation cover and growth, reduced invasive cover, and improved hydrological dynamics, improving the ability of marshes to provide habitats for birds, fish, and other wildlife.
	Nearly 53,000 linear feet of living shorelines have protected adjacent habitats and reduced coastal erosion on up to 440 acres of land. • Socioeconomic benefit: Reduced coastal erosion, while being at least as cost-effective as traditional gray infrastructure approaches for coastal protection, such as stone revetments. • Ecological benefit: Protection of adjacent habitat and benefits to wildlife by providing approximately 40 acres of newly restored habitat, including marshes, beaches, oyster reefs, and submerged aquatic vegetation.
	Removal of 23 dams and improvements to 10 culverts. • Socioeconomic benefit: Reduced flood risk during storms by lowering surface-water elevations by an average of 5 feet at modeled sites, improving the downstream conveyance of water and increasing floodplain storage. Additionally, dam removal, including the removal of 11 dams categorized as “hazardous,” prevented potential loss of human life and infrastructure damage from catastrophic dam failure. • Ecological benefit: Nearly 370 miles of stream habitat are newly accessible to fish – ending more than a century of blockages by dams and other structures. Improved fish access supports representative species in the region such as river herring, American shad, and American eel, increasing population sizes and thus increasing the likelihood that these populations will persist into the future.
	Beach and dune restoration for community protection and ecological resilience. • Socioeconomic benefit: Protected inland communities from recent storm damage by preventing flooding of infrastructure behind protective dunes. These community-focused projects restored 4 linear miles and 75 acres of beach and dune habitats. Preliminary observations of four projects found that the restored dunes were stable and resilient to recent coastal storms. • Ecological benefit: Nearly 11 linear miles and 140 acres of restored beaches and dunes, including the community-focused projects described above, are providing important habitat for beach-dependent wildlife, including two threatened birds (red knot and piping plover).

Box 11. Key findings for science and planning projects.

	One hundred twenty-six management plans or assessments, 85 site-specific designs, and 65 resilience tools are being created to identify, describe, or prioritize future actions that would improve community resilience. More than 50% of the projects have already led to on-the-ground actions that are directly increasing resilience, with a rapid progression from the planning to implementation stages.
	More than 700 data information products are being created, including presentations, reports, manuscripts, datasets, maps, and models. The information provided by these projects has filled key knowledge gaps and, in some cases, directly improved resilience-related decision-making.

4.2 Lessons Learned

The Hurricane Sandy Program responded to the need for rapid investments in coastal resilience following the devastating impacts of Hurricane Sandy. Unlike programs that are established following a careful planning and scoping process, the Hurricane Sandy Program was a rapid response to a Congressional investment of over $302 million for projects to benefit communities needing resilience from future storms. Approximately two-thirds of the funding went directly to multiple DOI bureaus to fund priority projects, while one-third of the funding went to a competitive external grant process administered by NFWF. This multi-pronged management structure enabled projects to be rapidly initiated, with 77% of the projects initiated within the first two years of the program.

Key insights and lessons learned from this evaluation include:

- Program Structure
  - By supporting **multiple activity categories**, the program is effective in enhancing coastal resilience to **multiple risks**, including sea level rise, storm surge, erosion, and inland flooding.
  - Hurricane Sandy Program projects fall into two overarching types depending on the type of activities they perform: **“on-the-ground” and “science and planning.” These activity types have complemented each other** – people leading on-the-ground projects have noted data gaps and the lack of plans and permits as constraints on implementation. Science and planning projects aim to fill those needs.
- Project Implementation
  - On-the-ground resilience activities experienced extensive delays, especially from **challenges associated with the design and permitting** of projects. These challenges were exacerbated when staff leading projects were inexperienced with the requirements of large-scale restoration work and when initial project deadlines were unrealistic.
  - Development of a system to **track scope changes and time extensions** allowed for clear communication about project changes.
  - Investments in site-specific designs have allowed projects to move rapidly from the planning to implementation stage. For example, **more than 50% of the planning projects have resulted in on-the-ground projects being implemented**.
- Project Results
  - **Early observations** of results for completed projects suggest that **on-the-ground projects generally are on track** to improve ecological and community resilience, with observed results being consistent with expected trajectories of recovery.

- Science and planning projects that **incorporated stakeholders and end users into project teams moved rapidly to uptake**, without delays resulting from the need to perform additional outreach.
- **Investments made by DOI and NFWF in metrics development and long-term monitoring will enable a robust understanding** of the full spectrum of benefits from resilience projects. Over the long-term, this information is intended to inform best practices, guide future enhancements to projects, address knowledge gaps, and sustain improvements in coastal resilience.

4.3 Recommendations

The Hurricane Sandy Program took advantage of the strengths of multiple bureaus within DOI and NFWF to fund a broad range of important resilience activities. Recommendations are derived both from suggestions put forward by DOI and NFWF program staff and by project leads, as well as from our own analysis during the evaluation. Many of the recommendations are aimed at future funders of coastal resilience projects, as well as at restoration and resilience practitioners and local decision-makers.

On-the-Ground Projects

Recommendation 1: Funders and practitioners for coastal resilience projects should anticipate and accommodate changes in schedule, scope, and budget as data are collected and project designs are developed, particularly for projects that do not already have detailed plans in place. Project leads should not be pressured to submit overly optimistic schedules and budgets in proposals as a condition of funding. For example, a two-year timeframe from contract signing to the end of implementation is unlikely to be met unless designs and permits are already in place.

The ability to modify projects is a critical part of project success. Programs that can flexibly accommodate changes in response to additional data gathering and design efforts will better support successful projects. Project proponents should include realistic project schedules and not be forced into artificial two-year time schedules. A more realistic timeline would include three–five years for implementation and initial adaptive management, plus additional time for longer-term monitoring. Implementation timelines may be faster for projects that already have completed their data collection and design steps (see Recommendation 3).

Funders, decision-makers, and the public should understand that ecological restoration projects are typically not a “quick fix” for improving coastal resilience (in fact, no coastal resilience “quick fixes” exist, because hardened shoreline features also require lengthy permitting times). For example, the average duration for a Hurricane Sandy Program project was three years. Although some benefits are seen immediately (such as fish passage after dam removal), other ecological benefits may take 10 or more years to reach ecological maturity.

Recommendation 2: Encourage permitting agencies to proactively improve inter- and intra-agency coordination for permitting and compliance of coastal restoration projects. Project leads responsible for permitting and compliance should be identified early and encouraged to involve permitting agencies early in the design process.

Improved inter-agency coordination for permitting and compliance would reduce an important source of project delays, particularly for projects perceived as “novel” in a specific location. Because permitting and compliance are often handled by local or regional offices, lessons learned in other regions do not appear to be effectively transferred within agencies. Project leads who will be responsible for permitting and compliance should be identified early, particularly for multi-agency projects where different potential leads are possible. Project leads are encouraged to involve permitting agencies early in the design process to facilitate the acquisition of required permits. For example, DOI held workshops involving multiple project leads and state and federal partners to help prepare for permits and designs.

Science and Planning Projects

Recommendation 3: Encourage investments in site-specific designs and permitting for coastal resilience projects, even if implementation funding is not yet available.

Investments in site-specific designs and permitting will position projects to obtain implementation funding when available and proceed rapidly to the implementation phase. Site-specific designs based on site assessments are a key to success, because standardized applications of a restoration technique that are not tailored to site conditions will often lead to project failure. Early investments in design and permitting can also promote obtaining leveraged funding for implementation, as the risks and uncertainty of a project are reduced as more information is gathered. Designs should incorporate future anticipated changes, such as higher temperatures and sea level rise, to maximize the resilience potential of a project.

Recommendation 4: Science and planning project teams should be encouraged or required to include stakeholders and end users, where possible, and to invest in outreach and engagement to stakeholders as a critical part of the success of science and planning projects.

Including stakeholders and end users within project teams or investing in outreach and engagement to stakeholders will increase the utility and uptake of science and planning projects. Data management plans that ensure the data created through science projects are readily accessible is also a key element to enhancing the long-term value of these projects.

Monitoring and Evaluation

Recommendation 5: Encourage support for long-term, systematic monitoring of coastal resilience projects. This funding is required for understanding the long-term economic and ecological benefits of coastal resilience projects. Investments in this site-specific monitoring will enable future projects to be more effective and cost-efficient.

Long-term systematic monitoring of coastal resilience projects, as is currently occurring with the Hurricane Sandy Program projects, is critical for a robust understanding of the benefits and cost-effectiveness of different coastal resilience approaches. This long-term, site-specific monitoring should include both ecological and socioeconomic metrics as a “standard operating procedure” for current and future resilience projects. Replicating this type of long-term systematic monitoring in the future will create an even greater knowledge base of coastal resilience effectiveness. This may need to be accomplished through separate monitoring grants that focus on monitoring objectives and can be separated from implementation funding.

Overarching and Administrative Functions

Recommendation 6: For emergency funding packages, a combination of on-the-ground and science and planning projects are recommended, as this combination of projects provides benefits to specific communities, while also enabling broader regional gains in resilience through the longer-term uptake of science and planning products.

Over time, the development of science and planning products, as well as the integration of lessons learned from long-term monitoring, should enable more strategic and cost-effective investments in on-the-ground projects, as key activities are identified and prioritized. While investments in these different types of activities is encouraged, the activities do not need to occur within the same grants or projects.

Recommendation 7: Establishment of an Executive Council and an Implementation Team provides an effective management framework, with the Executive Council providing high-level oversight on funding allocation and program progress, and the Implementation Team having management responsibility for implementation progress and cross-project coordination.

A management structure with a separate executive team and management team allows for rapid implementation and effective oversight of a rapidly deployed Congressional authorization. For the Hurricane Sandy Program, the Executive Council consisted of high-level agency staff, while the Implementation Team (known as the Regional Team) consisted of regional executives and bureau leads. Field-level expertise also plays an important role in vetting projects based on local knowledge of resource needs and potential regulatory hurdles. Similarly, project implementation can be expedited with the participation of knowledgeable grants and contracting staff.

Recommendation 8: Providing sufficient agency funding for program-wide activities enables important functions to occur such as external communication, administration, and oversight.

Providing sufficient funding for agency use can cover costs associated with program-wide activities such as project communication, administration, and oversight. Having funding available for these program-wide activities improves communication with the media and the public, allows for better financial tracking and oversight, and also provides a source of contingency funding for project shortfalls. This funding can be provided as a set percentage of project proposals (e.g., 5%).

4.4 Conclusion

The Hurricane Sandy Program has improved ecological and human community resilience in the region affected by Hurricane Sandy. The program has successfully moved through the stages of project planning and implementation – funding a wide range of projects that have provided direct on-the-ground benefits as well as catalyzed future resilience activities through better science and planning. Recognizing the need for long-term, systematic data collection to assess restoration success, NFWF and DOI are supporting additional, future long-term monitoring at 38 projects. This next phase of the program will provide the ability to measure and evaluate additional ecosystem services or benefits that can be realized through implementing natural and green infrastructure approaches, such as habitat restoration and living shorelines, to improve coastal resilience. This monitoring work is intended to further advance and inform decision-making regarding how best to achieve sustainable coastal resilience at local, state, and national levels.

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Appendix A. Hurricane Sandy Program Restoration Projects

Table A.1. Evaluated restoration projects supported through the Hurricane Sandy Program. This table presents project information for each evaluated restoration project (n = 160). Project information was based on available project documentation. The table is organized by project activity as categorized by the Abt evaluation team. All dollars are rounded to the nearest hundred.

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Marsh restoration	NFWF-41812	Preventing erosion and restoring hydrology in the Pine Barrens, New Jersey	Restore hydrology and prevent erosion in Pine Barrens in Burlington County and Ocean County, New Jersey. Project will improve stream and wetland resiliency, while protecting important habitat.	NJ	New Jersey Conservation Foundation	$280,000	$106,300
Marsh restoration	NFWF-42942	Increasing salt marsh acreage and resiliency for Blackwater National Wildlife Refuge, Maryland	Increase salt marsh acreage and enhance resiliency for the Blackwater National Wildlife Refuge and Fishing Bay Wildlife Management Area in southern Dorchester County, Maryland. Project will create 30 acres of new salt marsh, increase salt marsh productivity, and generate an invasive plant eradication map.	MD	The Conservation Fund	$3,500,000	$1,331,600
Marsh restoration	NFWF-42959[a]	Rejuvenating Sunset Cove's salt marsh and upland habitat, New York	Restore 3 acres of Sunset Cove's wetlands and 7 acres of upland habitat in Queens, New York. Project will enhance water quality, provide shellfish habitat, and increase public recreation access.	NY	New York City Department of Parks and Recreation	$4,850,000	$2,240,000
Marsh restoration	NFWF-43006[a]	Wetland restoration in Suffolk County, New York	Restore 400 wetland acres and build capacity to rehabilitate 1,500 acres in Suffolk County, New York. Project will strengthen wetland resiliency and provide capacity-building opportunities.	NY	County of Suffolk	$1,310,000	$688,700
Marsh restoration	NFWF-43095[a]	Reusing dredged material to restore salt marshes and protect communities, New Jersey	Piloted reuse of thin-layer deposition of dredged materials to restore 53 acres of salt marsh, shorebird nesting habitat, and dunes at the Avalon, Stone Harbor, and Fortescue sites in New Jersey. Project enhanced salt marsh and nesting habitats for wildlife, and reduced potential impacts from future storm flooding on nearby communities.	NJ	New Jersey Department of Environmental Protection – Office of Natural Resource Restoration	$3,420,000	$4,681,600
Marsh restoration	NPS-27	Dyke marsh restoration to promote resource protection from storm response and adaptation to sea level rise	Construct a 1,500-foot breakwater to restore marsh at Dyke Marsh in Virginia. Project will provide a storm buffer for George Washington Memorial Parkway and restore habitat.	VA	U.S. Army Corps of Engineers; National Park Service	$24,897,600	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Marsh restoration	USFWS-43[a]	Restoring resiliency to the Great Marsh, Parker River Parker River National Wildlife Refuge, Massachusetts	Enhance 27,000 acres of tidal marsh in the Great Marsh, Parker River Parker River National Wildlife Refuge, Massachusetts. Project will replace infrastructure and model decision-making to improve tidal function.	MA	U.S. Fish and Wildlife Service	$340,000	$506,000
Marsh restoration	USFWS-50[a]	Increasing water management capability at Great Dismal Swamp National Wildlife Refuge to enhance its resiliency for wildlife and people	Install or replace 13 water control structures and complete a station water management plan in the Great Dismal Swamp National Wildlife Refuge, Virginia. Project will reduce flood impacts, increase water storage, reduce fire vulnerability, and improve carbon sequestration conditions.	VA	U.S. Fish and Wildlife Service	$3,130,000	$2,929,000
Marsh restoration	USFWS-85	Pocomoke Sound marsh enhancement, Ferry Point, Nanticoke River	Treat 2,000 acres of wetlands to control invasive reeds and restore 600 acres of hydrology on Pocomoke Sound in Maryland. Project will improve area's resilience to sea level rise, protecting habitat and infrastructure.	MD	U.S. Fish and Wildlife Service; Maryland Department of Natural Resources	$638,000	$55,000
Living shorelines	NFWF-44068	Restoring over one hundred wetland acres in Great Egg Harbor Bay, New Jersey	Restore 150 wetland acres in Great Egg Harbor Bay, New Jersey. Project will enhance and raise damaged wetlands to mitigate future storm impacts and provide healthier habitats.	NJ	City of Ocean City	$2,630,000	$1,276,800
Living shorelines	NFWF-44109[a]	Replenishing Little Egg Harbor's marshes and wetlands, New Jersey	Little Egg Harbor Township, New Jersey, will conduct a marsh restoration and replenishment project to restore severely eroded shorelines. Project will implement a living shoreline designed as a marsh sill with oyster-friendly material to cultivate habitat, and provide beach replenishment including a stone breakwater to halt erosion.	NJ	Little Egg Harbor Township	$2,130,000	$76,800
Living shorelines	USFWS-31[a]	Fog Point living shoreline restoration, Martin National Wildlife Refuge	Construct 1,500 feet of living shorelines and protect 1,200 acres of tidal marsh in the Martin National Wildlife Refuge in Maryland. Project will stabilize a vulnerable shoreline to ensure resiliency of crab habitat and maintain a wetland buffer to the island's villages.	MD	U.S. Fish and Wildlife Service	$9,000,000	$1,083,500

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Living shorelines	USFWS-57[a]	Hail Cove living shoreline restoration, Eastern Neck National Wildlife Refuge	Protect 400 acres of tidal marsh and submerged aquatic vegetation (SAV) with a 3,500-foot living shoreline in the Eastern Neck National Wildlife Refuge, Maryland. Project will protect SAV in the Chester River and important bird habitat.	MD	U.S. Fish and Wildlife Service	$1,550,000	$16,000
Living shorelines	USFWS-76[a]	Living shoreline-oyster reef restoration and construction at Chincoteague National Wildlife Refuge, Virginia	Construct 3,500+ linear feet of shoreline and restore 2 acres of oyster reefs at Toms Cove and Assateague Bay in Virginia. Project will increase the resiliency of the refuge's infrastructure for future storms.	VA	U.S. Fish and Wildlife Service	$553,400	$0
Living shorelines	USFWS-77[a]	Gandy's Beach Shoreline Protection Project, Downe Township, Cumberland County, New Jersey	Install living shorelines at Gandy's Beach in New Jersey. Project will protect 2,750 linear feet of important beach and marsh habitat along Gandy's Beach Preserve and 330 linear feet of marsh shoreline in Nantuxent Creek.	NJ	The Nature Conservancy; U.S. Fish and Wildlife Service	$720,000	$0
Aquatic connectivity	NFWF-41787	Restoring Bellamy River's fish passage and reducing flooding through removal of two fish barriers, New Hampshire	Remove Bellamy River's two fish barriers in Dover, New Hampshire. Project will restore 11 river miles, re-introduce a fish passage, reduce flooding, and improve water quality and safety.	NH	New Hampshire Department of Environmental Services	$550,000	$168,100
Aquatic connectivity	NFWF-42874	Ausable watershed flood mitigation and fish passage restoration, New York	Replace at least three flood-prone culverts in the Ausable Watershed in northern New York. Project will restore fish passage for 25 miles, mitigate flooding, and reduce community costs.	NY	The Nature Conservancy	$620,000	$188,500
Aquatic connectivity	NFWF-43378	Restoring fish runs and fragmented trout populations by removing a fish barrier, Connecticut	Remove a hazardous and unused fish barrier in Enfield, Connecticut. Project will restore 2.6 miles of diadromous fish runs, reunite brook trout populations, and reduce flood hazards.	CT	State of Connecticut	$2,800,000	$1,000,000
Aquatic connectivity	NFWF-43834	Increasing community and ecological resiliency by removing a Patapsco River fish barrier, Maryland	Remove a Patapsco River fish barrier in the Patapsco Valley State Park Avalon area. Project will open 52.5 miles of stream, provide additional spawning habitat, and strengthen community resiliency.	MD	American Rivers, Inc.	$2,480,000	$5,677,000
Aquatic connectivity	NFWF-44022	Reconnecting and restoring the Allegany Reservoir, New York	Restore riparian buffer and reconnect 10 land-locked areas to the Allegany Reservoir in Cattaraugus County, New York. Project will strengthen the reservoir's resiliency.	NY	The Seneca Nation of Indians	$350,000	$226,400

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Aquatic connectivity	USFWS-9[a]	Aquatic connectivity and flood resilience: West Britannia and Whittenton Dam Removals, Mill River, Taunton, Massachusetts	Remove the West Britannia and Whittenton dams from the Mill River in Massachusetts. Project will open critical habitat and reduce the probability of flooding and dam breaches.	MA	U.S. Fish and Wildlife Service	$650,000	$837,000
Aquatic connectivity	USFWS-11	Muddy Creek wetland restoration project, Chatham, Massachusetts	Replace 2 stone culverts with a span bridge and open channel at Muddy Creek in Massachusetts. Project will restore 55 acres of habitat and enhance costal system resiliency.	MA	U.S. Fish and Wildlife Service	$3,762,000	$438,600
Aquatic connectivity	USFWS-21[a]	Aquatic connectivity and flood resilience in Connecticut and Rhode Island: Removing the White Rock and Bradford dams, assessing the Potter Hill Dam fishway on the Pawcatuck River, and removing the Shady Lea Mill Dam in North Kingstown	Remove the White Rock and Bradford dams on the Pawcatuck River, and the Shady Lea Mill Dam on Mattatuxet River. Project will open 25 miles of wetland and mitigate flood risks.	Multi: CT, RI	U.S. Fish and Wildlife Service	$2,294,300	$1,229,000
Aquatic connectivity	USFWS-33[a]	Parker River Tidal Restoration Project	Replace an undersized bridge on Rte. 28 in Yarmouth, Massachusetts, with a 30-foot bridge. Project will restore and connect habitat, reduce the risk of bridge failure, and improve infrastructure resiliency during future storm events.	MA	U.S. Fish and Wildlife Service	$3,718,000	$568,600
Aquatic connectivity	USFWS-34	Aquatic connectivity and flood resilience in Virginia: Replacing the Quantico Creek culvert in Dumfries	Replace a culvert in Quantico Creek, Dumfries, Virginia. Project will reconnect a river, improving fish passages and reducing flood risk.	VA	U.S. Fish and Wildlife Service	$330,800	$900,000
Aquatic connectivity	USFWS-51[a]	Aquatic connectivity and flood resilience: Pond Lily Dam removal, West River, New Haven, Connecticut	Remove the Pond Lily Dam and restore impounded area at the West River in Connecticut. Project will reduce flood hazard, restore natural stream flood resilience, mitigate climate change impacts, and reduce potential downstream flood damages.	CT	U.S. Fish and Wildlife Service	$661,500	$238,800

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Aquatic connectivity	USFWS-53[a]	Aquatic connectivity and flood resilience: Hyde Pond Dam removal, Whitford Brook, Mystic, Connecticut	Remove the Hyde Pond Dam at Whitford Brook in Mystic, Connecticut. Project will reduce flood hazard, restore natural stream flood resilience, mitigate climate change impacts, and reduce potential downstream flood damages.	CT	U.S. Fish and Wildlife Service	$551,300	$3,200
Aquatic connectivity	USFWS-68	Aquatic connectivity and flood resilience: Flock Process Dam removal, Norwalk River, Norwalk, Connecticut	Remove the Flock Process Dam on the Norwalk River in Connecticut. Project will restore 3.5 miles of stream access and reduce upstream flooding.	CT	U.S. Fish and Wildlife Service	$970,000	$169,000
Aquatic connectivity	USFWS-79	Aquatic connectivity and flood resilience: Norton Mill Dam removal, Jeremy River, Colchester, Connecticut	Remove the Norton Mill Dam on the Jeremy River in Colchester, Connecticut. Project will restore 17 miles of habitat and reduce flood risk for downstream properties.	CT	U.S. Fish and Wildlife Service	$727,700	$52,000
Aquatic connectivity	USFWS-89[a]	Aquatic connectivity and flood resilience in Maryland: Removing the Centreville Dam in Centreville and the Bloede Dam in Catonsville	Remove the Centreville and Bloede dams in Maryland. Project will restore up to 11 miles of habitat for species, restore river function, improve sediment transport, and reduce flooding.	MD	U.S. Fish and Wildlife Service	$1,212,800	$5,400,000
Aquatic connectivity	USFWS-94[a]	Aquatic connectivity and flood resilience in New Jersey: Removing the Hughsville Dam in Pohatcong and restoring the Wreck Pond inlet and dune in Sea Girt and Spring Lake	Remove the Hughesville Dam and install a fish passage culvert at Wreck Pond in New Jersey. Project will reduce future flooding in nearby communities, and increase fish passage for improved habitat access.	NJ	U.S. Fish and Wildlife Service	$3,050,000	$3,718,000
Beach and dune restoration	NFWF-41991[a]	Increasing Seven Mile Island's beach resiliency, New Jersey	Increase Seven Mile Island's beach resiliency in Cape May County, New Jersey. Project will improve habitat, protect communities, and contribute to a long-term resiliency strategy.	NJ	New Jersey Audubon Society	$1,280,000	$53,400
Beach and dune restoration	NPS-1A[a]	Mitigate impacts from artificial groin to Jacob Riis Beach to restore habitats and recreation resources	Fill 1-mile beach at Jacob Riis Park in New York after erosion from Hurricane Sandy. Project will protect historical, cultural, and natural aspects of the beach from future storms.	NY	U.S. Army Corps of Engineers Civil Works; National Park Service	$3,453,200	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Beach and dune restoration	USFWS-6[a]	Increase resilience of beach habitat at Pierce's Point, Reed's Beach, and Moore's Beach, New Jersey	Create berms, develop a cost-effective restoration plan, and study sand movement at Pierce's Point, Reed's Beach, and Moore's Beach in New Jersey. Project will restore and protect important habitat and create a foundation for sustainable shoreline management.	NJ	U.S. Fish and Wildlife Service	$1,650,000	$0
Green stormwater infrastructure	NFWF-42956	Strengthening Coney Island's resiliency through green streets, New York	Strengthen Coney Island's resiliency through installation of 14 green streets in New York City, New York. Project will mitigate flooding, filter over 2 million gallons of stormwater runoff, and serve as a model to other communities.	NY	New York City Department of Parks and Recreation	$990,000	$333,300
Coastal resilience science	BOEM-M13AC00012	Ecological function and recovery of biological communities within dredged ridge-swale habitats and in the South-Atlantic bight	Study of the recovery of benthic and fish communities following dredging of a burrow area in Florida. Project will lead to better understanding of the impacts of sediment removal activities for improved regional habitat management.	FL	University of Florida; Bureau of Ocean Energy Management	$4,300,000	$0
Coastal resilience science	BOEM-M13AC00031	Natural habitat association and the effects of dredging on fish at the Canaveral Shoals, east-central Florida	Study to assess natural movements and habitat preferences of federally managed fishes before, during, and after dredging in Canaveral Shoal, Florida. Project will obtain information on habitat uniqueness and value and use of ridge/swale and shoal complexes for fish communities.	FL	United States Navy; National Aeronautics and Space Administration; Bureau of Ocean Energy Management	$1,473,000	$0
Coastal resilience science	BOEM-M14AC00001	Sand needs and resources offshore New York	Review 3 types of sand demand estimates (e.g., nourishment at historical rates for routine projects) along the Atlantic Coast in New York. Project will support current and projected beach renourishment and dune construction projects.	NY	New York Department of State; Bureau of Ocean Energy Management	$400,000	$0
Coastal resilience science	BOEM-M14AC00002	Post Hurricane Sandy offshore New Jersey sand resources investigations	Publish sand characteristic map, assess existing sand data in federal offshore water, and identify future areas of need in Monmouth and Ocean County, New Jersey. Project will delineate acceptable sand resource volumes in federal waters and in state waters to allow for future planning and development of beach replenishment programs.	NJ	New Jersey Department of Environmental Protection; Bureau of Ocean Energy Management	$400,000	$60,000

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	BOEM-M14AC00003	Delaware offshore sand resource investigation	Synthesize geophysical data and sand resource needs in Rehoboth Beach, Indian River inlet, Fenwick Island, and Fenwick Shoal, Delaware. Project will identify data gaps and identify sand resources that meet textural criteria for beach nourishment in a manner that is protective of the environment.	DE	University of Delaware; Bureau of Ocean Energy Management	$200,000	$0
Coastal resilience science	BOEM-M14AC00004	Modernizing the Reconnaissance Offshore Sand Search (ROSS) database and a review and synthesis of existing geophysical data from selected areas on the Outer Continental Shelf (OCS Region) along Florida's central Atlantic Coast	Complete geophysical analysis for the Florida Federal Department of Environmental Protection ROSS/OSSI database and modernize the database, determine potential sand resources, and determine priority areas for future study in Florida. Project will improve capability of agencies to plan for cost-effective coastal protection and restoration projects.	FL	Florida Department of Environmental Protection; Bureau of Ocean Energy Management	$200,000	$0
Coastal resilience science	BOEM-M14AC00005	Geospatial sand resource assessment for Georgia coastal recovery and resiliency	Analyze and set parameters for existing sediment samples, create a geophysical database, and determine sand and gravel resources in Georgia beaches. Study will identify gaps for future study in support of resiliency and recovery planning.	GA	University of Georgia; Bureau of Ocean Energy Management	$200,000	$58,900
Coastal resilience science	BOEM-M14AC00006	Sand resource assessment at critical beaches on the Massachusetts Coast	Characterize the sediment in public beaches and determine the historical frequency of erosion and overwash events in Massachusetts, and identify potential areas of sand resources. Project will examine the proposed renewable energy leasing areas and make a very cursory and preliminary comparison with potential sand sources offshore.	MA	University of Massachusetts; Bureau of Ocean Energy Management	$199,600	$31,700
Coastal resilience science	BOEM-M14AC00007	Conversion of Maryland's offshore mineral resources data for geographic information system applications and baseline acoustic seafloor classifications of offshore borrow areas	Identify sand resources offshore Maryland in federal waters that meet the textural criteria for beach nourishment. The cooperative agreement will improve the capability to plan for cost-effective coastal protection and restoration projects.	MD	Maryland Department of Natural Resources; Bureau of Ocean Energy Management	$199,400	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	BOEM-M14AC00008	Exploration and habitat classification: Tools for building resiliency in Maine	Determine demand of sand resources in costal municipalities, identify possible sand and gravel regions for possible beach nourishment, and identify future sand resource needs in Maine. Project data will support sound local and regional economic development, shore and harbor planning, and sea level rise risk assessment and storm hazard mitigation.	ME	Maine Department of Agriculture; Bureau of Ocean Energy Management	$195,200	$245,500
Coastal resilience science	BOEM-M14AC00009	Assessing sand resources for North Carolina: inventory, needs assessment and reanalysis for post-Hurricane Sandy recovery and future resilience	Synthesize geologic data to prioritize future study areas and develop a revised evaluation of sand resources along North Carolina's coast. Project will be made public to be used for more resilient decision-making.	NC	East Carolina University; Bureau of Ocean Energy Management	$200,100	$10,000
Coastal resilience science	BOEM-M14AC00010	Assessment of offshore sand and gravel for beach nourishment in New Hampshire	Develop a sand resource needs assessment, provide a geophysical analysis of existing and potential sand resources including bathymetric maps, and determine the need for sand and gravel resources in New Hampshire beaches. Project information will be used to plan for cost-effective coastal protection and restoration projects utilizing marine mineral resources.	NH	University of New Hampshire; Bureau of Ocean Energy Management	$200,000	$9,300
Coastal resilience science	BOEM-M14AC00011	Identification of sand/gravel resources in Rhode Island waters while working toward a better understanding of storm impacts on sediment budgets	Synthesize geologic data to identify possible sand and gravel resources in federal waters offshore of Rhode Island. Project will estimate sand resource needs for beach nourishment and protect habitat and cultural resources within potential borrow areas.	RI	University of Rhode Island; Bureau of Ocean Energy Management	$200,000	$0
Coastal resilience science	BOEM-M14AC00012	South Carolina offshore sand resources: Data inventory, digital data conversion, and needs assessment	Generate a data synthesis of existing offshore data, determine potential need for sand and gravel resources, and prioritize areas for future studies on South Carolina beaches. Project will fill data gaps that have been identified and locate potential areas of sand resources in a manner that is protective of the environment.	SC	South Carolina Department of Natural Resources; Bureau of Ocean Energy Management	$200,000	$195,600

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	BOEM-M14AC00013-1	Assessment of offshore sand resources for Virginia beachfront restoration	Synthesize geologic data and determine future potential areas of sand resources in Virginia. Project will improve capability to plan for cost-effective coastal protection and restoration projects.	VA	Virginia Department of Mines, Minerals, and Energy; Bureau of Ocean Energy Management	$199,500	$101,100
Coastal resilience science	BOEM-M14PC00006	Geological and geophysical data acquisition: Inventory of potential beach nourishment and coastal restoration sand sources on the Atlantic Outer Continental Shelf	Collect and review 5,600 line-miles of geophysical data, collect 350 sediment samples, and provide mapping based on collected data in 14 states. Project data will support identification, characterization, and delineation of Outer Continental Shelf sand resources for use by coastal states in future coastal restoration, beach nourishment, and/or wetland restoration efforts.	Multi: CT, DE, FL, GA, MA, MD, ME, NC, NH, NJ, NY, RI, SC, VA	CB&I Federal Services LLC; Bureau of Ocean Energy Management	$500,000	$0
Coastal resilience science	BOEM-M15PS00030	Propagation characteristics of high-frequency sounds emitted during high-resolution geophysical surveys: Open water testing	Measure the sound field produced by various underwater acoustic sources to characterize functional differences and ecosystem changes in dredged and non-dredged areas in Maine. Project will assess habitat uniqueness and the value of ridge-swale and shoal complexes for federally protected fish communities.	ME	Naval Undersea Warfare Center Division; Bureau of Ocean Energy Management; U.S. Geological Survey	$470,000	$0
Coastal resilience science	GS1-1a	Establish a Sandy Region Coastal National Elevation Database (CoNED)	Create geospatial databases using digital elevation models and LiDAR data in 10 states. Project will create a comprehensive integrated database required for mitigation policies and emergency response.	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA	U.S. Geological Survey	$550,000	$0
Coastal resilience science	GS1-1b	Topographic surveys (LiDAR) for impact area assessment and reconstruction	Collect elevation data and integrate with existing programs in multiple states. Project will update sea level rise assessments and help validate storm surge inundation predictions.	Multi: DE, MD, NC, NJ, NY, PA, VA	U.S. Geological Survey; National Oceanic and Atmospheric Organization	$3,100,000	$0
Coastal resilience science	GS1-1c	Delivery systems for hazards, topographic and bathymetric elevation data	Update data from the Hazards Data Distribution System and 3D Elevation Program in 9 states. Project will provide rapid situational awareness to reduce storm response times by providing access to long-term, stable geographical data.	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey; National Oceanic and Atmospheric Organization	$650,000	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	GS1-2a	Coastal mapping products & impact assessments: Pre- and post-storm mapping of coastal impacts and vulnerability	Expand capacity to process EAARL-B system image processing to document coastal change in multiple states. Project will assess requirements to rebuild coastal beaches after storms to enhance resilience.	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA; NJ and NY priority	U.S. Geological Survey	$2,075,000	$0
Coastal resilience science	GS1-2b	Impacts to and vulnerability of coastal beaches: Develop coastal impact forecast models	Update LiDAR elevation data and forecasts of waves and surges across multiple states. Project will be used to improve the accuracy and impact of coastal change forecasts in response to storms.	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA; NJ and NY priority	U.S. Geological Survey	$1,950,000	$0
Coastal resilience science	GS1-2c	Coastal hazards information and decision support portal	Update the USGS Coastal Change Hazards portal by providing information to stakeholders in a number of states. Project will provide access to coastal data to fulfill the need for credible information to make management decisions.	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA	U.S. Geological Survey	$750,000	$0
Coastal resilience science	GS1-3a	Storm surge response, data collection, and data delivery	Establish a storm-tide center that increases instrumentation and data delivery along the northwest Atlantic Coast. Better storm-tide monitoring, warning, and characterization will improve community resiliency.	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA; NJ and NY priority	U.S. Geological Survey	$2,350,000	$0
Coastal resilience science	GS1-3b	Storm tide monitoring networks and data analysis	Establish a storm-tide network in vulnerable coastal areas along the Atlantic. The project will provide flexible deployment alternatives in emergency situations, and improve planning and forecasting models.	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA; NJ and NY priority	U.S. Geological Survey	$1,400,000	$0
Coastal resilience science	GS1-4a	Ecological contaminant exposures	Perform reconnaissance sampling in coastal bays and shorelines in New York and New Jersey. Project will assess ecological toxicity assessments and their impact on the food web.	Multi: NJ, NY	U.S. Geological Survey	$1,700,000	$0
Coastal resilience science	GS1-4b	Human contaminant exposures	Test human contaminant exposures in coastal environments using remote sensing, LiDAR, and other technologies in New York and New Jersey. Project will provide guidance for future cleanup.	Multi: NJ, NY	U.S. Geological Survey	$1,000,000	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	GS1-5a	Assess storm impact to wetland integrity and stability to assist recovery decisions	Map geographic information to create an understanding of Hurricane Sandy and other storm impacts in 9 states. Project will develop models to link trends in coastal lands and vegetation to processes that contribute to system resilience.	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$1,205,000	$0
Coastal resilience science	GS1-5b	Assess storm impact to waterfowl and migratory birds to support conservation	Establish pre-storm and post-storm populations of migratory birds using radar and field data in multiple states. Project will support management and model storm impacts over the next 24 years.	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$730,000	$0
Coastal resilience science	GS1-5c	Assess coast-wide storm impacts to forest habitats in coastal parks and refuges	Survey parks to classify coastal forest types and hurricane impacts in 4 states. Project will develop ecosystem models for coastal parks and refuges that predict habitat structure and succession from hurricane disturbance and sea level rise.	Multi: MD, NJ, NY, VA	U.S. Geological Survey	$365,000	$0
Coastal resilience science	GS1-5d	Develop data-driven models and ecological monitoring networks to support recovery and resilience	Strengthen the Surface Elevation Table (SET) to assess Hurricane Sandy impacts on vegetation and landscapes in 9 states. Project will expand the Joint Ecosystem Modeling (JEM) community and give managers better data on hurricane impacts and storms.	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$700,000	$0
Coastal resilience science	GS2-1A	Topographic surveys for priority watershed and ecological assessments	Collect LiDAR data for the 3D Elevation Program (3DEP) in 9 states. Project will support recovery and mitigation activities that rely on topographic data and support mitigation requirements for priority watershed analyses.	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey; National Oceanic and Atmospheric Organization	$4,050,000	$0
Coastal resilience science	GS2-2A	Barrier island and estuarine wetland physical change assessment	Provide a high-resolution assessment of changes in wetlands in Maryland and other Sandy-affected states. Project will be integrated with other data for a comprehensive vulnerability assessment.	Multi: DE, MD, NJ, VA	U.S. Geological Survey	$1,350,000	$0
Coastal resilience science	GS2-2B[a]	Linking coastal processes and vulnerability, Fire Island Regional Study	Conduct geographic surveys on Fire Island, New York. Project will inform ongoing coastal management plans to reduce hurricane and storm damage.	NY	U.S. Geological Survey	$4,800,000	$0
Coastal resilience science	GS2-2C	Coastal vulnerability and resource assessment, Delmarva Peninsula	Collect, process, and interpret geographic data on the Delmarva Peninsula across 4 states. Project will help define region's sand resources and study effects of sea level rise on sediments.	Multi: DE, MD, NY, VA	U.S. Geological Survey	$4,000,000	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	GS2-2D	Estuarine response to storm forcing	Collect hydrodynamic data and turn the data into a web portal at Barnegat and Chincoteague bays across 5 states. Project will quantify overall resilience of the bays.	Multi: DE, MD, NJ, NY, VA	U.S. Geological Survey	$2,200,000	$0
Coastal resilience science	GS2-3A	Enhance storm tide monitoring, data recovery, and data display capabilities	Collect targeted storm-tide and wave data near land and sea features in 9 states. Project will help provide managers and planners accurate and timely data to develop recovery efforts.	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$2,200,000	$0
Coastal resilience science	GS2-3B	Storm surge science evaluations to improve models, vulnerability assessments, and storm surge predictions	Collect land use and coastal morphology data as part of the Surge, Wave, and Tide Hydrodynamics (SWaTH) network in 9 states. Project will improve maps of coastline vulnerability and resilient infrastructure rebuilding.	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$1,500,000	$0
Coastal resilience science	GS2-4A	Mapping, measuring, and predicting vulnerability from contaminant hazards from Hurricane Sandy and other storms in the Northeast Coastal zone	Establish a contaminant vulnerability assessment network in 9 states. Project will support the development of resiliency and response monitoring strategies to determine baseline conditions.	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$2,000,000	$0
Coastal resilience science	GS2-5A	Evaluating ecosystem resilience	Develop maps and produce methods for resource management mitigation in multiple states. Project will forecast long-term viability of New Jersey coastal wetlands and projected changes due to severe storm impacts.	Multi: CT, DE, MA, NJ, NY, RI, VA	U.S. Geological Survey	$1,240,000	$0
Coastal resilience science	GS2-5D	Forecasting biological vulnerabilities	Provide a web-based application to deliver habitat model outputs in multiple states. Project will provide decision-makers with useful, credible data when determining the best use of restoration and recovery resources.	Multi: CT, DE, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$1,025,000	$0
Coastal resilience science	NFWF-42878	Assessing coastal impoundment vulnerability and resilience in the Northeast	Evaluate the Northeast's coastal impoundment vulnerability and resilience with national parks, refuges, and state lands in 10 states. Project will reduce risk to nearby communities and identify restoration efforts that will strengthen impoundment resiliency.	Multi: CT, DE, MA, MD, ME, NH, NJ, NY, RI, VA	New Jersey Audubon Society	$470,000	$170,000

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	NFWF-43129	Creating green stormwater infrastructure resiliency in Greater Baltimore and Annapolis watersheds, Maryland	Map, analyze, and assess Maryland's green stormwater infrastructure to enhance the greater Baltimore and Annapolis watersheds in Maryland. Project will provide resilience-enhancing opportunities and best practices for local government implementation.	MD	The Conservation Fund	$583,600	$222,700
Coastal resilience science	NFWF-43752	Creating a three dimensional wetland model for the Bombay Hook National Wildlife Refuge, Delaware	Develop a three-dimensional wetland model for the Bombay Hook National Wildlife Refuge, Delaware. Project will provide current wetland assessments, help evaluate restoration strategies, and predict the long-term sustainability of the marsh.	DE	University of Delaware	$400,000	$148,500
Coastal resilience science	NFWF-43932	Improving and quantifying wetlands' potential to reduce storm surge impacts, Virginia	Improve and quantify wetlands' potential to reduce storm surge impacts along the Chesapeake Bay shoreline within 4 Virginia nature preserves. Project will provide decision-makers with information that can influence future management policies.	VA	George Mason University	$440,000	$93,800
Coastal resilience science	NFWF-44017	Developing Rhode Island's coastal resiliency program	Develop monitoring network, coastal maps, and best engineering practices for southern shore of Rhode Island. Project will generate best practices and policies, and test modeling tools; and is the first step to developing a statewide coastal resiliency program.	RI	University of Rhode Island	$870,000	$380,700
Coastal resilience science	NFWF-44212	Improving Northeast Coast storm-related data interpretation and accessibility	Develop a data integration platform for existing storm-related resources that will especially benefit U.S. states affected by Hurricane Sandy. Project will improve access and intuitive data interpretation for all users, including decision-makers.	Multi: CT, DC, DE, MA, MD, NH, NJ, NY, OH, PA, RI, VA, WV	Northeastern Regional Association of Coastal and Ocean Observing Systems	$520,000	$133,300
Coastal resilience science	NPS-3-1	Modification to acquisition coordination, compilation, data management and change analysis of LiDAR and other geospatial data collected pre- and post-hurricane (subproject)	Study to gather public perception of parks, create science communication products and educational materials (including a Scientific Workshop), and enhance geospatial data in 4 states. Project will increase public and researcher knowledge for better communication in future storms.	Multi: MD, NJ, NY, VA	University of Rhode Island; National Park Service	$565,700	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	NPS-3-2	Field technician support for elevation mapping of NPS salt marshes and other sites for sea level rise planning and post- and future-storm evaluation (subproject)	Develop procedures for salt marsh elevation data collection, collect global positioning system (GPS) data for salt marshes, and train National Park Service staff on geospatial data collection in 4 states. Project data will support the WARMER model and provide more specific understanding of these salt marshes.	Multi: MD, NJ, NY, VA	University of Rhode Island; National Park Service	$768,900	$0
Coastal resilience science	NPS-3-3	Collection of high resolution topographical data and development of metrics associated with superstorm sandy impacts, recovery, and coastal geomorphological resiliency (subproject)	Install and operate a tide gauge and collocated weather station on Fire Island National Seashore in New York. Project data will be used to establish and publish tidal statistics for Fire Island.	Multi: NJ, NY	Rutgers University; National Park Service	$161,900	$0
Coastal resilience science	NPS-3-4	Tide-telemetry and coastal-flood-warning system Fire Island National Seashore (subproject)	Install and operate a tide gauge and collocated weather station on Fire Island National Seashore in New York. Project data will be used to establish and publish tidal statistics for Fire Island.	NY	U.S. Geological Survey New York Water Science Center; National Park Service	$84,200	$0
Coastal resilience science	NPS-3-5	Modeling salt marsh condition and resiliency in four National Parks based local sea level rise predictions to assist park managers in understanding local conditions and to develop mitigation strategies (subproject)	Compile and analyze new and existing salt marsh data in 4 states. Data will be used to improve resilience modeling for salt marshes in relation to existing and future sea level rises to better predict salt marsh resiliency over time.	Multi: MA, MD, NJ, NY	University of South Carolina; National Park Service	$248,000	$0
Coastal resilience science	NPS-14-1	Detecting water quality regime shifts in Jamaica Bay (subproject)	Identify and gather water quality data, create a specific dataset, and identify water quality patterns in Jamaica Bay, New York. Project data will be used to develop analytical tools for measuring resilience in Jamaica Bay.	NY	Brooklyn College (CUNY); National Park Service	$283,000	$0
Coastal resilience science	NPS-14-2	Health and resiliency of salt marshes in Jamaica Bay (subproject)	Assess the current state of salt marshes in Jamaica Bay, New York, by collecting marsh peat and pore water. Project will characterize the sediment and geochemical constraints on salt marsh resilience against sea level rise and elevated pore water levels.	NY	Stony Brook University; National Park Service	$276,000	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	NPS-14-3	Monitoring and evaluation of restoration and resilience: Jamaica Bay Unit, shoreline and geomorphology (subproject)	Collect shoreline position data using GPS equipment and two-dimensional (2D) monitoring in Jamaica Bay, New York. Project will evaluate establish dimensions of resilience and track changes against goals to enhance resilience.	NY	Rutgers University; National Park Service	$328,700	$0
Coastal resilience science	NPS-14-4a	Acidification, hypoxia, and algal blooms: Barriers to current and future ecosystem restoration and climate change resilience in Jamaica Bay (subproject)	Conduct field studies to measure temporal and spatial variability of carbonate chemistry and dissolved oxygen in Jamaica Bay, New York. Project will link variability to species populations and climate change.	NY	Stony Brook University; National Park Service	$246,500	$0
Coastal resilience science	NPS-14-4b	Restoration of Jamaica Bay fringing habitats: Post-Sandy status and new approaches for a resilient future (subproject)	Perform spatial and field assessments to understand impacts from Hurricane Sandy on Jamaica Bay in New York. Project will create geographic information system (GIS) database to model decision-making tools for predicting climate change and storm impacts.	NY	Rutgers University; National Park Service	$482,900	$0
Coastal resilience science	NPS-14-5	The Jamaica Bay Observing system: Process studies and groundwork for long-term ecosystem research and resilience (subproject)	Perform a field campaign that determines the relationship among tides, sediment, winds, and buoyancy in Jamaica Bay, New York. Project will measure ecosystem metabolism and map future changes.	NY	Brooklyn College (CUNY); National Park Service	$789,800	$0
Coastal resilience science	NPS-14-6	Coastal adaptation impacts on Jamaica Bay water quality, waves and flooding (subproject)	Conduct scientific research, monitoring, and inventory activities to manage natural resources in Jamaica Bay, New York. Project will run experiments to model climate change, sea level rise, and coastal adaptation impacts on water quality and storm damages.	NY	Stevens Institute of Technology; National Park Service	$700,000	$0
Coastal resilience science	NPS-14-8	Science and Resilience Institute at Jamaica Bay: Coordination of DOI and NPS sandy resilience projects (subproject)	Establish the Science and Resilience Institute at Jamaica Bay to engage in research and education activities in New York. Project will contribute to a better understanding of urban resilience.	NY	City University of New York; National Park Service	$85,000	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	NPS-14-9	The environmental history of Jamaica Bay: A foundational monograph (subproject)	Complete a foundational monograph measuring changes to Jamaica Bay in New York over time and distribute findings. Project will forecast future resilience of the bay and surrounding area.	NY	City University of New York; National Park Service	$47,000	$0
Coastal resilience science	NPS-35-1	Assessing the response of juvenile and adult hard clams to the new breach in Great South Bay: Post-Hurricane Sandy study (subproject)	Study how physical and biological parameters in Great South Bay, New York influence hard clam populations. Project will assess the effects of new breaches on hard clam communities.	NY	Stony Brook University; National Park Service	$98,200	$0
Coastal resilience science	NPS-35-2	Assessing the response of the Great South Bay plankton community to Hurricane Sandy (subproject)	Map surface seawater conditions to measure new inlet in Great South Bay and Moriches Bay. Project will serve as a major advance in the ability to respond to future breaches.	NY	Stony Brook University; National Park Service	$594,100	$0
Coastal resilience science	NPS-35-3	Assessing the response of the Great South Bay estuarine fauna to Hurricane Sandy: Focus on nekton utilization of seagrass habitats (subproject)	Quantify the impacts of a Hurricane Sandy breach on vegetative species in Great South Bay, New York, through intensive sampling. Project will advance ability to respond to future breaches.	NY	Stony Brook University; National Park Service	$327,600	$0
Coastal resilience science	NPS-35-4	Effects of storm induced barrier breach on community assemblages and ecosystem structure within a temperate lagoonal estuary (subproject)	Evaluate the effects of a barrier breach on the ecosystem health of Great South Bay, New York, using an ecosystem approach. Project will use data and other modeling to better respond to breach events in the future.	NY	Stony Brook University; National Park Service	$150,000	$0
Coastal resilience science	NPS-35-5	Impact of Hurricane Sandy on the Fire Island National Seashore water quality and seagrass resources (subproject)	Conduct water quality monitoring and seagrass monitoring at Fire Island National Seashore, New York, in response to a breach. Project will help better response to breach events in the future.	NY	Stony Brook University; National Park Service	$177,000	$0
Coastal resilience science	NPS-35-6	Assessing the response of indicator bacteria in Great South Bay to Hurricane Sandy (subproject)	Study the changes in Great South Bay and Moriches Bay, New York, indicator bacteria caused by a breach event. Project will advance response to breach events and manage future breach effects.	NY	Stony Brook University; National Park Service	$50,000	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	NPS-35-7	Science communication: Hurricane Sandy video project (subproject)	Develop a series of videos showcasing NPS resiliency and research initiatives in response to Hurricane Sandy. The videos are part of a wider outreach effort to develop educational content that effectively communicates the service-wide response to this 2012 storm.	NY	Harpers Ferry Center, National Park Service	$68,600	$0
Coastal resilience science	NPS-35-8	Continuation of post-Hurricane Sandy physical monitoring of the Old Inlet breach, Fire Island National Seashore: Phase two (subproject)	Understand and monitor the physical characteristics of Breach at Old Inlet, New York, using bathymetric surveys. Project will model breach stability to measure breach impact on water quality.	NY	Stony Brook University; National Park Service	$174,800	$0
Coastal resilience science	NPS-49-1	Assess groundwater resources at Assateague Island National Seashore (subproject)	Identify baseline conditions of groundwater resources and monitor well networks on Assateague Island in Maryland. Project will protect sensitive habitats threatened by sea level rise, storms, and rising temperatures.	MD	U.S. Geological Survey; National Park Service	$330,000	$0
Coastal resilience science	NPS-49-2	Assess groundwater resources at Fire Island National Seashore (subproject)	Identify baseline conditions of groundwater resources and monitor well networks on Fire Island National Seashore, New York. Project will protect sensitive habitats threatened by sea level rise, storms, and rising temperatures.	NY	U.S. Geological Survey; National Park Service	$212,800	$0
Coastal resilience science	NPS-49-3	Assess groundwater resources at Sandy Hook Unit of Gateway National Recreation Area (subproject)	Identify baseline conditions of groundwater resources and monitor well networks at the Gateway National Recreation Area in New Jersey. Project will protect sensitive habitats that are threatened by climate-driven changes.	NJ	U.S. Geological Survey; National Park Service	$460,000	$0
Coastal resilience science	NPS-72-1	Submerged marine habitat mapping, Fire Island National Seashore (subproject)	Conduct bathometry and sonar surveys on 2,500 acres of Fire Island National Seashore in New York to produce maps. Study will create a model to better protect sensitive habitats and resources.	NY	University of Rhode Island; National Park Service	$865,000	$0
Coastal resilience science	NPS-72-2	Submerged marine habitat mapping, Gateway National Recreation Area (subproject)	Mao the submerged holdings of the Gateway Recreation Area in New Jersey. Project will produce maps and track changes of bathymetry, bedform, and structures over time.	NJ	Rutgers University; National Park Service	$810,000	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	NPS-72-3	Submerged marine habitat mapping, Assateague Island National Seashore (subproject)	Survey the nearshore zone of Assateague Island, Maryland, to determine changes in sediment and habitat from Hurricane Sandy. Project will document storm-related changes on multiple scales.	MD	University of Delaware; National Park Service	$790,000	$0
Coastal resilience science	NPS-72-4	Submerged marine habitat mapping, Cape Cod National Seashore (subproject)	Collect vessel-based acoustic data and surface samples to develop maps of Cape Cod National Seashore in Massachusetts. Project will create critical resource maps to better understand potential future changes from major storms.	MA	Center for Coastal Studies; National Park Service	$510,000	$0
Coastal resilience science	USFWS-17	Building a predictive model for submerged aquatic vegetation prevalence and salt marsh resiliency in the face of Hurricane Sandy and sea level rise	Measure available SAV and forecast future SAV in 7 states. Project will increase understanding of climate change impacts on salt marshes and build models for future sea level rise scenarios.	Multi: CT, DE, MD, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$216,700	$45,300
Coastal resilience science	USFWS-24	Decision support for Hurricane Sandy restoration and future conservation to increase resiliency of tidal wetland habitats and species in the face of storms and sea level rise	Compile spatial data to assess the impact of Hurricane Sandy on tidal marshes and dependent species in 10 states. Project aims to sustain resilience of tidal marshes and species in the face of storm impacts and sea level rise.	Multi: CT, DE, MA, MD, ME, NH, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$2,200,000	$1,604,300
Coastal resilience science	USFWS-30	A stronger coast: Three USFWS Region 5 multi-National Wildlife Refuge projects to increase coastal resilience and preparedness	Identify trends and vulnerabilities of 70 miles of shoreline at wildlife refuges in 8 states. Project will protect erosion, infrastructure, fisheries, and recreation from future storm surges.	Multi: CT, DE, MA, ME, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$2,060,000	$1,143,500
Coastal resilience science	USFWS-32	Resilience of the tidal marsh bird community to Hurricane Sandy and assessment of restoration efforts	Quantify the effects of Hurricane Sandy on tidal marsh bird and plant communities in 8 states. Project will identify areas that will benefit from resource resilience and estimate marsh resilience in the face of climate-driven disturbances.	Multi: CT, DE, MA, MD, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$1,574,000	$2,050,400

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Coastal resilience science	USFWS-63	Collaboratively increasing resiliency and improving standards for culverts and road-stream crossings to future floods while restoring aquatic connectivity	Strengthen the science and technical tools to map and prioritize repair and replacement of road-stream crossings in 13 states. Project will reduce impacts to commerce from flooding and increase aquatic species population and habitat resilience.	Multi: CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VA, VT, WV	Wildlife Management Institute	$1,270,000	$350,000
Coastal resilience science	USFWS-64	Coastal Barrier Resources System comprehensive map modernization: Supporting coastal resiliency and sustainability following Hurricane Sandy	Modernize maps of the John H. Chafee CBRS spanning 8 states. Project will update maps to serve as mitigation tools that help communities plan for long-term resiliency by steering development away from vulnerable coastal natural resources.	Multi: CT, DE, MA, MD, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$5,000,000	$2,000,000
Coastal resilience science	USFWS-67	Decision support for Hurricane Sandy restoration and future conservation to increase resiliency of beach habitats and species in the face of storms and sea level rise	Develop decision support tools to understand the impacts of sea level rise and storms on coasts in 10 states. Project will increase resiliency of beach habitats to future storms and sea level rise, and incorporate best practices into decision-making.	Multi: CT, DE, MA, MD, ME, NH, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$1,750,000	$2,059,500
Community resilience planning	BLM-unknown	Seed banking for resiliency project	Collect and provide locally adapted plant materials for restoration of areas impacted in 10 states and the District of Columbia. Project will ensure ongoing restoration projects have immediate access to the local raw material needed to revegetate and facilitate resilience of coastal habitats.	Multi: CT, DC, DE, MA, MD, ME, NH, NJ, NY, RI, VA	Bureau of Land Management	$3,500,000	$0
Community resilience planning	BSEE-69	Improve resilience of the Ohmsett facility	Repair Hurricane Sandy damages at the Ohmsett National Oil Response Research and Renewable Energy Test Facility in New Jersey. Improvements include adaptation and mitigation improvements for future storms.	NJ	Bureau of Safety and Environmental Enforcement	$4,000,000	$0
Community resilience planning	NFWF-42279[a]	Building ecological solutions to coastal community hazards, New Jersey	Develop, design, and deliver green stormwater infrastructure techniques that add ecological value and enhance community resiliency. Project will benefit New Jersey coastal communities.	NJ	New Jersey Department of Environmental Protection	$3,440,000	$894,900

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Community resilience planning	NFWF-42697	Building green infrastructure into community policies, Rhode Island	Incorporate green stormwater infrastructure into community policies in Newport, Warwick, and North Kingstown, Rhode Island. Project will increase resiliency, build local decision-maker capacity, and serve as a replicable model for neighboring states.	RI	University of Rhode Island	$400,000	$0
Community resilience planning	NFWF-42714	Transforming Hoboken's Block 12 into a green infrastructure asset, New Jersey	Incorporate green stormwater infrastructure into Block 12's redesign in Hoboken, New Jersey. Project will increase stormwater management, reduce sewer overflow, and increase open space acreage.	NJ	City of Hoboken	$250,000	$3,615,400
Community resilience planning	NFWF-42957	Designing a daylighting plan to improve Harlem River's water quality and resiliency, New York	Create a daylighting plan that is critical to restoring Tibbetts Brook as a tributary to the Harlem River. Project will develop a conceptual plan and design for Tibbetts Brook's restoration.	NY	New York City Department of Parks and Recreation	$250,000	$2,116,000
Community resilience planning	NFWF-42984	Enhancing Mill River's flood resiliency and habitat corridor, Connecticut	Increase the Mill River's flood resiliency and recreate a habitat corridor in Stamford, Connecticut. Project will eradicate invasive species, replant native flora, and remove 15 properties from the 1% flood risk area.	CT	Mill River Collaborative	$3,750,000	$7,880,200
Community resilience planning	NFWF-43290	Developing a design that will Enhance Liberty State Park's marshes and upland habitats, New Jersey	Develop a design that will create 40 acres of salt marsh and enhance 150 acres of upland habitat at Liberty State Park in Jersey City, New Jersey. Project's design will improve ecosystem resiliency and create a new publicly accessible area within the park.	NJ	New Jersey Department of Environmental Protection – Office of Natural Resource Restoration	$250,000	$147,000
Community resilience planning	NFWF-43861	Creating a natural resource resiliency assessment and action plan, Rhode Island	Create a natural resource resiliency assessment and action plan for 2,064 acres in Charleston and the County of Washington, Rhode Island. Project will identify mitigation options that will strengthen watershed resiliency and protect nearby communities.	RI	Narragansett Indian Tribe	$180,000	$60,200
Community resilience planning	NFWF-44020	Developing a green infrastructure plan for Chester City, Pennsylvania	Develop a green stormwater infrastructure plan and design a demonstration project in Chester City, Pennsylvania. Project will incorporate green stormwater infrastructure policies, focus on citizen empowerment, and serve as a model to neighboring cities.	PA	Delaware Valley Regional Planning Commission	$290,000	$32,100

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Community resilience planning	NFWF-44140	Improving coastal resiliency through community engagement, Ohio and Rhode Island	Engage Ohio and Rhode Island communities in projects that will improve their coastal resiliency. Project will encourage communities to participate more, provide an ecosystem resiliency roadmap, and potentially lower flood insurance costs.	Multi: OH, RI	Association of State Floodplain Managers	$341,700	$86,100
Community resilience planning	NFWF-44199	Designing a plan to reuse dredged rock to protect the Boston Harbor shoreline, Massachusetts	Design a plan to reuse 1 million cubic yards of rock to create a protected Boston Harbor shoreline in Massachusetts. Project will develop a plan that will reduce wave energy, protect transplanted eelgrass, and repurpose dredged rock.	MA	Maryland Division of Marine Fisheries	$240,000	$160,100
Community resilience planning	NFWF-44245	Developing a resiliency management plan for Pawcatuck River watershed, Connecticut and Rhode Island	Developed the Wood-Pawcatuck Watershed Flood Resiliency Plan for 12 communities in southern Rhode Island and Connecticut. Project supported planning to assess the watershed vulnerability to flooding, erosion, and storms; and to enhance its resiliency, restore habitat, and protect local communities from these threats.	Multi: CT, RI	Wood-Pawcatuck Watershed Association	$720,000	$188,000
Community resilience planning	NFWF-44271	Creating a regional framework for coastal resilience in Southern Connecticut	Establish a Regional Framework for Coastal Resilience for 10 municipalities that run along the entire central coast of Connecticut. The project will integrate green stormwater infrastructure principles, prioritize projects, and contribute to a Regional Coastal Resiliency Plan.	CT	South Central Regional Council of Governments	$700,000	$0
Community resilience planning	NPS-14-7	Visionmaker Jamaica Bay: Evaluation and synthesis of community generated adaptation strategies to enhance resilient ecosystems in Jamaica Bay, NY (subproject)	Asses the current state of salt marshes in Jamaica Bay, New York, by collecting marsh peat and pore water. Project will characterize the sediment and geochemical constraints on salt marsh resilience against sea level rise and elevated pore water levels.	NY	Wildlife Conservation Society; National Park Service	$350,000	$0
Community resilience planning	NPS-23	Develop breach management plans for coastal national seashores to maximize ecological benefits	Develop and analyze the impacts of five feasible alternatives for breach management on Fire Island in Maryland and New York. Project will protect natural and cultural features while protecting human life and reducing physical damage.	Multi: MD, NY	Denver Service Center; National Park Service	$570,500	$0

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Multi-activity (community resilience planning and marsh restoration)	NFWF-41739[a]	Reusing dredged materials to enhance salt marsh in Ninigret Pond, Rhode Island	Restore 30 acres of salt marsh in Ninigret Pond and create 2 additional marsh restoration designs in the Salt Ponds Region in south Rhode Island. The project will strengthen the marsh's resiliency and serve as a model to similar restoration projects throughout the state.	RI	Rhode Island Coastal Resources Management Council	$3,250,000	$386,000
Multi-activity (community resilience planning, beach and dune restoration, and marsh restoration)	NFWF-41766[a]	Coastal resiliency planning and ecosystem enhancement for northeastern Massachusetts	Restore and enhance Great Marsh's wetlands and dunes. Local municipalities' vulnerability will be reduced through restoration projects, assessments, and coastal resiliency plans.	MA	National Wildlife Federation	$2,940,000	$1,597,300
Multi-activity (community resilience planning, beach and dune restoration, and green stormwater infrastructure)	NFWF-41795[a]	Strengthening Sachuest Bay's coastal resiliency, Rhode Island	Enhance over 100 acres of Sachuest Bay's beaches and wetlands in Middletown, Rhode Island. Project will improve water quality, enhance natural infrastructure, and improve existing grey infrastructure.	RI	Town of Middletown	$2,289,800	$644,300
Multi-activity (Coastal resilience science; and living shorelines)	NFWF-41931	Developing self-sustaining oyster population in Jamaica Bay, New York	Develop self-sustaining oyster population in Jamaica Bay, New York. Project will improve water quality and increase oyster larvae recruitment.	NY	New York City Department of Environmental Protection	$1,000,000	$375,000
Multi-activity (green stormwater infrastructure and living shorelines)	NFWF-42019	Restoring Bronx River shoreline at Starlight Park, New York	Restore ecosystem function and habitat for Bronx River in New York City. Project will re-naturalize the shoreline, restore habitat function, and remove contaminated soil.	NY	New York City Department of Parks and Recreation	$4,400,000	$880,000
Multi-activity (marsh restoration and green stormwater infrastructure)	NFWF-42442[a]	Strengthening Sunken Meadow State Park's resiliency, New York	Enhance Sunken Meadow State Park's 135 acres of salt marsh and remove runoff in Long Island, New York. Project will strengthen ecosystem resiliency and promote green stormwater infrastructure benefits.	NY	Connecticut Fund for the Environment	$2,500,000	$57,500

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Multi-activity (Coastal resilience science; community resilience planning; and living shorelines)	NFWF-42551	Green infrastructure in Accomack and Northampton counties, Virginia	Implemented green stormwater infrastructure projects and enhance decision-makers' coastal resiliency knowledge in Accomack and Northampton counties, Virginia. Project provided tools, knowledge, and a stakeholder process that can aid decision-makers' policies and actions.	VA	The Nature Conservancy	$1,460,000	$295,100
Multi-activity (community resilience planning and aquatic connectivity)	NFWF-42671	Enhancing seven communities, ecosystems, and infrastructure resiliency by removing seven fish barriers, Massachusetts	Remove 7 high-risk fish barriers and design plans for 3 additional barriers that cause flood damage within 9 Massachusetts communities. Project will increase flood resiliency, open 123 river miles for fish, and restore 57 acres of wetlands. Project will also identify and develop concept plans for 10 additional high-priority barriers.	MA	Fish and Game, Massachusetts Department of/ Division of Ecological Restoration	$4,488,000	$1,623,500
Multi-activity (marsh restoration and green stormwater infrastructure)	NFWF-42958[a]	Restoring Spring Creek Park's salt marsh and upland habitat, New York	Restore and enhance significant areas of coastal habitat, thereby re-establishing ecological functions and services in an important tributary to Jamaica Bay, and provide increased resiliency for adjacent neighborhoods through additional storm surge buffers and green stormwater infrastructure to reduce inland flooding. This project will ultimately provide an added line of defense against the vulnerability of southern Queens and Brooklyn to coastal storms.	NY	New York City Department of Parks and Recreation	$4,270,000	$6,967,500
Multi-activity (community resilience planning, and beach and dune restoration)	NFWF-43281[a]	Restoring Delaware Bay's wetlands and beaches in Mispillion Harbor Reserve and Milford Neck Conservation Area	Implement a system-wide approach to evaluate, design, and construct restoration and resiliency strategies along the central Delaware Bayshore. Project will enhance community and ecosystem resiliency by generating a restoration plan and restoring the beach and dune system.	DE	Delaware Department of Natural Resources	$4,500,000	$1,519,200
Multi-activity (Coastal resilience science; and living shorelines)	NFWF-43308	Developing a green infrastructure plan and network for the Lafayette River Watershed, Virginia	Implement 8 shoreline restoration projects, and develop a green stormwater infrastructure plan and framework for the Lafayette River watershed in Norfolk, Virginia. Project will strengthen the watershed's resiliency, engage 40 veterans in a green stormwater infrastructure training course, and involve 160 high school students in hands-on projects.	VA	City of Norfolk	$4,640,000	$257,300

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Multi-activity (community resilience planning, marsh restoration, and aquatic connectivity)	NFWF-43322[a]	Enhancing Wampanoag Tribe of Gay Head's land resiliency in Martha's Vineyard, Massachusetts	Assess and restore over 230 acres of tribal habitat in Martha's Vineyard, Massachusetts. Management plans and multi-jurisdictional partnerships will support marine protection and habitat restoration.	MA	Wampanoag Tribe of Gay Head	$670,000	$232,000
Multi-activity (community resilience planning, and beach and dune restoration)	NFWF-43429[a]	Creating a resilient Delaware Bay Shoreline in Cape May and Cumberland counties, New Jersey	Restore 50 acres of Delaware Bay's wetlands and 6 miles of beach in Cape May and Cumberland Counties, New Jersey. Project will improve horseshoe crab spawning, provide shorebird stopover area, and improve ecological and economic community resilience.	NJ	American Littoral Society	$4,750,000	$254,500
Multi-activity (aquatic connectivity and green stormwater infrastructure)	NFWF-43759	Reducing flood impacts and restoring habitat in the Brandywine River watershed, Pennsylvania	Restore over 250 acres of wetlands and riparian habitat in the Brandywine River watershed in Pennsylvania. Project will improve community flood resiliency, reconnect habitats, and reduce runoff.	PA	Stroud Water Research Center	$3,030,000	$500,000
Multi-activity (marsh restoration and living shorelines)	NFWF-43849	Developing coastal resiliency regional models, Virginia	Enhance over 3,700 acres of wetlands and forests in the Southern Watersheds Area of Virginia. Project will strengthen coastal resiliency and serve as an adaptation resource for community leaders and decision-makers.	VA	Wildlife Foundation of Virginia	$4,000,000	$383,800
Multi-activity (community resilience planning and green stormwater infrastructure)	NFWF-43931	Strengthening Marshes Creek through green and grey infrastructure, New Jersey	Rutgers University will develop and deliver 10 green stormwater infrastructure projects in the Tremley Point community, Linden, New Jersey. Project will reduce 6 million gallons of stormwater pollution annually; capture and infiltrate rainwater to help reduce community vulnerability to storms; and develop and deliver an on-the-ground green stormwater infrastructure and floodplain enhancement project involving restoration of 3.1 acres of upland, meadow, and floodplains with native species on a New Jersey State Blue Acres property in Tremley Point.	NJ	Rutgers University	$2,720,000	$222,400
Multi-activity (marsh restoration and living shorelines)	NFWF-43939	Restoring Newark Bay's wetlands, New Jersey	Restore Newark Bay's wetlands in New Jersey. The 12-acre restoration will buffer against shoreline erosion, improve flood control, and remove invasive plants.	NJ	City of Newark	$1,560,000	$15,000

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Multi-activity (community resilience planning; beach and dune restoration; and marsh restoration)	NFWF-43986[a]	Strengthening Monmouth Beach's marshes and dunes, New Jersey	Construct and enhance 5,000 feet of coastal dunes, and restore 17 acres of marsh in Monmouth Beach, New Jersey. Both terrains provide critical wildlife habitat and community protection.	NJ	Monmouth Beach, New Jersey	$1,780,000	$1,750,000
Multi-activity (community resilience planning and marsh restoration)	NFWF-44157[a]	Repairing infrastructure and designing wetland and beach restoration plans along the Central Delaware Bayshore	Design restoration plans for Delaware Bay's wetlands and beaches. Project will enhance community and ecosystem resiliency by generating restoration plans and replacing critical water control structures.	DE	Delaware Department of Natural Resources	$2,000,000	$1,170,100
Multi-activity (marsh restoration and living shorelines)	NFWF-44167[a]	Protecting North Beach's salt marsh and emergency route, Maryland	Create, restore, and improve North Beach's shoreline in Calvert County, Maryland. Project will prevent further erosion to North Beach's 105-acre salt marsh, protect surrounding communities, and prevent damage to MD Route 261, an emergency vehicle route.	MD	Town of North Beach	$540,000	$121,200
Multi-activity (community resilience planning and green stormwater infrastructure)	NFWF-44193	Incorporating green infrastructure resiliency in the Raritan River Basin, New Jersey	Perform 54 municipality assessments and impervious cover reduction action plans for the Raritan River Basin in New Jersey. Project will create a municipality strategy guide with recommendations, and implement projects that capture over 54 million gallons of stormwater annually.	NJ	Rutgers	$820,000	$353,600
Multi-activity (beach and dune restoration, marsh restoration, and living shorelines)	NFWF-44225[a]	Improving Shinnecock Reservation's shoreline habitats, New York	Restore Shinnecock Reservation's eelgrass, oyster, marsh, and beach habitats in Southampton, New York. Project will reduce erosion, increase habitat, and strengthen shoreline resiliency.	NY	Shinnecock Indian Nation	$3,750,000	$314,000
Multi-activity (marsh restoration and living shorelines)	USFWS-1[a]	Salt marsh restoration and enhancement at Seatuck, Wertheim and Lido Beach National Wildlife Refuges, Long Island, New York	Improve 432 acres of salt marsh and build a sill living shoreline at Lido Beach National Wildlife Refuges in New York. Project will enhance salt marsh resilience to large storm events and repair boardwalk infrastructure for future storm events.	NY	U.S. Fish and Wildlife Service	$11,093,000	$1,432,500

Activities	Project identification (ID) number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds
Multi-activity (beach and dune restoration, and marsh restoration)	USFWS-15[a]	Prime Hook National Wildlife Refuge coastal tidal marsh/barrier beach restoration	Restore tidal marsh and barrier beach ecosystems on Prime Hook Wildlife Refuge in Delaware. Project will improve the ability of marshes to withstand future storms and sea level rise.	DE	U.S. Fish and Wildlife Service	$19,805,000	$1,360,000
Multi-activity (marsh restoration and living shorelines)	USFWS-37[a]	Restoring coastal marshes in New Jersey National Wildlife Refuges	Restore 32,000 acres of tidal marsh along 60 miles of coast in New Jersey. Project will replace culverts and other infrastructure with green stormwater infrastructure for greater resilience against high wave energy.	NJ	U.S. Fish and Wildlife Service	$15,000,000	$3,000,000
Multi-activity (marsh restoration and living shorelines)	USFWS-65[a]	Protecting property and helping coastal wildlife: Enhancing salt marsh and estuarine function and resiliency for key habitats on impacted wildlife refuges from Rhode Island to southern Maine	Dredge river channel, raise marsh elevation, implement erosion control, improve marsh hydrology with tunnels, and target invasive species in 3 states. Project will reduce flood risk and improve recreation access.	Multi: RI, MA, ME	U.S. Fish and Wildlife Service	$4,150,000	$250,000

a. Project has secured additional, long-term monitoring funding through NFWF and DOI.

Table A.2. Non-evaluated restoration projects supported through the Hurricane Sandy Program. In some cases, NFWF and DOI reinvested funds into new, additional projects after the 2016 evaluation cutoff date. The projects in this table were added after the evaluation cutoff date and are not included in the evaluation. Project information is based on available project documentation. All dollars are rounded to the nearest hundred.

Project ID number	Project title	Project description	Project state	Project lead organization	Award amount	Matching funds	Total cost
N/A	Impoundment Restoration at Chincoteague National Wildlife Refuge	Convert 400-acre impoundment at Swan Cove pool (F-pool) into a tidal basin. Project will restore the tidal exchange with Toms Cove and increase Chincoteague Island resilience via marsh buffer.	VA	U.S. Fish and Wildlife Service	$1,900,000	$0	$1,900,000
N/A	Coonamessett River Restoration (dam removal/stream crossing)	Remove two dams, restore a former cranberry bog to natural wetland and riverine habitat, and replace a failed road crossing on the Coonamessett River. Project will improve public safety through removing/replacing aging infrastructure and improve water quality.	MA	U.S. Fish and Wildlife Service	$2,207,000	$3,895,000	$6,102,000
N/A	Cypress Branch Dam Removal, Chester River Watershed, Queen Anne's County, Millington, MD	Remove Branch Dam to open 8 mainstem miles of habitat and 10 additional miles of tributary habitat. Project will improve public safety through removing aging infrastructure and improve water quality.	MD	U.S. Fish and Wildlife Service	$450,000	$50,000	$500,000
USFWS-10	Round Hill salt marsh restoration project, Dartmouth, Massachusetts	Project cancelled in late 2017 due to lack of support from the Park Board. The project aimed to restore salt marsh functions and values lost due to historical filling.	MA	U.S. Fish and Wildlife Service	$0	$0	$0

Appendix B. Methods for Hurricane Sandy Program Evaluation

In this appendix we provide more detail about the key methodologies we used during the evaluation of the Hurricane Sandy Program. While we provide an overarching methodological description in the main report and each of the case studies (Abt Associates, 2019a–f), we provide more detail here on a subset of analyses that (1) we describe only briefly elsewhere, and (2) are sufficiently complex or important to merit a more careful discussion. More specifically, we provide information about key approaches we used to analyze and present information about:

- B.1. Marsh restoration projects
- B.2. Living shoreline projects
- B.3. Aquatic connectivity projects
- B.4. Beach and dune restoration projects
- B.5. Community resilience planning projects
- B.6. Coastal resilience science projects
- B.7. Overall project summaries.

B.1 Marsh Restoration Projects

For the marsh restoration case study (Abt Associates, 2019a), the only analysis that required a more detailed description than the information provided in the case study is the one associated with the development of trajectories of recovery after restoration.

For the development of the marsh recovery timeline, we conducted a web-based literature search to identify peer-reviewed publications that support observed and projected marsh restoration recovery trajectories. We used the terms "marsh restoration recovery" and "marsh restoration recovery trajectory" on Google Scholar to identify relevant literature. In addition, because our evaluation team members did extensive work on this topic area, we relied on publications that we had found through previous, formal literature searches to conduct meta-analyses of marsh restoration recovery trajectories.

Based on this search, we identified 10 key peer-reviewed publications with information that could be used to develop trajectories of ecological recovery following marsh restoration in the Hurricane Sandy region. We used the following citations from the literature review:

- Borja, Á., D.M. Dauer, M. Elliott, and C.A. Simenstad. 2010. Medium-and long-term recovery of estuarine and coastal ecosystems: Patterns, rates and restoration effectiveness. *Estuaries and Coasts* 33(6):1249–1260.
- Craft, C., P. Megonigal, S. Broome, J. Stevenson, R. Freese, J. Cornell, L. Zheng, and J. Sacco. 2003. The pace of ecosystem development of constructed *Spartina alterniflora* marshes. *Ecological Applications* 13(5):1417–1432.
- Craft, C.B. 2001. Soil organic carbon, nitrogen, and phosphorus as indicators of recovery in restored "Spartina" marshes. *Ecological Restoration* 19(2):87–91.
- Ebbets, A.L., D.R. Lane, P. Dixon, T.A. Hollweg, M.T. Huisenga, and J. Gurevitch. 2019. Using meta-analysis to develop evidence-based recovery trajectories of vegetation and soils in restored wetlands in the northern Gulf of Mexico. *Estuaries and Coasts* 1–19.

- Gray, A., C.A. Simenstad, D.L. Bottom, and T.J. Cornwell. 2002. Contrasting functional performance of juvenile salmon habitat in recovering wetlands of the Salmon River estuary, Oregon, USA. *Restoration Ecology* 10(3):514–526.
- Hollweg, T.A., M.C. Christman, J. Lipton, B.P. Wallace, M.T. Huisenga, D.R. Lane, and K.G. Benson. Meta-analysis of nekton recovery following marsh restoration in the northern Gulf of Mexico. (In review).
- Moreno-Mateos, D., M.E. Power, F.A. Comín, and R. Yockteng. 2012. Structural and functional loss in restored wetland ecosystems. *PLoS Biology* 10(1):p.e1001247.
- Sasser, C.E., E. Evers-Heber, B. Milan, and G.O. Holm Jr. 2013. Relationships of Marsh Soil Strength to Vegetation Biomass. Final Report to the Louisiana Coastal Protection and Restoration Authority through State of Louisiana Interagency Agreement No. 2503-11-45.
- Verdonschot, P.F.M., B.M. Spears, C.K. Feld, S. Brucet, H. Keizer-Vlek, A. Borja, M. Elliott, M. Kernan, and R.K. Johnson. 2013. A comparative review of recovery processes in rivers, lakes, estuarine and coastal waters. *Hydrobiologia* 704(1):453–474.
- Warren, R.S., P.E. Fell, R. Rozsa, A.H. Brawley, A.C. Orsted, E.T. Olson, V. Swamy, and W.A. Niering. 2002. Salt marsh restoration in Connecticut: 20 years of science and management. *Restoration Ecology* 10(3):497–513.

We used this literature in combination with expert judgment from ecologists at the Virginia Institute of Marine Science (VIMS) to develop conceptual timelines of recovery. The figures were drafted by Dr. Pamela Mason of VIMS, reviewed by Drs. Molly Mitchell and Donna Bilkovic of VIMS, and reviewed and modified as needed to reflect the literature review conducted by Dr. Karen Carney and Ms. Allison Ebbets of Abt.

B.2 Living Shoreline Projects

The analyses we present in the living shoreline case study (Abt Associates, 2019b), summarized in the full evaluation report (Abt Associates, 2019g), entail a suite of analysis and assumptions that merit a more full discussion in this appendix. Here, we provide more information about the key approaches, literature sources, and assumptions utilized in our cost-effectiveness analysis; and the development of living shoreline timelines of recovery.

B.2.1 Cost-Effectiveness Analysis

Cost-effectiveness analysis uses a quantified, usually nonmonetary, metric or index to reflect beneficial outcomes and is used to assess the relative benefit per dollar spent among alternatives. In this analysis, the performance or benefit metric used was the total land area (developed and habitat) in year 30 to represent the cumulative effect over time, relative to the present value of cost. Below, we discuss our approach to developing effectiveness metrics and project costs.

Effectiveness Metrics

The ideal effectiveness metrics are those that quantify documented beneficial outcomes of projects (e.g., such as nesting success of rare birds, flood damage avoided). In the case of Hurricane Sandy living shoreline projects, most had been completed in less than two years at the time of this analysis, and therefore provided limited observations of beneficial outcomes. In addition, monitoring data for potential outcomes were quite limited. Given these limitations, we chose to use the amount of area protected (i.e., the amount of land that would have been lost to erosion without protection) as our key effectiveness metric. We also used the amount of area restored (e.g., the amount of marsh habitat created or enhanced through restoration) as our other key effectiveness metric. Using area of land protected/restored is a common measure of restoration effectiveness and is expected to correlate with the many positive outcomes of property protection and habitat creation.

A disadvantage of using acres to judge project effectiveness is that it minimizes differences across project design types and between green or living shoreline approaches and gray (e.g., seawall, revetment) approaches, as discussed further below. In particular, it does not fully capture differences in ecosystem services provided by project type (Table B.1). The ecosystem services affect the ability of living shorelines to generate cultural benefits such as recreation, to regulate and sustain themselves, and to support the export of benefits to nearby systems (e.g., submerged aquatic vegetation and oyster reefs provide fish habitat that complements other nearby aquatic system components).

Table B.1. Comparison of ecosystem services provided by green and gray infrastructure

Ecosystem services	Green stormwater Infrastructure	Gray Infrastructure
Shoreline protection and stabilization (erosion control)	●	●
Nutrient and sediment retention (upland)	●	●
Nutrient cycling between terrestrial and aquatic systems	●	
Maintenance of natural physical dynamics of shorelines (sediment transport and accretion, and wetland migration)	●	
Flood risk reduction (storm surge reduction and inundation prevention)	●	●
Habitat retention (upland, non-tidal wetland)	●	●
Habitat creation or enhancement (upland, non-tidal wetland, tidal, and benthic systems)	●	
Biodiversity	●	
Recreational fishing enhancements of oyster reefs	●	
Property value enhancements associated with wetlands	●	

Estimation of Area Protected

We conducted a literature review to determine whether the performance of gray infrastructure and living shorelines differed in terms of their ability to prevent coastal erosion, as this would be a key factor in our analyses. However, the literature provided very little information regarding the relative performance of either type of intervention (Feagin et al., 2009; Shepard et al., 2011; NRC, 2014; Myszewski and Alber, 2016). Given the lack of clear guidance from the literature, we assumed that green and gray shoreline projects had an equal ability to protect upland areas over the 30-year period for the purposes of the cost-effectiveness analysis. We measured the future stream of coastal protection benefits relative to a "future without project" scenario using historical trends in erosion. We compiled annual erosion rates for each project, and calculated the total area protected from erosion by multiplying the annual erosion rate by 30 years (the assumed lifetime of both green and gray projects).

We obtained erosion rates from multiple sources. Where available (i.e., for six project sites), we used the rates reported by project leads in environmental assessments, reports, email correspondence, interviews, or other project documents. For four sites, we obtained erosion rates from the USGS Coastal Change Hazard's Portal (Suftin, 2019). For one project site, we used a range of erosion rates reported through an environmental assessment for one site and a range of erosion rates from the USGS Coastal Change Hazard's Portal for the other site. Because erosion rates were often reported as a range or were highly variable in the portal, we used a low and high erosion rate in our analyses to bracket benefits estimates.

Estimation of Area of Habitat Created

Both green and gray infrastructure projects have the potential to reduce loss of existing land positioned inland of the project, but only the green living shoreline projects created habitat. We used information provided by project leads in emails, final reports, permit applications, proposals, and environmental assessments to estimate the type and amount of habitat restored.

Project Costs

In this section, we describe our approach to estimate the total costs for a living shoreline (green) and a comparable revetment (gray) per site. We provide information about developing project costs and how we estimated the present value of costs over project lifetimes.

Project Lifespan

The lifespans of gray and green infrastructure are key to analyzing the key costs and benefits of each type of project. However, project lifetimes are not well-constrained and historical information may not be reliable for future projections, since the lifespans of shoreline projects have the potential to be limited by sea level rise. Data on project lifespans can also vary widely as a function of the construction quality, site characteristics, and coastal storm frequency and intensity. However, in our analyses, we assumed that both gray and green projects had a 30-year lifespan, consistent with expert judgment in conducting living shoreline cost-effectiveness analyses in the Chesapeake Bay (CAST, 2018).

Construction Costs

We developed construction cost data from project proposals, interim reports, and interviews with project principal investigators. In most cases, the planning and design costs were clearly covered by a project's Hurricane Sandy award. However, a handful of projects received planning and design costs from elsewhere, and, in these cases, we estimated planning costs as 15% of construction costs.

Some inconsistencies in cost estimation techniques across projects may remain, in part, because projects were at different phases of planning when they received funding and did not necessarily report all prior investments. We could not characterize such inconsistencies because reported costs were not consistently broken down into key project phases (planning, construction, and monitoring) or types (labor and equipment supplies). Furthermore, we were not able to account for the potential value of volunteer labor because these costs were not reported in most cases. Our analysis also omitted costs related to land acquisition, advertising, training, or entertaining volunteers, again due to insufficient reporting of such information.

To estimate costs of an equivalent gray project, we assigned each site a low-, medium-, or high-energy environment, based on local fetch and erosion rates. This is consistent with common guidance to design projects to fit the energy environment and sediment supply, in order to promote project success (Center for Coastal Resources Management, 2010). We then associated energy regime categories with the low-, average-, or high-unit costs of revetments available in the published and gray literature (Restore America's Estuaries, 2015). We estimated the total construction costs of the gray option as the unit cost ($/linear foot), multiplied by the length of the funded project. Costs were scaled because higher-energy environments typically require design elements (e.g., large rocks, wide sills), and the energy environment can affect the costs of equipment and labor.

Maintenance Costs

A common assertion is that natural infrastructure has substantially lower maintenance costs than gray infrastructure because it has the ability to adapt to sea level rise and, in some cases, dynamically adjust to changing conditions (NRC, 2014). However, even living shoreline projects that lack structural components can require maintenance to address damage from storms, intense wildlife grazing (nutria, geese, swans), and invasive species, among other factors; and these maintenance costs are non-trivial.

We evaluated the maintenance costs of green and gray projects using literature sources because the short lifetime of the Hurricane Sandy projects preclude their use as a key information source. We used the estimate provided by an expert panel that evaluated the effectiveness and costs of living shorelines in the Chesapeake Bay. While the group noted that living shoreline projects' maintenance costs are not well-understood (Forand et al., 2017), they estimated that maintenance costs would be 11.5% of construction costs for all project types (CAST, 2018). We applied the same percentage to both green and gray project types.

Annualization and Present Value of Costs

Annualized costs are used to estimate average annual costs in present value terms. The value of an annualized cost is "the amount one would have to pay at the end of each time period *t* so that the sum of all payments *in present value terms* equals the original stream of values" (U.S. EPA, 2010). Costs were annualized by first calculating the present value of costs in 2017 dollars. A comparison of projects that have different future maintenance costs requires that costs be evaluated in present value terms for accurate comparison. Calculating present value relies on a discount rate that is similar to an interest rate, except that it is used to reduce future values to their worth in present value.

We used the following equation to calculate the present value of costs:

$$PVC = C_0 + \sum_t \frac{C_t}{(1+r)^t},$$

where:

PVC = present value of costs; all construction costs are assumed to occur in the year 0
r = discount rate, set to 3%
t = time period or year in which the costs accrue.

Annualizing costs were estimated using the following equation:

$$AC = PVC * [(r * (1 + r)^n) / ((1 + r)^{n+1} - 1)],$$

where:

n = project lifespan, set to 30 years for both green and gray.

Cost-Effectiveness References

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B.2.2 Timelines of Ecological Recovery after Restoration

For the development of recovery timelines after restoration, we conducted a web-based literature search to identify peer-reviewed publications that support observed and projected living shorelines' restoration recovery trajectories. We used the following search terms on Google Scholar to identify relevant publications:

- Living shoreline recovery time
- Living shoreline recovery trajectory
- Living shoreline restoration recovery
- Living shoreline erosion control
- Living shoreline oyster establishment
- Living shoreline seagrass recover.

Based on this search, we identified eight key peer-reviewed publications with information about ecological recovery following living shoreline restoration. We downloaded, reviewed, and compiled relevant information about vegetation, habitat/wildlife use, and erosion control recovery timelines. We used the following citations from the literature review:

- Bilkovic, D.M. and M.M. Mitchell. 2017. Designing living shoreline salt marsh ecosystems to promote coastal resilience. In *Living Shorelines* CRC Press. pp. 293–316.
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We used this literature in combination with expert judgment from ecologists at the VIMS to develop conceptual timelines of recovery. The figures were drafted by Dr. Pamela Mason of VIMS, reviewed by Drs. Molly Mitchell and Donna Bilkovic of VIMS, and reviewed and modified as needed to reflect the literature review conducted by Dr. Karen Carney and Ms. Allison Ebbets of Abt.

B.3 Aquatic Connectivity Projects

For the aquatic connectivity case study (Abt Associates, 2019c), the only analysis that required a more detailed description than the information provided in the case study is the one associated with the development of trajectories of recovery after restoration.

For this analysis, we conducted a web-based literature search to identify peer-reviewed publications that support observed and projected aquatic connectivity recovery trajectories. We used the following search terms on Google Scholar to identify relevant publications:

- Dam removal recovery
- Dam removal recovery trajectory
- Coastal dam removal recovery trajectory
- Dam removal flood risk reduction.

Based on this search, we identified nine key peer-reviewed publications with information about ecological and geomorphic recovery following dam removal. Of these, seven were readily available as full text. We downloaded, reviewed, and compiled relevant information about connectivity, fish populations, and flood risk recovery timelines. We used the following citations from the literature review:

- Bednarek, A.T. 2001. Undamming rivers: A review of the ecological impacts of dam removal. *Environmental Management* 27(6):803–814.
- Catalano, M.J., M.A. Bozek, and T.D. Pellett. 2007. Effects of dam removal on fish assemblage structure and spatial distributions in the Baraboo River, Wisconsin. *North American Journal of Fisheries Management* 27(2):519–530.
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We used this literature in combination with expert judgment from ecologists at the VIMS to develop conceptual timelines of recovery. The figures were drafted by Dr. Pamela Mason of VIMS, reviewed by Drs. Molly Mitchell and Donna Bilkovic of VIMS, and reviewed and modified as needed to reflect the literature review conducted by Dr. Karen Carney and Ms. Allison Ebbets of Abt.

B.4 Beach and Dune Restoration Projects

For the beach and dune case study (Abt Associates, 2019d), we provide here a more detailed description of our approach for (1) categorizing projects, and (2) developing trajectories of recovery after restoration.

B.4.1 Categorization of Beach and Dune Projects

In reviewing archival materials, it became clear that there were two main goals of the beach and dune restoration projects in the Hurricane Sandy program: they were either focused on habitat restoration or community protection. Habitat restoration projects were those that sought to restore and create beach or dune habitat, specifically to support horseshoe crabs and migratory shorebirds. Community protection projects aimed to restore beaches or dunes to prevent erosion, enhance shoreline resilience, and mitigate flooding. To understand the overall project focus, team members reviewed proposal and final report documentation for all projects, and grouped projects into one of the categories based on descriptions of the overall project goals. Most projects included some components that could be classified in either category, but we were able to classify projects based on the overarching focus of the restoration activities.

B.4.2 Timelines of Ecological Recovery after Restoration

For the development of the beach and dune recovery timeline, we conducted a web-based literature search to identify peer-reviewed publications that support observed and projected beach and dune restoration recovery trajectories. We used the following search terms on Google Scholar to identify relevant publications:

- Beach dune restoration recovery
- Beach nourish restoration recovery
- Beach dune restoration storm protection time.

Based on this search, we identified 10 key peer-reviewed publications with information about ecological recovery following beach and dune restoration. We downloaded, reviewed, and compiled relevant information about vegetation, habitat/wildlife use, erosion control, and storm protection recovery timelines. We used the following citations from the literature review:

- Acosta, A.T.R., T. Jucker, I. Prisco, I. and R. Santoro. 2013. Passive recovery of Mediterranean coastal dunes following limitations to human trampling. In *Restoration of Coastal Dunes*. Springer, Berlin, Heidelberg. pp. 187–198.
- Feagin, R.A. 2005. Artificial dunes created to protect property on Galveston Island, Texas: The lessons learned. *Ecological Restoration* 23(2):89–94.
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protecting beaches, dunes, and barrier islands from erosion. *Frontiers in Ecology and the Environment* 13(4):203–210.

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We used this literature in combination with expert judgment from ecologists at VIMS to develop conceptual timelines of recovery. The figures were drafted by Dr. Pamela Mason of VIMS, reviewed by Drs. Molly Mitchell and Donna Bilkovic of VIMS, and reviewed and modified as needed to reflect the literature review conducted by Dr. Karen Carney and Ms. Allison Ebbets of Abt.

B.5 Community Resilience Planning Projects

For the community resilience planning study (Abt Associates, 2019e), we provide here a more detailed description of our approach for categorizing projects.

We used information provided by project leads in emails, final reports, permit applications, and proposals to categorize community resilience planning projects. Based on the type of products created by the project, we categorized the products as site-specific designs, management plans or assessments, and resilience tools. We tallied the number of products based on the number of discrete products created, such as documents, tools, and assessments. We also assessed each product type for the activities performed, and assessed each project on its progress toward implementation of those activities.

B.6 Coastal Resilience Science Projects

For the data mapping and modeling case study (Abt Associates, 2019f), we provide here a more detailed description of our approach for categorizing projects.

USGS organized its 25 coastal resilience science projects into five topic areas (or "themes") based on impact types and information needs (Buxton et al., 2013). To categorize coastal resilience science projects for purposes of the evaluation, we adopted the USGS themes, retitling them for simplicity as shown in Table B.2. We also added topic areas six and seven to categorize a few projects that did not fit into the five original USGS themes. We retained the original USGS categorization for the USGS projects. We categorized the non-USGS data, mapping and modeling projects into the topic areas based on the topics addressed and the products produced. For projects with multiple components that addressed different topic areas, we applied our best judgment to determine the primary project focus and categorized the project into that topic area.

Table B.2. USGS themes and evaluation topic areas

USGS theme	Evaluation topic area
1. Coastal topographic and bathymetric data to support hurricane impact assessment and response	1. Elevation data
2. Impacts to coastal beaches and barriers	2. Coastal change
3. Impacts of storm surge, including disturbed estuarine and bay hydrology	3. Storm surge and hydrology
4. Impacts on environmental quality, including exposure to chemical and microbial contaminants	4. Environmental quality
5. Impacts to coastal ecosystems, habitats, and fish and wildlife	5. Ecosystem impacts
Not applicable	6. Sand resources
Not applicable	7. Coordination and communication

B.7 Overall Project Summaries

As part of our restoration activity analysis, we developed a detailed database of restoration project summaries that includes project IDs, titles, descriptions, states, project leads, total project costs, dates of initiation and completion, and key restoration activities undertaken. When a project implemented multiple resilience activities (e.g., both marsh and living shoreline restoration), we also estimated the proportion of funding that was allocated to each activity within that project.

Each project has a unique project ID that is a combination of an original ID provided by the funding organization; we appended that ID with the funding organization (e.g., NFWF, USFWS) to enable tracking across projects after they were pooled. We pulled project titles and states from project documentation (proposals, interim and final reports). NFWF provided project descriptions for projects administered through their organization, and we provided two-line descriptions for the DOI-funded projects based on project documentation, including websites.

The project database includes award amounts, matching funds, and total costs. Award amounts and matching funds were primarily extracted from proposals and confirmed, if possible, by websites or final reports. Total project costs represent a combination of the amount requested and any existing, available matching funds. Some Bureau of Ocean Energy Management project costs involve discrepancies where the award and the first year funding does not match the amount requested. In these cases, we used award amounts to calculate total project costs and requested that DOI confirm the project costs. Matching funds for USFWS projects include leveraged partner funding and may include monetized values for in-kind contributions. For other agencies, costs should match the source figures exactly.

We verified project dates using either the final or interim report, if available. For projects administered by NFWF, we used the project start and end dates provided by NFWF. Status of projects funded by DOI were considered complete if a final report existed or the project completion date was provided by a website; if a final report was absent and there was no other information suggesting project completion, that project's status was assumed to be active. We confirmed with Rick Bennett (USFWS) on 7/1/2019 that all Bureau of Ocean Energy Management and Bureau of Land Management projects were completed and also confirmed with Sara Stevens (National Park Service) on 7/9/2019 that several National Park Service projects were completed. For a subset of Coastal resilience science projects, we assumed they were complete when the project had a confirmed end date prior to the completion of the evaluation.

For combination projects that included more than one resilience activity, we allocated funding to each activity based on costs outlined in the proposal. Due to uncertainties in attributing these costs, we allocated funding to individual restoration activities at the 10% level, except for the living shoreline projects (see below). We applied the proportional allocation of funds to different activities to both the award amount and matching funds. For living shoreline projects, Abt conducted a separate cost-effectiveness study, where we obtained detailed costs for specific activities directly from principal investigators. Costs for living shoreline activities were taken directly from this study, with costs for non-living shoreline activities in these projects allocated using the method described above.

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Abt Associates. 2019b. Case Study: Cost-Effectiveness of Reducing Coastal Erosion through Living Shorelines in the Hurricane Sandy Coastal Resiliency Program. Abt Associates, Rockville, MD.

Abt Associates. 2019c. Case Study: Restoration of Aquatic Connectivity in the Hurricane Sandy Coastal Resilience Program. Abt Associates, Rockville, MD.

Abt Associates. 2019d. Case Study: Restoring Beaches and Dunes through the Hurricane Sandy Coastal Resilience Program. Abt Associates, Rockville, MD.

Abt Associates. 2019e. Case Study: Community Resilience Planning in the Hurricane Sandy Coastal Resiliency Program. Abt Associates, Rockville, MD.

Abt Associates. 2019f. Case Study: Improving Resilience through Coastal resilience science in the Hurricane Sandy Coastal Resilience Program. Abt Associates, Rockville, MD.

Abt Associates. 2019g. Evaluation of Hurricane Sandy Coastal Resilience Program. Abt Associates, Rockville, MD.

Buxton, H.T., M.E. Andersen, M.J. Focazio, J.W. Haines, R.A. Hainly, D.J. Hippe, and L.J. Sugarbaker. 2013. Meeting the Science Needs of the Nation in the Wake of Hurricane Sandy – A U.S. Geological Survey Science Plan for Support of Restoration and Recovery. U.S. Geological Survey Circular 1390. Available: https://pubs.usgs.gov/circ/1390/. Accessed 6/19/2019.

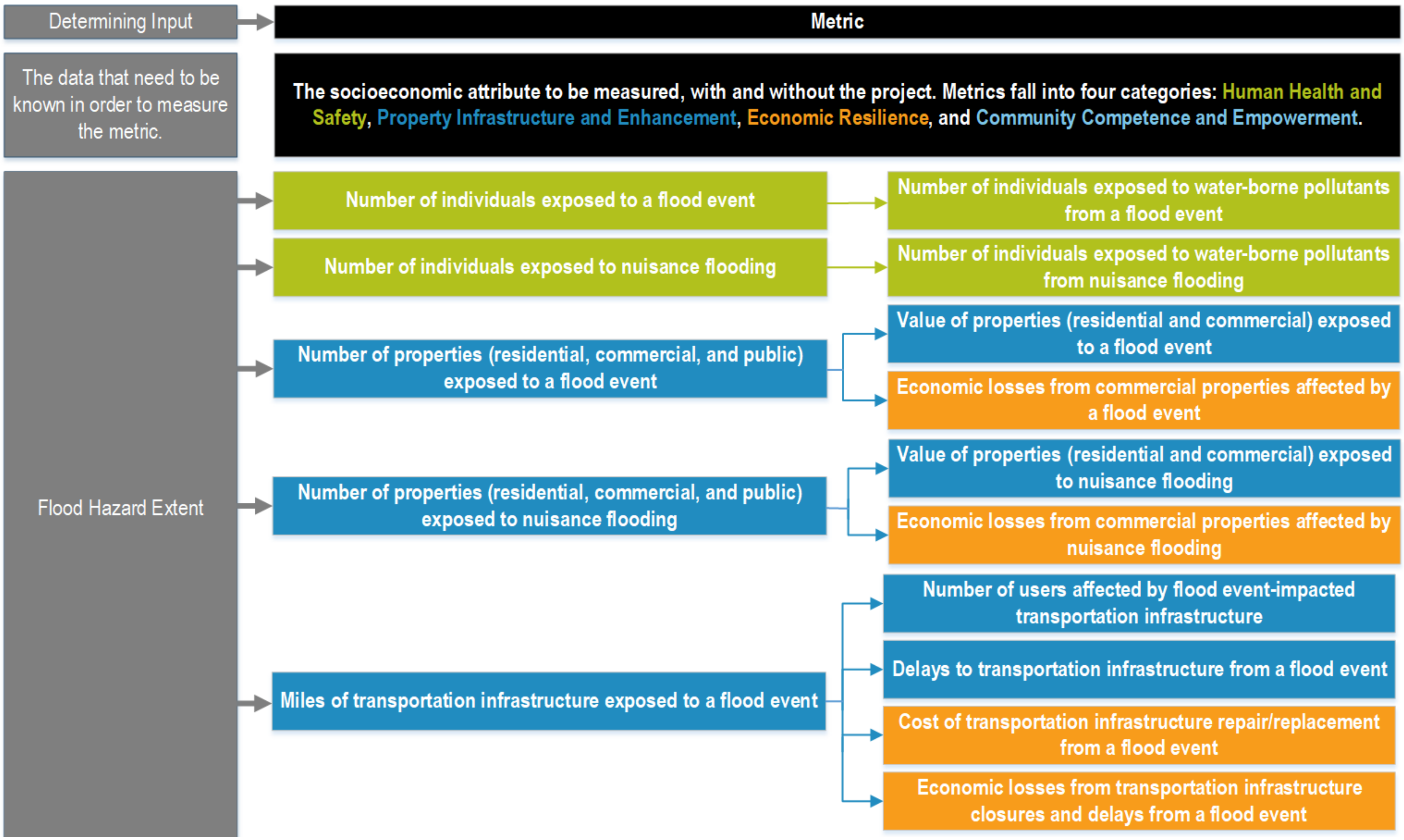
Appendix C. Long-Term Socioeconomic Monitoring Metrics Logic Chain

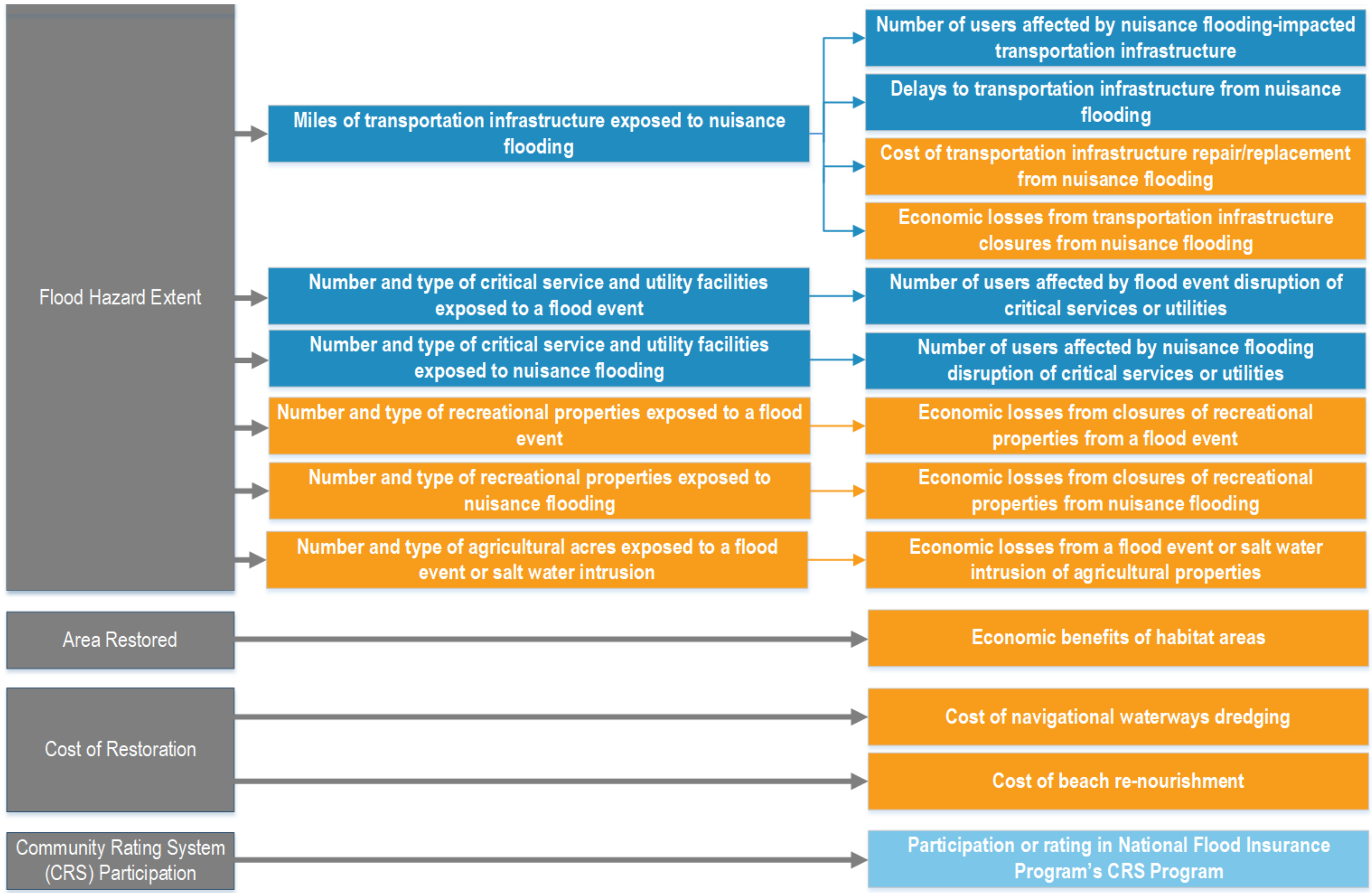
Following the creation of standardized performance metrics in the DOI (2015) report and subsequent discussions to refine metrics with the NFWF, Abt developed a list of 32 metrics for long-term socioeconomic monitoring. In developing the socioeconomic monitoring approach, Abt determined certain data that would be required to assess the metrics, termed "determining inputs." Furthermore, Abt identified that some metrics would need to be assessed first, in order to begin assessing other metrics. To visually display this workflow, Abt created a socioeconomic monitoring logic chain. This figure that follows shows the determining inputs that feed metrics into measuring the socioeconomic impacts of 37 on-the-ground restoration projects over time.[9]

Reference

DOI. 2015. Recommendations for Assessing the Effects of the DOI Hurricane Sandy Mitigation and Resilience Program on Ecological System and Infrastructure Resilience in the Northeast Coastal Region. U.S. Department of the Interior. Available: https://www.doi.gov/sites/doi.gov/files/migrated/news/upload/Hurricane-Sandy-project-metrics-report.pdf. Accessed 7/12/2019.

[9] Long-term monitoring includes 38 projects. One of these 38 projects did not have an on-the-ground component; therefore, this project is not included in the socioeconomic monitoring.


Determining Input
Metric
The data that need to be known in order to measure the metric.
The socioeconomic attribute to be measured, with and without the project. Metrics fall into four categories: Human Health and Safety, Property Infrastructure and Enhancement, Economic Resilience, and Community Competence and Empowerment.
Flood Hazard Extent
Number of individuals exposed to a flood event
Number of individuals exposed to water-borne pollutants from a flood event
Number of individuals exposed to nuisance flooding
Number of individuals exposed to water-borne pollutants from nuisance flooding
Number of properties (residential, commercial, and public) exposed to a flood event
Value of properties (residential and commercial) exposed to a flood event
Economic losses from commercial properties affected by a flood event
Number of properties (residential, commercial, and public) exposed to nuisance flooding
Value of properties (residential and commercial) exposed to nuisance flooding
Economic losses from commercial properties affected by nuisance flooding
Miles of transportation infrastructure exposed to a flood event
Number of users affected by flood event-impacted transportation infrastructure
Delays to transportation infrastructure from a flood event
Cost of transportation infrastructure repair/replacement from a flood event
Economic losses from transportation infrastructure closures and delays from a flood event


Flood Hazard Extent
Miles of transportation infrastructure exposed to nuisance flooding
Number of users affected by nuisance flooding-impacted transportation infrastructure
Delays to transportation infrastructure from nuisance flooding
Cost of transportation infrastructure repair/replacement from nuisance flooding
Economic losses from transportation infrastructure closures from nuisance flooding
Number and type of critical service and utility facilities exposed to a flood event
Number of users affected by flood event disruption of critical services or utilities
Number and type of critical service and utility facilities exposed to nuisance flooding
Number of users affected by nuisance flooding disruption of critical services or utilities
Number and type of recreational properties exposed to a flood event
Economic losses from closures of recreational properties from a flood event
Number and type of recreational properties exposed to nuisance flooding
Economic losses from closures of recreational properties from nuisance flooding
Number and type of agricultural acres exposed to a flood event or salt water intrusion
Economic losses from a flood event or salt water intrusion of agricultural properties
Area Restored
Economic benefits of habitat areas
Cost of Restoration
Cost of navigational waterways dredging
Cost of beach re-nourishment
Community Rating System (CRS) Participation
Participation or rating in National Flood Insurance Program's CRS Program

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Case Study: Restoring Beaches and Dunes through the Hurricane Sandy Coastal Resilience Program

Contract # 5359

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FINAL

2019

Case Study: Restoring Beaches and Dunes through the Hurricane Sandy Coastal Resilience Program

Prepared by Abt Associates, September 2019

Summary

Purpose

This case study forms part of a larger 2019 evaluation of the Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program) of the U.S. Department of the Interior (DOI) and the National Fish and Wildlife Foundation (NFWF). It provides an analysis of the ecological and community benefits of beach and dune restoration projects.

Scope

We examined 10 projects, encompassing 42 project sites, in the Hurricane Sandy Program portfolio that restored beach or dune habitat to improve wildlife habitat or protect and sustain coastal community resources or activities.

Findings

Key findings identified using archival materials, a survey and interviews of project leads, and peer-reviewed literature include:

- Nearly 11 linear miles and more than 140 acres of beach and dune habitats have been restored through the Hurricane Sandy Program, providing critical habitat for beach-dependent wildlife, including two federally threatened birds [red knot (*Calidris canutus rufa*) and piping plover (*Charadrius melodus*)], and protecting important community resources from coastal storm surge-related flooding and erosion.
- Nine of the 10 projects successfully completed their proposed activities by the time of this evaluation.
- Most projects were delayed relative to their proposed timelines, primarily due to seasonal limitations on restoration work, permitting delays, and the need for additional data collection or design work.
- Completed projects have generally met or exceeded their design objectives (i.e., linear feet or area restored).
- All ecologically focused projects have already observed improved outcomes for critical species in restored areas.
- Community-focused projects that have restored beaches and dunes to protect nearby community resources are functioning as expected, and have withstood recent coastal storms.
- To sustain their protective and ecological benefits, beaches and dunes may need to be re-nourished in the future.
- Generally, projects are recovering as quickly as expected after restoration, but more monitoring is needed to understand long-term outcomes.

Conclusion

Hurricane Sandy Program investments in restoring beaches and dunes are generally on track to improve ecological and community resilience in nearby areas. Early project results show that beach and dune restoration have increased available nesting habitat for the federally threatened piping plover, which can help sustain or increase their populations over time. The federally threatened red knot also appears to be benefiting from restoration-related increases in a key food source used during migration (i.e., horseshoe crab eggs), which may in turn improve survival and reproduction of this species in breeding areas. Early observations also suggest that restored and stabilized beaches and dunes have been resilient to recent storms, and have provided enhanced protection to nearby community resources. However, these observations are preliminary, and additional years of recovery and monitoring data are needed to more fully understand the likely long-term ecological and community benefits of beach and dune restoration actions.

1. Introduction

This case study forms part of a larger 2019 evaluation of the DOI and NFWF Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program). Between 2013 and 2016, the Hurricane Sandy Program, administered through DOI and NFWF, invested over $302 million to support 160 projects designed to improve the resilience of ecosystems and communities to coastal storms and sea level rise.[1] The program supported a wide array of activities, including aquatic connectivity restoration, marsh restoration, beach and dune restoration, living shoreline creation, community resilience planning, and coastal resilience science to inform decision-making. Each of these activities has a distinct impact on ecosystem and community resilience.

DOI and NFWF drafted the following questions to serve as the focus of the evaluation:

1. To what extent did projects **implement activities** as intended? What factors facilitated or hindered project success?
2. What **key outcomes** were realized for habitat, fish and wildlife, and human communities?
3. Is there evidence that investments in green infrastructure are **cost-effective** compared to gray infrastructure?
4. Did investments in tools and knowledge related to resilience **improve decision-making**?
5. What **information is needed** to better understand the long-term impacts of investments in resilience?

The evaluation includes six case studies, each providing a deeper level of analysis on a subset of the projects.

1.1 Purpose

This case study provides an in-depth analysis of the ecological and community resilience benefits of beach and dune restoration projects that were designed to improve wildlife habitat and/or protect and sustain key community resources or activities. The case study focuses on evaluation questions #1, #2, and #5 (above).

1.2 Scope

The case study examined 10 projects, encompassing 42 project sites, in the Hurricane Sandy Program portfolio that restored beach or dune habitat (see Section 3 for a more detailed description of the portfolio of beach and dune restoration projects and Appendix A for a full list of relevant projects).

1.3 Organization

The remainder of this document is organized as follows:

- Section 2 provides an overview of the methods and information sources used for this case study
- Section 3 provides a detailed overview of the beach and dune restoration projects included in the Hurricane Sandy Program
- Section 4 discusses key case study findings, organized by evaluation question and topic
- Section 5 provides a brief conclusion.

[1] The evaluation covers these 160 projects. In some cases DOI and NFWF reinvested unspent funds in new, additional projects after the December 2016 cutoff date, which are not included in the evaluation.

2. Methods Overview

This case study integrates information from the following information sources:

- Archival materials from Hurricane Sandy Program project files (e.g., proposals, interim and final reports)
- A survey of project leads via a web-based instrument
- Interviews with five project leads (i.e., grant recipients) who led beach and dune restoration projects
- Interviews with NFWF and DOI staff
- Quantitative information provided by project leads in their reports (e.g., miles of habitat restored)
- Literature searches addressing specific contextual issues (e.g., typical lag time between beach restoration activities and key ecological outcomes).

A more detailed description of evaluation methods can be found in Abt Associates (2019).

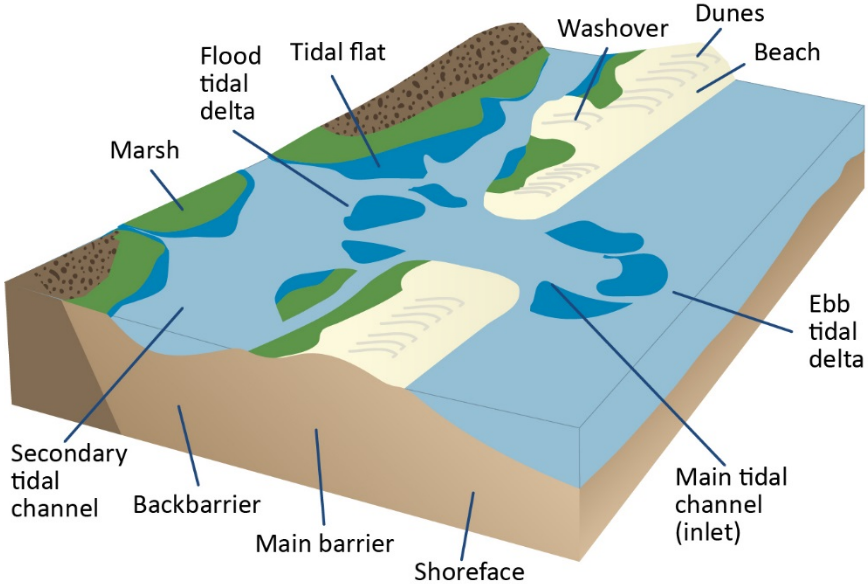
3. Overview of Projects

Beaches and coastal dune systems are critical elements of many coastal environments, and provide numerous benefits to wildlife and people, including:

- Supplying important habitat for aquatic and terrestrial fauna and flora
- Supporting many types of outdoor recreation
- Protecting coastal communities and resources from storm damage by absorbing damaging waves and mitigating storm surge.

Beaches and dunes, particularly those located on barrier islands, are not stable landforms, even in highly pristine natural areas. Rather, they migrate and change shape due to winds, waves, and currents; and changes in sea levels (NC Natural, 2011; Figure 1). For example, ocean currents and waves can stack sand along the shore and landward of the beach to form dunes, and tidal currents can also create deltas near tidal inlets (Wang and Roberts Briggs, 2015). Storms, however, can wash sand over beaches and dunes and into backbarrier areas, and also redistribute sand along the shore or to offshore areas (Wang and Roberts Briggs, 2015). However, when embedded in highly developed coastal areas, the ability of beaches and dunes to migrate can be constrained, and their tendency to do so can put key ecosystems or infrastructure at risk. Thus, increasing the resilience of beaches and dunes to coastal storms can benefit the habitats and coastal communities that depend on these beach and dune systems in their current configurations.

Figure 1. Beaches and dune systems are dynamic and evolving systems that change over time as winds, waves, and storms redistribute sand.



Source: Adapted from Wang and Roberts Briggs, 2015.

Intense coastal storms are a specific key threat to habitat and coastal communities. In fact, multiple beach and dune sites along the Atlantic Coast experienced severe damage from Hurricane Sandy, including erosion and flooding (Box 1). Hurricane Sandy also covered beaches in debris, which interfered with recreational access and horseshoe crab spawning, an important food resource for birds and wildlife. Restoring beaches and dunes can improve coastal resilience by supporting critical coastal habitats and sustaining barriers to storm surge and erosion.

Overall, the Hurricane Sandy Program invested more than $27.8 million in beach and dune restoration in 10 projects (Table A.2), 7 of which also included other resilience activities; the total funding for all of the activities in the 10 projects was $46.2 million.[2] The beach and dune projects were implemented in five states (Delaware, Massachusetts, New Jersey, New York, and Rhode Island; see Figure 2 and Table A.2). These projects typically implemented one or two major types of activities: (1) beach or dune nourishment (i.e., placing sand acquired through dredging on an eroding beach or dune), or (2) hard structure installment (e.g., groins or jetties). Hard structures are built perpendicular to a shoreline and reduce erosion by trapping sand suspended in currents, which promotes beach widening (NOAA, 2000). These two major activities were sometimes paired with others, including planting vegetation or installing fencing, which can improve surface stability, enhance sand accretion, and thus slow beach erosion.

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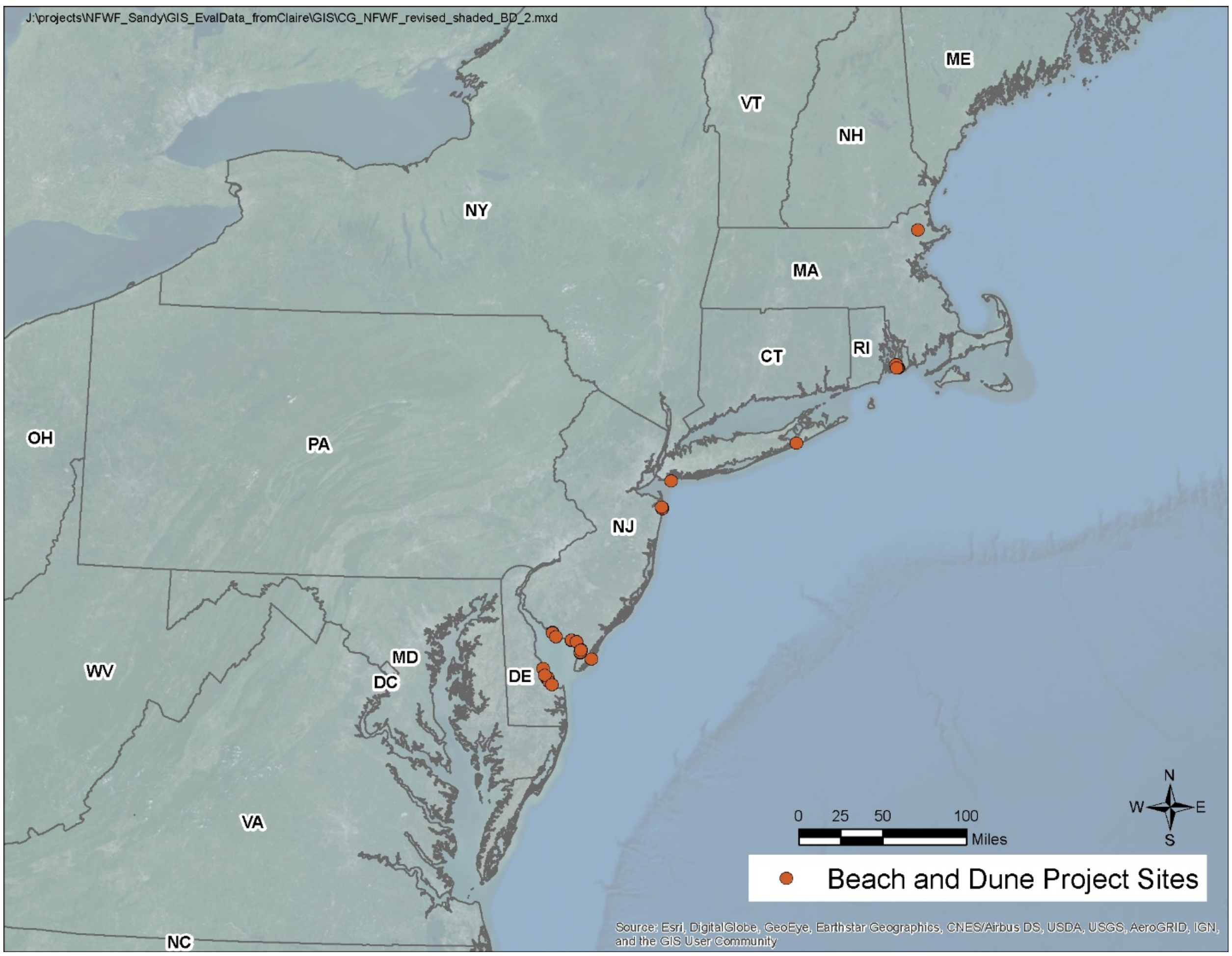
[2] Table A.2 presents the amount of project funding specifically allocated to beach and dune restoration activities. For three projects, this is the full project funding amount; and for seven projects, this is a subset of the total project funding. The allocation was based on available project documentation.

Box 1. Example of Hurricane Sandy damage to beach habitat.

The Borough of Monmouth Beach, NJ, suffered extensive damage from Hurricane Sandy, in part due to prior degradation and loss of nearby beach, dune, and marsh habitats that could have helped protect the borough from storm surge. During Hurricane Sandy, streets were flooded with up to six linear feet of water and approximately 33% of homes were damaged or destroyed. Over $6 million of damage was inflicted on the borough's infrastructure, including sewer and stormwater systems, buildings, and waterfront structures. The Monmouth Beach Elementary School incurred over $2.5 million of damages, and over 300 students were displaced to neighboring schools for almost the entire year.

Source: T&M Associates, 2019.

Figure 2. Location of beach and dune restoration activities.[a]



a. Since some projects conducted restoration activities in multiple sites (see Appendix A), the number of beach and dune projects sites (dots) in the figure exceeds 10.

The 10 projects implemented varied in size, location, cost, purpose, and restoration activities undertaken (Tables A.1 and A.2). However, all of the projects adopted one of two primary goals: habitat restoration or community protection (Box 2; Table A.1).

Box 2. Key beach and dune restoration goals.

Habitat restoration: Projects that restore and create beach or dune habitat, specifically to support horseshoe crabs and migratory shorebirds.

Community protection: Projects that restore beaches or dunes to prevent erosion, enhance shoreline resilience, and mitigate flooding.

Sources: Breese, 2018; project final reports.

4. Findings

Topic: Project Implementation (PI)

Finding PI.1: Nine of the 10 projects successfully completed their proposed activities.

Nine of the 10 projects included in this case study were completed[3] at the time of the evaluation, with one project still in progress. Of the nine that were completed, one was completed in 2014, one in 2016, one in 2017, five in 2018, and one in 2019.

Finding PI.2: Most projects were delayed relative to proposed timelines, primarily due to seasonal limitations on restoration work, permitting delays, and the need for additional data collection or design work.

Nearly every project in the beach and dune restoration portfolio experienced significant delays compared to proposed completion estimates. The data available through official contract amendments submitted to NFWF and DOI show that 8 of the 10 projects requested extensions for completing their work, with many projects requesting multiple contract extensions. These projects were delayed by an average of nearly two years (651 days). The most commonly cited cause of delays noted by project leads were seasonal limitations on restoration work, permitting delays, and the need for additional data collection or design work (Box 3).

[3] While our evaluation generally provides findings elicited through the review of archival materials received through December 2018, project status information reflects information gathered through April 2019 (updated project status information was obtained through a supplementary web search in March 2019 and an updated spreadsheet provided by NFWF).

Finding PI.3: Completed projects have generally met their design objectives.

Archival materials suggest that the nine completed beach and dune restoration projects typically met or exceeded their design goals, but some projects did not meet their proposed linear miles or area restored. More specifically, of the nine completed projects, five met or exceeded the linear miles restored that were proposed and one project fell short by a only a modest amount (0.17 linear miles). Two of the nine completed projects fell significantly short of what was proposed; more specifically, one achieved just 1.69 of the 3 proposed linear miles restored, and the other achieved 2.74 of the 5.73 proposed linear miles. For the latter project, at least part of the shortfall was due to challenges with permits – only 3.75 miles of the proposed 5.73 were approved for restoration through the permitting process. Five of the completed projects also proposed to restore a specific area of habitat; four achieved their restoration goals and one fell short by 4 acres (of the 30 acres proposed).

Like other on-the-ground projects, however, project reports and interviews with project leads suggest that beach and dune projects may need at least some adaptive management or maintenance after initial restoration efforts are complete. For example, one project noted that coastal storms occurring soon after restoration actions were completed damaged recently planted vegetation; these areas will likely need to be replanted. Another project's location was hit by a winter storm and the restored areas experienced serious damage from overwash and losses in elevation. More specifically, the project site lost approximately 42,000 cubic yards of sand, which moved to a near-shore bar.

Box 3. Factors that contributed to the delay of beach and dune restoration projects.

Seasonal limitations

In contract amendments and the survey, six project leads noted that the weather- and seasonal-dependent nature of beach and dune restoration activities contributed to delays. Weather events and growing seasons can limit the time available to perform restoration (e.g., vegetation planting), and work was sometimes delayed for months waiting for appropriate working conditions to return. In addition, permit conditions can restrict some construction activities, including dredging and beach and dune nourishment, to specific times of the year to avoid harming wildlife (e.g., during migration or breeding seasons).

Permitting delays

Five project leads described challenges with the permitting process as being a source of delays. For example, one project noted that before dredge materials could be approved for use in a restoration project, testing for contaminants on that material had to be analyzed and reviewed before the permitting process could move forward.

Additional data collection or design work

Three project leads noted that they needed to gather additional data or adjust their project designs given onsite conditions, which caused unexpected project delays. For example, one project noted that because sand resources were obtained for less than originally budgeted, beach restoration activities were expanded. This required additional time to design and implement those additional activities.

Source: Images and delay information from project reports and archival materials.

Topic: Project Outcomes (PO)

4.1 Human Community Outcomes

Finding PO.1: Four linear miles and 75 acres of community-focused beach and dune habitats have been restored to protect nearby community resources, and are functioning as expected.

Project lead-reported data show that the community-focused projects have restored 4 linear miles and 75 acres of beach and dune habitats.[4] These restored beaches and dunes can help protect inland resources, such as housing, roads, and recreational areas, by absorbing waves and reducing storm surge and related flooding and erosion. Preliminary observations from four of the five community-focused projects suggest that these restored beaches and dunes are performing as expected. More specifically, the four projects found that the dunes restored were stable and resilient to recent coastal storms (Box 4). In addition, one project, classified as primarily ecologically focused, noted that the restored beach withstood recent storms and reduced flooding in nearby residential and agricultural areas.

Box 4. Shoreline stabilization: Early observations.

A project in Massachusetts had three nor'easters pass over its restored dunes. **The dunes remained intact** but grasses that were not yet well-established were damaged.

Plantings and fencing installed at Great Marsh, MA (project final report).

Project leads in Rhode Island noted that **restored dune elevations held** against nor'easters and high tides, with no overtopping or washing out.

Middletown Beach Commission members at Sachuest Beach, RI (Dave Hansen, NewportRI.com).

[4] These data include projects that have not yet been completed, and thus the final number of miles and acres restored may change; for active projects, we assumed that projects will achieve the proposed miles and acres restored. Restored areas reported here are also distinct from those reported under Finding PO.2.

Box 4. Shoreline stabilization: Early observations.

A New Jersey project created a resiliency dune to protect a nearby coastal community. Following two major storms, the project reported that **the resiliency dune held**.

Project area and nearby community at Seven Mile Island, NJ (project final report).

A New Jersey project that constructed and enhanced coastal dunes noted that while nearby beaches were eroded during recent nor'easters, there was **no damage to restored dune areas**.

Dune restoration at Monmouth Beach, NJ (Stacy Small-Lorenz, National Wildlife Federation).

4.2 Habitat, Fish, and Wildlife Outcomes

Finding PO.2: Approximately 7 linear miles and 68 acres of beach and dune habitats have been restored by ecologically focused restoration projects, providing critical habitat for beach-dependent birds, including the federally threatened red knot and piping plover, as well as other beach-dependent wildlife.

Project lead-reported data show that ecologically focused beach and dune restoration projects have restored approximately 7 linear miles and 68 acres of beach and dune habitats.[5] Archival material and a literature review suggest that these restored areas can provide important habitat for critically important coastal species (Box 5).

For example, habitat loss is known to be a key factor contributing to the declines of the red knot and piping plover (USFWS, 2015), and restoring even small amounts of habitat can improve their survival. More specifically, beaches that provide high-quality habitat to support breeding horseshoe crabs can provide critical support to the red knot during their migration in the spring, when they rely on horseshoe crab eggs during stopovers on the Atlantic Coast (USFWS, 2015). In addition, the piping plover feeds and breeds on beaches, and suitable beach habitat has been in decline due to a combination of human development, human disturbance, predators, and storm-related disturbance and erosion (USFWS, 2007).

[5] These data include projects that have not yet been completed, and thus the final number of miles and acres restored may change; for active projects, we assumed that projects will achieve the miles and acres restored that were initially proposed. Restored areas reported here are also distinct from those reported under Finding PO.1.

Box 5. Examples of representative species noted by project leads as likely to benefit, or that are already benefiting, from beach and dune restoration projects.[a]

The red knot, a federally threatened species, use the Delaware Bay as an important stopover habitat on their migration between South America and the Arctic.

The piping plover, a federally threatened species with approximately 2,000 breeding pairs in the Atlantic region, depend on beach habitat for feeding and nesting; habitat loss is a key factor contributing to their decline.

The American oystercatcher (*Haematopus palliatus*) is a shorebird species that roost in beach, dune, and marsh areas.

After being hunted to near-extinction in the 19th century, the species is rebounding and serves as an indicator species for health of the coastal environment.

The horseshoe crab (*Limulus polyphemus*) species live in shallow waters and are known to nest on mid-Atlantic beaches, and their eggs are an important food source for migrating birds such as red knots.

a. See Finding PO.3 and Box 6 for observed improvements in wildlife utilization of restored beach/dune habitats.

Sources: USFWS, 2007, 2015, 2019a, 2019b; University or Michigan Museum of Zoology, 2019. Image credits: birds (Gregory Breese, USFWS; Kirk Rogers, USFWS; USFWS, 2019b); horseshoe crab (Wetlands Institute, 2013).

Finding PO.3: All ecologically focused projects have already observed improved outcomes for critical species in restored areas.

Project-lead reporting shows that all projects that were primarily focused on improving habitat for wildlife already observed positive outcomes by the time of the evaluation (Box 6). More specifically, projects observed increases in horseshoe crab breeding activity, bird utilization of beach habitat, bird breeding activity, and bird weight gains on restored beaches (Box 6). In fact, one project observed an increase in the nesting success of breeding piping plovers after beach restoration (Figure 3). Three of these projects also noted that restored areas were resilient to recent storms, showing very little erosion and suggesting that the benefits provided by these projects may be sustained over many years (see Finding PO.5 below).

In addition, while not the major focus of their restoration activities, two community-focused beach restoration projects also reported positive ecological outcomes. For example, one project noted that piping plovers and oystercatchers were nesting in restored beach areas, and nests in these elevated areas seemed less likely to be flooded than those established on lower, un-nourished areas. The project also noted that non-standardized counts of spring and fall migratory birds were higher after restoration. Another project simply noted that piping plovers were utilizing the newly restored area.

Box 6. Ecological benefits: Early observations of resilience improvements through improved habitat integrity and extent.

A New York project reported **increased horseshoe crab spawning and egg density, and greater increases in red knot weights during stopovers** on restored beaches compared to non-restored beaches.

The project team captures knots, turnstones, and sandpipers in the Delaware Bay (Stephanie Feigin, Conserve Wildlife NJ).

After beach restoration in Delaware, a project reported shorebirds **foraging and roosting in the new habitat**, along with horseshoe crab spawning.

Shorebirds at Mispillion Harbor, DE (Katie Peikes, Delaware Public Media).

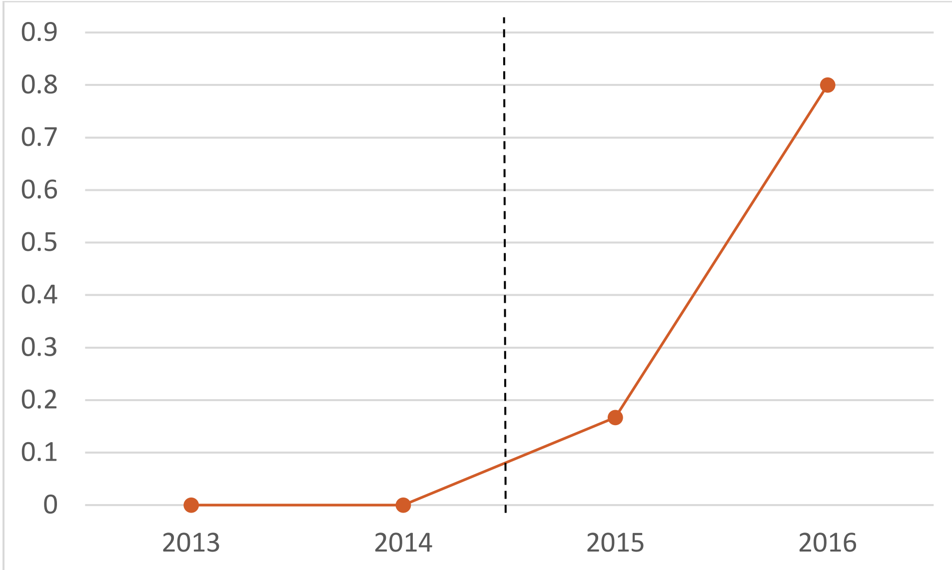
A New Jersey project restored three beaches and reported **improved horseshoe crab spawning and shorebird use**.

Horseshoe crabs spawning as restoration finishes at Reed's Beach, NJ (Shane Godshall, American Littoral Society).

A project in Delaware reported the **return and nesting of piping plovers, American oystercatchers, and least terns** on the restored beach. The project also noted an **increase in horseshoe crab abundance from pre-Hurricane Sandy numbers.**

Piping plover and horseshoe crabs on Fowler Beach at Prime Hook National Wildlife Refuge (Julie McCall, Delaware Online).

Figure 3. Number of piping plover chicks fledged per nesting pair on Stone Harbor Point before (2013 and 2014) and after (2015 and 2016) beach restoration.



4.3 Trajectories of Outcome Achievement

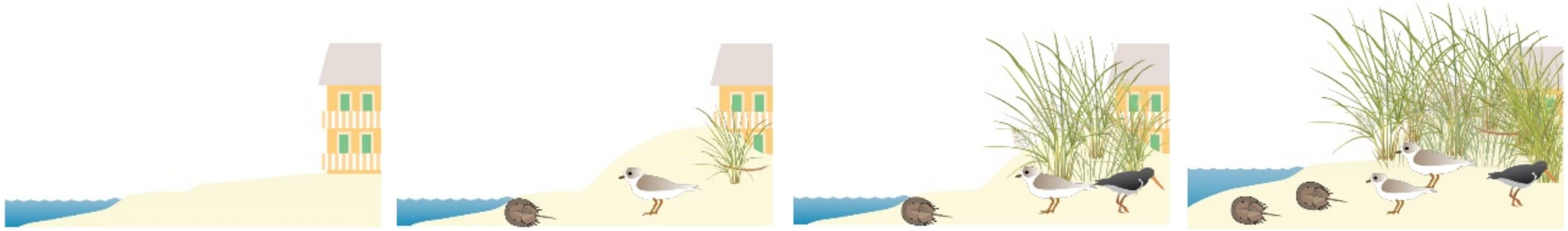
Finding PO.4: Generally projects are recovering as quickly as expected after restoration, but more monitoring is needed to understand long-term outcomes.

The benefits of most beach and dune restoration projects funded through the Hurricane Sandy Program will take time to materialize after restoration activities are completed. To better understand and convey the potential timing of the achievement of key outcomes, the Abt Associates (Abt) evaluation team developed conceptual timelines of recovery after restoration using information from key peer-reviewed articles in combination with professional judgment from our team's subject matter experts (Figure 4).

More specifically, while some components of beach and dune restoration may begin to recover immediately following restoration actions (e.g., stabilization, sand accretion), they may require more than 10 years to reach maximum function (Morton et al., 1994; Jones et al., 2008; Vestergaard, 2013; Walker et al., 2013; Figure 4).

Surface stabilization and storm protection, two of the primary reasons for implementing a beach and dune restoration project, begin immediately following restoration actions and improve over time, unless a severe storm damages the site. Initial beach or dune nourishment and vegetation planting provide needed stabilization and sand supply. Subsequently, the restored area tends to accrete more sand, and the dune gains more stability over time as the vegetation matures (Morton et al., 1994; Feagin et al., 2005, 2015; Acosta et al., 2013; Vestergaard, 2013; Walker et al., 2013; Sigren et al., 2014).

Figure 4. Site recovery following beach and dune restoration activities over time.



Realization timeframe[a]	Year 0 (pre-project)	Short-term (1–2 years) outcomes 2015–2022	Mid-term (3–7 years) outcomes 2017–2027	Long-term (10+ years) outcomes 2024+
Vegetation	Native vegetation is sparse or non-existent	Absent storm disturbance, initial plantings begin to establish and provide early stabilization to beaches and dunes	Absent storm disturbance, vegetation cover, species richness, and spatial structure begin to mature; further stabilization provided	Dune vegetation continues to establish and mature; absent storm disturbance, may approach natural conditions after 24+ years
Habitat/ wildlife use	Site supports few or no representative species	Absent storm disturbance, invertebrates and arthropods begin to recolonize and may support birds and other wildlife	Absent storm disturbance, wildlife such as horseshoe crabs, piping plover, oystercatchers, and prey species continue to recolonize	Absent storm disturbance, wildlife such as horseshoe crabs, piping plover, oystercatchers, and prey species continue to recolonize
Surface stability and storm protection	Provides little to no storm protection	Absent storm disturbance, vegetation and increased elevation provide improved stability and short-term storm protection	Absent storm disturbance, more mature vegetation and ongoing accretion/stabilization provide improved storm protection	Absent storm disturbance, more mature vegetation and ongoing accretion/stabilization provide improved storm protection

a. Assuming projects completed between 2014 and 2020.

Sources: **Vegetation**: Morton et al., 1994; Feagin et al., 2005; Acosta et al., 2013; Pickart, 2013; Vestergaard, 2013. **Habitat/wildlife use**: Rakocinski et al., 1996; Jones et al., 2008; professional judgment. **Surface stability and storm protection**: Morton et al., 1994; Feagin et al., 2005, 2015; Vestergaard, 2013; Walker et al., 2013; Sigren et al., 2014.

Early observations from Hurricane Sandy Program projects noted in Findings PO.1 and PO.3 above are generally consistent with what the literature and Abt team experts identified as likely short-term outcomes of beach and dune restoration (i.e., outcomes that would be observed one to two years after restoration; Figure 4). For example, there have been increases in horseshoe crab reproduction, bird habitat utilization, and bird nesting success in restored sites (Box 6; Figure 3). In addition, newly restored beaches and dunes have stabilized in multiple project areas, showing little damage in the face of significant coastal storms that occurred after restoration (Box 6). These improvements in wildlife and stabilization would generally be expected to improve over time unless an extreme coastal storm causes extensive damage or erosion; after such an event, new restoration actions may be required to sustain desired ecological and community benefits (see Finding PO.5).

Finding PO.5: To retain their protective and ecological values, beaches and dunes will likely need to be re-nourished in the future.

While the evidence described above suggests that completed restoration projects have successfully increased wildlife habitat, stabilized beach and dune coastal areas, and are providing improved protection to communities from coastal storms, the restored areas will likely need to be re-nourished and maintained to sustain those benefits. As noted in the overview of projects, beach and dune systems are naturally highly dynamic, being changed and eroded by waves, wind, and sea level rise. In fact, the literature suggests that restored beaches and dunes will typically need to be re-nourished every three to seven years (NOAA, 2000; Speybroeck et al., 2006). However, major storm events can quickly erode areas to pre-project profiles and require re-nourishment more quickly. For example, in Ocean City, New Jersey, a $2.5 million beach nourishment project lasted just 2.5 months before a major storm eroded the beach and necessitated emergency re-nourishment (NOAA, 2000). On the other hand, as noted in Box 4, some of the Hurricane Sandy Program projects have demonstrated resilience to storms that have occurred post-restoration. The need for re-nourishment will likely depend on the severity of the storm event and other environmental factors, such as sea level rise.

It is important to note that many beach and dune restoration projects are done with the explicit knowledge that future storms are likely to damage restored sites, and they may need active and ongoing maintenance, management, and re-nourishment. In fact, a given restoration project could be considered a success if it successfully protects inland ecosystems and infrastructure during a storm, even if the restored beaches and dunes are severely damaged during that storm and the project requires re-nourishment.

Topic: Information Gaps (IG)

Finding IG.1: Long-term monitoring is needed to understand the full benefits of beach and dune restoration projects, and this may be provided through additional new funding from NFWF and DOI.

Given the time lags between restoration actions and full ecological and community benefits (Figure 4), it will likely take many years to understand the full benefits of the beach and dune restoration actions undertaken through the Hurricane Sandy Program. Recognizing the need for more data to assess beach and dune restoration success, NFWF and DOI are supporting additional, long-term monitoring for all projects in this case study through 2024 (see Table A.2). Projects will be tracking beach and dune dimensions (e.g., height, width), vegetative cover, and avian habitat use (e.g., abundance, distribution, breeding productivity).

Socioeconomic monitoring will also assess how beach and dune restoration affect human well-being, primarily by evaluating reductions in hazardous flooding and the resulting impact on human health and safety, recreation, and infrastructure. These data will improve understanding of the quality and longevity of the habitat and protection provided by the beaches and dunes restored through the Hurricane Sandy Program.

5. Conclusion

Overall, these findings suggest that investments the Hurricane Sandy Program has made in restoring beaches and dunes are on track to improve both ecological and community resilience in nearby areas. Early project results typically show that beach and dune restoration has increased available nesting habitat for the federally threatened piping plover, which can help sustain or increase their populations over time. The federally threatened red knot also appear to be benefiting from restoration-related increases in horseshoe crab eggs, which are helping the red knot increase weight gains during spring migration stopovers; this may in turn improve survival and reproduction in breeding areas. Early observations also suggest that restored and stabilized beaches and dunes have been resilient to recent storms, and have provided enhanced protection to nearby communities. However, these observations are preliminary, and many more years of recovery and monitoring data are needed to more fully understand the likely long-term ecological and community benefits of beach and dune restoration actions. Of particular interest will be understanding how long the benefits of beach and dune restoration will last in the face of future coastal storms and sea level rise.

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Appendix A. Project Summaries

Table A.1. Primary goals of the beach and dune restoration projects, along with project-specific activities and goals.

Primary goal	State	Project ID	Location	Activities	Project-specific goals
Community protection	MA	NFWF-41766	Plum Island and Salisbury Beach	Dune nourishment, vegetation planting, mobi mat and snow fencing installation.	Stabilize vulnerable areas and protect homes, infrastructure, and other community resources.
	NJ	NFWF-43986	Monmouth Beach	Beach nourishment, dune construction/restoration, sand fencing installation, vegetation planting.	Protect the Borough of Monmouth Beach (~ 3,200 residents) from storm surge.
	NJ	NFWF-41991	Stone Harbor Point	Beach/dune nourishment, vegetation planting.	Protect the Borough of Stone Harbor Point (~ 800 residents) from storm surge.
	NY	NPS-1A	Riis Beach	Beach nourishment.	Protect recreational and cultural resources and reduce human-wildlife conflict.
	RI	NFWF-41795	Second Beach at Sachuest Bay	Beach/dune nourishment, geotextile reinforcement, mobi mat installation.	Protect Second Beach, a key recreational resource, from storm surge and sea level rise.[a]
Habitat restoration	DE	NFWF-43281	Beaches in Mispillion Harbor Reserve and Milford Neck Conservation Area	Beach/dune nourishment, vegetation planting, rock sill improvement.	Restore and stabilize habitat for spawning horseshoe crab and foraging shorebirds, and protect newly restored beaches from coastal storms.
	DE	USFWS-15	Prime Hook National Wildlife Refuge	Beach nourishment, vegetation planting.	Restore and stabilize habitat for spawning horseshoe crab and foraging shorebirds, and protect newly restored marsh from coastal storms.
	NJ	USFWS-06	Pierce’s Point, Reed’s and Moore’s Beach	Debris removal, dune/berm construction, beach nourishment.	Restore and stabilize habitat for spawning horseshoe crab and foraging shorebirds.
	NJ	NFWF-43429	Beaches in Cape May and Cumberland counties	Beach nourishment.	Restore and stabilize habitat for spawning horseshoe crab and foraging shorebirds.
	NY	NFWF-44225	Shinnecock Reservation	Beach nourishment, vegetation planting, rock installation.	Restore shoreline to protect nearby wildlife habitat and tribal resources from storm surge and sea level rise.[b]

a. We categorized the NFWF-41991 project as a community resilience project; however, it is also providing notable ecosystem benefits, including habitat for nesting and migratory shorebirds.
b. We categorized the NFWF-44225 project as an ecological resilience project; however, it is also providing notable community benefits, including protecting recreational and cultural resources and upland tribal housing.

Table A.2. Beach and dune restoration projects supported through the Hurricane Sandy Program.[a] This table presents the amount of project funding specifically allocated to beach and dune restoration activities. For three projects, this is the full project funding amount; and for seven projects, this is a subset of the total project funding. The allocation was based on available project documentation. All dollars rounded to the nearest hundred.

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds	Area restored (length restored in feet, area in acres)[c]
				Values represent beach and dune activities only[b]		
NFWF-41766	Coastal resiliency planning and ecosystem enhancement for northeastern Massachusetts	MA	National Wildlife Federation	$882,000	$479,200	5,280 feet, 20 acres
NFWF-41795	Strengthening Sachuest Bay's coastal resiliency, Rhode Island	RI	Town of Middletown	$1,602,800	$451,000	5,280 feet, 23 acres
NFWF-41991	Increasing Seven Mile Island's beach resiliency, New Jersey	NJ	New Jersey Audubon Society	$1,280,000	$53,400	Not reported, 26 acres
NFWF-43281	Restoring Delaware Bay's wetlands and beaches in Mispillion Harbor Reserve and Milford Neck Conservation Area	DE	Delaware Department of Natural Resources	$4,050,000	$1,367,300	3,485 feet, 7.5 acres
NFWF-43429	Creating a resilient Delaware Bay Shoreline in Cape May and Cumberland counties, New Jersey	NJ	American Littoral Society	$4,275,000	$229,000	14,467 feet, 56.5 acres
NFWF-43986	Strengthening Monmouth Beach's marshes and dunes, New Jersey	NJ	Monmouth Beach, New Jersey	$1,246,000	$1,225,000	5,280 feet, 6 acres
NFWF-44225	Improving Shinnecock Reservation's shoreline habitats, New York	NY	Shinnecock Indian Nation	$1,399,700	$117,200	3,010 feet, 3.73 acres
NPS-1A	Mitigate impacts from artificial groin to Jacob Riis Beach to restore habitats and recreation resources	NY	U.S. Army Corps of Engineers Civil Works; National Park Service	$3,453,200	$0	5,280 feet, not reported
USFWS-6	Increase resilience of beach habitat at Pierce's Point, Reed's Beach, and Moore's Beach, New Jersey	NJ	U.S. Fish and Wildlife Service	$1,650,000	$0	5,914 feet, not reported
USFWS-15	Prime Hook National Wildlife Refuge coastal tidal marsh/barrier beach restoration	DE	U.S. Fish and Wildlife Service	$7,922,000	$544,000	8,923 feet, not reported

a. All projects have secured additional, long-term monitoring funding through NFWF and DOI.

b. Costs in the table do not represent the full cost of the project and may not reflect total match.

c. These data include projects that have not yet been completed, and thus the final number of acres restored may change; for active projects, we assumed that projects will achieve the proposed acres restored.

BOLD THINKERS DRIVING REAL-WORLD IMPACT

Case Study: Advancing Coastal Resilience Science through Data, Mapping, and Modeling in the Hurricane Sandy Coastal Resilience Program

Contract # 5359

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FINAL

2019

Case Study: Advancing Coastal Resilience Science through Data, Mapping, and Modeling in the Hurricane Sandy Coastal Resilience Program

Prepared by Abt Associates, September 2019

Summary

Purpose

This case study forms part of a larger 2019 evaluation of the Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program) of the U.S. Department of the Interior (DOI) and the National Fish and Wildlife Foundation (NFWF). It provides an analysis of the contributions of coastal resilience science projects to the program's overall objectives.

Scope

We examined 86 coastal resilience science projects in the Hurricane Sandy Program portfolio that produced scientific knowledge to identify key risks and vulnerabilities to coastal storms, and to inform resilience-related decision-making in the region. The scientific activities included in this case study -- including data, mapping, and modeling projects -- were not conducted to support the implementation of a specific on-the-ground restoration project. Instead, their results were intended to help guide future storm response, restoration, and resilience actions.

Findings

Key findings identified using archival materials, a survey and interviews of project leads, and websites and media reports include:

- Coastal resilience science projects resulted in the creation of more than 700 deliverables, including presentations, reports, manuscripts, datasets, maps, and models.
- Nearly all of the projects have successfully completed their proposed activities.
- The information provided by these projects has filled key knowledge gaps and, in some cases, directly improved resilience-related decision-making.
- The ultimate impact of some coastal resilience science activities could be enhanced by providing more direct outreach to relevant decision-makers.
- More time is needed to observe the uptake of the coastal resilience science products into decision-making processes; depending on the decision, additional time may then be needed to observe the impact on coastal resilience.

Conclusion

Hurricane Sandy Program investments in coastal resilience science projects have filled key knowledge gaps and helped to directly improve resilience-related decision-making. These projects have led to notable successes including, for example, an online coastal hazards portal that has already been used to track and predict coastal impacts of multiple hurricanes, tropical storms, and severe winter storms. Overall, these projects were highly productive and generated more than 700 deliverables, including presentations, reports, manuscripts, datasets, maps, and models. However, more time is needed for decision-makers to incorporate the scientific products and information generated through the program into additional decisions beyond the individual examples described in this case study. An issue that may constrain the impact of some of these projects is the limited outreach to decision-makers to raise awareness, and to ensure the suitability and usability of the data and tools being developed.

1. Introduction

This case study forms part of a larger 2019 evaluation of the DOI and NFWF Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program). Between 2013 and 2016, the Hurricane Sandy Program, administered through DOI and NFWF, invested over $302 million to support 160 projects designed to improve the resilience of ecosystems and communities to coastal storms and sea level rise.[1] The program supported a wide array of activities, including aquatic connectivity restoration, marsh restoration, beach and dune restoration, living shoreline creation, community resilience planning, and coastal resilience science to inform decision-making. Each of these activities has a distinct impact on ecosystem and community resilience.

DOI and NFWF drafted the following questions to serve as the focus of the evaluation:

1. To what extent did projects **implement activities** as intended? What factors facilitated or hindered project success?
2. What **key outcomes** were realized for habitat, fish and wildlife, and human communities?
3. Is there evidence that investments in green infrastructure are **cost-effective** compared to gray infrastructure?
4. Did investments in tools and knowledge related to resilience **improve decision-making**?
5. What **information is needed** to better understand the long-term impacts of investments in resilience?

The evaluation includes six case studies, each providing a deeper level of analysis on a subset of the projects.

1.1 Purpose

This case study provides an in-depth analysis of projects focused on resilience-related science activities, including those that collected data or developed maps or models to support resilience-focused decision-making. Hereafter, the projects in this case study are collectively referred to as either "coastal resilience science" projects or "data, mapping, and modeling" projects. This case study focused on evaluation questions #1, #4, and #5 (above). It identifies key findings regarding science project implementation and examines the available evidence about the impact of these projects on resilience-related decision-making to date.

1.2 Scope

We examined 86 coastal resilience science projects in the Hurricane Sandy Program portfolio. Projects in this category produced scientific knowledge that can be used to identify key risks and vulnerabilities to coastal storms, and to inform resilience-related decision-making in the region. To be included in this category, a project must have generated new scientific knowledge (e.g., collected new field data, analyzed or reprocessed existing data, developed new models/simulations) with the intention of informing resilience decisions. Projects that collected data, produced maps, or built models to support the implementation of specific on-the-ground restoration projects were included in other case studies that focused on the relevant restoration action (e.g., enhancing aquatic connectivity, beach and dune restoration). See Section 3 for a

[1] The evaluation covers these 160 projects. In some cases DOI and NFWF reinvested unspent funds in new, additional projects after the December 2016 cutoff date. These new projects are not included in the evaluation.

more detailed description of the portfolio of coastal resilience science projects; and Appendix A for a full list of the 86 projects.

1.3 Organization

The remainder of this document is organized as follows:

- Section 2 provides an overview of the methods and information sources used for this case study
- Section 3 provides a detailed overview of the coastal resilience science projects included in the Hurricane Sandy Program
- Section 4 discusses key case study findings, organized by evaluation question and topic
- Section 5 provides a brief conclusion.

2. Methods Overview

This case study integrates information from the following information sources:

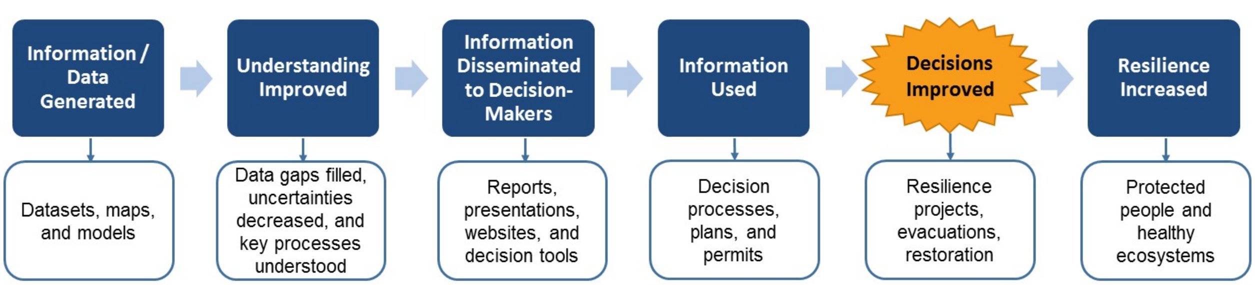
- Archival materials from Hurricane Sandy Program project files (e.g., proposals, interim and final reports)
- A survey of project leads via a web-based instrument
- A review of websites and media reports covering project execution and outcomes
- Interviews with NFWF and DOI staff, and individual project leads.

A more detailed description of evaluation methods can be found in Abt Associates (2019).

3. Overview of Projects

Improving scientific knowledge through making investments in coastal resilience science can fill key data gaps, decrease uncertainties, and increase understanding of key biophysical and ecological processes related to resilience. When this information is insufficient, sound decision-making related to resilience can be constrained. For example, it can be difficult to know how to prioritize coastal restoration projects over the long-term without understanding which areas are most vulnerable to coastal erosion during storms. When a storm is predicted, insufficient information about where the impact of that storm is likely to be focused can hamper efforts to effectively allocate emergency response resources. If relevant scientific activities are properly designed, implemented, and shared with relevant decision-makers, they can improve resilience-related decision-making and, ultimately, increase resilience (see Figure 1).

Figure 1. Logic model showing how coastal resilience science projects can support improved decision-making, with relevant examples from each step in the logic chain.



The Hurricane Sandy portfolio supported 86 projects that conducted data, mapping, and modeling in whole or in part to improve coastal resilience. Overall, the Hurricane Sandy Program invested more than $82.5 million in coastal resilience science in 86 projects (Table A.1), 3 of which also included other resilience activities; the total funding provided by the program for all of the activities in the 86 projects was $87.8 million.[2] The projects were distributed among a subset of bureaus within DOI, as follows (with the amount of funding provided specifically to coastal resilience science activities in parentheses):

- Bureau of Ocean Energy Management (BOEM) (17 projects, $9.7 million)
- National Park Service (NPS) (29 projects, $10.7 million)
- U.S. Geological Survey (USGS) (24 projects, $42.9 million)
- U.S. Fish and Wildlife Service (USFWS) (7 projects, $14.1 million)
- NFWF (9 projects, $5.1 million).

These projects addressed a broad range of science topics with the potential to inform resilience decision-making. To better understand and convey the scope covered by the projects, we further categorized them into seven topic areas, adapted from topic areas the USGS used to organize its projects (Buxton et al., 2013; see Table 1).[3]

In Table 2, we summarize the number of projects in the seven topic areas described below, as well as the total funding allocated to those projects; we also show the number of projects funded in each topic area by each DOI Bureau and NFWF. Archival materials show that the types of research conducted within each of the bureaus were consistent with its overall mission and key activities. For example, BOEM regulates the use of off-shore sand resources, and its projects were focused on improving understanding of the nature and location of those resources and how well they match beaches or dunes in need of nourishment. As another example, a key activity of USGS is to provide information about the impacts of coastal storms; a few of its projects have focused on expanding and improving the organization's ability to provide real-time information about potential storm surge in the Northeast.

[2] Table A.1 presents the amount of project funding specifically allocated to coastal resilience science activities. For 83 projects, this was the full project funding amount. For three projects, this is a subset of the total project funding. The allocation was based on available project documentation.

[3] USGS organized its 24 coastal resilience science projects into 5 topic areas based on impact types and information needs. We categorized the non-USGS projects into these topic areas (which we modified slightly for simplicity) based on the topics addressed and the products produced. For projects with multiple components that addressed different topic areas, we applied our best judgment to determine the primary project focus and categorized the project into that topic area. We also added topic areas six and seven to categorize a few projects that did not fit into the five original USGS topic areas.

Table 1. Project topic areas covered by coastal resilience science projects.

Topic area	Examples of relevant project activities
1. Elevation Data	• Collected high-resolution elevation data. • Produced maps and hydrologic models based on these data.
2. Coastal Change	• Collected and examined pre- and post-storm shoreline data. • Produced maps, models, and forecasts of coastal change. • Created visualization tools showing historical and potential future coastal changes. • Developed reports assessing trends and vulnerabilities.
3. Storm Surge and Hydrology	• Developed real-time monitoring networks and tools for describing meteorological conditions. • Gathered and analyzed data regarding water levels and inundation rates. • Produced maps, impact models, and inventories of vulnerable resources and infrastructure. • Improved storm-vulnerability predictions and evaluated best practices for addressing those vulnerabilities.
4. Environmental Quality	• Examined data on water quality, contamination, and health and ecological risks resulting from Hurricane Sandy. • Produced maps, visualization tools, and publications assessing the occurrence, distribution, transport processes, and trends of contaminants and risks.
5. Ecosystem Impacts	• Collected data on vegetation, animal species and their habitats, and the responses of both to storm impacts. • Produced reports, inventories, maps, and models of ecosystems and ecological processes. • Developed improved monitoring methods, online tracking data and visualization tools, and tools to evaluate or prioritize restoration methods.
6. Sand Resources	• Identified and characterized sand resources. • Identified sand resources to avoid due to contamination or insufficient resources. • Produced reports, inventories of resources and needs, maps and geographic databases, and ratings or classifications of the available resources
7. Coordination and Communication	• Supported collaboration and coordination among researchers and other stakeholders, primarily focused on Jamaica Bay, New York. • Developed reports, publications, presentations, and communication tools.

Table 2. Coastal resilience science projects by bureau and topic area. Dollars rounded to nearest hundred.

Topic area	Bureau (number of projects)					Total count	Allocated award
	BOEM	NPS	USGS	USFWS	NFWF		
1. Elevation Data	–	2	4	–	–	**6**	$9,280,700
2. Coastal Change	–	3	7	2	2	**14**	$26,441,400
3. Storm Surge and Hydrology	–	5	4	1	4	**14**	$12,520,500
4. Environmental Quality	–	2	3	–	–	**5**	$5,229,500
5. Ecosystem Impacts	2	12	6	4	2	**26**	$22,320,700
6. Sand Resources	15	–	–	–	–	**15**	$3,963,700
7. Coordination and Communication	–	5	–	–	1	**6**	$2,769,700
Total	**17**	**29**	**24**	**7**	**9**	**86**	$82,526,200

4. Findings

Topic: Project Implementation (PI)

Finding PI.1: Nearly all the projects have successfully completed their proposed activities, with typically minimal changes in scope or timeline.

Nearly all of the coastal resilience science projects (82 of 86) were completed by the time of this evaluation, and an additional 4 are expected to be completed by December 2019. Of the 82 projects completed, 5 were completed in 2015, 49 in 2016, 8 in 2017, and 20 in 2018.

In the survey, about half (48%) of the project leads indicated that there was a change in the scope of their projects. Nearly all changes, however, were reportedly minor and involved increases in the amount or changes in the type of data collected, as opposed to decreases in project activities or outputs or delays in the work performed.

Topic: Improved Decision-making (ID)

Finding ID.1: Coastal resilience science projects resulted in the creation of more than 700 deliverables, including presentations, reports, manuscripts, datasets, maps, and models.

Using information from archival materials, we estimate that the coastal resilience science projects funded through the Hurricane Sandy Program produced more than 700 deliverables (Table 3). The types of deliverables produced are consistent with the scientific nature of the projects: presentations and publications were the two most commonly created products, along with datasets, models, and maps. More than 60 communication products were also produced, but more than half of these products were developed by projects in topic area 7, which is focused on coordination and communication. Projects in the other topic areas produced fewer communication products.

Table 3. Coastal resilience science products and deliverables.

Product or deliverable	Topic area (# of products)							Total
	1. Elevation Data	2. Coastal Change	3. Storm Surge and Hydrology	4. Environmental Quality	5. Ecosystem Impacts	6. Sand Resources	7. Coordination and Communication	
Presentations	9	37	20	14	84	12	59	**235**
Publications[a]	1	60	13	16	31	23	20	**164**
Data Sets/Databases	10	30	23	2	9	24	39	**137**
Outreach/Communications Products	0	6	11	1	9	0	36	**63**
Models/Software	1	4	6	0	11	0	10	**32**
Maps/Visualization Tools	6	3	3	2	10	3	1	**28**
Websites	2	4	2	1	4	0	4	**17**
Education/Training	1	0	1	0	5	0	9	**16**
Enhanced Monitoring Systems	0	2	6	0	0	0	8	**16**
Procedures/Management Practices	0	0	7	0	1	0	6	**14**
Analyses/Forecasts	0	2	0	0	2	0	0	**4**
Photos/Videos	1	3	0	0	0	0	0	**4**
Total	**31**	**151**	**92**	**36**	**166**	**62**	**192**	**730**

a. The publication count does not include draft publications at the time of project reporting.

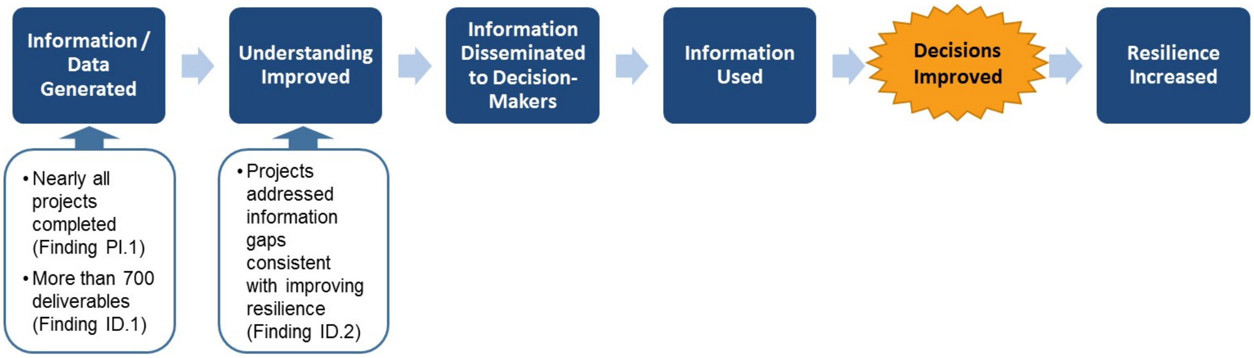
Finding ID.2: Coastal resilience science projects were designed to address key knowledge gaps consistent with the program's focus on improving coastal resilience.

Our examination of archival materials suggests that the types of science projects funded by the Hurricane Sandy Program are consistent with the goal of supporting efforts to improve coastal resilience in the region. For example, the coastal resilience science projects and deliverables address the seven coastal resilience topic areas described in Table 1, and all have the potential to inform resilience decision-making, thereby improving resilience over various time scales. More specifically, the projects are improving the understanding of coastal elevation, storm surge dynamics, storm-related ecosystem vulnerabilities, potential contaminant risks associated with coastal storm damage, and sand resources that can be used to protect natural and human communities. Using information from archival materials, the project lead survey, and interviews, we summarized the key data gaps that these projects are addressing, and describe how project-generated information can improve resilience decision-making (Table 4). Figure 2 shows the relevance of this finding, and previous findings, to the logic model introduced above.

Table 4. How coastal resilience science projects are addressing key data gaps relevant to resilience-related decision-making, by project topic area.

Topic area	Information gap	Relevance to resilience
1. Elevation Data	More extensive, high-quality coastal elevation data	• Improved elevation data will support improved models (e.g., groundwater, hydrologic, sediment transport, and flood inundation). • Improved process models will better inform decisions about flood risk management, infrastructure construction, restoration management, water supply and quality management, agricultural practices, and adaptation to sea level rise and storm surge.
2. Coastal Change	Improved understanding and communication of key coastal vulnerabilities to storms	• Improved data, models, and tools can improve the ability to understand and visualize key coastal vulnerabilities. • Better information about coastal change and vulnerabilities can guide decisions about zoning, building codes, and where and where not to build infrastructure; establish coastal protection structures; nourish beaches and dunes; dredge or modify channels; or restore wetlands.
3. Storm Surge and Hydrology	More comprehensive coastal monitoring, and real-time updates about key meteorological variables and near-shore storm hydrodynamics	• Improved data, models, and tools can improve the ability to identify, in real time, where storm damage is likely to be concentrated. • Better data, models, and tools can inform decisions about emergency response during a storm (e.g., when and where to issue storm and flood warnings, when and where to evacuate, where to position emergency response equipment).
4. Environmental Quality	Improved understanding of storm impacts on human and wildlife exposure to contaminants	• Improved understanding can inform decisions about where water quality monitoring should be concentrated, and where potential wildlife or fishery impacts might be the greatest. • Can also be used to identify projects that would most effectively mitigate the impacts of storms on water quality.
5. Ecosystem Impacts	Improved understanding of key ecosystem and species vulnerabilities to storms and sea level rise	• Better information can inform land use planning, development, tourism, and wildlife conservation and ecosystem restoration actions. • These more informed decisions will mitigate risks to ecosystems from coastal storms and sea level rise, making them more resilient.
6. Sand Resources	More information about the location and composition of off-shore sand resources	• Improved information can guide decisions about where to find compatible sand resources for beach replenishment and re-nourishment projects, which are key to community and ecosystem storm protection in many areas.
7. Coordination and Communication	Enhanced coordination of resilience-related actions	• These projects directly aided in planning and coordinating a variety of decisions, including community development, restoration actions, climate change adaptation, and hazard mitigation.

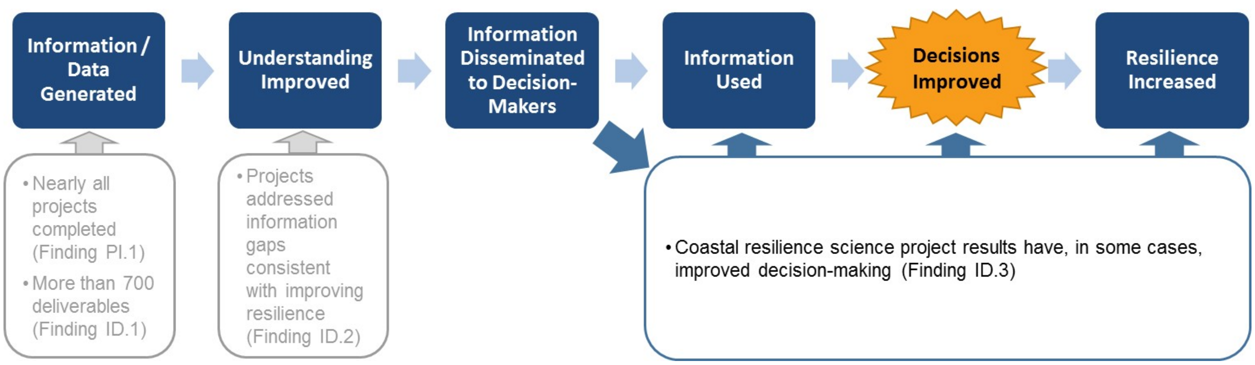
Figure 2. Coastal resilience science projects filled key data gaps and resulted in improved understanding.



Finding ID.3: Coastal resilience science efforts, in some cases, have directly improved resilience-related decision-making.

In some cases, there was evidence in project or media reports, or project lead interviews of the direct application of project data, maps, or tools in important decision-making processes. We share key highlights from relevant projects below in Boxes 1–3, focusing on coastal resilience science project activities, respectively. Figure 3 shows these cases in the context of the logic model introduced above.

Figure 3. Coastal resilience science projects have, in some cases, improved decision-making.



Box 1. Data-focused project activities: Examples of project-generated information used to improve resilience.

The Hurricane Sandy Program supported **expanding an existing USGS monitoring network of sensors** that measure storm tide, waves, and other meteorological parameters (i.e., **Surge**, **Wave, and Tide Hydrodynamics or SWaTH**). More specifically, the project created a virtual "storm-tide center" in the region to improve the number and utility of network sensors. Network ehancements have made storm data more readily available to local emergency responders and the Federal Emergency Management Agency (FEMA), which use these data to inform decisions about road closures, evacuations, and recovery operations. The **SWaTH network was deployed for a nor'easter in January 2016** and during **Hurricane Hermine** to predict where the storm damage would be concentrated.

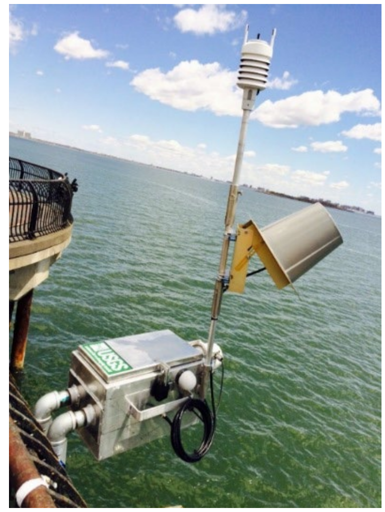


Figure: SWaTH sensor. Source: USGS.

USFWS supported the creation of the **North Atlantic Aquatic Connectivity Collaborative (NAACC)** – a network of partners in 13 states working to improve road-stream crossings. The NAACC provides a central database of road-stream crossing infrastructure, protocols, and training sessions for infrastructure assessments; and web-based tools for prioritizing upgrades. The creation of the **NAACC led to a collaborative effort among Essex County, The Nature Conservancy (TNC), and the USFWS to replace a problematic culvert** with a design that would **improve both onsite flooding and fish passage**.

Figure: Culvert restoration in North Elba, NY. Source: TNC.

A BOEM project in Massachusetts developed **topographic profiles** and conducted **grain-size analyses** on sediment samples in **18 beaches** that are currently experiencing erosion. Samples were taken during the summer and winter to evaluate seasonal and spatial variability. The information gathered through these activities is being used to **match native-beach material** with compatible **offshore sand resources for potential beach nourishment projects**.

Figure: Sand sampling transect at Humarock Beach, Scituate, MA. Source: BOEM.

Box 2. Mapping-focused project activities: Examples of project-generated information used to improve resilience.

The official **maps of the Coastal Barrier Resources System (CBRS)** were first created more than 35 years ago, having used what are now outdated base maps and cartographic techniques. The **Hurricane Sandy Program supported USFWS in revising these maps** to fix technical mapping errors; add missing areas; and make the data more accessible and user-friendly for public officials, surveyors, real estate agents, developers, and others planning coastal infrastructure projects, habitat conservation efforts, and flood risk mitigation measures. As of February 15, 2019, **FEMA** has **updated its flood insurance rate maps to use the new, dynamically updated digital CBRS boundaries.** The revised boundaries have gone through a period of public review and are being prepared for consideration by Congress to be adopted into law.

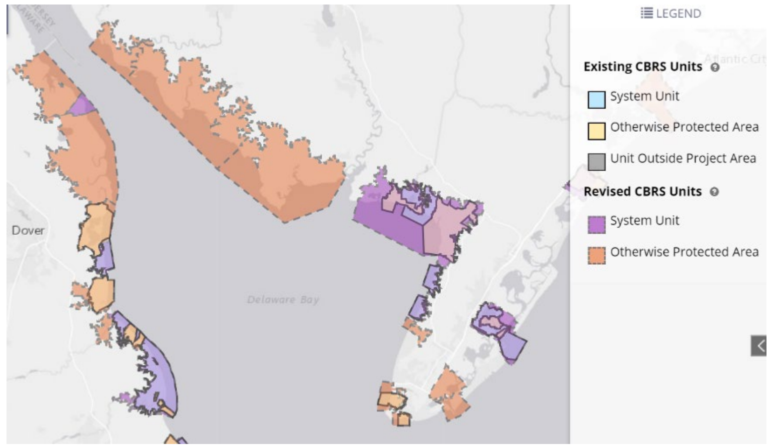


Figure: Example of CBRS map from Delaware Bay. Source: USFWS.

The Hurricane Sandy Program supported the creation of the **Virginia Eastern Shore Coastal Resilience Tool** (https://maps.coastalresilience.org/virginia/), which serves as a resource for understanding key threats to coastal systems and the resilience actions that can reduce vulnerability. The **Accomack-Northampton Planning District Commission** recently **revised its Eastern Shore Hazard Mitigation Plan using this tool**. Rather than solely focusing on historical flood risks, the commission has begun to incorporate future risk of storm surge in concert with rising sea level projections to plan for future hazards due to coastal flooding. The tool has also been **adopted by the Southern Tip Ecological Partnership** to **inform** its **conservation and protection priorities** related to migratory bird habitat and other coastal conservation lands. The tool was also used in the development of the **Chincoteague National Wildlife Refuge/Assateague Island National Seashore Comprehensive Conservation Plan** and Environmental Assessment.

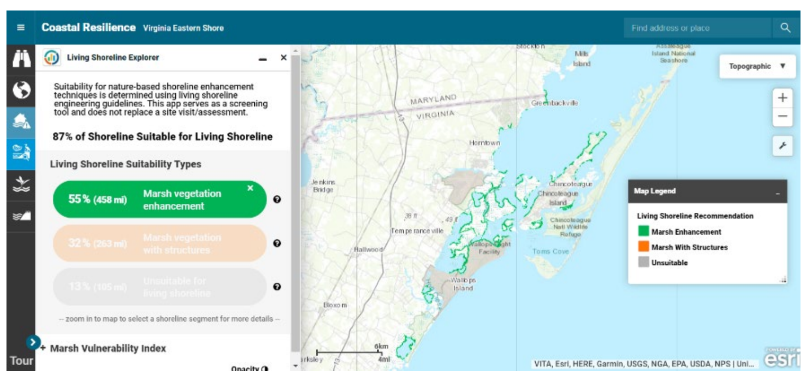


Figure: Screenshot of Virginia Eastern Shore Coastal Resilience Tool.

Box 3. Modeling-focused project activities: Examples of project-generated information used to improve resilience.

Three USGS projects supported the development of the **Coastal National Elevation Database (CoNED)** Topographic and Bathymetric Digital Elevation Model (TBDEM). Data from this model improved a **coastal resilience tool** developed by **TNC** for New Jersey, enabling the state to **support critical decision-making regarding coastal habitat restoration**.

Photo: Staff collect high-resolution elevation data. Source: URI.

USGS developed an online **Coastal Change Hazards Portal (CCHP)** with tools to visualize coastal changes caused by major storms, chronic erosion, and sea level rise for resource managers and others. Real-time applications of the CCHP have included **tracking and predicting coastal impacts of Hurricanes Matthew and Joaquin, Tropical Storm Colin, and severe winter storms (nor'easters) in 2015 and 2016**. "The ability to easily locate and access USGS research and data through the new Coastal Change Hazards Portal is of great value for coastal managers," said Massachusetts Office of Coastal Zone Management Director Bruce Carlisle. "This information directly supports our work with local cities and towns to assess risk and communicate current and future hazards."

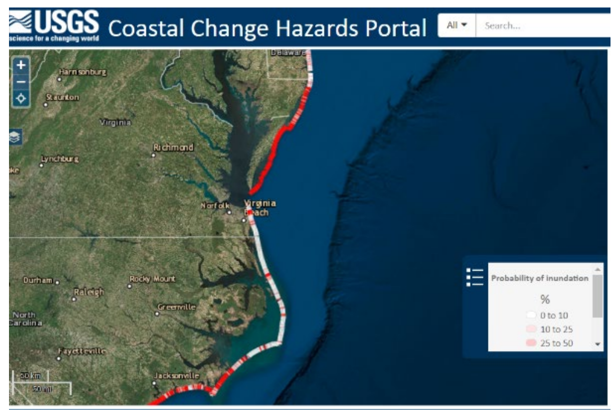
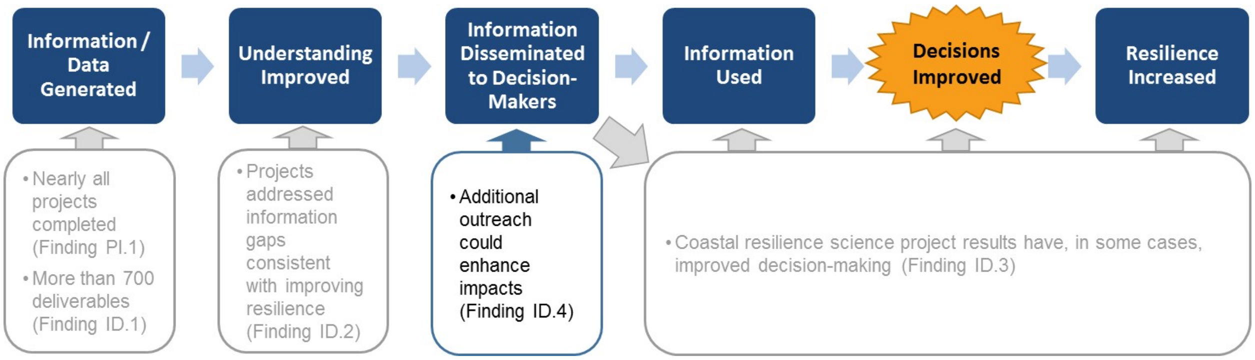


Figure: Screenshot of CCHP used to visualize the likelihood of inundation during a storm. Source: USGS.

Finding ID.4: The ultimate impact of coastal resilience science activities could be enhanced by supporting more outreach to relevant decision-makers.

While projects were generally successful in meeting their goals of developing the datasets, maps, and models that they had proposed and there were some instances of improved decision-making, most projects ended their activities once deliverables had been developed (e.g., reports, manuscripts, presentations). Few projects had integrated plans to reach out to potential users of their data, maps, models, or tools, either during or after project implementation. As a result, even though the research being done has the potential to inform resilience decisions (and is consistent with a given DOI bureau's mission), the products delivered by some projects may not be known by, appropriate for, or accessible to people who will ultimately influence on-the-ground decision-making. Figure 4 shows this finding in the context of the logic model.

Figure 4. Additional outreach could enhance the impacts of coastal resilience science activities.



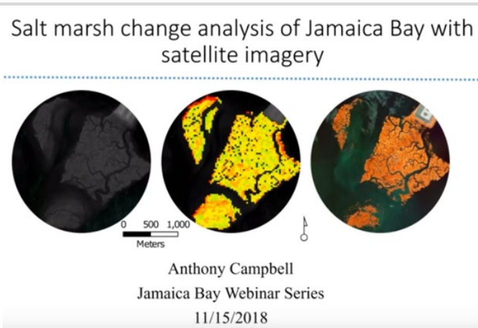
In the survey, several project leads acknowledged that limited outreach was a key challenge in applying the knowledge produced by projects to on-the-ground decision-making. For example, 14% of survey respondents noted that insufficient outreach with decision-makers, the public, or other scientists, was a key factor constraining project success.

This finding is also supported by the data shown in Table 3 shown earlier. The data show that the majority of coastal resilience science project outputs were in the form of presentations (74% of which were to scientific conference or student audiences) and publications, instead of more direct forms of outreach; but there were some outreach and communication products, two of which are included in Box 4.

Box 4. Examples of active decision-maker outreach for coastal resilience science project outputs.

Workshops on the **Greater Baltimore Wilderness Coalition** provided a final summary of the project's work to over 300 local area professionals and staff from agencies and local governments.

Photo: Workshop participants.
Source: The Conservation Fund.



A mid-project symposium by the **Science and Resilience Institute at Jamaica Bay** brought together project teams with public agency decision-makers, stakeholders, and researchers. Approximately 70 people attended, including representatives from 6 public agencies, 8 community or environmental nonprofit organizations, and 11 universities.

Figure: Cover slide for a symposium presentation.
Source: Science and Resilience Institute.

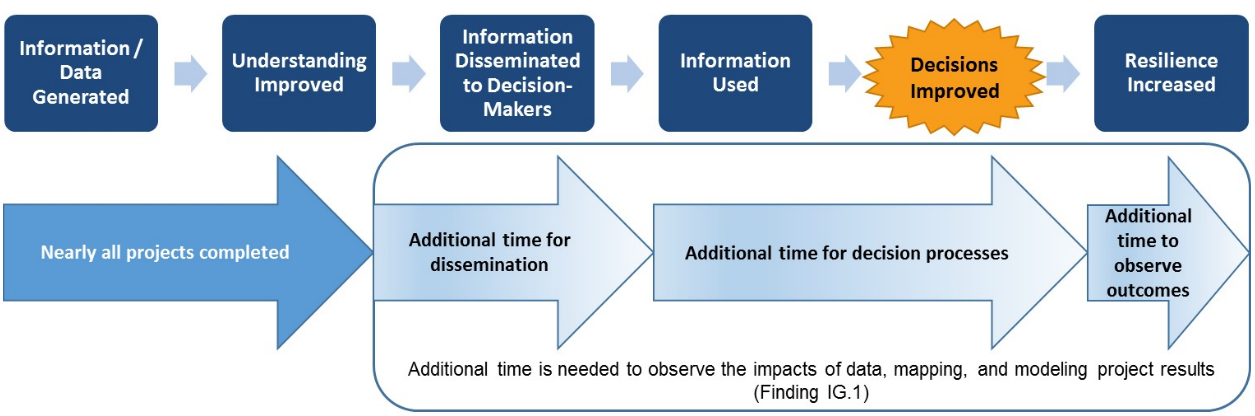
Different factors may have facilitated or accelerated uptake by decision-makers in the cases identified in Finding ID.3. For example, the SWaTH project expanded an existing sensor network and the CBRS project updated existing maps, both of which were already in use by decision-makers. The CCHP project was already underway when the Hurricane Sandy Program funding became available, making it a more mature project from the outset and thus more primed for the project's data uptake. For the NAACC, information sharing was intrinsic to its design, and thus it created a network of individuals from different agencies and organizations that could and were likely to immediately use the project's outputs. A key uptake-related recommendation from the team that created the Virginia Eastern Shore Coastal Resilience Tool was to "designate more time and resources for communicating results….Ratio of model/tool building to communicating/training should be 1:4."

Topic: Information Gaps (IG)

Finding IG.1: More time is needed to observe the uptake of the coastal resilience science products into decision-making processes; depending on the decision, additional time may then be needed to observe the impact on coastal resilience.

As with on-the-ground interventions (e.g., marsh or beach/dune restoration), the direct resilience benefits of coastal resilience science may take time to fully materialize. For example, it may take time for decision-makers to become aware of relevant new scientific knowledge, particularly when direct outreach is limited (see Finding ID.4). It may take even longer for an opportunity to apply that information to policies or specific decisions. For example, information products that enhance the ability to detect and predict storm surge impacts may be utilized very soon after they are created, but products that are designed to inform decisions about long-term investments in coastal restoration (e.g., National Wildlife Refuge Comprehensive Conservation Plans) may take longer to be applied. Furthermore, depending on the specific decision informed (e.g., climate change adaptation plan, restoration of a marsh), more time may be required before resilience impacts of the decision are realized. Therefore, longer-term assessments of the application of coastal resilience science project information are needed to fully understand their resilience-related impacts. Figure 5 shows the additional time needed in the context of the logic model.

Figure 5. Additional time is needed to observe the impacts of coastal resilience science project results in many cases.



5. Conclusion

Hurricane Sandy Program investments in coastal resilience science projects have filled key knowledge gaps and helped to directly improve resilience-related decision-making. These projects have led to notable successes, including an online coastal hazards portal that has already been used to track and predict coastal impacts of multiple hurricanes, tropical storms, and severe winter storms. Overall, these projects were highly productive and generated more than 700 deliverables, including reports, presentations, manuscripts, datasets, maps, and models. However, more time is needed for decision-makers to incorporate the scientific products and information generated through the program into additional decisions beyond the individual examples described in this case study. An issue that may constrain the impact of some of these projects is the limited outreach to decision-makers to raise awareness, and to ensure the suitability and usability of the data and tools being developed.

6. References

Abt Associates. 2019. Evaluation of Hurricane Sandy Coastal Resilience Program. Abt Associates, Rockville, MD.

Buxton, H.T., M.E. Andersen, M.J. Focazio, J.W. Haines, R.A. Hainly, D.J. Hippe, and L.J. Sugarbaker. 2013. Meeting the Science Needs of the Nation in the Wake of Hurricane Sandy – A U.S. Geological Survey Science Plan for Support of Restoration and Recovery. U.S. Geological Survey Circular 1390. Available: https://pubs.usgs.gov/circ/1390/. Accessed 9/2/2019.

Appendix A. Coastal Resilience Science Projects

Exhibit A.1. Coastal resilience science projects supported through the Hurricane Sandy Program. All dollars rounded to the nearest hundred.

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
BOEM-M13AC00012	Ecological function and recovery of biological communities within dredged ridge-swale habitats and in the South-Atlantic bight	FL	University of Florida; Bureau of Ocean Energy Management	$4,300,000	$0
BOEM-M13AC00031	Natural habitat association and the effects of dredging on fish at the Canaveral Shoals, east-central Florida	FL	United States Navy; National Aeronautics and Space Administration; Bureau of Ocean Energy Management	$1,473,000	$0
BOEM-M14AC00001	Sand needs and resources offshore New York	NY	New York Department of State; Bureau of Ocean Energy Management	$400,000	$0
BOEM-M14AC00002	Post Hurricane Sandy offshore New Jersey sand resources investigations	NJ	New Jersey Department of Environmental Protection; Bureau of Ocean Energy Management	$400,000	$60,000
BOEM-M14AC00003	Delaware offshore sand resource investigation	DE	University of Delaware; Bureau of Ocean Energy Management	$200,000	$0
BOEM-M14AC00004	Modernizing the Reconnaissance Offshore Sand Search (ROSS) database and a review and synthesis of existing geophysical data from selected areas on the Outer Continental Shelf (OCS Region) along Florida's central Atlantic Coast	FL	Florida Department of Environmental Protection; Bureau of Ocean Energy Management	$200,000	$0
BOEM-M14AC00005	Geospatial sand resource assessment for Georgia coastal recovery and resiliency	GA	University of Georgia; Bureau of Ocean Energy Management	$200,000	$58,900
BOEM-M14AC00006	Sand resource assessment at critical beaches on the Massachusetts Coast	MA	University of Massachusetts; Bureau of Ocean Energy Management	$199,600	$31,700

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
BOEM-M14AC00007	Conversion of Maryland's offshore mineral resources data for geographic information system applications and baseline acoustic seafloor classifications of offshore borrow areas	MD	Maryland Department of Natural Resources; Bureau of Ocean Energy Management	$199,400	$0
BOEM-M14AC00008 (note, shown as 00013-2 in some sources)	Exploration and habitat classification: Tools for building resiliency in Maine	ME	Maine Department of Agriculture; Bureau of Ocean Energy Management	$195,200	$245,500
BOEM-M14AC00009	Assessing sand resources for North Carolina: inventory, needs assessment and reanalysis for post-Hurricane Sandy recovery and future resilience	NC	East Carolina University; Bureau of Ocean Energy Management	$200,100	$10,000
BOEM-M14AC00010	Assessment of offshore sand and gravel for beach nourishment in New Hampshire	NH	University of New Hampshire; Bureau of Ocean Energy Management	$200,000	$9,300
BOEM-M14AC00011	Identification of sand/gravel resources in Rhode Island waters while working toward a better understanding of storm impacts on sediment budgets	RI	University of Rhode Island; Bureau of Ocean Energy Management	$200,000	$0
BOEM-M14AC00012	South Carolina offshore sand resources: Data inventory, digital data conversion, and needs assessment	SC	South Carolina Department of Natural Resources; Bureau of Ocean Energy Management	$200,000	$195,600
BOEM-M14AC00013-1	Assessment of offshore sand resources for Virginia beachfront restoration	VA	Virginia Department of Mines, Minerals, and Energy; Bureau of Ocean Energy Management	$199,500	$101,100
BOEM-M14PC00006	Geological and geophysical data acquisition: Inventory of potential beach nourishment and coastal restoration sand sources on the Atlantic Outer Continental Shelf	Multi: CT, DE, FL, GA, MA, MD, ME, NC, NH, NJ, NY, RI, SC, VA	CB&I Federal Services LLC; Bureau of Ocean Energy Management	$500,000	$0

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
BOEM-M15PS00030 (in some cases shown as M15PG00005)	Propagation characteristics of high-frequency sounds emitted during high-resolution geophysical surveys: Open water testing	ME	Naval Undersea Warfare Center Division; Bureau of Ocean Energy Management; U.S. Geological Survey	$470,000	$0
NFWF-41931	Developing self-sustaining oyster population in Jamaica Bay, New York	NY	New York City Department of Environmental Protection	$100,000	$37,500
NFWF-42551	Green infrastructure in Accomack and Northampton counties, Virginia	VA	The Nature Conservancy	$1,034,100	$209,000
NFWF-42878	Assessing coastal impoundment vulnerability and resilience in the Northeast	Multi: CT, DE, MA, MD, ME, NH, NJ, NY, RI, VA	New Jersey Audubon Society	$470,000	$170,000
NFWF-43129	Creating green stormwater infrastructure resiliency in Greater Baltimore and Annapolis watersheds, Maryland	MD	The Conservation Fund	$583,600	$222,700
NFWF-43308	Developing a green infrastructure plan and network for the Lafayette River Watershed, Virginia	VA	City of Norfolk	$725,600	$40,200
NFWF-43752	Creating a three dimensional wetland model for the Bombay Hook National Wildlife Refuge, Delaware	DE	University of Delaware	$400,000	$148,500
NFWF-43932	Improving and quantifying wetlands' potential to reduce storm surge impacts, Virginia	VA	George Mason University	$440,000	$93,800
NFWF-44017	Developing Rhode Island's coastal resiliency program	RI	University of Rhode Island	$870,000	$380,700

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
NFWF-44212	Improving Northeast Coast storm-related data interpretation and accessibility	Multi: CT, DC, DE, MA, MD, NH, NJ, NY, OH, PA, RI, VA, WV	Northeastern Regional Association of Coastal and Ocean Observing Systems	$520,000	$133,300
NPS-3-1	Modification to acquisition coordination, compilation, data management and change analysis of LiDAR and other geospatial data collected pre- and post-hurricane (subproject)	Multi: MD, NJ, NY, VA	University of Rhode Island; National Park Service	$565,700	$0
NPS-3-2	Field technician support for elevation mapping of NPS salt marshes and other sites for sea level rise planning and post- and future-storm evaluation (subproject)	Multi: MD, NJ, NY, VA	University of Rhode Island; National Park Service	$768,900	$0
NPS-3-3	Collection of high resolution topographical data and development of metrics associated with superstorm sandy impacts, recovery, and coastal geomorphological resiliency (subproject)	Multi: NJ, NY	Rutgers University; National Park Service	$161,900	$0
NPS-3-4	Tide-telemetry and coastal-flood-warning system Fire Island National Seashore (subproject)	NY	U.S. Geological Survey New York Water Science Center; National Park Service	$84,200	$0
NPS-3-5	Modeling salt marsh condition and resiliency in four National Parks based local sea level rise predictions to assist park managers in understanding local conditions and to develop mitigation strategies (subproject)	Multi: MA, MD, NJ, NY	University of South Carolina; National Park Service	$248,000	$0
NPS-14-1	Detecting water quality regime shifts in Jamaica Bay (subproject)	NY	Brooklyn College (CUNY); National Park Service	$283,000	$0
NPS-14-2	Health and resiliency of salt marshes in Jamaica Bay (subproject)	NY	Stony Brook University; National Park Service	$276,000	$0

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
NPS-14-3	Monitoring and evaluation of restoration and resilience: Jamaica Bay Unit, shoreline and geomorphology (subproject)	NY	Rutgers University; National Park Service	$328,700	$0
NPS-14-4a	Acidification, hypoxia, and algal blooms: Barriers to current and future ecosystem restoration and climate change resilience in Jamaica Bay (subproject)	NY	Stony Brook University; National Park Service	$246,500	$0
NPS-14-4b	Restoration of Jamaica Bay fringing habitats: Post-Sandy status and new approaches for a resilient future (subproject)	NY	Rutgers University; National Park Service	$482,900	$0
NPS-14-5	The Jamaica Bay Observing system: Process studies and groundwork for long-term ecosystem research and resilience (subproject)	NY	Brooklyn College (CUNY); National Park Service	$789,800	$0
NPS-14-6	Coastal adaptation impacts on Jamaica Bay water quality, waves and flooding (subproject)	NY	Stevens Institute of Technology; National Park Service	$700,000	$0
NPS-14-8	Science and Resilience Institute at Jamaica Bay: Coordination of DOI and NPS sandy resilience projects (subproject)	NY	City University of New York; National Park Service	$85,000	$0
NPS-14-9	The environmental history of Jamaica Bay: A foundational monograph (subproject)	NY	City University of New York; National Park Service	$47,000	$0
NPS-35-1	Assessing the response of juvenile and adult hard clams to the new breach in Great South Bay: Post-Hurricane Sandy study (subproject)	NY	Stony Brook University; National Park Service	$98,200	$0
NPS-35-2	Assessing the response of the Great South Bay plankton community to Hurricane Sandy (subproject)	NY	Stony Brook University; National Park Service	$594,100	$0

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
NPS-35-3	Assessing the response of the Great South Bay estuarine fauna to Hurricane Sandy: Focus on nekton utilization of seagrass habitats (subproject)	NY	Stony Brook University; National Park Service	$327,600	$0
NPS-35-4	Effects of storm induced barrier breach on community assemblages and ecosystem structure within a temperate lagoonal estuary (subproject)	NY	Stony Brook University; National Park Service	$150,000	$0
NPS-35-5	Impact of Hurricane Sandy on the Fire Island National Seashore water quality and seagrass resources (subproject)	NY	Stony Brook University; National Park Service	$177,000	$0
NPS-35-6	Assessing the response of indicator bacteria in Great South Bay to Hurricane Sandy (subproject)	NY	Stony Brook University; National Park Service	$50,000	$0
NPS-35-7	Science communication: Hurricane Sandy video project (subproject)	NY	Harpers Ferry Center, National Park Service	$68,600	$0
NPS-35-8	Continuation of post-Hurricane Sandy physical monitoring of the Old Inlet breach, Fire Island National Seashore: Phase two (subproject)	NY	Stony Brook University; National Park Service	$174,800	$0
NPS-49-1	Assess groundwater resources at Assateague Island National Seashore (subproject)	MD	U.S. Geological Survey; National Park Service	$330,000	$0
NPS-49-2	Assess groundwater resources at Fire Island National Seashore (subproject)	NY	U.S. Geological Survey; National Park Service	$212,800	$0
NPS-49-3	Assess groundwater resources at Sandy Hook Unit of Gateway National Recreation Area (subproject)	NJ	U.S. Geological Survey; National Park Service	$460,000	$0
NPS-72-1	Submerged marine habitat mapping, Fire Island National Seashore (subproject)	NY	University of Rhode Island; National Park Service	$865,000	$0
NPS-72-2	Submerged marine habitat mapping, Gateway National Recreation Area (subproject)	NJ	Rutgers University; National Park Service	$810,000	$0

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
NPS-72-3	Submerged marine habitat mapping, Assateague Island National Seashore (subproject)	MD	University of Delaware; National Park Service	$790,000	$0
NPS-72-4	Submerged marine habitat mapping, Cape Cod National Seashore (subproject)	MA	Center for Coastal Studies; National Park Service	$510,000	$0
USFWS-17	Building a predictive model for submerged aquatic vegetation prevalence and salt marsh resiliency in the face of Hurricane Sandy and sea level rise	Multi: CT, DE, MD, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$216,700	$45,300
USFWS-24	Decision support for Hurricane Sandy restoration and future conservation to increase resiliency of tidal wetland habitats and species in the face of storms and sea level rise	Multi: CT, DE, MA, MD, ME, NH, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$2,200,000	$1,604,300
USFWS-30	A stronger coast: Three USFWS Region 5 multi-National Wildlife Refuge projects to increase coastal resilience and preparedness	Multi: CT, DE, MA, ME, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$2,060,000	$1,143,500
USFWS-32	Resilience of the tidal marsh bird community to Hurricane Sandy and assessment of restoration efforts	Multi: CT, DE, MA, MD, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$1,574,000	$2,050,400
USFWS-63	Collaboratively increasing resiliency and improving standards for culverts and road-stream crossings to future floods while restoring aquatic connectivity	Multi: CT, DE, MA, MD, ME, NH, NJ, NY, PA, RI, VA, VT, WV	Wildlife Management Institute	$1,270,000	$350,000
USFWS-64	Coastal barrier resources system comprehensive map modernization: Supporting coastal resiliency and sustainability following Hurricane Sandy	Multi: CT, DE, MA, MD, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$5,000,000	$2,000,000

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
USFWS-67	Decision support for Hurricane Sandy restoration and future conservation to increase resiliency of beach habitats and species in the face of storms and sea level rise	Multi: CT, DE, MA, MD, ME, NH, NJ, NY, RI, VA	U.S. Fish and Wildlife Service	$1,750,000	$2,059,500
GS1-1a	Establish a Sandy Region Coastal National Elevation Database (CoNED)	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA	U.S. Geological Survey	$550,000	$0
GS1-1b	Topographic surveys (LiDAR) for impact area assessment and reconstruction	Multi: DE, MD, NC, NJ, NY, PA, VA	U.S. Geological Survey; National Oceanic and Atmospheric Organization	$3,100,000	$0
GS1-1c	Delivery systems for hazards, topographic and bathymetric elevation data	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey; National Oceanic and Atmospheric Organization	$650,000	$0
GS1-2a	Coastal mapping products & impact assessments: Pre- and post-storm mapping of coastal impacts and vulnerability	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA; NJ and NY priority	U.S. Geological Survey	$2,075,000	$0
GS1-2b	Impacts to and vulnerability of coastal beaches: Develop coastal impact forecast models	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA; NJ and NY priority	U.S. Geological Survey	$1,950,000	$0

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
GS1-2c	Coastal hazards information and decision support portal	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA	U.S. Geological Survey	$750,000	$0
GS1-3a	Storm surge response, data collection, and data delivery	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA; NJ and NY priority	U.S. Geological Survey	$2,350,000	$0
GS1-3b	Storm tide monitoring networks and data analysis	Multi: CT, DE, MA, MD, NC, NJ, NY, PA, RI, VA; NJ and NY priority	U.S. Geological Survey	$1,400,000	$0
GS1-4a	Ecological contaminant exposures	Multi: NJ, NY	U.S. Geological Survey	$1,700,000	$0
GS1-4b	Human contaminant exposures	Multi: NJ, NY	U.S. Geological Survey	$1,000,000	$0
GS1-5a	Assess storm impact to wetland integrity and stability to assist recovery decisions	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$1,205,000	$0
GS1-5b	Assess storm impact to waterfowl and migratory birds to support conservation	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$730,000	$0
GS1-5c	Assess coast-wide storm impacts to forest habitats in coastal parks and refuges	Multi: MD, NJ, NY, VA	U.S. Geological Survey	$365,000	$0

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
GS1-5d	Develop data-driven models and ecological monitoring networks to support recovery and resilience	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$700,000	$0
GS2-1A	Topographic surveys for priority watershed and ecological assessments	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey; National Oceanic and Atmospheric Organization	$4,050,000	$0
GS2-2A	Barrier island and estuarine wetland physical change assessment	Multi: DE, MD, NJ, VA	U.S. Geological Survey	$1,350,000	$0
GS2-2B	Linking coastal processes and vulnerability, Fire Island Regional Study	NY	U.S. Geological Survey	$4,800,000	$0
GS2-2C	Coastal vulnerability and resource assessment, Delmarva Peninsula	Multi: DE, MD, NY, VA	U.S. Geological Survey	$4,000,000	$0
GS2-2D	Estuarine response to storm forcing	Multi: DE, MD, NJ, NY, VA	U.S. Geological Survey	$2,200,000	$0
GS2-3A	Enhance storm tide monitoring, data recovery, and data display capabilities	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$2,200,000	$0
GS2-3B	Storm surge science evaluations to improve models, vulnerability assessments, and storm surge predictions	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$1,500,000	$0
GS2-4A	Mapping, measuring, and predicting vulnerability from contaminant hazards from Hurricane Sandy and other storms in the Northeast Coastal zone	Multi: CT, DE, MA, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$2,000,000	$0

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent coastal resilience science activities only[a]	
GS2-5A	Evaluating ecosystem resilience	Multi: CT, DE, MA, NJ, NY, RI, VA	U.S. Geological Survey	$1,240,000	$0
GS2-5D	Forecasting biological vulnerabilities	Multi: CT, DE, MD, NC, NJ, NY, RI, VA	U.S. Geological Survey	$1,025,000	$0

a. Costs in the table do not represent the full cost of the project and may not reflect the total match.

Abt ASSOCIATES

BOLD THINKERS DRIVING REAL-WORLD IMPACT

Case Study: Community Resilience Planning in the Hurricane Sandy Coastal Resilience Program

Contract # 5359

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FINAL

2019

Case Study: Community Resilience Planning in the Hurricane Sandy Coastal Resilience Program

Prepared by Abt Associates, September 2019

Summary

Purpose

This case study forms part of a larger 2019 evaluation of the Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program) of the U.S. Department of the Interior (DOI) and the National Fish and Wildlife Foundation (NFWF). It provides an analysis of the coastal resilience impacts of community resilience planning projects.

Scope

We examined 28 community resilience planning projects in the Hurricane Sandy Program portfolio. These projects created site-specific designs, management plans or assessments, and models or mapping tools for improving coastal resilience.

Findings

Key findings identified using archival materials, a survey and interviews of project leads, and internet searches include:

- Hurricane Sandy Program community resilience planning projects created 126 management plans or assessments, 85 site-specific designs, and 65 resilience tools to identify, describe, or prioritize future actions that would improve community resilience. These plans promote the broader adoption of key resilience activities, such as dam removal, funded by the Hurricane Sandy Program.
- The adoption and implementation of planning products by communities varied across projects, with availability of funding noted as a key factor in the speed of uptake.
- The majority of the projects (18 of 28) have successfully completed their proposed activities.
- More than half (15 of 28) of the community resilience planning projects have already led to actions that are directly increasing resilience, with a rapid progression from planning to implementation.

Conclusion

Overall these findings suggest that **investments in the Hurricane Sandy Program have catalyzed resilience benefits by attracting additional funding for on-the-ground resilience activities and promoting resilience activities to a broader set of communities.** Project leads developed planning products that provided site-specific designs for future projects, identified key assets and vulnerabilities, recommended actions for improving resiliency, and shared knowledge and outreach on potential strategies. These products also increased the visibility of natural and nature-based solutions to coastal hazards, and promoted the uptake and implementation of such solutions in communities beyond those funded directly by Hurricane Sandy Program grants. Early success stories (such as projects obtaining funding and moving rapidly toward implementation after plans were completed) indicate the potential value of resilience planning projects. Overall, however, the direct resilience benefits of planning efforts will take time to fully materialize, as plans need to be adopted and funding obtained before implementation proceeds.

1. Introduction

This case study forms part of a larger 2019 evaluation of the DOI and NFWF Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program). Between 2013 and 2016, the Hurricane Sandy Program, administered through both DOI and NFWF, invested over $302 million to support 160 projects designed to improve the resilience of ecosystems and communities to coastal storms and sea level rise.[1] The program supported a wide array of activities including aquatic connectivity restoration, marsh restoration, living shoreline creation, community resilience planning, and coastal resilience science to inform decision-making. Each of these activities has a distinct impact on ecosystem and community resilience.

DOI and NFWF drafted the following questions to serve as the focus of the evaluation:

1. To what extent did projects **implement activities** as intended? What factors facilitated or hindered project success?
2. What **key outcomes** were realized for habitat, fish and wildlife, and human communities?
3. Is there evidence that investments in green infrastructure are **cost-effective** compared to gray infrastructure?
4. Did investments in tools and knowledge related to resilience **improve decision-making**?
5. What **information is needed** to better understand the long-term impacts of investments in resilience?

The evaluation includes six case studies, each providing a deeper level of analysis on a subset of the projects.

1.1 Purpose

This case study provides an in-depth analysis of projects that focused on planning activities associated with improving community resilience. This case study focused on evaluation questions #1, #2, and #5 (above). We identify key findings about the development of these planning products and examine the available evidence about the impacts of these planning activities on community resilience.

1.2 Scope

This case study examined 28 community resilience planning projects in the Hurricane Sandy Program portfolio. Projects in this category produced plans, strategies, and recommendations for improving resilience. To be included in this category, a project must have focused on planning activities, including site-specific designs, community or regional management plans or vulnerability assessments, and resilience tools tied to specific planning activities. Projects that primarily focused on generating new scientific knowledge were included in the data, mapping, and modeling case study (Abt Associates, 2019a). See Section 3 for a more detailed description of the portfolio of community resilience planning projects; and Appendix A for a full list of the 28 projects.

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[1] The evaluation covers these 160 projects. In some cases DOI and NFWF reinvested unspent funds in new, additional projects after the December 2016 cutoff date. These new projects are not included in the evaluation.

1.3 Organization

The remainder of this document is organized as follows:

- Section 2 provides an overview of the methods and information sources used for this case study
- Section 3 provides a detailed overview of the community resilience planning projects included in the Hurricane Sandy Program
- Section 4 discusses key case study findings, organized by evaluation question and topic
- Section 5 provides a brief conclusion.

2. Methods Overview

This case study integrates information from the following information sources:

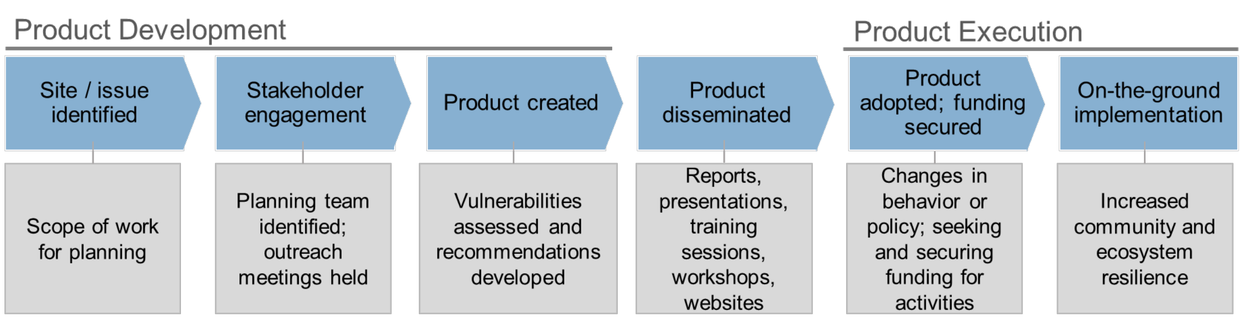
- Archival materials from Hurricane Sandy Program project files (e.g., proposals, interim and final reports)
- A survey of project leads via a web-based instrument
- Interviews with 15 project leads who led community resilience projects
- Interviews with NFWF and DOI staff
- Quantitative information provided by project leads in their reports (e.g., number of outreach activities completed, number of people reached through outreach activities)
- Internet searches about specific projects, with a particular focus on identifying follow-on resilience-building actions.

A more detailed description of evaluation methods can be found in Abt Associates (2019b).

3. Overview of Projects

Engaging in planning activities can increase the potential for rapid and effective resilience actions in the future. For example, when site-specific designs are developed for on-the-ground restoration projects, these projects can proceed more rapidly to implementation once funding is received. At the community or regional level, management plans and tools can help identify the activities that will result in the greatest resilience benefits to the community. Overall, if planning activities are properly scoped and developed, they can expedite implementation of activities that improve community resilience (see Figure 1).

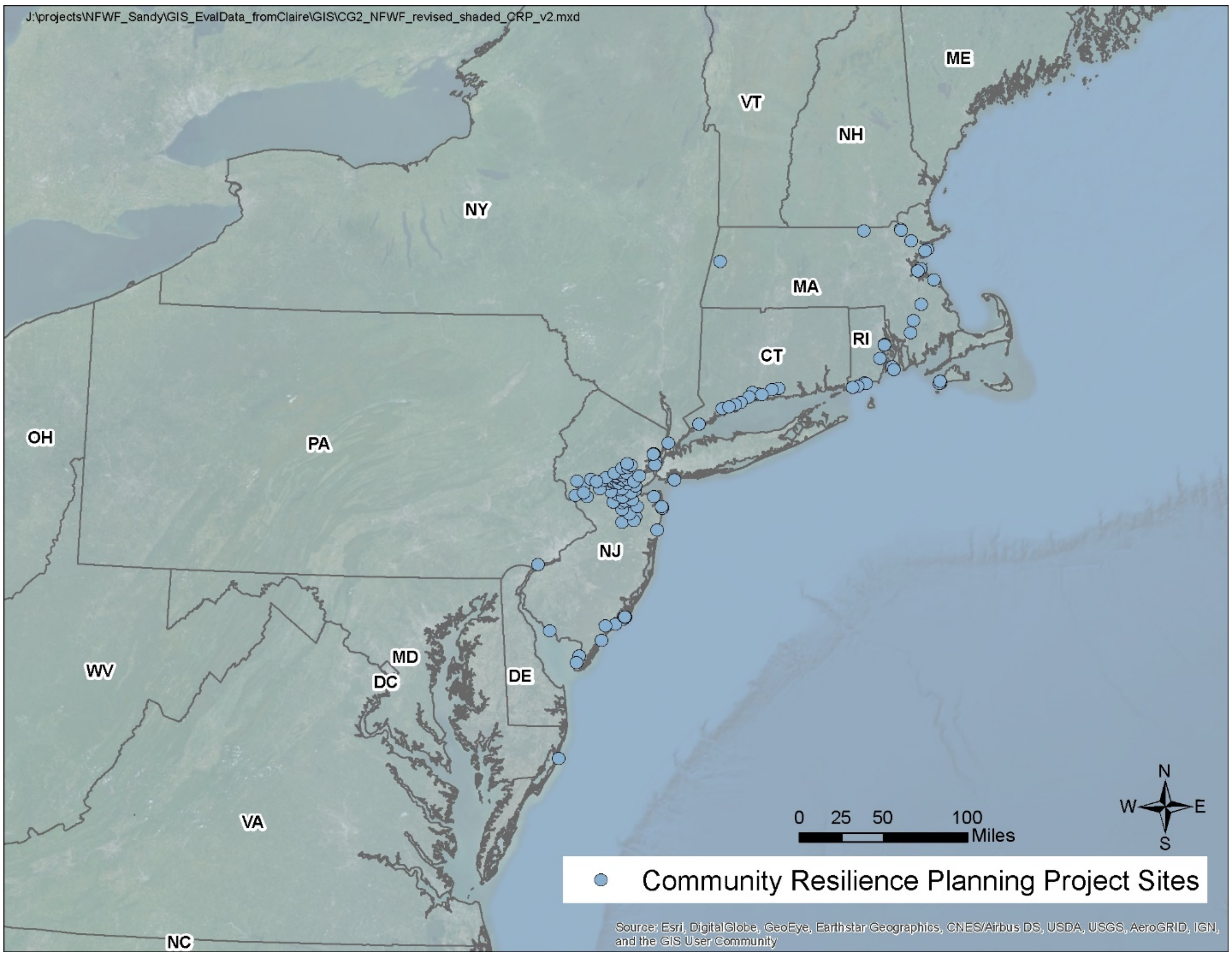
Figure 1. Logic model showing how community resilience planning projects can support improved resiliency, with relevant examples from each step in the logic chain



The Hurricane Sandy Program portfolio supported 28 projects that specifically focused on engaging in planning activities to improve coastal resilience; the program invested more than $22.9 million in community resilience planning activities across these projects (see Figure 2). Twelve of these projects also included other resilience activities; the total funding provided by the program for all of the activities in the 28 projects was $50.9 million.[2] The projects were implemented by NFWF and by a subset of bureaus within DOI, as follows (with the amount of funding provided specifically to community planning activities in parentheses):

- NFWF (24 projects, $14.5 million)
- National Park Service (NPS) (two projects, $0.9 million)
- Bureau of Land Management (BLM) (one project, $3.5 million)
- Bureau of Safety and Environmental Enforcement (BSEE) (one project, $4.0 million).

Figure 2. Location of community resilience planning activities.[a]



a. Since some projects conducted planning activities in multiple sites (see Appendix A), the number of community resilience planning project sites (dots) in the figure exceeds 28.

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[2] Table A.1 presents the amount of project funding specifically allocated to community resilience planning activities. For 16 projects, this was the full project funding amount. For 12 projects, this is a subset of the total project funding. The allocation was based on available project documentation.

4. Findings

Topic: Project Implementation (PI)

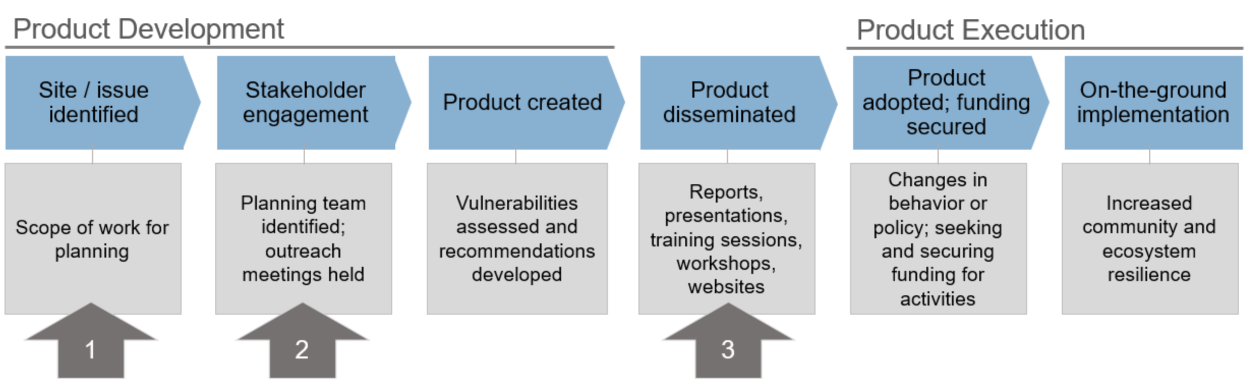
Finding PI.1: Nearly 65% of the projects had successfully completed their proposed planning activities at the time of evaluation. There were typically minimal changes in scope of the planning activities.

Eighteen of the 28 community resilience planning projects were completed[3] at the time of the evaluation, with 10 projects still considered active. For the projects that focused solely on planning, only two had changes in scope and both were minor. As discussed below, some planning projects had remaining funding and time to progress from the planning to implementation stage, which required a change in scope.

Finding PI.2: A combination of factors delayed 21 of the 28 projects, including data gathering and coordination.

Contract amendment data available through NFWF and DOI show that 21 of the 28 projects that included community resilience planning activities were delayed by an average of about one-and-a-half years (516 days), compared to the original completion estimates. However, 11 of these projects also included significant on-the-ground restoration components, and in all 11 cases, those project delays were related to on-the-ground activities (i.e., permitting project design, contracting, or procurement issues). The remaining 10 projects experienced delays at different stages in the planning cycle, including the need for additional data collection or changes to project design prior to creation (Figure 3 – Arrow 1), additional time to effectively coordinate project activities with other partners (Figure 3 – Arrow 2), and difficulties in completing outreach to key audiences of planning efforts (Figure 3 – Arrow 3).

Figure 3. Planning steps associated with project delays.



[3] While our evaluation generally provides findings elicited through the review of archival materials received through December 2018, project status information reflects information gathered through April 2019 (updated project status information was obtained through a supplementary web search in March 2019 and an updated spreadsheet provided by NFWF).

Topic: Project Outcomes (PO)

4.1 Human Community Outcomes

Finding PO.1: The program has supported the creation of 276 individual planning products that are designed to identify, describe, or prioritize future actions that would improve community resilience.

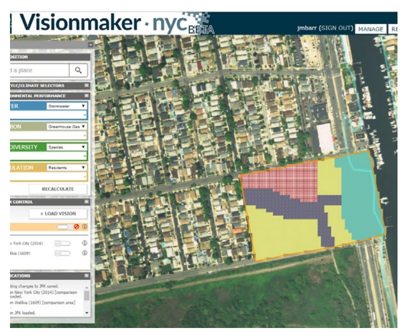
Projects that included community resilience planning created different types of planning products as their final deliverables. To better understand the scope and purpose of these planning products, we categorized them into three different types of products (Box 1). Projects completed one or more of each type of product. To be included in this category, a project must have focused on planning activities; projects that primarily focused on generating new scientific knowledge were included in the data, mapping, and modeling case study.

Box 1. Products created by community resilience planning projects.

Site-specific designs. Projects created detailed plans for restoration activities at specific sites, including plans for restoration of aquatic connectivity, marsh restoration, beach and dune restoration, and green infrastructure.

Management plans or assessments. Projects created documents detailing key vulnerabilities and assets within their chosen area (ranging from a single community to a region), and provided recommendations for actions to improve resilience.

Resilience tools. Projects created datasets, mapping interfaces, websites, or online tools to inform resilience. These tools were published for use by community leaders and the general public to incorporate in their planning activities.



Source: Project reports.

Using the information from archival materials, we estimate that the community resilience planning projects funded through the Hurricane Sandy Program produced 276 planning products (Table 1). Human communities benefit from these planning products because they enable sound decision-making about future resilience investments.

Table 1. Projects and their resulting community resilience planning products and implementation activities, organized by number of products. (Dashes indicate no product was created or implementation is not yet proceeding.)

Project identification (ID)	Project title	Number of products by category			Type of Implementation
		Design	Plan or assessment	Tool	
NFWF-44193	Incorporating green infrastructure resiliency in the Raritan River Basin, New Jersey	54	55	56	Install green infrastructure
NFWF-42697	Building green infrastructure into community policies (RI)	3	1	2	–
NFWF-43429	Creating a resilient Delaware Bay shoreline in Cape May and Cumberland counties, New Jersey	1	8	–	–
NFWF-44020	Developing a green infrastructure plan for Chester City, Pennsylvania	1	1	–	Install green infrastructure
BLM-unknown	Seed banking for resiliency project: An end of year report to the Department of Interior on 2015 activities and planned activities in 2016	–	3	1	Perform seed collections
NFWF-43281	Restoring Delaware Bay's wetlands and beaches in Mispillion Harbor Reserve and Milford Neck Conservation Area	2	–	1	Restore beach
NFWF-42671	Enhancing seven communities, ecosystems, and infrastructure resiliency by removing seven fish barriers, Massachusetts	13	–	–	Remove dams
NFWF-41739	Reusing dredged materials to enhance salt marsh in Ninigret Pond, Rhode Island	2	–	–	Restore marsh
NFWF-43931	Strengthening Marshes Creek through green and grey infrastructure, New Jersey	2	–	–	–
NFWF-42714	Transforming Hoboken's Block 12 into a green infrastructure asset, New Jersey	1	–	–	Install green park
NFWF-42957	Designing a daylighting plan to improve Harlem River's water quality and resiliency, New York	1	–	–	–
NFWF-42984	Enhancing Mill River's flood resiliency and habitat corridor, Connecticut	1	–	–	Install green park
NFWF-43290	Developing a design that will enhance Liberty State Park's marshes and upland habitats, New Jersey	1	–	–	Restore marsh
NFWF-43986	Strengthening Monmouth Beach's marshes and dunes, New Jersey	1	–	–	–
NFWF-44199	Designing a plan to reuse dredged rock to protect the Boston Harbor shoreline, Massachusetts	1	–	–	Install rocky berm/reef

Project identification (ID)	Project title	Number of products by category			Type of Implementation
		Design	Plan or assessment	Tool	
BSEE-69	Improve resilience of the Ohmsett facility	1	–	–	Renovate facility
NFWF-42279	Building ecological solutions to coastal community hazards (NJ)	–	33	–	Restore instream habitat; install living shorelines
NFWF-44245	Developing a resiliency management plan for Pawcatuck River Watershed, Connecticut and Rhode Island	–	13	–	–
NFWF-44271	Creating a regional framework for coastal resilience in Southern Connecticut	–	4	–	–
NFWF-41766	Coastal resiliency planning and ecosystem enhancement for Northeastern Massachusetts	–	2	–	–
NFWF-43322	Enhancing Wampanoag Tribe of Gay Head's land resiliency in Martha's Vineyard, Massachusetts	–	2	–	Replant vegetation
NFWF-41795	Strengthening Sachuest Bay's coastal resiliency, Rhode Island	–	1	–	Install BMPs
NFWF-43861	Creating a natural resource resiliency assessment and action plan, Rhode Island	–	1	–	–
NFWF-44140	Improving coastal resiliency through community engagement, Ohio and Rhode Island	–	1	–	–
NPS-23	Final Fire Island wilderness breach management plan/environmental impact statement	–	1	–	–
NFWF-42551	Green infrastructure in Accomack and Northampton counties (VA)	–	–	2	Tool applied to plans
NFWF-44157	Repairing infrastructure and designing wetland and beach restoration plans along the Central Delaware Bayshore	–	–	2	–
NPS-14-7	Visionmaker Jamaica Bay: Evaluation and synthesis of community generated adaptation strategies to enhance resilient ecosystems in Jamaica Bay, NY (subproject)	–	–	1	–

Site-Specific Designs

Fifteen community resilience planning projects focused on creating site-specific designs for future on-the-ground resilience projects. These included “shovel-ready designs” that can be implemented as soon as implementation funding is in place and “conceptual designs” that can enable project leads to prioritize future resilience projects based on factors such as cost, degree of benefit, and likelihood of success. The 15 projects completed a total of 85 site-specific design products. Approximately half of these projects proceeded with implementation of their planning activities (Box 2).

Box 2. Site-specific designs: An example of developing plans to expedite future resilience projects.

A Massachusetts project created **site-specific designs for removing three dams** at risk for causing flood damage. After the plans were created, the project secured additional funding to move ahead with **removal of all three dams**. The project also developed **conceptual plans and cost estimates for an additional 10 new dam removals** based on a statewide public safety and ecological benefit prioritization process. With the conceptual plans in place, 1 of the 10 sites is planned to move forward with removal.

Ipswich Mills Dam, funded for a removal feasibility study, scheduled to be removed in summer 2019.

Source: Ipswich River Watershed Association.

Management Plans or Assessments

Fourteen community resilience planning projects created 126 management plans or assessments that provided recommendations and guidance for improving resilience at the city, regional, or watershed level (Box 3). These planning products served two main purposes:

- To identify key assets and vulnerabilities within a city, region, or watershed so that future projects can focus on activities and areas that provide the greatest benefits for resilience
- To provide specific recommendations for future activities, including green infrastructure installation, marsh management strategies, and watershed conservation and management plans.

Box 3. Management plans and assessments: An example of developing plans to expedite future resilience projects.

This project developed a framework document describing actions to expand the use of green stormwater infrastructure to enhance stormwater management, reduce water volume and flooding, and protect water quality in a Pennsylvania community. **The plan defines green stormwater infrastructure approaches, describes the applicability of different approaches within the community, outlines relevant regulatory requirements, and offers potential first steps toward implementation.** At the time of the plan's publication, which coincided with the city's broader climate adaptation planning strategy, the city announced a community-based public-private partnership to invest $50 million in the design, construction, and maintenance of green stormwater infrastructure within the community over the next two decades.

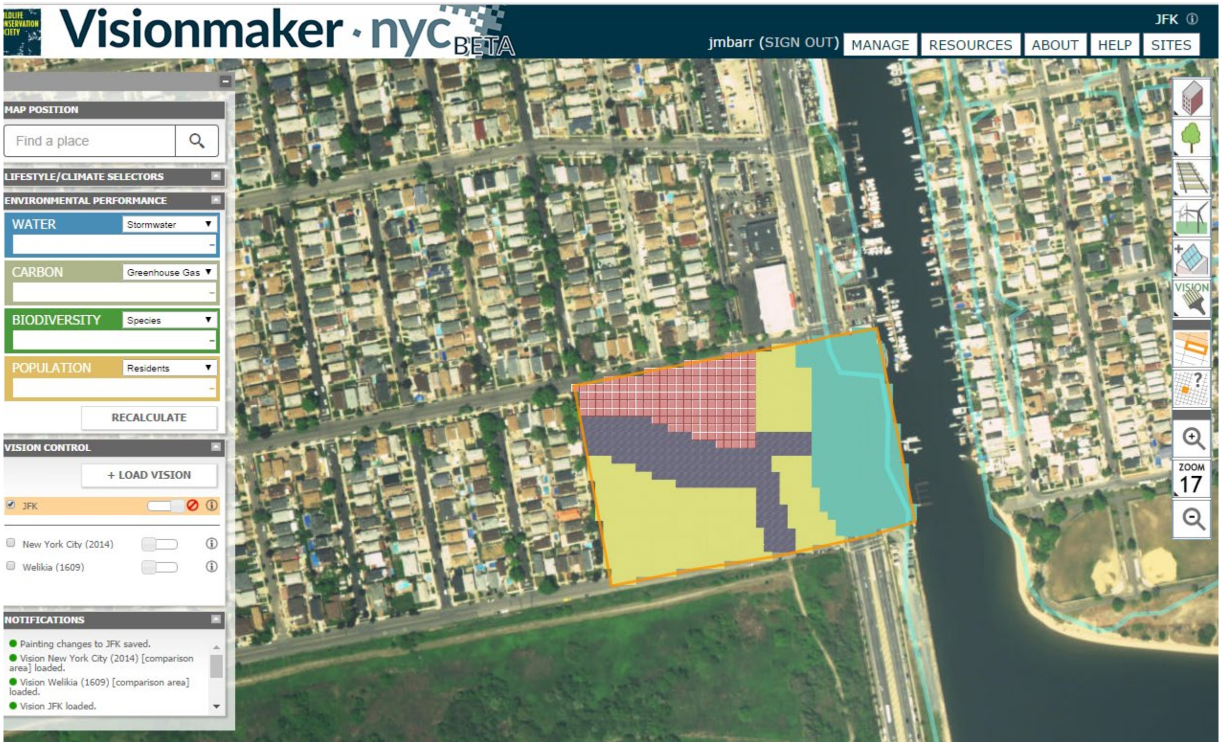
A screenshot of the City of Chester Green Stormwater Infrastructure Plan.

Resilience Planning Tools

Seven community resilience planning projects created 65 models, maps, and web tools to provide resilience recommendations for future planning efforts. These tools are designed to inform future restoration and communicate available resilience options to the interested public and municipal leaders for implementation (Box 4).

Box 4. Resilience planning tools: An example of developing plans to expedite future resilience projects.

A New York project developed a free online tool called Visionmaker Jamaica Bay. The tool incorporates current values of relevant environmental metrics such as greenhouse gas emissions, combined sewer overflows, and population density. Users are able to modify ecosystems and infrastructure, and select climate scenarios to create "visions" to evaluate ecosystem and economic responses to various resilience strategies.



A screenshot of the Visionmaker Jamaica Bay tool from the Howard Beach neighborhood in New York City.

Finding PO.2: Adoption and implementation of planning products by communities varied across projects, with availability of funding noted as a key factor in the speed of uptake.

Following creation of these planning products, 14 projects reported hosting workshops, training sessions, or other forms of direct outreach to share their products ("Product disseminated" step in Figure 3). Teams held community and decision-maker engagement workshops, created outreach documents, and sent products directly to relevant stakeholders. The success of these outreach and engagement efforts was not measured systematically across projects. Anecdotally, projects noted positive reactions to their planning products and a willingness by communities to incorporate them into their planning processes. Overall, project leads noted that getting engagement and buy-in for their products from elected officials, community planners, and relevant city staff was a success factor in advancing the use and implementation of the plans.

Project leads for some projects described limitations or slowness in the uptake of their planning products, primarily due to funding limitations or to a lack of experience within communities for new resilience approaches. For example, one project created flood management plans for several communities, but noted the communities had limited funding and staff to readily incorporate major recommendations such as dam removals. The communities did readily incorporate some smaller elements into their planning, such as revisions to town ordinances and green infrastructure installations. Another project created several community vulnerability assessments, and noted that while the reception to their resilience guide was positive, individuals and governments were slow to integrate the new approaches into existing management strategies. They attributed this slowness to the relatively new approach of incorporating ecological solutions into community planning.

Factors contributing to successful uptake of planning products are described below under PO.3.

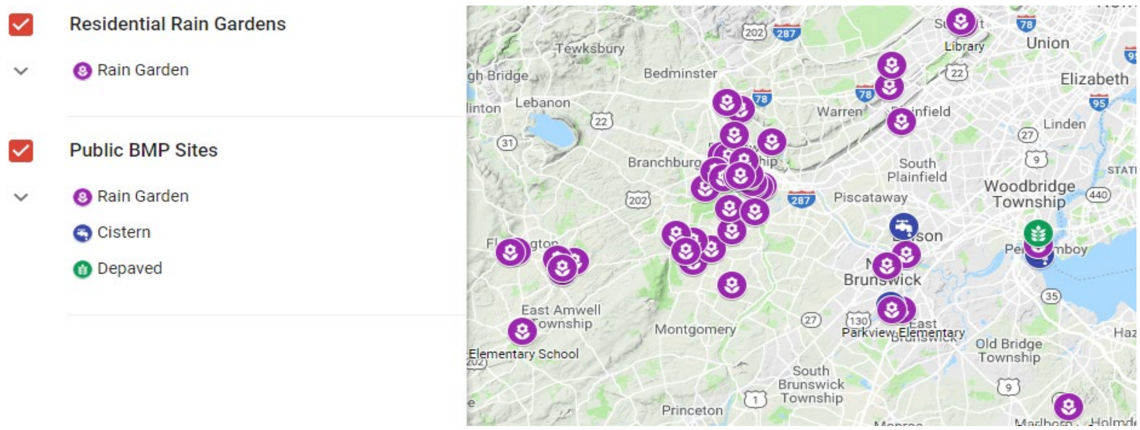
Finding PO.3: For 54% of the community resilience planning projects, planning activities have already led to actions that have directly increased resilience and promoted adoption of resilience activities beyond the original project areas.

Fifteen of the 28 community resilience planning projects have reported that implementation of the planned activities is already moving forward (Table 1; Box 5). Projects anecdotally reported that the existence of plans was a key factor in gaining funding and buy-in to move resilience efforts forward. Several projects' (see Boxes 2 and 5) Hurricane Sandy grants originally only focused on planning, but were modified to incorporate on-the-ground implementation of their planned activities. This rapid progression occurred because the planning documents enabled the project team to quickly leverage additional funding and proceed directly to implementation. In some cases, project success and implementation also spread outside the original project area or audience.

In addition to leveraging additional funding, project leads noted some common factors that led to successful adaptation or implementation of their planning products. The most important success factor was gaining buy-in from the public and relevant municipal actors throughout the development, dissemination, and execution of products. Gaining their input, and tailoring products to the concerns and needs of the actors, increased the likeliness of uptake upon project completion. Project leads also noted that a greater degree of specificity led to better uptake of the plans. For example, the creation of detailed plans for particular sites led to obtaining implementation funding. Providing comprehensive recommendations for actions to be taken enabled target audiences to better envision the benefits, compared to more general planning advice. While specificity was a factor for success, projects also emphasized the need for flexibility in plans. Several projects noted that any challenges that arose (e.g., new suggestions from stakeholders, funding and permitting setbacks, site-related issues) could be more easily overcome by having backup options or the ability to adjust their plans.

Box 5. Examples of successful planning product incorporation and implementation.

A **New Jersey project** from Rutgers University created land cover assessments and site-specific designs of green infrastructure. Although the project originally envisioned focusing solely on the planning stage, development of the plans enabled the project to move forward to implementation under the Hurricane Sandy Program grant. The project used Hurricane Sandy Program funds to install 67 structures, including residential rain gardens and incorporation of green infrastructure best management practices (BMPs) at public sites. The structures in total are estimated to manage drainage across approximately five acres and prevent approximately two million gallons of stormwater from entering local waterbodies, thereby improving water quality and reducing flood risk. This project then catalyzed additional resilience activities. Project outcomes were presented at a Regional Green Stormwater Infrastructure Meeting at the University of Connecticut (UConn) in spring 2015, which resulted in a joint National Oceanic and Atmospheric Administration proposal for Rutgers University to work with UConn to develop similar green infrastructure planning products in Connecticut.



Source: Rutgers.edu.

A **Rhode Island project** reported that the three communities targeted in their plan had adopted their recommendations for stormwater retrofits and near-term implementation of green infrastructure. The project also noted that their green infrastructure planning product was incorporated into a larger state-wide program, expanding the target project audience from three initial communities to a larger network of municipal planners.

Source: Project final report.

A **New Jersey project** provided technical assistance to 10 municipalities to identify or implement new ecologically based resilience strategies, with a goal of implementing projects in 5 of the municipalities. Although delays occurred, by the end of the grant the project had exceeded its initial goals, and 9 of the 10 municipalities had successfully implemented their planned projects. These projects restored 1,010 linear feet of instream habitat and installed 550 linear feet of living shorelines.

Source: Project final report.

4.2 Habitat, Fish, and Wildlife Outcomes

Finding PO.4: Implementation of community resilience planning products will result in the restoration of marsh, beach, and aquatic areas; and the installation of living shorelines and green infrastructure.

As noted in Table 1, 15 projects are already moving toward implementation, including restoring marsh, beach, and aquatic habitats; removing dams to enhance aquatic connectivity; and installing living shorelines and green infrastructure. Additional projects have planned activities in these same categories but have not yet obtained the funding for implementation. As described in separate case studies, on-the-ground implementation of these activities will lead to habitat, fish, and wildlife benefits as the projects mature (Abt Associates, 2019c–f).

Topic: Information Gaps (IG)

Finding IG.1: More time is needed to observe how and to what extent different planning products are used to move forward with implementing on-the-ground resilience activities.

Similar to data, mapping, and modeling projects, the direct resilience benefits of planning efforts take time to fully materialize. Key steps (as described in the logic chain; Figure 1) can include (1) promotion of the planning documents or tools, (2) adoption of planning documents or tools by relevant decision-makers, (3) further prioritization of proposed resilience activities within the plans, (4) acquisition of funding for implementation (which may include the need for further site-specific designs and environmental permitting), and (5) implementation of on-the-ground interventions. As described in the marsh and beach/dune restoration case studies, there is also a time lag between project implementation and full realization of the resilience benefits of those activities as the project matures. Although some projects moved quickly from the planning to implementation stages (see Finding PO.3), we expect that longer-term assessments are needed to fully understand how and to what extent these recently completed planning products have led to resilience benefits such as improving habitats or reducing flood risk for communities.

5. Conclusion

Community resilience planning projects created a variety of products to better understand, communicate, and prepare for potential activities to increase coastal resilience. The format of these products included site-specific designs, management plans or assessments, and resilience tools, depending on the specific planning need targeted. These products have increased the visibility of natural and nature-based solutions to coastal hazards. Planning activities have promoted the uptake and implementation of such solutions in communities originally targeted by the grants, as well as across broader areas that have made use of the planning products. In some cases, the plans have enabled rapid progression to project implementation. Further time and assessment are needed to understand the full uptake of the planning products and how they have catalyzed long-term resilience benefits in coastal communities.

6. References

Abt Associates. 2019a. Case Study: Improving Resilience through Data, Mapping, and Modeling in the Hurricane Sandy Coastal Resilience Program. Rockville, MD.

Abt Associates. 2019b. Evaluation of Hurricane Sandy Coastal Resilience Program. Rockville, MD.

Abt Associates. 2019c. Case Study: Improving Marsh Resilience through the Hurricane Sandy Coastal Resiliency Program. Rockville, MD.

Abt Associates. 2019d. Case Study: Cost-Effectiveness of Reducing Coastal Erosion through Living Shorelines in the Hurricane Sandy Coastal Resiliency Program. Rockville, MD.

Abt Associates. 2019e. Case Study: Restoration of Aquatic Connectivity in the Hurricane Sandy Coastal Resilience Program. Rockville, MD.

Abt Associates. 2019f. Case Study: Restoring Beaches and Dunes through the Hurricane Sandy Coastal Resilience Program. Rockville, MD.

Appendix A. Project Summaries

Table A.1. Community resilience planning projects supported through the Hurricane Sandy Program. This table presents the amount of project funding specifically allocated to community resilience planning activities. For 16 projects, this is the full project funding amount; and for 12 projects, this is a subset of the total project funding. The allocation was based on available project documentation. All dollars rounded to the nearest hundred.

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent community resilience planning activities only	
BLM-unknown	Seed banking for resiliency project	Multi: CT, DC, DE, MA, MD, ME, NH, NJ, NY, RI, VA	Bureau of Land Management	$3,500,000	$0
BSEE-69	Improve resilience of the Ohmsett facility	NJ	Bureau of Safety and Environmental Enforcement (BSEE)	$4,000,000	$0
NFWF-41739	Reusing dredged materials to enhance salt marsh in Ninigret Pond, Rhode Island	RI	Rhode Island Coastal Resources Management Council	$325,000	$38,600
NFWF-41766	Coastal resiliency planning and ecosystem enhancement for northeastern Massachusetts	MA	National Wildlife Federation	$294,000	$159,700
NFWF-41795	Strengthening Sachuest Bay's coastal resiliency, Rhode Island	RI	Town of Middletown	$229,000	$64,400
NFWF-42279	Building ecological solutions to coastal community hazards, New Jersey	NJ	New Jersey Department of Environmental Protection	$3,440,000	$894,900
NFWF-42551	Green infrastructure in Accomack and Northampton counties, Virginia	VA	The Nature Conservancy	$292,000	$59,000
NFWF-42671	Enhancing seven communities, ecosystems, and infrastructure resiliency by removing seven fish barriers, Massachusetts	MA	Fish and Game, Massachusetts Department of/ Division of Ecological Restoration	$448,800	$162,400
NFWF-42697	Building green infrastructure into community policies, Rhode Island	RI	University of Rhode Island	$400,000	$0
NFWF-42714	Transforming Hoboken's Block 12 into a green infrastructure asset, New Jersey	NJ	City of Hoboken	$250,000	$3,615,400

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent community resilience planning activities only	
NFWF-42957	Designing a daylighting plan to improve Harlem River's water quality and resiliency, New York	NY	New York City Department of Parks and Recreation	$250,000	$2,116,000
NFWF-42984	Enhancing Mill River's flood resiliency and habitat corridor, Connecticut	CT	Mill River Collaborative	$3,750,000	$7,880,200
NFWF-43281	Restoring Delaware Bay's wetlands and beaches in Mispillion Harbor Reserve and Milford Neck Conservation Area	DE	Delaware Department of Natural Resources	$450,000	$151,900
NFWF-43290	Developing a design that will Enhance Liberty State Park's marshes and upland habitats, New Jersey	NJ	New Jersey Department of Environmental Protection – Office of Natural Resource Restoration	$250,000	$147,000
NFWF-43322	Enhancing Wampanoag Tribe of Gay Head's land resiliency in Martha's Vineyard, Massachusetts	MA	Wampanoag Tribe of Gay Head	$67,000	$23,200
NFWF-43429	Creating a resilient Delaware Bay Shoreline in Cape May and Cumberland counties, New Jersey	NJ	American Littoral Society	$475,000	$25,400
NFWF-43861	Creating a natural resource resiliency assessment and action plan, Rhode Island	RI	Narragansett Indian Tribe	$180,000	$60,200
NFWF-43931	Strengthening Marshes Creek through green and grey infrastructure, New Jersey	NJ	Rutgers University	$272,000	$22,200
NFWF-43986	Strengthening Monmouth Beach's marshes and dunes, New Jersey	NJ	Monmouth Beach, New Jersey	$178,000	$175,000
NFWF-44020	Developing a green infrastructure plan for Chester City, Pennsylvania	PA	Delaware Valley Regional Planning Commission	$290,000	$32,100
NFWF-44140	Improving coastal resiliency through community engagement, Ohio and Rhode Island	Multi: OH, RI	Association of State Floodplain Managers	$341,700	$86,100
NFWF-44157	Repairing infrastructure and designing wetland and beach restoration plans along the Central Delaware Bayshore	DE	Delaware Department of Natural Resources	$200,000	$117,000

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent community resilience planning activities only	
NFWF-44193	Incorporating green infrastructure resiliency in the Raritan River Basin, New Jersey	NJ	Rutgers	$410,000	$176,800
NFWF-44199	Designing a plan to reuse dredged rock to protect the Boston Harbor shoreline, Massachusetts	MA	Maryland Division of Marine Fisheries	$240,000	$160,100
NFWF-44245	Developing a resiliency management plan for Pawcatuck River watershed, Connecticut and Rhode Island	Multi: CT, RI	Wood-Pawcatuck Watershed Association	$720,000	$188,000
NFWF-44271	Creating a regional framework for coastal resilience in Southern Connecticut	CT	South Central Regional Council of Governments	$700,000	$0
NPS-14-7	Visionmaker Jamaica Bay: Evaluation and synthesis of community generated adaptation strategies to enhance resilient ecosystems in Jamaica Bay, NY (subproject)	NY	Wildlife Conservation Society; National Park Service	$350,000	$0
NPS-23	Develop breach management plans for coastal national seashores to maximize ecological benefits	Multi: MD, NY	Denver Service Center; National Park Service	$570,500	$0

Abt ASSOCIATES

BOLD THINKERS DRIVING REAL-WORLD IMPACT

Case Study: Improving Marsh Resilience through the Hurricane Sandy Coastal Resilience Program

Contract # 5359

PREPARED FOR:

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FINAL

2019

Case Study: Improving Marsh Resilience through the Hurricane Sandy Coastal Resilience Program

Prepared by Abt Associates, September 2019

Summary

Purpose

This case study forms part of a larger 2019 evaluation of the Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program) of the U.S. Department of the Interior (DOI) and the National Fish and Wildlife Foundation (NFWF). It provides an analysis of the *ecological resilience* benefits of marsh restoration projects.

Scope

We examined 24 projects in the Hurricane Sandy Program portfolio focused on enhancing ecological resilience at marsh sites through activities such as adding sediment to marshes to increase elevation, planting native marsh plants, removing invasive species, and dredging tidal channels to enhance hydrological connections and re-establish appropriate flood durations.

Findings

Key findings identified from archival materials, a survey and interviews of project leads, and peer-reviewed literature include:

- The portfolio of Hurricane Sandy Program marsh restoration projects restored or created over 190,000 acres of habitat.
- Projects that are complete have generally met design goals, though some mid-project adjustments were required for some projects to achieve success.
- Most projects had only recently been completed, or were not complete, at the time of the evaluation.
- A combination of factors delayed nearly all projects on average by more than 18 months, including permitting challenges, additional data collection or design work, and weather.
- Generally projects are recovering as quickly as expected after restoration, but results within projects are mixed, with some areas not maintaining expected elevation or plant cover.
- Resilient marshes have key, observable characteristics in common; some of these characteristics are being measured by restoration projects, allowing for an assessment of resilience improvements.
- Early observations suggest that many restored sites are likely to have improved resilience, but more time and data are needed to provide a robust assessment.

Conclusion

, these findings suggest that **investments the Hurricane Sandy Program has made in restoring marshes are generally on track to providing enhanced ecological resilience to marsh and nearby ecosystems.** Early project results typically show enhancements in marsh vegetation cover and growth, reduced invasive cover, and increased elevation of marshes, although these enhancements are not necessarily uniform in all project areas. Early project results also show improved hydrological dynamics – reconnecting marshes to nearby tidal systems or managing water level in freshwater systems. All of these near-term achievements are improving the ability of marshes to provide habitat for birds, fish, and other wildlife; and will improve their ability to withstand or recover from future storms or other forms of disturbance. However, these observations are preliminary, and several more years of recovery and monitoring data are needed to more fully understand the likely long-term impact of restoration actions on marsh ecosystem resilience.

1. Introduction

This case study forms part of a larger 2019 evaluation of the DOI and NFWF Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program). Between 2013 and 2016, the Hurricane Sandy Program, administered through DOI and NFWF, invested over $302 million to support 160 projects designed to improve the resilience of ecosystems and communities to coastal storms and sea level rise.[1] The program supported a wide array of activities, including aquatic connectivity restoration, marsh restoration, beach and dune restoration, living shoreline creation, community resilience planning, and coastal resilience science to inform decision-making. Each of these activities has a distinct impact on ecosystem and community resilience.

DOI and NFWF drafted the following questions to serve as the focus of the evaluation:

1. To what extent did projects **implement activities** as intended? What factors facilitated or hindered project success?
2. What **key outcomes** were realized for habitat, fish and wildlife, and human communities?
3. Is there evidence that investments in green infrastructure are **cost-effective** compared to gray infrastructure?
4. Did investments in tools and knowledge related to resilience **improve decision-making**?
5. What **information is needed** to better understand the long-term impacts of investments in resilience?

The evaluation includes six case studies, each providing a deeper level of analysis on a subset of the projects.

1.1 Purpose

This case study provides an in-depth analysis of resilience activities that focused on marsh restoration, and is focused on evaluation questions #1, #2, and #5 (above). More specifically, we focused this case study on understanding the *ecological* resilience benefits of a subset of marsh restoration projects that were designed primarily to provide ecological, as opposed to socioeconomic, benefits. For the purposes of this case study, we **define *ecological resilience* as the capacity of an ecosystem to respond to a perturbation or disturbance either by resisting damage or recovering quickly from that damage**. Marsh restoration not only provides storm protection for nearby ecosystems, but also protects human communities and infrastructure from storm surge and chronic flooding associated with sea level rise. The resulting socioeconomic benefits of marsh restoration, when combined with building a living shoreline to reduce coastal erosion, are discussed in the Living Shorelines Case Study of the Hurricane Sandy Evaluation.

1.2 Scope

We examined 24 projects in the Hurricane Sandy Program portfolio that implemented marsh restoration primarily to improve the ecological resilience of those ecosystems. Twelve of these projects were selected for a more in-depth assessment of implementation issues and ecological outcomes achieved to date through marsh restoration. The selected projects all were completed or close to completion by 2017, had incorporated robust monitoring, and included at least one of the four most common marsh restoration actions implemented in the Hurricane Sandy Program

[1] The evaluation covers these 160 projects. In some cases DOI and NFWF reinvested unspent funds in new, additional projects after the December 2016 cutoff date. These new projects are not included in the evaluation.

portfolio (i.e., hydrologic reconnection, thin-layer deposition, invasive species control, and planting marsh vegetation). See Section 3 for a more detailed description of marsh restoration projects and Appendix A for a full list of relevant projects, including those selected for in-depth review. Many projects that focused on marsh restoration also included other types of resilience interventions (e.g., beach/dune restoration). We focus solely on the marsh habitat-related aspects of these projects in this case study, but provide an analysis of the potential synergies of different resilience activities in the main report.

1.3 Organization

The remainder of this document is organized as follows:

- Section 2 provides an overview of the methods and information sources used for this case study
- Section 3 provides a detailed overview of the marsh restoration projects included in the Hurricane Sandy Program
- Section 4 discusses key case study findings, organized by evaluation question and topic
- Section 5 provides a brief conclusion.

2. Methods Overview

This case study integrates information from the following sources:

- Archival materials from Hurricane Sandy Program project files (e.g., proposals, interim and final reports)
- A survey of project leads via a web-based instrument
- Interviews with eight project leads (i.e., grant recipients) who led the marsh restoration projects
- Quantitative information provided by project leads in their reports (e.g., acres of habitat restored)
- Literature searches addressing specific contextual issues (e.g., key marsh ecosystem properties associated with ecological integrity, the typical lag time between marsh restoration actions and full vegetative maturity).

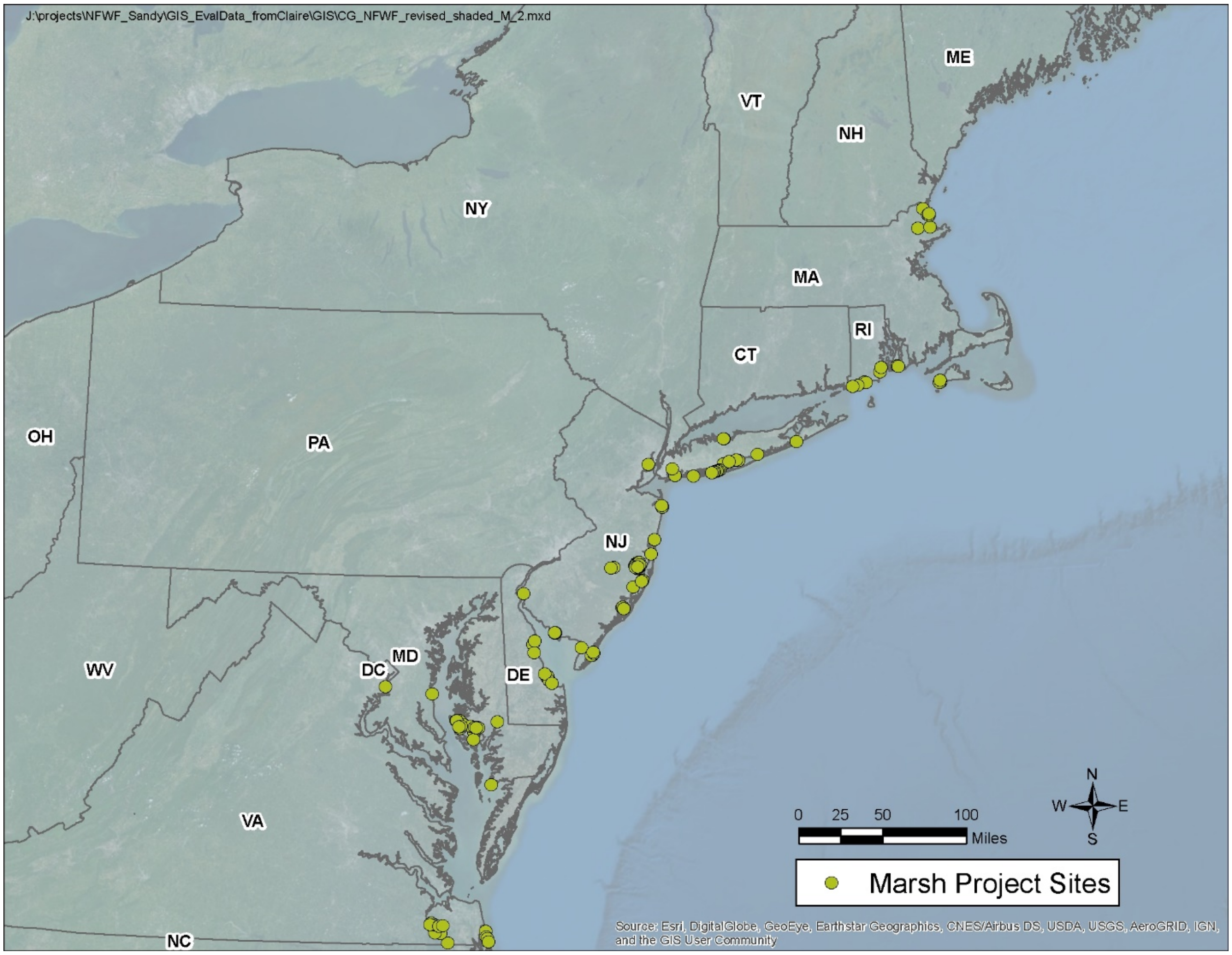
A more detailed description of evaluation methods can be found in Abt Associates (2019).

3. Overview of Projects

One of the objectives of the Hurricane Sandy Program is to strengthen natural ecosystems affected by Hurricane Sandy and reduce their vulnerability to future storms and sea level rise. Resilient ecosystems are more likely to continue providing critical ecosystem services, including habitat for threatened and endangered species, storm protection for nearby habitat and communities, as well as recreation and scenic beauty. DOI and NFWF have supported a range of habitat restoration activities designed to strengthen natural ecosystems, but a key focus of their efforts has been the restoration of freshwater and coastal marshes because of the important role they play in supporting key wildlife, protecting coastal resources, and supporting commercial and recreational fisheries.

Overall, there were 24 projects that included ecologically focused marsh restoration, and they spanned 7 states (Delaware, Maryland, Massachusetts, New Jersey, New York, Rhode Island, and Virginia; Figure 1); 15 of these projects also supported other resilience activities. Overall, the Hurricane Sandy Program invested more than $92.6 million in marsh restoration in 24 projects (Table A.1), 15 of which also included other resilience activities; the total funding provided by the program for all of the activities in the 24 projects was $119.7 million.[2]

Figure 1. Location of marsh restoration activities.[a]



a. Since some projects conducted restoration activities in multiple sites (see Appendix A), the number of marsh restoration project sites (dots) in the figure exceeds 23.

Hurricane Sandy projects undertook four primary marsh restoration activities: hydrologic reconnection, thin-layer deposition, invasive species control, and planting marsh vegetation (see Box 1). In addition to the actions described in Box 1, many marsh restoration projects also installed water control structures of various types, removed debris or contaminated sediment, and planted riparian vegetation. For the 12 projects that were included in our in-depth analysis, we characterized the specific combination of restoration actions they undertook (Table 1). See Box 2 for examples of marsh restoration projects being carried out in different states.

[2] Table A.1 presents the amount of project funding specifically allocated to marsh restoration activities. For nine projects, this was the full project funding amount. For 15 projects, this is a subset of the total project funding. The allocation was based on available project documentation.

Box 1. Key marsh restoration activities.

Hydrologic reconnection removes artificial drainage or water conveyance structures and restores natural marsh channels. It aims to restore tidal hydrology and support healthy, native marsh vegetation, which is expected to help maintain marsh elevation and improve their persistence in the face of sea level rise.

Thin-layer deposition aims to increase marsh elevation to support native marsh vegetation and preserve marsh habitat. It is commonly used in areas with active ponding, a sign that the marsh is losing elevation, and will eventually be flooded and convert to open-water habitat.

Removing or controlling invasive species is performed to improve habitat quality and resilience.

Planting native marsh vegetation can enhance vegetative recovery. This is nearly always performed in conjunction with at least one other restoration action (e.g., thin-layer deposition, hydrologic reconnection, invasive species removal).

Table 1. Information about the 12 projects included in the in-depth analysis for this case-study, including project identification (ID), title, location, major activities performed, and status as of June 2019.

Project ID	Title	State	Thin-layer deposition	Hydrologic reconnections	Invasive species control	Planting vegetation	Status[a] (Anticipated completion date)
NFWF-41739	Reusing dredged materials to enhance salt marsh in Ninigret Pond, Rhode Island	RI	●	●		●	Active (2019)
NFWF-41766	Coastal resiliency planning and ecosystem enhancement for northeastern Massachusetts	MA			●		Complete
NFWF-42942	Increasing salt marsh acreage and resiliency for Blackwater National Wildlife Refuge (NWR), Maryland	MD	●		●	●	Complete[b]
NFWF-42958	Restoring Spring Creek Park's salt marsh and upland habitat, New York	NY			●	●	Active (2019)
NFWF-43095	Reusing dredged material to restore salt marshes and protect communities, New Jersey	NJ	●			●	Complete
NFWF-43849	Developing coastal resiliency regional models, Virginia	VA				●	Complete
USFWS-1	Salt marsh restoration and enhancement at Seatuck, Wertheim, and Lido Beach NWRs, Long Island, New York	NY	●	●	●		Active (2018)
USFWS-15	Prime Hook NWR coastal tidal marsh/barrier beach restoration	DE	●	●	●	●	Complete
USFWS-37	Restoring coastal marshes in New Jersey NWRs	NJ	●	●			Active (2018)
USFWS-43	Restoring resiliency to the Great Marsh, Parker River NWR, Massachusetts	MA		●	●		Complete
USFWS-65	Protecting property and helping coastal wildlife: Enhancing salt marsh and estuarine function and resiliency for key habitats on impacted wildlife refuges from Rhode Island to southern Maine	Multi-state	●	●	●	●	Complete
USFWS-85	Pocomoke Sound marsh enhancement, Ferry Point, Nanticoke River	MD			●		Complete

a. Expected year of completion is included in parentheses for active projects. In a few cases, projects are listed as active even if they were expected to be completed in 2018 or if their major restoration activities were completed because final reports have not yet been submitted.

b. Major project activities are complete, but adaptive management is underway and lessons learned are being documented.

Box 2. Marsh restoration activities by state.

Delaware: Two projects. Projects focused on restoring marsh hydrology primarily by removing or restoring water control structures and restoring drainage channels.

Before and after restoration of a water control structure in Little Creek Wildlife area, DE.

Maryland: Three projects. One project included thin-layer deposition (pictured), and the other two projects involved channel creation and invasive species removal.

Thin-layer dredge is applied to Blackwater NWR.

New Jersey: Five projects. Most projects have performed thin-layer deposition, along with other activities such as coir log installation and planting native vegetation.

Project ecologist shows coir logs installed to contain applied dredge at New Jersey-Cape May Wetlands Wildlife area (Cape May County Herald).

Massachusetts: Three projects. Projects removed invasive plants and restrictions to tidal flow.

Biologist explains ditch remediation technique used to restore natural marsh habitat and tidal flow in the Great Marsh (Margie Brenner, USFWS).

Rhode Island and Maine: Two projects (one in RI only and one in both states). Projects focused on thin-layer deposition, including a large application of dredged material to provide a template and lessons learned for future projects.

Hydraulic placement of dredged sediment on Ninigret Salt Marsh (Chaffee and Frisel; 2017).

New York: Six projects. Projects created channels in existing marsh habitat, as well as regrading and planting upland marsh habitat.

Volunteer plants Spartina *marsh grass in Sunken Meadow State Park (Save the Sound).*

Virginia: Three projects. Projects improved water levels on freshwater wetlands by installing water control structures.

Right: Hydrologic technician demonstrates newly installed aluminum culvert (Jonathon Gruenke, Daily Press).

4. Findings

Topic: Project implementation (PI)

Finding PI.1: Most projects had only recently been completed, or were not complete, at the time of the evaluation.

Archival and web-based materials show that 8 out of the 12 projects in the in-depth analysis were completed[3] at the time of the evaluation, with 4 projects still active. Of the eight projects completed, two were completed in 2016, one in 2017, and five in 2018.

Finding PI.2: A combination of factors delayed nearly all projects, including permitting challenges, additional data collection or design work, and weather.

A combination of issues resulted in nearly every examined project experiencing significant delays compared to original completion estimates. The data available through official contract amendments submitted to NFWF and DOI show that 11 of the 12 projects in the in-depth analysis requested extensions for completing their work, with many projects submitting multiple contract extensions. Of the 12 projects with confirmed timelines, requested extensions delayed projects on average by more than a year-and-a-half (627 days). Most projects cited a combination of factors that contributed to project delays (Box 3).

Finding PI.3: Projects that are complete have generally met design goals, though adjustments were required for some projects to achieve success.

Project reports and project lead interviews suggest that the completed marsh restoration projects have generally met their construction goals. For example, all eight projects included in the in-depth analysis that were completed at the time of the evaluation reported reaching target elevations, restoring tidal regimes, or removing invasives as designed. In addition, final project reports showed that across all projects, 1,600 more acres were restored than proposed and individual projects nearly always met or exceeded the proposed marsh acreage restored. However, project reports and interviews suggested that adaptive management should be expected and built into project timelines. For example, in thin-layer deposition projects, the deposition of sediment was sometimes uneven and project leads moved dredge sediment or added more sediment to some locations. For hydrologic reconnection projects, typically some adjustments to the site needed to be conducted to increase flow and reduce ponding (e.g., cleaning out channels).

[3] While our evaluation generally provides findings elicited through the review of archival materials received through December 2018, project status information reflects information gathered through April 2019 (updated project status information was obtained through a supplementary web search in March 2019 and an updated spreadsheet provided by NFWF).

Box 3. Factors contributing to the delay of marsh restoration projects.

Permitting of novel, complex approaches

In reports, interviews, and contract amendments, five project leads noted that existing permitting systems were often not well-equipped to handle the projects, often due to the novel and multifaceted nature of the marsh restoration work. One project lead noted in a report, "Federal and state permitting systems are not well suited to address climate resiliency action or restoration work in an aquatic environment. Because we did not fit into a navigation or harbor improvement category, the regulators needed to be creative in their application of existing guidelines, standard protocols, and permitting forms." NFWF and DOI staff noted that a specific challenge encountered by multiple project leads was securing permits for a project that caused short-term damage to a marsh but improved its functioning over the long-term (e.g., sediment deposition on top of an existing marsh kills vegetation for a short period of time, but ultimately makes the marsh more productive and resilient). This type of "regulatory rigidity" is a common barrier to securing permits for ecologically focused restoration projects (Ulibarri et al., 2017).

Additional data collection or design work

Four project leads noted that they needed to do extensive research or testing to ensure proper project design or implementation, which caused project delays. For example, one project was utilizing thin-layer deposition in a novel context (i.e., wetlands in a micro-tidal environment, where marsh collapse is not due to coastal erosion but to gradual sea level rise, and where sediment accretion is minimal). Project leads needed to ensure that the proper approach was used to increase marsh height while also maintaining natural vegetation.

Seasonal limitations

Five project leads noted that the weather- and seasonal-dependent nature of marsh restoration activities, particularly dredging and vegetation planting, contributed to delays. Weather events and growing seasons can limit the time available to perform restoration, and work was sometimes delayed for months while waiting for appropriate working conditions to return. In addition, permit conditions can restrict some construction activities, including dredging, to specific times of the year to avoid harming wildlife (e.g., during migration or breeding seasons).

Contracting or procurement

Six project leads reported difficulties in contracting or procurement. Some delays were due to the contractor bidding process. One project noted that it was difficult to secure contractors because of the complex nature of the work and the narrow timeframes involved.

Topic: Project outcomes (PO)

4.1 Habitat, Fish, and Wildlife Outcomes

Finding PO.1: The portfolio of Hurricane Sandy Program marsh restoration projects restored or created more than 190,000 acres of coastal marsh, freshwater wetland, and associated habitats, providing critical support to fish and wildlife in the region.

Project lead-reported data show that the portfolio of marsh restoration projects included in this case study have restored or created a total of 190,491 acres, including 71,223 acres of coastal marsh habitat, 119,236 acres of freshwater wetland habitat, 19 acres of riparian habitat, and 13 acres of associated upland habitat as part of their overall activities.[4]

Coastal marsh habitats are important nursery, foraging, and refuge habitats for many commercially and recreationally important species of fish and crustaceans found along the Atlantic Coast, including blue crab (*Callinectes sapidus*), striped mullet (*Mugil cephalus*), Atlantic croaker (*Micropogonias undulatus*), and black drum (*Pogonias cromis*).

Coastal marsh habitats also provide breeding and foraging habitats for many migratory and resident bird species, including those species of conservation concern either at the federal or state level[5] (Box 4).

[4] These data include projects that have not yet been completed, and thus the final number of miles and acres restored may change; for active projects, we assumed that projects will achieve the proposed miles and acres restored.

[5] Salt marsh is comprised of low and high marsh habitats, which provide distinct benefits to different wildlife species, including birds (e.g., the endangered black rail requires high marsh habitat for nesting). However, we discuss the collective benefits of both types of salt marsh habitats in this evaluation because most projects did not distinguish between them in their reporting.

Box 4. Representative bird species noted by project leads as likely to benefit, or that are already benefiting, from marsh restoration projects*.

Seaside sparrow (*Ammodramus maritimus*) depend on salt marsh habitat for breeding and foraging. (photo: Wikipedia). Multiple subspecies are along the Atlantic Coast, most of which are of conservation concern (photo: Wikipedia).

Red knot (*Calidris canutus)* are migratory shorebirds that depend on mid-Atlantic marsh and beach habitats for foraging during migration. Red knot are protected as a threatened species under the Endangered Species Act (photo: Gregory Breese, USFWS).

Black skimmer (*Rynchops niger*) use marsh-adjacent areas to forage, including tidal areas, estuaries, ditches, and rivers. The North American Waterbird Conservation Plan lists the black skimmer as a species of high concern (photo: Andreas Trepte/ Wikimedia).

Saltmarsh sparrow (*Ammodramus caudacutus*) live solely in salt marshes, where their nests are threatened by sea level rise. Approximately 80% of the population has disappeared over the last 15 years and it is currently being considered for listing under the Endangered Species Act (photo: Evan Lipton, Macaulay Library).

Sources: Atlantic Coast Joint Venture (2014), Audubon (2014, Undated), USFWS (2018, 2019), Cornell Lab of Ornithology (2019), NYSDEC (Undated).

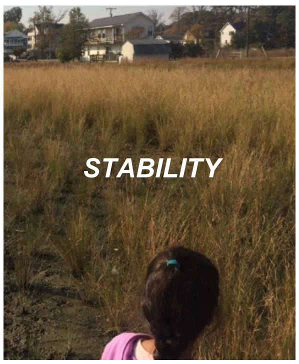
Finding PO.2: Resilient marshes have key, observable characteristics in common, some of which are being measured by restoration projects, allowing for an assessment of resilience improvements.

Our team analyzed whether key, measureable marsh characteristics exist that are typically associated with high marsh integrity and resilience. We then used this information to assess whether the restoration actions were improving marsh ecosystem resilience.

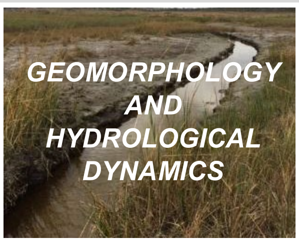
We conducted a literature review that identified four primary ecosystem traits indicative of marsh integrity and resilience, each of which can be affected through restoration actions: **marsh vegetation, marsh stability, and geomorphology and hydrological dynamics**. Our literature review also identified that the health of the **surrounding landscape** also influences marsh integrity and resilience (Box 5, Table 2).

Box 5. Resilience indicators for marsh restoration.

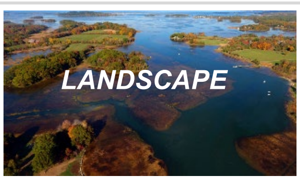
- **Increased plant productivity and stability** can reduce waves and erosion, stabilize sediment, and help marshes persist over time.
- **Decreased invasive species** can allow for increased native vegetation cover, which provides requisite foraging and nesting habitats for native wildlife.



- **The presence of stabilizing species**, such as ribbed mussels (*Geukensia demissa)*, can stimulate the root growth of cordgrass and other marsh plants. They can also bind sediment, which increases marsh height and reduces erosion.
- **Increased accretion rates** (the rate of sediment and vegetative additions to a marsh) can help maintain marsh elevation and buffer the effects of erosion and sea level rise, helping maintain a marsh's position in the landscape.
- **Decreased erosion rates** improve marsh stability; high coastal erosion rates can lead to marsh habitat degradation and loss.
- **Decreased wave energy and power** reduce the likelihood of marsh erosion and collapse.



- **Wider marshes with gentle slopes** generally enhance resilience through reducing erosion, dampening waves, and supporting robust plant communities.
- **Appropriate flooding duration** enhances marsh vegetation establishment, productivity, and persistence. Target metrics for the tidal regime at a restored marsh (e.g., the duration and frequency of inundation) will vary based on local conditions.



- **Increased cover of natural areas** near the marsh (e.g., forests, brushlands, shrubs, inland wetlands) is linked to improved wetland condition and persistence. Intensive development and agriculture can also be a source of nutrient pollution, which may alter vegetation dynamics and possibly contribute to marsh collapse.

Sources: **Vegetation**: 1. Gleason et al., 1979; Christiansen et al., 2000; Turner et al., 2001, 2004; Gedan et al., 2011; Shepard et al., 2011; Fagherazzi et al., 2012; Staszak and Armitage, 2012. 2. Benoit and Askins, 1999; Meyerson et al., 2000; Currin et al., 2003; Jivoff and Able, 2003; Gratton and Denno, 2005. **Stability**: 2. Shafer et al., 2003; Roland and Douglass, 2005; Fagherazzi et al., 2013. 3. Mendelssohn and Morris, 2000. 4. Kuenzler, 1961; Bertness, 1984; Nielsen and Franz, 1995; Angelini et al., 2015; Leonardi et al., 2018. **Geomorphology and Hydrology**: 1. Moeller et al., 1996; Möller et al., 1999; Zedler et al., 1999; Schwimmer, 2001; Tonelli et al., 2010; Palmer and Wainger, 2011. 2. Palmer and Wainger, 2011. **Landscape:** Findlay and Houlahan, 1997; Findlay and Bourdages, 2000; Bertness et al., 2002; Deegan et al., 2012.

Because most projects reviewed were either recently completed or still being implemented at the time of the evaluation, we also identified a subset of the above metrics that could serve as leading indicators of ecological resilience (Table 2). These metrics are (1) commonly measured on marsh restoration projects, (2) respond relatively quickly following restoration, and (3) linked to improved ecological resilience in the peer-reviewed literature.

Table 2. Marsh indicators of ecological resilience that were used for assessing restoration-related marsh improvements. We articulate how restoration-driven changes in key marsh characteristics may improve marsh resilience over the short- and long-term.

<table>
<tr><th>Resilience indicators</th><th>Metrics</th><th># of projects monitoring[b]</th><th>Relation to resilience</th></tr>
<tr><td rowspan="4">Vegetation</td><td>% cover and/or stem density[a]</td><td>9</td><td rowspan="4">● Short-term: Contributes to ability to minimize or recover quickly from storm damage
● Long-term: Contributes to ability to adapt to changing environmental conditions (e.g., temperature, precipitation)</td></tr>
<tr><td>Belowground biomass</td><td>2</td></tr>
<tr><td>Persistence</td><td>0</td></tr>
<tr><td>Presence of invasive species[a]</td><td>9</td></tr>
<tr><td rowspan="4">Stability</td><td>Erosion rates</td><td>0</td><td rowspan="4">● Short-term: Contributes to ability to minimize or recover quickly from storm damage
● Long-term: Contributes to ability to maintain ecological/food web dynamics under changing conditions</td></tr>
<tr><td>Wave energy/power</td><td>0</td></tr>
<tr><td>Accretion rates</td><td>6</td></tr>
<tr><td>Presence of stabilizing species</td><td>1</td></tr>
<tr><td rowspan="4">Geomorphology and hydrologic dynamics</td><td>Elevation[a]</td><td>7</td><td rowspan="3">● Short-term: Contributes to ability to minimize storm damage</td></tr>
<tr><td>Width</td><td>0</td></tr>
<tr><td>Area</td><td>1</td></tr>
<tr><td>Flooding duration[a]</td><td>8</td><td>● Short-term: Promotes native salt marsh vegetation</td></tr>
<tr><td>Landscape</td><td>Natural vegetation within buffer</td><td>0</td><td>● Short-term: Protects/conserves natural habitat
● Long-term: Provides opportunity to migrate landward in response to sea level rise</td></tr>
</table>

a. Metrics that could serve as leading indicators of improved resilience.

b. Represents the number of projects conducting monitoring with support of the Hurricane Sandy Program. Third party monitoring, which may be occurring at some sites, is not included in this table.

4.2 Metric Measurements in Marsh Restoration Projects

Multiple restoration projects measured changes in key resilience metrics to help assess project performance (Table 2). More specifically, all 12 projects proposed to monitor some aspects of marsh vegetation, and most projects (9 of 12) included geomorphologic and/or hydrologic monitoring. Other marsh resilience variables (e.g., belowground biomass, marsh accretion) were less commonly measured (Table 2).

Finding PO.3: Early observations suggest that many restored sites are likely to have improved resilience, but more time and data are needed to provide a robust assessment.

Observations made through project reports, archival materials, and project lead interviews indicate that marsh restoration efforts have resulted in improvements in some indicators of marsh resilience (i.e., those described in Table 2). The most reported data are related to (1) marsh vegetation and (2) geomorphology and hydrologic dynamics, as they are the best early indicators of project success. However, no information was yet available about marsh stability (e.g., accretion rates), and no Hurricane Sandy Program projects are measuring the impact of the broader landscape on marsh resilience. Taken together, this means that our ability to assess the impact of restoration on marsh resilience is limited at this time. However, after more time has passed and more complete data are available, a fuller assessment of the impact of marsh restoration on ecological resilience will be possible. Below, we discuss early project resilience-related observations for projects that implemented hydrologic reconnection and thin-layer deposition; note that some projects implemented both of these major activities (Table 1) and thus are included in both discussions.

Hydrologic reconnection projects. Five of six projects in our in-depth assessment that included hydrologic connection activities (see Table 1) provided post-restoration information. Early observations are summarized in Box 6. The five projects all reported success in reconnecting the marsh hydrologically (i.e., projects observed improvements in tidal flow and the re-establishment of appropriate flood durations), with some adaptive management necessary to achieve desired outcomes. While many projects were recently completed, early observations suggest that the vegetation community is responding relatively quickly to changing environmental conditions and transitioning to native salt marsh species.

Thin-layer deposition projects. Five of seven projects in our in-depth assessment that included thin-layer deposition (see Table 1) provided post-restoration information. Early observations are summarized in Box 7. The projects were generally able to reach the target elevation of the marsh, sometimes after taking needed corrective action (e.g., redistributing sediment). As with the hydrologic reconnection projects, vegetation cover and productivity are generally increasing in all projects, though some specific areas within projects are underperforming with respect to elevation, percent cover of vegetation, or vegetation growth. Projects are aiming to improve vegetation-related outcomes through the redistribution of sediment or through replanting.

Box 6. Hydrologic reconnection projects: Early observations of resilience related metrics.[a]

A multi-state project noted that hydrologic modifications appeared to be effective at two sites, resulting in **reduced impounded water** on the marsh surface at both sites. Since the impounded water has been removed, some areas that previously had standing water are now **becoming vegetated**.

Following initial restoration activities, another channel was added to the Sachuest NWR (USFWS)

A Delaware project observed **reduced water levels** post-restoration in much of the marsh interior. Tidal wetland grasses and other **vegetation had begun to recolonize** many of the exposed mud flat areas. Based on remote sensing, there has been an observed reduction of 700 acres of open water and an increase of over 500 acres of vegetated marsh in the 2 years post-project.

A small channel dug on Prime Hook NWR to reconnect the flow of water (Cape Gazette).

One component of a New Jersey project included restoring tidal flow to a marsh that was formerly impounded for mosquito control. The cuts were successfully made in the impoundments, and **increased tidal flow** has been observed.

Community surrounding Forsythe NWR, NJ (Lia McLaughlin, USFWS).

While not fully complete, a New York project anecdotally observed **reduced water ponding** on the marsh surface and **increased flushing**. At both of its sites, **vegetation growth** was observed during the post-construction growing season.

Wertheim Salt Marsh, NY (Greg Thompson, USFWS)

a. See Table 2 for a list of relevant metrics related to marsh resilience, and the specific subset that marsh projects have been tracking to date

Box 7. Thin-layer deposition projects: Early observations of resilience related metrics.[a]

A New Jersey project **reached elevation targets** post-construction, but some areas have been losing elevation from compaction or erosion. **Vegetation became established relatively quickly**, but in **some areas underperformed**; these areas were planted with vegetation two years after restoration.

Vegetation growth before and after one growing season at Forsythe NWR, NJ (Jessie Buckner, TNC; Jaci Wollard, NJDEP).

A Maryland project **reached target elevations** and **vegetation came back strongly** within the first year. Additional plantings were done in the second year, increasing vegetative cover. Project leads also **observed seaside sparrows** onsite following restoration.

Seaside sparrow nesting in the salt marsh at Blackwater NWR, MD (USFWS).

Two Maryland project sites also conducted thin-layer deposition in combination with hydrologic reconnection on the marsh platform. The project successfully **raised marsh elevation**, but vegetation survival has been mixed. At one site, plantings appeared to be stressed in the first year, but the **vegetation survived and grew well** during the second season. At another site, however, plantings had high mortality likely due to compaction of sediment and hypersaline conditions.

A Delaware project placed approximately 640,000 cubic yards of dredged material to restore the marsh tidal channels. Marsh vegetation has **recolonized approximately 25%** of the damaged wetlands.

Spartina grasses repopulating in the Prime Hook NWR marsh area (Ron MacArthur, Cape Gazette).

Vegetation growth was observed in a New York project site after marsh elevation increased. However, ponding was observed in some locations and is being addressed; project leads expect vegetation will continue to re-establish.

Workers at the Lido Beach WMA (Robin Donohue, USFWS).

The examples listed from Lido Beach and Seatuck NWRs were two sites funded through the same Hurricane Sandy Program project.

a. See Table 2 for a list of relevant metrics related to marsh resilience, and the specific subset that marsh projects have been tracking to date

4.3 Trajectories of Outcome Achievement

Finding PO.4: Generally projects are recovering as quickly as expected after restoration, but results within projects are mixed.

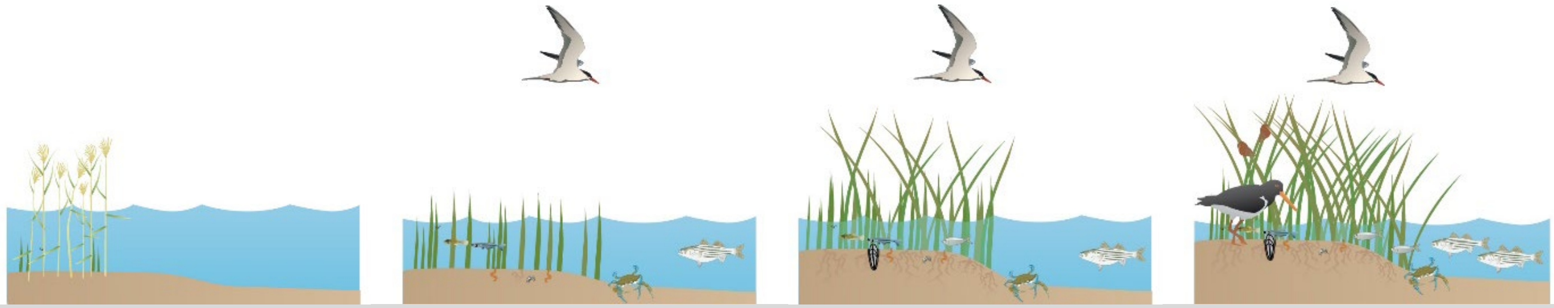
Ecological benefits of most marsh restoration projects funded through the Hurricane Sandy Program will take time to materialize after restoration activities are completed. To better understand and convey the potential timing of the achievement of key outcomes, the Abt Associates (Abt) evaluation team developed conceptual timelines of recovery after restoration using information from key peer-reviewed articles in combination with professional judgment from our team's subject matter experts (Figure 2).

More specifically, while ecological components of the marsh (e.g., vegetation, wildlife use of habitat, hydrologic functions) typically begin recovering immediately following restoration actions, they may require 10–100 years to reach maximum function (Warren et al., 2002; Craft et al., 2003; Moreno-Mateos et al., 2012; Verdonschot et al., 2013; Ebbets et al., 2019; Hollweg et al., In review). The rate of vegetation recovery can depend on many factors, including the specific type of restoration (e.g., hydrologic reconnection vs. created marsh) and whether the vegetation was planted or allowed to recolonize naturally.

Improvements in water quality and storm protection are also expected to be realized soon after restoration. In the context of hydrologic connectivity projects, water quality is tied to the return of tidal influence, which flushes formerly stagnant water and brings in oxygenated water. Storm protection for nearby ecosystems and communities will likely improve over time as restored marsh elevation increases with sediment accretion and strength (Sasser et al., 2013), though these benefits are likely to be constrained by future sea level rise.

The early observations noted in finding PO.3 above are generally consistent with what the literature and Abt team experts identified as likely short-term outcomes of marsh restoration (i.e., outcomes that will be observed one to two years after restoration; Figure 2). For example, vegetation is recovering in nearly all project sites, hydrological dynamics have been restored in reconnection projects, and birds and other wildlife are beginning to utilize newly restored marshes (Boxes 6 and 7). However, as noted in finding PO.3, some areas of specific projects have been underperforming (Boxes 6 and 7). The reasons for underperformance in these areas varied, and included storm-related disturbance, overly thick applications of dredging material, and plantings being located in hypersaline areas with potential sediment compaction. In addition, as noted in Figure 2, mid-term outcomes for marsh restoration projects may take several years to materialize, and long-term outcomes may not be apparent for more than a decade. This suggests that for projects implemented from 2017 to 2020, long-term outcomes for even the most successful projects are not likely to be realized until 2027–2030.

Figure 2. Site recovery following marsh restoration activities over time.



Realization timeframe[a]	Year 0 (pre-project) –	Short-term (1–2 years) outcomes 2018–2022	Mid-term (3–7 years) outcomes 2020–2027	Long-term (10+ years) outcomes 2027+
Vegetation[b]	Native vegetation may be sparse or missing; invasive species frequently dominate.	Vegetation planted during restoration begins to establish.	Vegetative productivity approaches reference conditions; predominantly native vegetation.	Vegetation comparable to reference marshes achieved between 15 and 30 years after restoration.
Habitat/ wildlife use[b]	Habitat does not support key biota.	Native biota begin returning (e.g., macroinvertebrates, fish); birds return as vegetation establishes.	Biota continue returning to restored locations, increasing in abundance but not approaching reference conditions.	Fish and bird assemblages increase, and may match reference marsh conditions.
Hydrology	Hydrologic functions (e.g., tidal influence, freshwater inputs) are compromised.	Many hydrologic features (e.g., tidal influence, sediment deposition) return to natural conditions immediately following restoration.	Features that respond more slowly (e.g., water table) continue to recover.	Hydrologic dynamics are similar to those of reference sites (20 years post-restoration).
Water quality[c]	Water is stagnant and often contaminated.	Water quality begins to improve as tidal flushing and oxygenated water return.	Water quality continues to improve as hydrologic conditions recover (e.g., tidal dynamics, sediment trapping).	Water quality continues to improve as hydrologic conditions recover (e.g., tidal dynamics, sediment trapping).
Storm protection	Degraded marshes provide little or no storm protection.	Storm protection begins to improve as marsh elevation increases and vegetation becomes established.	Marsh elevation, vegetation, and storm protection continue to increase.	Marsh elevation, vegetation, and storm protection continue to increase, but may be constrained by sea level rise.

a. Assuming projects completed between 2017 and 2020.

b. Most relevant to projects that include thin-layer deposition.

c. Most relevant to projects that include hydrologic reconnection.

Sources: **Vegetation**: Warren et al., 2002; Craft et al., 2003; Moreno-Mateos et al., 2012; Ebbets et al., 2019. **Habitat/wildlife use**: Warren et al., 2002; Craft et al., 2003; Borja et al., 2010; Moreno-Mateos et al., 2012; Verdonschot et al., 2013; Hollweg et al., In review. **Hydrology**: Warren et al., 2002; Moreno-Mateos et al., 2012. **Water quality**: Professional judgment. **Storm protection**: Sasser et al., 2013; Leonardi et al., 2018; professional judgment.

Topic: Information gaps regarding resilience impacts (IG)

Finding IG.1: Most projects were not initially funded by the program to gather long-term, post-restoration measures of ecological resilience; however, some projects secured monitoring support from other partners.

Monitoring for most projects was short-term and focused on ensuring that they met design goals; it was not intended for assessing long-term resilience impacts of the project after project completion. The findings discussed under Project Outcomes, above, reflect these short-term monitoring results.

Project leads noted in archival materials that long-term monitoring requires dedicated funding because it is time-consuming, costly, and requires technical expertise. Typically, standard performance metrics are not included in permit-required monitoring plans, and thus are not included in most project budgets. While most projects did not initially secure funding for long-term, post-project monitoring through the Hurricane Sandy Program, 6 of the 12 projects partnered with other funders, organizations, or volunteers to conduct at least some post-project monitoring at their sites. In one case, project leads received a two-year grant from the U.S. Environmental Protection Agency to continue ecological monitoring. It is also likely that projects completed at NWRs will be monitored as part of routine refuge maintenance. In addition, additional funding for long-term monitoring has been secured from NFWF and DOI for 17 of the 23 projects (see Finding IG.3 below).

Finding IG.2: Project monitoring often includes only a small subset of indicators of marsh resilience.

As shown in Table 2, only a subset of the potential indicators of marsh resilience are being measured by Hurricane Sandy Program project implementers. Most of the monitoring being done is focused on metrics that are likely to change soon after restoration (e.g., vegetation and marsh geomorphology/hydrology). While some projects did plan to measure accretion, a key indicator of marsh stability, no projects planned to assess wave energy or erosion rates, key factors that affect the long-term resilience of marshes. In addition, no projects planned to examine the composition of the nearby landscape, another key factor that can influence marsh resilience. While this latter measure of marsh resilience may not be expected to be directly affected by restoration actions, landscape composition could be used to help explain differences in restoration success across different projects. See Finding PO.2 above for additional information about how these metrics were identified and are related to marsh resilience.

Finding IG.3: Subsequent funding from NFWF and DOI will support the long-term monitoring needed to assess the impact of restoration on marsh ecosystem resilience, though some data gaps will likely remain.

Recognizing the need for long-term, systematic data collection to assess restoration success, NFWF and DOI are supporting additional, future long-term monitoring for 17 of the 23 marsh restoration projects through 2024 (see Table A.1). To identify the most appropriate metrics for these projects to measure over the long-term, NFWF and DOI leveraged work done by an internal DOI metrics expert group, which developed a suite of standardized performance metrics for different types of Hurricane Sandy resilience projects (DOI, 2015). Projects selected for long-term monitoring had to propose a specific subset of these metrics for monitoring. Most of the projects including in long-term monitoring are assessing the ecological effectiveness of restoration actions by measuring changes in habitat use by marsh birds (i.e., abundance, distribution, breeding productivity), salt marsh vegetation (i.e., cover and community composition), and elevation (e.g., real-time kinematic measurements) over time. A smaller subset of projects are evaluating other metrics, including nekton abundance and diversity, water quality, and accretion. All of the ecological metrics included are consistent with those identified in the DOI (2015) report, but have been adapted in some cases to meet project specific needs. While these data will provide important information about marsh resilience over time, fewer than four projects plan to monitor wave energy and erosion rates; these key data gaps will likely remain for most projects.

In addition to these ecologically focused metrics, NFWF and DOI are also supporting long-term monitoring to understand the impacts of marsh restoration on human well-being, primarily through the benefits gained by reducing flooding related impacts on human health, infrastructure, including transportation and critical facilities, and economic resilience. As with the ecological monitoring described above, the socioeconomic metrics being monitored were previously identified as potential standardized performance metrics for Hurricane Sandy resilience projects (Abt Associates, 2015).

5. Conclusion

Investments that the Hurricane Sandy Program has made in restoring marshes are generally on track to providing enhanced ecological resilience to marshes and nearby ecosystems. Early project results typically show enhancements in marsh vegetation cover and growth, reduced invasive cover, and increased elevation of marshes, although these enhancements are not necessarily uniform in all project areas. Early project results also show improved hydrological dynamics – reconnecting marshes to nearby tidal systems or managing water levels in freshwater systems. All of these near-term achievements are improving the ability of marshes to provide habitat for birds, fish, and other wildlife, and will improve their ability to withstand or recover from future storms or other forms of disturbance. However, these observations are preliminary, and several more years of recovery and monitoring data are needed to more fully understand the likely long-term benefits of restoration actions on marsh ecosystem resilience. More specifically, more information is needed about whether (1) vegetation continues to grow and flourish, (2) marsh elevation is maintained at appropriate levels, and (3) marsh stability improves over time. Further monitoring and sharing of lessons learned is particularly important given the novel and innovative nature of some of the projects, and the setbacks in some areas that a few projects have noted to date.

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Appendix A. Project Summaries

Table A.1. Marsh restoration projects supported through the Hurricane Sandy Program. This table presents the amount of project funding specifically allocated to marsh restoration activities. For nine projects, this is the full project funding amount; and for 15 projects, this is a subset of the total project funding. The allocation was based on available project documentation. Projects organized by those selected for the in-depth assessment of implementation issues and ecological outcomes achieved to date through marsh restoration. All dollars rounded to the nearest hundred.

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds	Acres of marsh restored[d]
				Values represent marsh restoration activities only[c]		
NFWF-41739[a, b]	Reusing dredged materials to enhance salt marsh in Ninigret Pond, Rhode Island	RI	Rhode Island Coastal Resources Management Council	$2,925,000	$347,400	30
NFWF-41766[a, b]	Coastal resiliency planning and ecosystem enhancement for northeastern Massachusetts	MA	National Wildlife Federation	$1,764,000	$958,400	503
NFWF-41812	Preventing erosion and restoring hydrology in the Pine Barrens, New Jersey	NJ	New Jersey Conservation Foundation	$280,000	$106,300	1,111
NFWF-42442[b]	Strengthening Sunken Meadow State Park's resiliency, New York	NY	Connecticut Fund for the Environment	$750,000	$17,300	4
NFWF-42942[a]	Increasing salt marsh acreage and resiliency for Blackwater National Wildlife Refuge, Maryland	MD	The Conservation Fund	$3,500,000	$1,331,600	782
NFWF-42958[a, b]	Restoring Spring Creek Park's salt marsh and upland habitat, New York	NY	New York City Department of Parks and Recreation	$3,843,000	$6,270,800	6
NFWF-42959[b]	Rejuvenating Sunset Cove's salt marsh and upland habitat, New York	NY	New York City Department of Parks and Recreation	$4,850,000	$2,240,000	10
NFWF-43006[b]	Wetland restoration in Suffolk County, New York	NY	County of Suffolk	$1,310,000	$688,700	400
NFWF-43095[a, b]	Reusing dredged material to restore salt marshes and protect communities, New Jersey	NJ	New Jersey Department of Environmental Protection – Office of Natural Resource Restoration	$3,420,000	$4,681,600	53

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds	Acres of marsh restored[d]
				Values represent marsh restoration activities only[c]		
NFWF-43322[b]	Enhancing Wampanoag Tribe of Gay Head's land resiliency in Martha's Vineyard, Massachusetts	MA	Wampanoag Tribe of Gay Head	$335,000	$116,000	700
NFWF-43849[a]	Developing coastal resiliency regional models, Virginia	VA	Wildlife Foundation of Virginia	$3,139,600	$301,200	3,783
NFWF-43939	Restoring Newark Bay's wetlands, New Jersey	NJ	City of Newark	$780,000	$7,500	17
NFWF-43986[b]	Strengthening Monmouth Beach's marshes and dunes, New Jersey	NJ	Monmouth Beach, New Jersey	$356,000	$350,000	0
NFWF-44157[b]	Repairing infrastructure and designing wetland and beach restoration plans along the Central Delaware Bayshore	DE	Delaware Department of Natural Resources	$1,800,000	$1,053,100	1,353
NFWF-44167[b]	Protecting North Beach's salt marsh and emergency route, Maryland	MD	Town of North Beach	$261,100	$58,600	5
NFWF-44225[b]	Improving Shinnecock Reservation's shoreline habitats, New York	NY	Shinnecock Indian Nation	$375,000	$31,400	5
NPS-27	Dyke marsh restoration to promote resource protection from storm response and adaptation to sea level rise	VA	U.S. Army Corps of Engineers; National Park Service	$24,897,600	$0	5
USFWS-1[a, b]	Salt marsh restoration and enhancement at Seatuck, Wertheim and Lido Beach National Wildlife Refuges, Long Island, New York	NY	U.S. Fish and Wildlife Service	$10,498,700	$1,355,800	516
USFWS-15[a, b]	Prime Hook National Wildlife Refuge coastal tidal marsh/barrier beach restoration	DE	U.S. Fish and Wildlife Service	$11,883,000	$816,000	4,000
USFWS-37[a, b]	Restoring coastal marshes in New Jersey National Wildlife Refuges	NJ	U.S. Fish and Wildlife Service	$7,500,000	$1,500,000	34,909

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds	Acres of marsh restored[d]
				Values represent marsh restoration activities only[c]		
USFWS-43[a, b]	Restoring resiliency to the Great Marsh, Parker River Parker River National Wildlife Refuge, Massachusetts	MA	U.S. Fish and Wildlife Service	$340,000	$506,000	27,000
USFWS-50[b]	Increasing water management capability at Great Dismal Swamp National Wildlife Refuge to enhance its resiliency for wildlife and people	VA	U.S. Fish and Wildlife Service	$3,130,000	$2,929,000	113,000
USFWS-65[a, b]	Protecting property and helping coastal wildlife: Enhancing salt marsh and estuarine function and resiliency for key habitats on impacted wildlife refuges from Rhode Island to southern Maine	Multi: RI, MA, ME	U.S. Fish and Wildlife Service	$3,983,300	$240,000	300
USFWS-85[a]	Pocomoke Sound marsh enhancement, Ferry Point, Nanticoke River	MD	U.S. Fish and Wildlife Service; Maryland Department of Natural Resources	$638,000	$55,000	2,000

a. Denotes a project included in the in-depth analysis for the case study.

b. Denotes a project for which long-term monitoring funding has been secured through NFWF and DOI.

c. Costs in the table do not represent the full cost of the project and may not reflect the total match.

d. These data include projects that have not yet been completed, and thus the final number of acres restored may change; for active projects, we assumed that projects will achieve the proposed acres restored.

BOLD THINKERS DRIVING REAL-WORLD IMPACT

Case Study: Restoration of Aquatic Connectivity in the Hurricane Sandy Coastal Resilience Program

Contract # 5359

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FINAL

2019

Case Study: Restoration of Aquatic Connectivity in the Hurricane Sandy Coastal Resilience Program

Prepared by Abt Associates, September 2019

Summary

Purpose

This case study forms part of a larger 2019 evaluation of the Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program) of the U.S. Department of the Interior (DOI) and the National Fish and Wildlife Foundation (NFWF). It provides an analysis of the resilience impacts of aquatic connectivity projects.

Scope

We examined 19 projects in the Hurricane Sandy Program portfolio that were primarily focused on removing dams, improving fish passage, replacing or removing culverts, replacing low-head bridges, and/or improving instream habitat. These activities were designed to reconnect rivers and streams for fish and wildlife use and mitigate storm-related flooding and safety risks.

Findings

Key findings identified using information from archival materials, a survey and interviews of project leads, and peer-reviewed literature include:

- Dam removal and culvert replacement resulted in improved fish access to nearly 370 miles of upstream river habitat, supporting key species in the region.
- While nearly all projects were completed by the time of the evaluation, most were delayed by more than a year due to many factors, including permitting challenges, a loss of landowner cooperation, or the need to avoid harming wildlife with project actions.
- Early improvements in fish passage, water quality, and instream habitat have already been achieved by some projects.
- Dam removal lowered water elevations in project areas, reducing flood risk in nearby areas.
- For a subset of projects, dam removal improved human safety by removing risks associated with recreational activities and catastrophic dam failure.
- The observed ecological benefits of aquatic connectivity projects to date are consistent with expected time lags between restoration and ecological outcomes.
- Long-term ecological monitoring and detailed site-based modeling are needed to understand the full ecological and socioeconomic impacts of aquatic connectivity projects.

Conclusion

Taken together, these findings suggest that **Hurricane Sandy Program investments in improving aquatic connectivity have increased the resilience of natural and human communities close to restored areas.** The program enhanced fish access to a substantial amount of previously inaccessible freshwater habitat, which can improve fish productivity and survival, making those populations more resilient to disturbances. Similarly, people who live, work, or recreate near dams are less likely to be harmed by storms, through either reduced flood risk or improved safety.

1. Introduction

This case study forms part of a larger 2019 evaluation of the DOI and NFWF Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program). Between 2013 and 2016, the Hurricane Sandy Program, administered through DOI and NFWF, invested over $302 million to support 160 projects designed to improve the resilience of ecosystems and communities to coastal storms and sea level rise.[1] The program supported a wide array of activities, including aquatic connectivity restoration, marsh restoration, beach and dune restoration, living shoreline creation, community resilience planning, and coastal resilience science to inform decision-making. Each of these activities has a distinct impact on ecosystem and community resilience.

DOI and NFWF drafted the following questions to serve as the focus of the evaluation:

1. To what extent did projects **implement activities** as intended? What factors facilitated or hindered project success?
2. What **key outcomes** were realized for habitat, fish and wildlife, and human communities?
3. Is there evidence that investments in green infrastructure are **cost-effective** compared to gray infrastructure?
4. Did investments in tools and knowledge related to resilience **improve decision-making**?
5. What **information is needed** to better understand the long-term impacts of investments in resilience?

The evaluation includes six case studies, each providing a deeper level of analysis on a subset of the projects.

1.1 Purpose

This case study provides an in-depth analysis of resilience activities focused on "aquatic connectivity" and is specifically focused on evaluation questions #1, #2, and #5 (above). For the purposes of this case study, we define ***aquatic connectivity*** **as activities that enhance or re-establish the linkages between stream ecosystems, most typically up- and downstream of an existing dam or culvert that has blocked the free movement of water or aquatic organisms**. More specifically, this case study provides a fuller understanding of the nature and benefits of aquatic connectivity-focused projects, as well as identifying key lessons learned regarding aquatic connectivity project implementation and impact assessment.

1.2 Scope

We examined all 19 projects in the Hurricane Sandy Program portfolio that aimed to re-establish connected waterways and mitigate storm-related flooding and safety risks primarily through the following activities: removing dams, improving fish passage (through sill lowering or fish ladder installation), replacing or removing culverts, or replacing low-head bridges (see Section 3 for a more detailed description of the portfolio of aquatic connectivity projects and Appendix A for a full list of relevant projects).

[1] The evaluation covers these 160 projects. In some cases DOI and NFWF reinvested unspent funds in new, additional projects after the December 2016 cutoff date. These new projects are not included in the evaluation.

1.3 Organization

The remainder of this document is organized as follows:

- Section 2 provides an overview of the methods and information sources used for this case study
- Section 3 provides a detailed overview of the aquatic connectivity projects included in the Hurricane Sandy Program
- Section 4 discusses key case study findings, organized by evaluation question and topic
- Section 5 provides a brief conclusion.

2. Methods Overview

The case study integrates information from the following information sources:

- Archival materials from Hurricane Sandy Program project files (e.g., proposals, interim and final reports)
- A survey of project leads via a web-based instrument
- Interviews with seven project leads (i.e., grant recipients) who led aquatic connectivity projects
- Interviews with NFWF and DOI staff
- Quantitative information provided by project leads in their reports (e.g., miles of upstream river habitat newly accessible to fish)
- Literature searches addressing specific contextual issues (e.g., typical lag time between dam removal and the restoration of key ecological dynamics near and upstream of the dam).

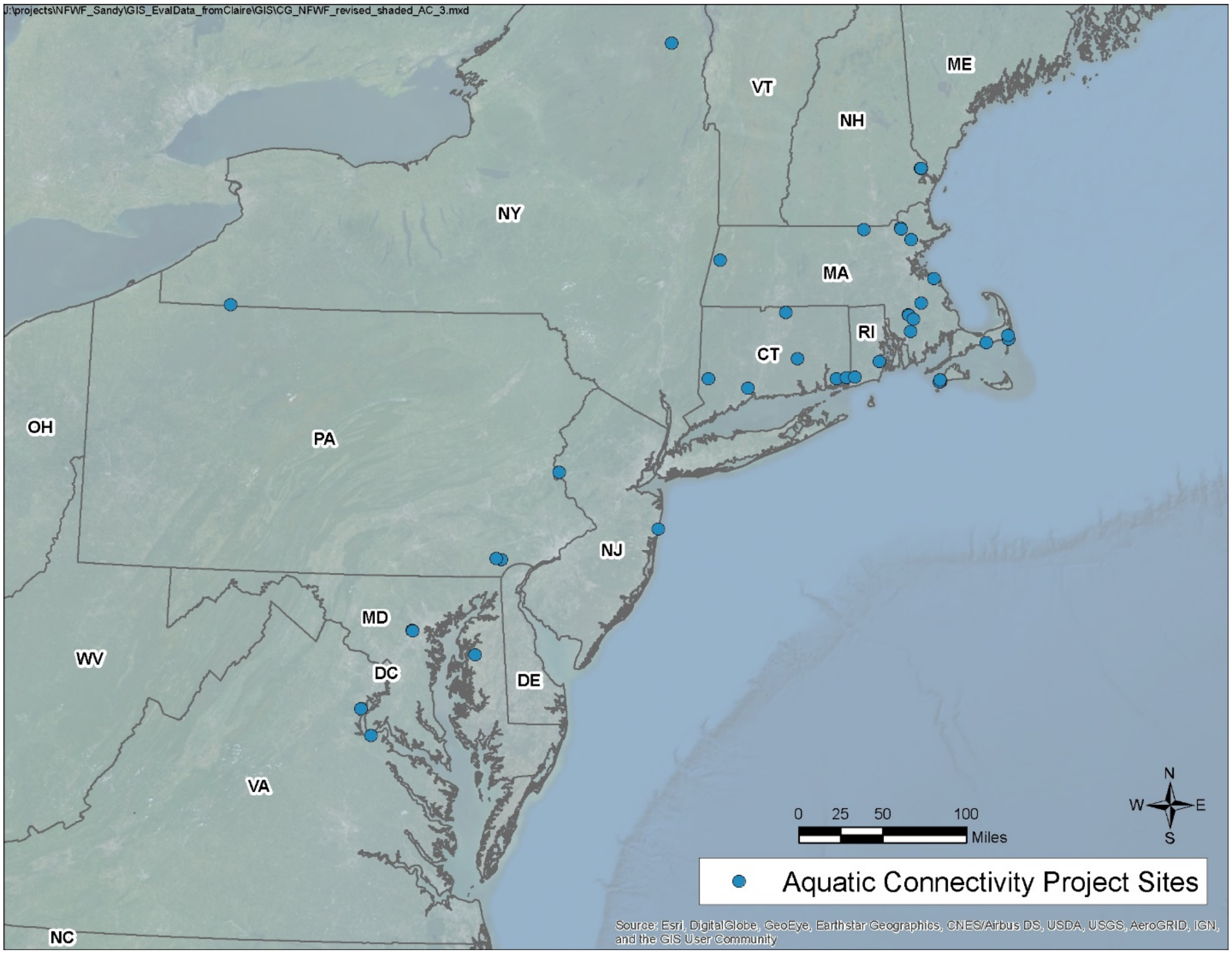
A more detailed description of evaluation methods can be found in Abt Associates (2019).

3. Overview of Projects

Throughout New England and the mid-Atlantic, dams that were once used to power mills, store power for local industries, or generate power are now disused. These dams, while once the center of economic activity for many communities, now degrade habitat and water quality, prevent fish passage to critical upstream habitat, and pose a threat to human property and safety during large storms, during which they can cause flooding and/or fail. In some instances, dams are an attractive nuisance, creating life-threatening conditions for the public. Poorly designed culverts can also prevent fish passage and cause flooding in nearby roadways. Restoration projects in the “aquatic connectivity” category, the focus of this case study, serve to re-establish connected waterways and mitigate storm-related flooding and safety risks primarily by removing dams, improving or replacing culverts or bridges, and improving fish passage.

Nineteen Hurricane Sandy Program projects, located in nine states, focused on the restoration of aquatic connectivity (Figure 1). Of these, 11 projects were administered by the U.S. Fish and Wildlife Service (USFWS) and 8 by NFWF. Most Hurricane Sandy Program aquatic connectivity projects were focused on dam removals, resulting in 23 dam removals overall (see Table A.1). In addition, 10 culverts were either replaced or improved to allow fish passage, one bridge was replaced, and multiple other barriers to fish passage were mitigated (see Table A.2). In addition to the habitat restoration provided by barrier removal, many projects also directly enhanced aquatic habitat, such as by removing sediment that was blocking culverts, or enhancing stream habitat through the placement of natural or artificial fish habitat structures. The dams removed had blocked fish access to upstream habitat for nearly 170 years on average (Figure 2). Overall, the Hurricane Sandy Program invested more than $30.6 million in aquatic connectivity in 19 projects (Table A.3), 3 of which also included other resilience activities; the total funding provided by the program for all of the activities in the 19 projects was $32.9 million.[2]

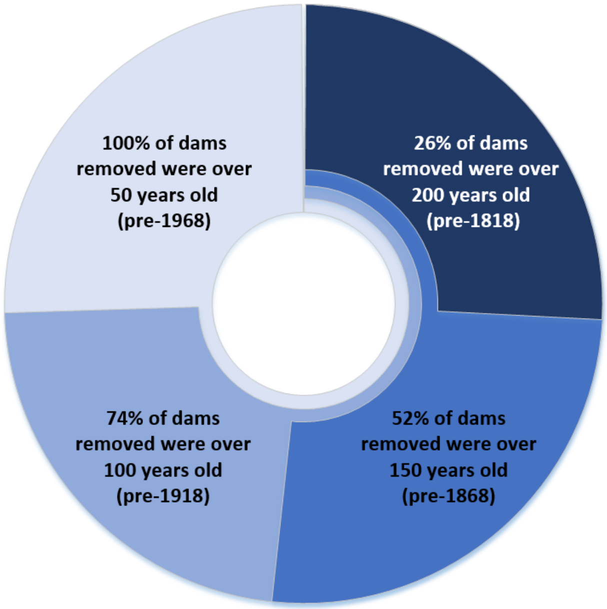
Figure 1. The location of aquatic connectivity restoration activities.[a]



a. Since many projects conducted restoration activities in multiple sites (see Appendix A), the number of aquatic connectivity restoration project sites (dots) in the figure exceeds 19.

[2] Table A.1 presents the amount of project funding specifically allocated to aquatic connectivity activities. For 16 projects, this was the full project funding amount. For three projects, this is a subset of the total project funding. The allocation was based on available project documentation.

Figure 2. Age of dams removed as part of the Hurricane Sandy Program. The dams removed had blocked fish access for decades to centuries.



4. Findings

Topic: Project Implementation (PI)

Finding PI.1: Nearly all projects have successfully completed their proposed activities.

Archival and web-based materials show that 15 out of the 19 projects have been completed,[3] with only 4 projects still in progress. Reviews of contract amendments showed that only one project incorporated a major change of scope, which involved changing the location of the dam removal.

Finding PI.2: A variety of factors delayed the implementation of most projects, including permitting challenges, weather, needed project design adjustments, a loss of landowner cooperation, or the need to avoid harming wildlife with project actions.

While most projects were completed by the end of the evaluation, a range of issues resulted in most projects experiencing significant delays compared to their original completion estimates. The data available through official contract amendments submitted to NFWF and DOI show that 15 of the 19 projects, covering multiple dam removal or culvert replacement sites, requested time extensions, often for a variety of reasons. According to these amendments, **permitting issues** were the most common cause of project delays (noted in contract amendments for eight projects). Multiple project leads in the survey and interviews noted that they found permitting to be a cumbersome and somewhat unpredictable process.

[3] While our evaluation generally provides findings elicited through the review of archival materials received through December 2018, project status information reflects information we gathered through April 2019 (updated project status information was obtained through a supplementary web search in March 2019 and an updated spreadsheet provided by NFWF).

Other reasons for delays included:

- Weather-related effects on restoration activities (noted in contract amendments for six projects),
- Required changes in restoration project design (six projects),
- Landowners rescinding permission to proceed with proposed project activities (four projects), and
- Delaying project activities to avoid harming wildlife during sensitive times of the year (e.g., avoiding construction during the migration or breeding seasons; three projects).

Topic: Project Outcomes (PO)

Below, we discuss the ecological and community-related outcomes achieved through the Hurricane Sandy Program aquatic connectivity projects. We also discuss whether the outcomes observed to date are consistent with expected trajectories of recovery after aquatic connectivity restoration.

4.1 Human Community Outcomes

Finding PO.1: Dam removal and culvert replacements and improvements lowered water elevations in project areas upstream of the former barrier, reducing flood risk.

A key potential benefit of dam removal is permanently reducing flood risk in nearby areas, particularly in urban environments where infrastructure is located close to dams. Dams and undersized culverts or bridges restrict peak flows upstream of the barrier during storms, and thus can cause localized flooding. Modeling done at 16 different Sandy dam removal sites anticipated reduced water elevations in all locations (see Table 1). While the flow conditions at which water elevation was assessed varied among project sites, mean water levels across projects consistently decreased in the area upstream of the former barrier, even during a modeled 100-year flood when the greater amount of water tends to reduce the benefit of the dam removal. Project leads also reported that flood risk was lowered in sites where culvert improvements or replacements widened river spans and improved the conveyance of water downstream (Box 1).

Table 1. Anticipated changes in water elevation upstream of the former dam after dam removal in 16 project sites, based on reported hydraulic modeling of different flow conditions and flood regimes. Negative values indicate a reduction in water elevation, and dashes indicate that no data were available for that simulation.[a]

State	Project ID	Dam name	Difference in water surface elevation before and after project completion (ft)				
			Average flow conditions	2-year flood	10-year flood	50-year flood	100-year flood
CT	NFWF-43378	Springborn Dam	-11.6	–	-12.8	-12.6	–
	USFWS-51	Pond Lily Dam	-7.4	–	–	–	-2.8
	USFWS-21	White Rock Dam	-2	-3	–	–	–
MA	USFWS-9	West Britannia Dam	–	-4.75	–	–	
	NFWF-42671	Balmoral Dam	–	-0.12	–	–	–
		Marland Place Dam	–	-3.42	–	–	-0.07
		Rattlesnake Brook Dam	-3.41	-2.8	-2.22	–	-1.12
		South Middleton Dam	–	-5.65	-3.76	–	-2.29
		Tel Electric Pond Dam	–	–	–	–	-2
		Millie Turner Dam	-5.84	-6.37	-6.6	-6.45	-6.4
MD	USFWS-89	Bloede Dam	–	-20	-21	–	-18
NH	NFWF-41787	Upper Sawyer Mill Dam[b]	–	-5.5	-6	-7	-7.4
NJ	USFWS-94	Hughesville Dam	–	-9.5	–	-9.25	-9.25
Median anticipated reduction in water elevation due to dam removal			**5.0 ft**	**5.1 ft**	**6.3 ft**	**8.1 ft**	**2.8 ft**

a. Data presented are projections for flooding near the dam site from hydraulic modeling done at each dam site prior to removal, as part of the permitting process; only a subset of the modeling results were shared in project reports, and thus we only include these reported data in the table.

b. NFWF did not fund the dam removal, but only funded the design for a future potential dam removal project, due to concerns about sediment contamination.

Box 1. Aquatic connectivity projects reduce future flooding risks and damages.

Projects mitigate flooding risks in locations with historic flooding following major past events

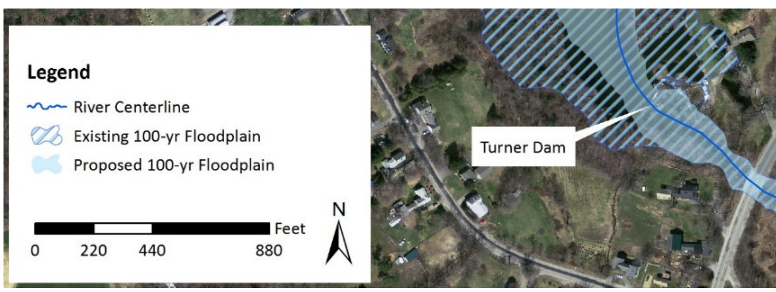
View of Upper and Lower Sawyer Mill dams on the Bellamy River in Dover, NH. The dams are part of a historic, redeveloped mill complex that straddles the river and is currently occupied by business and residents.

Photo source: Project archival materials.

In 2006 and 2010, major storms caused repeat damage and flooding. These dams are also ranked on federal and state inventories as high hazard, posing a threat to public safety in the event of a flood-induced failure.

Photo source: Project-related Request for Quotations.

By reducing size of 100-year floodplains, dam removals decrease exposure to damaging floods



Removal of the Millie Turner Dam on the Nissitissit River, a tributary of the Nashua River in Massachusetts, is expected to decrease the area in the 100-year floodplain and the number of properties potentially exposed to flooding events (left). The dam was also ranked as a high hazard dam in poor condition.

Photo source: Millie Turner Dam Preliminary Design for Removal, Final Report, Appendix A.

Replacing and "right-sizing" narrow culverts increased water conveyance and decreased flooding

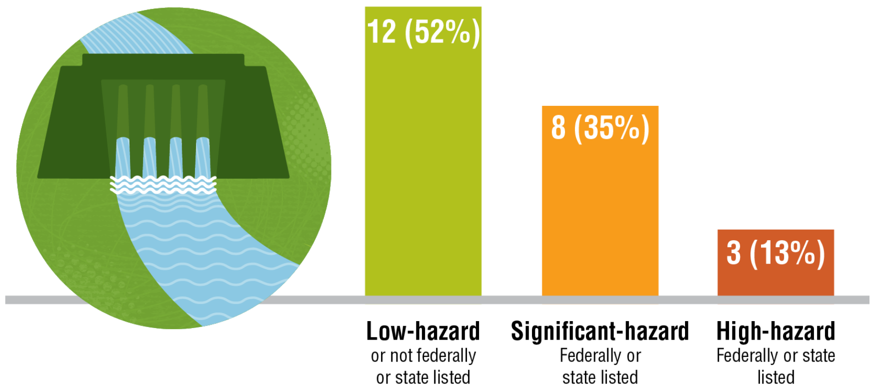
Replacing narrow culverts with a wider bridge improved water conveyance and minimized the risk of flooding. One project performed replacements at six sites; one culvert replacement at New Bridge Brook in Wilmington, NY (above) widened the river span from 4 linear feet to 22 linear feet. The project noted resulting improvements in tidal hydrology, water quality, and vegetation.

Source: Project final report.

Finding PO.2: For a subset of projects, dam removal improved human safety.

Many dams removed through the Hurricane Sandy Program were disused and deteriorating dams. These deteriorating dams could fail during storms, posing significant hazards to the safety and well-being of downstream communities and businesses. Three of the dam sites in the Hurricane Sandy Program were listed as high hazard by either federal or state authorities, and eight were listed as moderate hazard (Figure 3).[4] Thus, the removal of these 11 dams improved human safety for those who live, work, or recreate close to these sites. Furthermore, dams of any hazard and condition rating can pose direct, life-threatening hazards to swimmers and others who recreate near them (Kobell, 2015). For example, at least 9 dam-related deaths occurred since the 1980s at Bloede Dam, which was removed with support from the Hurricane Sandy Program and multiple other funders (USFWS, 2018).

Figure 3. Count of dams removed listed as low, significant, or high hazard on federal or state dam inventories.



Sources: MA ODS, 2012; Ipswich River Water Association, 2014; USFWS, 2015b, 2015c, 2017; RI DEM, 2017; CT DEEP, 2019; MD DE, 2019; USACE, 2019.

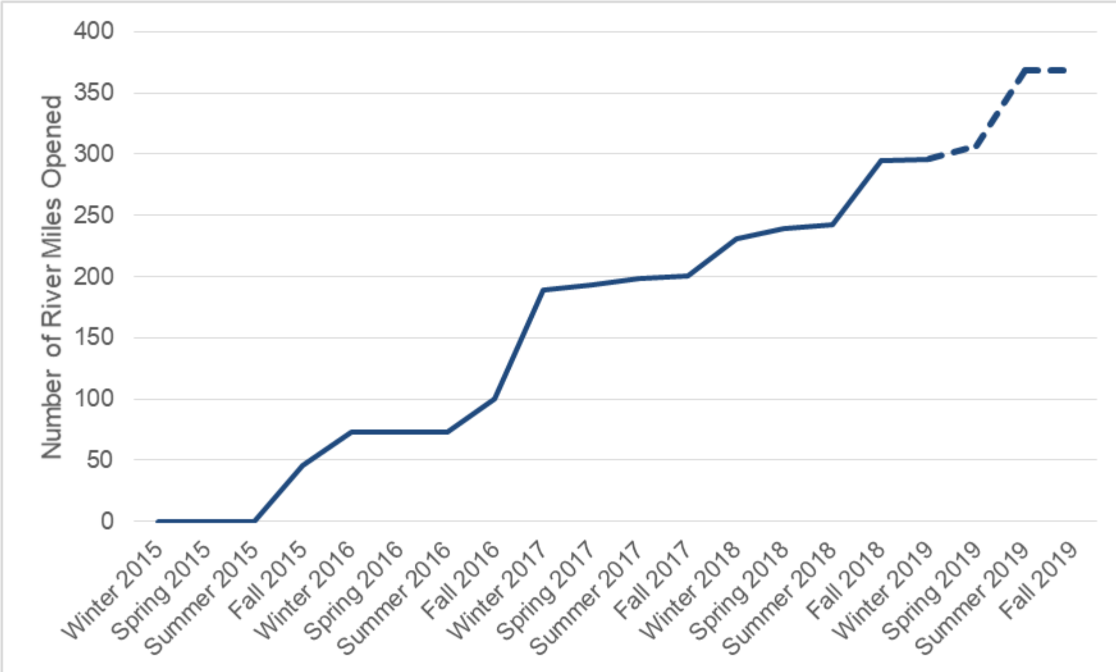
4.2 Habitat, Fish, and Wildlife Outcomes

Finding PO.3: Dam removal and culvert replacement/improvement resulted in improved fish access to nearly 370 miles of stream habitat, supporting key species in the region.

Project lead-reported data show that dam removal and culvert replacement/ improvement have resulted in fish gaining access to just over 368 miles of habitat that had been inaccessible to diadromous fish for decades to centuries (Figures 2 and 4; Tables A.1 and A.2 in Appendix A). This tally represents a minimum estimate of improved habitat access, as most project leads reported only mainstem river miles opened and did not include tributaries (see Tables A.1 and A.2).

[4] Hazard classifications vary between federal and state dam inventories. In general, a high hazard potential indicates that dam failure would result in probable loss of life and extensive property damage, a significant hazard potential indicates that dam failure would result in no probable loss of human life but could result in property damage, and a low hazard potential indicates that dam failure would cause no loss of human life and minimal property damage.

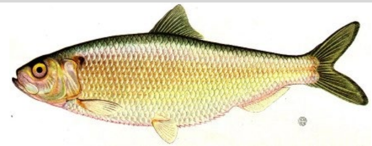
Figure 4. Minimum river miles opened through aquatic connectivity projects over time.



Dashed line indicates dams scheduled to be removed after the completion of this evaluation.

The literature suggests that access to this new habitat could be critical to sustaining and growing populations of a wide range of fish that utilize freshwater rivers and streams during part of their life cycle. For example, project leads noted four representative species that would benefit from their aquatic connectivity projects: alewife (*Alosa pseudoharengus*), American eel (*Anguilla rostrata*), American shad (*Alosa sapidissima*), and blueback herring (*Alosa aestivalis*) (see Box 2). All four species use river and stream habitats for feeding, reproduction, resting, or migrating, and therefore would potentially benefit from improved access to freshwater habitat (ASMFC-1 through ASMFC-4, Undated). Removing dams before they fail can also prevent the destruction of critical fish habitat. Furthermore, 11 of the dams removed had been identified as high priority[5] for removal by the Northeast Aquatic Connectivity Assessment Tool, which identifies where removals of barriers to fish passage are likely to provide the most ecological benefits (Martin and Apse, 2011).

[5] All dams in this tool are reported in 5% tiers; these 11 dams were ranked in the top 20% for their potential benefit to diadromous and resident fish if removed or bypassed.

Box 2. Examples of representative species likely to benefit, or that are already benefiting, from aquatic connectivity projects.[a, b]	
Alewife is a common species that migrate from the ocean to upstream rivers and lakes to spawn. It is a crucial component of the marine and freshwater food chains, serving as prey for larger commercial fish and other wildlife. River herring stocks (which include both alewife and blueback herring) are at near historic lows coast-wide. Alewife and other migratory fish populations are depleted due to historical overfishing, habitat fragmentation and loss, and other factors.	
Blueback herring migrate from saltwater into freshwater to spawn, and serve as prey for bass and other large recreational and commercial species. As noted above, river herring stocks are at near historic lows coast-wide.	
American shad, a staple food for pre-colonial Native Americans, were historically over-harvested in the mid-Atlantic region and serve as an important forage fish for larger fish. Stocks are currently at all-time lows.	
American eel are an important prey species for commercial fish. A catadromous species that lives in freshwater and migrates to saltwater to spawn, they have the largest range of any fish species in North America. American eel stocks are depleted, due to historical overfishing, habitat loss, and other factors.	

a. Drawings not to scale.

b. See Finding PO.4 and Box 3 for observed improvements in fish utilization of restored aquatic habitat.

Sources: USFWS (2015a), State of Maine Department of Marine Resources (2016), ASMFC-A and -B (2019), Chesapeake Bay Program (2019), ASMFC-1 through ASMFC-4 (Undated).

However, the ultimate impact of any given aquatic connectivity project on aquatic populations will depend on the nature of the intervention (e.g., dam removal, culvert replacement), the amount and quality of habitat available upstream of the project site, the size and age distribution of the preexisting population, and the size and depth of the river (Pess et al., 2008, 2012) as well as factors external to the project that affect the population (at-sea predation, for example). In the Information Gaps section below, we provide a more in-depth discussion of the information needed to determine the long-term impact of aquatic connectivity projects.

Finding PO.4: Early improvements in fish passage, water quality, and instream habitat have already been achieved by some projects.

While most aquatic connectivity projects were only recently completed at the time of our evaluation, some have already achieved improvements in fish passage, instream habitat, water quality, and fish use of upstream habitat. For example, shad and herring were quickly observed in habitats upstream of dam removals in New Jersey and Massachusetts (see Box 3). At the Norton Paper Mill Dam removal site, a project lead noted in an interview that the dam removal quickly flushed out sediment and debris that had accumulated behind the dam for decades, exposing rocks and boulders, and making the upstream habitat similar to historical conditions. In addition, 10 aquatic connectivity projects not only restored habitat through barrier removals, but also worked to directly improve instream habitat through removing sediment, planting riparian vegetation, or installing fish habitat structures. These types of habitat improvements can provide benefits to fish immediately following restoration, though their full benefits may not be realized for many years (see Finding PO.5 below for a more detailed discussion of timelines of ecosystem recovery post-restoration).

Box 3. Fish outcomes observed to-date.

Shad return to the Musconetcong River, NJ, following the Hughesville Dam removal

The Hughesville Dam was a river-spanning, 15-foot high safety hazard and impediment to fish passage on the Musconetcong River. Following its removal in 2016, American shad were reported upstream for the first time since upstream passage was blocked in 1768. "The return of shad, a benchmark species indicative of the overall health and diversity of a waterway, is an exciting milestone," said the Department of Environmental Protection's (DEP) Commissioner Bob Martin. "This achievement is the direct result of an ongoing partnership among state and federal agencies, nonprofit groups, and dam owners – all committed to making this beautiful waterway free-flowing again."

Source: NJ DEP Press Release, June 15, 2017.

Herring return to the Shawsheen River, MA, following the Balmoral and Marland Place dam removals

Balmoral and Marland Place dam removals were both completed around January 2017. The following spring, Emerson professor Jon Honea organized 46 volunteers to help count herring swimming upstream of these sites in the Shawsheen River. A total of 95 herring were observed, suggesting an estimated season run size of ~ 425 herring. The high-quality breeding habitat upstream from these dams had previously been inaccessible for almost 200 years.

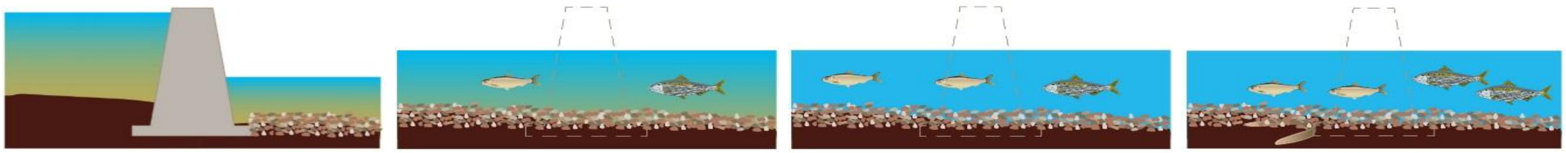
Source: Lyman, 2017.

4.3 Trajectories of Outcome Achievement

Finding PO.5: Observed ecological benefits of aquatic connectivity projects to date are consistent with expected time lags between construction of the restoration project and long-term ecological outcomes.

The ecological and socioeconomic benefits of many projects funded through the Hurricane Sandy Program will take time to materialize after restoration activities are completed. To better understand and convey the potential timing of the achievement of key outcomes, the Abt Associates (Abt) evaluation team developed conceptual timelines of recovery after restoration using information from key peer-reviewed articles in combination with professional judgment from our team's subject matter experts (Figure 5).

Figure 5. Description of short-, medium-, and long-term outcomes related to aquatic connectivity, fish, and flooding.



Realization timeframe[a]	Year 0 (pre-project)	Short-Term (1–2 years) Outcomes 2017–2021	Mid-Term (3–5 years) Outcomes 2019–2024	Long-Term (10+ years) Outcomes 2026+
Connectivity	Barrier alters hydraulics, traps sediment.	Flow continuity and sediment transport/redistribution begin immediately; water temperature changes; historic/rocky substrates may be exposed.	Sediment redistribution continues, exposure of historic/rocky substrate, restoration of historic flow conditions begins, water temperature changes; pioneer riparian vegetation establishes.	Channel morphology, and sediment dynamics continue to improve, some streams may require storm events to approach pre-dam conditions; mature riparian vegetation begins to return.
Fish	Habitat does not support diadromous fish, lake/warm water species typically inhabit areas upstream of the dam.	Diadromous fish species may begin to return/recolonize upstream habitats, some initial macroinvertebrate die-off due to sediment redistribution.	Diadromous fish continue to re-colonize and re-establish, some populations increase.	Native diadromous fish continue to return, rate and degree of recovery varies with geomorphology and recovery rate of other biota and other factors.
Flooding Reduction	Barrier or risk of failure can cause flooding.	Immediate elimination of risk of failure, reduction in inundation risk.	Water flows begin to approach reference condition, additional decrease in floodplain area upstream of the former dam.	Water flows continue to approach reference condition, additional decrease in floodplain upstream.

a. Assuming projects completed between 2016 and 2019.

Sources: **Connectivity:** Bednarek, 2001; Doyle et al., 2005; Tullos et al., 2014; Foley et al., 2017a, 2017b. **Fish:** Bednarek, 2001; Catalano et al., 2007; Marks et al., 2010; Foley et al., 2017a, 2017b. **Flooding:** professional judgment. Some elements on diagram courtesy of the Integration and Application Network, University of Maryland Center for Environmental Science (ian.umces.edu/symbols/).

Early observations of key outcomes for some projects are generally consistent with what the literature and Abt team experts identified as likely trajectories of key outcomes over time. As noted above, project leads have already observed fish passage and reduced water temperatures at many dam removal sites, and modeled projections of water surface elevations show reduced flood risk after dam removal. However, as noted in Figure 5, final outcomes for dam removal may take 10 years or more to materialize. This suggests that for projects implemented from 2015–2019, long-term outcomes for even the most successful projects are not likely to be fully realized until approximately 2025–2030.

More specifically, hydraulics, sediment mobilization and redistribution, and aquatic species population recovery may all begin immediately following dam removal. However, the timing and degree of recovery are influenced by many factors, including river management, the presence of other dams, geomorphic conditions, and existing biological communities (e.g., Bednarek, 2001; Doyle et al., 2005; Foley et al., 2017a, 2017b). For example, some rivers and dams may require a high-flow year in the water body to completely redistribute impounded sediments (Foley et al., 2017b). In addition, riparian vegetation, which can influence flow, sediment transport, and geomorphic features, may take many decades (30 years or more) to fully recover (Doyle et al., 2005).

Similarly, diadromous fish often migrate upstream of the former impoundment within one year following a dam removal (e.g., Catalano et al., 2007; Foley et al., 2017a, 2017b). However, full recovery of diadromous fish populations and historical riverine fish assemblages can take decades. A wide range of factors influence population recovery (as opposed to migration by individuals), including geomorphic conditions, temperature, flow, riparian habitat, pressure from non-native species, and the recovery of other aquatic species such as macroinvertebrates and mussels (Bednarek, 2001; Doyle et al., 2005; Marks et al., 2010), as well as factors beyond the project site, such as at-sea effects, and other environmental conditions. The dynamics of recovery are also important to consider. Ecological recovery after dam removal is a complex and non-linear process, with some ecosystem components often recovering more quickly, or more fully, than others (Doyle et al., 2005).

Topic: Information Gaps Regarding Resilience Impacts (IG)

Finding IG.1: Long-term ecological monitoring is needed to understand the full impact of aquatic connectivity projects.

As noted earlier in the case study, dam removal is known to have a range of benefits to fish that utilize streams for refuge, foraging, and reproduction. However, as described in Finding PO.5 above, there is typically a significant lag time between restoration activities and the full realization of ecological outcomes related to fish and other wildlife. More specifically, it is likely to take many years for fish to successfully re-establish reproduction in areas that have been inaccessible to them for decades to centuries (Doyle et al., 2005). Because our evaluation ended soon after most projects were finished and before six of them were completed, our team was not able to ascertain whether medium- or long-term outcomes have been realized. In addition, monitoring to determine whether such outcomes are achieved was not included in the restoration proposed for projects in this program, as such monitoring is typically beyond what funders of restoration activities support.

To address this information gap, NFWF and DOI are supporting efforts to assess longer-term fish, habitat, and water quality outcomes in a subset of sites. More specifically, eight aquatic connectivity projects will be undertaking field measurements of fish abundance, assemblage, and migration patterns. Data collection is currently in its early phases and will last from spring 2018 through 2023. These additional data will help improve understanding of how riverine and adjacent systems can rebound after restoration and the long-term benefits of aquatic connectivity projects.

Finding IG.2: Detailed modeling is needed to fully understand the impact of dam removal and/or culvert replacement on flood risk in nearby communities.

As noted under Finding PO.1 above, 16 different projects modeled the anticipated impact of dam removal on water surface elevation, suggesting that flood risk has been reduced in these sites. However, these modeling efforts did not include detailed analyses of how changes in water elevation directly impact nearby infrastructure. This information gap prevents a full understanding of the flood mitigation benefits associated with dam removals completed through the Hurricane Sandy Program. In addition, the models are based on project designs, but have not been re-run after construction to predict future water elevations once the dams have been removed.

However, NFWF and DOI are supporting inundation modeling in a subset of sites to better characterize and quantify flood risk reduction in project sites over the long-term. More specifically, a joint USFWS- and USGS-led effort is performing HEC-RAS modeling for 9 of the 23 different dam removal sites. The output from these models will be used to create detailed inundation maps of nearby communities and to compare inundation patterns before and after dam removal. This will offer clear, quantifiable insights regarding the flood risk benefits provided through dam removal under different flow scenarios. NFWF and DOI are also supporting long-term monitoring to understand the impacts of project-related flooding reduction on human health and well-being, transportation, critical facilities, and recreation.

5. Conclusion

Investments that the Hurricane Sandy Program made in improving aquatic connectivity have increased the resilience of natural and human communities close to restored areas. The program enhanced fish access to a substantial amount of previously inaccessible freshwater habitat, which can improve fish productivity and survival, making those populations more resilient to disturbances. Similarly, people who live, work, or recreate near dams are less likely to be harmed by storms, through reduced flood risk and improved safety. While the flood risk and safety benefits of dam removal are apparent immediately after project completion, the full ecological benefits of dam removal, including population and ecosystem resilience to storms, may not materialize for many years. Further monitoring and assessment is needed to understand the long-term benefits and costs of these types of interventions.

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Appendix A. Project Summaries

Table A.1. Dam removals completed by aquatic connectivity projects in the Hurricane Sandy Program.

State	Project ID	Dam name	Main river name	Height (ft)	Year built	Removal date by season	Minimum river miles opened
CT	USFWS-79	Norton Paper Mill Dam	Jeremy River	20	1726	Fall 2016	17
CT	USFWS-53	Hyde Pond Dam	Whitford Brook	5	1814	Fall 2015	4.1[a]
CT	USFWS-68	Flock Process Dam	Norwalk River	14	1850	Summer 2018	3.5
CT	NFWF-43378	Springborn Dam	Scantic River	26	1890	Fall 2017	2.6
CT	USFWS-51	Pond Lily Dam	West River	6	1794	Winter 2016	2.6
MA	NFWF-42671	South Middleton Dam	Ipswich River	10	1953	Summer 2019	57
MA	NFWF-42671	Millie Turner Dam	Nashua River	10	1750	Fall 2015	40[a]
MA	USFWS-9	West Britannia Dam	Mill River	8	1824	Winter 2018	30
MA	NFWF-42671	Cotton Gin Dam	Satucket River	10	1820	Winter 2017	13
MA	NFWF-42671	Barstowe's Pond Dam	Taunton River	8	1920	Spring 2018	8
MA	NFWF-42671	Rattlesnake Brook Dam	Taunton River	4	1882	Fall 2016	7
MA	NFWF-42671	Hunters Pond Dam	Bound Brook	5	1820	Summer 2017	5
MA	NFWF-42671	Tel Electric Pond Dam	Housatonic River	20	1933	Summer 2019	4.8
MA	NFWF-42671	Balmoral Dam	Shawsheen River	6.8	1920	Spring 2017	2.1
MA	NFWF-42671	Marland Place Dam	Shawsheen River	12.5	1920	Spring 2017	2
MD	USFWS-89 and NFWF-43834	Bloede Dam	Patapsco River	34	1907	Fall 2018	52[a]
MD	USFWS-89	Centreville Dam	Corsica River	5	1933	Fall 2015	2
NH	NFWF-41787	Upper Sawyer Mill Dam	Bellamy River	15	1880	Spring 2019	11
NH	NFWF-41787	Lower Sawyer Mill Dam	Bellamy River	18	1935	Fall 2018	
NJ	USFWS-94[b]	Hughesville Dam	Musconetcong River	17	1889	Fall 2016	1[b]
RI	USFWS-21	Bradford Dam	Pawcatuck River	6	1819	Winter 2017	70[a]
RI / CT	USFWS-21	White Rock Dam	Pawcatuck River	6	1770	Spring 2016	
RI	USFWS-21	Shady Lea Mill Dam	Mattatuxet River	5	1820	Spring 2018	0.5

a. For these projects, project leads stated the total of both mainstem and tributary miles opened. Minimum river miles opened from other projects may also include improved access to tributaries with important fish habitat, but these data were not reported.
b. This project also funded improvement of a culvert. See the Wreck Pond site in Table A.2.

Table A.2. Culvert replacements, bridge replacements, and fish passage improvements completed by aquatic connectivity projects in the Hurricane Sandy Program.

State	Project ID	Site name	Activity	Activity date by season	Minimum river miles opened	Other aquatic connectivity restoration activities
NY	NFWF-42874	Ausable Watershed	Replaced 4 culverts with fish-friendly structures.	Winter 2016	24	Not reported
MA	NFWF-43322	Herring Creek	Dredged sediment to restore tidal flows; restored herring and eel migration route (blueback herring and American eels) and spawning grounds for crabs (Atlantic horseshoe crabs).	Winter 2019	0.3	Not reported
PA	NFWF-43759	Brandywine River Watershed	Restored floodplain wetlands to store overbank flow and reconnect floodplains.	Winter 2015	N/A	1.6 acres of floodplain reconnected. Also completed riparian restoration and in-channel habitat restoration.
NY	NFWF-44022	Allegany Reservoir and River	Restored hydrological connections of landlocked nursery and wetland areas to the Allegany Reservoir through debris removal; mitigated 7 fish barriers.	Winter 2016	Not reported	15 acres of restored hydrology, and mitigation of 7 fish barriers, including culverts and dams.
MA	USFWS-11	Muddy Creek Wetland	Replaced two culverts with a bridge and open channel.	Spring 2015	Not reported	Restored a mix of approximately 55 acres of estuarine and subtidal wetlands.
MA	USFWS-33	Parkers River Watershed	Replaced 1 bridge with a larger span structure and replaced 2 culverts.	Winter 2019	1.04	Restored 60 acres of salt marsh, improved 93 acres of fish and shellfish habitat in the tidally influenced Seine Pond, and improved migratory fish passage to 63 acres of spawning habitat.
VA	USFWS-34	Quantico Creek	Restored streambank above a culvert to eliminate sediment build-up.	Winter 2017	6.25	Not reported
NJ	USFWS-94	Wreck Pond	Created bypass box culvert and reconstructed berm and dune system over the new culvert.	Fall 2016	2	Not reported

Table A.3. Aquatic connectivity projects supported through the Hurricane Sandy Program. This table presents the amount of project funding specifically allocated to aquatic connectivity activities. For 16 projects, this is the full project funding amount; and for three projects, this is a subset of the total project funding. The allocation was based on available project documentation. All dollars rounded to the nearest hundred.

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
NFWF-41787	Restoring Bellamy River's fish passage and reducing flooding through removal of two fish barriers, New Hampshire	NH	New Hampshire Department of Environmental Services	$550,000	$168,100
NFWF-42671	Enhancing seven communities, ecosystems, and infrastructure resiliency by removing seven fish barriers, Massachusetts	MA	Fish and Game, Massachusetts Department of/ Division of Ecological Restoration	$4,039,200	$1,461,200
NFWF-42874	Ausable watershed flood mitigation and fish passage restoration, New York	NY	The Nature Conservancy	$620,000	$188,500
NFWF-43322[a]	Enhancing Wampanoag Tribe of Gay Head's land resiliency in Martha's Vineyard, Massachusetts	MA	Wampanoag Tribe of Gay Head	$268,000	$92,800
NFWF-43378	Restoring fish runs and fragmented trout populations by removing a fish barrier, Connecticut	CT	State of Connecticut	$2,800,000	$1,000,000
NFWF-43759	Reducing flood impacts and restoring habitat in the Brandywine River watershed, Pennsylvania	PA	Stroud Water Research Center	$1,515,000	$250,000
NFWF-43834	Increasing community and ecological resiliency by removing a Patapsco River fish barrier, Maryland	MD	American Rivers, Inc.	$2,480,000	$5,677,000
NFWF-44022	Reconnecting and restoring the Allegany Reservoir, New York	NY	The Seneca Nation of Indians	$350,000	$226,400
USFWS-11	Muddy Creek wetland restoration project, Chatham, Massachusetts	MA	U.S. Fish and Wildlife Service	$3,762,000	$438,600
USFWS-21[a]	Aquatic connectivity and flood resilience in Connecticut and Rhode Island: Removing the White Rock and Bradford dams, assessing the Potter Hill Dam fishway on the Pawcatuck River, and removing the Shady Lea Mill Dam in North Kingstown	Multi: CT, RI	U.S. Fish and Wildlife Service	$2,294,300	$1,229,000
USFWS-33[a] (-43 in final report)	Parker River Tidal Restoration Project	MA	U.S. Fish and Wildlife Service	$3,718,000	$568,600

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
USFWS-34	Aquatic connectivity and flood resilience in Virginia: Replacing the Quantico Creek culvert in Dumfries	VA	U.S. Fish and Wildlife Service	$330,800	$900,000
USFWS-51[a]	Aquatic connectivity and flood resilience: Pond Lily Dam removal, West River, New Haven, Connecticut	CT	U.S. Fish and Wildlife Service	$661,500	$238,800
USFWS-53[a]	Aquatic connectivity and flood resilience: Hyde Pond Dam removal, Whitford Brook, Mystic, Connecticut	CT	U.S. Fish and Wildlife Service	$551,300	$3,200
USFWS-68	Aquatic connectivity and flood resilience: Flock Process Dam removal, Norwalk River, Norwalk, Connecticut	CT	U.S. Fish and Wildlife Service	$970,000	$169,000
USFWS-79	Aquatic connectivity and flood resilience: Norton Mill Dam removal, Jeremy River, Colchester, Connecticut	CT	U.S. Fish and Wildlife Service	$727,700	$52,000
USFWS-89[a]	Aquatic connectivity and flood resilience in Maryland: Removing the Centreville Dam in Centreville and the Bloede Dam in Catonsville	MD	U.S. Fish and Wildlife Service	$1,212,800	$5,400,000
USFWS-9[a]	Aquatic connectivity and flood resilience: West Britannia and Whittenton Dam Removals, Mill River, Taunton, Massachusetts	MA	U.S. Fish and Wildlife Service	$650,000	$837,000
USFWS-94[a]	Aquatic connectivity and flood resilience in New Jersey: Removing the Hughsville Dam in Pohatcong and restoring the Wreck Pond inlet and dune in Sea Girt and Spring Lake	NJ	U.S. Fish and Wildlife Service	$3,050,000	$3,718,000

a. Denotes a project for which long-term monitoring funding has been secured through NFWF and DOI.

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Case Study: Cost-Effectiveness of Reducing Coastal Erosion through Living Shorelines in the Hurricane Sandy Coastal Resilience Program

Contract # 5359

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FINAL

2019

Case Study: Cost-Effectiveness of Reducing Coastal Erosion through Living Shorelines in the Hurricane Sandy Coastal Resilience Program

Prepared by Abt Associates, September 2019

Summary

Purpose

This case study forms part of a larger 2019 evaluation of the Hurricane Sandy Coastal Resilience Program (Hurricane Sandy Program) of the U.S. Department of the Interior (DOI) and the National Fish and Wildlife Foundation (NFWF). It provides an in-depth analysis of the program's living shorelines, with a particular emphasis on understanding their cost-effectiveness as compared to a traditional gray infrastructure approach (i.e., a stone revetment) to reduce coastal erosion.

Scope

We examined 17 projects, encompassing 29 project sites, in the Hurricane Sandy Program portfolio to reduce coastal erosion through the creation of living shorelines. Eleven of these 17 projects, encompassing 22 project sites, were selected for an in-depth cost-effectiveness analysis.

Findings

Key findings identified using archival materials, a survey and interviews of project leads, and peer-reviewed literature include:

- The Hurricane Sandy program created nearly 53,000 linear feet of living shorelines, protecting the coastlines behind these shorelines and avoiding coastal erosion on up to 440 acres of land; these projects will help sustain wildlife and human use of these areas over the next few decades.[a]
- To protect existing coastlines, living shoreline projects restored habitat; these projects restored approximately 40 acres of marshes, beaches, oyster reefs, and submerged aquatic vegetation (SAV). [a]
- For erosion protection, living shorelines were typically more cost-effective than stone revetments, and their cost-effectiveness improved when considering additional benefits of the habitat restored.
- Living shorelines are providing more ecological benefits through habitat restoration than stone revetments, bulkheads, or other gray systems.

Conclusion

Hurricane Sandy Program investments in living shorelines appear to be a cost-effective and ecologically sound approach for reducing coastal erosion and improving resilience. Living shorelines were more cost-effective than a comparable gray infrastructure approach (i.e., a stone revetment) at reducing coastal erosion at project sites, assuming the two approaches perform similarly over time. The cost-effectiveness of living shorelines was even higher when we included the amount of habitat restored in our calculations. While data were not available to provide a robust assessment of on-the-ground performance of specific projects, anecdotal observations suggest that erosion has been reduced and habitat is recovering in project areas. These observations are preliminary, however, and more years of recovery and monitoring data are needed to better understand long-term ecological and socioeconomic impacts of living shorelines.

a. This number includes all living shoreline projects (both active and completed), meaning this number may be subject to change from adjustments to in progress projects.

1. Introduction

This case study of living shorelines forms part of a larger 2019 evaluation of the DOI and NFWF Hurricane Sandy Coastal Resiliency Program (Hurricane Sandy Program). Between 2013 and 2016, the Hurricane Sandy Program, administered through DOI and NFWF, invested over $302 million to support 160 projects designed to improve the resilience of ecosystems and communities to coastal storms and sea level rise.[1] The program supported a wide array of activities, including aquatic connectivity restoration, marsh restoration, beach and dune restoration, living shoreline creation, community resilience planning, and coastal resilience science to inform decision-making. Each of these activities has a distinct impact on ecosystem and community resilience.

DOI and NFWF drafted the following five questions to serve as the focus of the evaluation:

1. To what extent did projects **implement activities** as intended? What factors facilitated or hindered project success?
2. What **key outcomes** were realized for habitat, fish and wildlife, and human communities?
3. Is there evidence that investments in green infrastructure are **cost-effective** compared to gray infrastructure?
4. Did investments in tools and knowledge related to resilience **improve decision-making**?
5. What **information is needed** to better understand the long-term impacts of investments in resilience?

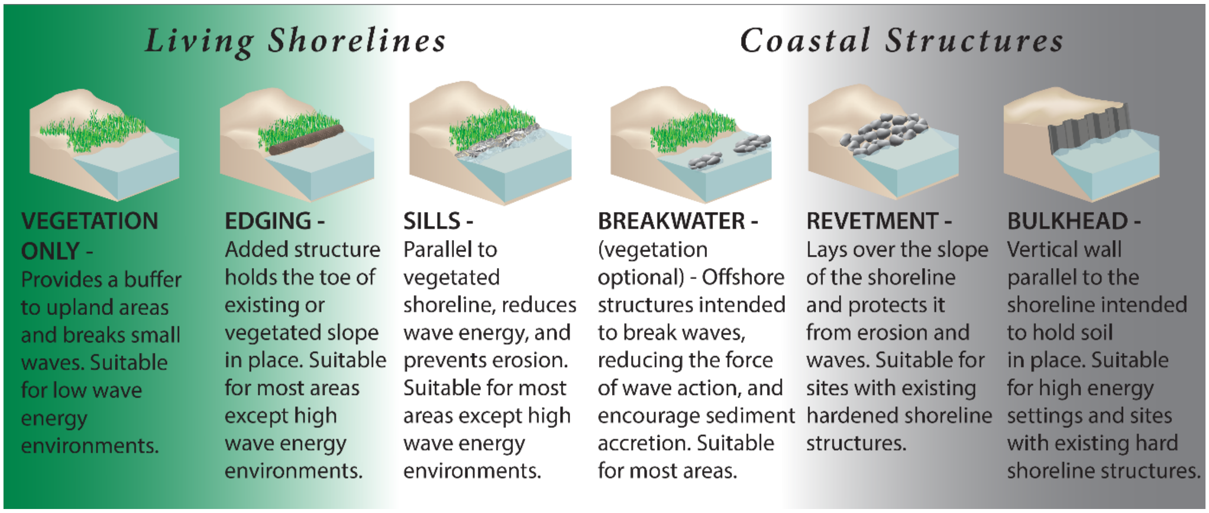
The evaluation includes six case studies, each providing a deeper level of analysis on a subset of the projects.

1.1 Purpose

This case study provides a cost-effectiveness analysis of living shorelines, and focuses on evaluation questions #1, #2, #3, and #5. More specifically, we compare the cost-effectiveness of living shorelines to an equivalent "gray infrastructure" reference project (i.e., a stone revetment) that is assumed to provide the same amount of protection from erosion (Box 1). Living shorelines are stabilized using soft (e.g., vegetation and sand) elements alone or in combination with hard structures such as oyster reefs, rock sills, or anchored large wood. Living shorelines can both protect and stabilize the shoreline; and restore or enhance aquatic, wetland, and beach habitats. In addition, living shoreline and other natural infrastructure projects increase stability over time, whereas hard infrastructure (e.g., stone revetment and bulkhead) deteriorates over time.

[1] The evaluation covers these 160 projects. In some cases DOI and NFWF reinvested unspent funds in new, additional projects after the December 2016 cutoff date. These new projects are not included in the evaluation.

Box 1. Shoreline stabilization techniques, where objects on the left side of this continuum represent green, living shoreline techniques; and projects on the right represent gray, harder shorelines stabilization techniques.



Source: Figure 1 in NOAA (2015).

1.2 Scope

The case study examined 17 projects, encompassing 29 project sites, in the Hurricane Sandy Program portfolio that implemented living shorelines to reduce coastal erosion. Eleven of these projects, encompassing 22 project sites, were selected for the in-depth, cost-effectiveness analysis. These projects were selected because the costs of the living shoreline activity could be disaggregated from total project costs (see Appendix A for a full list of relevant projects, including those selected for this cost-effectiveness analysis). Many projects that incorporated living shoreline construction also included other types of resilience interventions (e.g., marsh or beach/dune restoration). In this case study, we focus solely on the living shoreline-related aspects of these projects; however, we provide an analysis of the potential synergies of different resilience activities in the main evaluation report.

1.3 Organization

The remainder of this document is organized as follows:

- Section 2 provides an overview of the methods and information sources used for this case study
- Section 3 provides a detailed overview of the living shoreline projects included in the Hurricane Sandy Program
- Section 4 discusses key case study findings, organized by evaluation question and topic
- Section 5 provides a brief conclusion.

2. Methods Overview

This case study integrates information from the following information sources:

- Archival materials from Hurricane Sandy Program project files (e.g., proposals, interim and final reports)
- A survey of project leads via a web-based instrument

- Interviews and emails with 12 project leads (i.e., grant recipients) who led living shoreline projects
- Interviews with NFWF and DOI staff
- Quantitative information provided by project leads in their reports (e.g., linear feet of living shorelines constructed, acres of habitat restored)
- Literature or data searches addressing specific contextual issues (e.g., restoration recovery trajectories, erosion rates, stone revetment costs).

Using this information, we conducted two types of cost-effectiveness analyses. In the first analysis, we compared the cost per unit area protected (i.e., erosion prevented) of each living shoreline to a comparable "gray infrastructure" project (i.e., stone revetment) that was scaled to fit the site's wave energy conditions. In the second analysis, we compared costs of each project per area of land protected and area of habitat restored to the comparable stone revetment project. We estimated total project costs (in present value over a 30-year life span) by summing planning, design, construction, and maintenance costs. Our analyses captured differences in maintenance costs between green and gray projects, but we assumed that erosion control effectiveness was comparable, based on available evidence. We also compared the implementation cost per foot of shoreline length among projects for additional insights. See Appendix A for project details that fed into these analyses, and the evaluation report (Abt Associates, 2019) for a more detailed description of evaluation methods.

3. Overview of Projects

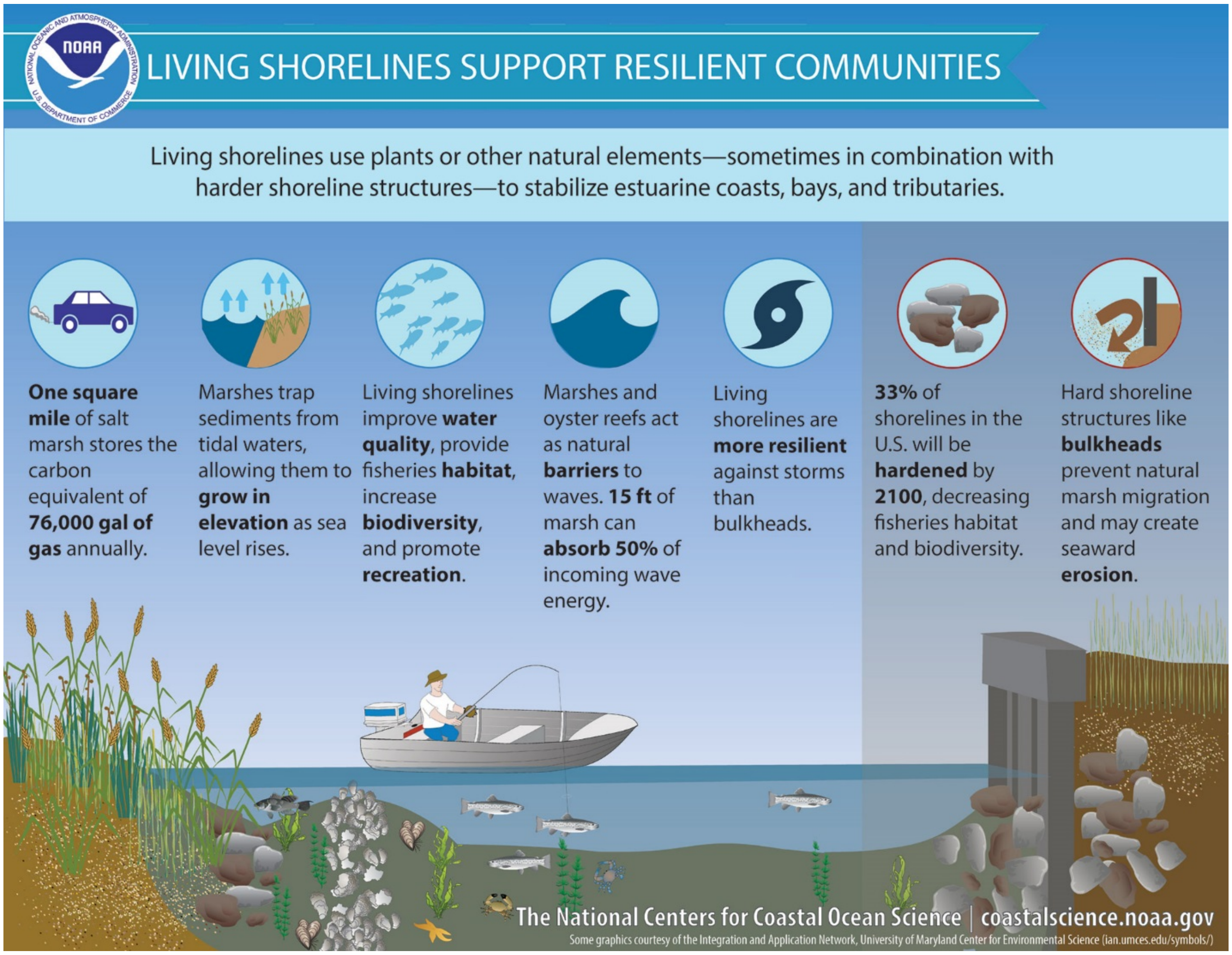
Coastal erosion is a critical threat to coastal communities and ecosystems along the Atlantic Coast. While coastal erosion is a natural process, it can lead to the degradation or loss of valuable coastal resources. Stabilizing shorelines can help make coastal areas more resilient to intense storms and sea level rise, which are likely to increase in the future. The creation of living shorelines is an increasingly popular approach to reducing coastal erosion, in large part due to the potential ecological benefits that can be provided through the habitat protected and created through their construction, particularly in contrast to comparable gray infrastructure approaches (Figure 1). NFWF and DOI supported the construction of living shorelines as an environmentally sound approach for protecting important coastal resources in areas affected by Hurricane Sandy.

Overall, the Hurricane Sandy Program invested more than $37.6 million in living shorelines in 17 projects (Table A.1), 11 of which also included other resilience activities; the total funding provided by the program for all of the activities in the 17 projects was $68.2 million.[2] Living shorelines were implemented in five states: Maryland, New Jersey, New York, Rhode Island, and Virginia (Figure 2; Table A.1).

Living shorelines varied in design and in the type of ecosystems being restored and protected, due to differing site attributes and project objectives. Most living shorelines used a combination of soft and hard natural materials (e.g., hybrid projects), but some living shorelines used only soft materials. We categorized the living shorelines as hybrid-major, hybrid-minor, or oyster-natural (see Box 2).

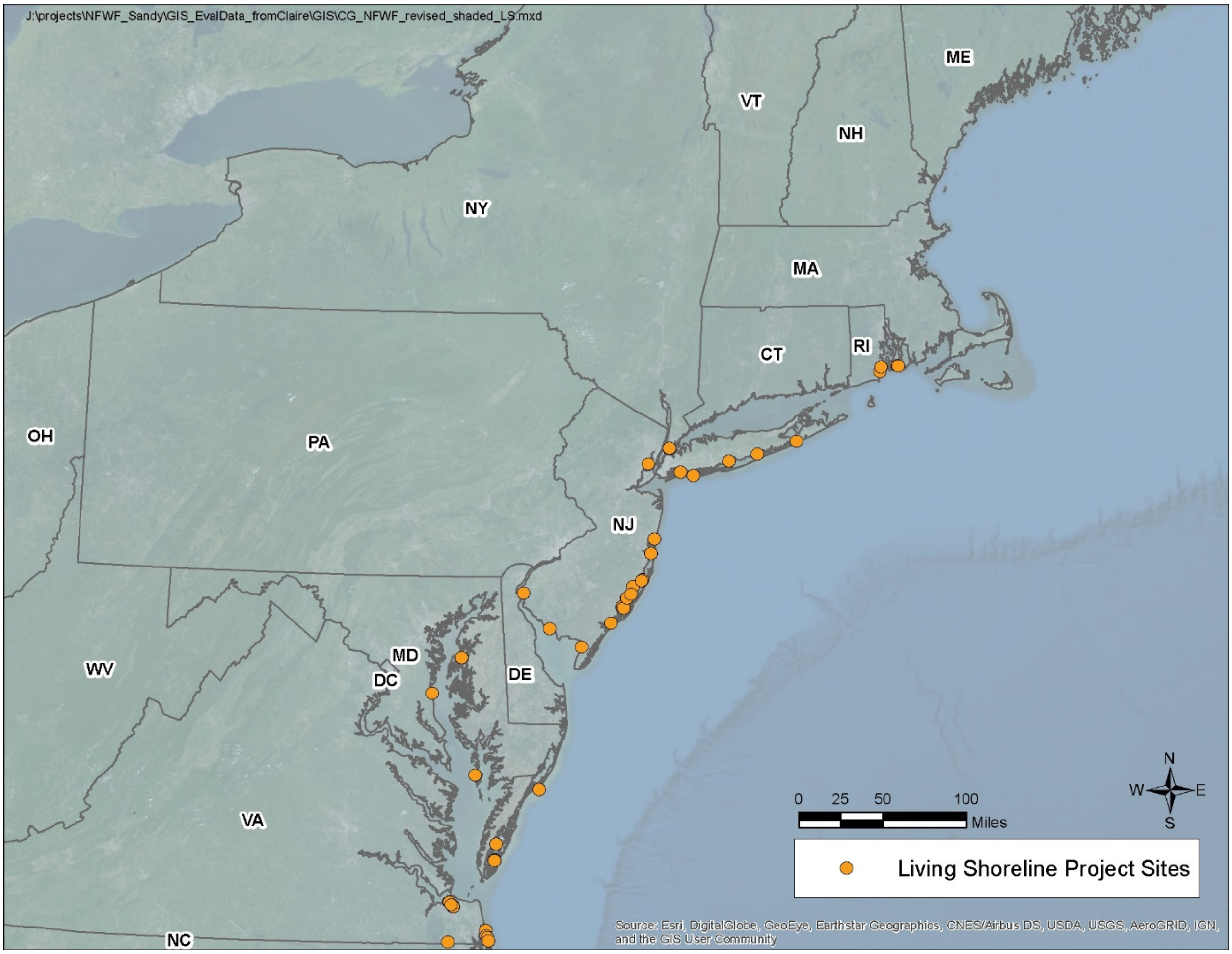
[2] Table A.1 presents the amount of project funding specifically allocated to living shoreline activities. For 6 projects, this is the full project funding amount; and for 11 projects, this is a subset of the total project funding. The allocation was based on available project documentation.

Figure 1. Conceptual representation of the benefits of using living shorelines to stabilize coastlines.



Source: NOAA, 2019.

Figure 2. Location of living shorelines restoration activities.[a]



a. Since some projects conducted restoration activities in multiple sites (see Appendix A), the number of sites (dots) exceeds 17 (the total number of living shorelines).

Box 2. Categories of living shorelines.

Hybrid-major if project used large rock sills or off-shore wave attenuation structures, such as breakwaters (14 of 29 sites).

Hybrid-minor if project used relatively small rock sills or structures to stabilize sites (7 of 29 sites).

Oyster-natural if project used oyster castles, oyster reefs, or soft materials such as coir logs to stabilize shorelines (8 of 29 sites).

Living shorelines were designed to protect coastal communities, including roads and public use facilities near the coast as well as marshes and beaches that further protect coastal communities from storm surge and waves. To protect coastlines, many of these projects also restored habitat within the footprint of the constructed breakwater. For example, projects revegetated marshes, re-nourished beaches, and created oyster reefs to improve wildlife habitat behind the breakwater of the living shoreline. These habitats serve to increase surface roughness, further reducing wave action and reducing erosion; they also support fish and wildlife in the area (see the Project Outcomes section for a more detailed discussion of the community and ecological benefits from land protection and habitat restoration).

The size of the living shorelines varied substantially among projects. The 11 living shorelines included in the cost-effectiveness analysis ranged from 35 to over 20,000 linear feet, with an average length of just over 2,000 linear feet (Table A.2). The costs of design, construction, and maintenance of the living shorelines also varied from approximately $5,000 to over $8 million, with an average cost of approximately $880,000 (Table A.2).

4. Findings

Topic: Project Implementation (PI)

Finding PI.1: Approximately half of the living shorelines successfully completed their proposed activities at the time of the evaluation.

Archival and web-based materials show that 8 of the 17 projects included in this case study were completed[3] at the time of the evaluation, with 9 active projects. Of the eight completed, three projects were completed in 2016, one in 2017, three in 2018, and one in 2019.

Finding PI.2: A combination of factors delayed most projects, including seasonal limitations on restoration work, the need for additional data collection or design work, and difficulties with contracting or procurement.

A combination of issues resulted in nearly every project in the living shorelines portfolio experiencing significant delays compared to proposed completion estimates. The data available through official contract amendments submitted to NFWF and DOI show that 14 of the 17 projects requested extensions for completing their work, with many projects requesting multiple contract extensions. These projects were delayed on average by a year and a half (548 days). Each project nearly always cited a combination of factors that contributed to project delays (see Box 3).

[3] While our evaluation generally provides findings elicited through the review of archival materials received through December 2018, project status information reflects information gathered through April 2019 (updated project status information was obtained through a supplementary web search in March 2019 and an updated spreadsheet provided by NFWF).

Box 3. Factors that contributed to the delay of living shorelines restoration activities.

Seasonal limitations

Nine project leads noted that the weather- and seasonal-dependent nature of living shoreline construction and restoration activities, particularly dredging and vegetation planting, contributed to delays. Weather events and growing seasons can limit the time available to perform restoration, and work was sometimes delayed for months by waiting for appropriate working conditions to return. In addition, construction is often restricted to specific times of the year to avoid harming wildlife (e.g., during migration or breeding seasons).

Additional data collection or design work

Eight project leads noted that they needed to gather additional data or adjust their project designs given onsite conditions, which caused unexpected project delays. For example, one project lead noted that the complexity of drainage in a site required hiring an external contractor to provide analysis and recommendations, resulting in a delay in designing and installing the proper water control structure.

Contracting or procurement

Six project leads reported difficulties in contracting or procurement that led to delays, some of which were due to securing agreements with contractors or engineering firms. At other times, it was difficult for project leads to ensure that contractors had completed all required work before seasonal construction limitations kicked in.

Finding PI.3: Completed living shorelines have generally achieved their design objectives.

Archival materials suggest that completed living shorelines generally met their construction goals. For example, archival materials provided detailed information about realized project objectives for six of the eight completed projects. Five of the six projects reported either reaching or exceeding project design goals in terms of acres of habitat restored, linear feet of living shoreline constructed or protected, or oysters recruited. Only one project constructed a living shoreline that was smaller than proposed (by 920 linear feet) due to conflicting activities occurring at one site preventing activities, and degradation of their installed structures due to faulty manufacturing at another site.

Project reports and project lead interviews, however, suggested that at least some adaptive management should be expected and built into project timelines and project budgets. For example, four projects noted the need to replant some marsh vegetation due to mortality from wildlife grazing, sediment compaction, hypersaline waters, or other causes. In addition, two projects noted the need to redesign and reinstall living shorelines after the first attempt failed because of inadequate fill in high wave-energy environments.

Topic: Project Outcomes (PO)

4.1 Human Community Outcomes

Finding PO.1: Nearly 53,000 linear feet of living shorelines will protect the shoreline and avoid erosion on up to 440 acres of land that people can use or benefit from, including marshes, roads, residential areas, beaches, and public facilities, helping sustain human use of these areas over the next few decades.

Living shorelines protect natural habitat and infrastructure by reducing or avoiding coastal erosion. Project lead-reported data show that the living shorelines included in this case study will protect nearly 53,000 linear feet of shoreline. Based on coastal erosion rates provided by project leads or federal and state data, we estimate these projects protect or reduce coastal erosion from approximately 300 to 440 acres of land over the 30-year project lifespan (Table 1; estimates of area protected depend on assumed erosion rates). Living shorelines that protect marshes both reduce waves and storm surge for communities living near the shore and provide habitat for commercially important fish. These living shorelines also protect:

Table 1. Area estimated to be protected by land type.

Land use type protected	Area to be protected after 30 years (acres)[a, b]	
	Low	High
Marsh	240.9	344.1
Road	39.3	72.4
Residential	5.5	8.4
Beach	5.1	14.2
Public use facilities	0.8	1.0
Total	**291.6**	**440.1**

a. Low and high estimates of area to be protected depend on assumed erosion rates.
b. This number includes all living shoreline projects (both active and completed), meaning this number may be subject to change as projects close and provide final numbers.

- Critical roads, including those used as emergency evacuation routes or for beach access (Box 4)
- Residential areas
- Beaches for human use, including for recreation and for hosting community and cultural events
- Public use facilities, such as visitor centers, educational kiosks, and boat launches in national wildlife refuges.

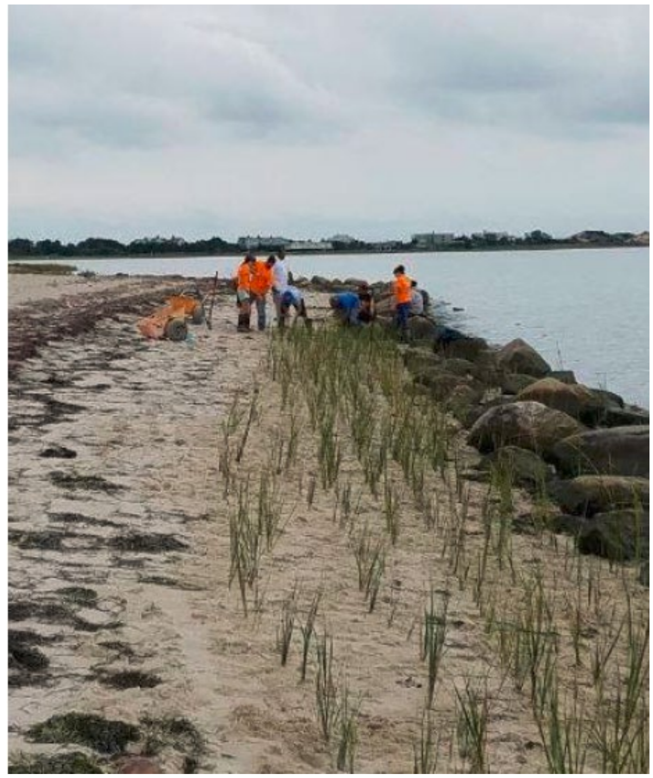
Box 4. A living shoreline under construction in the Town of North Beach, Maryland. Project prevents further erosion, protects the surrounding community and an emergency vehicle route.

4.2 Habitat, Fish, and Wildlife Outcomes

Finding PO.2: Living shorelines restored nearly 40 acres of habitat, including marshes, beaches, oyster reefs, and SAV.

These projects also restore or create habitat behind the living shoreline to further protect natural habitat and infrastructure (Box 5). Project lead-reported data show that the portfolio of living shoreline restoration projects included in this case study have restored or created nearly 40 acres of wildlife habitat, including approximately 22 acres of marshes, 11 acres of beaches, 5 acres of oyster reefs, and 2 acres of SAV (Table 2). It is important to note that these acres of habitat are only those directly behind the footprint of the protection provided by the breakwater of each living shoreline. In most cases, project leads integrated living shoreline activities into a larger project with multiple components, including large areas of marsh or beach restoration. However, these larger restoration efforts outside of the footprint of the living shorelines are included and assessed in other case studies (e.g., marsh restoration or beach and dune case studies), and thus are not included here.

Box 5. Living shoreline restoration at Shinnecock Reservation in Southampton, New York. Project reduces reduce erosion, increases habitat, and strengthens shoreline resiliency.



While on average each living shoreline project only directly protects and restores a modest amount of habitat, these habitats can play an important role in providing foraging, resting, and reproductive habitats for key bird, fish, and other wildlife in the region. For example, the salt marsh sparrow, red knot, alewife, and river herring all depend on salt marsh habitat for foraging and reproduction (Audubon, 2014; ASMFC, 2019; Cornell Lab of Ornithology, 2019). Beach habitat can support endangered species, including the regionally threatened piping plover and red knot (Audubon, 2014; USFWS, 2019; see the salt marsh and beach/dune case studies for more details about habitat-related benefits to wildlife). Oyster reefs and SAV improve water quality and provide critical

Table 2. Summary of area of habitat restored

Habitat type restored	Area restored (acres)[a, b]
Marsh	21.5
Beach	10.7
Oyster reef	5.3
SAV	1.7
Total	**39.2**

a. We assumed that these areas persist for the anticipated 30-year project life.
b. This number includes all living shoreline projects (both active and completed), meaning this number may be subject to change from adjustments to in progress projects.

habitat for a wide variety of forage fish, invertebrates, and shellfish, further supporting the larger fish and birds that feed on organisms that depend on reefs. While full realization of these benefits is expected to accrue over time, six projects reported initial improvements in oyster reef recruitment and anecdotal observations of increases in bird and fish numbers at restored sites.

4.3 Trajectories of Outcome Achievement

Finding PO.3: Early observations at living shoreline project sites are consistent with expected timelines of recovery after restoration, but project information about habitat recovery was limited.

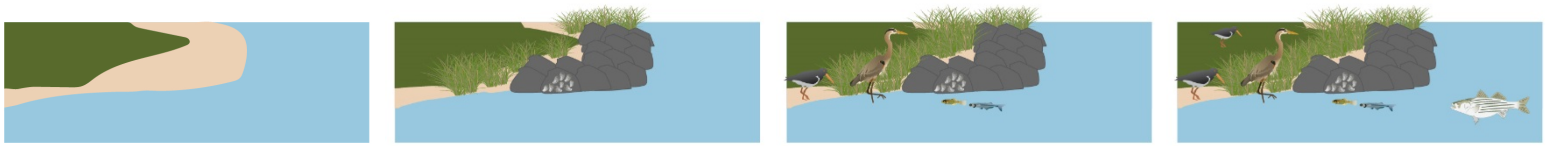
The ecological benefits of most living shorelines funded through the Hurricane Sandy Program will take time to materialize after restoration activities are completed. To better understand and convey the potential timing of the achievement of key outcomes, the Abt Associates evaluation team developed conceptual timelines of recovery after restoration using information from key peer-reviewed articles in combination with professional judgment from our team's subject matter experts (Figure 3).

More specifically, while some ecological components of living shorelines may begin to recover immediately following restoration actions (e.g., shoreline stabilization, recruitment of invertebrates such as oysters, seagrass recruitment), they may require more than 10 years to reach maximum function (Piazza et al., 2005; Davis et al., 2006; Scyphers et al., 2011; Manis, 2013; Bilkovic and Mitchell, 2017). While relatively few studies examine the long-term recovery of living shorelines, those with data for restored areas older than 10 years indicate that recovery continues for many years. For example, wildlife populations associated with living shorelines continue to increase after 10 years, and vegetation – particularly marsh vegetation – may take 10–30 years to match reference site conditions (Moreno-Mateos et al., 2012; Bilkovic and Mitchell, 2017; Lee et al., 2018).

Erosion control, often the primary reason for implementing a living shoreline project, begins immediately following restoration actions and continues to improve throughout the life of the project. The initial breakwater provides immediate protection, which provides opportunities for oysters and other filter-feeding species to become established; seagrass, if present, may also begin to establish in areas immediately behind and adjacent to the breakwater (Piazza et al., 2005; Scyphers et al., 2011; Manis, 2013; Patrick et al., 2014; Sharma et al., 2016). As marsh vegetation, seagrasses, and oyster reefs mature, the elevation and surface roughness of the area increases, providing increased erosion control protection (Bilkovic and Mitchell, 2017; Lee et al., 2018).

Initial observations of living shoreline recovery in Hurricane Sandy Program projects are consistent with the likely short-term outcomes described above. For example, six projects (completed between 2016 and 2018, plus one active project to be completed in 2019) reported use of restored habitat by wildlife, which primarily consisted of oyster reef recruitment, survival, or growth following restoration, with occasional fish and bird use of the habitat noted.
Four projects reported observations indicating improved erosion control, including shoreline stabilization and reduced wave energy. One project observed mixed improvements in vegetation; however, most projects were focused on assessing the success of installed oyster reefs, and examining the response of vegetation was not a high priority at this early stage.

Figure 3. Site recovery following living shoreline restoration activities over time.[a]



Realization timeframe[b]	Year 0 (pre-project)	Short-term (1–2 years) outcomes 2018–2022	Mid-term (3–7 years) outcomes 2020–2027	Long-term (10+ years) outcomes 2027+
Vegetation	Native vegetation may be sparse or missing; invasive species frequently dominate marshes.	Vegetation planted during restoration begins to establish; seagrass recruitment begins.	Marsh vegetative productivity approaches reference conditions; continued seagrass recruitment.	Vegetation comparable to reference marshes and seagrass beds achieved between 15 and 30 years after restoration.
Habitat/wildlife use	Area provides minimal support to key wildlife species.	Depending on restoration action(s), early recruitment of filter-feeding species begins (e.g., oysters, mussels, barnacles); seagrass habitat begins to establish; mudflats or beaches stabilize.	Native biota increase in restored areas, including macroinvertebrates, fish, and birds; seagrass continues to recolonize adjacent areas; continued stabilization of mudflats and beaches.	Ongoing population increases for all biota as habitat conditions improve and stabilize.
Erosion control	Unrestored habitat is prone to erosion.	Shoreline stabilization begins immediately following living shorelines structure installation through reduced wave energy, and increased sediment stability and accretion.	Reduced wave energy, sediment accretion, and vegetation growth help stabilize shorelines.	Shoreline elevation is stabilized or increases, supported by reduced wave energy, established vegetation, and surface roughness.

a. Marsh recovery timelines, which are relevant to living shoreline installations, are covered in detail in the marsh restoration case study. Habitat and wildlife use here is focused on the habitat provided by the breakwater or restored seagrass areas.

b. Assuming projects completed between 2017 and 2020.

Sources: **Vegetation:** Warren et al., 2002; Craft et al., 2003; Moreno-Mateos et al., 2012; Patrick et al., 2014; Sharma et al., 2016; Ebbets et al., 2019. **Habitat/wildlife use:** Piazza et al., 2005; Davis et al., 2006; Scyphers et al., 2011; Manis, 2013; Bilkovic and Mitchell, 2017; Hollweg et al., In review. **Erosion control:** Piazza et al., 2005; Scyphers et al., 2011; Manis, 2013; Bilkovic and Mitchell, 2017; Lee et al., 2018; professional judgment.

Topic: Cost-Effectiveness (CE)

This section highlights key findings of our analysis comparing the cost-effectiveness of a living shoreline to that of a comparable stone revetment. We made three important analytical assumptions that are critical to understanding and interpreting the results presented below. First, because the projects analyzed had been completed within two years of the evaluation, we had limited information to assess project performance in terms of erosion control. The literature also provided little information about living shoreline performance, particularly over the long-term. We thus assumed that projects that were fully implemented were successful at achieving their land protection and restoration goals; the same assumption was made for comparable stone revetments. Put simply, we assumed that both the living shoreline and stone revetment ceased all erosional loss at the site for 30 years, and this represented the amount of land protected by the project. Second, we bracketed our analysis using both "high" and "low" local erosion rates to estimate the annual amount of land protected (i.e., we calculated the amount of land that would have been lost if the project had not been implemented and assumed that all of this land would be successfully protected by the project). Third, we assumed that the comparable stone revetment projects were focused only on protecting existing land and thus did not restore habitat.

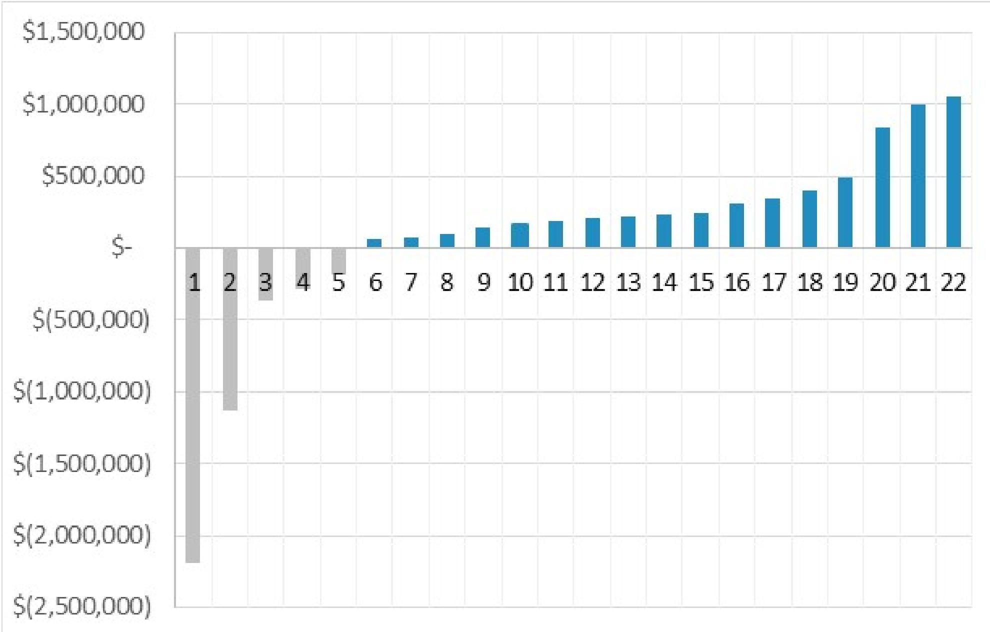
Finding CE.1: Living shorelines provided more ecological benefits than stone revetments.

As noted in Finding PO.1 above, the portfolio of living shoreline projects restored or created approximately 40 acres of wildlife habitat in addition to shoreline habitat being protected by the projects. While we assume both stone revetment and living shoreline projects protect existing shoreline habitat equally well, these restoration-related benefits are only secured through living shorelines.

Finding CE.2: Living shorelines were typically more cost-effective than stone revetments for erosion protection.

In almost all cases, living shoreline costs per area protected were lower than that of the comparable stone revetment. The average difference in costs per acre protected across all 22 project sites was approximately $84,800 for an assumed low erosion rate (Table A.2). The difference between stone revetment and living shoreline costs over 30 years (the assumed project lifetime) ranged from approximately a negative $2.2 million (i.e., the stone revetment was less expensive) to a positive $1.1 million (the living shoreline was less expensive; Figure 4; Table A.2). Negative values, which indicate that the living shoreline was less cost-effective than the stone revetment, were seen at only 5 of the 22 sites, all of which are located in low-energy environments with smaller waves (Figure 4; Table A.2). Cost-effectiveness results were similar when simply comparing implementation costs (construction plus planning) instead of using present value, suggesting that the assumptions we used to create the present value of costs, such as applying a discount rate, do not substantially affect our findings.

Figure 4. Differences in living shoreline costs per area protected versus comparable stone revetment costs.[a]

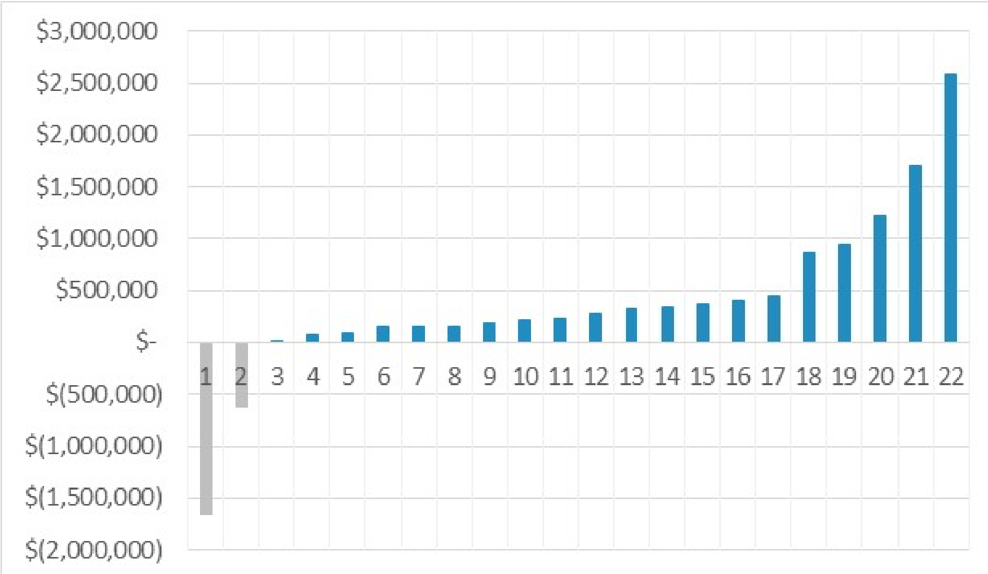


a. Values are sorted from low to high cost differences. Gray = living shoreline more costly; blue = living shoreline less costly. See Table A.2 for full project information (project identification numbers are not included here for visual simplicity).

Finding CE.3: When the additional benefits of habitat created were considered, living shorelines were substantially more cost-effective than gray approaches.

The cost-effectiveness of living shorelines increased markedly with including area restored in our assessment of cost-effectiveness (Table A.2). Including the amount of habitat restored into our measurement of cost-effectiveness for living shorelines reduced the estimated costs per unit of land area benefiting by approximately 30–40% (Table A.2). In addition, using this modified benefit metric, the cost-effectiveness of living shorelines compared to stone revetments increased by roughly 5- to 8-fold (Table A.2), and only two living shoreline sites had lower cost-effectiveness than comparable stone revetment projects (Figure 5, Table A.2). Living shorelines with the highest cost-effectiveness compared to equivalent stone revetments were those that added the most habitat (i.e., marsh, oyster reefs, or SAV).

Figure 5. Differences in living shoreline costs per area protected and restored versus comparable stone revetment costs.[a]

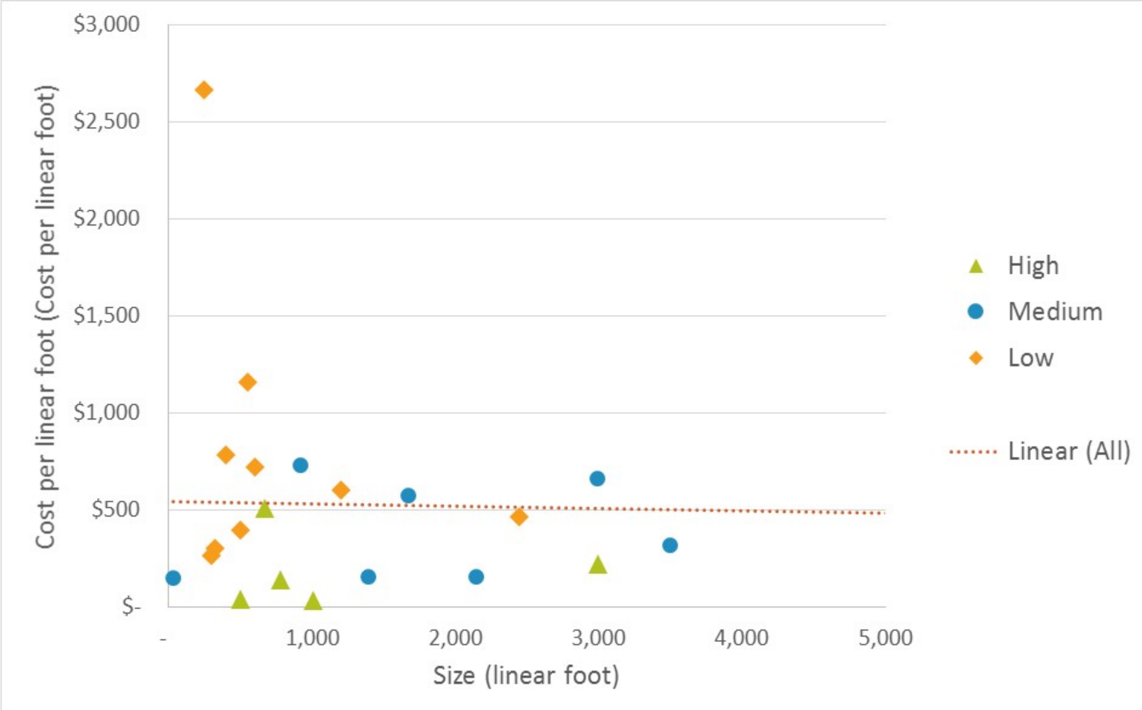


a. Values are sorted from low to high. Gray = more-costly living shorelines; blue = less-costly living shorelines. See Table A.2 for full project information (project identification numbers are not included here for visual simplicity).

Finding CE.4: There were no substantial economies of scale in creating living shorelines.

We found only weak evidence of economies of scale with project size (Figure 6), and the small negative relationship between unit cost and size was not statistically significant. When hybrid-major projects (i.e., those that used a large amount of rocks) were isolated (see triangles in Figure 6), the regression slope became slightly more negative, indicating a greater reduction of unit costs with size; however, the relationship was still not statistically significant. An outlier far to the right (i.e., data from Fog Point, which restored 20,950 linear feet of shoreline) was omitted from the graph to improve readability; although we included the outlier in the regression analyses, our findings were not affected by its inclusion.

Figure 6. Economies of scale in living shoreline projects. Project costs for each foot of living shoreline do not decrease significantly with project size.



Topic: Information Gaps (IG)

Finding IG.1: More time is needed to assess how well living shorelines prevent erosion and improve resilience.

The evaluation team was not able to fully assess the on-the-ground performance of living shorelines projects because they were either not finished or had only recently been completed at the time of this evaluation. The ability of living shorelines to reduce coastal erosion will not be fully realized until restored habitat is allowed to mature, and our understanding of their effectiveness will be limited until they are tested by weather events. As noted above, we assumed in our cost-effectiveness analyses that living shorelines would be equally effective at preventing erosion as stone revetments, bulkheads, or other gray systems, as long as they have been designed to fit the energy conditions at a site. This critical assumption needs to be tested with site-based data in the future.

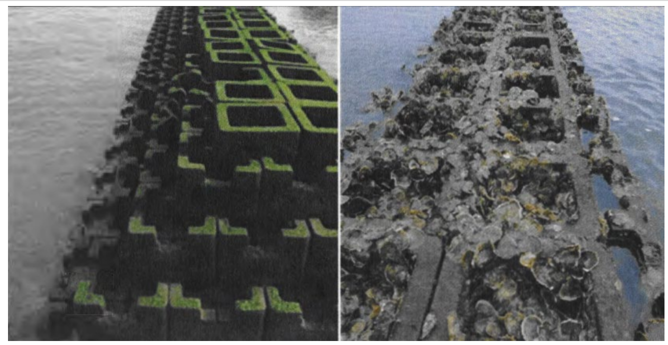
We also lacked information to test a common assumption associated with living shorelines – that they will be more resilient to sea level rise and changing weather patterns than comparable gray infrastructure projects, and may require less maintenance. This is assumed to be true because natural ecosystems, such as marshes, have the ability to respond to environmental forces. For example, marsh accretion rates have been observed to match rates of sea level rise under some conditions, and oyster reefs have some capacity to adapt to changing wave or water conditions. This is in contrast to gray infrastructure, which can be built to withstand future sea level increases, but cannot adapt if forces exceed design conditions.

To address these gaps, long-term monitoring of erosion, sediment accretion, vegetation dynamics, and maintenance costs will be needed to assess whether living shorelines successfully promote resilience and offer cost savings compared to gray infrastructure approaches. Long-term monitoring at living shorelines sites (described in Finding IG.4) will capture the ecological data needed to test our effectiveness and resilience assumptions.

Finding IG.2: Very few habitat benefits provided by living shorelines were directly measured by projects.

Living shorelines support more acreage of natural ecosystems than stone revetment, bulkhead, or other gray systems, but project monitoring is not typically focused on assessing how well those ecosystems support wildlife and human uses. Instead, project monitoring is typically focused on ensuring that project design goals have been met (e.g., linear feet of shoreline constructed, the establishment of oyster populations; Box 6). However, to fully understand the benefits provided by living shorelines (and to allow a more accurate and complete cost-effectiveness analysis), more information is needed about how these projects affect meaningful ecological and social endpoints (e.g., foraging use, nesting success, recreational use).

Box 6. Oyster recruitment and growth on an oyster castle breakwater in June 2016 and November 2017 at Gandy's Beach, New Jersey.



Finding IG.3: Project costs need to be consistently and carefully tracked, and documented.

Our team had difficulty securing estimates of key aspects of project costs, which are critical to the cost-effectiveness analysis. For example, it was often not clear whether total project costs included project design, volunteer labor hours, or cost-sharing arrangements. While our team filled these gaps through either soliciting information directly from project leads or by leveraging information from the peer-reviewed literature, future analyses would benefit from consistent data gathering and reporting on living shoreline project costs. Furthermore, ongoing rehabilitation and maintenance costs will be key to understanding the full long-term costs of living shorelines, and should be carefully tracked and documented.

Finding IG.4: Some of the information gaps described above may be addressed through a new long-term monitoring initiative run through NFWF and DOI.

Recognizing the need for long-term, systematic data collection to assess restoration success, NFWF and DOI are supporting additional, future long-term monitoring for 10 of the 17 living shoreline projects through 2024 (Table A.1).

To identify the most appropriate metrics for these projects to measure over the long-term, NFWF and DOI leveraged work done by an internal DOI metrics expert group, which developed a suite of standardized performance metrics for different types of Hurricane Sandy resilience projects (DOI, 2015). Projects selected for long-term monitoring had to propose a specific subset of these metrics for their projects. Most of the projects including in long-term monitoring are assessing the ecological effectiveness of their restoration actions by measuring changes in the health of living shorelines (e.g., oysters coverage and population), water quality benefits (e.g., water temperature and salinity), and shoreline stability (e.g., structure resilience to waves, shoreline position and topography). All of the ecological metrics included are consistent with those identified in the DOI (2015) report, but have been adapted in some cases to meet project-specific needs. While these data will provide important information about marsh resilience over time, fewer than four projects plan to monitor wave energy and erosion rates; these key data gaps will likely remain for most projects.

In addition to these ecologically focused metrics, NFWF and DOI are also supporting long-term monitoring to understand the impacts of living shorelines on human well-being, primarily through the benefits gained by reducing impacts on human health, infrastructure, including transportation and critical facilities, and economic resilience from storm surge, waves or inundation. As with the ecological monitoring described above, the socioeconomic metrics being monitored were previously identified as potential standardized performance metrics for Hurricane Sandy Program resilience projects (Abt Associates, 2015).

5. Conclusion

Hurricane Sandy Program investments in living shorelines generally seem to be a cost-effective and ecologically sound approach for reducing coastal erosion and improving resilience. Our analysis shows that living shorelines were more cost-effective than a comparable gray infrastructure approach (i.e., a stone revetment) at reducing coastal erosion at project sites, assuming the two approaches provide the same level of erosion reduction over time. The cost-effectiveness of living shorelines was even higher when we included the amount of habitat restored in our calculations. While data were not available to provide a robust assessment of on-the-ground performance of specific projects, anecdotal observations suggest that erosion has been reduced and habitat is recovering in project areas, which helps protect coastal communities from storm surge and waves. These observations are preliminary, however, and many more years of recovery and monitoring data are needed to more fully understand the long-term ecological and socioeconomic impacts of living shorelines. More specifically, additional information is needed about (1) coastal erosion rate changes at project sites; (2) the nature and rate of recovery of habitats restored in a living shoreline; (3) project costs, particularly those related to maintenance and repair; and (4) whether living shorelines adapt to local conditions over time as expected. Recognizing the need for long-term, systematic data collection to assess restoration success, NFWF and DOI are supporting additional, future long-term monitoring for 10 of the 17 living shoreline projects through 2024 using standardized ecological and socioeconomic metrics.

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Appendix A. Project Summaries

Table A.1. Living shoreline restoration projects supported through the Hurricane Sandy Program. This table presents the amount of project funding specifically allocated to living shoreline activities. For 6 projects, this is the full project funding amount; and for 11 projects, this is a subset of the total project funding. The allocation was based on available project documentation. Projects included in the cost-effectiveness analysis are listed first. All dollars rounded to the nearest hundred.

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent living shoreline activities only[c]	
NFWF-41931	Developing self-sustaining oyster population in Jamaica Bay, New York	NY	New York City Department of Environmental Protection	$900,000	$337,500
NFWF-42019	Restoring Bronx River shoreline at Starlight Park, New York	NY	New York City Department of Parks and Recreation	$3,960,000	$792,000
NFWF-42551[a]	Green infrastructure in Accomack and Northampton counties, Virginia	VA	The Nature Conservancy	$133,900	$27,100
NFWF-43308[a]	Developing a green infrastructure plan and network for the Lafayette River Watershed, Virginia	VA	City of Norfolk	$3,914,400	$217,100
NFWF-43849[a]	Developing coastal resiliency regional models, Virginia	VA	Wildlife Foundation of Virginia	$860,400	$82,600
NFWF-43939	Restoring Newark Bay's wetlands, New Jersey	NJ	City of Newark	$780,000	$7,500
NFWF-44068	Restoring over one hundred wetland acres in Great Egg Harbor Bay, New Jersey	NJ	City of Ocean City	$2,630,000	$1,276,800
NFWF-44109[b]	Replenishing Little Egg Harbor's marshes and wetlands, New Jersey	NJ	Little Egg Harbor Township	$2,130,000	$76,800
NFWF-44167[a, b]	Protecting North Beach's salt marsh and emergency route, Maryland	MD	Town of North Beach	$278,900	$62,600
NFWF-44225[a, b]	Improving Shinnecock Reservation's shoreline habitats, New York	NY	Shinnecock Indian Nation	$1,975,300	$165,400
USFWS-1[a, b]	Salt marsh restoration and enhancement at Seatuck, Wertheim and Lido Beach National Wildlife Refuges, Long Island, New York	NY	U.S. Fish and Wildlife Service	$594,300	$76,700
USFWS-31[a, b]	Fog Point living shoreline restoration, Martin National Wildlife Refuge	MD	U.S. Fish and Wildlife Service	$9,000,000	$1,083,500
USFWS-37[b]	Restoring coastal marshes in New Jersey National Wildlife Refuges	NJ	U.S. Fish and Wildlife Service	$7,500,000	$1,500,000

Project identification number	Project title	Project state	Project lead organization	Award amount	Reported matching funds
				Values represent living shoreline activities only[c]	
USFWS-57[a, b]	Hail Cove living shoreline restoration, Eastern Neck National Wildlife Refuge	MD	U.S. Fish and Wildlife Service	$1,550,000	$16,000
USFWS-65[a, b]	Protecting property and helping coastal wildlife: Enhancing salt marsh and estuarine function and resiliency for key habitats on impacted wildlife refuges from Rhode Island to southern Maine	Multi: RI, MA, ME	U.S. Fish and Wildlife Service	$166,700	$10,000
USFWS-76[a, b]	Living shoreline-oyster reef restoration and construction at Chincoteague National Wildlife Refuge, Virginia	VA	U.S. Fish and Wildlife Service	$553,400	$0
USFWS-77[a, b]	Gandy's Beach Shoreline Protection Project, Downe Township, Cumberland County, New Jersey	NJ	The Nature Conservancy; U.S. Fish and Wildlife Service	$720,000	$0

a. Denotes a project included in the cost-effectiveness analysis for the case study.

b. Denotes a project for which long-term monitoring funding has been secured through NFWF and DOI.

c. Costs in the table do not represent the full cost of the project and may not reflect the total match.

Table A.2. Living shoreline restoration projects and project sites included in the cost-effectiveness analysis.

Project identification	Project site	Energy environment	Living shoreline (LS)							Stone revetment			LS cost difference (Revetment – LS)	
			Type	Length (linear feet)	Acres protected	Acres restored	Total cost	$/acre protected[a]	$/acre protected + restored[a]	Acres protected	Total cost[a]	$/acre protected[a]	$/acre protected[a]	$/acre protected + restored[a]
NFWF-42551	1. Man and Boy Marsh	High	Oyster-natural	1,008	5.9	0.0	$39,864	$6,732	$6,692	5.9	$1,436,816	$242,638	$235,906	$235,945
	2. Little Tom's Cove (Chincoteague)	High	Oyster-natural	504	3.2	0.1	$24,562	$7,700	$7,537	3.2	$718,408	$225,212	$217,512	$217,675
	3. Short Prong Marsh	High	Oyster-natural	780	5.5	0.1	$126,769	$23,204	$22,713	5.5	$1,111,822	$203,510	$180,306	$180,797
NFWF-43308	1. Beach Ave, Norfolk	Low	Hybrid-major	1,202	0.8	0.8	$863,358	$1,042,925	$527,137	0.8	$713,894	$862,374	($180,551)	$335,237
	2. Hermitage Museum West Side, Norfolk	Medium	Hybrid-major	923	0.6	2.6	$797,591	$1,254,715	$248,032	0.6	$931,923	$1,466,037	$211,322	$1,218,004
	3. Knitting Mill, Norfolk	Low	Hybrid-major	550	0.4	0.1	$755,864	$1,995,481	$1,485,617	0.4	$326,657	$862,374	($1,133,107)	($623,243)
	4. North Shore, Norfolk	Medium	Hybrid-major	1,681	1.2	1.0	$1,136,983	$982,093	$517,348	1.2	$1,697,250	$1,466,037	$483,943	$948,689
	5. Villa Circle, Norfolk	Low	Hybrid-major	2,450	1.7	1.6	$1,353,833	$802,353	$418,195	1.7	$1,455,108	$862,374	$60,021	$444,180
NFWF-43849	1. False Cape	Low	Hybrid-major	600	0.5	0.2	$512,554	$932,617	$642,407	0.5	$356,353	$648,402	($284,215)	$5,995
	2. Back Bay Visitor Center	Low	Hybrid-major	400	0.4	0.4	$373,530	$1,019,484	$499,063	0.4	$237,569	$648,402	($371,082)	$149,338
	3. Horn Point	Low	Hybrid-major	500	0.5	0.0	$233,972	$510,868	$489,685	0.5	$296,961	$648,402	$137,534	$158,717
NFWF-44167	1. North Beach	High	Hybrid-major	670	2.3	0.6	$405,708	$175,847	$139,555	2.3	$955,026	$413,940	$238,093	$274,385
NFWF-44225	1. Shinnecock Reservation	Medium-high	Hybrid-minor	3,250	0.7	0.2	$2,542,761	$3,442,507	$2,738,166	0.7	$3,281,418	$4,442,535	$1,000,028	$1,704,369

Project identification	Project site	Energy environment	Living shoreline (LS)							Stone revetment			LS cost difference (Revetment – LS)	
			Type	Length (linear feet)	Acres protected	Acres restored	Total cost	$/acre protected[a]	$/acre protected + restored[a]	Acres protected	Total cost[a]	$/acre protected[a]	$/acre protected[a]	$/acre protected + restored[a]
USFWS-1	1. Lido Beach	Low	Hybrid-major	250	0.3	0.1	$791,104	$2,702,783	$2,163,788	0.3	$148,480	$507,279	($2,195,504)	($1,656,509)
	2. Seatuck NWR	Medium-high	Oyster-natural	35	0.1	0.1	$5,939	$68,253	$37,137	0.1	$35,338	$406,104	$337,851	$368,968
USFWS-31	1. Fog Point, Martin NWR	High	Hybrid-major	20,950	216.4	18.4	$10,096,671	$46,652	$43,000	216.4	$29,862,388	$137,980	$91,328	$94,980
USFWS-57	1. Hail Cove; Eastern Neck NWR	Medium	Hybrid-major	3,500	7.2	1.2	$1,306,628	$180,688	$155,163	7.2	$3,533,835	$488,679	$307,991	$333,516
USFWS-65	1. John H Chafee NWR	Low	Hybrid-minor	325	0.1	4.4	$115,232	$1,560,057	$25,757	0.1	$193,025	$2,613,256	$1,053,198	$2,587,499
	2. Sedge Island rock apron	Low	Hybrid-major	300	0.2	-	$94,747	$458,576	$458,576	0.2	$178,177	$862,374	$403,798	$403,798
USFWS-76	1. Assateague Bay	Medium	Oyster-natural	2,150	11.2	-	$390,741	$34,952	$34,952	11.2	$2,170,784	$194,177	$159,225	$159,225
	2. Tom's Cove	Medium	Oyster-natural	1,400	16.8	2.5	$254,436	$15,175	$13,178	16.8	$1,413,534	$84,303	$69,129	$71,125
USFWS-77	1. Gandy's Beach	High	Hybrid-minor	3,080	4.2	0.5	$814,156	$191,908	$173,402	4.2	$4,390,270	$1,034,849	$842,941	$861,448
Total				**46,508**	**280.2**	**34.9**	**$23,037,002**	**$17,455,571**	**$10,847,100**	**280.2**	**$55,445,035**	**$19,321,239**	**$1,865,668**	**$8,474,139**
Average				**2,022**	**12.7**	**1.6**	**$1,047,136**	**$793,435**	**$493,050**	**12.7**	**$2,520,229**	**$878,238**	**$84,803**	**$385,188**

a. All cost-effectiveness values are for the low-erosion scenario, in present value dollars, and discounted at 3%. Only includes the 22 project sites included in the cost-effectiveness analysis.