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Evaluation of Hurricane Sandy Coastal Resilience Program

Contract # 5359

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Virginia Institute of Marine Science,
Center for Coastal Resources Management
Crucial Economics Group, LLC

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Final Version
September 13, 2019

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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.



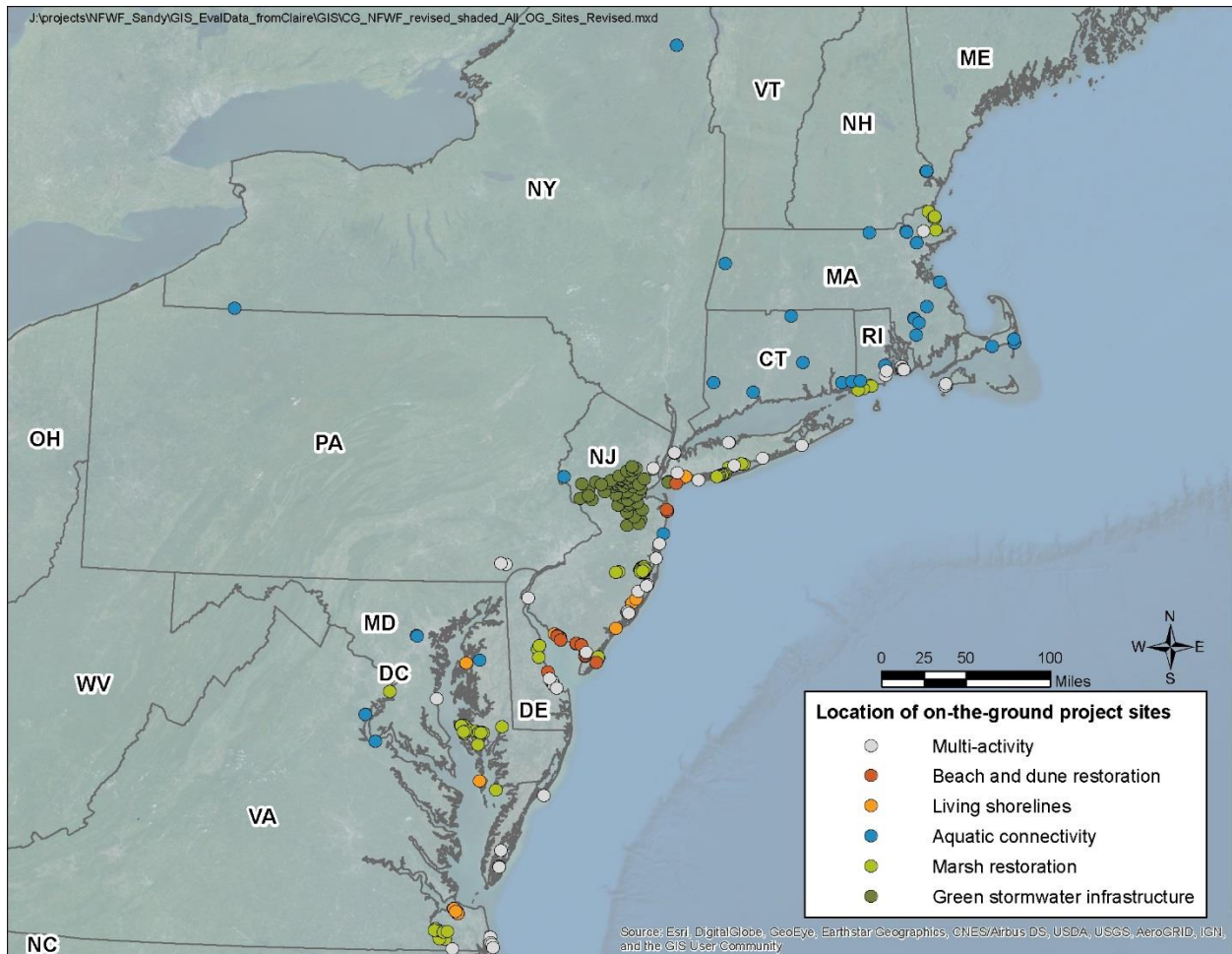
Monitoring and Evaluation	
	Long-term monitoring. A subset of 38 of the Hurricane Sandy projects will be monitored from 2018 to 2023 to assess the trajectory of their project activities against a suite of metrics related to these activities. This monitoring includes both ecological and socioeconomic 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 categories¹:

- 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.

	<p>Marsh restoration projects are restoring approximately 190,000 acres of marsh – equivalent to approximately 300 square miles.</p> <ul style="list-style-type: none"> • <i>Socioeconomic benefit:</i> Improved resilience to future storms by absorbing waves, and reducing storm surge and related flooding and coastal erosion. • <i>Ecological benefit:</i> 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.
	<p>Nearly 53,000 linear feet of living shorelines have protected adjacent habitats and reduced coastal erosion on up to 440 acres of land.</p> <ul style="list-style-type: none"> • <i>Socioeconomic benefit:</i> Reduced coastal erosion, while being at least as cost-effective as traditional gray infrastructure approaches for coastal protection, such as stone revetments. • <i>Ecological benefit:</i> 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.
	<p>Removal of 23 dams and improvements to 10 culverts.</p> <ul style="list-style-type: none"> • <i>Socioeconomic benefit:</i> 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. • <i>Ecological benefit:</i> 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.
	<p>Beach and dune restoration for community protection and ecological resilience.</p> <ul style="list-style-type: none"> • <i>Socioeconomic benefit:</i> 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. • <i>Ecological benefit:</i> 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.

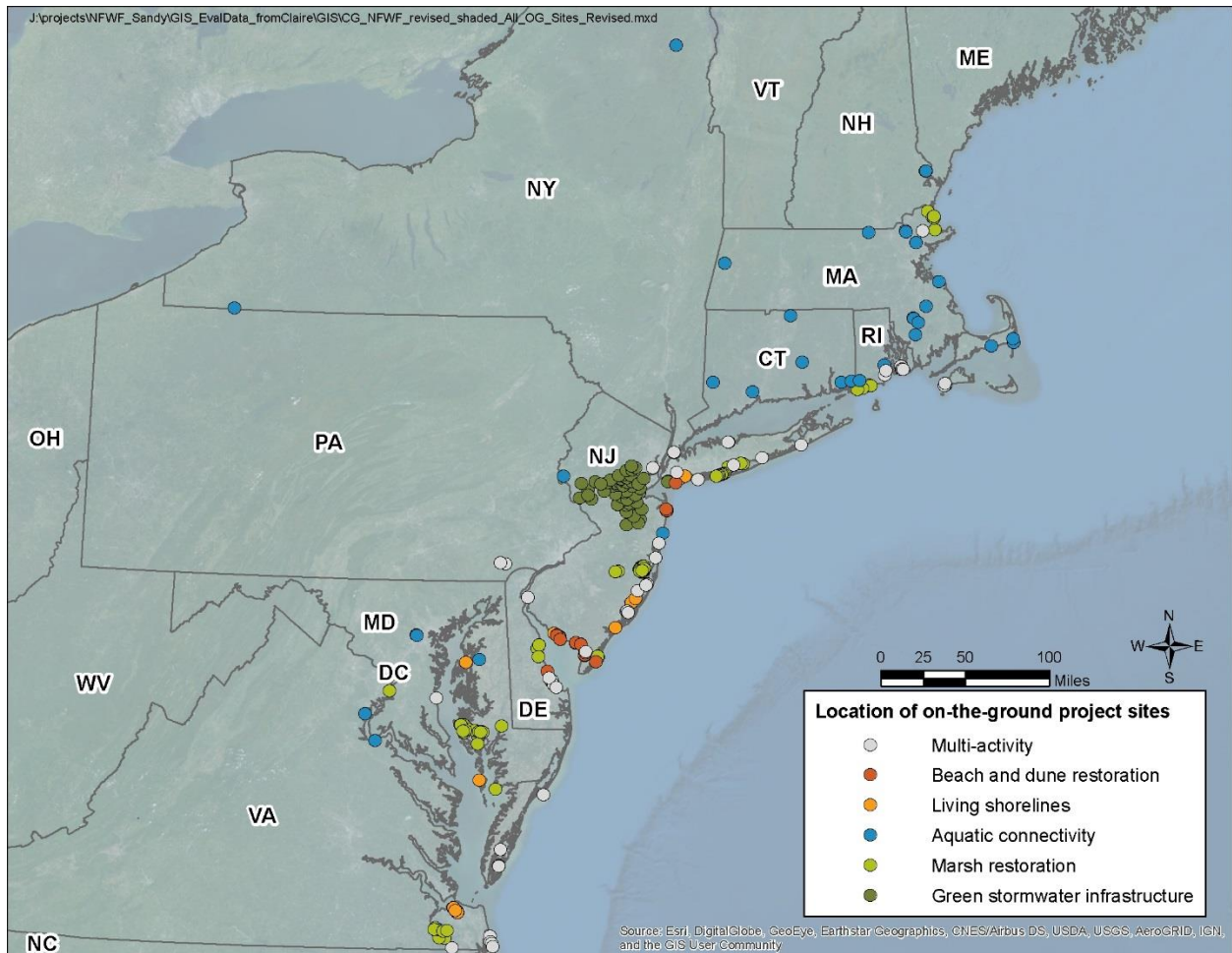
To assess the impact of these projects, NFWF and DOI have also funded long-term monitoring and evaluation of the Hurricane Sandy portfolio to more fully understand the ecological and economic benefits of the resilience projects (Box 2).

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.

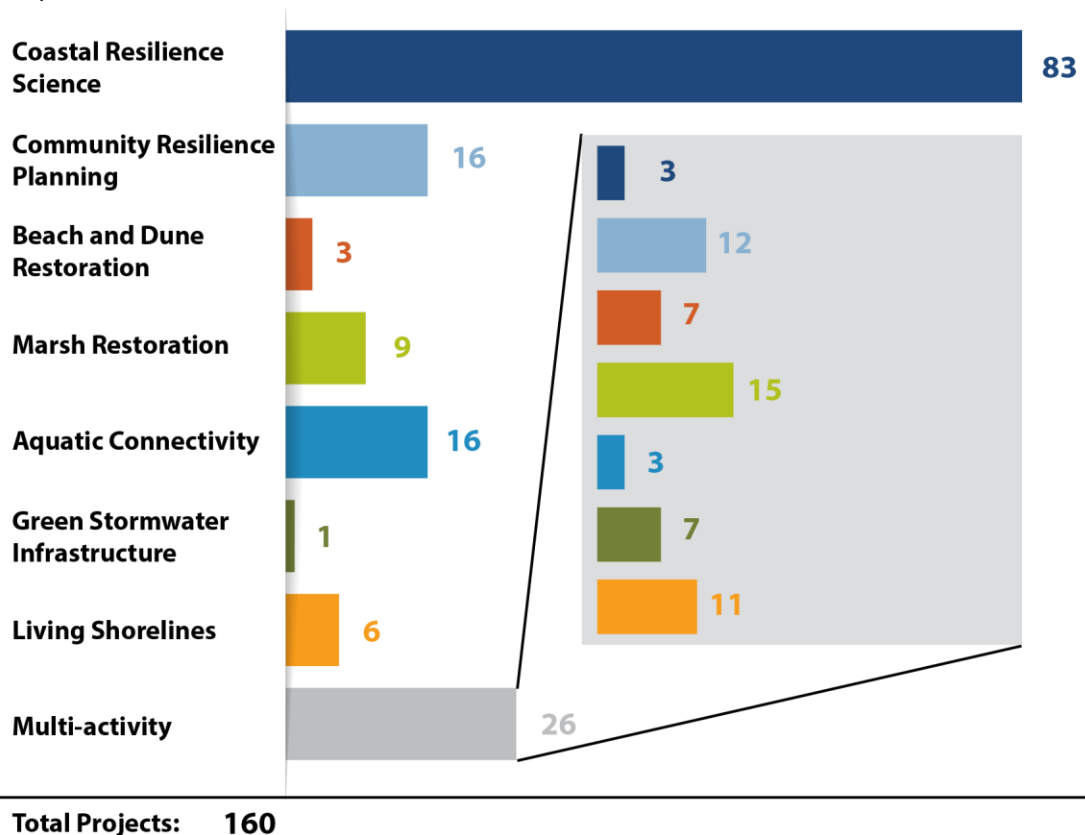
On-the-ground projects supported through DOI and NFWF were located in 10 states and the District of Columbia: Connecticut, Delaware, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, and Virginia (Figure 1).

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.

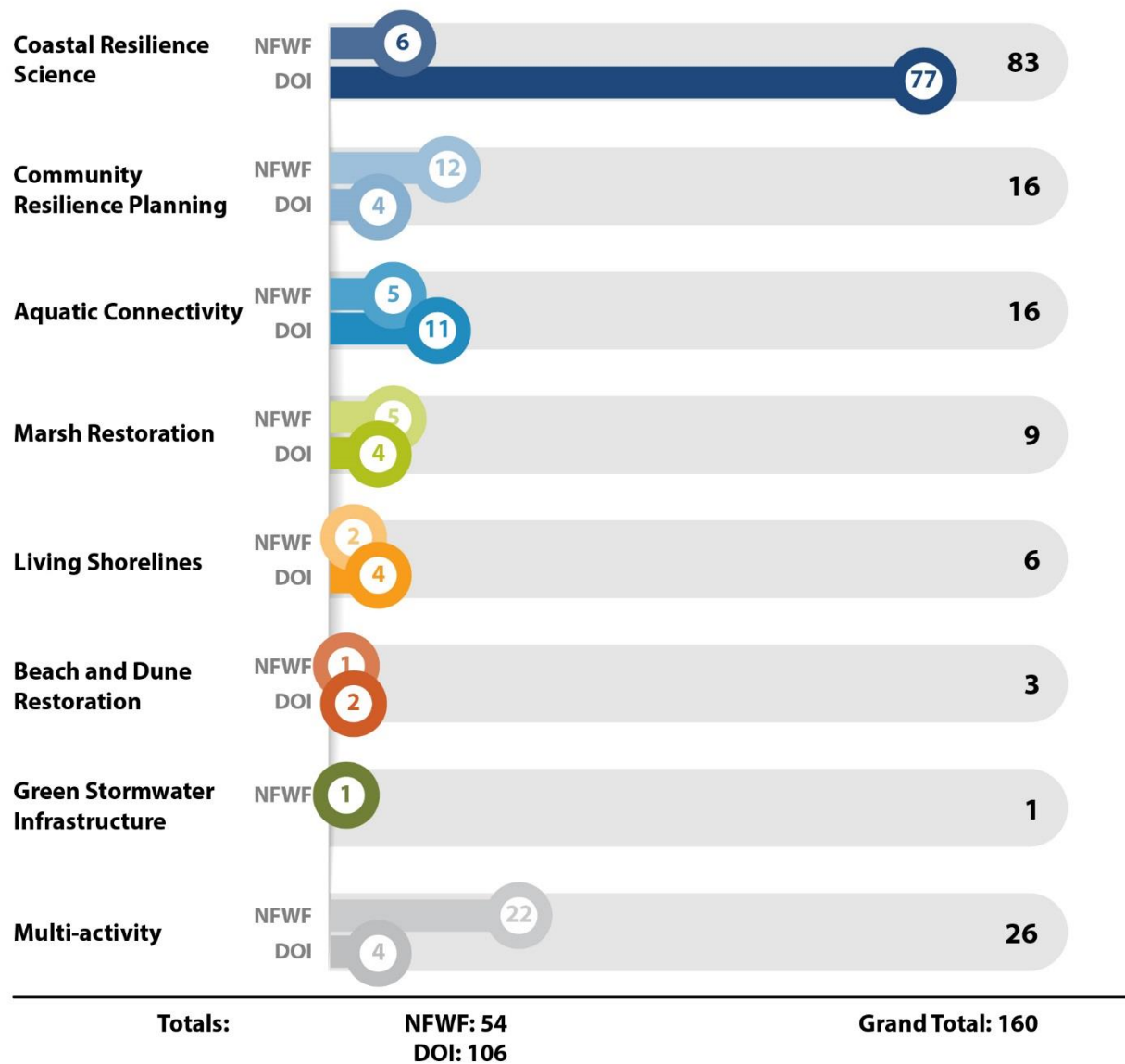
The Hurricane Sandy Program invested more than \$302 million in resilience activities. Funding allocated to each project activity ranged from \$92.6 million (marsh restoration) to \$8.4 million (green stormwater infrastructure). Marsh restoration had the highest average project award size (\$3.9 million), 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 categories³:

- 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.

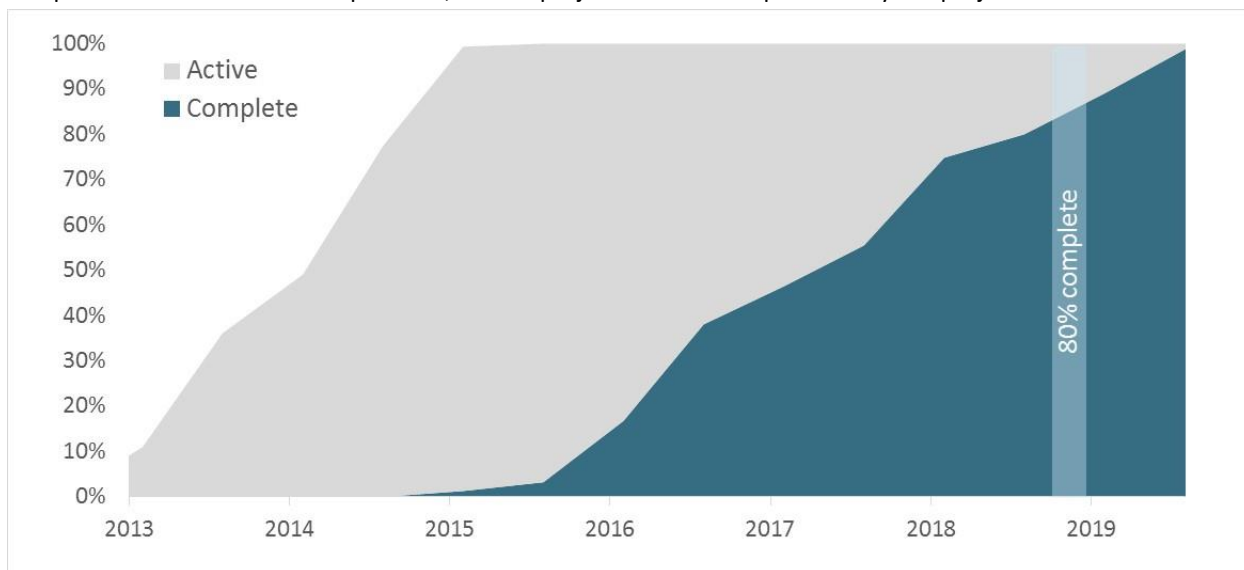
Archival and web-based materials show that over 80% of the projects have been completed (133 out of 160); 27 projects are still considered active.⁴ In addition to these 160 projects, 1 additional project originally approved for funding was completely canceled following community opposition, with the 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.

 <p>Permitting delays</p>	<p>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.</p>
 <p>Seasonal limitations</p>	<p>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).</p>
 <p>Additional data collection or project design work</p>	<p>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.</p>
 <p>Contracting or procurement</p>	<p>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).</p>

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).



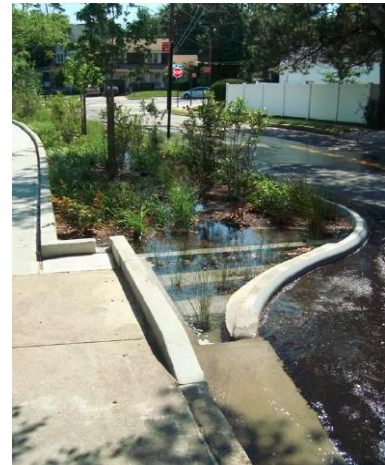
Green stormwater infrastructure – reduced risks of runoff and flooding from storms

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).

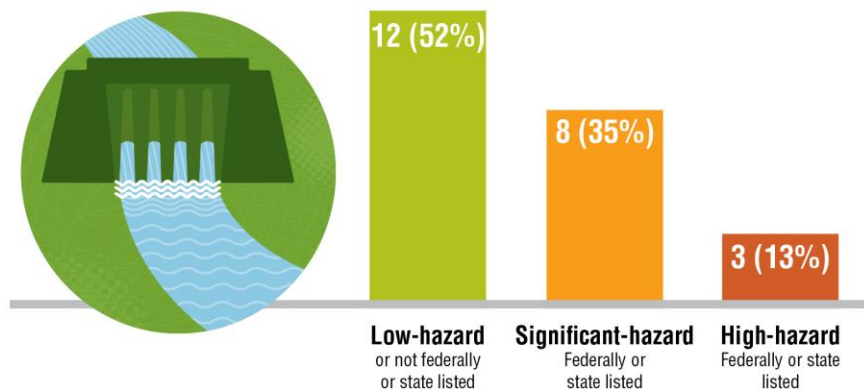
A project in New York **installed four green streets in New York City**, which will help mitigate flooding and filter more than 860,000 gallons of stormwater runoff for over 4,700 square feet. This project will serve as a model for other communities as New York City expands its green infrastructure initiatives.



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


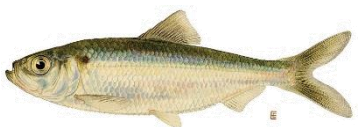







a. Eight green stormwater infrastructure projects reported drainage area acreage; only six reported capture capacity of gallons per year.

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

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	
<p>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.</p>	
<p>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.</p>	
<p>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.</p>	
<p>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.</p>	
<p>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).</p>	
 Beach and Dune Restoration	
<p>Red knot,* a federally threatened species, use the Delaware Bay as an important stopover habitat on their migration between South America and the Arctic.</p>	
<p>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.</p>	
<p>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.</p>	<p>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.</p> 
<p>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).</p>	
<p>* 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).</p>	

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.


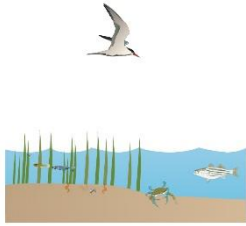







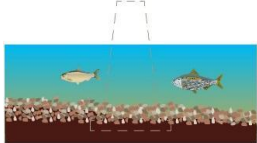
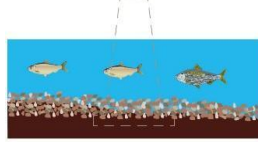
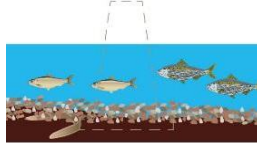




<p> Living shoreline</p> <p>As part of a living shoreline, shell bags have successfully protected vegetation from scouring erosion and improved sediment accretion at the northern end of Gandy's Beach, New Jersey.</p>  <p><i>Source: NJ DEP Press Release, June 15, 2017.</i></p>	<p> Green stormwater infrastructure</p> <p>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.</p>  <p><i>Twelve acres of impervious surface (project proposal).</i></p>
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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				
	<ul style="list-style-type: none"> No to sparse native vegetation No to little storm protection Few or no key species Hydrologic functions compromised. 	<ul style="list-style-type: none"> 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				
	<ul style="list-style-type: none"> No to sparse native vegetation Minimal support to key wildlife Habitat prone to erosion. 	<ul style="list-style-type: none"> 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				
	<ul style="list-style-type: none"> Barrier alters hydraulics, traps sediment Few or no diadromous fish Flooding risk. 	<ul style="list-style-type: none"> 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				
	<ul style="list-style-type: none"> No to sparse native vegetation No to little storm protection Few or no key species. 	<ul style="list-style-type: none"> 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)

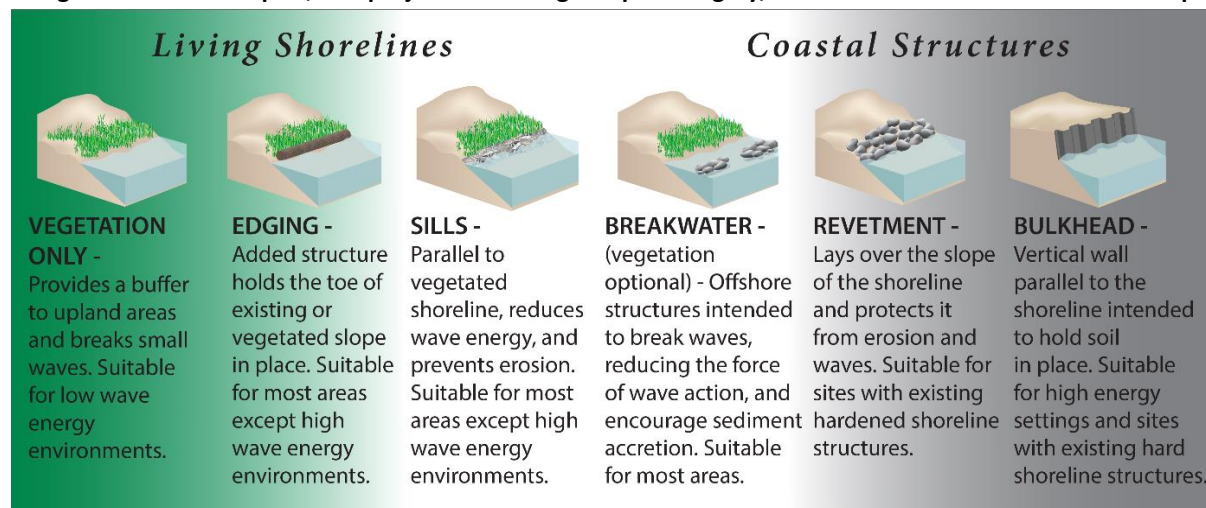
Cost-effectiveness compares the relative costs and projected outcomes, or effects, of different courses of action. This type of analysis estimates the costs per unit of benefit using a consistent metric, such as the number of acres protected or the value of damages avoided. By using consistent metrics 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.

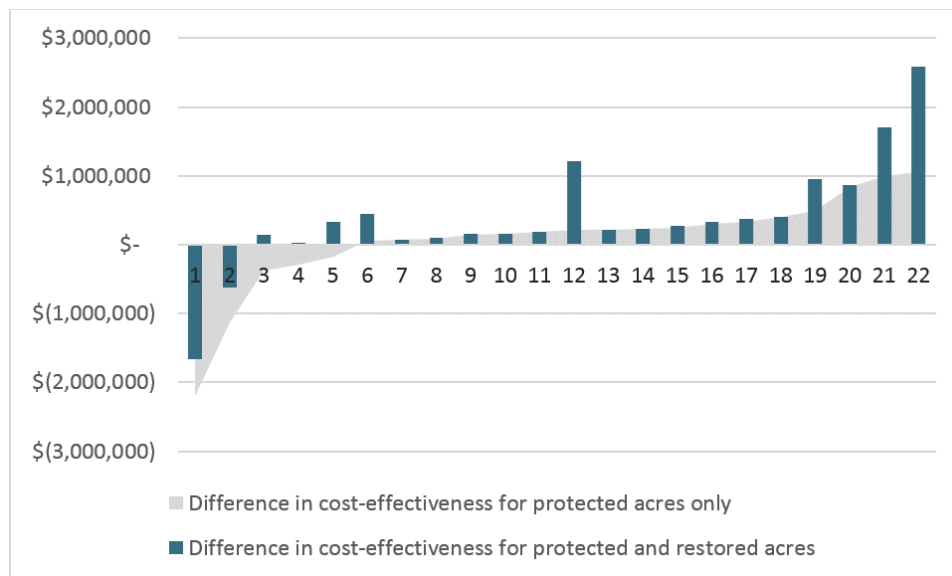
⁷ Eleven of the total 17 living shoreline projects were selected for the in-depth, cost-effectiveness analysis because the costs of the living shoreline activity could be disaggregated from total project costs. These 11 projects encompassed 22 project sites.

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.

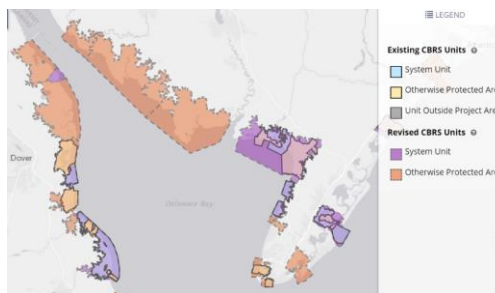


Culvert restoration in North Elba, NY.
Source: TNC.



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.

	<p>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.</p>
	<p>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.</p>
	<p>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.</p>
	<p>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.</p>

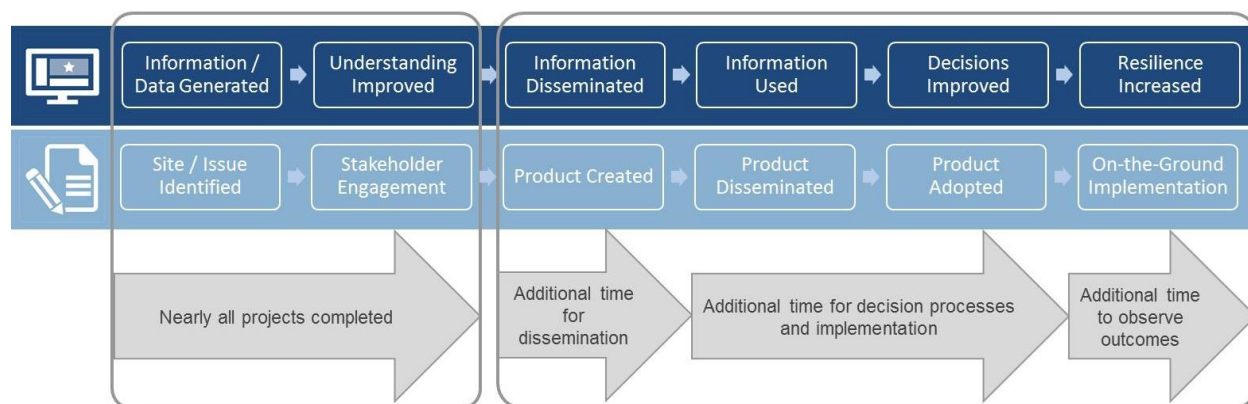
In addition to these ecologically focused metrics, NFWF and DOI are also supporting long-term monitoring to understand the impacts of on-the-ground restoration on human well-being, primarily through the benefits gained by reducing flooding-related impacts on human health, transportation, critical facilities, 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.

	<p>Marsh restoration projects are restoring approximately 190,000 acres of marsh – equivalent to approximately 300 square miles.</p> <ul style="list-style-type: none"> • 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.
	<p>Nearly 53,000 linear feet of living shorelines have protected adjacent habitats and reduced coastal erosion on up to 440 acres of land.</p> <ul style="list-style-type: none"> • 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.
	<p>Removal of 23 dams and improvements to 10 culverts.</p> <ul style="list-style-type: none"> • 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.
	<p>Beach and dune restoration for community protection and ecological resilience.</p> <ul style="list-style-type: none"> • 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

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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

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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

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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

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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 Hughesville 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

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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

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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

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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 coastal 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

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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

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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

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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

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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

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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

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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

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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

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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

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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 bathymetry 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)	Map 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

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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

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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

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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

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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 resiliency in Southern Connecticut	Establish a Regional Framework for Coastal Resiliency 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 resiliency 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

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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

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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

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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

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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

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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:

$$AC = PVC * \left[\left(r * (1 + r)^n \right) / \left((1 + r)^n - 1 \right) \right],$$

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.
- Davis, J.L., R.L. Takacs, and R. Schnabel. 2006. Evaluating ecological impacts of living shorelines and shoreline habitat elements: An example from the upper western Chesapeake Bay. *Management, Policy, Science, and Engineering of Nonstructural Erosion Control in the Chesapeake Bay* 55.
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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.
- Doyle, M.W., E.H. Stanley, C.H. Orr, A.R. Selle, S.A. Sethi, and J.M. Harbor. 2005. Stream ecosystem response to small dam removal: Lessons from the Heartland. *Geomorphology* 71(1–2):227–244.
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- Stanley, E.H. and M.W. Doyle. 2003. Trading off: The ecological effects of dam removal. *Frontiers in Ecology and the Environment* 1(1):15–22.
- Tullos, D.D., D.S. Finn, and C. Walter. 2014. Geomorphic and ecological disturbance and recovery from two small dams and their removal. *PLoS ONE* 9(9):108091.

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.
- Feagin, R.A., J. Figlus, J.C. Zinnert, J. Sigren, M.L. Martínez, R. Silva, W.K. Smith, D. Cox, D.R. Young, and G. Carter. 2015. Going with the flow or against the grain? The promise of vegetation for

protecting beaches, dunes, and barrier islands from erosion. *Frontiers in Ecology and the Environment* 13(4):203–210.

- Jones, A.R., A. Murray, T.A. Lasiak, and R.E. Marsh. 2008. The effects of beach nourishment on the sandy-beach amphipod *Exoediceros fossor*: Impact and recovery in Botany Bay, New South Wales, Australia. *Marine Ecology* 29:28–36.
- Morton, R.A., J.G. Paine, and J.C. Gibeaut. 1994. Stages and durations of post-storm beach recovery, southeastern Texas coast, USA. *Journal of Coastal Research* 884–908.
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- Vestergaard, P. 2013. Natural plant diversity development on a man-made dune system. In *Restoration of Coastal Dunes*. Springer, Berlin, Heidelberg. pp. 49–66.
- Walker, I.J., J.B. Eamer, and I.B. Darke. 2013. Assessing significant geomorphic changes and effectiveness of dynamic restoration in a coastal dune ecosystem. *Geomorphology* 199:192–204.

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.

References

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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

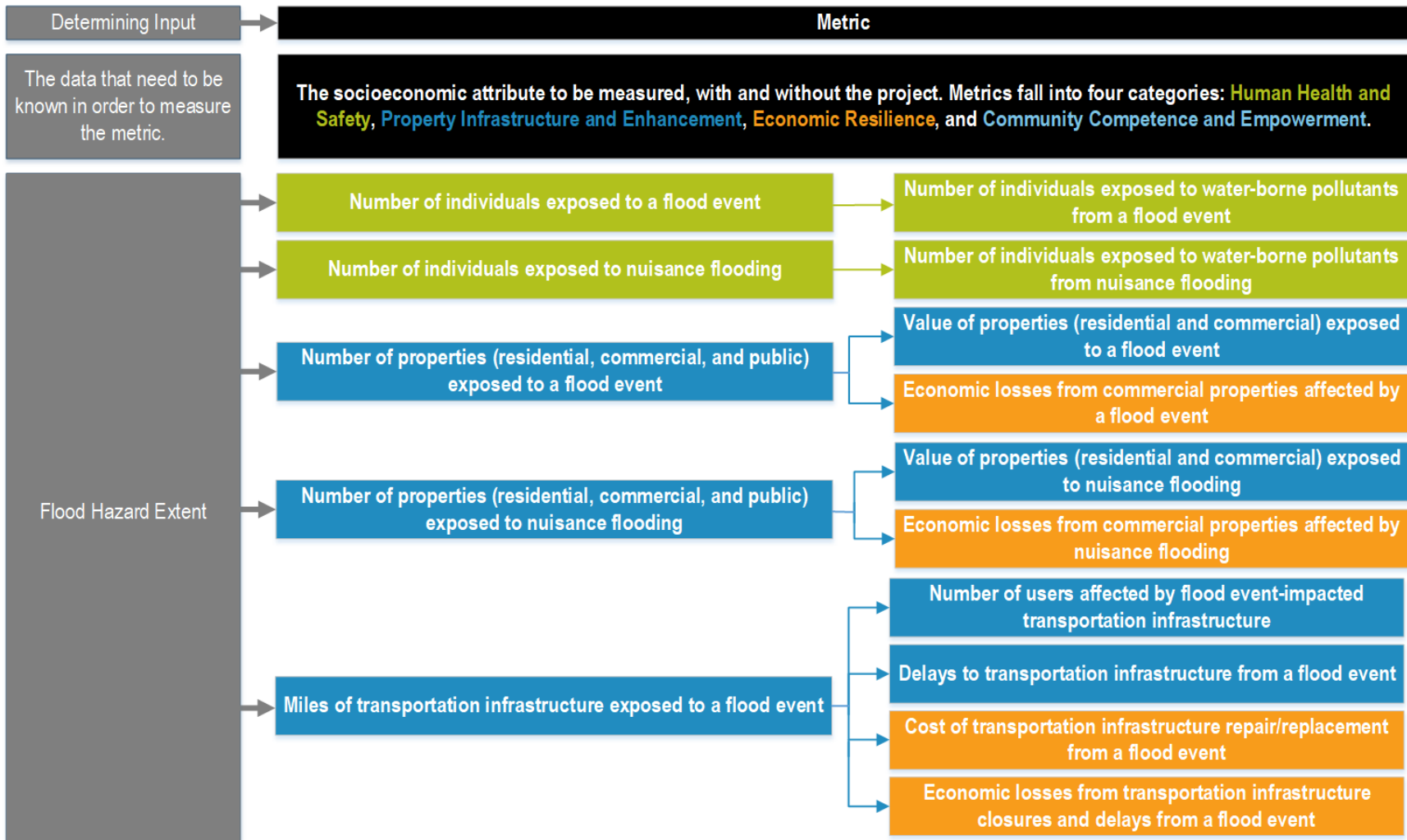
Reference

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.

Evaluation

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