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Science for Safer Communities and Sustainable Resources

Using Science to Strengthen our Nation's Resilience to Tomorrow's Challenges—Understanding and Preparing for Coastal Impacts

Hurricane Sandy caused unprecedented damage across some of the most densely populated coastal areas of the northeastern United States (fig. 1). The costly, landscape-altering destruction left in the wake of this storm is a stark reminder of our Nation's need to become more resilient as we inevitably face future coastal hazards.

As our Nation recovers from this devastating natural disaster, it is clear that accurate scientific information is essential as we seek to identify and develop strategies to address trends in coastal landscape change and reduce our future vulnerability to major storm events. To address this need, the U.S. Geological Survey (USGS) received $43.2 million in supplemental appropriations from the Department of the Interior (DOI) to conduct the scientific research needed to guide response, recovery, and rebuilding activities and to develop effective strategies for protecting coastal communities and resources in the future.

The USGS provides information, tools, and expertise for monitoring storm surges, quantifying the processes that control coastal and inland flood inundation and erosion, and assessing and forecasting coastal change. The USGS also provides expertise for assessing and forecasting impacts to natural habitats and ecosystems as well as threats from introduced contaminants. The USGS is a critical partner providing the data needed to support emergency response and management to secure coastal infrastructure, protect natural resources, and ensure public safety.

The USGS response to Hurricane Sandy is guided by a comprehensive science plan (Buxton and others, 2013) that uses an integrated approach to address the storm's impacts and to inform management decisions that support the recovery and restoration of coastal communities as well as enhance our resilience as we prepare for future events. The science plan facilitates the coordination of USGS activities with those of other agencies and stakeholders. New and ongoing data collection, analysis, and research will focus on developing and refining our understanding of past and potential future coastal impacts in such diverse areas as topography and bathymetry; beaches and barriers; storm-surge, riverine, estuarine, and bay hydrodynamics; environmental quality and exposures to persisting contaminants; and ecosystems, habitats, and fish and wildlife. Together, these efforts provide the foundation for developing science-based coastal-management policies that improve the resilience of our communities and our stewardship of natural environments and resources.

As we work to implement the Hurricane Sandy Science Plan, the USGS is committed to being responsive to stakeholder needs, improving and facilitating access to predictive tools to protect coastal communities and resources, and enhancing our Nation's capabilities to respond to the next hurricane.
–Suzette M. Kimball, Acting Director, U.S. Geological Survey

This fact sheet describes how the USGS is combining interdisciplinary science with state-of-the-art technologies to achieve a comprehensive understanding of coastal change caused by Hurricane Sandy. By assessing coastal change impacts through research and by developing tools that enhance our science capabilities, support coastal stakeholders, and facilitate effective decision making, we continue to build a greater understanding of the processes at work across our Nation's complex coastal environment—from wetlands, estuaries, barrier islands, and nearshore marine areas to infrastructure and human communities. This improved understanding will increase our resilience as we prepare for future short-term, extreme events as well as long-term coastal change.

Figure 1. Aerial view of Mantoloking, New Jersey, showing barrier island community damaged as a result of Hurricane Sandy. Photograph by Karen Morgan, USGS.

Coastal Topography and Bathymetry

A fundamental lesson of Hurricane Sandy and previous catastrophic hurricanes is that vulnerability to storms is primarily a consequence of coastal elevation. The height at which communities, infrastructure, and resources are located in relation to the position of average tides and water levels, storm surge and waves, and floodwaters determines the extent of their exposure to forces of overwhelming strength and power. Reliable, accurate, and accessible elevation information is a priority for communities anticipating impacts from, and preparing response strategies to, these forces. Post-storm elevation data also are critical for the design and planning of resilient and cost-efficient post-storm redevelopment projects.

Developing a Coastal National Elevation Dataset—The USGS is creating a seamless and integrated Coastal National Elevation Dataset (CoNED) by compiling topographic and bathymetric elevation data from multiple sources (fig. 2). A CoNED for the entire Hurricane Sandy impact region will be constructed to serve post-Sandy recovery and other needs, including assessing coastal landscape change and vulnerability;

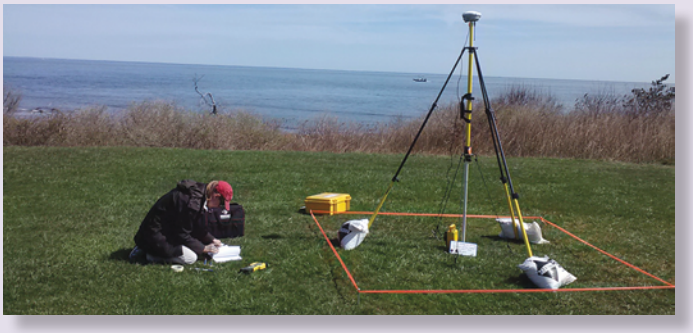

Figure 2. U.S. Geological Survey scientist establishing a base station in Montauk, New York, as part of a global positioning system (GPS) survey to collect "ground truth" elevation data for the Coastal National Elevation Dataset being developed for the Hurricane Sandy impact region. Photograph by Jeffrey Danielson, USGS.

designing restoration, redevelopment, and protection projects; predicting future hurricane storm surge and coastal and inland flooding; and devising strategies for adaptation to sea-level rise and other effects of climate change.

Conducting topographic surveys for impact area assessment and reconstruction—The USGS is conducting surveys using light detection and ranging (lidar), a remote-sensing technology mounted on aircraft, to collect very high resolution elevation data to support scientific studies related to hurricane impacts, recovery, and rebuilding; emergency response assessment and planning; post-Sandy shoreline condition documentation; and watershed and resource management activities. The USGS is collecting and compiling data for coastal and inland areas on the basis of the extent of hurricane damage and the age and quality of available data. The new elevation data will become part of The National Map (*http://nationalmap.gov*) and the 3-Dimensional Elevation Program (3DEP; *http://nationalmap.gov/3DEP/*), a USGS-led multiagency initiative to systematically acquire improved, high-resolution elevation data across the United States.

Impacts to Coastal Beaches and Barriers

Our Nation's coastlines are a dynamic system of cliffs, rocky tidal areas, beaches, dunes, barrier islands, wetlands, and estuaries. Coastal beaches and barriers are important not only as the first line of defense against storm impacts on densely populated communities and coastal ecosystems, but also for their biological, economic, and recreational value. Our ability to sustain our coastal resources is inextricably linked to our ability to mitigate the impacts of sea-level rise and future storms.

The USGS is working with partners at the Federal, State, and local levels to develop maps, coastal-change response models, and vulnerability forecasts and assessments (fig. 3). As tools and information products are developed across the Hurricane Sandy impact region, research is focused in several key areas with the goal of filling gaps in our understanding of the ways in which storms alter coastal systems and the effects of those changes on resource health and sustainability, as well as public safety. Through this research, the USGS continues to advance our knowledge of the linkages among nearshore geology, ocean processes, climate change, and coastline response.

Assessing storm impacts, mapping coastal systems, and supporting decision makers—The USGS supports the needs of many partners and collaborators by developing tools to rapidly map coastal regions and deliver quantitative assessments of coastal change due to storms. Interpretive maps and other products enable coastal-zone managers and researchers to assess

USGS scientists are generating and sharing critical information to aid in the recovery of the areas impacted by Hurricane Sandy, helping to protect our valuable coastal resources and to make communities more resilient against future extreme storms. –David Applegate, Associate Director for Natural Hazards, U.S. Geological Survey

storm impacts, monitor recovery resulting from both natural and human actions, and ensure that forecasts of vulnerability to future storms accurately reflect the changing structure of beaches and barrier islands. Data collected through geologic surveys that extend across the shoreline and into the marine system are being used to inform models and identify geologic features that affect long-term trends in coastal change. These scientific activities are critical to emergency preparedness, disaster response, and redevelopment planning.

Assessing vulnerability of beaches, estuaries, and wetlands as one system—The USGS is continuing to build on a proven national program for real-time forecasting of vulnerability of beaches to storms and other drivers of coastal change. Existing assessments of the vulnerability of Northeast and mid-Atlantic beaches are being updated with results of post-Hurricane Sandy coastal mapping. Research on Fire Island and Jamaica Bay in New York, on the Delmarva Peninsula, and in Barnegat Bay in New Jersey is designed to enhance current forecasting tools and improve our ability to understand and evaluate impacts on wetlands, dunes, and back-barrier estuaries. The USGS is validating models with oceanographic data (fig. 4) and simulating multiple coastal scenarios to test and forecast the vulnerability of natural

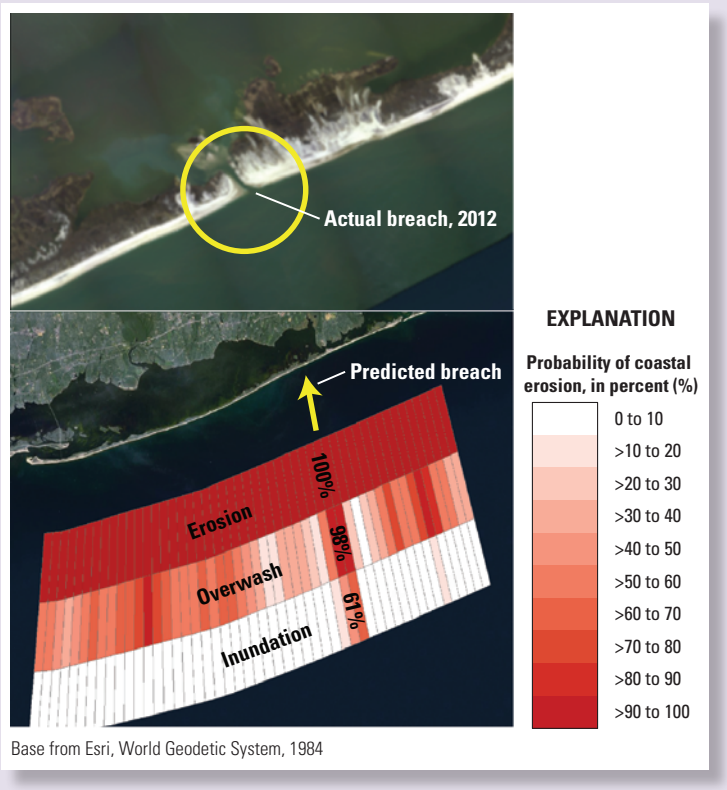

Figure 3. U.S. Geological Survey forecast of the probability of erosion, overwash, and inundation that successfully predicted coastal inundation and identified the location where the barrier island was breached as a result of Hurricane Sandy, Fire Island, New York. (Forecast probabilities modified from Buxton and others, 2013, fig. 2; aerial image of breach from National Oceanic and Atmospheric Administration)

and engineered coasts, the stability of wetlands, and the potential for estuarine flooding caused by future storms, long-term coastal trends, and sea-level rise. Coastal managers and decision makers can use these models and assessment tools to evaluate threats to natural and cultural resources, and to examine the sustainability of natural and nature-based features (such as wetlands, dunes, and vegetated buffers) and their effectiveness at reducing vulnerability and enhancing coastal resilience.

Figure 4. U.S. Geological Survey scientists deploying buoys and oceanographic instrumentation near Fire Island, New York, to measure waves and meteorological conditions. Photograph by Sandy Baldwin, USGS.

Storm-Tide and Wave Hydrodynamics

Understanding the evolution and dissipation of overland storm tides and waves as they move across natural and manmade landscapes is critical to increasing coastal resilience and establishing early warning systems for coastal storm hazards. In the aftermath of Hurricane Sandy, the USGS is building an overland Surge, Wave, and Tide Hydrodynamics (SWaTH) network along the Atlantic Coast from Virginia to Maine (fig. 5) to provide more timely storm-surge and wave data to enhance public awareness, help forecasters predict surge impacts, and inform emergency responders.

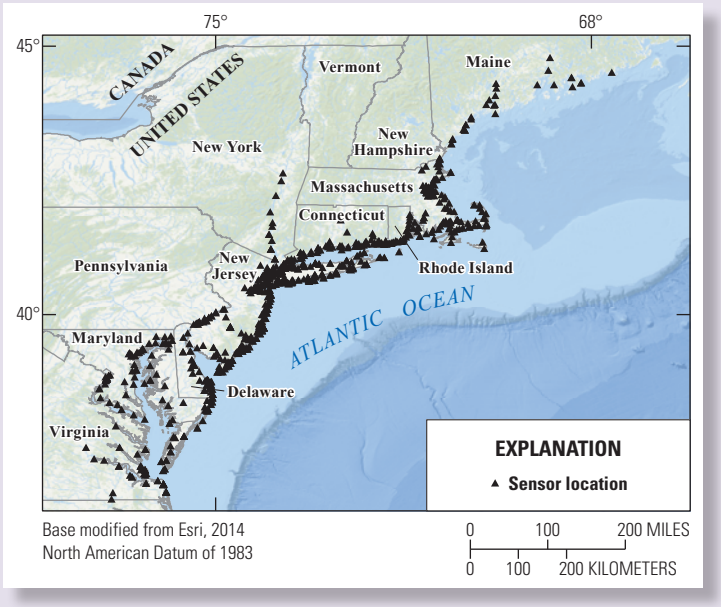

Figure 5. Proposed U.S. Geological Survey storm-tide sensor network for the northeastern United States.

Monitoring storm tides—For several decades, the USGS has provided critical information about nearshore and overland storm hydrodynamics to aid emergency response and resource allocation before, during, and immediately after landfall of hurricanes and Nor'easters. In the Northeast, much of this information was provided by using near-real-time tide gages on inland and shallow coastal waters and overland flooding (Hoppe, 2007). These gages supplemented and extended the National Oceanic and Atmospheric Administration (NOAA) tide-gage network, which monitors the open ocean, bays, and sounds. Because the network was sparse, however, information about variations in storm characteristics, topography, or bathymetry that resulted in large spatial and temporal differences in storm tide was incomplete, potentially hampering storm characterization and damage assessment.

In recent years, USGS storm-response activities have focused on providing the detailed water-elevation data needed to improve surge models. Centralized caches of storm-surge sensors (SSSs) and real-time rapid deployment gages (RDGs) (fig. 6) were deployed reactively at locations identified extemporaneously for a particular storm. Sensor deployment was slowed, however, as hydrographers sought to identify and instrument useful monitoring locations. Post-storm data delivery also was hampered because of the need to survey the reference elevation of each new site to a common vertical datum.

Figure 6. U.S. Geological Survey rapid deployment gage installed to collect real-time water-level and meteorological data, Pettaquamscutt River, Narragansett, Rhode Island. Photograph by Andrew Waite, USGS.

Implementing the SWaTH network—The SWaTH network (fig. 5) is the result of a collaborative strategy designed to provide integrated hydrodynamic information from both fixed and mobile technologies. Implementation of the SWaTH network includes flood-hardening approximately 40 existing near-real-time tide gages, establishing about 20 new near-real-time tide gages, and procuring about 60 new RDGs. It also includes identifying and establishing as many as 500 or more potential data-collection sites, surveying them to a common vertical datum, and equipping them with fixed-place brackets that will readily accept and secure RDGs and SSSs. The net result will be an increase in real-time and event-logged overland water-elevation data that will be efficiently and effectively delivered to aid in determining appropriate storm response and recovery actions.

Although wetlands and beach setbacks may be effective tools for reducing damage caused by storm surge, little information is available to document or quantify these effects. The SWaTH network will feature transects equipped with high-data-rate

sensors deployed across selected beaches, islands, and wetlands to observe and record the variation in water elevation and wave height as storm tide and waves travel inland.

Impacts on Environmental Quality and Persisting Contaminant Exposures

Coastal areas that lie in the path of storm surge or floodwaters are vulnerable to degradation from a wide range of chemical and microbial contaminants that can be mobilized from disturbed sediments or damaged infrastructure, transported, and relocated, increasing the risk of both ecological and human exposure (fig. 7). Other potential contamination sources include combined sewer overflows; debris from buildings, automobiles, and boats; inundated infrastructure such as gas stations, landfills, and chemical storage facilities; disturbed sediments and hazardous-waste sites; and saltwater encroachment. The persisting effects of this contamination are unknown. Debris may continue to release toxic materials over prolonged periods, and alteration of coastal hydrodynamics can affect salinity, coastal habitats, and contaminant exposure.

Figure 7. Oily debris field in Sheepshead Bay, New York, after Hurricane Sandy. Photograph by Jonathan Lally, U.S. Coast Guard.

Addressing the persisting risk of ecological and human exposure—The USGS is testing sediment and tissue from targeted species of finfish and shellfish from coastal and aquatic environments in New York and New Jersey for persisting storm-related contaminants that may have become trapped in estuaries, harbors, and other nearshore environments (fig. 8). Information gained from this study will help scientists determine contaminant sources, identify possible pathways of chemical exposure and the mechanisms by which storms cause contaminants to be released to the environment, prioritize contaminants of concern, and identify high-risk areas. Accurate information about long-term ecological health in areas affected by Hurricane Sandy will help coastal communities minimize the release of contaminants and their adverse consequences during future storms.

The USGS is also working to improve our understanding of pathways of human exposure to pathogens and chemical contaminants that may linger in soils in the built environment and public areas, persist in exposed finfish or shellfish, or leach from dredge spoils and compromised infrastructure, potentially causing a long-term risk to human health. Samples collected as part of the ecological study will also help define potential short- and long-term human exposure risks, such as those resulting from ingestion of contaminated fish. Together, these strategies will help inform long-term cleanup efforts along the coast and will allow communities to prepare for the future by providing new information to help minimize the sources of contaminants that may pose a persisting risk to human health and safety.

Figure 8. USGS hydrologist examining a bed-sediment sample collected in Great South Bay, New York, in response to potential water and sediment contamination resulting from Hurricane Sandy. Photograph by Irene Fisher, USGS.

Assessing, mapping, and predicting vulnerability to contamination hazards resulting from coastal storms in the Northeast—Contaminant monitoring sites that allow documentation of conditions before and after storms will be identified and, where possible, colocated with sites in the USGS SWaTH (described above) and Surface Elevation Table (SET, described below) networks as well as networks maintained by other agencies, such as the U.S. Environmental Protection Agency (EPA). Colocation of contaminant monitoring sites with surge, wave, and tidal real-time monitoring sites results in a more robust monitoring network that provides a unique capability to assess the threat of storm-induced movement of contaminants in the environment. It also provides the data needed to develop models that forecast where and when contaminants will be released to the environment as a result of storm impacts. This capability will enable first responders, land managers, and other decision makers to mitigate contaminant threats in the immediate aftermath of storms as well as increase resilience to future storms.

Impacts to Coastal Ecosystems, Habitats, and Fish and Wildlife

The Department of the Interior manages public lands affected by Hurricane Sandy, including approximately 30 National Wildlife Refuges and 6 National Parks and National Seashores that provide critical habitat for migratory waterfowl and threatened or endangered species (fig. 9). Coastal refuges and parks protect beaches and wetlands that decrease the impacts to coastal communities from storms and provide recreational opportunities for millions of visitors, including those from metropolitan areas from Boston to Washington, D.C.

The USGS provides decision makers with the science needed to support the assessment, recovery, and resilience of the Nation's natural resources. Managers of DOI lands have trust responsibilities under the Endangered Species Act and the Migratory Bird Treaty Act, as well as additional cooperative responsibilities with State and local authorities for the protection of native commercial or recreationally harvested fish and wildlife species. Studies conducted by the USGS and its partners provide essential baseline data and long-term support for coastal-zone planning, conservation planning, resource management, hazard reduction, and risk mitigation in the wake of past and future natural disasters.

Figure 9. Edwin B. Forsythe National Wildlife Refuge in southern New Jersey, which provides critical habitat for migrating birds along the highly populated Atlantic Coast of the northeastern United States. Photograph by U.S. Fish and Wildlife Service; from U.S. Department of the Interior, 2014.

Assessing storm impacts on wetland integrity and stability to support recovery decisions—USGS expertise in wetland ecology and remotely sensed imagery is being applied to document changes to wetland forests and marshes caused by Hurricane Sandy. Radar, lidar, Landsat (satellite), and air-photo imagery is being interpreted to determine impacts to wetland vegetation from surge inundation, high winds, and shoreline changes. Fine-scale elevation changes are being determined by using data from the Surface Elevation Table (SET) (*http://www.pwrc.usgs.gov/set/*) network maintained by the USGS and partners (fig. 10), and marsh sediment cores are being collected and analyzed to determine fine-scale impacts to coastal wetlands.

Assessing storm impacts on migratory birds to support conservation—The USGS is documenting the impacts of Hurricane Sandy on birds by studying declining populations of secretive marsh and shore birds on public lands; analyzing radar data on pre- and post-storm migratory bird flight patterns; and assessing changes to migratory stop-over habitats, resident habitats, food sources, reproductive capacities, and the timing of life-cycle events.

Documenting and evaluating coast-wide storm impacts on coastal forests—The USGS is investigating the complex relations linking forest type, structure, and size thresholds to coastal buffering capacity. This information is being used to classify coastal forest types and storm impacts on the basis of forest condition, mortality, species composition, woody debris and wrack deposits, high-water surveys of flooding extent, and residual soil salinity correlated with wind speed and surge penetration. Maps

Figure 10. U.S. Geological Survey scientist taking a reading at a Rod Surface Elevation Table (RSET) in a salt marsh in Jamaica Bay, New York. Photograph by Don Cahoon, USGS.

are being prepared that highlight the forest types and conditions affected by tides and storm surges for use in predicting forest recovery, evaluating alternatives for forest restoration, and assessing their potential for success.

Delivering Data, Tools, and Products to Support Sound Decision Making and Improve Hazard Preparedness

The USGS collects and analyzes data, develops tools, and creates products with wide and diverse applications. The information and tools it produces range from baseline elevation, geologic, and environmental data to numerical models that quantify environmental responses and assess the relative vulnerability to hazards associated with alternative facility and infrastructure designs. The USGS is continually improving access to its data and other products by enhancing interfaces and functionality, increasing storage and processing capacities, and streamlining quality-assurance processes. These efforts help to ensure that critical information and tools are delivered quickly and reliably for use by scientists, partners, stakeholders, and decision makers as they plan and execute recovery and mitigation activities and work to increase resilience against future hazards.

Empowering coastal communities—The USGS is committed to empowering coastal communities and other stakeholders to prepare for coastal hazards by providing direct access to critical data, analyses, tools, forecasts, and assessments. By sharing spatial data and output in geographic information system data layers, the USGS ensures that users at Federal, regional, State, and local levels can access these diverse products through easily available online systems, including USGS data portals, the NOAA Digital Coast online mapper, *Data.gov*, and the Federal Emergency Management Agency (FEMA) Web site.

Delivering data to predict and assess flooding, storm surge, coastal vulnerability, and ecological impacts—Enhancements to The National Map elevation data delivery systems and the Hazards Data Distribution System (HDDS) will improve access to Hurricane Sandy imagery, topographic and bathymetric lidar data, derived elevation products, and CoNED data. SWaTH data deliverables will include water-elevation and wave-height and -frequency information, as well as selected meteorological data for some locations. The existing USGS Web-based data delivery system for such information, the Hurricane Sandy Storm Tide Mapper (U.S. Geological Survey, 2014), is designed primarily for post-storm-surge recovery operations and research, but the new system will provide the critical mapping, data summation, and evaluation tools needed by emergency managers and first responders for real-time situational awareness and rapid assessment during storms.

The USGS is building technology, tools, and online portals that provide interactive access to basic operational data, maps of shoreline-change rates, assessments of erosion probability, and forecasts of risk to endangered-species habitats from storms as well as from long-term sea-level rise. Coastal stakeholders will have direct access to these data, tools, and assessments. This geospatial platform also provides a means to communicate new data, analyses, and forecasts to other scientists, the public, and USGS collaborators such as academia, State agencies, and nongovernmental organizations.

Developing monitoring networks and data-driven models for ecological assessments—The USGS is using data from multiple monitoring networks to develop models of storm impacts on vegetation and coastal morphology, and to forecast effects of landscape alterations and response processes on the health of and trends in wetlands, submerged habitats, and ecosystem services. Biological, environmental, and physical data will be synthesized

to expand the capabilities of existing numerical models that evaluate impacts of Hurricane Sandy and potential future events as well as longer term changes on habitats and wildlife. The USGS is continuing to modify and improve Web-based tools to deliver ecological models, data standards, visualization and analysis tools, and decision support tools to aid scientific research and resource management in the areas affected by Hurricane Sandy as well as increase understanding to ensure improved preparation for future events.

Stakeholders

The USGS is committed to serving diverse partners and stakeholders by providing the science needed to improve coastal resilience. Stakeholders at many levels are relying on USGS data, tools, and analyses to guide effective decision making as they plan and execute recovery and rebuilding activities. Sound, decision-ready science provides the basis to ensure effective management and protection of coastal resources, infrastructure, and communities.

The National Ocean Policy Implementation Plan (National Ocean Council, 2012) calls for documenting coastal and marine elevations throughout the United States to improve coastal change analysis. Post-Hurricane Sandy elevation data are needed to assess storm impacts, guide recovery activities, forecast coastal vulnerability, establish a new baseline, and enhance coastal resilience in preparation for future storms. The USGS, NOAA, and the U.S. Army Corps of Engineers (USACE) are using accurate, consistent lidar elevation data, which are fundamental to many stakeholder needs, to update East Coast topographic maps and nautical charts. Areas to be remapped were selected with input from State and local officials, the National Park Service (NPS), the U.S. Fish and Wildlife Service (USFWS), and other managers of public lands.

Coastal resource managers at all levels rely on new technologies and science-based analyses from the USGS to optimize recovery efforts, evaluate rebuilding activities, and make sound resource management decisions. Specifically, the USACE uses USGS data and knowledge for large-scale assessments of offshore sand deposits for beach nourishment projects. The USFWS is using USGS analyses of new nesting habitat of the piping plover (fig. 11), a shorebird classified as threatened along the Atlantic Coast (U.S. Fish and Wildlife Service, 2014), in the Hurricane Sandy impact area to enhance recovery of this important species. Both the NPS and the USFWS rely on USGS data, tools, and analyses to identify priorities and develop strategies to protect facilities and infrastructure, and to fulfill their mission as stewards of sustainable cultural resources and healthy coastal ecosystems.

SWaTH network implementation will result in improved storm-surge, wave, and tide monitoring, warning, modeling, and characterization to help reduce future flood damage and loss of life. The USACE, NOAA, and others are already making plans to improve the performance of prediction models using the new data. These data also will be used by FEMA to more effectively characterize long-term flood potential. Collaboration with coastal communities and states that contribute additional monitoring sites and local observations to the SWaTH network will maximize the benefits of long-term land-use planning and increase resilience in coastal communities and environments.

Figure 11. Piping plover, a threatened species along the Atlantic Coast. Photograph by Jim Fenton, used with permission.

The EPA, the NPS, the States of New York and New Jersey, and local agencies will benefit from USGS work on the possible effects of hazardous chemicals and other contaminants that may have been released into the environment during Hurricane Sandy. The USGS will inform stakeholders about the risks associated with the contaminants that remain and the mechanism by which they were introduced into the environment. USGS studies that define prestorm environmental quality will help affected communities prepare for the health implications of future hurricane-induced environmental contamination. This knowledge will allow decision makers to devise redevelopment strategies that build community resilience to future storms.

USGS studies of the effects of Hurricane Sandy on DOI and adjacent coastal lands will improve our ability to identify and protect valuable natural ecosystem services such as attenuating storms, filtering contaminants from sediments, providing habitat for wildlife, and offering recreational opportunities to residents of and visitors to coastal areas of the Northeast and mid-Atlantic states. USGS data and analyses will help managers understand the nature and extent of the storm's impacts on coastal wetlands and wildlife, informing and facilitating science-based evaluations of restoration and management alternatives and helping decision makers allocate limited resources to the most effective mitigation efforts. Habitat and other characteristics that are shown to have enhanced resilience to the storm's effects can be used to guide restoration efforts, especially in those areas identified as being most vulnerable. This information is valuable not only to managers of Federal lands, but also to communities that benefit from resilient coastal ecosystems.

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For More Information:
http://www.usgs.gov/hurricane/sandy/

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