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

Circular 1390

U.S. Department of the Interior
U.S. Geological Survey

Cover. Front photograph: U.S. Geological Survey (USGS) scientist deploys an acoustic doppler current profiler to measure water velocity profiles in a new inlet formed during Hurricane Sandy on Fire Island, New York. Photograph by USGS.

Background image: NASA's Terra satellite acquired this image of Hurricane Sandy off the southeastern United States, October 28, 2012. Image courtesy of NASA (http://visibleearth.nasa.gov/view.php?id=79548).

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SALLY JEWELL, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

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Dr. Asbury H. (Abby) Sallenger

(1949–2013)

This science plan benefited tremendously from the long-term efforts of Dr. Asbury H. Sallenger, a research scientist with the U.S Geological Survey who was committed to improving our understanding of the processes that affect our coastlines, their natural ability to protect coastal communities and ecosystems, and how we can improve coastal resilience and public safety.

Foreword

U.S. Geological Survey (USGS) employees have a legacy of responding promptly to natural and manmade disasters—providing science to assist emergency responders and to guide management actions for recovery, resilience, and future preparedness. USGS science has supported response to earthquakes, tsunamis, volcanic eruptions, wildfires, floods, the World Trade Center catastrophe, and the Deepwater Horizon oil spill, as well as all the major hurricanes that have impacted the United States over the last two decades.

Hurricane Sandy made landfall near Brigantine, New Jersey, late on October 29, 2012. In advance of the storm, the USGS Storm Team was already helping to prepare safety officials and the public for the impact of the storm by readying real-time tidal and river monitoring stations; deploying additional water-level monitoring stations to measure rising ocean levels; characterizing baseline, pre-storm coastal elevations; identifying coastal areas at greater risk of inundation and erosion; and declaring a landslide alert in vulnerable areas. During the storm, USGS instruments continued to collect real-time data. After the storm, the Storm Team collected high water marks, water-quality samples in downstream reaches of major rivers, and aerial photographs and elevations of the post-storm coastline.

On November 2nd, I commissioned the USGS Hurricane Sandy Science Team to coordinate continuing USGS activities with stakeholders and other agencies and to develop a science plan for continued data collection and analysis that would guide recovery and restoration efforts. This document is that science plan. As we implement this science plan, we are committed to being responsive to stakeholder needs, promptly sharing our science to achieve improved coastal resilience, and improving our capabilities to respond to the next hurricane.

In the aftermath of Hurricane Sandy, we saw pictures of the coastal devastation that reduced neighborhoods to rubble. We heard stories of brave firemen, policemen, neighbors, and other rescuers who helped frightened residents flee rising waters and burning buildings. People who could not help personally gave through the Red Cross. Certainly, this was a national tragedy that brought out the best in people. My personal heroes of Hurricane Sandy include the men and women of the USGS who worked tirelessly in the days ahead of the storm's landfall and, as the floodwaters retreated, continued to create and issue predictions of coastal impacts, deploy scientific instrumentation, and collect ephemeral data documenting the storm's impact. These efforts give us hope that our preparation for and response to the next superstorm will reduce the death toll, decrease the economic impact, and mitigate the loss of natural resources.

Suzette M. Kimball
Acting Director

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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

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Executive Summary

In late October 2012, Hurricane Sandy moved up the eastern seaboard of the United States, merged with two other substantial low pressure systems, and came ashore during a spring high tide. Landfall of the resulting 1,000-mile-wide superstorm was centered on the New Jersey coastline, one of the most populous regions of the Nation, delivering hurricane-force winds, storm tides exceeding 19 feet, driving rain, and plummeting temperatures. Hurricane Sandy resulted in 72 direct fatalities in the mid-Atlantic and northeastern United States, and widespread and substantial physical, environmental, ecological, social, and economic impacts; preliminary U.S. damage estimates are near $50 billion. Alterations to the coastline throughout the impacted area significantly increased the region's vulnerability to future storm events, posing new risks to communities and ecosystems. The legacy of debris and disturbance is a potential persisting threat to environmental quality. The disruption of natural ecosystems puts the health and recovery of local habitats and the associated wildlife at risk. Furthermore, efforts to design coastal communities for long-term resilience are hampered by a lack of understanding of potential trends in the frequency and intensity of tropical storms.

The U.S. Geological Survey (USGS) serves the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life. The USGS has played an important role in the response to a wide range of natural and human-caused disasters and has responded to every major hurricane for almost two decades. USGS information, expertise, and capabilities provide a significant scientific resource to disaster responders, resource managers, and the public.

Before the landfall of Hurricane Sandy, the USGS provided forecasts of potential coastal change; collected oblique aerial photography of pre-storm coastal morphology; deployed storm-surge sensors, rapid-deployment streamgages, wave sensors, and barometric pressure sensors; conducted Light Detection And Ranging (lidar) aerial topographic surveys of coastal beaches, barriers, and communities; and issued a landslide alert for landslide prone areas. During the storm Tidal Telemetry Networks in New York and New Jersey provided real-time quality-assured information from fixed stations to emergency responders on water levels in bays and inlets. Long-term network and rapid-deployment real-time streamgages and water-quality monitors provided information on river levels and changes in water quality including salinity. Immediately after the storm, the USGS serviced real-time instrumentation, retrieved data from over 140 storm-surge sensors, and collected other essential environmental data, including more than 830 high-water marks that identified the extent and elevation above land surface of the storm surge. Post-storm lidar surveys documented storm impacts to coastal barriers informing response and recovery and providing a new baseline to assess vulnerability of the reconfigured coast. The USGS Hazard Data Distribution System served storm related information from many agencies on the Internet on a daily basis. USGS data and information on Hurricane Sandy are accessible through the Internet at *www.usgs.gov/sandy*.

This science plan was developed immediately following Hurricane Sandy to coordinate continuing USGS activities with other agencies and to guide continued data collection and analysis to ensure support for recovery and restoration efforts. The data, information, and tools that are produced by implementing this plan will: (1) further characterize impacts and changes, (2) guide mitigation and restoration of impacted communities and ecosystems, (3) inform a redevelopment strategy aimed at developing resilient coastal communities and ecosystems, (4) improve preparedness and responsiveness to the next hurricane or similar coastal disaster, and (5) enable improved hazard assessment, response, and recovery for future storms along the hurricane prone shoreline of the United States.

The activities outlined in this plan are organized in five themes based on impact types and information needs. These USGS science themes are:

- Theme 1: Coastal topography and bathymetry.
- Theme 2: Impacts to coastal beaches and barriers.
- Theme 3: Impacts of storm surge and estuarine and bay hydrology.
- Theme 4: Impacts on environmental quality and persisting contaminant exposures.
- Theme 5: Impacts to coastal ecosystems, habitats, and fish and wildlife.

Communication with partners and stakeholders regarding science needs is essential for successful implementation of this plan. The best science has limited utility unless it is effectively disseminated and used to inform the highest priority decisions. Therefore a major emphasis in the implementation of this plan will be on interacting with stakeholders to better understand their specific data and information needs, to define the best way to make information available, and to support applications of USGS science and expertise to decisionmaking. The USGS can play an important supporting role to local, State, and Tribal governments, as well as to other Federal agencies by providing scientific information on the factors that affect the impacts of, and coastal vulnerability to, large storms and other coastal disasters. The USGS also can help ensure that real-time and other data-collection networks are nationally consistent and suitable for integrated assessment and prediction of storm behavior and impact.

Hurricane Sandy data and science products will be documented, made easily accessible, and archived. An integrated data and information delivery system will be developed that provides "one-stop" accessibility to all USGS information relevant to recovery and restoration from Hurricane Sandy and resiliency and preparedness to future storms. Users of USGS information will be consulted to ensure that ease of access, usability of the information delivery system, and technical support enhance application to management decisionmaking.

U.S. Geological Survey scientist uses a global positioning system to survey the elevation of a high-water mark at Liberty State Park in Jersey City, New Jersey, after Hurricane Sandy (photograph by Crystal Hammer, U.S. Geological Survey).

Introduction

Background

In late October 2012, after inflicting substantial damage to property and resources, and more than 60 fatalities in the Caribbean, Hurricane Sandy moved up the eastern seaboard of the United States (fig. 1). It merged with two other significant low pressure systems from the north before turning west and coming ashore during a full moon and the associated spring high tide. Landfall of the resulting 1,100-mile-wide superstorm was centered on the New Jersey coastline, delivering hurricane-force winds, storm tides exceeding 19 feet, driving rain, and plummeting temperatures. Hurricane Sandy hit one of the most populous regions of the Nation, and resulted in 72 direct[1] fatalities in the mid-Atlantic and northeastern United States, and widespread and substantial physical, environmental, ecological, social, and economic impacts; preliminary U.S. damage estimates are near $50 billion (Blake and others, 2013). Hurricane Sandy caused severe loss of property as a result of severe winds, storm surge, and the associated coastal flooding; dramatically altered the physical structure of barrier islands, coastlines, dunes and berms, and coastal vegetation; and significantly altered natural ecosystems, including National Parks and National Wildlife Refuges. Although the impacts to coastal areas were severe, riverine-based inland flooding was much less than anticipated as a result of inland precipitation in amounts less than forecast. The alterations to the current coastline throughout the impacted area significantly increased the region's vulnerability to future storm events, posing new risks to communities and ecosystems. The legacy of debris and disturbance is a potential persisting threat to environmental quality. The disruption of natural ecosystems puts the recovery of local habitats and associated wildlife in question. Furthermore, efforts to design coastal communities for long-term resilience are hampered by a lack of understanding of potential trends in the frequency and intensity of tropical storms.

[1] "Direct" fatalities result from events directly related to storm surge, rough seas, freshwater floods, lightning, and wind. Deaths occurring from factors such as heart attacks, house fires, electrocutions from downed power lines, vehicle accidents on wet roads, and so forth, are considered "indirect" deaths.

> "Atlantic tropical cyclone variability is closely correlated with tropical Atlantic climate variability on a broad range of time-scales. A major challenge in detecting past trends in various measures of tropical cyclone activity is the need to identify the causal factors underpinning the observed Atlantic climate variability, which is required to separate tropical cyclone variability into naturally and anthropogenically forced constituents. Even when regional climate variability can be attributed to anthropogenic causes, the question of how tropical cyclones respond to such variability remains."
> Burkett and Davidson, 2012, p. 28.

> "USGS science has been instrumental in helping communities use zoning and building standards to mitigate earthquake losses and in the prediction of volcanic activity to keep people and property out of harm's way, … I have every reason to expect that a focus on science related to hurricanes will have a similar return on investment. Perhaps, with the help of some compelling science, Hurricane Sandy will be another catalyst for helping coastal residents in hurricane country learn how to live more safely near the ocean."
> Marcia McNutt, Former Director, U.S. Geological Survey.

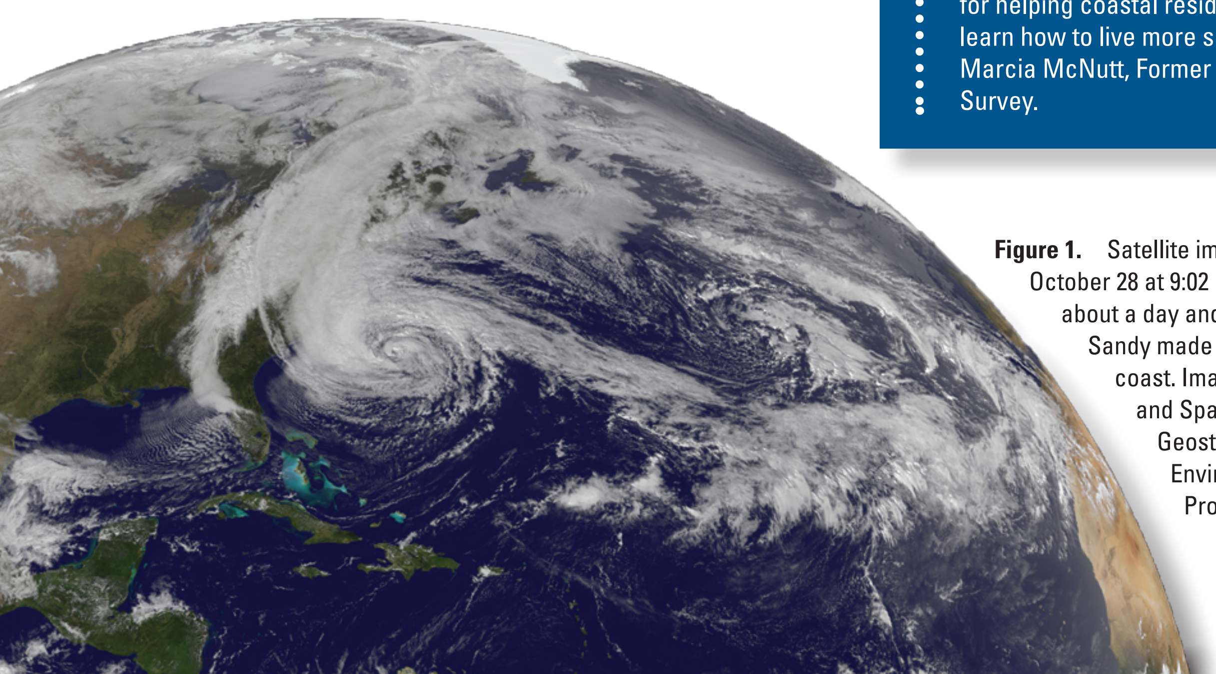


Figure 1. Satellite image of Hurricane Sandy on October 28 at 9:02 a.m. Eastern Daylight Time, about a day and one-half before Hurricane Sandy made landfall on the New Jersey coast. Image from National Aeronautics and Space Administration (NASA) Geostationary Operational Environmental Satellite (GOES) Project.

USGS Roles and Responsibilities

The U.S. Geological Survey (USGS) serves the Nation by providing reliable scientific information to describe and understand the Earth; minimize loss of life and property from natural disasters; manage water, biological, energy, and mineral resources; and enhance and protect our quality of life (U.S. Geological Survey, 2013a). The USGS has played a significant role in the response to a wide range of natural and anthropogenic disasters including hurricanes, earthquakes, volcanic eruptions, floods, droughts, wildfires, industrial accidents, acts of terrorism (the World Trade Center catastrophe), and pandemics (avian influenza). The USGS has responded to every major hurricane for almost two decades, including Hurricane Katrina, and continually is improving USGS pre- and post-storm response. The USGS can play an important supporting role to local, State, and Tribal governments, as well as to other Federal agencies by providing scientific information on the factors that affect the impacts of, and coastal vulnerability to, large storms and other coastal disasters. The USGS also can help ensure that real-time and other data-collection networks are nationally consistent and suitable for integrated assessment and prediction of storm behavior and impact. USGS information, expertise, and capabilities provide a significant scientific resource to disaster responders, resource managers, and the public.

Immediate USGS Storm Response

Recognizing the significant threats posed by Hurricane Sandy, the USGS mobilized before the storm's landfall and initiated data gathering and research to support the Nation's scientific needs (U.S. Geological Survey, 2013b). Before and during the storm, the USGS provided forecasts of potential coastal change (figs. 2 and 3); collected oblique aerial photography of pre-storm coastal morphology (land and submerged elevations); conducted lidar aerial topographic surveys of coastal beaches, barriers, and communities; and issued a landslide alert for landslide prone areas in Maryland, Delaware, northeastern Virginia, and southern Pennsylvania as a result of forecasts of heavy rainfalls (U.S. Geological Survey, 2013c). In addition, the USGS deployed 143 storm-surge sensors, 8 rapid-deployment streamgages, 9 wave sensors, and 63 barometric pressure sensors. Tidal Telemetry Networks in New York and New Jersey (supported by partnerships with stakeholders and maintained and operated by the USGS) and rapid-deployment streamgages provided real-time information from 46 locations along and near the coast to emergency responders about rising coastal water levels in bays and inlets and the associated threat to emergency evacuation routes. Real-time streamgages provided information on river levels rising as a result of inland flooding and storm tide. Real-time water-quality monitors provided information on basic changes in water quality, including encroachment of saline waters.

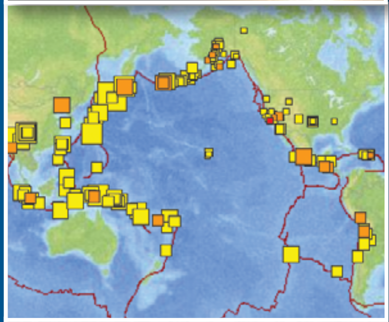
"The data provided by the USGS tide gages that were placed along the Connecticut coastline prior to the landfall of Hurricane Sandy provided extremely valuable information on tide levels during the storm. The data downloaded from the USGS gages after Hurricane Sandy has greatly aided Connecticut in determining the return frequency for a hurricane like Sandy and also confirmed that Sandy was a record-breaking storm for much of the coastline. In addition, this data will help local planners and architects during the rebuilding process to mitigate losses from future storm events."
Douglas Glowacki, Emergency Management Program Specialist, Connecticut Department of Emergency Services and Public Protection.

Many ocean front homes were destroyed or severely damaged during Hurricane Sandy. The photograph shows what remains of houses in the community of Davis Park on Fire Island, New York (photograph by Cheryl Hapke, U.S. Geological Survey). See photographs taken before and after Hurricane Sandy along the coasts of New York and New Jersey at *http://coastal.er.usgs.gov/hurricanes/sandy/photo-comparisons/*.

USGS Roles and Responsibilities Related to Disasters

The U.S. Geological Survey (USGS) issues warnings of potential volcanic hazards to emergency-management authorities and the public in threatened areas. Noxious volcanic gas emissions have caused widespread lung problems. Airborne ash clouds have disrupted the health, lives, and businesses of hundreds of thousands of people; caused millions of dollars of aircraft damage; and nearly brought down passenger flights. The photograph (USGS) shows the Redoubt Eruption, 2009.

The USGS provides information products for earthquake loss reduction, including hazard and risk assessments, comprehensive real-time earthquake monitoring, and public outreach. The graphic shows an Internet-based, interactive earthquake mapping tool that enables the public to map recent earthquakes. The size of the square is proportional to the intensity of the earthquake, and on this map range in intensity from 2.5 to 7.8 on the Richter Scale. The earthquake mapping tool is available on the Internet at http://earthquake.usgs.gov/earthquakes/map/.



USGS is assessing the potential environmental health threats associated with wildfires. Hazardous materials released to the environment when buildings and other structures burn can pose a health risk from contaminant exposures in air, soil, and water. The photograph (USGS) shows USGS scientists collecting samples of ash and burned soil after the 2010 Fourmile Canyon Fire, near Boulder, Colorado.

The USGS responded to the Deepwater Horizon well failure in April 2010 in numerous ways, including identifying chemical and biological changes that may have been caused by the arrival of crude oil product and the associated health risks. The photograph, courtesy of Shane Stocks, USGS, shows USGS scientists collecting samples at beach sites in the Gulf of Mexico. Samples collected before and after petroleum-associated product arrived on shore were analyzed for inorganic and organic chemicals, benthic invertebrates, and oil and microorganism fingerprints.

Beginning in April 26, 2012, the Boise River reached flood stage. The photograph shows USGS hydrologic technicians installing a rapid deployment streamgage on the U.S. Highway 95 bridge near Parma, Idaho. Three rapid deployment streamgages were installed on bridges on the Boise River (near Eagle, Star, and Parma). These streamgages provided additional information on water levels and streamflow to emergency response teams in ungaged areas. Photograph courtesy of Tim Merrick, USGS.

The USGS plays an important role in understanding the role of migratory and other wild birds in the epidemiology of Avian Influenza. USGS scientists and their partners use satellite telemetry to track movements of waterfowl and shorebirds to help monitor migration patterns of wild birds and the associated potential pathways for the spread of Avian Influenza. The photograph, courtesy of John Takekawa, USGS, shows a bar-headed goose (*Anser indicus*) being released in Koonthankulum Sanctuary, India, equipped with a miniaturized global positioning system satellite transmitter.

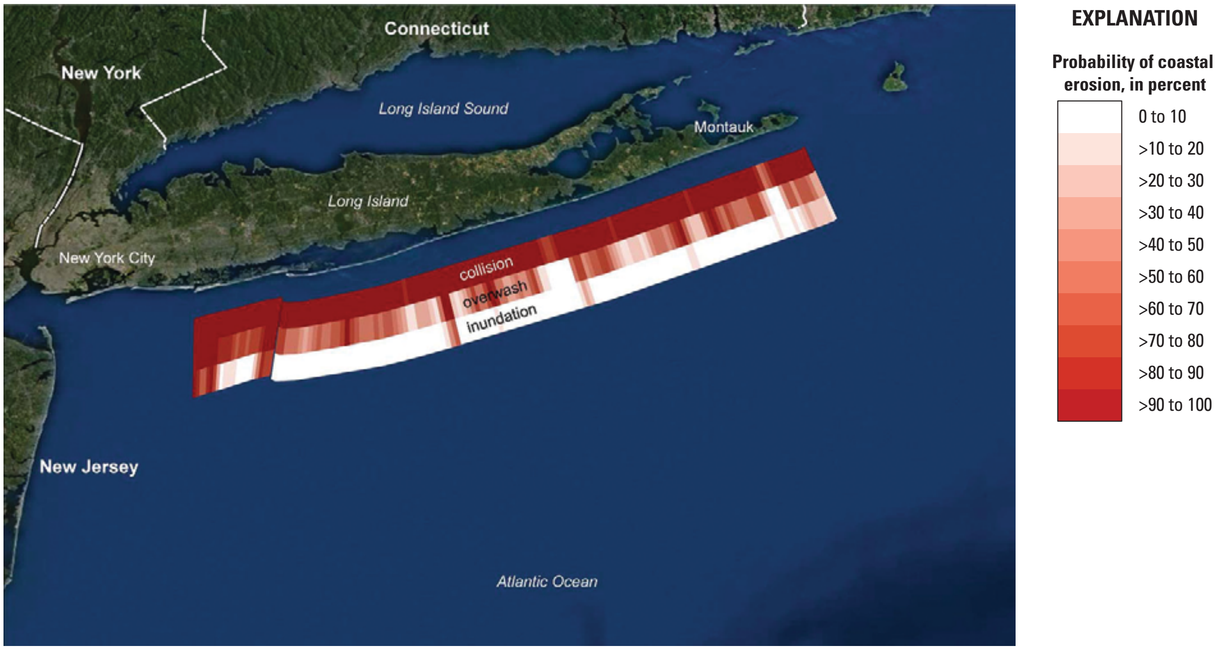


Figure 2. Forecast of the probability of collision (wave erosion of dune fronts), overwash (waves wash over dunes and transport sand inland), and inundation (beach and dunes are completely submerged with potential inlet formation) along the sandy beaches of Long Island, New York (U.S. Geological Survey, 2013d). Figure 3 provides photographs of examples of collision, overwash, and inundation.

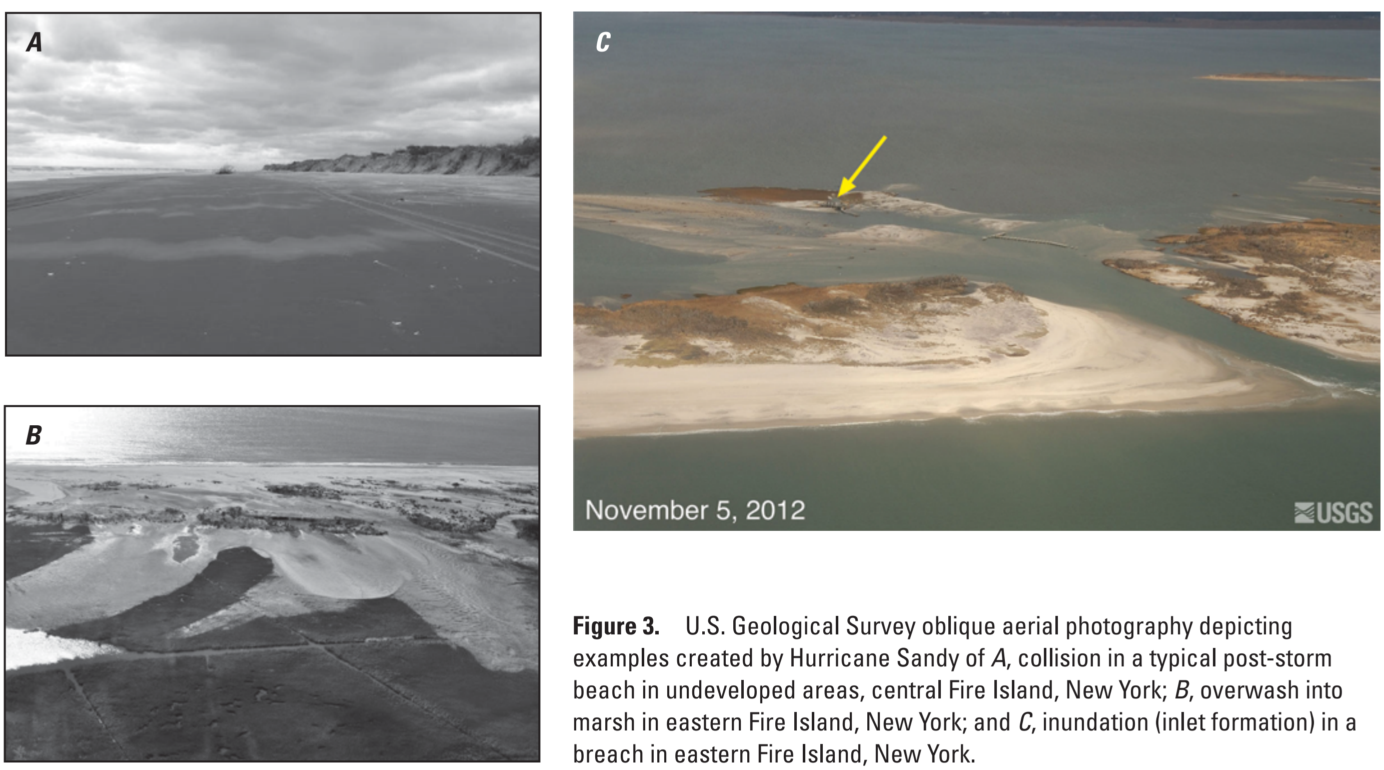
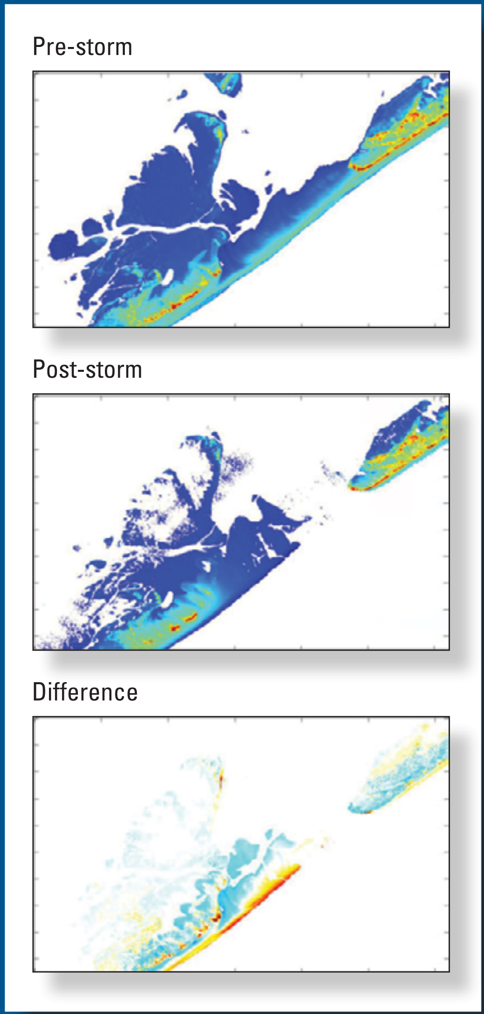


Figure 3. U.S. Geological Survey oblique aerial photography depicting examples created by Hurricane Sandy of *A*, collision in a typical post-storm beach in undeveloped areas, central Fire Island, New York; *B*, overwash into marsh in eastern Fire Island, New York; and *C*, inundation (inlet formation) in a breach in eastern Fire Island, New York.

USGS Contributions in Response to Recent Hurricanes

Hurricanes generate powerful storm surges, waves, and currents capable of moving large amounts of sand, destroying buildings and infrastructure, and reshaping our Nation's coastline. U.S. Geological Survey (USGS) hurricane science focuses on understanding the magnitude and variability of the impacts of hurricanes and extreme storms on the coastal barriers and communities of the United States. The USGS provides capabilities for monitoring storm surges; assessing hurricane damage; quantifying the processes that control inundation and erosion; improving capabilities to forecast, and forecasting coastal change resulting from severe storms; and providing information to support emergency response and management of coastal infrastructure, natural resources, and public safety.

Oblique aerial photographs of Chandeleur Islands before and after Hurricane Isaac. The yellow arrow in each image points to the same feature. The view is looking west from over the Gulf of Mexico across the oil-protection berm in the pre-Isaac photo to a remnant part of the Chandeleur Islands (arrow). The berm in this area appears to have completely eroded during Isaac.



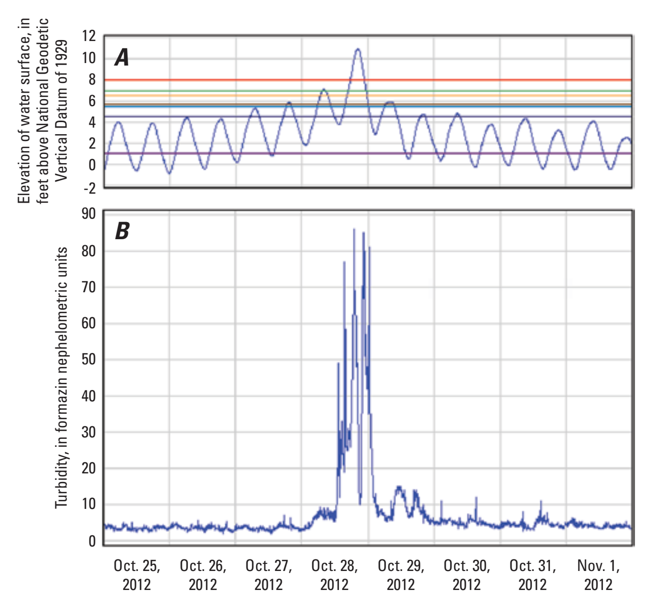
Lidar topographic mapping for a portion of Core Banks, North Carolina, before (August 11–15, 2009) and after (August 28, 2011) Hurricane Irene shows changes caused by the storm. In these images, the Atlantic Ocean is on the bottom, and color shading indicates elevation—from red which indicates topographic highs to blue which indicates topographic lows. The difference image shows over 1 meter of vertical erosion in the beaches that were breached. Here, red indicates maximum erosion. Areas shaded in orange and red on the seaward side of the islands indicate wide-spread shoreline retreat. Blue shows areas of maximum accretion, such as overwash deposits where waves and surge have moved sand landward.

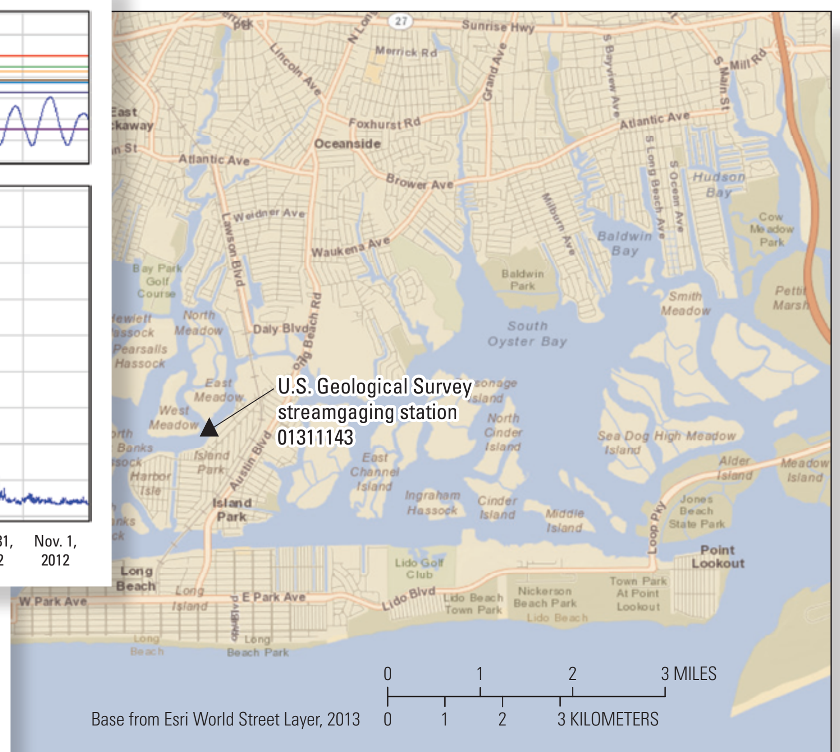
Flooding from Hurricanes Katrina and Rita in August and September 2005 left behind thick accumulations of sediments on streets, lawns, parking lots, and other surfaces in the greater New Orleans and Slidell, Louisiana, area. Concerns that contamination by pathogens and chemicals in these sediments might pose a health risk motivated USGS to characterize contamination in these hurricane flood sediments (Plumlee and others, 2007). The photograph (USGS) shows a USGS scientist collecting sediment data for chemical and microbiological analysis. Data on lead concentrations in sediments were used to inform emergency responders, cleanup workers, and local residents of possible exposure risks. Also, benzopyrene and to a lesser extent the organochlorine pesticide dieldrin were measured above U.S. Environmental Protection Agency soil-screening criteria.

In the immediate aftermath of the storm, over 160 USGS personnel from offices across the Nation (including Georgia, South Carolina, North Carolina, and Ohio) were deployed to collect essential environmental data and service data-collection instrumentation (figs. 4 and 5). Over 830 high-water marks were identified, defining the extent and depth of the storm surge, and helping to quantify the factors that control inundation and to improve storm-surge models that will help prepare for future storms and guide redevelopment efforts. River water-quality samples were collected by field crews to identify potentially harmful changes in water quality. Post-storm lidar surveys from North Carolina to New York documented storm impacts to coastal barriers informing response and recovery, and providing a baseline to assess vulnerability of the reconfigured coast (fig. 6). Imagery products including satellite remote sensing and aerial photography from National Oceanographic and Atmospheric Administration (NOAA) and the Civil Air Patrol were posted promptly on the USGS Hazard Data Distribution System (HDDS) on a daily basis (U.S. Geological Survey, 2013e) (fig. 7). USGS data and information are accessible as soon as available from the Internet (U.S. Geological Survey, 2013d). The USGS Coastal Storm Team responsible for immediate post-storm response was deactivated on November 6, 2012. On November 2nd, the Director formed a Science Team to coordinate continuing USGS activities with other agencies and to develop a science plan for continued data collection and analysis intended to help guide recovery and restoration efforts. This document is that science plan.

"The coastal impact assessment products provided by the USGS have been a critical resource for us on the Federal team to help identify and prioritize impact-related data collection, issue identification and resource evaluation."
Sandy Eslinger, NOAA, and Coastal Coordinator for the New York Interagency Natural and Cultural Resources Recovery Team.

"USGS efforts to measure pre- and post-storm Sandy water levels in the bays and water velocity in the breach at Old Inlet has been a help in answering questions regarding the impact of breaches through the barrier islands. The USGS has also been helpful in flying lidar to demonstrate storm impacts and measuring high-water marks on the mainland, which will allow us to understand the flooding impact…so that we can use [this information] to help define the areas that were compromised and follow with identification of assets at risk and options for risk reduction."
Fred Anders, New York Department of State, Division of Coastal Resources.





Data from real-time monitor Hog Island Channel at Island Park, New York (U.S. Geological Survey station 01311143), showing *A*, water elevation; and *B*, turbidity. The impact of Hurricane Sandy late of October 29, 2012 is readily apparent.

Figure 4. Photographs showing permanent real-time water-level monitoring station, Barnegat Bay, at Waretown, New Jersey, *A*, before and *B*, after Hurricane Sandy (U.S. Geological Survey). The New Jersey and New York Tidal Telemetry Networks have 38 fixed stations in estuaries and bays, and are supported jointly by the U.S. Geological Survey and other Federal, State, and local governments.

Figure 5. A U.S. Geological Survey scientist recovering a stormtide water-level sensor along the Hudson River in Hoboken, New Jersey (photograph by Kerry A. Caslow, U.S. Geological Survey).

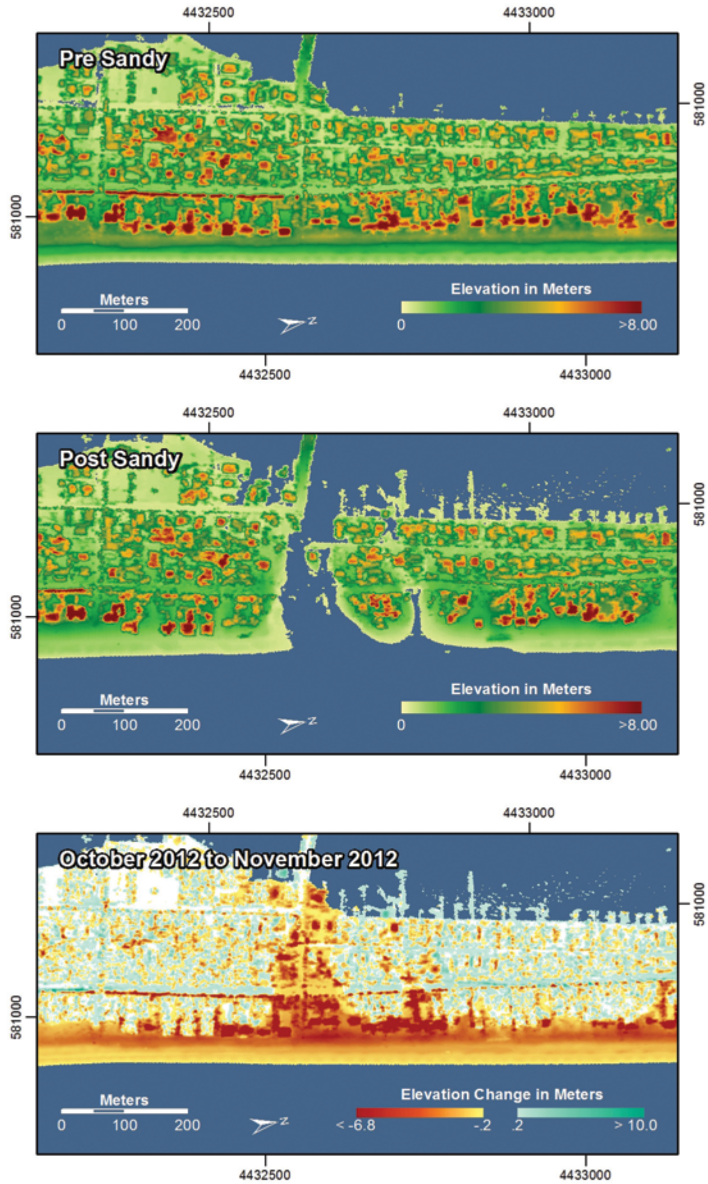


Figure 6. Comparison of pre- and post-storm elevation maps (U.S. Geological Survey, 2013b) at Mantoloking, New Jersey before and after Hurricane Sandy (top and center panels respectively); the bottom panel shows elevation difference. Storm surge and waves eroded the beach and dunes and a breach cut through the approximately 250-meter-wide island, destroying houses and roads (see fig. 7). Overwash deposition occurred in many areas. This lidar survey was conducted immediately after the storm before the breach had been filled.

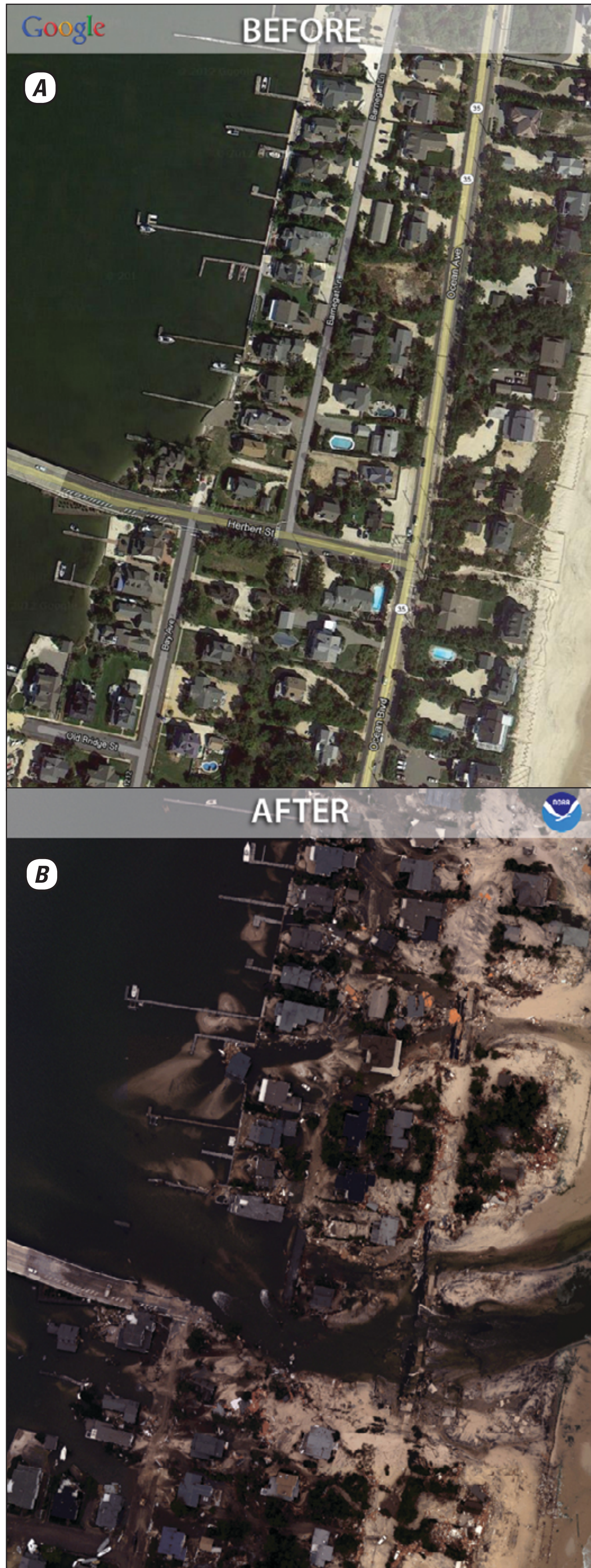


Figure 7. Aerial photographs of the Mantoloking area of New Jersey, taken *A*, before; and *B*, immediately following Hurricane Sandy, showing dramatic storm damage, coastal erosion, and inlet formation (National Oceanic and Atmospheric Administration, 2013). The post-storm photograph was taken before restoration activities had begun.

USGS Hurricane Sandy Science Plan

This plan supplements USGS response activities before and immediately after Hurricane Sandy. The data, information, and tools that are produced will:

1. Further characterize impacts and changes,
2. Guide mitigation and restoration of impacted communities and ecosystems,
3. Inform a redevelopment strategy aimed at developing resilient coastal communities and ecosystems,
4. Improve preparedness and responsiveness to the next hurricane or similar coastal disaster, and
5. Enable improved hazard assessment, response, and recovery for future storms along the hurricane prone shoreline of the United States.

The activities outlined in this plan are organized in five themes based on impact types and information needs. Each theme, below, is introduced, followed by the stakeholder scientific needs and the USGS contributions to those needs. These USGS science themes are:

Theme 1: Coastal topography and bathymetry.

Theme 2: Impacts to coastal beaches and barriers.

Theme 3: Impacts of storm surge and estuarine and bay hydrology.

Theme 4: Impacts on environmental quality and persisting contaminant exposures.

Theme 5: Impacts to coastal ecosystems, habitats, and fish and wildlife.

Hurricane forces and impacts are depicted in figure 8, which also reflects the organization and integration of USGS science activities in response to Hurricane Sandy as represented in these science themes. Improved coastal topographic and bathymetric data (theme 1) are fundamental to assessing and addressing the impacts described in themes 2 through 5. These data provide an essential baseline for all hurricane impacts and the corresponding assessment and restoration. Themes 2 through 5 describe storm impacts that require characterization, process understanding, and development of forecasting capabilities to assess alternative restoration strategies. Studies associated with these four impact-related themes build upon each other; will draw on data, information, and knowledge from other themes; and will require coordination of scientists with expertise in each of the theme areas. For example, characterizing and assessing the impacts of storm surge will build on knowledge of coastal morphology. Defining impacts on environmental quality will rely on assessments and models of the redeposition of debris and disturbed contaminants and persisting changes in water circulation patterns. Finally, making an integrated assessment of the total effects of Hurricane Sandy on ecosystems will build on the information

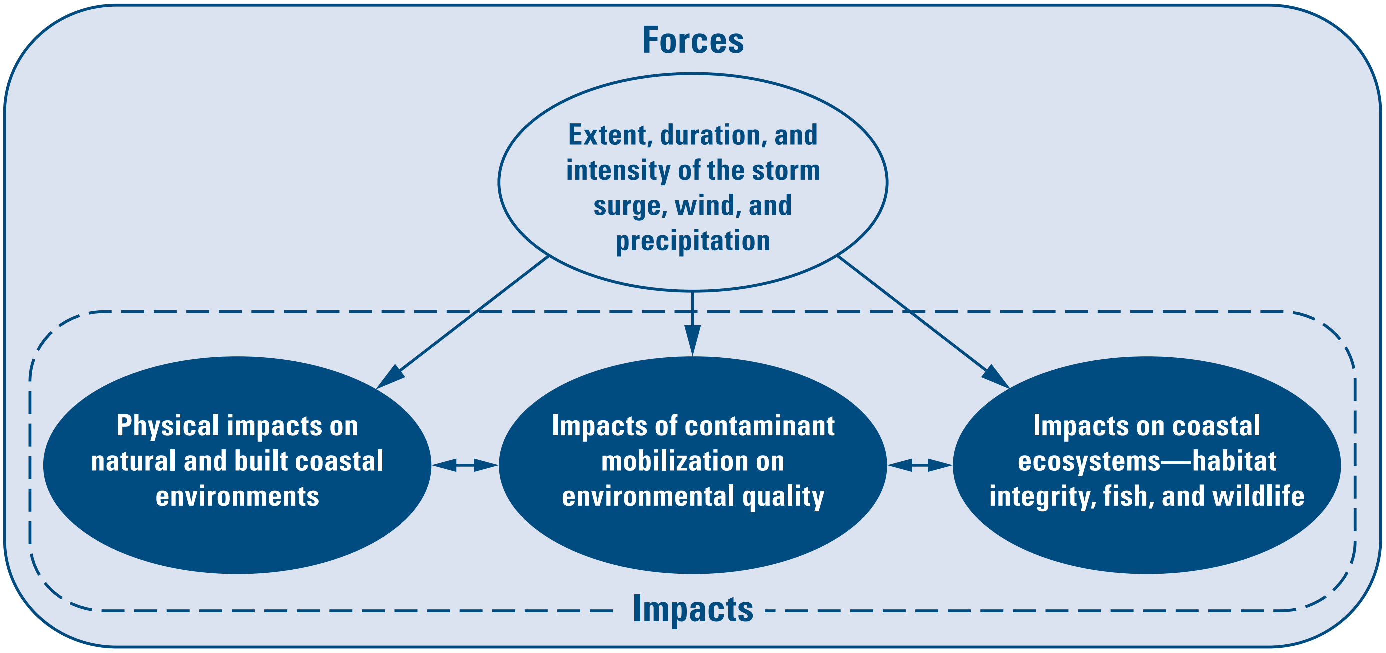


Figure 8. Types of hurricane forces and impacts, and reflecting the organization and integration of the U.S. Geological Survey science response to Hurricane Sandy.

and knowledge gained across all other themes, requiring an understanding of the interacting processes and factors.

The contributions associated with each theme in the following sections were developed with input from other Federal agencies and stakeholders with which USGS commonly has longstanding relationships and ongoing cooperative science activities. More information is provided on stakeholder coordination later in this plan. The full effect of USGS efforts will be realized through coordination with other Federal agencies, and State, Tribal, and local governments, which will be engaged to ensure effective translation of USGS information and products to mitigation, restoration, and preparedness decisionmaking.

USGS Science activities will receive input from the Department of Interior Strategic Sciences Group (SSG), formed by the Secretary in January 2012 to provide rapid, interdisciplinary scientific assessments during environmental crises or disasters affecting America's natural resources. The SSG deployed a crisis science team to support the Hurricane Sandy Rebuilding Task Force and will help ensure that recovery efforts undertaken by the Department of the Interior (DOI) and its bureaus will be guided by the best available science and lessons learned from past events, including the Deepwater Horizon oil spill and Hurricane Katrina.

Theme 1: Coastal Topographic and Bathymetric Data to Support Hurricane Impact Assessment and Response

The fundamental lesson of Hurricane Sandy, and prior catastrophic hurricanes, is that storm vulnerability is first and foremost a consequence of coastal elevation. The height at which infrastructure, resources, and communities sit in relation to average tides and water levels, storm waves, surge, and flood waters determines their exposure to overwhelmingly powerful damaging forces. Reliable, accurate, and accessible elevation information are priorities for communities anticipating impacts and preparing response strategies. Post-storm elevation also is critical for design of resilient and cost-efficient post-storm redevelopment.

A key milestone in the National Ocean Policy Implementation Plan (National Ocean Council, 2012) calls for describing coastal and marine elevation throughout the United States and for improving coastal change analysis. The USGS 3D Elevation Program (U.S. Geological Survey, 2013f) initiative identifies the ambitious goal of improving the elevation data for the Nation to respond to governmental and private sector requirements. USGS will use the structure of the USGS 3D Elevation Program to advance the goal of improved elevation data leading, in part, to more resilient communities and improved natural landscape functions. Through improved information management and integrated information-access systems, this critical information will be readily and immediately available to address the long-term Hurricane Sandy response needs and for future use regardless of the need.

Stakeholder Science Needs

The U.S. Atlantic and Gulf coasts are vulnerable to hurricane impacts and lack the comprehensive integrated onshore/offshore baseline elevation data required to fully support hazard mitigation policies, redevelopment planning, and emergency preparedness and disaster response. These baseline data need to be accurate, up-to-date, and readily available before a devastating hurricane impacts one of these coastal areas. Post-Hurricane Sandy data are needed to guide recovery activities, to assess impacts, to forecast increased coastal vulnerability, and to establish the new baseline for future events and decisions. Lidar elevation data are used to create advanced and highly precise elevation profiles of the coastal and near shore areas. Bathymetric lidar data are used to map changes in water depth in waterways and shallow bays, estuaries, and coastal areas. Lidar provides consistent and highly accurate information that is fundamental to numerous stakeholder needs.

The following Hurricane Sandy response needs will be directly supported with lidar based products:

- Assessment of coastal erosion, landscape change, and vulnerability;
- Assessment of effectiveness of infrastructure and natural features such as sand dunes for protecting built and natural landscapes;
- Design of restoration, redevelopment, and protection projects, including supporting building code development;
- Prediction of future hurricane storm surge and coastal and inland flooding;
- Assessment of persisting environmental threats from debris and disturbed contaminants;
- Inventory and assessment of wetland and agricultural land resources;
- Development of strategies for climate change adaptation from sea-level rise and other effects; and
- Assessments of dune, forest, and wetland benthic structure and ecosystem physical vulnerability.

USGS Contributions

Topographic surveys (lidar) for impact area assessment and reconstruction.—Post-Sandy elevation data within the Hurricane Sandy designated impact area will be collected where data do not exist or where existing data do not meet recovery, mitigation, and assessment requirements for priority watershed and ecosystem analyses. The new data will be integrated with other existing data and made available through the 3D Elevation Program. New data will be processed into improved elevation models. Areas with direct impacts and in need of data to complete assessments and to support reconstruction activities will be priority targets for new surveys. The topographic surveys (lidar) will target coastal and direct-impact areas (fig. 9). The Coastal National Elevation Dataset (U.S. Geological Survey, 2013g) project builds bathymetric elevation data models and integrates them with the topographic elevation data models.

Establish a Hurricane Sandy Region Coastal National Elevation Database (CoNED).—Topographic and bathymetric (topobathymetric) elevation data from multiple sources will be processed and combined with the National Elevation Dataset to create a seamless and integrated CoNED within the Hurricane Sandy impact area. A regional topobathymetric elevation database (CoNED) and derivative products for the entire Hurricane Sandy impact region will be constructed. Derivative products include (1) a Hurricane Sandy sub-region elevation dataset with enhanced vertical accuracy within low-lying extreme inundation hazard zones, (2) high-resolution bare earth lidar datasets over vulnerable urbanized zones, (3) a multi-temporal topobathymetric database over geomorphically dynamic coastal sub regions, (4) hydrologically enforced and corrected topographic datasets for selected major river basins, and (5) maps that depict Hurricane Sandy impact region data gaps in elevation dataset coverage, age, and quality to guide coordinated interagency investments in coastal mapping.

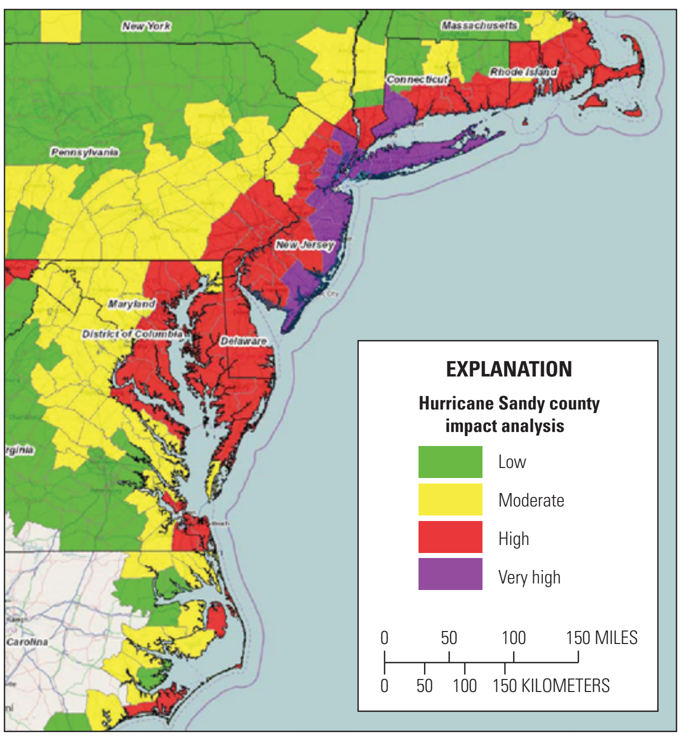


Figure 9. The Federal Emergency Management Agency Modeling Task Force Hurricane Sandy Impact Analysis is being used as a guide for resource investments in science to support recovery and resilience, including where to conduct additional post-storm lidar elevation surveys (Federal Emergency Management Agency, 2013).

Delivery systems for hazards, topographic, and bathymetric elevation data.—Hurricane Sandy data delivery capabilities will be improved to support requirements for hazards data and for new data collections to be delivered through the HDDS and the 3D Elevation Program applications. The HDDS model outputs and real-time data feeds will be used to provide rapid situational awareness. The HDDS area of interest model will employ geospatial analytics to identify those areas (for example, bridges, dams, critical infrastructure, and highly populated areas) that may warrant satellite monitoring. Post-event disaster imagery planning and acquisition for the HDDS will be expedited by combining near real-time hazard impact assessments with knowledge about populated areas. Data collection areas will be targeted during events. Aerial imagery, lidar, and other data can be quickly acquired. Overall, the result will be efficient and informed tasking of limited resources. The second component of this project will include 3D Elevation Program system improvements to provide access to raw lidar data and elevation data products from The National Map (U.S. Geological Survey, 2013h) and the National Elevation Dataset. These data support immediate analysis of impacts to coastal and inland areas, for planning recovery and mitigation activities and for supporting site level engineering.

Theme 2: Impacts to Coastal Beaches and Barriers

The Nation's coast is fringed by beaches, dunes, barrier islands, wetlands, and bluffs. These natural coastal barriers provide the first defense to storm impacts and are critical factors to assessing the vulnerability of adjacent lands, waters, living resources, and people. The ability of these barriers to provide critical benefits and services, and to mitigate the impact of future storms, erosion, and sea-level rise, are critical determinants of storm impacts and should inform decisions on recovery and rebuilding.

Barrier islands line about one-half the U.S. coast, including most of the region impacted by Hurricane Sandy. The evolution of these landforms is affected by natural processes, human development and other actions, natural trends such as climate change and sea-level rise, and storm events, such as Hurricane Sandy. From North Carolina, through New York and Massachusetts, Sandy's waves and surge eroded and overtopped protective dunes and beaches; transported sand (overwash) inland across roads, wetlands, and property; and breached barrier islands, thereby isolating communities. The post-Sandy barrier system is vastly different than that which existed prior to the storm. The "new" barrier landscape that will determine our vulnerability to future storms is yet to be established and will depend largely on actions taken in the coming months and years through the recovery and rebuilding phases. The Hurricane Sandy impact region includes developed and undeveloped areas, highly urbanized and commercial properties, infrastructure critical to human protection and economic viability, and natural systems that help protect development and environmental capital, such as National Parks and National Wildlife Refuges. The USGS has a sustained national program to understand and forecast the vulnerability of coastal beaches, wetlands, and barrier islands to storm impacts and the other factors that affect their evolution.

Stakeholder Science Needs

Emergency responders and coastal managers need assessments of the potential impacts of future storms on coastal beaches and barriers, access to credible forecasts of the effects of recovery and mitigation actions and future development on coastal vulnerability and resilience, and knowledge to identify the areas most vulnerable to impacts of future storms so as to effectively direct response and recovery resources before and in the immediate aftermath of storms. Forecasts of coastal vulnerability of a generic storm similar to Hurricane Sandy done immediately before Hurricane Sandy, and shortly after the storm using post-storm coastal topography and bathymetry are compared in figure 10. The results indicate significant increase in coastal vulnerability after the storm. In order to make effective decisions coastal managers and planners need knowledge of the current and future extent, configuration, and evolution of coastal barrier systems to understand how coastal vulnerability evolves as a consequence of barrier response to future storms and sea-level rise, and the information and tools to evaluate the efficacy and sustainability of alternative barrier development, post-storm recovery, and engineering scenarios. Recognizing that coastal barriers impact the vulnerability and health of adjacent resources and communities, coastal managers and planners need information and tools to protect and preserve the health and resilience of coastal landscapes, waters, communities, resources, and habitats impacted by the condition of coastal barriers. This information can be used to ensure that management strategies for coastal resources reflect the influence and likely future state of coastal barriers and to

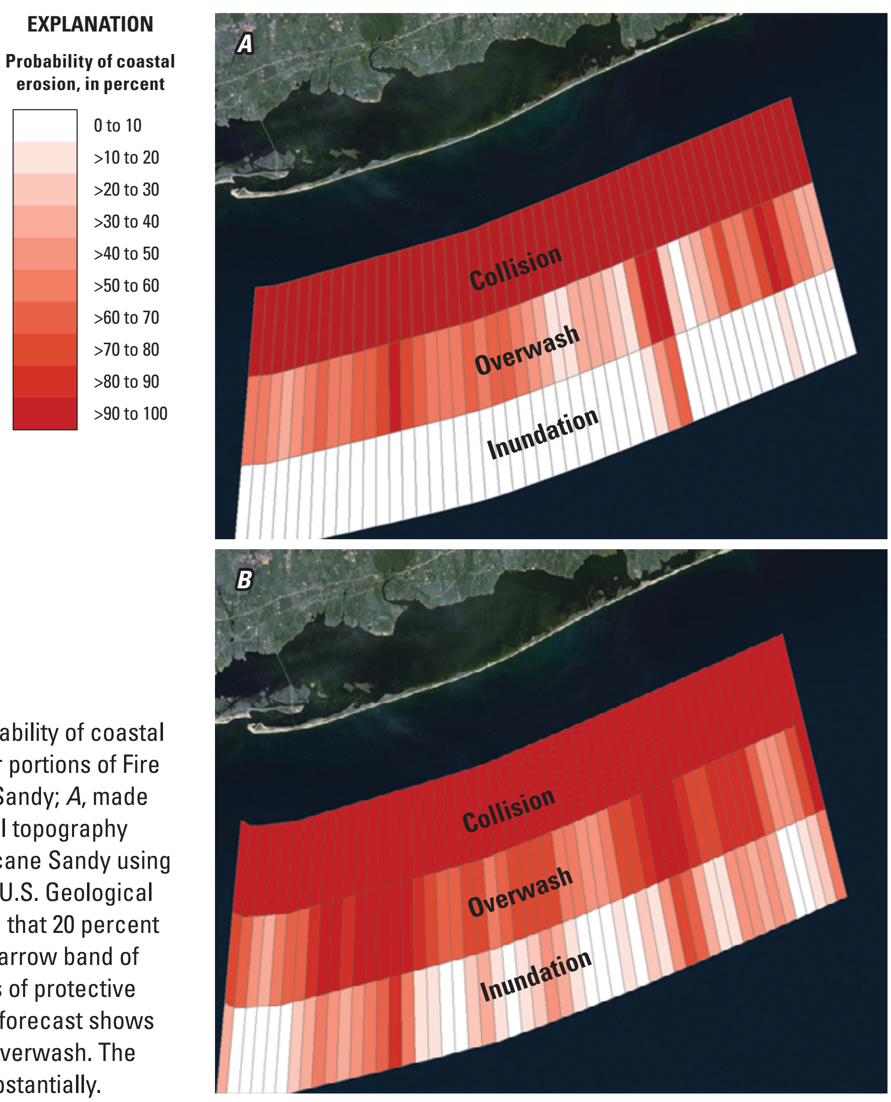


Figure 10. Comparison of forecasts of the probability of coastal impacts (collision, overwash, and inundation) for portions of Fire Island, New York, due to a storm like Hurricane Sandy; *A*, made prior to Hurricane Sandy using pre-storm coastal topography and bathymetry; and *B*, made shortly after Hurricane Sandy using post-storm coastal topography and bathymetry (U.S. Geological Survey, 2013d). The pre-storm forecast indicated that 20 percent of the shoreline was likely to overwash, with a narrow band of shoreline vulnerable to inundation. After the loss of protective dunes, beaches, and vegetation, the post-storm forecast shows that 70 percent of the shoreline is now likely to overwash. The area vulnerable to inundation also increased substantially.

support decisions on the management of beach and barrier systems consistent with objectives for the broader interconnected coastal system. Coastal managers need to know how offshore sand mining, changes in the physical structure of islands and coastlines, and changes in coastal vegetation will affect vulnerability to future storms and sea-level changes.

USGS Contributions

Pre- and post-storm mapping of coastal impacts and vulnerability.—The USGS will process all available topography and bathymetry data collected by the USGS. The information will be used to assess coastal impacts, to provide digital interpretive products that document coastal change (overwash and debris distribution, dune/beach loss, physical habitat modification, channel migration and elevation change), and to characterize the post-storm condition of coastal resources. Improvements in existing hardware and software will ensure that capacity for rapid provision of data, products, and assessments is enhanced prior to future storm events.

Develop coastal impact forecast models.—The USGS will provide updated vulnerability assessments of mid-Atlantic and northeastern United States beaches to future impacts from "model" storms, and identify areas vulnerable to extreme, potentially catastrophic, erosion during landfall. Historic rates of shoreline retreat will be updated and the impact of previous storms on the beaches in the region, including magnitudes of shoreline, dune, and beach erosion, will be quantified. The efficacy of proposed and alternative rebuilding efforts (such as dune restoration) will be evaluated. The data from Hurricane Sandy and past storms will be used to improve the accuracy and impact of the coastal change forecasts. National Climate Assessment scenarios for future sea-level rise will be incorporated into vulnerability assessments. Social, economic, and infrastructure/critical facility elements will be added to assessments to facilitate dialogue on societal risk and decision making to reduce risk.

Provide web access and delivery of coastal impact assessments and data.—The USGS will create an online portal for data and tools to assess coastal change vulnerability and apply USGS data and analyses to immediate and specific needs. The portal will provide direct access for coastal stakeholders to assessments of potential storm and sea-level change impacts on our Nation's coasts, as well as tools to assess rates of shoreline change and probabilities of erosion during storms and because of long-term sea-level rise. The USGS Digital Shoreline Analysis System (U.S. Geological Survey, 2013i), the community-standard for estimating rates of shoreline change, will serve as the framework for an expanded coastal change hazards portal.

Coastal wetland physical change assessment.—Existing USGS coastal vulnerability assessments and forecasts will be enhanced to include wetland-dominated coastlines present along coastal barriers and bays, increasing the availability of decision-support tools for restoration and recovery of coastal ecosystems and adjacent communities and infrastructure.

Linking coastal processes and vulnerability, Fire Island regional study.—The USGS will conduct targeted studies on the Fire Island barrier system to (1) quantify how offshore sand resources suitable for recovery efforts were impacted by Hurricane Sandy; (2) monitor ocean currents, waves and sediment transport; (3) collect geophysical data to assess sediment availability for post-storm recovery; (4) establish linkages between nearshore geology, ocean processes, and island response; and (5) build models that predict the coastal response to oceanographic forcing, assess vulnerability of natural and built portions of the barrier system, and predict barrier island evolution.

Linking coastal processes and vulnerability, Assateague Island regional study.—The USGS will map the regional geologic framework and identify the physical processes governing the evolution of the Delmarva coastal system, including valuable DOI assets that experienced significant Hurricane Sandy impacts. Activities include assessment of (1) coastal and estuarine shoreline erosion; (2) formation, quantity, and potential consequences of using offshore sand for beach and dune restoration; (3) factors that affect barrier island and inlet stability and estuarine water circulation; (4) sea-level change history and future impacts on barrier islands, beaches, and wetlands; (5) coastal habitat extent and quality; and (6) models describing sediment erosion, transport, and deposition, and coastal vulnerability as a consequence of storm events, long-term sea-level rise, and management actions.

Estuarine assessment.—The USGS will provide (1) topographic-bathymetric maps of estuarine-barrier island systems; (2) maps of sediment movement before and after storms; (3) maps of pre- and post-storm habitat quality; (4) maps of inundation risk under barrier-island breaching scenarios; (5) sea-level rise scenario mapping of wetland stability; and (6) assessments of changing ecosystem and coastal community vulnerability under future conditions. Specific locations and relevant issues include:

- Raritan Bay, New Jersey: Assessment of contaminated sediment redistribution,
- Barnegat Bay, New Jersey: Assessment of disturbance to seagrass habitat and flushing under storm conditions,
- Great South Bay, New York: Assessment of coastal inundation under breaching scenarios, and
- Chincoteague Bay, Maryland/Virginia: Assessment of wetland development under storm and sea-level rise scenarios.

Theme 3: Impacts of Storm Surge, Including Disturbed Estuarine and Bay Hydrology

The storm surge created by the winds and waves of Hurricane Sandy was the primary driver of coastal community destruction and dramatic changes in the coastal and near-coastal environment. The energy of the surge caused physical changes to the landscape and the landward extent of the surge transported saline waters, sediment, and debris to ecologically sensitive environments that are rarely impacted by ocean effects. Upon approach to the coast, the combination of the surge's arrival with the tide of a full moon created a storm tide (the combined rise in water elevation from both tide and storm surge) that attained a peak of over 19 feet, an elevation not observed in the last 100 years (fig. 11). Although models predicting the level of the storm tide at the coast generally were accurate, predictions of the extent, depth, and severity of the storm tide as it moved inland were based almost entirely on topographic features and land surface elevation. The observed distribution of the storm tide across the land surface was not uniform; in several instances, the impacts of the storm tide were higher than expected, illustrating the critical need for a better understanding of how storm surge and landscape features interact to dissipate or increase storm impacts.

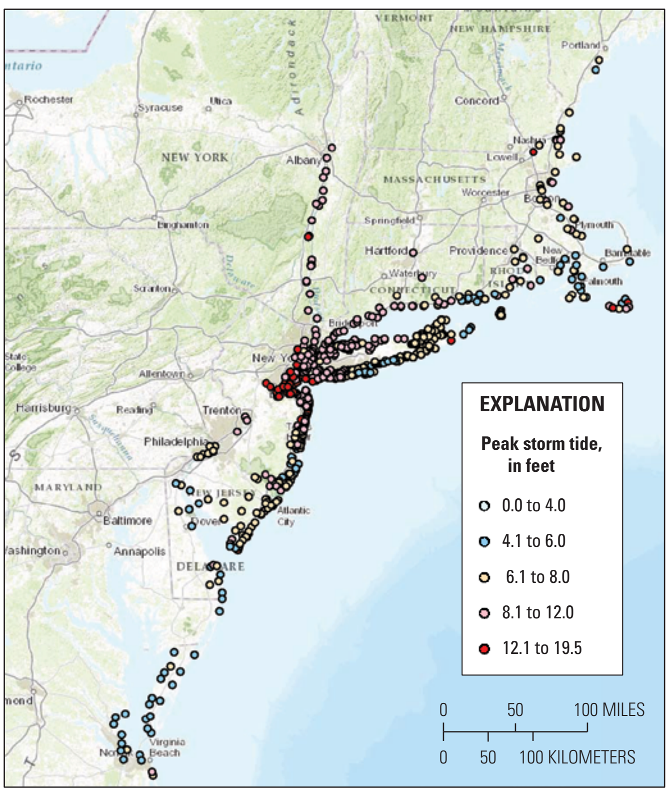


Figure 11. Peak stormtide elevations compiled from deployed storm surge sensors and high-water marks identified and surveyed immediately post storm. The map was generated using the U.S. Geological Survey Hurricane Sandy Storm Tide Mapper, an online tool for mapping a range of hurricane-related data and information (U.S. Geological Survey, 2013j).

Stakeholder Science Needs

Delivering storm tide monitoring data in an easily accessible manner and as rapidly as possible is critical to the Federal Emergency Management Agency (FEMA), other emergency agencies, and local emergency responders. Real-time information is needed to inform emergency responders of inundation of evacuation routes and critical infrastructure. Following an event, processing and delivery of USGS quality-assured surge data will allow surge modelers within the U.S. Army Corps of Engineers (USACE) and National Oceanic and Atmospheric Administration (NOAA) to improve forecast and planning models. Emergency managers, first responders, and community planners require reliable forecasts of the extent, depth, and energy of storm surge as it moves inward along the landscape; greatly increased real-time and near-real-time situational awareness; and more timely and accurate post-storm flood and damage assessments. Coastal community planners need better tools to assess flooding risks and mitigation strategies. Ocean scientists and engineers need substantially improved data on storm surge and other processes to better calibrate storm-surge and water-circulation models to improve forecast models and, through them, the ability of responders to safeguard life and property.

USGS Contributions

Storm-surge response and data collection.—Current real-time capabilities are available in only a small fraction of available sensors. In addition, providing field support and deploying USGS sensor equipment from existing USGS Storm Tide Center locations in Atlanta, Georgia; Orlando, Florida; and Ruston, Louisiana (the existing USGS Storm Tide Centers); is challenging during storm events impacting the mid-Atlantic and northeastern United States or in situations of multiple impending storms. A Storm Tide Center will be established in the northeastern United States with adequate equipment and trained staff to improve dramatically the USGS response to hurricanes, nor'easters, and other significant storms impacting the mid-Atlantic and northeastern United States. The USGS will also enhance the national USGS storm-surge support network by increasing the number and mobility of water-level and water-quality sensors in staging areas for rapid deployment to areas forecast to be vulnerable to storm surge, and increase the amount of real-time and near-real-time storm-surge data that are available to emergency responders by increasing real-time sensors capacity.

Storm tide monitoring networks and data analysis.—The USGS will refurbish and enhance fixed-station, rapid-deployment, storm tide networks to facilitate more efficient deployment and recovery of sensors to support monitoring and forecast updates. Fixed-place rapid-deployment storm tide monitoring networks will be established using a combination of long-term tide gages and rapid-deployment sensors in predetermined locations to measure the extent and magnitude of storm tide, wave heights, and meteorological parameters. The USGS will (1) pre-establish (including elevation surveying to a datum) fixed-place deployable sensor locations; (2) fill gaps in storm tide networks along the United States Atlantic coast identified by stakeholders to meet local response data needs, and systematically reduce storm-surge forecast model uncertainty; (3) establish the capability to deploy rapidly a network of sensors to meet water-level, flow, and quality data needs, and observe water and wind interaction with built structures and natural features during emergency situations; and (4) collect water velocity and directional data during storms in selected areas along the coast to improve the definition of bay, estuary, and river channel flows.

Storm-surge data recovery and delivery.—The USGS will (1) increase the efficiency of data recovery and processing by modifying software, procuring rugged data-retrieval hardware, Real-Time Network Global Positioning System (RTN GPS) surveying equipment, and acquiring wireless connectivity; (2) improve data analysis, delivery, and the display system used to provide real-time and recovered data to emergency responders, community planners, forecasters, modelers, and the public; (3) improve the data delivery and display systems by developing field crew applications that feed mapper and web services directly; and (4) identify high vulnerability areas for deployment of real-time water-level and water-quality sensors. Storm-surge data will be linked with GIS tools permitting rapid analysis of storm-surge data.

Storm tide data analysis and scientific understanding.—The USGS will develop maps of flood levels and storm-surge inundation near key infrastructure and evacuation routes. Using a geographic information system, a tool will be developed to assess current storm-surge network design. The tool will be applied to improve the spatial resolution and density of storm-surge monitoring locations based on detailed coastal geomorphology and desired storm-surge model uncertainty, and will be released for use by others with specific local-scale concerns. The USGS will collect water level, flow velocity, flow direction, bathymetric, and sediment transport data using traditional and emerging hydroacoustic techniques in areas of concern, including the area of breaches such as at the Fire Island National Seashore (fig. 12), and at damaged ecological areas, such as at the E.B. Forsythe and Chincoteague National Wildlife Refuges, to identify the hydrologic mechanisms that caused the damages and assist the National Park Service (NPS) and the Fish and Wildlife Service (FWS) with evaluating the relative effectiveness of alternative restoration plans.

Figure 12. U.S. Geological Survey scientists taking an acoustic measuring flow velocity profile in new inlet formed during Hurricane Sandy on Fire Island, New York (U.S. Geological Survey). The scientists are using a remote control Acoustic Velocity Current Profiler.

Theme 4: Impacts on Environmental Quality, Including Exposure to Chemical and Microbial Contaminants

Low-elevation coastal areas impacted by storm-surge or river-floodwater damage are vulnerable to a range of chemical and microbial contamination issues. Contaminants can be mobilized and transported from disturbed sediments and damaged infrastructure and relocated in sediments and waters producing an increased risk of both acute and chronic low-level human and ecological exposure. Other potential contamination sources include combined sewer overflows; debris from buildings, automobiles, and boats; inundated infrastructure such as gas stations, landfills, chemical storage facilities, and hazardous waste sites; and saline water intrusion in estuaries and on shorelines. During Hurricane Sandy numerous wastewater treatment facilities failed for prolonged periods, releasing raw sewage to the environment. Public health agencies advised the public to disinfect water and other materials; however, the persisting effect of such releases is undetermined, including in local recreational waters. Debris from the built environment may release toxic materials over prolonged periods. Alteration of bay and estuarine hydrodynamics can affect salinity levels, fisheries and shellfish habitat, and contaminant exposures. The quality of the substantial amount of disturbed sediments in terms of legacy contaminants is undefined.

> "Given the large scale failures in wastewater management, extensive damage to homes, vehicles (boats and cars) and businesses, in addition to the widespread movement of water and sediment due to the storm, it is essential to better understand effects of the storm on human health and aquatic life, determine if and where remediation is needed and help plan for greater resiliency to minimize effects from future storms. The work proposed by the Department and partners, such as the USGS, related to identifying sources of contaminant exposures to biota and humans in aquatic environments, bottom sediments, soils, and debris, including extending the investigation to more persistent contaminants and their exposure pathways and receptor organisms, will advance this understanding and improve effectiveness in future resiliency planning and managing risks from future storms."
> Jill Lipoti, Ph.D., Director, Division of Water Monitoring and Standards, New Jersey Department of Environmental Protection.

Stakeholder Science Needs

Resource managers are concerned with the health of coastal ecosystems that are sensitive to changes in salinity, excess nutrients, and toxic contaminants. Subtle changes in environmental quality can affect coastal wetland and bay habitats, plant communities, finfish and shellfish populations, threatened and endangered species, and reduce the associated ecosystem services.

Prioritization of environmental quality mitigation actions requires a comprehensive understanding of the contaminants mobilized by flooding and erosion during the storm and of potential short-term and long-term exposure risks from dusts, sediment, and waters. Most immediate recovery activities (for example, dewatering infrastructure, moving sand, mud, and other storm-related deposits and debris, and dredging) are designed to restore routine community functions, and are not designed to identify and mitigate risk of long-term contaminant exposures. Stakeholders need to know (1) how effective cleanup activities have been in reducing risks of contaminant exposures to humans and ecosystems, (2) if these activities have inadvertently created contaminant exposure pathways, (3) if exposure risks persist, and (4) how the contaminants originally were introduced to the environment. Stakeholders, including the U.S. Environmental Protection Agency (EPA) Oceans and Coastal Protection Division and National Estuary Program, the States of New York and New Jersey, the NPS, local governments, and utilities, have requested that the USGS undertake environmental contamination assessments in priority impacted estuaries. In some cases, these studies will build upon previous or ongoing USGS studies that serve to define pre-storm environmental quality.

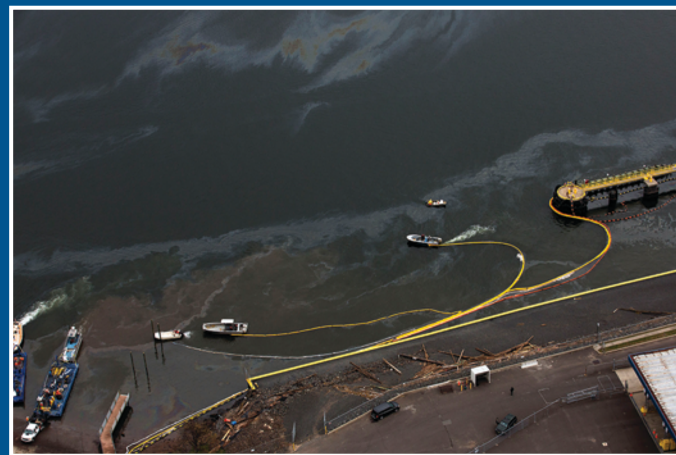
Knowledge of the long-term fate and health implications of hurricane-induced environmental contamination will inform decisions and inform development of appropriate strategies to anticipate, remediate, or otherwise respond to the contamination. An understanding of the sources of contaminants from Hurricane Sandy will inform redevelopment strategies that build resilience to future storms.

USGS Contributions

Ecological contaminant exposures: Characterize persisting risk of ecological exposure to storm-released contaminants and water-quality changes in coastal and aquatic environments.—The USGS will characterize sources and movement of contaminants, including emerging contaminants and endocrine disruptors in priority impacted estuaries, bays, and beaches. Studies will focus on high priority ecosystems as identified by stakeholders, such as Barnegat Bay, Jamaica Bay, South Shore Estuary Reserve Gateway National Recreation Area, Great South Bay, and the Peconic Estuary. Sampling sites will be identified based on information about redeposition of sediment and debris from the built environment from USGS studies in themes 1 and 3. Water and sediment chemistry data from pre-storm USGS studies will be compiled to define background environmental quality conditions. Ecological toxicity assessments will focus on chronic health endpoints such

Characterizing Persisting Threats to Environmental Quality

Hurricane Sandy caused significant physical disruption of the natural and built environments. Many structures were destroyed, releasing contaminants from households and businesses, oil tanks, household and commercial chemicals. Numerous wastewater treatment facilities failed spilling untreated sewage into coastal waters for extended periods of time. The long-term effect of these contaminant releases is still unclear. The situation is significantly different from Katrina, which impacted a coastal zone that was largely sediment starved. In the northeastern United States, there is a need for rapid response to remove sand and water from homes, subways and other living areas, however contamination issues remain a concern.



The upper photograph shows control measures being taken in the Arthur Kill between Staten Island, New York and New Jersey, in response to an oil release caused by Hurricane Sandy (photograph courtesy of John Minchillo, Associated Press). Significant coastal flooding in major metropolitan areas can release contaminants to the environment. The lower photograph shows cars and debris in a flooded low area in New York City. (Photograph courtesy of European Pressphoto Agency)

Impacts on the storm surge had devastating impacts on coastal communities potentially releasing contaminants from structures and vehicles. Photographs *A* and *B* (before and after Hurricane Sandy) show damage to a marina in Normandy Beach, New Jersey. Photographs *C* and *D* (before and after Hurricane Sandy) show destruction of coastal structures at Lavallette, New Jersey.

as endocrine disruption, cancers, and immune suppression. Tissue analyses of targeted species also will be conducted to assess exposures and impact within the food web. The USGS will characterize contaminant cycling from source to mobilization to exposure pathways to biological uptake and effects. Modeling analyses will be employed to assess the long-term implications of contamination (such as determining if natural processes will mitigate contamination), and the overall impact on the affected ecosystems. Activities are being coordinated with local and state environmental agencies, USEPA, NOAA, and the NPS.

Human contaminant exposures: Characterize persisting risk of human exposure to storm-released chemical and microbial contaminants in the built environment.—The USGS will address human health risks that persist long after the storm. Studies will encompass a broad range of contaminant types that may persist in the environment into the future as normal human activities resume, and the associated potential chronic and sublethal effects. Studies will focus on characterizing human contaminant exposure pathways and the associated environmental media, such as residual sediments and dusts in the built environment, recreational waters, beach sediments, drinking water, and consumption of affected fish or shellfish. Potentially hazardous contaminants released from debris from the built environment and from sediments eroded and re-deposited by the surge; chemical and microbial contamination released or mobilized due to spills, storm surge, cleanup activities, and wastewater releases; or other Sandy-related impacts will be characterized. Remote sensing technologies will be used to identify and target contamination sites with high risk of human exposure. Processes that affect contaminant release (such as leaching from debris), transport and persistence (such as contaminant transformation by oxidation, volatilization, photo-oxidation, and biodegradation), biological uptake, and chemical fingerprinting to identify specific contamination sources will determine the need for mitigation actions. Activities are being coordinated with health agencies, including USEPA, National Institute of Environmental Health Science (NIEHS), and the Centers for Disease Control and Prevention (CDC).

Theme 5: Impacts to Coastal Ecosystems, Habitats, and Fish and Wildlife

The DOI is responsible for management of lands and species affected by Hurricane Sandy. These include approximately 30 National Wildlife Refuges and 6 National Parks and Seashores that provide critical habitat for migratory waterfowl and federally listed species; and coastal barriers that protect wetlands and coastal communities, and provide recreational opportunities for millions of visitors, including those from nearby major urban and metropolitan areas in the Boston to Washington D.C. corridor. These habitats support social systems, economic and food security, environmental stability, and other ecosystem services.

As the DOI science agency it is essential that the USGS provide science to support assessment, response, recovery, and increased resiliency of these natural resources. Coastal managers of DOI lands have trust responsibilities under the Federal Endangered Species Act and the Migratory Bird Treaty Act, as well as additional cooperative responsibilities with State and local authorities responsible for the protection of native, commercial, and recreationally harvested fish and wildlife species. Decision makers need to understand the long-term consequences of hurricane effects on wildlife and their habitats in order to effectively develop and implement conservation strategies. How animal species fared along the coast during Hurricane Sandy, and how their food supplies, habitats, and reproductive success may have been impacted, are all questions of importance. The information produced from post-hurricane studies conducted by the USGS and partners will provide essential baseline and long-term support for coastal zone planning, conservation planning, resource management, hazard reduction, and risk mitigation in the wake of natural disasters such as Hurricane Sandy.

Stakeholder Science Needs

Managers and stakeholders need an integrated assessment of the multiple stressors imposed by Hurricane Sandy on the condition of coastal ecological resources including the impacts on habitat, vegetation, fish, and wildlife resources. The biota was exposed to both physical (ocean surge, tide, wind, sediment) and chemical (salinity extremes, pollutants) stressors. Resource health and survival will depend on the nature, magnitude, and duration of exposure to these stressors.

Understanding where and why Hurricane Sandy has caused changes is critical information for managers seeking to efficiently and effectively protect and restore important coastal wetland and forest habitats, and protect trust species, particularly waterfowl and migratory birds. USGS scientists currently are conducting plant and animal studies in these environments and characterizing the processes that impact them to inform habitat restoration and future management. It is highly important to begin these assessments as soon as possible. Given the likely physical and chemical damage to wetland environments, especially near New Jersey and New York, the spring growing season of 2013 may well be in jeopardy, with potential consequences for coastal vulnerability if wetlands are not rejuvenating healthy root systems.

USGS Contributions

Assess storm impact to wetland integrity and stability to assist recovery decisions.—The USGS will document changes to mid-Atlantic and northeastern United States coastal wetlands using data from the Surface Elevation Table (SET) network currently maintained by USGS and public and private partners (fig. 13). Imagery, data from SETs, and marsh sediment cores will be collected to assess post-storm coastal marsh conditions. Trends in coastal lands and vegetation will be linked to the processes that contribute to system resilience or deterioration (loss of function). The Submergence Vulnerability Index will be used to assess wetland vulnerability to future sea-level rise and storm events. Field and remote mapping will be used to detect changes in structure and function of wetland marshes and submerged aquatic vegetation, and onset of latent wetland changes, such as marsh dieback. Multidecadal changes to the mid-Atlantic and northeastern United States coastline will be documented. An analysis of wetland processes (such as response to increased salinity) will be used to produce improved wetland vulnerability assessments.

Assess storm impact to waterfowl and migratory birds to support conservation.—The USGS will document the impacts of Hurricane Sandy on coastal birds using historic and current data from the USGS, FWS, and others. Pre-storm and current bird population numbers will be defined; study sites will be established on public lands to define declining populations of secretive marsh and shore birds; radar (NEXRAD) and other field data (including satellite telemetry data) on migratory bird flight patterns pre- and post-storm will be gathered; changes in migratory stop-over habitats will be assessed; habitats, food sources, reproductive capacities, and phenology will be assessed; seasonal mean bird density will be calculated to establish a baseline of bird distributions; and wetland conditions and food supply for bird migration and breeding will be documented. Statistical analyses of stopover patterns, trends in bird distribution patterns using NEXRAD, and predictive models of the impact of major meteorological events on coastal bird migration will be provided.

Assess coast-wide storm impacts to forest habitats in National Parks and National Wildlife Refuges.—The USGS will delineate and classify coastal forest types and injury (based on forest condition, salt burn and mortality, species composition, woody debris and wrack deposits, flooding extent, and residual soil salinity) across the entire United States Atlantic seaboard for the more than 30 DOI National Parks and National Wildlife Refuges. Line transect surveys will capture degree and expression of windfall and surge damage on coastal maritime and tidal freshwater forests of the most impacted DOI assets. A coast-wide map product will delineate the various forest types and conditions of coastal forest affected by tides and storm surges and will be used for predicting forest recovery and for assessing and prioritizing alternatives for forest restoration. Forest resource vulnerability models that integrate climate change projections of increasing storm intensities and sea-level rise will be developed. Damage probability functions for select tree species will be developed and used to identify species tolerant to wind and salinity extremes.

Figure 13. A U.S. Geological Survey scientist taking a reading at a Rod Surface Elevation Table (RSET) and establishing adjacent marker horizons (Don Cahoon, U.S. Geological Survey). The RSET is located in a salt marsh in Jamaica Bay, New York.

Develop data-driven models and ecological monitoring networks to support recovery and resilience.—The USGS will develop models of storm impacts to vegetation and coastal morphology and forecast how alterations in barrier configuration and processes impact the location and health of wetlands (marshes and forests), submerged habitats, and ecosystem services. Models of impacts on vegetation composition, distribution, productivity, and landscape fragmentation will be developed. The USGS will provide data standards, visualization and analysis tools, and decision support tools to aid scientific research and resource management in the Hurricane Sandy impact region by building on existing networks such as the Landscape Conservation Cooperatives (LCCs) and the Chesapeake Bay Program. The USGS will develop a plan with DOI stakeholders to locate and integrate new Surface Elevation Table installations to provide an improved strategic sampling network for assessing wetland resilience. Forecasting the impacts of future hurricanes/storms will include: trend analysis of historical data of northeastern United States hurricanes/storms (intensity, frequency, and duration); numerical simulations of storm surge, salt water intrusion, sediment deposition, and erosion caused by future hurricanes/storms; and forecasts of the potential impacts of future storms on vegetation and morphology for coastal protection planning for effective restoration.

Stakeholder Coordination and Communication

Communication with partners and stakeholders regarding science needs is essential for successful implementation of this plan. The USGS is widely acknowledged as a source of high-quality, objective, and unbiased scientific information; however, the best science has limited utility unless it is effectively disseminated and used to inform the highest priority decisions. A major emphasis in the implementation of this plan, therefore, will be on interacting with Federal Agencies; State, Tribal and local governments; and non-governmental organizations to better understand their specific data and information needs, to define the best way to make USGS products available, and to support applications of USGS science and expertise to decisionmaking.

The USGS has coordinated with numerous other Federal agencies since before Hurricane Sandy, including FEMA, NOAA, USACE, NPS, FWS, Bureau of Ocean Energy Management (BOEM), USEPA, NIEHS, and CDC. Coordination efforts are building upon existing interagency relations, networks, and ongoing projects in all five of the USGS science themes in this plan. Existing interagency coordinating entities have been utilized by the USGS Sandy Science Team to identify priority science needs for inclusion in this plan. These entities include the National Science and Technology Council (NSTC) Subcommittee on Disaster Reduction (USGS co-chair), the Interagency Ocean and Coastal Mapping (IOCM) committee, the National Digital Elevation Program (NDEP), and the Stormtide Monitoring Workgroup (FEMA, NOAA, USACE, and USGS) of the Interagency Coordinating Committee on Hurricanes. The IOCM committee has met to develop coordinated plans for processing and delivery of merged topographic-bathymetric products. The NDEP coordinates collection of elevation data; members include USGS, FEMA, NOAA, DOI agencies, and other major players. The group has met multiple times since Hurricane Sandy and will continue to coordinate collection of elevation data. Furthermore, the USGS has representatives in both the New York and New Jersey Joint Field Offices (JFOs) and those representatives are currently meeting formally with States through the NDRF (National Disaster Response Framework) working with the DOI representative.

Much of this plan builds upon established stakeholder relationships and ongoing cooperative projects with State and local stakeholders. Examples include: (1) the New York and New Jersey Tidal Telemetry Networks, which is managed by the USGS and provides valuable real-time and historical information directly to local emergency managers and the public (such as when emergency evacuation routes are inundated); (2) studies of coastal processes and barrier island evolution in Great South Bay, New York; (3) studies of circulation, salinity, and toxic contaminants in Barnegat Bay, New Jersey (fig. 14); (4) studies of wetland evolution and sedimentation in coastal wetlands through the SET Program with NPS, FWS, The Nature Conservancy, and others; and (5) existing collaborative development of sea-level rise vulnerability tools with NPS, FWS, the LCCs, and Climate Science Centers (CSCs). The USGS is involved in many LCC activities and has integrated those activities and relationships into this plan.

The USGS and NOAA are the designated lead agencies (Office of Management and Budget, 2010) for topographic (USGS) and bathymetric (NOAA) elevation data. These activities are being coordinated with other Federal agencies collecting and managing elevation data through the National Digital Elevation Program steering committee and the NSTC Interagency Working Group on Ocean and Coastal Mapping

A U.S. Geological Survey scientist obtaining water-surface elevation data relative to a known reference elevation and deploying a stormtide sensor at SSS-CT-NLD-025 Poquonock River at Avery Point, Connecticut, October 27, 2012 (photograph by Jonathan Morrison, U.S. Geological Survey).

(IWG-OCM). A multi-agency (FWS, NPS, NOAA, USACE, States and others) coordination activity has been initiated to refine post-Sandy data collection priorities. As co-chair of the NSTC IWG-OCM, the USGS will ensure additional data collection and development of data processing and delivery capabilities is coordinated across agencies and reflects DOI interests. The USGS will continue to engage DOI bureaus, the NDRF response teams, and State agencies to refine specific project priorities during implementation.

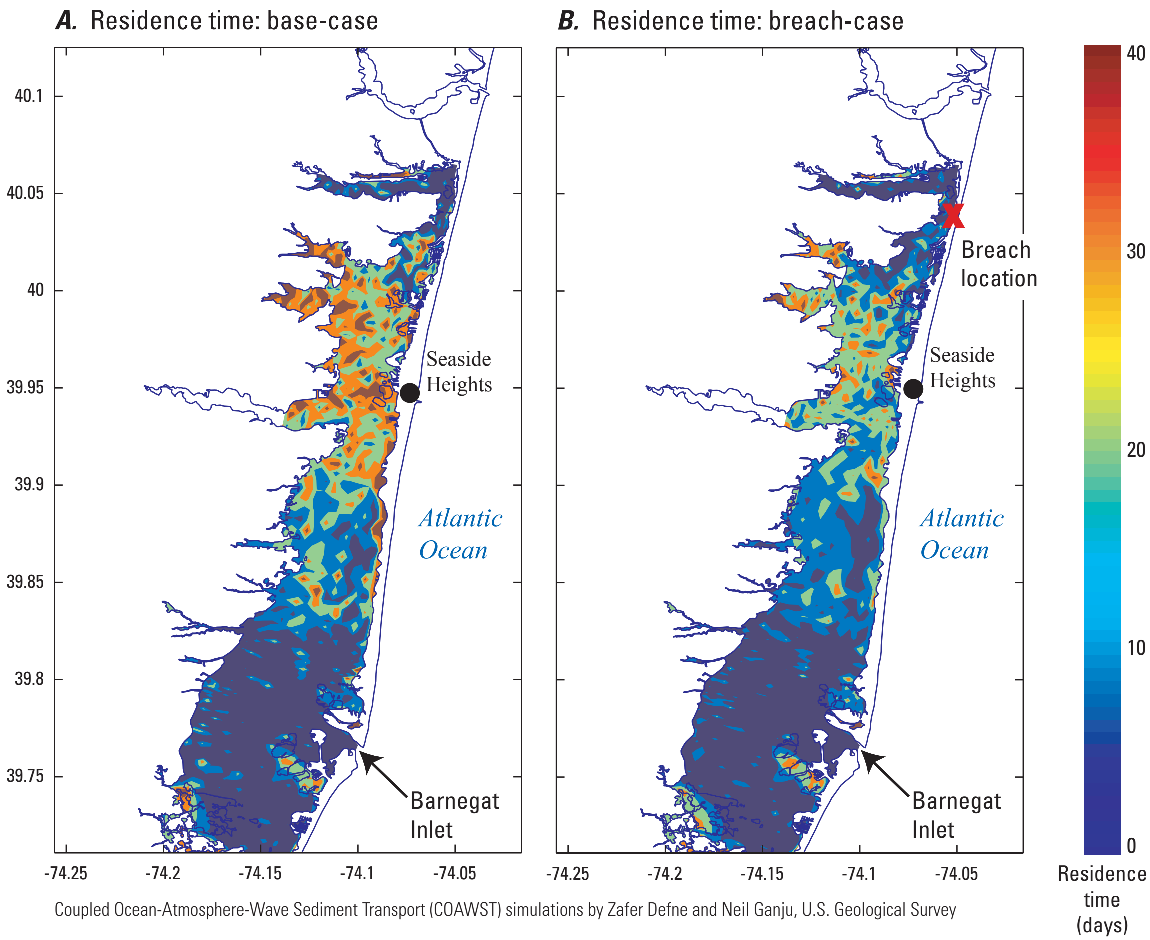
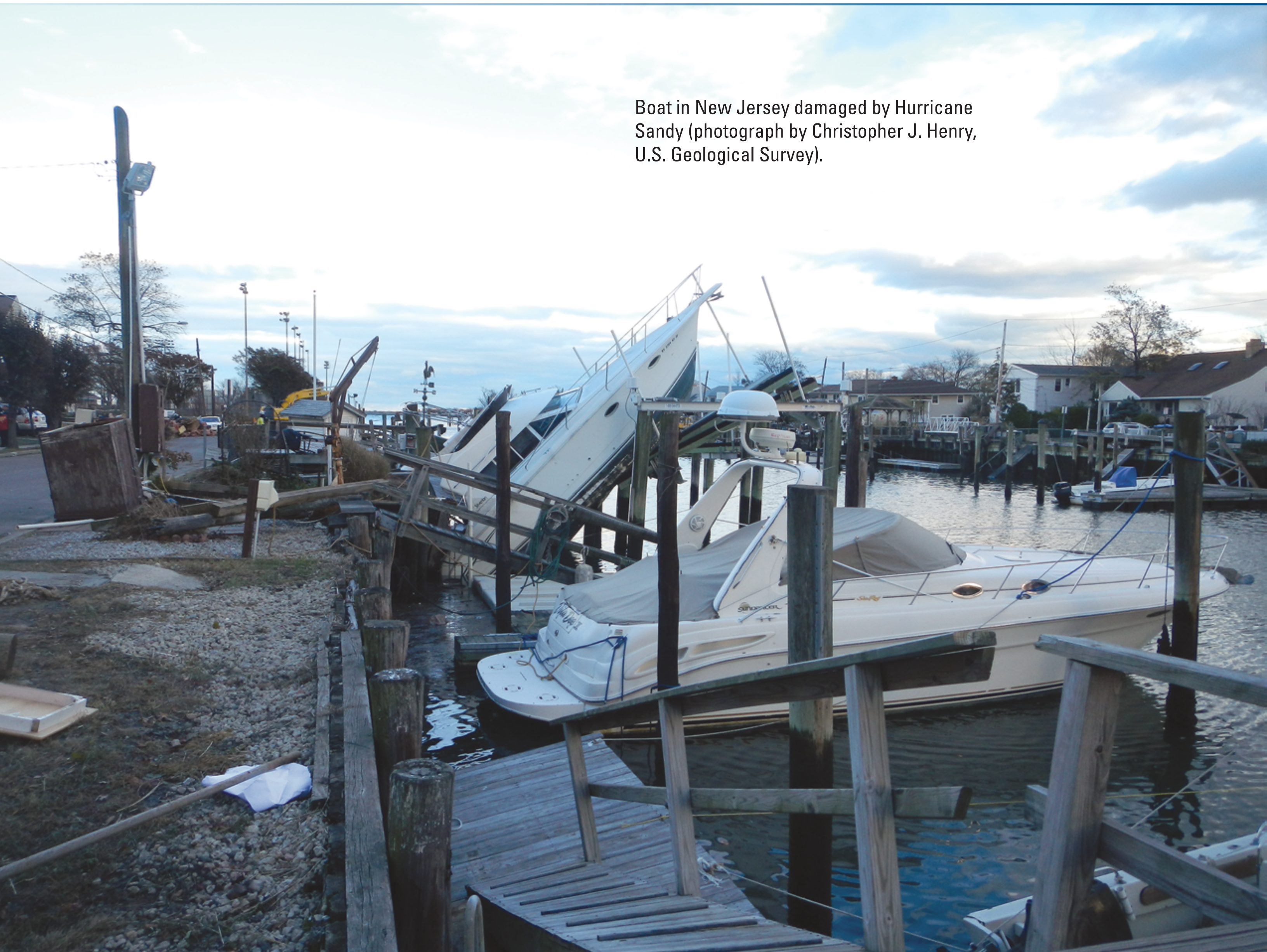


Figure 14. An existing U.S. Geological Survey (USGS) model of flow and water quality in Barnegat Bay, New Jersey, was used to predict the impact of inlet formation during Hurricane Sandy on residence time of water within the bay; *A*, pre-inlet formation; and *B*, post-inlet formation (Defne and Ganju, 2012). As a member of the Barnegat Bay Partnership, the USGS is conducting an investigation of bay circulation, water quality, and sediment quality and toxicity. The project supports Governor Christie's Barnegat Bay 10-Point Action Plan (*http://www.state.nj.us/dep/barnegatbay/*). USGS will use existing data from this study to evaluate how Hurricane Sandy impacted the Bay.

Information Management and Accessibility

USGS Hurricane Sandy data and science products will be documented, easily accessible, and managed for long-term retention. An integrated data and information delivery system will be developed that provides "one-stop" accessibility to all USGS information relevant to recovery and restoration from Hurricane Sandy and resiliency and preparedness to future storms. All data and information products from this plan will be accessible through the Internet (U.S. Geological Survey, 2013b), the appropriate technical contacts will be identified to enable effective technical support for the use of those data, and to gather information on additional data and information needs and how our information can be more effectively provided. Users of USGS information will be consulted to ensure the ease of access and usability of the delivery system. Examples of these data and information include analytical model outputs, physical samples and analyses, time series data (such as storm-surge elevation data), geo-located site data (such as locations and elevations of high-water marks), and other event-specific data.

USGS science centers and other offices will provide for the effective management and distribution of these event datasets. Some data are collected to specifications already in place and managed as enterprise (Nationally managed) datasets. Elevation data (raw and processed, elevation models), imagery (large aerial flights), and stream-flow data are examples of USGS Nationally managed datasets. These datasets will be integrated and archived in USGS national data systems. The USGS Community for Data Integration is actively working to build a long-term strategy for addressing the complex data integration challenges for scientific data.



Boat in New Jersey damaged by Hurricane Sandy (photograph by Christopher J. Henry, U.S. Geological Survey).

U.S. Geological Survey scientists surveying high-water marks on Ellis Island (left) and Liberty Island (right), New York (photographs by Amy Simonson (left), and Michael Noll (right), U.S. Geological Survey).

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