Coastal Resilience Long Island:
Adapting Natural and Human Communities to Sea Level Rise and Coastal Hazards

A Case Study from The Nature Conservancy, February 2010

Project Overview

Despite a growing awareness of sea level rise and coastal storm risks, communities and local decision makers still have limited access to the full suite of information needed to protect natural and human coastal communities from these conditions. Options do exist for addressing losses and protecting communities by proactively managing coastal natural resources, but these options depend on coastal managers having better access to critical information.

Human communities are at further risk as we lose natural buffers, including coastal wetlands and dunes. Coastlines have always been dynamic, and with the increase in storm intensity exacerbated by sea level rise, they are at a greater risk than ever. Wetlands and other coastal ecosystems that provide habitat, natural buffers to storms, and other services are threatened.

A growing body of evidence suggests that ecosystem-based adaptation can be a cost-effective strategy for all management sectors. Prominent insurers and investors are incorporating and advocating risk reduction using the protective value of ecosystems and other natural infrastructure, such as coastal wetlands, barrier islands, trees, mangroves, and other vegetation, as part of development appraisals.

Coastal resilience is the ability of coastal communities to respond to and recover from stressors. The Coastal Resilience Long Island project (see *www.coastalresilience.org*) explores flooding scenarios resulting from sea level rise and storm surge for the south shore of Long Island, New

York, to help stakeholders understand and incorporate responses to these stressors in their decision-making. The Long Island coastline has both highly developed lands and valuable marine resources in the coastal zone, and the costs of coastal hazards are increasing as investments in coastal development swell. Much of Long Island's private property is only inches above sea level, placing millions of dollars in public and private funds at risk.

The project's interactive Web mapping application, the Future Scenarios Mapper, helps users visualize flooding given a range of sea level rise and storm scenarios, presenting these in a user-friendly framework that can inform decision-making. This tool demonstrates that mutually beneficial solutions for human and natural communities can be created by combining hazard mitigation and biodiversity conservation in coastal zones.

The Future Scenarios Mapper allows users to examine current ecological, biological, socioeconomic, and management information alongside inundation scenarios from sea level rise and storms, developed from widely accepted climate and hazard models. This helps the user visualize and better understand vulnerabilities, and when combined with the project website's information on context and policy, helps communities take action to achieve both ecological and socioeconomic objectives.

Background

Long Island, New York, is an excellent place to demonstrate multi-objective, ecosystem-based management (EBM) approaches and tools for decision-making. The New York state legislature has recently created the Oceans and Great Lakes Ecosystem Conservation Council, whose charge is to use EBM on the ground and in the water. The Long Island Chapter of the Nature Conservancy (TNC) is already working with the council, town officials, the New York State Departments of State and Environmental Conservation, and a wide range of stakeholders to apply EBM concepts to Long Island's Great South Bay.

The coastal resilience framework incorporates information on biodiversity and coastal hazards to assist coastal managers in visualizing and managing for climate change. From the beginning, the project was guided by the following primary objectives:

- Building a spatial database and interactive map server that provides decision support for meeting both biodiversity and hazard mitigation objectives;
- Conducting workshops with local (town councils and boards) and state (New York Department of State and the New York Ocean and Great Lakes Ecosystem Conservation Council) officials on the utility of the database and interactive decision support;
- Constructing a website (*www.coastalresilience.org*) that explains the approach, methods, and strategies for ecosystem-based adaptation to climate change; and
- Identifying reasonable and viable alternatives that reduce losses and vulnerability of coastal communities for people and ecosystems.

Partners
TNC believes strongly in the efficacy of partnerships and collaborative projects that meet the needs of those involved and have an influential effect on others. Project partners included the following:

- The Center for Climate Systems Research (CCSR) at Columbia University and NASA Goddard Institute for Space Studies
- The National Oceanic and Atmospheric Administration's Coastal Services Center
- The Association of State Floodplain Managers (ASFPM)
- The University of Southern Mississippi (USM) and their Department of Geography and Geology
- The Marine Science Institute of the University of California Santa Barbara (UCSB)
- The Pace Land Use Law Center

This project assembled an interdisciplinary team that included seasoned practitioners in government and conservation, tool developers and trainers, and distinguished scientists. The team's specific skills included the following:

- Coastal inundation mapping, including the use of Global Climate Models (GCMs) and the Sea, Lake and Overland Surges from Hurricanes (SLOSH) model
- Geographic information system (GIS) applications in elevation mapping, socioeconomics (e.g., utilizing U.S. Census information), and ecology (e.g., salt marsh distribution and their relationship to future inundation scenarios)
- Web mapping services and database management
- Community vulnerability and risk assessments
- Local and state law and policy
- Conservation strategies

With this interdisciplinary team, the project was able to consider both ecological and socioeconomic objectives and represent them spatially in the Future Scenarios Mapper.

Technical Specifications for Developing the Web Mapping Service

Operating System: Windows Server 2003 R2 Enterprise x64 Edition

Hardware Specifications:

Virtual Machine residing on a Dell 2950III running Xen Server

RAM: 22GB allocated

CPU: 7 processing cores @ Intel Xeon E5440 2.83Ghz

Running on 300GB 15k SAS Drives, extremely low latency drives.

Connected over CalRen Fibre @ 10 Gb/s

Software Specifications:

ArcGIS Server 9.3 for consuming spatial data and creating the mapping services

JavaScript OpenLayers 2.8 is the Web development Graphic User Interface (GUI)

The Process

The Coastal Resilience project was conducted over an 18-month period from January 2008 to July 2009, bringing together local and state managers and planners on Long Island in three workshops to vet the information and discuss how online spatial information could facilitate better decision-making. The Future Scenarios Mapper provided the basis for discussing how ecological and socioeconomic objectives could be considered together to discover appropriate actions in the face of climate change. **The ultimate aim of the project was, and is, to provide communities with easy access to information for their planning, zoning, acquisition, and permitting decisions.**

Developing the Future Scenarios Mapper

Spatial data are a core component to this project, allowing visualization, exploration, and analysis of multi-layered issues influencing coastal resilience. The data layers included in the Future Scenarios Mapper allow users to consider ecological factors (e.g., marsh elevation, submerged aquatic vegetation) and socioeconomic factors (e.g., land use cover, population density) under current and potential future water level conditions.

Scale

Stressors occur at multiple scales, and the goal for this project was to demonstrate potential solutions for ecosystem-based adaptation targeted at local and state planning scales. There were challenges associated with matching the scales of available information to the south shore of Suffolk County and in presenting and illustrating geospatial interactions of multiple management objectives. Further, the project team had to carefully consider how global climate considerations applied to local human and natural communities.

The team was able to acquire, process, and analyze a wide variety of geospatial data for the project. Information used to develop the data layers was culled from a variety of existing sources. Projected inundation scenarios were developed by personnel at the Goddard Institute of Space Studies as well as NOAA's Coastal Services Center. The data listed below were used to represent future coastal hazard scenarios or identify spatially explicit social-ecological interactions. For detailed information on how the team acquired, assessed, and mapped the data to create the future inundation scenarios, see section two – " Coastal Inundation Mapping Methods."

Mapping Coastal Inundation

The elevation data used for mapping were a lidar-based digital elevation model (DEM) provided by Suffolk County Information Services. These data were used to map sea level rise and storm surge. Note that lidar is process-intense and requires significant amounts of computer space!

Sea Level Rise (SLR) – One of the principal components of the Coastal Resilience Future Scenarios Mapper is the forecasting of inundation on the south shore of Long Island under different SLR projections. These projections were developed from the best available scientific information about greenhouse gas emissions and sea level rise by faculty members from the Columbia University Center for Climate Systems Research (CCSR). Projections are included as

options in the mapping tool, labeled as “conservative,” “medium,” and “high” sea level rise scenarios.

Flooding and Storm Surge – The “bathtub” method of mapping water surfaces on a digital elevation model (DEM) was used for this project. This method simply “raises the water surface,” filling in land elevations as seas rise. A major drawback of this method is that it does not take into account or model the hydraulics of SLR. Though very basic, in the absence of a more sophisticated modeled SLR surface, this method can be performed quickly and efficiently for many SLR scenarios. Compounding sea level rise, global climate change will likely lead to more frequent and intense flooding of coastal areas. This includes both high-recurrence interval flooding (i.e., “basement flooding” or semi-annual flooding) and storm-induced flooding (i.e., northeasters or hurricanes).

See section two – “Coastal Inundation Mapping Methods” for detailed information about the scientific justification and project decisions and steps for mapping water-level projections, and for detailed descriptions of the high-recurrence and storm-flooding projections developed for the project and included in the Future Scenarios Mapper.

Assessing Ecological Resources

The project team selected specific species, habitat types, and ecological communities that are either representative of the ecosystem, highly sensitive to human disturbance, considered to be of ecological concern, or afforded some level of protection. The most prevalent ecological indicators used in the Coastal Resilience project are briefly described below.

Tidal Marshes – Among the most productive ecosystems on Earth, tidal wetlands and marshes perform many functions that are highly valued by society, called “ecosystem services.” Wetlands support the health of the coastal ecosystem and the recreational and economic activities that depend on it.

Piping Plovers – Many species depend on the dynamic nature of barrier island beaches, including beach-nesting species such as the piping plover. The Atlantic coast piping plover population is designated as threatened under the federal Endangered Species Act, is considered endangered under New York State Environmental Conservation Law, and receives protected status under the Migratory Bird Treaty Act, as well as in several local ordinances.

Barrier Islands – The barrier islands that fringe Long Island’s south shore provide protection from storms and storm surge for the human communities along the mainland coast, but they also serve as unique habitats for many species. Fire Island provides critical habitat for several rare and endangered species, and serves as a migratory corridor for birds, sea turtles, and marine mammals.

Conducting Ecological Analyses

The objective of this phase of work, focusing on the tidal marsh complexes along the southern shores of Long Island, was to examine relationships between marshes and adjacent lands that

either limit or offer space for the potential landward migration of marshes as sea levels rise. In addition, the project team wanted to explore potential storm buffering functions that marshes could provide and therefore calculate their potential to protect coastal communities.

The team conducted three analyses for tidal marshes:

Potential migration impediments – Because wetlands require adjacent space to migrate into, the relationship between marsh distribution and impediments such as roads, land slope, and shoreline hardening was mapped.

Population protection potential – This is an index of a marsh's potential ability to act as a buffer against flooding and other storm impacts, taking into account marsh size and adjacent human population density.

Potential viability – This index is based on marsh size, marsh elevation, and potential migration impediments. These results were displayed as "lower" to "higher" potential viability.

Marsh Loss

Outcomes of coastal inundation mapping can be used to display the effects of inundation on marsh loss. To create scenarios depicting the ability of tidal marshes to migrate vertically and horizontally, SLR projections and high-recurrence flooding rates can be used. Ideally these scenarios are used in conjunction with calculations of sediment accretion and landward migration rates to determine potential marsh loss. There are several issues limiting the analysis in this project to a general estimation, such as the difficulty in determining the low water line from lidar data and the accuracy and date of the marsh data.

More detail on these layers and their application in the spatial analysis undertaken are found in section three – "Ecological and Socioeconomic Assessment Methods."

Assessing Socioeconomic Resources

Long Island's shores have some of the most highly developed lands in the coastal zone. Much of this private property is only inches above sea level, which puts millions of dollars in public and private funds at great risk. Even moderate sea level rise will result in a significant increase in the likelihood of flooding. More significant rise—or the occurrence of a catastrophic storm—would be devastatingly expensive and potentially put many people in harm's way.

Human Populations – Accurate portrayal of human population distributions within coastal zones provide critical baseline information for assessing risk. The project team used population data from the U.S. Census Bureau (2000) to depict these distributions and to create various compilation indices.

Infrastructure – A shoreline analysis was conducted to map shoreline hardening. Ortho-rectified aerial photos were used to identify shoreline structures, with oblique images used to further validate a structure's presence. The NOAA Coastal Change Analysis Program (C-CAP), providing

nationally standardized land cover and land change information for the coastal regions of the U.S., was used to identify four classes representing infrastructure: high, medium, and low-density development, and agriculture.

Response – The vicinity and location of critical facilities, including emergency operation centers, fire and police services, and medical facilities, are extremely important to know in the event of hurricanes, storms, and other coastal hazards. These facilities provide crucial services to communities and are important resources before, during, and after natural disasters. The project used data from the National Institute of Building Sciences (2001).

Conducting Socioeconomic Analyses

The goal of the socioeconomic analyses was to determine the consequences of SLR and storm surge hazards for human populations, allowing managers to explore opportunities to minimize these consequences. The project team chose variables that best represent the socioeconomic vulnerability of Suffolk County, and data, obtained from the U.S. Census Bureau, were processed to create indices, listed below, that identify populations and housing resources that may be vulnerable to storm surge and SLR.

Critical Infrastructure and Facilities Index – This index ranks census block groups based on the amount of critical infrastructure and facilities located within each. Extensive infrastructure increases a block group's vulnerability as communities within and adjacent to it are likely highly dependent on the services it provides.

Social Vulnerability Index – The index focuses on population and housing characteristics that traditionally indicate socioeconomic vulnerability. These variables were mapped at the census block group scale, the smallest geographical unit for which the census provides detailed demographic data.

Overall Community Vulnerability Index – This index is a combination of the Social Vulnerability and Critical Facilities and Infrastructure indices to represent the combined vulnerability to flooding of the people, property, and resources in a community. The index is mapped by census block groups in four categories, from most to least vulnerable.

Estimated Commercial and Residential Economic Exposure – These parameters represent the full replacement value of commercial and residential structures. This data set is the result of geographic analysis and display using HAZUS-MH, a tool developed by the Federal Emergency Management Agency (FEMA). HAZUS-MH uses geographic information system software to estimate potential economic losses from earthquakes, hurricane winds, and floods.

Economic Loss

Sea level rise (SLR), storms, and scenarios that combined their effects on economic exposure were selected to examine economic losses from flooding of infrastructure, including housing, transportation, and commercial structures. For this project, projections of economic loss were

constructed using HAZUS-MH to estimate potential building and infrastructure losses from flooding events. HAZUS is capable of estimating flood losses for buildings, infrastructure, and the population exposed to the flood hazard. Potential economic losses can be visualized by either U.S. block groups or summarized across towns and villages along the southern shores of Long Island.

For a detailed discussion of the ecological and socioeconomic analyses, see section three – "Ecological and Socioeconomic Assessment Methods."

Determining Policy

Although an increasing number of states and local governments are beginning to consider the effects of climate change, only a small number have specifically addressed SLR and its impacts. Staff members at the Pace University School of Law's Land Use Law Center conducted an analysis of selected local land use ordinances and regulations that include specific mention of SLR or that incorporate appropriate policy responses that may be used to address SLR.

The Pace report outlines the national framework for local responses to SLR, followed by the state framework and then the local planning and regulatory responses. Land use planners and other practitioners can look to the examples detailed in the report for guidance in developing their own regulations and planning approaches.

The report is a starting point for discussion of more comprehensive and effective local responses. It demonstrates how some local governments are trying to implement policies and regulations that fit the very specific and very individual needs of their communities. New York, even without a formal state policy on SLR, has—in its land use law and in its coastal statutes and regulations—given local governments extensive authority to enact laws and policies similar to those drawn from throughout the country.

The Pace report reviews a range of strategies employed by local governments to address and plan for SLR, including the following:

- Executive orders
- Regional plans
- Comprehensive plans
- Shoreline management plans and local waterfront revitalization plans
- Post-storm redevelopment planning
- Land use regulations and best management practices

The report concludes with local planning and regulatory strategies for New York municipalities that draw on the methods employed by local governments outside of New York. This section presents a five-phased approach: the development of policies for local government to adopt, discussion of studies and citizen participation, discussion of building moratoria and planning,

and consideration of regulations and inter-municipal cooperation. Specific recommendations in this approach include the following

- Amending key laws
- Planning for and implementing smarter, safer post-storm redevelopment
- Acquiring land in harm's way
- Restoring habitats that provide protection
- Moving vulnerable public structures

For more information, visit the next sections on **Coastal Inundation Mapping Methods** and **Ecological and Socioeconomic Assessment Methods**, or contact:

Sarah Newkirk
The Nature Conservancy on Long Island
(631) 367-3225
coastalresilience@tnc.org
www.coastalresilience.org

Coastal Inundation Mapping Methods

Obtain and Prepare Elevation Data

The elevation data used for sea level rise and storm surge mapping were a lidar-based digital elevation model (DEM) provided by Suffolk County Information Services. The DEM was classified to bare earth, had a horizontal resolution of 5 feet (152.4 centimeters), a vertical accuracy of 0.42 feet (12.8 centimeters), and was based on the North American Vertical Datum of 1988 (NAVD88).

Prepare Water Levels

1. **Projecting Future Water Levels**
    a. *Sea Level Rise (SLR)* – One of the principal components of the Coastal Resilience Future Scenarios Mapper is the forecasting of inundation on the south shore of Long Island under different sea level rise (SLR) projections. These projections were developed from the best available scientific information about greenhouse gas emissions and sea level rise by faculty members from the Columbia University Center for Climate Systems Research (CCSR), which is affiliated with The National Aeronautics and Space Administration (NASA) Goddard Institute for Space Studies. Project personnel examined the range of Global Climate Models (GCMs) reviewed by the International Panel on Climate Change (IPCC) and chose seven of them to use in forecasting SLR.

    The GCM data are archived on the Program for Climate Model Diagnosis and Intercomparison (PCMDI) website (*www-pcmdi.llnl.gov*), which serves as a depository for IPCC data. Project team members reviewed the data sets archived on the PCMDI website and chose seven models, all of which have the correct, complete information to use in SLR forecasting. The seven models chosen are from the following scientific centers:

    - Goddard Institute for Space Studies, New York, NY – (GISS)
    - NOAA Geophysical Fluid Dynamics Laboratory, Princeton, NJ – (GFDL)
    - United Kingdom Meteorological Office, UK – (UKMO)
    - National Center for Atmospheric Research, Boulder, CO – (NCAR)
    - Meteorological Institute of the Rheinische Friedrich-Wilhelms Universität, Bonn, Germany – (MIUB)
    - Meteorological Research Institute, Japan – (MRI)
    - National Frontier Research Center for Global Change, Japan The Model for Interdisciplinary Research on Climate − (MIROC)

    Calculations were then performed on the GCM data to downscale the models to include local variables such as historical information from tide gauges at Battery

and Montauk stations, land subsidence, local differences in mean ocean density, circulation changes, thermal expansion of sea water, and global variables including components for thermal expansion of the oceans caused by global temperature increases and changes in the ice mass (including Greenland, Antarctica, and glaciers) from temperature increases.

Greenhouse gas emissions used in forecasting were chosen to represent a range of reasonable future emissions from the suite of IPCC scenarios (Special Report on Emissions Scenarios from 2000). For this project, the A1B, and A2 IPCC scenarios were considered for incorporation into the Future Scenarios Mapper. Each emissions scenario represents "a unique blend of demographic, social, economic, technological, and environmental assumptions." The A1B scenario assumes that the effects of economic growth are partially offset by the use of new technologies to address emissions and a decline in global population after 2050. The result is a relatively rapid increase in emissions for the first half of the 21st century, followed by a decrease in emissions after 2050. We considered this emission projection to be a "conservative" estimate. The A2 scenario assumes relatively rapid population growth and high and growing greenhouse gas emissions. We considered this to be a "medium" level estimate.

Many in the scientific community have expressed concerns that the IPCC data underestimate potential SLR. To address this concern, the Long Island projections made with these inputs were supplemented by a qualitatively determined, upper-bound scenario taking into account the low-probability, high-impact events associated with more rapid ice sheet melting in Greenland and the west Antarctic than is shown by the GCMs. This scenario uses current information about ice melting rates as well as paleoclimatological data that indicate that global sea level rose 394 feet starting around 20,000 years ago, reaching nearly present-day levels around 8,000-7,000 years ago. CCSR included ice sheet melting and determined an additional one and two meter rise on the A2 scenario over the next century. We considered the one meter rise to be the "high" level estimate.

Project staff members used all the above information to generate probability distributions of SLR for the individual and combined GCMs over seven decades, from the 2020s to the 2080s. Sea level rise projections using the GCMs have a 'model-based probability'. This represents what is the most likely outcome based upon projections across the seven models. It does not taken into account the possibility that all the GCM's could be wrong; instead it looks for consensus. For each decade CCSR and NASA produced GCM sea level rise projections (3 IPCC emission scenarios x 7 GCMs). Since the sea level rise projections vary from model to model, these scenarios are estimates, and therefore no specific model output should be considered a prediction of future conditions.

b. *Flooding and Storm Surge* – Compounding sea level rise, global climate change will likely lead to more frequent and intense flooding of coastal areas. This includes both high-recurrence interval flooding (i.e., "basement flooding" or semi-annual flooding) as well as storm-induced flooding (i.e., northeasters or hurricanes).

   i. *High Recurrence Flooding* – Historical tide data and the most current storm surge tidal hydrodynamic data were used to develop flood recurrence curves for 1-, 2-, 5-, 10-, 25-, and 40-year flood events for the study area. Tide data at the Battery and at Montauk gauges were used to estimate recurrence periods of high water and surges. Hourly historical water levels and predicted tides for the Battery, New York, were downloaded from NOAA's Tides and Currents website for the period 1959 through 2007. Only years with complete sets of hourly data were used. The Battery gauge has 40 years of complete daily records, and these were used to estimate storm surge probabilities up to 1 in 40.

      These flood recurrence curves would be similar to the surges at Fire Island (FI); surges in the Great South Bay (GSB) would be lower. The fall-off of surge can be estimated by taking Sea, Lake and Overland Surges from Hurricanes (SLOSH) storms for these frequencies. Using this approach, the surge in GSB would be about 40 percent of the surge at FI for the 10-year recurrence surge. For the 1-year recurrence interval, the fall-off would be somewhat less, because the stormwaters are more readily able to get through the inlets in a smaller storm, but 40 percent can be used as a first approximation. Northeasters do not have the same drop-off differential, since they come over longer periods of time than hurricanes.

   ii. *Storm Surge* – Work on this phase of the project relied heavily on predictions from the National Hurricane Center's SLOSH model, which "estimate[s] storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes by taking into account pressure, size, forward speed, track, and winds" (*www.nhc.noaa.gov/HAW2/english/surge/slosh.shtml*).

      The project mapped Maximum Envelopes of Water (MEOWs) from the SLOSH model. MEOWs portray what could happen when a specific storm makes landfall and are used to plan for specific types of storms. For any of the SLOSH model runs, the accuracy is quoted as being within 20 percent of the observed storm surges; no further explanation is given. Additionally SLOSH does not incorporate waves or precipitation and is generally considered to be at a coarse, regional scale. SLOSH represents maximum storm surge values obtained from a series of

parallel model runs over the life of the simulated hurricane. Thus, in effect, it is as if every location has taken a direct hit from the storm at the same time, which although not realistic, is useful in preparing for a worst-case scenario.

Although northeasters are widely considered the type of high impact storm to hit Long Island, the team did not model them (other than what is implicitly in the tide gauge observations). Northeasters tend to be less intense than hurricanes but affect areas for longer periods of time.

It is important to note that storm surge is an episodic event and does not typically cause permanent inundation, as does sea level rise.

2. Determining a Vertical Reference Level

a. *Sea Level Rise* – To meaningfully communicate SLR to local decision makers, the SLR values were mapped to the Mean High Water (MHW) tide line or vertical datum. Vertical datum conversions were necessary to map the correct MHW plus SLR values on the DEM, which was based on the NAVD88 vertical datum.

   Note: Although quite robust and detailed, because the lidar data set lacks bathymetric data that penetrate water, the team was unable to map current and short-term inundation scenarios to tides in the lower half of the tidal range (i.e., Mean Low Water). Ideally an integrated lidar data set with land and water elevations would be used for mapping current and future inundation scenarios across the full range of tide.

b. *Storm Surge* – The SLOSH model output was in the National Geodetic Vertical Datum of 1929 (NGVD29) and included tide estimates in the model, which meant the water levels only needed to be converted to NAVD88 in order to map them on the DEM.

3. Computing the Vertical Datum Shift

a. *Sea Level Rise* – To determine the conversion factor between the NAVD88 and MHW vertical datums for the project area, the Montauk, New York (eastern end), and Battery, New York (western end), tide gauge datum conversion webpages were accessed. These two pages list the difference between NAVD88 and MHW for each gauge. The two conversion values were averaged to derive a datum conversion value applicable to the entire DEM. The resulting conversion factor was 1.45 feet (0.94 feet at Montauk and 1.95 feet at Battery). Since NAVD88 is “lower” than MHW at the two gauges, 1.45 feet is added to a NAVD88 value to reference it in MHW, thus 0 feet MHW is equal to 1.45 feet NAVD88. When basing SLR projections on MHW, the tide line acts as the “zero.” For

example, MHW plus 1 foot of SLR results in mapping 2.45 feet on a NAVD88-based DEM

b. Storm Surge – Using the SLOSH model output, vertical datum conversions were done using Vertcon, a NOAA National Geodetic Survey conversion tool available at *www.ngs.noaa.gov/TOOLS/Vertcon/vertcon.html*. This tool converts between the NGVD29 and NAVD88 vertical datums.

Map and Visualize Inundation

1. **Sea Level Rise** – After converting vertical datums, the team mapped selected SLR and high-recurrence flooding projections onto the original elevation values of the DEM. The team calculated these as the original land elevation minus the SLR value. Negative values represented inundation.

   According to the way fields were calculated above, the zero is constantly moving "up" as SLR is subtracted from the DEM. This means that 0 feet can always be symbolized as the water's edge from one SLR projection to the next. However, the values in the data were NAVD88 and needed to be displayed and communicated as MHW. Therefore, the datum conversion value was applied during display and 1.45 feet was symbolized as the water's edge across all SLR projections.

   Three different decades (2020s, 2050s, and 2080s) are included as options in the mapping tool, labeled as "conservative," "medium," and "high" sea level rise scenarios that correspond respectively with A1B, A2, and A2 plus ice sheet melting IPCC scenarios described above.

2. **Flooding and Storm Surge** – To understand the spatial relationship between high-recurrence flooding and inundation caused by storms, the team mapped the 5-year surge flood in the Future Scenarios Mapper.

   The surge zone mapping process described in the Digital Coast Inundation Toolkit was performed on each of the SLOSH output layers. MEOW category 2 and 3 hurricanes, corresponding to storm surges with a 40- and 70-year return period, respectively, were chosen for the Future Scenarios Mapper and were combined with Goddard sea level rise projections. These two model outputs were exported from the SLOSH Display Program:

   - Category 2 MEOW, moving 40 mph North-Northeast with landfall at high tide
   - Category 3 MEOW, moving 60 mph North with landfall at mean tide (termed "catastrophic storm" in the Future Scenarios Mapper)

In addition, SLR values were incorporated into the storm surge inundation layers to visualize the combination of storm surge and SLR.

For more information, visit the **Project Overview**, or the next section on **Ecological and Socioeconomic Assessment Methods**, or contact:

Sarah Newkirk
The Nature Conservancy on Long Island
(631) 367-3225
coastalresilience@tnc.org
www.coastalresilience.org

Ecological and Socioeconomic Assessment Methods

The Nature Conservancy (TNC) developed a demonstration project to help stakeholders on Long Island understand likely sea level rise (SLR) and coastal storm impacts and risks, visualizing them to identify management options that diminish losses and increase the resilience of natural and human coastal communities. The following document describes the process for analyzing the viability and adaptability of ecological resources potentially impacted by sea level rise and coastal storm impacts. It also discusses completing socioeconomic analyses to determine the consequences of SLR and storm surge hazards for human populations, providing information that allows managers to explore opportunities to minimize these consequences.

Ecological Resources

The project team selected specific species, habitat types, and ecological communities of the Long Island coastal waters ecosystem that are either representative of the ecosystem, highly sensitive to human perturbation, considered to be a keystone or of ecological concern, or are afforded some level of protection. The most prevalent ecological indicators used in the Coastal Resilience project are briefly described below.

Tidal Marshes

Coastal wetlands protect coastal water quality by filtering land-derived nutrients and contaminants. They are an important component of the coastal food web, they provide valuable wildlife habitat, and they protect upland and shoreline areas from flooding and erosion associated with storms.

The tidal marsh data set we used came from a 1974 wetland inventory data set with a 1995 update for the Shinnecock Bay area (New York Department of Environmental Conservation). We mapped the distribution of marsh types in addition to calculating various metrics for understanding the potential for marshes to shift landward as sea levels rise. These include potential migration impediments, population protection potential, and potential viability, as described below.

Piping Plovers

The piping plover is a small North American shorebird which breeds on coastal beaches from Newfoundland to North Carolina, wintering along the Atlantic coast from North Carolina south along the Gulf coast and in the Caribbean. The Atlantic coast piping plover population is designated as threatened under the federal Endangered Species Act, and is considered endangered under New York State Environmental Conservation Law. Piping plovers also receive protected status under the Migratory Bird Treaty Act, as well as several local ordinances.

Plover breeding habitat data were created during the 2005 breeding season with Global Positioning System units (GPS) by Jennifer Seavey at the University of Massachusetts Landscape Ecology Lab. The delineation of the inland habitat boundary was based on the presence of dense vegetation, steeply eroded banks, or man-made structures. The ocean-side habitat edge,

identified by the high water line, was considered a one-day, within-breeding-season benchmark by which to measure relative habitat width in a dynamic system. Users can map relative habitat suitability for piping plovers in the Future Scenarios Mapper.

Barrier Islands

The barrier islands that fringe Long Island's south shore, particularly Fire Island, encompass vital coastal wetlands essential to water quality, fisheries, and the biological diversity of coastal, nearshore, and terrestrial environments. The health of the barrier island complex is fundamental to the health of the bay system overall. The natural processes of cross-island and longshore sediment movement, particularly the event-driven movements that occur during storm events, are responsible for the natural creation and modification of beaches, dunes, and flood tide deltas which ultimately become colonized by marsh plants and submerged rooted vascular plants.

A beach dune map layer was derived from a land cover classification created by Jennifer Seavey of the University of Massachusetts. These data were "heads-up" digitized from 2004 high-resolution orthoimagery provided by New York State's Office of Cyber Security and Critical Infrastructure Coordination (*www.nysgis.state.ny.us/gateway/mg/index.html*) and the U.S. Geological Survey's Seamless Data Distribution System (*http://seamless.usgs.gov*). These natural color imagines were taken in April, and have a horizontal resolution of 0.3 meters.

Ecological Analyses

These analyses focus on the tidal marsh complexes along the southern shores of Long Island. The team conducted three analyses for tidal marshes: potential migration impediments, population protection potential, and potential viability.

To grow horizontally, wetlands require adjacent space to migrate into. New York's tidal wetlands themselves are well protected by federal, state, and local law, but the areas next to many of these wetlands are already developed. Without additional protection of adjacent areas, property owners next to marshes might fortify their property as sea level rises to prevent inundation of their property. But this action closes off a migration pathway for the wetland, leaving it nowhere to go. Potential migration impediments were calculated based on marsh distribution New York State Department of Environmental Conservation (NYS DEC), shoreline hardening (from data collected by TNC Long Island), land slope (Suffolk County lidar), and roads (New York State Department of Transportation) to indicate whether existing marshes can migrate by mapping impediments within 50 feet of existing marsh. Impediments are defined as hardened shorelines, roads, or slopes greater than 15 degrees.

Population protection potential is an index of a marsh's potential ability to protect adjacent human communities, which takes into account marsh size and adjacent human population density. This index provides a general estimation of a marsh's potential to act as a buffer from flooding and other storm impacts. The NYS DEC marsh data set was used to determine the size of marshes. Adjacent population was determined by dasymetrically mapping U.S. Census Bureau block-scale population data using housing density values per parcel. The number of

people per 10-square-meter cell within 1 kilometer of marshes was summed and displayed as adjacent population. Marsh size and adjacent population layers were added with the result being arranged from “less” to “more” protection potential.

The mapping tool also allows users to map marsh potential viability, an index of marsh size, marsh elevation, and potential migration impediments. To more accurately estimate a marsh’s ability to migrate—and therefore more accurately reflect its potential viability—more detailed data on local marsh accretion rates and fine-scale local land cover are needed. For this index, the NYS DEC marsh inventory and Suffolk County lidar data sets were used to determine marsh size and elevation, respectively. A range of potential migration impediments was also incorporated into the index. Slope impediments were determined by extracting slopes greater than or equal to 100 and within 50 feet of existing marshes. Road impediments, taken from a New York State Department of Transportation database, were considered to be roads within 50 feet of existing marshes. Hardened shorelines within 50 feet of existing marshes were also considered to be impediments. The length of all impediments within 50 feet of marshes was summed, resulting in a total linear distance of potential marsh impediments. A potential migration impediments indicator was calculated by dividing the summed adjacent impediment distance by the total marsh perimeter, which resulted in the percentage of marsh perimeter potentially impeded. The data layers on marsh size, marsh elevation, and potential migration impediments were added together and results were displayed as “lower” to “higher” potential viability.

Marsh Loss

Outcomes of coastal inundation mapping can also be used to study their effects on ecological indicators. Depending on the frequency and intensity of the inundation, there are different time scales to consider. To examine tidal marshes and their ability to migrate vertically and horizontally, the SLR projections and high-recurrence flooding can be used. However, the project team was not able to apply sediment accretion and landward migration rates and did not use marsh migration models to determine loss. Therefore we relied on the assumption that present-day marshes below the Mean Low Water (MLW) tide line would be permanently inundated.

Determining the low water line from lidar data proved to be problematic, limiting the calculation of marsh loss. To accurately determine low water, high-resolution bathymetric lidar that penetrates the water’s surface is needed. Barring having these data, this calculation should be interpreted as a general estimation of potential marsh loss if the rate of SLR exceeds the rate of marsh migration and accretion.

A further limitation was the accuracy and date of the marsh data. This analysis used the 1974 NYS DEC marsh data set and the 1995 update for the Shinnecock Bay area described earlier. To more accurately estimate future marsh loss, more detailed data than are currently available would need to be employed, including local marsh accretion rates and fine-scale local land cover data. This analysis provides a general estimation and should not be used to identify which marshes are a “lost cause” and which ones will persist. To most accurately capture the viability

of marshes, a marsh-specific, "on the ground" analysis would need to be employed. This data set, however, remains the primary spatial data set upon which regulatory decisions are made in Suffolk County. Because of the historical nature of this data set, it likely contains inaccuracies as the spatial distribution of marshes in Suffolk County has undoubtedly changed over the past 30 years.

The team was able to calculate MLW under the 2080s, International Panel on Climate Change (IPCC) A2 sea level rise scenario with ice sheet melting because of the major shift in tide lines. For that decade the MLW mark has shifted significantly landward such that it can be accurately mapped. Therefore the 2080s high sea level rise scenario could be used to calculate marsh loss as a proof-of-concept for further analyses as more appropriate data become available.

Socioeconomic Resources

The main social indicators used in the Coastal Resilience project are briefly described below.

Human Populations

Accurate depictions of human population distributions within coastal zones provide critical baseline information for assessing risk. The team used several metrics of human population from the U.S. Census Bureau (2000) and also used these data to derive various compilation indices.

Parcel data were reclassified into high-, medium-, and low-density residential development according to the land use type and parcel size. Approximately 7 percent of Suffolk County's parcel database did not contain a land use attribute. The team used the 2005 land cover data set (NOAA Coastal Services Center 2005) to fill in missing land use attributes within the parcel database. Nonresidential parcels were used as an exclusionary class in the dasymetric calculation.

In addition to distributing population data across parcels, the 2008 parcel database of Suffolk County, New York, classified parcels as "vacant" according to the Real Property Tax Service Agency. These parcels can be residential, commercial, industrial, or municipal (*www.co.suffolk.ny.us/departments/tax.aspx*). Both the population distribution and vacant parcels were loaded into the Future Scenarios Mapper.

Infrastructure

A shoreline analysis was conducted to map shoreline hardening. Ortho-rectified aerial photos collected by Suffolk County in the spring of 2004 were used to identify shoreline structures. A new tool, Pictometry, which uses oblique images taken in 2006, as well as direct overhead aerial photos (also from 2006), was used to further validate a structure's presence.

The NOAA Coastal Change Analysis Program (C-CAP) maintains nationally standardized land cover and land change information for the coastal regions of the U.S. C-CAP products feature inventories of coastal intertidal areas, wetlands, and adjacent uplands with the goal of monitoring these habitats by updating the land cover maps every five years. C-CAP products are

developed using multiple dates of remotely sensed imagery and consist of raster-based land cover maps for each date of analysis. The team used four classes to represent infrastructure: high, medium, and low-density development, and agriculture.

Response
The vicinity and location of critical facilities, including emergency operation centers, fire and police services, and medical facilities, are extremely important to know in the event of hurricanes, storms, and other coastal hazards. These facilities provide crucial services to communities and are important resources before, during, and after natural disasters. These data come from the National Institute of Building Sciences (2001).

Socioeconomic Analyses
The framework for choosing appropriate socioeconomic indicators for the project was derived from the NOAA Coastal Services Center's Community Vulnerability Assessment Tool (*www.csc.noaa.gov/rvat_tools/*), an adaptable, multi-step process that can help coastal communities better understand and adapt to coastal hazard risks and vulnerabilities. The method leads communities through a process to identify social, economic, infrastructural, and environmental resources that may be vulnerable to coastal hazards. Demographic variables such as gender, race, age, language, and income are indicative of populations that may be at greater risk from disturbances such as hurricanes and therefore more socially vulnerable.

The team chose variables that best represent the socioeconomic vulnerability of Suffolk County. These data, obtained from the U.S. Census Bureau, were processed to create indices that identify populations and housing resources that may be vulnerable to storm surge and SLR. The first step was to determine what community assets (ecological, social, and economic) are exposed to the hazards by conducting an inventory of crucial resources located in high-risk areas. From these indices, including critical infrastructure and facilities, social vulnerability and overall community vulnerability were constructed.

Critical Infrastructure and Facilities Index
The Critical Infrastructure and Facilities index ranks census block groups according to the amount of critical infrastructure and facilities located within each. Extensive infrastructure increases a block group's vulnerability as communities within and next to it are likely highly dependent on the services it provides. Infrastructure and services related to public safety, communications, and utilities, and community facilities were counted and measured for each. Block groups were then ranked from most to least vulnerable for inclusion in the Critical Infrastructure and Facilities Index. The index includes specific information on transportation terminals, cable lifeline length, road density, critical, utility and community facilities.

Social Vulnerability Index
The project team reviewed several risk and vulnerability assessment methods that provided guidance on measuring social vulnerability. The methods included those of the NOAA Coastal Services Center Community Vulnerability Assessment Tool (CVAT), Granger (Granger, 2003, Natural Hazards 30: 165-185), and the Social Vulnerability Index for the U.S. (Cutter, Boruff, *et*

al. 2003, Social Science Quarterly 84:2). These methods recommended several social variables that characterize social vulnerability. To obtain this information, the project team used 2000 U.S. Census SF3 data tables, focusing on population and housing characteristics that traditionally indicate socioeconomic vulnerability. Tables for each variable were retrieved and mapped at the census block group scale, the smallest geographical unit for which the census provides detailed demographic data. For each variable, the block groups were ranked from most vulnerable to least vulnerable for inclusion in the Social Vulnerability Index. The index includes information on population and population density, housing unit density, median income, length of residency, housing unit median year built, percent population under age five, over age 65, with no diploma, lacking English speaking skills, non-Caucasian, single female parent, below poverty, requiring public assistance, renter occupied, seasonally occupied units, mobile homes, and households without an automobile.

Overall Community Vulnerability Index
The Overall Community Vulnerability Index combines the Social Vulnerability and Critical Facilities and Infrastructure Indices to represent the combined vulnerability to flooding of the people, property, and resources in a community. The index is mapped by census block groups in four categories, from most to least vulnerable.

Estimated Commercial and Residential Economic Exposure
These parameters represent the full replacement value of commercial and residential structures. This is not the assessed, market, or retail value of the property and does not include land value. This data set is the result of geographic analysis and display using HAZUS-MH, a tool developed by the Federal Emergency Management Agency (FEMA). These data were used to calculate results of economic loss from specific inundation scenarios.

Economic Loss
To examine economic losses from flooding of infrastructure, including housing, transportation, and commercial structures, the team selected SLR, storms, and scenarios that combined their effects on economic exposure.

FEMA's HAZUS flood model uses a comprehensive inventory in estimating losses at the national scale. However, more localized data can be used if available. The inventory consists of a proxy for the general building stock in the continental U.S. In addition, the model contains national data for essential facilities (e.g., police stations), high potential loss facilities (e.g., dams), selected transportation (e.g., highway bridges) and lifeline systems (e.g., potable water treatment plants), demographics, agriculture products (e.g., corn), and vehicles. This inventory is used to estimate damage (percent) and the direct economic losses for some elements (i.e., the general building stock) or the associated impact to functionality for essential facilities.

The General Building Stock (GBS) is an engineering-based estimation of floor area (square feet), value (2006 dollars), and count of all structures by occupancy (residential, commercial, industrial, agricultural, religion/nonprofit, education, and government). The floor area, value, and structure count information is derived from U.S. Census data for residential building stock

and Dun and Bradstreet for commercial and industrial building stock. The valuation model used to determine replacement cost is based on industry standard cost data published in the 2006 edition of R.S. Means publisher's *Square Foot Costs*, which provides the dollar replacement cost per square foot.

The General Building Stock data were used for HAZUS analysis for this project. Suffolk County did not have better building location and attribute data (e.g., first floor heights, building value) available. Only the estimated building replacement values were used for displaying results.

Potential economic losses can be visualized in the Future Scenarios Mapper by either U.S. block groups or summarized across towns and villages along the southern shores of Long Island. The Future Scenarios Mapper allows the user to perform analyses using the project's six inundation scenarios.

These scenarios help the user visualize and better understand vulnerabilities, and when combined with the project website's information on context and policy, help communities take action to achieve both ecological and socioeconomic objectives.

For more information, visit the **Project Overview** or **Coastal Inundation Mapping Methods** sections, or contact:

Adam Whelchel
The Nature Conservancy Connecticut Chapter
(203) 568-6296
coastalresilience@tnc.org
www.coastalresilience.org