

# Coastal Zones

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## Introduction

The anticipated global sea level rise due to climate warming will greatly amplify risks to the coastal population of New York State, leading to permanent inundation of low-lying areas (including wetlands), more frequent flooding by storm surges, and potential for increased beach erosion. Saltwater could reach farther up estuaries, such as the Hudson River, potentially contaminating urban water supplies, while increased water depth could alter the propagation of both the tide and storm surges up the Hudson River to the Federal Dam in Troy. These hazards will continue to be exacerbated by development in the coastal zone.

The Intergovernmental Panel on Climate Change (IPCC) concluded in 2007 that global sea level will likely rise between 7 and 23 inches by the end of the century (2090–2099), relative to the base period (1980–1999), not counting unexpected rapid changes in ice flow from the Greenland and Antarctic ice sheets. However, these projections may be too low, as they do not consider the uncertainty associated with ice sheet melting processes or cover the full likely temperature range given in the Fourth Assessment Report (up to 6.4°C) (Rahmstorf et al., 2007; Rohling et al., 2008; Pfeffer et al., 2008; Horton et al., 2008). Regional sea level rise projections used in the assessment explicitly include a “rapid ice-melt scenario” based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimate studies (See Chapter 1, “Climate Risks,” for a complete description of this method). Most of the observed current climate-related rise in global sea level over the past century can be attributed to expansion of the oceans as they warm; however, it is anticipated that the melting of land-based ice may become the dominant contributor to global sea level rise in the future.

Historically, the rise in regional (or relative) sea level—a measurement of sea level height that includes local effects such as the vertical movement of land, local ocean temperatures, atmospheric pressure, and tides—has varied through time and accelerated during the 20th century as global temperatures have increased (Gornitz et al., 2002; Gehrels et al., 2005; Donnelly et al., 2004; Holgate and Woodworth, 2004; IPCC, 2007). Regional sea level was rising at rates of 0.34 to 0.43 inch per decade over the past thousand years; however, current rates are ranging between 0.86 and 1.5 inches per decade with a 20th century average rate of 1.2 inches per decade (see Chapter 1, “Climate Risks”).

## 5.1 Sector Description

The U.S. Coastal Zone Management Act of 1972, as amended in 1996, defines the coastal zone as the land inward of the shoreline needed to control or manage uses that are likely to directly and significantly impact coastal waters or are likely to be “affected by or vulnerable to sea level rise.” New York State considers coastal waters to extend three miles into the open ocean, and up to the state lines of Connecticut and New Jersey along the shore.

In the ClimAID assessment, we consider the coastal zone to include the shoreline of New York State, including coastal wetland areas and inland areas adjacent to the shoreline that are likely to be affected by sea level rise and coastal storms. We also consider impacts and adaptation strategies for Great Lakes coastlines were not included in this assessment even though these regions are clearly part of the coastal zone, as they could not be properly analyzed given scheduling and budgeting constraints. Additional resources should be made available to conduct a comprehensive assessment of climate-change-related impacts and adaptation strategies specifically targeted at the Great Lakes regions (an investigation that would require multi-state collaboration). In particular, this assessment effort focuses on identifying 1) climate change risks affecting the coastal zone, arising from sea level rise, storm surges, increased water temperatures, and changes in precipitation; 2) critical vulnerabilities (populations, ecosystems, and regional coastal communities); and 3) potential adaptation strategies for coastal communities.

The New York State coastline is composed of a combination of glacial bluffs, pocket beaches, and extensive barrier island/bay systems. Long Island is particularly vulnerable to the effects of shoreline erosion since it is largely formed of sand and gravel deposits left by the retreating glaciers, after the end of the last Ice Age around 20,000 years ago. The South Shore of Long Island is a sandy environment consisting largely of barrier islands, spits, and back-barrier salt marshes that are very erodible and subject to inundation.

Coastal ecosystems include nearshore subtidal areas, the low marsh intertidal zone (**Figure 5.1**, top), high marsh (**Figure 5.1**, bottom), beaches, dunes, stream channels, rocky platforms (**Figure 5.2**), seagrass meadows, algal beds, and tidal flats (Nordstrom and

Roman, 1996). Even in a densely populated urban environment such as New York City these coastal ecosystems provide numerous functions and values. These include wildlife habitat, storm surge protection, wave attenuation, pollution absorption, and aesthetic appeal. More than 300 bird species spend part of their life cycle in New York's coastal shores, feeding, resting, or nesting. Every May and June, thousands of horseshoe crabs come to spawn on the sandy beaches of Long Island, New York City, and Westchester County. Many bird species depend on the horseshoe crab eggs or other invertebrates of the tidal zone to replenish their fatty reserves and continue on migration routes along the Atlantic flyway.

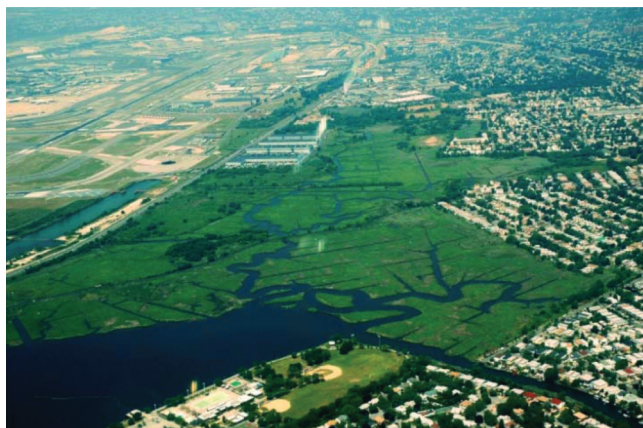
New York State's coastal marshes are limited to the north and south shores of Long Island (Suffolk and Nassau Counties), New York City (Queens, Brooklyn, Staten Island, and the Bronx), Westchester County, and up the Hudson River. In the tidally influenced portion of the Hudson River Estuary (up to the Troy Dam), the

dominant ecological communities are freshwater and brackish tidal marshes, freshwater tidal swamps, tidal creeks, mud and sand flats, and freshwater subtidal aquatic beds (Edinger, 2002). However, these are limited to north of the Tappan Zee Bridge as there is little or no break in shoreline armoring (bulkheads and riprap) from Manhattan to the bridge.

### 5.1.1 Economic Value

The coastal zone is not a category in the North American Industrial Classification System (NAICS) (U.S. Bureau of Economic Analysis, n.d.), since values produced by economic activity in the coastal zone are distributed among a wide variety of industry, government, commercial, and private activities. One way to consider value is the estimated insured value of properties in coastal counties in the state in 2004. This was nearly \$2 trillion: \$1,901.6 billion, or 61 percent of the total insured value in the state of \$3,123.6 billion (AIR, 2005; see Annex II, "Economics," of full ClimAID Report).

Insured losses from previous storms can give a general idea of the current costs of climate-related impacts to the sector. This information is available for hurricanes, winter storms, and thunderstorms. The losses from winter storms and hurricanes are principally located in the coastal zone, whereas losses from thunderstorms occur throughout the state. The largest insured loss since 1990 (in 1992) was approximately \$1 billion (in present dollars) from winter storms; from 1990 to 2010 there are nine other years with losses of more than \$0.4



Location: Idlewild Park, Queens, NY. Photo credit: Mike Feller



Location: Pelham Bay, Bronx, NY. Photo credit: Ellen Kracauer Hartig

**Figure 5.1** Salt marshes in the urban environment



Photo credit: Mike Feller

**Figure 5.2** Rocky shoreline at Pelham Bay Park, Bronx



billion (ISO, 2010). Additionally, Pielke et al. (2008, p. 35) adjusted the losses from the 1938 hurricane to account for inflation, changes in population density (and thus exposures), and asset value, and estimated that the 1938 storm, if it occurred today, would cause \$39.2 billion (2005 dollars) in economic damages (see Annex III, “Economics,” of full ClimAID Report).

This information gives a picture of the order of magnitude of coastal zone storms losses without further adaptation measures. As sea level rises, the probability of any given amount of flooding rises so that a storm in the future may cause a larger amount of flooding than the same storm today. See Annex III, “Economics,” of full ClimAID Report for further details.

### 5.1.2 Non-Climate Stressors

The ClimAID assessment is focused on climate-related stresses influencing the coastal zone of New York State. However, as in any complex system, there are multiple

forces interacting to produce the observed behavior. Often it is difficult to attribute the response of the system to any particular forcing function; therefore, it is necessary to briefly mention some of the non-climate stressors impacting the various coastal components described in this sector. Many of these stresses are associated with human consumption of natural resources and land-use practices. For example, coastal development, construction of drainage alterations, and impervious surfaces have led to a reduction in groundwater recharge and degraded coastal water quality (Bavaro, 2005). The interconnection among precipitation, land use, and local fish populations has also been documented, suggesting increased urbanization may lead to a reduction in stream biodiversity and migratory fish run sizes (Limburg and Schmidt, 1990). A number of human-induced factors (including sewage discharges and contaminated stormwater runoff from developed and agricultural areas) cause pollution and pathogen outbreaks that can lead to closures of shellfish harvesting areas. The relationship between agricultural lands, storm-water

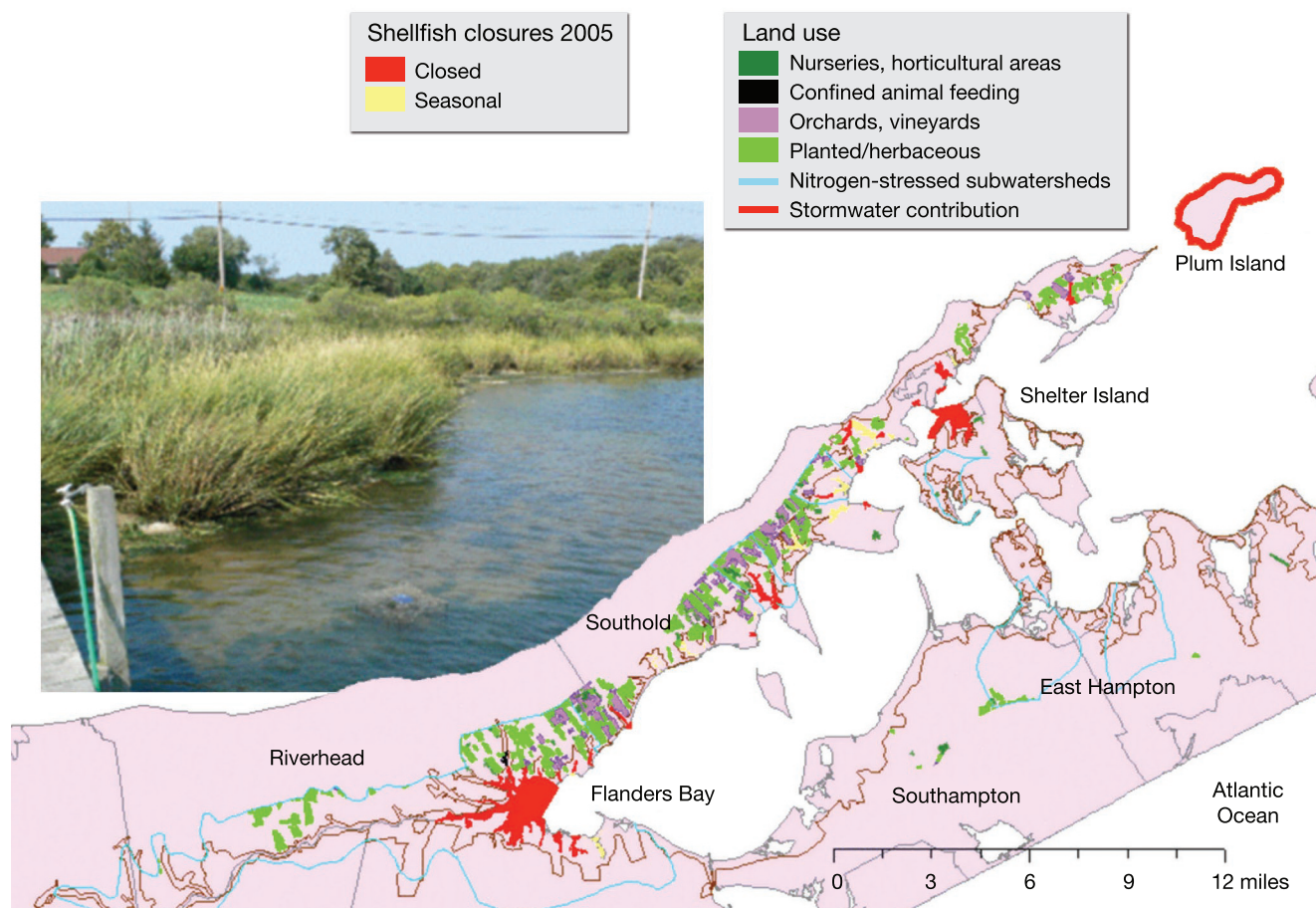


Photo of Flanders Bay wetlands. Figure courtesy of Frank Buonaiuto

**Figure 5.3** Peconic River Estuary shellfish closures and land use practices



drainage, nitrogen additions, and shellfish closures for the Peconic River Estuary for 2005 is illustrated in **Figure 5.3**. In addition to stresses related to water quality, fish stocks (as well as other marine ecosystem components) may be affected by harvesting practices, diseases (not necessarily climate related), and normal population dynamics (e.g., predation, competition, and recruitment variability). Intense development along the coast increases vulnerability to inundation as well as the demand for groundwater, which could lead to drawdown of aquifers and increased saltwater intrusion. Coastal infrastructure also inhibits natural geographic migration of wetlands and barrier islands.

## 5.2 Climate Hazards

For the ClimAID assessment, three climate risks were considered of particular importance for the Coastal Zone: rising sea levels, increasing coastal water temperatures, and changes in precipitation patterns.

### 5.2.1 Sea Level Rise

Sea level rise projections were constructed for New York City and up the Hudson River Estuary to the Troy Dam. The projections, which were downscaled from IPCC global climate model (GCM) simulations for various greenhouse gas emission scenarios, were limited in resolution, which resulted in very little difference between New York City and Montauk Point (refer to Chapter 1, “Climate Risks,” for details on calculation methodology). In addition to the IPCC GCM calculations, a rapid ice-melt scenario was included as a result of current trends. The range of sea level rise projections for Regions 4 and 5 of the ClimAID Assessment is summarized in **Table 5.1**. See

Region 4: New York City and Long Island	2020s (inches)	2050s (inches)	2080s (inches)
GCM-based <sup>1</sup>	+2 to +5	+7 to +12	+12 to +23
Rapid ice-melt scenario <sup>2</sup>	~5 to +10	~19 to +29	~41 to +55
Region 5: East Hudson and Mohawk River Valleys	2020s (inches)	2050s (inches)	2080s (inches)
GCM-based <sup>1</sup>	+1 to +4	+5 to +9	+8 to +18
Rapid ice-melt scenario <sup>2</sup>	~4 to +9	~17 to +26	~37 to +50

<sup>1</sup> Shown is the central range (middle 67%) of values from global climate model-based probabilities rounded to the nearest inch.

<sup>2</sup> The rapid-ice melt scenario is based on acceleration of recent rates of ice melt in the Greenland and West Antarctic ice sheets and paleoclimate studies.

**Table 5.1** ClimAID Assessment sea level rise projections

Chapter 1 for a more complete discussion of the model scenarios used to construct the central range estimates.

The rapid ice-melt sea level rise scenario is based on extrapolation of recent accelerating rates of ice melt from the Greenland and West Antarctic ice sheets and on paleoclimatic studies that suggest sea level rise on the order of ~0.39 to 0.47 inch per year may be possible. The potential for rapid ice-melt should be considered in part because of the large magnitude of consequence should it occur. To assess the risk of accelerated sea level rise over the coming years, scientific understanding as well as many key indicators should be monitored and reassessed. For example, one component of the monitoring efforts should focus on properties of the coastal zone, such as the geographic extent and health of coastal wetlands and the distribution of certain marine organisms like blue crabs and lobsters. Monitoring of coastal landforms, such as the barrier islands along the south shore of Long Island, is also necessary as the response of these systems to accelerated sea level rise has yet to be determined.

### 5.2.2 Increasing Coastal Water Temperatures

Water temperature plays a dominant role in shaping marine ecosystems. As ocean temperatures continue to rise, the range of suitable habitat in the Northeast for many commercially important fish and shellfish species is projected to shift northward. However, it is not clear what the local production of those species would be during such transitions (Frumhoff et al., 2007). Regional surface and bottom water temperatures are influenced in part by large-scale oceanic and atmospheric circulation (which exhibits annual, inter-annual, and inter-decadal variability), annual cycles in solar radiation, migrating weather systems, and, more locally, by freshwater discharge.

Over the course of the 20th century, regional sea-surface temperatures have risen more than 1.0°F. Water temperature changes can result in shifts in faunal assemblages (groupings of organisms) that affect marine ecosystems and economic activities in unknown ways. Every species has a thermally suitable range for habitat that, when compromised, induces a forced migration to seek another location suitable to its life cycle. Water temperatures influence organism survival and growth,

egg and larvae development, and spawning and feeding behavior. When water temperatures rise, ecosystems become vulnerable to shellfish diseases, harmful algae blooms, and exotic species that force indigenous species to compete for resources, including dissolved oxygen (DO). Oxygen solubility will decrease as water temperatures increase, further stressing marine organisms. Understanding the impact of increased water temperatures is critical to planning for ecosystem stresses associated with climate change.

Regional sea-surface temperature projections were developed for the 2050s (the 30-year average from 2040 to 2069) for comparison with a 1980s baseline derived from the Community Climate System Model (CCSM) and the Geophysical Fluid Dynamics Laboratory (GFDL) models under the A2 and B1 Special Report on Emissions Scenarios (SRES) emissions scenarios. All show substantial increases on the order of 1.8–2.5°F for near-shore waters, depending on the model and emissions combination. However, global climate models (GCMs) represent only some of the complex connections between ocean and atmosphere when determining water-temperature projections and are often limited in resolution.

### 5.2.3 Change in Regional Precipitation

The spatial and temporal distribution of precipitation will inevitably impact New York State's coastal regions. Changes in local precipitation in areas such as Nassau and Suffolk counties will affect rates of groundwater recharge, lake levels, stream flow, and the delivery of nutrients and pollutants to coastal waters. Changes in temporal and spatial precipitation patterns for the northernmost counties will also influence the tributary inflows and discharge of the Hudson River. During periods of increased precipitation and discharge, the position of the salt front will move downstream. Droughts, particularly in summer when air temperatures would increase rates of evaporation, would force the salt front to migrate upstream. Increases in annual precipitation for coastal regions in New York State (New York City and Nassau and Suffolk counties), which is currently about 47 inches, are expected to range from 0 to 5 percent by the 2020s, 0 to 10 percent by the 2050s, and 5 to 10 percent by the 2080s (see Chapter 1, "Climate Risks," for details). Changes in the amount of precipitation will not be uniformly distributed throughout the year, and some of

the expected variability in precipitation will be associated with extreme events. Similar changes in precipitation are anticipated for the other ClimAID regions, with Regions 5, 6, and 7 (East Hudson and Mohawk River Valleys; Tug Hill Plateau; Adirondack Mountains) potentially experiencing a 5 to 15 percent increase in precipitation by the 2080s. In addition, increases in precipitation would alter near-shore salinities, potentially impacting fish and shellfish populations.

### 5.2.4 Other Climate Factors

Additional climate factors considered important for the coastal zone are coastal storms and floods. For storm track frequency and variations in river discharge, the climate models used for this assessment effort are not able to predict with the necessary degree of certainty changes in either of these factors.

#### *Coastal Storms*

While permanently lost land is projected to occupy a relatively narrow coastal strip by the 2080s higher storm surges associated with higher sea levels could periodically engulf a much greater area. Also, wave action will erode and reshape the shoreline, affecting the location and extent of storm surge inundation. The current 1-in-100-year flood (also known as the 1 percent annual chance flood and defined as a flood that has a 1-percent chance of being equaled or exceeded in any given year) will occur more frequently, with future 1-in-100-year flood events achieving higher flood elevations. The greater frequency of severe flooding events affecting the increasing number of waterfront residences may lead to abandonment of ground floors (as in Venice) or ultimately of entire buildings. Evacuation of vulnerable populations in high-risk areas during major storms may pose difficulties in that many evacuation routes may themselves become flooded.

Low-lying coastal regions throughout New York are vulnerable to surge (elevated water levels) from both tropical (originating in the tropics, e.g., tropical storms and hurricanes) and extratropical (mid-latitude) storm systems. Elevated coastal water levels, strong winds, and large amounts of precipitation during these storm events result in billions of dollars in damages. In addition to flooding, some of the more severe storms

have disrupted transportation and power distribution systems. A partial list of the more severe historical storms to impact New York appears in **Table 5.2**.

Historic hurricanes in New York State include the “Great September Gale of 1815” and the category 2 hurricane of 1821, which flooded lower Manhattan as far north as Canal Street (Ludlum, 1963). The “Midnight Storm” of 1893 destroyed Hog Island, and the 1938 “Long Island Express,” a category 3 hurricane, passed across eastern Long Island and generated a storm surge ranging from 10 to 15 feet along the south shore. This single event dramatically altered the barrier island system by overwashing dunes (e.g., storm waters overtopping the barrier island) lower than 20 feet above mean sea level and creating numerous inlets, including the present-day Shinnecock Inlet. Even though other severe storms have impacted the state, there have been no other direct hits by major hurricanes (> cat 3; see **Table 5.3** for a description of hurricane categories) across New York City and Long Island since the 1938 Long Island Express (National Hurricane Center, 2008). Even though it is unclear if the changing climate will result in more frequent hurricanes in the Atlantic, warming ocean temperatures throughout the surface mixed layer have the potential to produce stronger storms. New York State should consider hurricane threats when reviewing and adopting adaptation strategies, even though their occurrence is less predictable than that of extratropical storm systems.

In contrast to hurricanes, in which storm surge damage is generally confined to the coastal areas near landfall, extratropical storms (regionally referred to as nor’easters) can cause millions of dollars in damage over a larger region along the coast. In addition, extratropical storms often span several tidal cycles, increasing the risk of flooding to coastal communities. For example, there was \$300 million in property damage and major coastal erosion along the mid-Atlantic coast during the March 1962 extratropical cyclone (Dolan, 1987), while the 1993 March Superstorm effectively shut down transportation along the entire U.S. East Coast (Kocin et al., 1995). More locally, the December 1992 nor’easter, which generated water levels in excess of 8 feet above mean sea level, flooded parts of the New York City subway and Port Authority Trans-Hudson (PATH) train systems (Colle et al., 2008).

Scale Number (category)	Winds (mph)	Typical Characteristics of Hurricanes by Category*			
		Barometric Pressure		Surge	Damage
		(Millibars)	(Inches)	(Feet)	
1	74–95	>979	>28.91	4–5	Minimal
2	96–110	965–979	28.50–28.91	6–8	Moderate
3	111–130	945–964	27.91–28.47	9–12	Extensive
4	131–155	920–944	27.17–27.88	13–18	Extreme
5	>155	<920	<27.17	>18	Catastrophic

\* This revised version of the Saffir-Simpson Hurricane Wind Scale assigns hurricane category based on the maximum sustained surface wind speed only. Central pressure values are no longer used as proxy for wind speed, and storm surge is currently forecast using multiple factors such as storm size, forward speeds, and local bathymetry and topography.

Source: Blake et al., 2007 and NOAA

**Table 5.3 The Saffir/Simpson Hurricane Scale**

Tropical Storms			Extratropical Storms		
Date	Name	Cat.	Date	Name	Cat.
9/3–9/5/1815	Great September Gale of 1815	3	3/6–3/8/1962	*Ash Wednesday Storm	
9/3/1821	Norfolk and Long Island Hurricane	1-2	2/6/1978	Major blizzard	
9/1858	New England Storm	1	3/28–3/29/1984	Major blizzard	
9/1869	Eastern New England Storm	1	10/29–11/2/1991	*Halloween Storm, “Perfect Storm”	3
8/23/1893	Midnight Storm	1–2	12/11–12/12/1992	*Major nor’easter	3
9/21/1938	Long Island Express	3	3/13–3/14/1993	“Storm of the Century”	3
9/15/1944	Great Atlantic Hurricane	1	2/17/2003	Major blizzard	
8/1954	Hurricane Carol	3	3/12/2006	Major blizzard (record snow, but little surge)	
9/12/1960	Hurricane Donna	3	11/11–11/14/2009	Nor’easter (“Nor’Ida”)	3
9/21/1961	Hurricane Esther	1-2			
6/1972	Hurricane Agnes	1			
8/10/1976	Hurricane Belle	1			
9/27/1985	Hurricane Gloria	2–3			
8/1991	Hurricane Bob	2			
9/1999	Hurricane Floyd	2			

\* Extratropical storms with the highest surges since 1960.

Note: Levels are based on intensity scale developed by Salamon et al., 2009.

Source: NPCC Climate Risk Information Workbook, FIMP; Gornitz and Couch, in Rosenzweig and Solecki (2001); NOAA NOS <http://tidesandcurrents.noaa.gov>; NY Times

**Table 5.2 New York State tropical and extratropical storm systems**



Extratropical storms frequently occur on the East Coast of the United States; as a result, several studies have been conducted in order to determine typical characteristics of these systems, including timing and regions of formation, structure, and general tracking patterns (Reitan, 1974; Colucci, 1976; Zishka and Smith, 1980; Hayden, 1981; Hirsch et al., 2001). Approximately 12 strong extratropical cyclones are generated each year, with the maximum number of storms occurring during the month of January. Although, as expected, extratropical storms exhibit interannual variability (Davis et al., 1993, Colle et al., 2008), the number (Hirsch et al., 2001) and intensity (DeGaetano, 2008) of extratropical storms generally increase during El Niño years and the positive phase of the North Atlantic Oscillation (DeGaetano et al., 2002).

Intensity scales have been developed for East Coast winter storms using atmospheric and oceanographic conditions. These research efforts highlight the regional variability of storm strengths and the need for sustained local monitoring of the meteorological conditions and resulting coastal impacts (Dolan and Davis, 1992; Zielinski, 2002; Salmun et al., 2009). Moderate coastal flooding appears to be associated with northward-tracking cyclones along the East Coast (Colle et al., 2010), but the relationship between extratropical storm intensity and storm surge has been difficult to quantify. In addition to the regional-scale atmospheric circulation associated with extratropical cyclones, coastal flooding also depends on local factors, such as waves (Salmun et al., 2009), winds, coastline configuration, and bathymetry.

### *Coastal Floods and Recurrence Intervals*

New York State's complex coastal geometry and bathymetry make modeling and forecasting coastal floods extremely difficult. Approximately 85 percent of the coastal flood warnings issued by the National Weather Service for New York from 2001 to 2006 did not materialize (Colle et al., 2010). This high false alarm rate is attributed in part to the general lack of information and understanding about the movement of water and waves near the shore. There have been recent advances in ocean and surge modeling to help researchers and emergency managers operating in New York State (Colle et al., 2008). However, the link between the detailed meteorological evolution of the storm systems and the

development of surge (atmospherically forced elevated water levels) in this region requires additional investigation, making it even more difficult to understand how storm systems and their impacts on the New York region will evolve as the climate changes.

The National Weather Service issues coastal flood advisories and coastal flood warnings for New York State when storm systems elevate regional water levels approximately 2 feet (minor surge event) and 3 feet (moderate surge event) above mean high water (MHW) at the Battery, respectively (Colle et al., 2010). During the period 1959–2007, New York experienced 244 minor and 46 moderate surge events, which combined with the observed tide to produce 174 minor (flood advisory) and 16 moderate (flood warning) flooding events. This illustrates how sensitive the flooding of low-lying coastal regions is to the timing of storm surges and tides. Similar to extratropical storm activity, the most active surge years have been associated with El Niño events. The number of minor surge events has decreased gradually from a relatively active period during the 1960s to noticeably fewer events in the late 1980s and 2000–2007 (Colle et al., 2010). In particular, the 10-year period from 1997 to 2007 was one of the calmest moderate surge periods in the last 50 years, which may indicate that the cyclone intensity and/or tracks may be different than 10 to 20 years ago. It is not clear at this time if the change in cyclone characteristics is a direct result of climate change or part of a natural multi-decadal cycle.

Since 1990, the frequency of minor surge events (water levels elevated 2 feet above astronomically predicted tide) has been decreasing, yet the number of minor flood events (flood advisories, water levels elevated 2 feet above mean high water) has been steadily increasing. This suggests that sea level rise over the last few decades has already been enhancing the number of nuisance flooding (coastal flood advisory) events in New York State (Colle et al., 2010).

Currently the number of moderate flooding events (coastal flood warnings) does not appear to be influenced by climate change and resulting sea level rise. However, assuming a surge pattern similar to the 1997–2000 period, central sea level rise projections (see Chapter 1, “Climate Risks”) of 5, 12, and 23 inches at the Battery for the 2020s, 2050s, and 2080s, respectively, would result in 4, 16, and 136 moderate flooding events annually. Under a rapid ice-melt

scenario, New York State could experience between 200 and 275 moderate flooding events each year by 2080 (Brian Colle, personal communication, 2009).

Coastal flooding is a dynamic process, and individual storm events can exhibit large variations in regional water levels along the coast. Flood levels can be computed from water level observations if a sufficient record is available, or from a combination of deterministic modeling and probability analysis. Several methods for determining flood levels and associated recurrence intervals are available, and when the computation is for insurance purposes, a certified flood plain manager ensures the analysis is in accordance with Federal Emergency Management Agency (FEMA) standards.

Still water levels (not including waves) associated with 1-in-10-year and 1-in-100-year events for New York City (Horton et al., 2010) and Westhampton Beach for various time horizons are shown in **Table 5.4**. It should be noted that changes in the still water levels are for illustrative purposes and are expected to vary geographically, being influenced by offshore bathymetry and shoreline configuration. Coastal communities should conduct more localized gauge and modeling investigations to improve water level calculations. As an example, projected changes in the 1-in-10-year coastal flood for Long Beach and the surrounding bay communities for GCM-based and rapid ice-melt scenarios are presented in **Figure 5.4**. A detailed investigation of the 1-in-100-year coastal flood for communities on Long Beach and along Great South

Bay is presented in Case Study A: 1-in-100-year Flood and Environmental Justice.

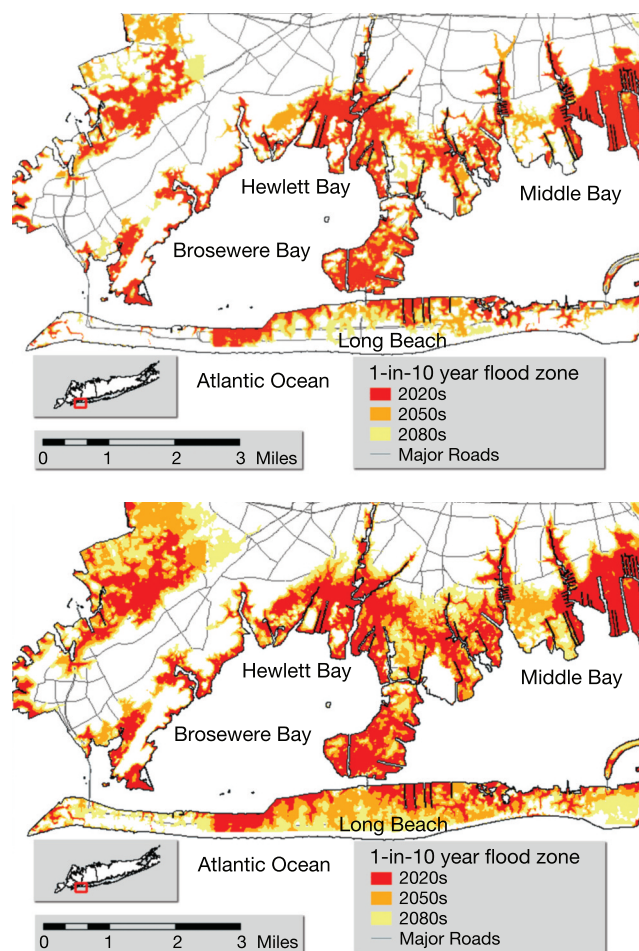
As sea levels rise, coastal flooding associated with storms will very likely increase in intensity, frequency, and duration. The changes in coastal flood intensity listed in **Table 5.4** are solely due to gradual changes in sea level through time. Any increase in the frequency or intensity of storms themselves would result in even more frequent and damaging future flood occurrences relative to the current 1-in-10- and 1-in-100-year coastal flood events. By the end of the 21st century, sea level rise alone would increase the frequency of coastal flood levels that currently occur on average once per decade to once every one to three years for New York City and once every one to two years for Westhampton Beach. In addition, water levels associated with these events are likely to increase by 1 to 2 feet. The more severe current 1-in-100-year event, which is less well characterized than that of the 1-in-10-year event, may

New York City Extreme Event	Baseline (1971–2000)	2020s	2050s	2080s
1 in 10 yr flood	~10 yr	~8–10 yr	~3–6 yr	~1–3 yr
1 in 10 yr swl	6.3 ft	6.5–6.8 ft	7.0–7.3 ft	7.4–8.2 ft
1 in 100 yr flood	~100 yr	~65–80 yr	~35–55 yr	~15–35 yr
1 in 100 yr swl	8.6 ft	8.8–9.0 ft	9.2–9.6 ft	9.6–10.5 ft
Westhampton Beach Extreme Event	Baseline (1971–2000)	2020s	2050s	2080s
1 in 10 yr flood	~10 yr	~7–8 yr	~2–5 yr	~1–2 yr
1 in 10 yr swl	4.9 ft	5.1–5.3 ft	5.5–5.9 ft	5.9–6.7 ft
1 in 100 yr flood	~100 yr	~80–90 yr	~60–70 yr	~35–60 yr
1 in 100 yr swl	8.5 ft	8.7–8.9 ft	9.1–9.5 ft	9.5–10.3 ft

Note: SWL = Still water level.

Source: NPCC 2010 and Columbia Center for Climate Systems Research

**Table 5.4** Current and projected recurrence intervals and flood levels for New York City and Westhampton Beach based on ClimAID model-based sea level rise projections from 7 GCMS for the 2020s, 2050s, and 2080s.



**Figure 5.4** Projected flood maps for 1-in-10-year storm event for Long Beach and surrounding bay communities for the ClimAID GCM-based (top) and rapid ice-melt scenarios (bottom)

occur on average approximately four times as often by the end of the century (NPCC, 2010).

Low-lying coastal communities on Long Island and New York City could find themselves repeatedly under water at high tide, with consequent property damage. The greater likelihood of coastal flooding (as well as heavier rainfall) would result in an increase in street, basement, and sewer flooding; an increase in flood risk to low-elevation transportation, energy, and communications infrastructure; more frequent delays on low-lying highways and public transportation; increased structural damage and saltwater exposure to infrastructure, commercial, and residential property; increased inflow of seawater to storm sewers and wastewater treatment plants and reduced ability of gravity discharge of sewer-effluent overflows; encroachment of saltwater into freshwater sources and ecosystems; and increased beach erosion and sand placement needs.

Many of the entrances to bridges and tunnels, segments of the highways and railroads, and similarly, many wastewater treatment plants and sewer outfall systems lie at or below the 10-foot contour and are potentially vulnerable to severe present-day coastal storm flooding, let alone projected higher future levels (See Chapters 9 and 10, “Transportation” and “Telecommunications”). Even brief but heavy precipitation downpours, as exemplified by the August 8, 2007 storm, have led to shutdowns of portions of the New York City subway system (Metropolitan Transportation Authority, 2007) and highway flooding. Even greater transportation disruptions, affecting not only subways and some highways, but PATH trains, railways, and air transportation, occurred during the December 1992 nor’easter and hurricanes such as Hurricane Donna in 1960, Hurricane Gloria in 1985, and Hurricane Floyd in 1999.

A recent study prepared for the New York City Department of Environmental Protection found that sea level rise and coastal inundation could affect the heights of tide gates designed to prevent the inflow of seawater and backing up of outfall sewers (NYCDEP, 2008). More tide gates may need to be installed at outflow locations to prevent such inflows, and more frequent repairs of the gates may become necessary. If high tide levels during storms cause backup of sewage, more could be forced into wastewater treatment plants, necessitating the throttling of flows to protect the plants from flooding. Increased street, basement, and sewer

flooding could result. Coastal flooding could increase salinity of influent into wastewater pollution control plants (WPCPs) and lead to corrosion of equipment. More delays and service interruptions on public transportation and low-lying highways can be expected. More frequent flooding and wave action could increase structural damage to infrastructure.

## 5.3 Vulnerabilities and Opportunities

Because of the highly developed nature of the coast in New York State, a considerable portion of population, private property, and infrastructure in the coastal zone will be potentially at risk to enhanced inundation and flooding due to sea level rise associated with climate change.

### 5.3.1 Coastal Erosion

Waves, currents, and tides constantly reshape the shoreline, and as sea level rise accelerates, these forces have the potential to dramatically alter New York State’s coast. Even at present rates of sea level rise, over 70 percent of the world’s sandy beaches are eroding (Bird, 2008). Beach erosion is frequently intensified by human activities, such as interrupting littoral drift by jetties or groins, and beach sand mining. Ultimately, the rate of erosion is typically several orders of magnitude greater than the vertical rise in sea level itself (Frumhoff et al., 2007). Any narrowing and potential loss of barrier islands due to sea level rise would place many waterfront communities at higher risk to the effects of storm flooding.

Long Island has had an extensive history of beach erosion dating from at least the 19th century, which has been exacerbated in some areas by 20th century construction of hard structures (e.g., groins, jetties, etc.). Many of these structures were put in place after the disastrous 1938, 1944, and 1953 hurricanes. These were intended to prevent erosion, but interrupted the natural flow of sand carried by longshore currents from Montauk Point to New York City, which led to erosion of beaches downdrift. If not for periodic beach nourishment (addition of sand from off-shore to the beach) by the U.S. Army Corps of Engineers, the beaches would have already narrowed considerably, making the shorelines much more vulnerable to coastal storm damage.



Though effective, beach nourishment programs are quite costly. Nor-Ida (the November 11–14, 2009, nor'easter combined with remnants of Hurricane Ida) resulted in major beach erosion along the south shore of Long Island, including the Rockaways and Plumb Beach in Brooklyn. Point Lookout, the eastern end of Long Beach Island, lost over 219,000 cubic yards of sand from a 5,000-foot stretch of shoreline. In the same storm a 10,000-foot length of shoreline along Robert Moses State Park lost approximately 260,000 cubic yards of sand (David Yang, personal communication, August 2010). At a sand placement cost between \$25 and \$35 per cubic yard, damages associated with erosion just at these two locations were estimated at \$12–17 million. In addition, structural damage to groins along Point Lookout was estimated to be around \$6 million. For Rockaway Beach, the Army Corps of Engineers and other government agencies have committed to conducting beach replenishment to maintain these public resources. For Plumb Beach, used primarily for passive recreation, the USACE is designing a beach nourishment and breakwater project to protect a section of the Belt Parkway that is rapidly eroding (David Yang, personal communication, May 2011).

Other features subject to erosion induced by sea level rise are the glacial bluffs of the north shore and eastern south shore of Long Island (**Figure 5.5**). Bluff erosion supplies sediments to the beach and near-shore coastal system. The amount of material supplied depends on the height of the bluff and the rate of erosion. There are many factors contributing to bluff erosion, but some of the most severe erosion events occur during storms when high water levels allow large waves to attack the base (i.e., toe), removing material and destabilizing the bluff face. The coarse material usually remains on the beach (**Figure 5.5**), while sand and fine-grained materials are transported offshore and to neighboring beaches by waves and currents. In addition to toe erosion by wave action, intense rainfall erodes the bluff face, while percolating rainwater increases the potential for mass wasting.

The few existing studies on the eastern shore of Long Island suggest that only a relatively small portion of the sand eroded from the bluffs is required to maintain the longshore transport system and beaches (Buonaiuto and Bokuniewicz, 2005). Most of the fine-grained material appears to be transported offshore, but a small portion may be deposited in local marshes.

Increased sea level rise may be expected to raise water levels and increase the frequency of wave attack at the base of bluffs. Initially, this would tend to accelerate bluff recession and increase the rate of supply of sediment and other material to the near-shore system. Depending on the type of material and rate at which it is delivered relative to the magnitude of other coastal processes, this change in the supply could have different impacts that are difficult to predict, given our limited understanding of these systems in terms of sediment budgets and transport pathways.

In areas where the bluff composition is primarily fine-grained material not suitable for beach building, sea level rise may be expected to cause increased bluff recession and release more silts and clays. Most of this material will be delivered offshore but some will also be deposited in harbors and marshes. In areas with bluffs composed primarily of sand and other coarse material, increased rates of sea level rise may change



Photo credit: Frank Buonaiuto

**Figure 5.5** Bluff coastline near Montauk Point

the present “equilibrium” between sediment supply and other processes, resulting in enhanced spit accretion, possible beach widening, and/or the formation of other sedimentary structures such as offshore bars, which, in turn, could reduce the rate of bluff recession.

Some of the sands derived from bluff erosion, combined with sand supplied from the continental shelf, contribute to the littoral transport that maintains the state’s barrier island system. Over thousands of years, the barrier islands on the south shore of Long Island have migrated landward in response to rising sea level. Barrier-island migration is primarily controlled by the slope of the coastal plain, sediment supply, the rate of sea level rise, and energy supplied by storms. Some portions of the barrier islands have not migrated over the last 750 to 1,300 years, while others appear to be migrating on timescales of hundreds of years, driven primarily by large storm events (Leatherman and Allen, 1985). It is not certain whether the islands migrate solely by a relatively continuous process (rollover) or by a combination of processes that include continuous rollover punctuated by periods where the barrier essentially drowns in place and then skips or jumps to a new position further landward depending on the rate of sea level rise and sediment supply. This is primarily due to the fact that both the processes driving these systems and the history of barrier island migration and barrier island shoreline changes are poorly documented and understood. Although continuous rollover appears to be the most likely process over the last 6,000 years, there may even have been periods of time when islands didn’t exist.

Inlets that persist for more than several years are believed to be the primary mechanism for transporting sand from the ocean to the bay side of the barrier and providing the platform that allows the barrier to move landward. Overwash processes lower the dune but maintain or raise the elevation of the barrier behind the dune. Massive dune destruction and overwashing have been reported after many historic storms but overwash sediments rarely reach the bay shore, except after major hurricanes and occasionally along the easternmost barriers (Jay Tanski, personal communication, November 2009).

In some areas, marshes have formed on the flood tidal deltas of former inlets. The relative contributions of the

various sources of inorganic sediment used for marsh building (mainland runoff, re-suspension from the bay bottom, breaching, and inlets, etc.) are not known.

Shoreline change rates measured over the last 100 years show that generally the shoreline is receding at relatively low average rates of 1 to 2 feet per year. The largest shoreline changes, both accretion and erosion, are found in the vicinity of stabilized inlets and other structures and are related to the disruption of the longshore transport of sediment along the coast (Kana, 1995). The shoreline change rates in these areas are significantly larger than what would be expected due to sea level rise alone. On decadal timescales, storms and human and natural disruptions of the longshore transport of sand are more important than sea level rise in determining shoreline behavior.

Accelerated sea level rise will tend to exacerbate barrier island erosion problems. At low-to-moderate increases in the rates of rise, the effects of sea level rise will still be of lesser magnitude than storm events and disruptions of the longshore sediment transport in those areas experiencing the most severe erosion problems over the next 30 to 50 years. At the higher rates of projected sea level rise (e.g., the rapid ice-melt scenario), the migration of barrier islands landward should accelerate, but this migration may not be initiated in some sections of the barrier island for hundreds of years due to the present volume of sand in the barrier profile.

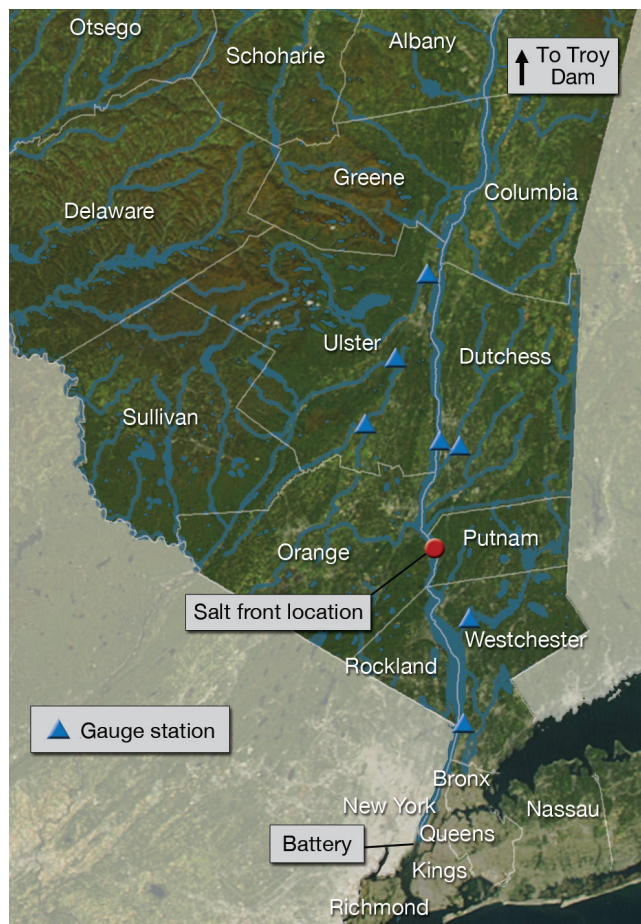
Barrier migration would be preceded by narrowing and lowering of the barriers and increased breaching (in which water intrusion splits islands into two or more parts) and new inlet formation, resulting in changing conditions in the back barrier lagoons. At the most extreme rates of increased rate of rise, the barriers islands may not be able to maintain themselves if sea level rise outpaces the ability of the system to supply sediment naturally. This will expose the bay and mainland shoreline to more oceanic conditions as the barrier disappears.

### 5.3.2 The Hudson River Estuary

The Hudson River Estuary is a narrow, 152-mile arm of the sea that extends from the southern tip of Manhattan north to the Troy Dam (**Figure 5.6**). The river, which has a maximum width of 3 miles in the



Tappan Zee (along the boundary between Rockland and Westchester counties), is influenced by rising sea levels and storm surge up to the dam at Troy. The total length of exposed, eroding river bank along the Hudson River appears to be small, only a few miles in aggregate. Much of the shoreline is rock or it has been stabilized by the construction of the railroad lines. The Hudson River Estuary's shoreline has been dramatically altered over the last 150 years to support industry and other development, contain channel dredge spoils, and to withstand erosive forces of ice, wind, and waves. About half of the natural shoreline has been engineered with revetments, bulkheads, or cribbing, or reinforced with riprap. Many shorelines contain remnant engineered structures from previous human activities. The remaining "natural" shorelines (which have been affected by human activities such as disposal of dredge spoil, invasive species, and contaminants) include a mix of wooded, grassy, and unvegetated communities on mud, sand, cobbles, and bedrock.



**Figure 5.6** Hudson River Estuary with location of salt front on 10/30/2009

The average tidal range along the Hudson River is about 4 feet, peaking at 5 feet at either end of the estuary. The transition from freshwater to saltwater occurs in the lower half of the river, and the position of the salt front (interface between saltwater and freshwater) depends in part on the deposition of sediment on the river bed and the flow of freshwater down the Hudson River (discharge). As the climate changes and sea levels rise, the position of the saltwater and propagation of tide and storm surge throughout the estuary will be altered (see Case Study B. Modeling Climate Change Impacts in the Hudson River Estuary).

Climate change could affect the location of the salt front in three ways: 1) reduction in precipitation can reduce stream flow, allowing the salt front to move upstream, 2) increase in temperature can increase evaporation, reducing freshwater runoff, which in turn would cause the salt front to migrate upstream, and 3) rising sea level may push the mean position of the salt front upstream (Rosenzweig and Solecki, 2001). The rates of northward salt front migration could be higher especially for the rapid ice-melt scenario. However, even in the face of recent, post-glacial sea level rise, there is evidence that saltwater has retreated out of the estuary slightly over the last 6,000 years (Weiss, 1974).

Vertical land movements, tributary inputs, and channel characteristics influence local rates of sea level rise and the propagation of tides and storm surge in the estuary. In addition, changes in channel characteristics associated with increased water levels would alter shoaling (wave transformation) processes, which might lead to changes in tide and surge amplitudes.

Hurricanes and nor'easters are generally accompanied by strong winds, surge, and heavy rain. Not only is the influence of surge propagation throughout New York Harbor and the Hudson River Estuary critical, but the impact of increased freshwater discharge to the coastal regions during storm events is also critical. The timing of freshwater input from the New York and northern New Jersey rivers and direct runoff from the surrounding urban landscape will influence overall water levels around New York City as well as supply nutrients and other land-deposited pollutants to coastal waters. Depending on the time of the year, the excess nutrients and pollutants could lead to further degradation of water quality.



Major river systems discharging into New York Harbor include the Hackensack, Passaic, and Raritan Rivers in New Jersey, as well as the Hudson River. Combined, these river systems constitute a drainage area of approximately 16,640 square miles. This complicated drainage system can influence harbor water levels for several days following a rainfall event, a process that was well documented for Hurricane Floyd (Bowman et al., 2004).

### 5.3.3 Freshwater Resources

In addition to influencing the position of the salt front and storm surge propagation within the Hudson River, sea level rise and changes in precipitation will impact Long Island's water table. The water table will gradually rise at approximately the same rate as sea level. As a result, depending on local conditions, the geographic extent of ponds and wetlands and the carrying capacity of streams may change. This will depend partly on the amount and timing of precipitation in the region. Saltwater entering the aquifers (salt water intrusion and salinization) is a slow process. It is likely that much less than 1 percent of the freshwater reserves would be affected in 100 years. Quantifying the impact that changes in sea level and precipitation patterns will have on Long Island's water table is difficult given the much larger effects of anthropogenic forces such as flood control, groundwater withdrawal, and sewerage.

### 5.3.4 Coastal Ecosystems

Coastal ecosystems are at risk from rising sea levels. Already many tidal marshes are receding in horizontal extent and appear to be collapsing internally as if they are drowning in place (Hartig et al., 2002). Indications include a "Swiss cheese" appearance as they become increasingly ponded (see the Mississippi Delta for an example). While the exact cause of wetland loss is not known, future sea level rise will exacerbate the losses. Current losses are being blamed on multiple stressors, including channelization and armoring of the shoreline (causing sediment starvation), boat waves, excess nutrient loadings (e.g., nitrogen from treated sewage effluent), changes in tidal range (Swanson and Wilson, 2008), excessive bird grazing, overabundance of mussels and sea lettuce, as well as sea level rise.

For coastal ecosystems north of the Tappan Zee Bridge, substantial marsh loss has not been recently documented, although inventories do show loss of native subtidal aquatic beds. These aquatic beds, which are strongly light-limited in the turbid Hudson, are also likely to be sensitive to rising sea levels.

New challenges in protecting remaining coastal ecosystems come from accelerated sea level rise. Where slopes are gradual and land can accommodate the change (even at the expense of forested habitat), under an accelerated sea level rise regime vegetated tidal habitats will shift inland. However, where squeezed between rising sea levels and either human infrastructure or steep slopes, these systems will diminish in size or disappear. The effect is that a previously diverse habitat lying between the deeper waters and uplands (that included the beaches, coastal shoals, mudflats, or marshes) becomes converted to a more simplified, deeper water habitat. A recently released report on coastal sensitivity in the Mid-Atlantic region included the following findings (US EPA/CCSP, 2009):

- Rising water levels are already an important factor in submerging low-lying lands, eroding beaches, converting wetlands to open water, and exacerbating coastal flooding. All of these effects will be increased if the rate of sea level rise accelerates in the future.
- Most coastal wetlands in the Mid-Atlantic would be lost if sea level rises 3 feet in this century. Even a 20-inch rise would threaten most wetlands.

In the New York region, tidal marshes developed over the last 5,000 years after the last glaciers melted and the rate of sea level rise slowed down. Coastal wetlands usually maintain a delicate balance among rates of sea level rise, upward accretion, wave erosion, and sediment deposition, any changes in which could affect the stability of the marsh (Burger and Shisler, 1983; Orson et al., 1985; Allen and Pye, 1992; Varekamp et al., 1992; Nydick et al., 1995; Nuttle, 1997). A salt marsh lies very close to mean sea level and experiences frequent inundation by the tides, which provide nutrients and suspended sediments for accretion. If the marsh grows too high, tidal inundation decreases, with a corresponding decrease in nutrient and sediment supply, thus slowing down accretion and upward growth. Given a sufficient inorganic sediment and nutrient supply, as well as accumulated organic

material, accretion rates for some marshes along the U.S. Gulf of Mexico and Atlantic Coasts can match or exceed present-day local sea level rise (Dean et al., 1987; Titus et al., 1988; Nuttle, 1997). However, where relative rates of sea level rise are too rapid and exceed rates of mineral sedimentation and/or organic accretion, the marsh may begin to drown in place, a process observed in many East Coast wetlands (Downs et al., 1994; Wray et al., 1995; Leatherman and Nicholls, 1995; Kearney et al., 2002; DeLaune et al., 1994; Anisfeld and Linn, 2002; Warren and Niering, 1993). Shifts in marsh vegetation distributions are also sensitive indicators of sea level rise and accretion rates (Bertness, 1991; Donnelly and Bertness, 2001).

In New York, while some marshes are thriving, recent studies indicate dramatic losses of other salt marshes over the last several decades (Table 5.5). At Jamaica Bay (Gateway National Recreation Area), island salt marsh area declined by 20 percent between the mid-1920s and mid-1970s; since then this trend has accelerated and close to 30 percent has subsequently been lost (Hartig et al., 2002; Rosenzweig and Solecki, 2001; Gornitz et al., 2002; NYSDEC, 2003). Only 7 out of 13 salt marsh islands in Shinnecock Bay (southeastern Long Island) that were present in 1974 remained by 1994 (Fallon and Mushacke, 1996). The apparent submergence of these islands was partially compensated by inland migration of salt marshes, an indicator that sea level rise is a contributing factor.

Location	Acres  (1974)	Acres and Year of Observation		Change Since 1974	
			(1995 to 2000)	(% Loss)	(% Loss / Year)
North Shore and Long Island Sound					
Alley Pond Park/Flushing Bay	18	17	1999	3	0.1
Manhasset Bay	25	9	1994	60	3.0
Marshlands Conservancy	35	24	2000	31	1.2
Pelham Bay Park					
Hutchinson River near Coop City	51	28	1999	45	1.8
Orchard Beach/City Island	77	51	1999	33	1.3
Stony Brook Harbor Area	299	190	1999	36	1.5
Udalls Cove Park	20	13	1999	38	1.5
South Shore					
Jamaica Bay	1969	1223	1999	38	1.5
Oyster Bay Area	1300	1016	1998	22	0.9
Shinnecock Bay—Islands only	30	17	1995	40	1.9

Note: Coastal marsh acreage in New York State observed in 1974 and the late 20th century, and percentage change in area. Source: (Hartig et al., 2002, 2004; Fallon and Mushacke, 1996; and NYSDEC, 2004)

**Table 5.5** Reductions in extent of vegetated salt marshes, NY, between 1974 and 2000

More recently, Mushacke (NYSDEC, 2004) has documented additional marsh loss on the north and south shores of Long Island. Multiple factors, including dredging, bulkheading, and excessive nutrient enrichment, may be dominant at these sites. The New York State Department of State (NYSDOS), under the Coastal Zone Management Act, is also recording coastal wetland changes on Long Island's south shore. In the areas examined, there were losses as well as gains, although gains were not enough to compensate for losses (Jeffrey Zappieri, personal communication, 2003).

Marsh loss in Long Island and New York City has been documented through GIS analysis of historic aerial photographs (Table 5.5). By comparing 1974 images with those from between 1994 and 2000, a percent loss per year was derived. Marsh losses over the period were mainly between 1 and 2 percent per year. These losses were unexpected prior to the analysis, and the exact causes have yet to be determined. While sea level rise is among several stressors that may be acting together on vulnerable marshes, it may become the dominant factor in future decades as it outpaces sedimentation and vertical accretion.

Table 5.6 indicates the rate of sea level rise according to local tide gauges, the oldest of which was installed in 1856 and is located at the Battery in New York City. According to this tide gauge, sea level rise has been approximately 0.109 inch per year, or almost 1 foot per century over this period. In order for marshes to be sustainable, they need to at least keep pace with sea level rise. As indicated in Table 5.5, many marshes are already not keeping pace and are receding. The wetland loss rate, for example, at Jamaica Bay, Udalls Cove Preserve, and Stony Brook Harbor is 1.5 percent per year.

Station	Sea Level Rise (inches/yr)	Sea Level Rise (ft/century)	Record Length (years)
Bridgeport, CT	0.101	0.84	1964–2006
New London, CT	0.089	0.74	1938–2006
Montauk, NY	0.109	0.90	1947–2006
New York City, NY	0.109	0.90	1856–2006
Port Jefferson, NY	0.096	0.80	1957–1992
Willels Point, NY	0.093	0.78	1931–2006
Atlantic City, NJ	0.157	1.31	1911–2006
Cape May, NJ	0.160	1.33	1965–2006
Sandy Hook, NJ	0.154	1.28	1932–2006

Source: <http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml>

**Table 5.6** Relative sea level rise for the Atlantic coastal areas of New York, New Jersey and Connecticut according to local tide gauges

**Table 5.7** gives known accretion rates for different marshes together with the rate of sea level rise according to the nearest tide gauge station. This provides a first-order guide in assessing the ability of these particular marshes to keep pace with increasing water levels. It should be noted that this analysis does not include subsurface compaction, which may be occurring.

Additional measurements are being taken at some marshes using sediment elevation tables (SETs) together with marker horizons. At Fire Island National Seashore SETs were placed together with feldspar markers to measure both shallow subsidence and accretion at the surface (Roman et al., 2007). As measured over a five-year period at three different marsh locations, there was a net loss of elevation. At two of the locations, surface accretion was greater than the rate of sea level rise; nevertheless, the rate of accretion was not enough to compensate for the overall land subsidence plus sea level rise. Likewise, in Jamaica Bay, initial data analysis indicates that while accretion is occurring beyond the rate of sea level rise, low marsh-dominated areas are subsiding at accelerated rates (Elders Point Marsh), while high marsh areas are experiencing more minimal loss rates (JoCo Marsh) (Jim Lynch, personal communication, 2009). As described in Case Study C: Salt Marsh Change at New York City Parks and Implications of Accelerated Sea Level Rise, Elders Point Marsh is

being supplied with sediment supplements to raise the marsh elevation artificially.

The impacts of GCM-based and rapid ice-melt sea level rise scenarios on tidal wetlands for the 2020s, 2050s, and 2080s (**Table 5.1**) are evaluated for Long Island, New York City and Lower Hudson Valley, and separately for the Mid-Hudson Valley and Capital Region (**Table 5.8**). A sensitivity study was performed in order to evaluate the ability of marshes to keep pace with sea level rise alone (not accounting for subsurface

State	Marsh Zone	Accretion Rate (in/yr)	SLR (in/yr)	Source
Alley Pond (Queens, NY)	high	0.14	0.09	Cochran et al. (1998)
Caumsett Park (Nassau, NY)	high	0.16	0.09	Cochran et al. (1998)
Goose Creek (Bronx, NY)	high	0.09	0.09	Cochran et al. (1998)
Hunter Island (Bronx, NY)	high	0.04	0.09	Cochran et al. (1998)
Jamaica Bay (Queens, NY)		0.11-0.17	0.11	Kolker (2005)
Jamaica Bay (Queens, NY)	high	0.2	0.11	Zeppie (1977)
Jamaica Bay (Queens, NY)	low	0.31	0.11	Zeppie (1977)
Stony Brook, Youngs Island (Suffolk, NY)	high to low	0.09-0.11	0.09	Cademartori (2000)
Stony Brook, Youngs Island (Suffolk, NY)		0.14-0.19	0.09	Cochran et al. (1998)

Note: Lead 210 was used as method for determining accretion rates from soil cores. As SET/marker horizon data become available marsh accretion rates will be accompanied by rate of subsurface subsidence to determine change in net marsh elevation.

**Table 5.7** Surface accretion rates measured in the salt marshes of the New York city region compared with the mean rate of sea level rise

Decade	2020s			2050s			2080s		
Accretion Rate (in)	L	M	H	L	M	H	L	M	H
Lower Hudson Valley, New York City & Long Island									
Central Range									
lower range	-0.50	<b>1.00</b>	<b>2.50</b>	-2.50	<b>2.00</b>	<b>6.50</b>	-4.50	<b>3.00</b>	<b>10.50</b>
upper range	-3.50	-2.00	-0.50	-7.50	-3.00	<b>1.50</b>	-15.50	-8.00	-0.50
Rapid Ice-Melt									
lower range	-3.50	-2.00	-0.5	-14.50	-10.00	-5.50	-33.50	-26.00	-18.50
upper range	-8.50	-7.00	-5.50	-24.50	-20.00	-15.50	-47.50	-40.00	-32.50
Mid-Hudson Valley & Capital Region									
Central Range									
lower range	<b>0.50</b>	<b>2.00</b>	<b>3.50</b>	-0.50	<b>4.00</b>	<b>8.50</b>	-0.50	<b>7.00</b>	<b>14.50</b>
upper range	-2.50	-1.00	<b>0.50</b>	-4.50	0.00	<b>4.50</b>	-10.50	-3.00	<b>4.50</b>
Rapid Ice-Melt									
lower range	-2.50	-1.00	<b>0.50</b>	-12.50	-8.00	-3.50	-29.50	-22.00	-14.50
upper range	-7.50	-6.00	-4.50	-21.50	-17.00	-12.50	-42.50	-35.00	-27.50

Note: L = Low (0.1 inch/yr), M = Medium (0.2 inch/yr), and H= High (0.3 inch/yr) accretion rates. Negative numbers indicate drowned marshes; positive numbers in bold indicate marsh survival. This simple model accounts only for sea level rise and accretion; subsurface compaction, subsidence, and other potential causes of marsh loss are neglected. Accretion calculated from 2010 to 2020s (15 years); 2010 to 2050s (45 years); 2010 to 2080s (75 years). Numbers represent the difference in assumed accretion rates and rates of sea level rise from Table 5.1.

**Table 5.8** Chances for marsh survival given projected sea level rise (inches) and low, medium, and high rates of accretion for the 2020s, 2050s, and 2080s



compaction). The range of sea level rise projections from **Table 5.1** is used in combination with observed low (0.1 inch per year), medium (0.2 inch per year), and high (0.3 inch per year) accretion rates to offer a simple model of marsh survival in the coming decades. In order to construct the projections, each accretion rate was multiplied by the time span from the year 2010 to the mid-point of each decade (i.e., 2025, 2055, and 2085), and the accumulated accreted elevation is compared with the projected sea level rise. If sea level is greater than the potential accreted marsh, the marsh is considered drowned (negative numbers). If the potential accreted marsh has an elevation at least as great as the projected sea level, the marsh survives (positive numbers).

For Long Island, New York City, and Lower Hudson Valley, results indicate that only given medium or high accretion rates would marshes survive under the central range of projected sea level rise by the 2020s. None would survive the rapid ice-melt scenario. According to the analysis, the marshes have a slightly better chance in the Mid-Hudson Valley and Capital Region, with more marshes surviving in the GCM-based scenarios. In addition, marshes could survive a rapid ice-melt scenario only until the 2020s if they had a high-enough marsh accretion rate.

The marshes of New York State provide a dense urban population close access to a natural ecosystem rich in wildlife and recreation opportunities, function as buffering protection against coastal storm damage, furnish important habitat for migratory birds along the Atlantic Flyway, and act as productive nurseries for local fisheries (Wells, 1998). Losing marsh acreage to submergence at a rate of 1 percent and more per year compromises their function and value. Further research is needed to improve our understanding of the underlying causes of marsh loss in New York State in order to be able to conserve these marshes for future generations.

### 5.3.5 Fish and Shellfish Populations

New York has an extensive marine coastline, composed of Long Island Sound, all of Long Island's south shore, and portions of New York City. The lower Hudson River also is saline, grading toward freshwater northward. New York's marine waters lie in the northern portion of the Virginian Zoogeographic Province (Cape Cod to

Cape Hatteras). This province is situated between the colder Acadian and the warmer Carolinian provinces. Fish diversity in New York's marine waters is high. Briggs and Waldman (2002) list 326 recorded marine and estuarine species.

#### *The Marine Environment of New York*

The high biodiversity in New York State marine waters is due in part to the great variety of habitats (e.g., estuaries, coastal bays, tidal straits, ocean beaches, continental shelf) and to the pronounced seasonal temperature changes that occur (Briggs and Waldman, 2002). The inner New York Bight has a range of about 25°C between summer and winter surface temperatures (from 1°C to 26°C) and bottom temperatures vary from a maximum of about 21°C in summer to less than 1°C in winter. Although many temperature-tolerant fish occur in New York waters year-round, these large seasonal temperature changes favor migratory rather than sedentary fish fauna (Grosslein and Azarovitz, 1982).

A relevant ecological feature of the lower Hudson River and Long Island's south shore bays is that they receive warm waters as eddies that pinch off from Gulf Stream meanders. These warm-core rings, approximately 100 kilometers in diameter, also carry early life stages of "tropical" fish that mature in New York waters through summer and early autumn. Although species composition varies, this is an annual phenomenon, and regularly includes groupers (*Epinephelus*), snappers (*Lutjanus*), butterflyfishes (*Chaetodon*), and jacks (*Carangidae*).

New York also lies at the juncture of the commercially viable ranges of two important crustaceans: American lobster and blue claw crab. Lobster is a cold water species that is harvested in numbers as far south as Long Island Sound and the New York Bight. Blue claw crab is a southern species that is abundant as far north as Long Island Sound.

To date, little attention has been focused on the biological effects of sea temperature changes in New York waters. Circumstantial evidence indicates that some faunal shifts already have occurred, most notably the extirpation late in the 20th century of a boreal species, rainbow smelt, in the Hudson River (Waldman, 2006) and in tributary streams to Long Island Sound. Another cold water species, Atlantic tomcod, also is

showing declines in the Hudson River (Waldman, 2006) and is rare or absent in other former New York habitats. In contrast, a euryhaline (tolerates fresh to salt waters) species, gizzard shad, once found north only to Sandy Hook, has since the 1970s colonized the Hudson River and has become established as far north as the Merrimack River, Massachusetts.

### *Predicted Effects of Climate Change on Temperatures of New York Waters*

Water temperatures in the Hudson River already have shown substantial warming. Although their data from Poughkeepsie do not include the past 20 years, Ashizawa and Cole (1994) found a statistically significant trend of 0.22°F per decade between 1920 and 1990, a change they believed was consistent with global increases.

For the New York Bight, our forecasted sea surface temperature changes for the 2050s in comparison with a 1980s baseline derived from the CCSM and GFDL models under two emissions scenarios all show substantial increases for its near-shore waters. These increases are on the order of 1.8 to 3.2°F, depending on the model and emissions combination. Visual inspection of sea surface isotherms from the mid-1900s at 1°F resolution (Fuglister, 1947) indicates that differences of these magnitudes between Long Island and warmer waters to its south correspond geographically with points between the southern tip of the Delmarva Peninsula and Delaware Bay, varying by month. Thus, the present-day fish community of the Delaware coast provides a glimpse of what the fish community of New York may resemble in the 2050s.

### *Likely Responses of Fish and Shellfish to Temperature Changes in New York Waters*

There is considerable overlap in marine fish communities between the Delmarva region and New York, but there also are differences. Warm-water fish frequently seen in this southern region (Hildebrand and Schroeder, 1928) that are only rarely observed in New York include tarpon, cobia, and cownose ray. A higher-order difference is the greater prominence of members of the drum family (Sciaenidae) rarely seen in New York, including croaker, spotted seatrout, and red drum. The Delmarva region also does not support inshore

winter fisheries for gadoids seen in New York Bight waters in cold months, such as Atlantic cod, pollock, silver hake, and squirrel hake.

Among important macrocrustaceans, blue claw crabs flourish in the warmer waters of the mid-Atlantic and should not decline because of higher temperatures. However, lobsters are at the southern edge of their inshore range in New York and have already shown declines that may be linked to warming waters (Howell et al., 2005).

Other fish whose northern ranges have extended to New York in the past include black drum and sheepshead. Both were recreationally and commercially harvested in New York Harbor and New York Bight waters in the 1800s but have been exceedingly scarce since. The reason may be habitat loss: Both are closely associated with oyster reefs, which declined sharply at the same time (Waldman et al., 2006). Both warming waters and increasing numbers of oysters (naturally occurring and through restoration projects) may result in increased abundances of these fish in New York.

A difficulty in discerning climate-driven changes in marine fish distributions is that the signal from the climatic effects may be highly confounded by other factors. Even under nearly constant environmental conditions, fish distributions are not static. Population theory and observations indicate that fish populations occupy the most optimal habitats under low abundances but also disperse into less optimal habitats at high abundances (MacCall, 1990). This means that mainly mid-Atlantic species that are only rarely or periodically seen in numbers in New York waters may occur there largely as a function of density dependence (relative population size within an area) and not because of favorable temperatures. Primarily southerly fishes that have appeared in New York during high population abundances include spot and Spanish mackerel (Waldman et al., 2006). Bluefish and weakfish are two other economically important fishes that are numerous in New York waters only during periods of high coast-wide abundances.

Another source of complexity is changes in fish and crustacean communities that occur because of ecological regime shifts, of which climate change may be a major driver. At nearly the same latitude as Long Island Sound in the waters of Rhode Island, Oviatt (2004) showed that modest increases in water

temperatures caused large ecological shifts, in which macrocrustaceans (e.g., crabs, lobster) and southern pelagic fish (e.g., bay anchovy, butterfish) were favored at the expense of boreal demersal fishes (e.g., winter flounder, red hake).

A challenge in assessing changes in New York's marine fish community in the future will be to parse the effects of climate change from the normal seasonal and density-dependent vagaries of fish population dynamics. Annual long-term monitoring of fish and macrocrustaceans is critical to detecting climate-associated faunal changes in New York's marine waters. Both tracking fish community assemblages over time and observing the annual abundances of certain key species that are on the edges of their northern or southern distributions are important.

#### *Impact of Increased CO<sub>2</sub> Concentrations and Ocean Acidification in New York Waters*

The ocean is becoming more acidic as increasing atmospheric carbon dioxide is absorbed at the sea surface. Models and measurements suggest that surface pH has decreased by 0.1 pH unit since 1750 (Bindoff et al. 2007). It has been estimated that approximately half of the increased carbon dioxide emissions due to burning of fossil fuels since the Industrial Revolution has been absorbed in the ocean's surface waters (Sabine et al. 2004). However, continued acidification will reduce the ability of the ocean to take up atmospheric CO<sub>2</sub> and have potential negative impacts on finfish, shellfish, and plankton populations.

Much of the early research has been focused on calcifiers, which are believed to be most vulnerable during early developmental and reproductive stages of their life cycles. Kurihara (2008) notes that ocean acidification has negative impacts on the fertilization, cleavage, larva, settlement, and reproductive stages of several marine calcifiers, including echinoderm, bivalve, coral, and crustacean species. In addition, this research suggests that future changes in ocean acidity will potentially impact the population size and dynamics as well as the community structure of these species, influencing the overall health of marine ecosystems.

For New York coastal water, the relatively minor increases in ocean acidity brought about by high levels of carbon dioxide are likely to have significant

detrimental effects on the growth, development, and survival of hard clams, bay scallops, and Eastern oysters (Talmage and Gobler, 2009). Recent research has shown that the larval stages of these shellfish species are extremely sensitive to enhanced levels of carbon dioxide in seawater; under carbon dioxide concentrations estimated to occur later this century, clam and scallop larvae showed a more than 50 percent decline in survival (Talmage and Gobler, 2009). These larvae were also smaller and took longer to develop into the juvenile stage. Oysters also grew more slowly at this level of carbon dioxide, but their survival was only diminished at carbon dioxide levels expected next century. The more time these organisms spend in the water column, the greater their risk of being eaten by a predator. A small change in the timing of the larval development could have a large effect on the number of larvae that survive to the juvenile stage and could dramatically alter the composition of the entire population (Talmage and Gobler, 2009).

Although it appears that fish are able to maintain their oxygen consumption under elevated carbon dioxide levels, the impacts of prolonged CO<sub>2</sub> exposure on reproduction, early development, growth, and behavior of marine fish are important areas that need urgent investigation (Ishimatsu et al., 2008). Changes in ocean chemistry might also affect marine food webs and biogeochemical cycles but are less certain because of their complexity (Haugan et al., 2006). Important global biogeochemical cycles (e.g., of carbon, nutrients, and sulfur) and ecosystem processes (changes in community structure and biodiversity) other than calcification may be vulnerable to future changes in carbonate chemistry and to declining pH.

## 5.4 Adaptation Strategies

As beaches retreat, wetlands disappear, and storm damage becomes more severe, coastal development and infrastructure will face increasing threats, regional tourism and fishing industries could suffer, and the insurance industry will increasingly be called upon to buffer economic losses (Frumhoff et al., 2007). Communities and industries must be able to adapt to these changes over the long term, in a manner that is economically, socially, and environmentally sustainable.



### 5.4.1 Adaptations for Key Vulnerabilities

It is difficult to determine an effective course of action, since natural processes within these dynamic systems operate on different time scales and are poorly understood. Implementation of adaptation strategies is further complicated by the division of power and jurisdiction in the coastal zone between various levels of government and different agencies. Regional-scale adaptation strategies presented in the ClimAID report assume that the legal and institutional changes necessary for implementation can be achieved. However, there will likely be competing and/or conflicting adaptation strategies depending on the objective. This will require a public process to achieve resolution. This section introduces some basic adaptation strategies and frameworks for evaluating the most effective methods to reduce vulnerability.

#### *Coastal Storms, Coastal Floods, and Coastal Erosion*

For coastal flooding and storm damage reduction, regional adaptation strategies will depend on economic, social, and environmental factors such as the desired level of protection, level of development, presence of critical infrastructure and natural resources, and consequences to the environment and neighboring communities. An example framework for evaluating possible adaptation strategies from the perspective of storm damage reduction to infrastructure is provided in **Table 5.9**. For example, beach nourishment (addition of sand from offshore or inland areas) is often used to protect coastal communities from flooding, and the level of protection depends on the design criteria, which

are often constrained by financial resources and stakeholder/sponsor requirements. Sand can be placed on beaches relatively quickly (less than one year) and the projects are usually designed to last around five years. The actual life of the project depends strongly on the rate of erosion, which is associated with storm activity. As the rate of sea level rise increases, the rates of erosion increase and sand placement projects will become more expensive. Approximately 1 million cubic yards of sand are placed on New York beaches each year (Lynn Bocamazzo, personal communication, 2009). It has been estimated that the additional sand volume needed to compensate for sea level rise could range between 2.3 percent and 11.5 percent of the total current placement for the 2020s and 18 percent to 26 percent by the 2050s (Gornitz and Couch, in Rosenzweig and Solecki, 2001). A substantial volume of suitable sand (approximately 10 billion cubic yards) is present on the continental shelf and could be mined for this purpose (Bliss et al., 2009).

Depending on the level of development, communities may choose to implement a slow retreat or phased withdrawal from the coast. This could entail the use of hard (e.g., seawalls, storm surge barriers, rip rap) and soft (e.g., beach nourishment and beach drainage, beach vegetation) engineering solutions as well as the adoption of more policy-based strategies. For example, coastal communities may periodically place sand on beaches or use seawalls and groins to protect critical infrastructure. Coastal development and storm damage could be reduced by re-evaluating the delineation of coastal erosion hazard areas, improving building codes to promote more storm-resistant structures, increasing

Adaptation Strategy	Level of Development	Level of Protection	Time Imp/Life*	Potential Consequences	SLR**	
					GCM	RIM
Beach Nourishment	All	Up to 1-in-100 yr flood	< 1-yr/ 3–7 yrs	Steepen profile, reduce overwash sediments to bay, habitat disruption	X	X
Moderate Engineering Solutions*	Urban to suburban	Up to 1-in-100 yr flood	2–5 yrs/ 20–50 yrs	Reduced littoral sediments creates downdrift erosion	X	
Macro Engineering Solutions**	Urban	> 1-in-100 yr flood level	10–15 yrs/ 75–150 yrs	Alter regional hydrodynamics, habitat disruption		X
Slow Retreat	Suburban to rural	NA	NA	Depends on strategies used	X	
Rapid Retreat	Suburban to rural	NA	NA	Loss of equity, decreased property values		X
Do Nothing	All	NA	NA	Catastrophic loss of property and natural resources	X	X

\* Time necessary for implementation of adaptation measure and life expectancy of project. Estimates do not include the political/legal/scientific processes necessary for design and implementation.

\*\* Sea level rise scenarios, GCM for central range and RIM for rapid ice-melt.

# Moderate engineering structures such as seawalls, revetments, groins, and bulkheads.

## Macro engineering structures such as storm surge barriers and dikes.

**Table 5.9** Example adaptation strategy framework for flood-damage reduction

building setbacks, and implementing rolling easements in regions of new development. In addition, depending on the financial resources and land availability, communities may institute buyout or land swap programs to encourage migration out of flood-prone regions. These strategies could be coupled with re-establishment of natural shoreline habitats to promote tourism and ecosystem services.

For urbanized areas, phased withdrawal may not be possible and communities may choose to use micro- (e.g., bulkheads, groins, seawalls) and macro-engineering (e.g., storm surge barriers, system of levees and dikes) solutions to prolong the use of coastal properties and infrastructure. For example, lower Manhattan is home to such critical transportation infrastructure as FDR Drive, West Street, the West Side Highway, the Port Authority Trans-Hudson (PATH) tunnels linking Manhattan and New Jersey, and the Brooklyn-Battery auto tunnel entrance.

The 2010 report of New York City Panel on Climate Change (Rosenzweig and Solecki, 2010) recommends that sea level rise projections should be incorporated into regulatory maps of coastal areas, including FEMA Flood Insurance Rate Maps (FIRMs) and their A- and V- Zones, the SLOSH model, and the delineation of the Coastal Zone Boundary and Coastal Erosion Hazard Areas.

Currently concrete bulkheads and seawalls protect much of this region; however, higher projected ocean levels may mean that these structures will need additional protection. Rather than armor the coastline of New York City and the surrounding boroughs, it may be more cost effective to construct storm surge barriers and dikes. Initial hydrodynamic studies have explored

the feasibility of such a project; however, the economic, social, and environmental impacts have not been assessed (Bowman et al., 2004). Regardless of the adaptation strategy a community chooses to institute, a strong public outreach component should be undertaken for successful implementation.

### Coastal Ecosystems

The framework presented in **Table 5.9** could be expanded to include various sustainable technologies or criteria for evaluation, or developed for other coastal components. For example, some possible adaptation strategies for saltwater wetlands are illustrated in **Table 5.10**. These strategies are applicable for a wide range of rates of sea level rise and therefore may not include sea level rise as a critical evaluation criterion.

#### 5.4.2 Co-Benefits, Unintended Consequences, and Opportunities

Coastal systems are dynamic, and a loss of beach or habitat in one area may result in the gain or opportunity for expansion of habitats in another area. For example, increased beach erosion may lead to dune overwash and, in more severe cases, barrier island breaching and migration. Breaching and the creation of new inlets could adversely impact existing marshes but could also provide areas for the potential creation of new marshes under the right conditions. However, not enough is known about the sedimentary systems or budgets within the state's bays to make predictions about the relative importance of these features in terms of supplying inorganic sediments necessary for marsh maintenance and accretion.

Adaptation Strategy	Level of Development	Level of Protection	Time Imp/Life*	Potential Consequences
Wetland restoration	All	Appropriate waterfront sites where tidal inundation can be restored	2–5 yrs/ 10–100 yrs	Convert former wetlands along the waterfront that had been used for other land uses
Wetland creation	All	In newly established flood zones as SLR continues	2–10 yrs/ 10–100 yrs	Where new flooding is occurring, convert upland sites along the waterfront to wetlands
Sediment augmentation in submerging marshes	All	Up to mean higher high water (MHHW) line	2–5 yrs/ 10–100 yrs	Sediment must be diverted/taken from elsewhere
Wetland regulations: Use maximum allowable buffer area to allow for inland migration of marshes	All	150–300 feet beyond the wetland boundary	5–10 yrs 10–40 yrs	Development community will challenge tighter controls on wetland adjacent area permits

\* Time necessary for implementation of adaptation measure and life expectancy of project. Estimates do not include the political/legal/scientific processes necessary for design and implementation.

**Table 5.10** Example strategy framework for wetland adaptation

Warmer waters will also be more hospitable to fish species that normally range near New York, but rarely reach it under current conditions. For example, blue claw crabs are becoming more abundant in New York waters, and this particular fishery should be enhanced as the climate changes.

## 5.5 Equity and Environmental Justice Considerations

As climate change progresses, New York State's coastal ecosystem will undergo physical, chemical, and biological transformations. These transformations will have uneven impacts on coastal residents and coastal communities.

### 5.5.1 Vulnerability

The coastal vulnerability index (CVI) provide a comprehensive summary of vulnerability arising from geologic and hydrodynamic processes; however, they do not incorporate socioeconomic interactions (Thieler and Hammar-Klose, 1999). A combination of both physical and social factors can provide some measure of coastal resilience of a population or region and begin to identify potential inequities.

Flooding and natural hazards can disproportionately impact certain socioeconomic groups, such as people of color and low-income communities (Wu et al., 2002; Fothergill et al., 1999). Often this is an expression of physical vulnerability, such as pre-Katrina New Orleans, where low-lying areas at risk of inundation were home largely to African Americans. Frequently, physical vulnerability to a hazard is compounded by intrinsic individual vulnerabilities—related to age and physical immobility, for example—as well as a host of contextual vulnerabilities that can surface in every phase from prevention to relief, recovery, and reconstruction (Morrow, 1999). Contextual vulnerabilities are frequently an expression of underlying socioeconomic inequities and barriers: Low-income communities are less likely to have access to a full range of preventative strategies, such as resources to fortify property, prepare emergency provisions, and acquire insurance (Morrow, 1999; Yarnal, 2007).

Discriminatory practices and policies—from insurance redlining to constrained transportation options—may create systematic barriers to communities of color (Wright and Bullard, 2007). Other groups, such as renters, may lack the proper incentives to make precautionary investments, while people who speak English as a second language may be particularly vulnerable to miscommunications about preventative strategies and risks (Fothergill et al., 1999). Even when the risks have been made clear, housing discrimination or lack of affordable options may prevent certain groups from accessing the full range of relocation options (Wright and Bullard, 2007).

Some subsets of women may also have particular vulnerabilities. In general, women earn lower average incomes than men, tend more than men to be single parents, and are more likely to perform the labor of childcare, housework, and caring for elderly family members (Root et al., 2000). During extreme events and post-disaster recovery, these burdens and responsibilities may manifest as a disproportionate amount of hardship, lost income, increased labor, and emotional stress related to family care (Bolin et al., 1998; Morrow, 1999).

Relief, recovery, and reconstruction efforts are often associated with unequal access to emergency and recovery loan assistance and inadequate resources for compensation of health and property losses. At a community or city level, planning for sea level rise and increased coastal flooding at this stage requires an inherently strong equity framework: Both real and perceived inequities have plagued rebuilding following past hurricanes and coastal storms, when victims have often found themselves confronted with pre-planned packages of redevelopment doled out in top-down fashion to a handful of influential corporations (Wright and Bullard, 2007). Furthermore, federal disaster funds often focus first on issues of critical regional connectivity (restoring major arteries and highways), which increases the likelihood that local jurisdictions with little capacity will have to take responsibility for the finer-grained service restoration, the scale at which inequities often play out.

**Table 5.11** shows an estimated breakdown of the population living in the 100-year floodplain in New York City and Long Island. Population estimates were generated using data from the 2000 census aggregated at the block group level and weighted by the area of



each block group located within FEMA's 100-year floodplain boundaries. These estimates likely underestimate both the current total population in the floodplain and the affected subpopulations.

While it is difficult to discern precisely how a 1-in-100-year storm event would impact the regional economy of Long Island and New York City, **Table 5.11** gives some indication of the stakes. It also offers a snapshot of fundamental regional differences in household economies and demographics. Estimated aggregate value of all owner-occupied housing located within the 100-year floodplain in ClimAID Region 4 (New York City and Long Island) topped \$27.5 billion in the 2000 census (not adjusted for inflation). In contrast to the

distribution of vulnerable renters, which is skewed heavily toward the urban centers of New York City, approximately half the regional value of owner-occupied housing is located in Nassau County. This graduated pattern of suburban homeownership and urban renting parallels differences in population density across the coastal region of Region 4. Of the more than 500,000 people estimated to reside in the 100-year floodplain, a majority lives in coastal New York City with density decreasing gradually across Nassau and Suffolk (**Figure 5.7**).

Many coastal communities on the south shore of Long Island are fairly affluent. Indeed, **Table 5.12** indicates that residents within FEMA's 100-year floodplain tend

	New York City	Nassau County	Suffolk County	Total
<b>Population</b>				
Total population	286,374	159,644	70,523	516,541
Over 65	41,305	24,188	9,882	75,375
Below poverty line	61,260	8,895	4,550	74,703
African American	72,559	7,932	2,013	82,504
Latino	64,447	13,652	4,745	82,844
Foreign born	77,036	21,542	6,114	104,691
<b>Housing</b>				
Occupied housing units	110,194	58,206	27,103	195,503
Renter occupied housing units	77,003	13,930	5,428	96,360
Aggregate value of owner-occupied housing (Millions)	\$8,255	\$13,342	\$6,171	\$27,768

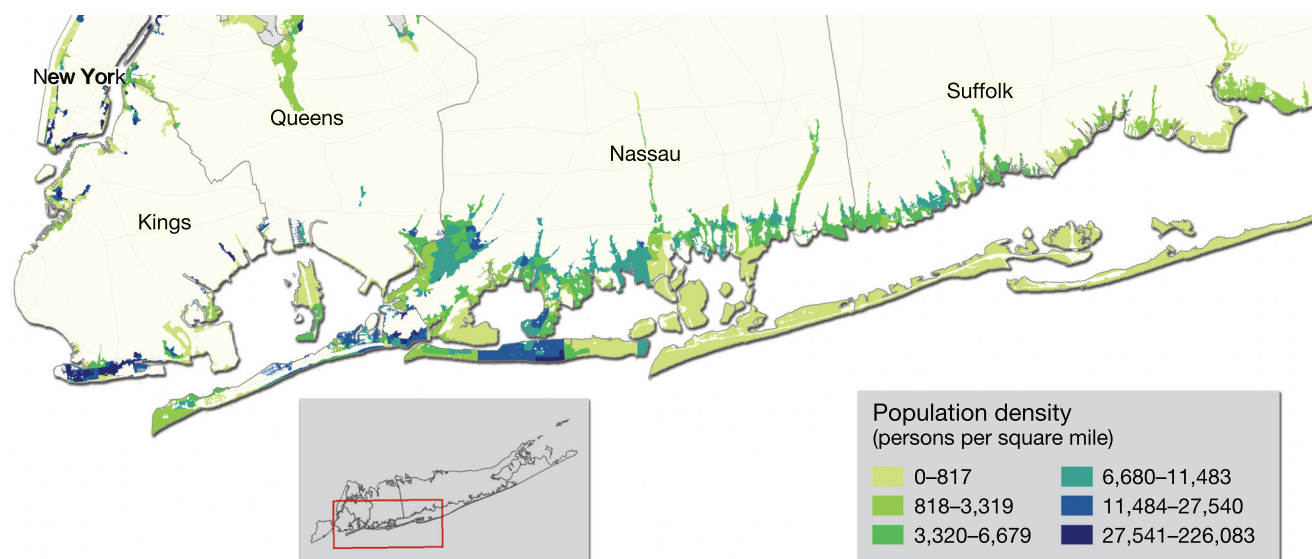
Source: US Census 2000; authors' calculations as described above

**Table 5.11** Profile of the population residing in the 100-year floodplain (ClimAID Region 4—New York City and Long Island)

	In Floodplain	Out of Floodplain
Median Income	\$56,132	\$48,551
Median housing value, owner occupied housing	\$235,297	\$229,149
Female head of households as percentage of total	20.2	26.5
% in poverty	12.8	17.1
% less than high school	18.7	25.5
% over 65	14.2	12.2
% African American	12.6	23.0
% Hispanic	15.4	22.1
% renter	41.5	54.1
% vacant housing	9.5	5.2
% foreign born	18.9	30.2

Source: U.S. Census 2000; weighting by authors' calculations

**Table 5.12** Area-weighted characteristics of population in census block groups in and out of the 100-year floodplain for New York City and Suffolk and Nassau Counties

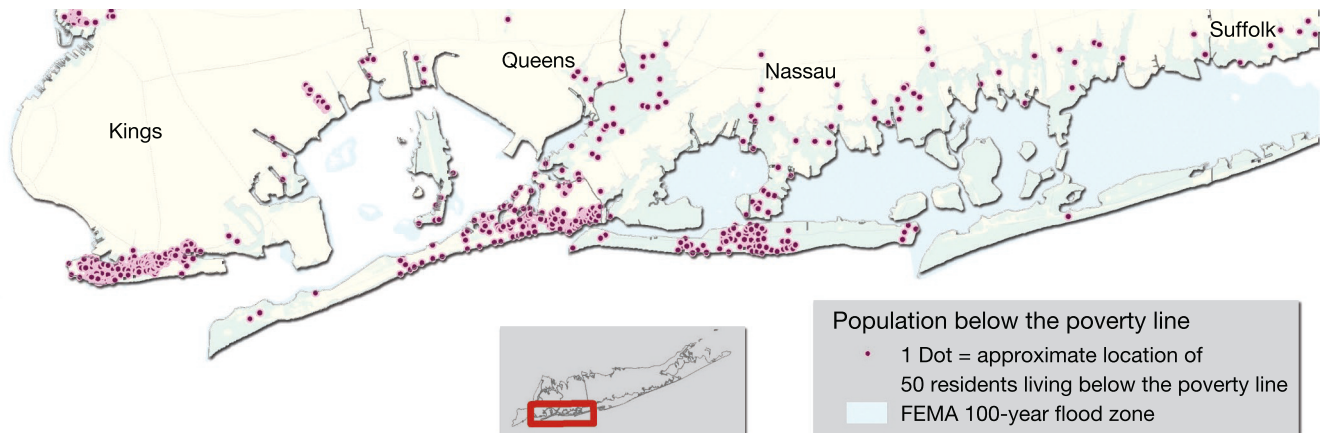


**Figure 5.7** Population density within the FEMA 100-year floodplain boundaries

Source: US Census 2000

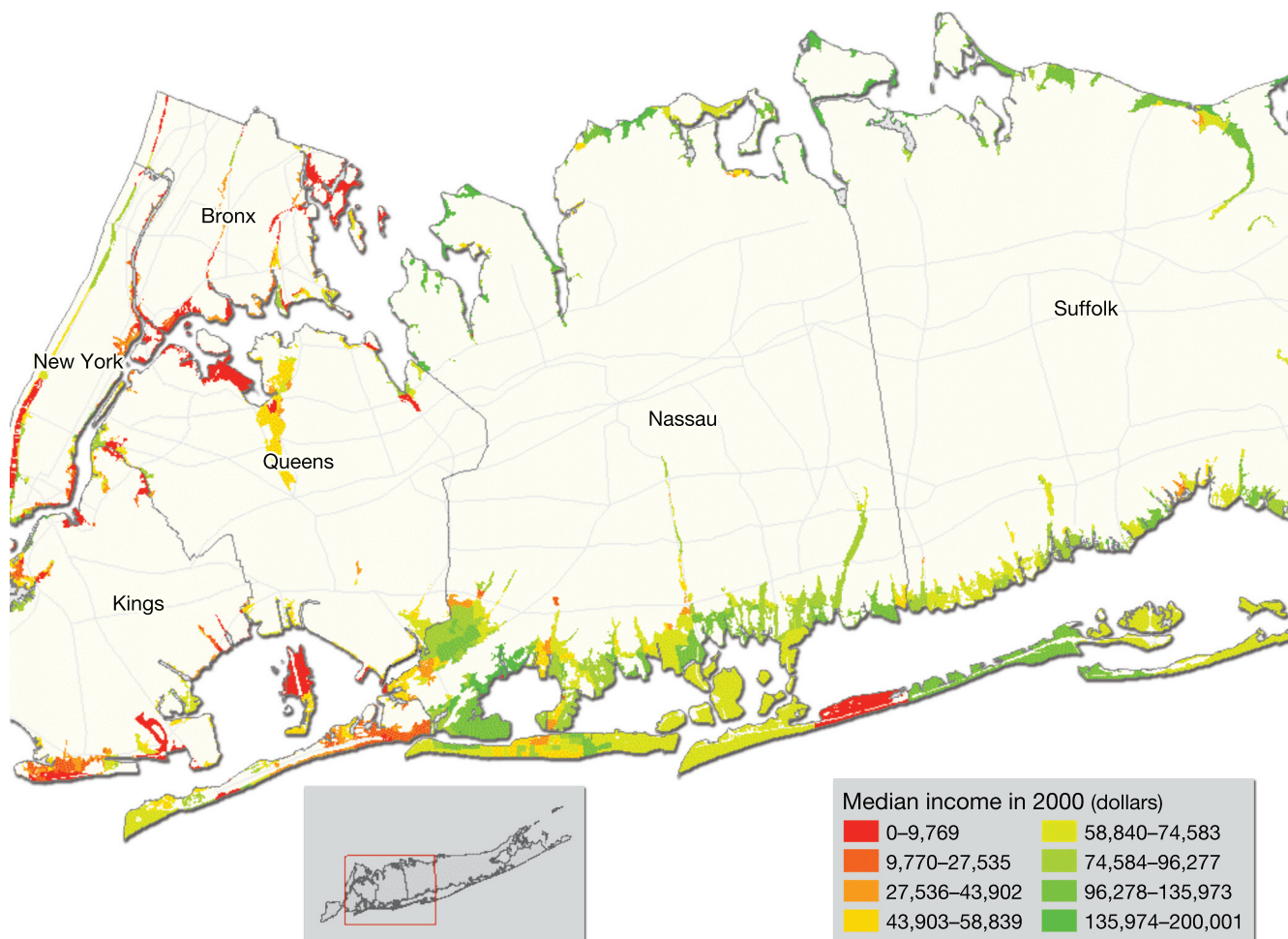
to have higher incomes, live in more expensive homes, and represent a lower minority population than those outside the floodplain. Examining the distribution of certain higher-risk subsets within this population can help locate potential environmental injustice effects. Low-income households, for example, are confronted

with constrained resource options for both long-term adaptation and immediate coping (Wu et al., 2002). In the coastal floodplain of ClimAID Region 4, nearly 75,000 people live under the poverty line. More than 80 percent of this population resides in New York City. In New York City in particular, wealthier and poorer



Source: US Census 2000

Figure 5.8 Population in FEMA's 100-year floodplain living below the poverty line



Source: US Census 2000

Figure 5.9 100-year floodplain and household income by census block group

neighborhoods often co-exist in close proximity near the shore (e.g., Coney Island, Brighton Beach, the Rockaways) and are thus potentially equally exposed to the physical consequences of flooding from a major storm or hurricane (**Figure 5.8**). Equity issues may arise in the form of structural damage associated with variations in construction, ease of timely evacuation and availability of transportation, or the ability to recover after a storm.

Previous research also has suggested that racial and ethnic minorities are more vulnerable when exposed to similar events than non-minority populations (see for example, Fothergill et al., 1999). Hurricane Katrina provided a vivid reminder of this uneven burden in 2005 (Yarnal, 2007). In coastal New York City and Long Island, just over 82,000 African Americans and nearly the same number of Latinos live in the 100-year floodplain. Examination of **Table 5.11** suggests that African Americans and Latinos are significantly overrepresented in New York City's flood zone relative to the distribution of the total population in coastal New York, which likely reflects a legacy of suburban settlement patterns on Long Island (i.e., fewer minorities the further away from New York City). This population distribution, in combination with the disproportionately high concentration of poverty and the greater proportion of renters, suggests that New York City would face fundamentally different equity challenges than Nassau and Suffolk counties. In contrast, proportionally higher rates of home ownership and greater income may signal a measure of resilience across more wealthy regions of Long Island (**Figure 5.9**).

### 5.5.2 Equity Issues in Adaptation

Several alternative adaptation strategies—managed retreat, beach nourishment, and engineering solutions—have varying economic impacts. Earlier studies have shown that beach nourishment preserves the recreational values of coastal beaches, while engineering solutions may be needed to maintain fixed structures. Landry et al. (2003) and Kriesel et al. (2005) estimate the relative value (willingness to pay) for alternative adaptation strategies. Their basic finding is that the relative value of the three basic adaptation strategies is a function of the value of coastal property to be protected. Preemptive planning for flood security should evaluate the specific distributional burdens and

benefits of each adaptation strategy. For illustrative purposes a few adaptation strategies are discussed in the following section, along with a review of critical equity issues.

#### *Infrastructure*

Building climate-secure hard infrastructure offers an amenity that may create new patterns of winners and losers. Which communities will be protected and in what ways? Who bears the cost of building hard infrastructure, such as seawalls or levees? Where are they placed and whom do they protect? What areas of a city or town are treated as critical while others are deemed non-priorities? These equity issues extend into strategies that include “softer” design. Choosing which wetlands to restore, beaches to fortify with additional sand, or structures and lands to elevate are not simple issues of exposure to risk. They involve making difficult decisions about distributing benefits and costs among communities and prioritizing some areas potentially at the expense of others.

#### *Managed Relocation*

Managed relocation from floodplains is another adaptation strategy that is accompanied by a portfolio of equity concerns related to the specific measures employed in the policies, from the relocation incentives to the environmental restoration of reclaimed lands. For example, if retreat will be a rapid buy out of highest risk areas, how does one choose these areas and the specific properties within them? What mechanisms are in place to hedge against the risk of redlining and inequitable selection of properties for priority buy-out?

Upland areas could be transformed by migration and localized population pressures. These communities may experience gentrification, increased cost of services from in-migration, and burdens of displacement from lowland areas. The viability and cohesion of low-income communities tend to be vulnerable under these conditions. Retreat from the southern coast of Long Island, for example, where housing issues are already a critical concern, may displace households, increase housing demand, and push up property values, a process that may indirectly burden the low-income population.



Managed retreat may materialize less as proactive planning and more as reactive incrementalism or planned obsolescence, such as service cutbacks, squeezing areas into shrinkage, or “choking” growth. In effect, such strategies outsource adaptation planning to individuals, meaning that those with the widest range of job and residence options and the ability to forecast policy changes would be the most quick to migrate. Lower-income populations could find themselves at an adaptive disadvantage, because they lack either the capital to invest in new housing or the socioeconomic flexibility allowing them to transfer jobs and livelihoods locations. Relocation can be difficult for any business, but minority-owned businesses may be especially vulnerable. They tend to be smaller, less well capitalized, less able to get loans, and subject to discrimination.

### *Adaptation, Insurance, and Equity*

Existing risk-spreading mechanisms are in flux. The insurance industry is undergoing changes in the way it approaches insuring high-risk regions, and in some areas, such as parts of Long Island, companies have withdrawn their products, limiting insurance options for property owners (Insurance Journal, 2007). What options will be available in their place, and for what level of risk government will bear responsibility are long-range distributional issues. Coastal erosion and increasing inundation of areas with infrastructure will take their toll in repair, recovery, and replacement costs. Similarly, the need for increased emergency management has a price tag that has to be distributed. Whether monies are distributed as community-level preparedness programs versus federally budgeted disaster aid, for example, has different implications in terms of the distribution of responsibility, the allocation of labor, and differential resource burdens.

## 5.6 Conclusions

This section details the basic findings on vulnerabilities and opportunities associated with climate change for the coastal zone of New York State, summarizes potential adaptation measures, and identifies some critical knowledge gaps that hinder more effective planning efforts, as identified in the ClimAID assessment.

### 5.6.1 Main Findings on Vulnerabilities and Opportunities

#### *Coastal Storms*

- Because of the highly developed nature of the coast in New York State, a considerable portion of population, private property, and infrastructure will be potentially at risk of enhanced inundation and flooding due to sea level rise associated with climate change.
- While permanently lost land is projected to involve a relatively narrow coastal strip by the 2080s, the higher storm surges associated with higher sea levels could periodically engulf a much greater area. Also, wave action will erode and reshape the shoreline, affecting the location and extent of storm surge inundation.

#### *Coastal Floods and Recurrence Intervals*

- Moderate flooding events may become more frequent. Sea level rise projections of 5, 12, and 23 inches at the Battery for the 2020s, 2050s, and 2080s would result in 4, 16, and 136 moderate flooding events annually, respectively. Under a rapid ice-melt scenario, New York State could experience between 200 and 275 moderate flooding events each year by the 2080s.
- As sea levels rise, coastal flooding associated with storms will very likely increase in intensity, frequency, and duration. By the end of the 21st century, sea level rise alone would increase the frequency of coastal flood levels that currently occur on average once per decade to once every one to three years for New York City and once every one to two years for Westhampton Beach, with water levels associated with these events increasing by 1 to 2 feet. The more severe current 1-in-100-year event may occur on average approximately four times as often by the end of the century.
- The greater likelihood of coastal flooding (as well as heavier rainfall) would result in an increase in street, basement, and sewer flooding; an increase in flood risk to low-elevation transportation, energy, and communications infrastructure; more frequent delays on low-lying highways and public transportation; increased structural damage and saltwater exposure to infrastructure, commercial, and residential property; increased inflow of seawater to storm sewers and wastewater treatment

plants and reduced ability of gravity discharge of sewer-effluent overflows; encroachment of saltwater into freshwater sources and ecosystems; and increased beach erosion and sand placement needs.

- Sea level rise and coastal inundation could affect the heights of tide gates designed to prevent the inflow of seawater and backing up of outfall sewers.

### *Coastal Erosion*

- Waves, currents, and tides constantly reshape the shoreline, and as sea level rise accelerates, these forces have the potential to dramatically alter New York State's coast.
- Sea level rise may increase the frequency of wave attack at the base of glacial bluffs, accelerating recession and erosion and increasing the rate of supply of sediment and other material to the near-shore system. This change in sediment supply could have different impacts that are difficult to predict given the limited understanding of sediment budgets and transport pathways.
- Shoreline change rates measured over the last 100 years show that generally the shoreline is receding at relatively low average rates of 1 to 2 feet per year, but that some areas are stable and others are accreting.
- Accelerated sea level rise will tend to exacerbate barrier island erosion. At low-to-moderate increases, the effects of sea level rise will still be of lesser magnitude than storm events and disruptions in longshore sediment transport. At higher rates of projected sea level rise, the migration of barrier islands landward should accelerate, but this migration may not be initiated in some sections of the barrier island for hundreds of years. At the most extreme rates of increased rate of rise, the barrier islands may not be able to maintain themselves if sea level rise outpaces the ability of the system to supply sediment naturally

### *The Hudson River Estuary*

- Climate change could affect the location of the salt front of the Hudson River Estuary in three ways: 1) reduction in precipitation could reduce stream flow, allowing the salt front to move upstream, while an increase in precipitation would have the opposite effect; 2) increase in temperature could increase evaporation, reducing freshwater runoff, which in

turn would cause the salt front to migrate upstream; and 3) rising sea level may push the mean position of the salt front upstream.

- Sea level rise and storm surge will continue to affect the entire Hudson Estuary up to the dam at Troy.

### *Freshwater Resources*

- Sea level rise and changes in precipitation will cause Long Island's water table to rise at approximately the same rate as sea level. As a result, the geographic extent of ponds and wetlands could change along with the carrying capacity of streams.
- Saltwater entry into aquifers would be slow, with less than 1 percent of the freshwater reserves affected over 100 years.

### *Coastal Ecosystems*

- Coastal ecosystems are at risk from rising sea levels, which may impose additional stress and exacerbate wetland losses in some sensitive regions.
- At Jamaica Bay Gateway National Recreation Area, New York, island salt marsh area declined by 20 percent between the mid-1920s and mid-1970s. Since then this trend has accelerated, and close to 30 percent has subsequently been lost. The wetland loss rate at Jamaica Bay, Udalls Cove Preserve, and Stony Brook Harbor is 1.5 percent per year. Only 7 out of 13 salt marsh islands in Shinnecock Bay (southeastern Long Island) that were present in 1974 remained by 1994. Since the 1970s, rate of marsh losses on Long Island and New York City have been between 1 and 2 percent per year. According to the tide gauge at The Battery in New York City, sea level has been rising at a rate of approximately 1 foot per century. While sea level rise is among several stressors that may be acting together on vulnerable marshes, it may become the dominant factor in future decades as it outpaces sedimentation and vertical accretion.
- For Long Island, New York City, and Lower Hudson Valley, marshes would only survive under the central range of projected sea level rise by the 2020s, given medium or high accretion rates. None would survive the rapid ice-melt scenario. Marshes have a slightly better chance in the Mid-Hudson Valley and Capital Region, with more marshes surviving in the central-range set of scenarios and

some potentially surviving a rapid ice-melt scenario until the 2020s.

### *Fish and Shellfish Populations*

- Water temperatures in the Hudson River already have shown substantial warming on the order of 0.22°F per decade between 1920 and 1990, which is projected to be consistent with global increases.
- For the New York Bight, projected sea surface temperature changes for the 2050s in comparison with a 1980s baseline show substantial increases on the order of 1.8 to 3.2°F, depending on the climate model and greenhouse gas emissions combination.
- Blue claw crabs flourish in the warmer waters of the mid-Atlantic and should not decline because of higher temperatures. However, lobsters are at the southern edge of their inshore range in New York and have already shown declines that may be linked to warming waters.
- Warming waters and increasing numbers of oysters (naturally occurring and through restoration projects) may result in increased abundances of black drum and sheepshead in New York.
- Warmer waters around New York will be more hospitable to fish species that normally range near New York but rarely reach it under current conditions.
- For New York coastal waters the relatively minor increases in ocean acidity brought about by high levels of carbon dioxide may have significant detrimental effects on the growth, development, and survival of hard clams, bay scallops, and Eastern oysters.

## 5.6.2 Adaptation Options

This section briefly introduces some basic adaptation options that could increase coastal community and ecosystem resilience to climate-induced hazards.

- Incorporate climate change and sea level rise information into State and local adaptation strategies and planning related to coastal land use, waterfront development, open space and natural habitat preservation, and emergency response and evacuation.
- Identify coastal area responses to sea level rise impacts at multiple timescales, such as more

frequent and extensive storm flooding, areas of permanent inundation, land loss due to erosion, various wetland responses, barrier island migration and breaching, and the migration of the salt front in estuarine environments. Evaluate the level of risk to human and natural systems, infrastructure, and population in these areas to prioritize and guide risk reduction and adaptation responses.

- Compile a detailed inventory of shoreline assets located in at-risk areas, their elevations, and the design lifetime for all sectors of coastal communities throughout New York State.
- Acquire currently vacant shorefront property in high-risk areas to serve as buffer zones against coastal flooding and sea level rise. Re-zone these for low-density use, recreation, and/or potential wetlands migration.
- Encourage responsible shoreline development in view of increasing sea level rise and coastal storm risks by providing guidance, incentive programs, and financial assistance to localities and sectors most at risk.
- Develop tools such as flood maps to effectively communicate sea level rise risks and community vulnerability to decision makers and the public.
- Establish a network of stakeholders and volunteers to assist in monitoring for sea level rise impacts and to coordinate outreach and education efforts.
- Coordinate regional efforts to update and re-evaluate periodically the range of risks associated with sea level rise and coastal storms, and modify existing environmental regulations and permitting accordingly.

In addition, the New York State Sea Level Rise Task Force (SLRTF) offers a comprehensive set of policy recommendations to reduce vulnerability from sea level rise and coastal hazards. Its recommendations include legal and regulatory changes as well as strategies for developing funding mechanisms for research, monitoring, and adaptation, and an evaluation of the public health risks associated with sea level rise and coastal hazards (New York State Sea Level Rise Task Force, 2010).

## 5.6.3 Knowledge Gaps

Climate change assessment efforts are often limited by the level of understanding of natural processes (barrier



island evolution, ecosystem functions, and interactions), the lack of spatial and temporal monitoring data, the availability and quality of existing data, and modeling capabilities. As new research methods emerge and scientific understanding of natural systems evolves, climate adaptation strategies and existing regulations (building codes, setbacks) should be reconsidered. Recommendations to improve assessment tools and understanding of natural processes operating in coastal regions specific to New York State are listed below.

- The responses of barrier islands and tidal wetlands to accelerated rates of sea level rise, such as the rapid ice-melt scenario, are currently unknown. Monitoring barrier island and tidal wetland evolution and determining the influence of regional geologic controls on their spatial variability would improve process-level understanding of these systems.
- Regional sediment management strategies require an understanding of transport processes along the coast as well as across the continental shelf. Presently the quantity of sand and processes by which it moves from the inner shelf to the littoral zones are unknown. This will influence the selection of “borrow” sites for sand that may be placed on beaches.
- Quantifying and monitoring land use and coastal water quality will help determine the most suitable land-use practices and adaptation strategies to improve coastal environments and increase resiliency.
- Assessment of ecosystem services for natural and engineered shorelines will aid in identifying potential adaptation strategies for more urbanized sections of the coastline.
- Establishing a monitoring program for submarine groundwater discharge throughout Long Island with particular focus on low-lying areas will allow tracking of the influence of submarine groundwater discharge on submerged aquatic vegetation.
- Systematic and standardized protocols (every two to five years) for all New York State coastal regions are needed. Mapping could include bathymetry, topography to the 500-year floodplain, and the extent of existing wetlands.
- Development of a comprehensive, easily accessed GIS-based data repository will facilitate interagency collaboration and future assessment efforts. The repository should include all monitored and modeled data, such as an inventory of hardened

shorelines, land use, critical infrastructure, sea level rise rates, distribution of habitats and species, historic shorelines, and storm water level recurrence intervals.

- Hydrodynamic modeling capability for the Hudson River is required to investigate the effect of climate change on the position of the salt front and on nutrient loads associated with extreme precipitation events.
- Research on climate-related impacts and adaptation strategies for Great Lakes coastlines is critical, since these regions were not included in this assessment.

### Case Study A. 1-in-100-year Flood and Environmental Justice

New York coastal communities are vulnerable to both tropical and extra-tropical storms. As the climate changes there is a potential for more-intense storm systems to impact New York State, and coupled with an accelerating rate, of sea level rise the likelihood of experiencing what is currently considered a 1-in-100-year event is increasing. The highly developed nature of the coast, the large population, and considerable private property and infrastructure at risk require society to develop holistic adaptive management strategies that promote community resilience. The implementation of various strategies will depend strongly on population and critical infrastructure density, as well as societal priorities. This particular ClimAID case study is focused on flood adaptation strategies for the urban and suburban regions of Long Beach (**Figure 5.10**) and communities along the mainland coastline of Great South Bay (**Figure 5.11**). In particular, a severe coastal storm consistent with the 1-in-100-year event (the theoretical storm that produces the 100-year floodplain) is considered for this analysis. The purpose is to illustrate where New York State and coastal communities may need to transition from phased withdrawal or managed relocation to fortification strategies, while highlighting community vulnerabilities associated with socioeconomic conditions. This case study suggests that managed relocation might be the appropriate strategy for agricultural or low-density residential land; engineering strategies might be required for urbanized lands; and an intermediate strategy (beach nourishment, for example), for moderate-density residential areas.

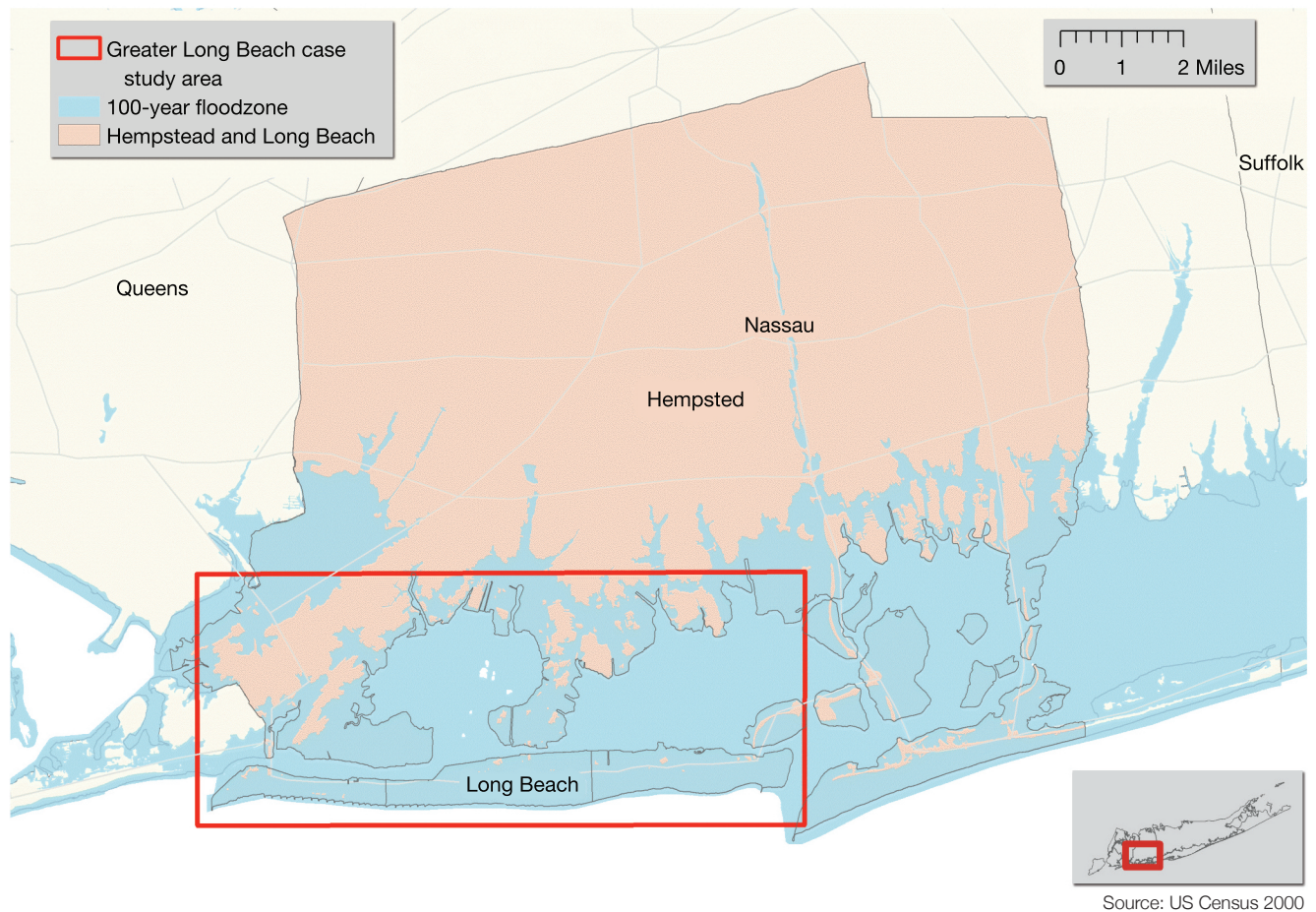


Figure 5.10 Long Beach and surrounding Bay communities

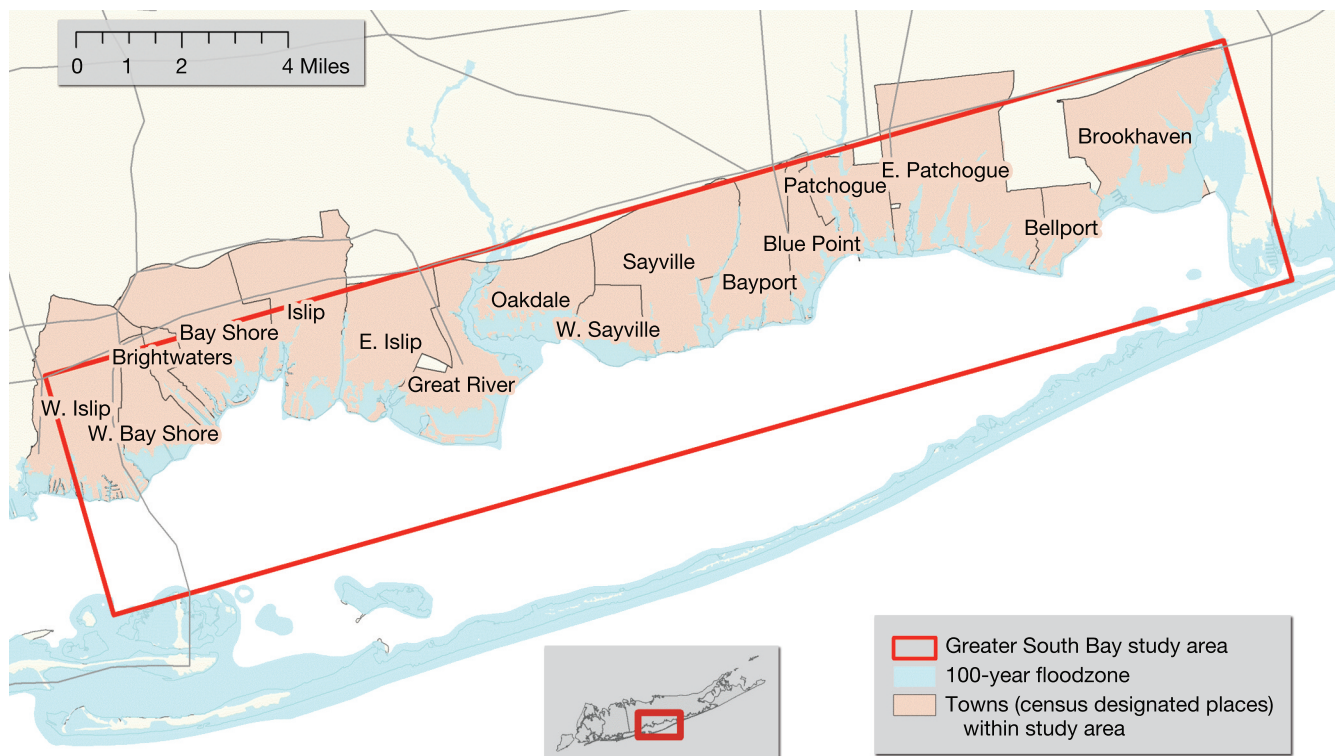


Figure 5.11 Mainland coast of Great South Bay

Social vulnerabilities are generally expressed at a more local or household level. Land use and coastal decision making is also done at a local scale. Still, one of the unique challenges of climate change is that it frequently is regional in exposure, so climate change adaptation strategies require a wider regional planning focus. Being attuned to who is excluded by the telescoping of scale and regionalization of focus will help make the planning process more inclusive, valid, and responsive.

## Analysis of Vulnerability to Storm Events

A number of variables generally associated with vulnerability were chosen from the 2000 census at the census block group level.<sup>1</sup> A comparison was made of mean values in the 100-year floodplain and means outside the floodplain. For Long Beach, the 100-year floodplain was compared to block groups within the Town of Hempstead, as defined in Census 2000 as a Minor Civil Division (**Figure 5.10**). For Great South Bay, the present-day 100-year floodplain was compared to block groups falling within the Census Designated Places of the case study area: Bayport, Bay Shore, Bellport, Blue Point, Brightwaters, Brookhaven, East Islip, East Patchogue, Great River, Islip, Oakdale, Patchogue, Sayville, West Bay Shore, West Islip, and West Sayville (**Figure 5.11**).

In general, for both case study areas, differences between the populations in the floodplain and those outside were relatively small (**Tables 5.13** and **5.14**).

However, median household incomes and the values of homes were slightly higher within the floodplain in both case studies, which likely reflects the amenity value of living by the coast. Key indicators of vulnerability or inequity in the distribution of burdens and benefits, such as race, poverty, and educational attainment, showed slight differences, but are not concentrated in flood-prone populations.

At a finer scale within the case study regions, there nevertheless is a wide range in the incidence of potential vulnerability from neighborhood to neighborhood. For example, **Figure 5.12** suggests that much of the disabled population in and around Long Beach is clustered in a few distinct locations. Patterns such as these may present opportunities for targeted emergency planning. Other social indicators, such as percent poverty, percent non-white, and the number of female-headed households, tend to cluster spatially and occur concurrently, which may indicate concentrated populations that are likely to be more sensitive to the impact of flood events (**Figure 5.13**, for example).

Social disparities are evident within Great South Bay as well. The highest rates of poverty and greatest proportion of renters, minorities, and foreign-born residents tend to center in Bay Shore and Patchogue (**Figures 5.14** and **5.15**). In general, the less densely populated areas between these centers are wealthier, better educated, and enjoy higher rates of home ownership.

	In Floodplain	Out of Floodplain
Median income	\$75,653	\$72,014
Median housing value, owner occupied housing	\$287,262	\$224,955
Female head of households as percentage of total	14.7	16.5
% in poverty	6.7	5.2
% less than high school	11.1	14.1
% over 65	14.7	14.2
% African American	5.4	15.1
% Hispanic	9.6	10.6
% renter	24.7	16.7
% vacant housing	5.7	1.8
% foreign born	14.1	17.4

Source: U.S. Census 2000; authors' calculations

**Table 5.13** Characteristics of population in census block groups in and out of 100-year floodplain for the Long Beach case study area

	In Floodplain	Out of Floodplain
Median income	\$73,323	\$65,834
Median housing value, owner occupied housing	\$238,480	\$176,489
Female head of households as percentage of total	13.3	15.1
% in poverty	6.2	4.8
% less than high school	11.4	12.4
% over 65	14.1	12.0
% African American	2.5	4.7
% Hispanic	7.5	8.7
% renter	22	21.1
% vacant housing	5.4	2.8
% foreign born	8.4	7.4

Source: U.S. Census 2000; authors' calculations

**Table 5.14** Characteristics of population in census block groups in and out of 100-year floodplain for the Great South Bay case study area



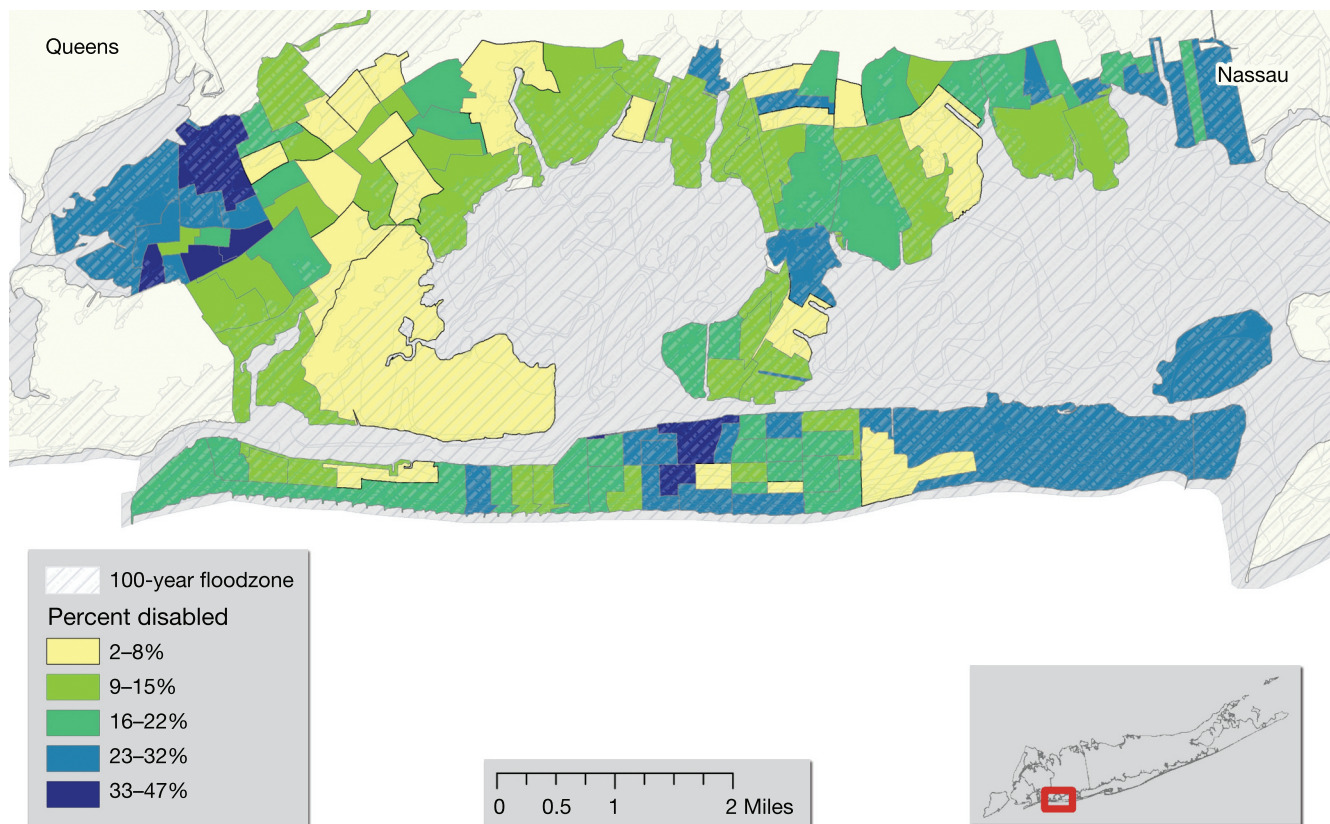


Figure 5.12 Concentration of disabled population in Long Beach region

Source: US Census 2000

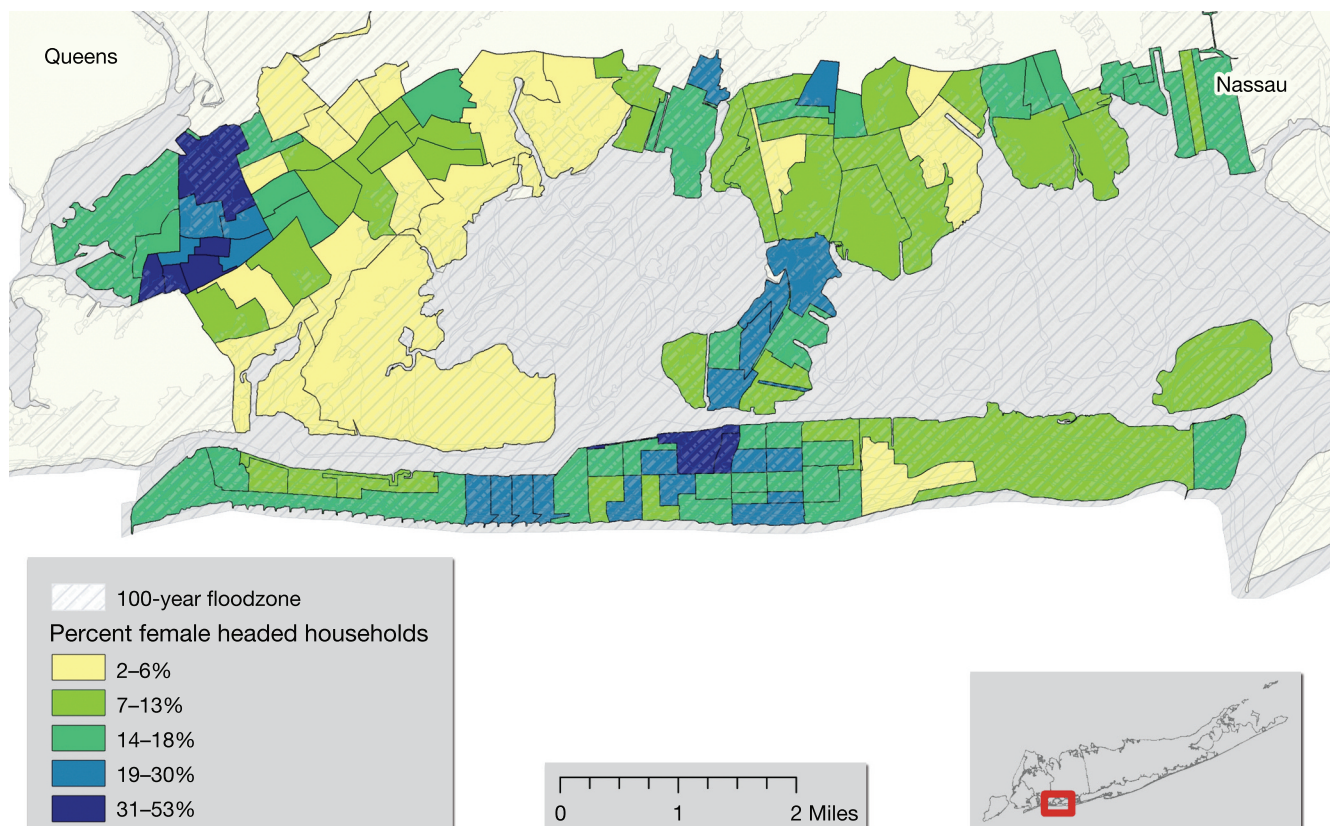
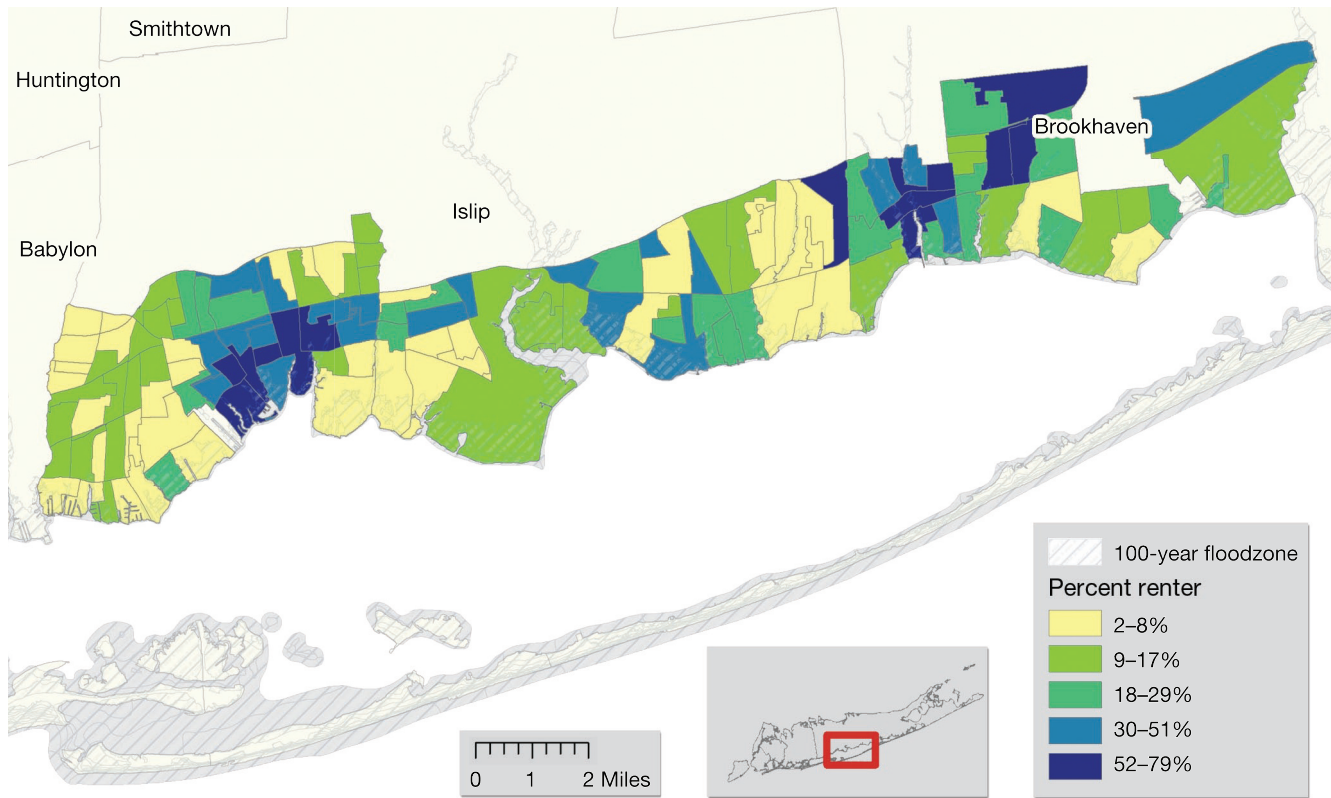


Figure 5.13 Female-headed households in Long Beach region

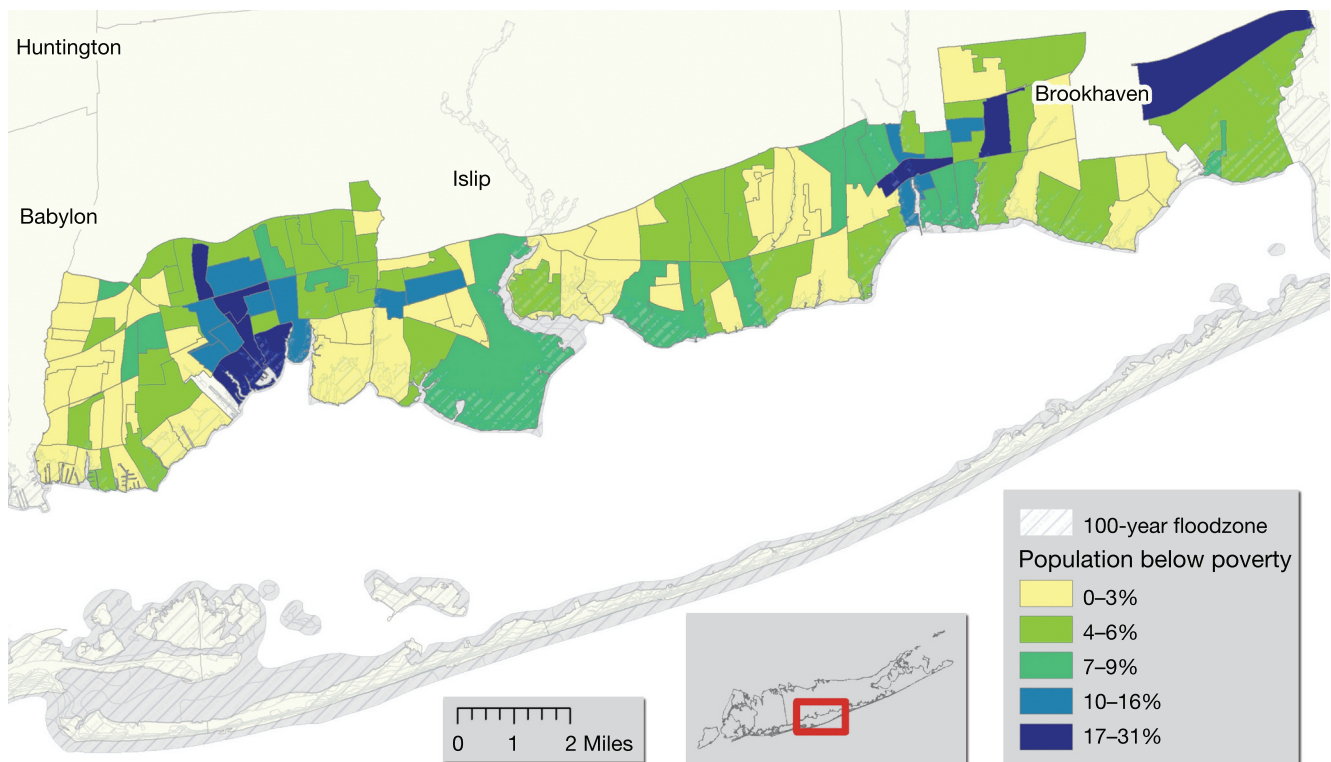
Source: US Census 2000





Source: US Census 2000

Figure 5.14 Local variation in density of renters in Great South Bay



Source: US Census 2000

Figure 5.15 Concentrated poverty in Great South Bay

## Adaptation, Economic Impacts, and Distributional Inequities

Identifying and understanding how economic impacts associated with severe coastal storms will change

temporally under different sea level rise scenarios is critical for developing effective adaptation and sustainable management strategies. For the Long Beach and Great South Bay study regions, two sea level rise scenarios were considered, the GCM-based central

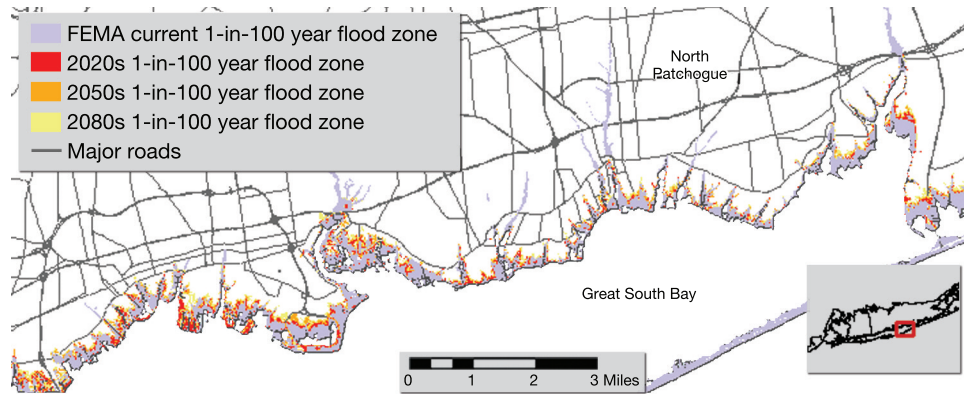


Figure 5.16 1-in-100-year flood zone for Great South Bay based on the GCM-based central range sea level rise scenario

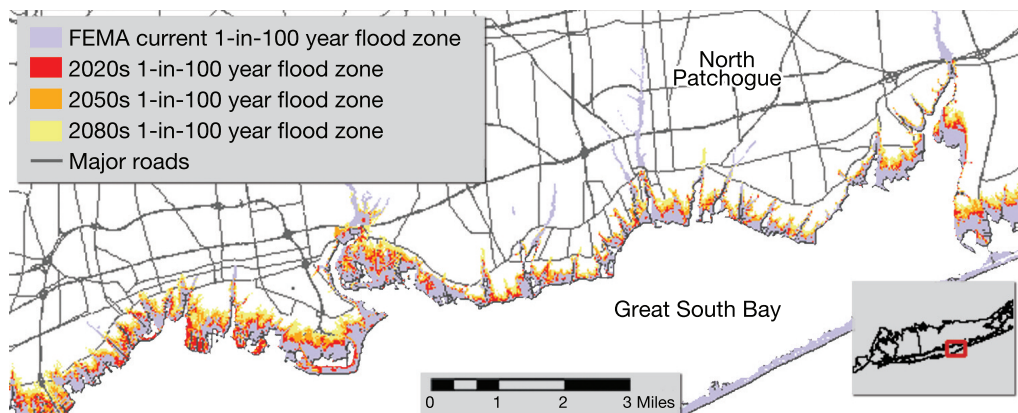


Figure 5.17 1-in-100-year flood zone for Great South Bay based on the rapid ice melt sea level rise scenario

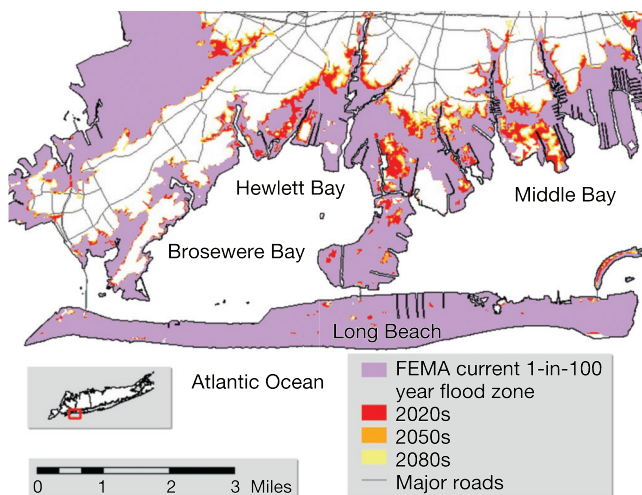


Figure 5.18 1-in-100-year flood zone for Long Beach based on the GCM-based central range sea level rise scenario

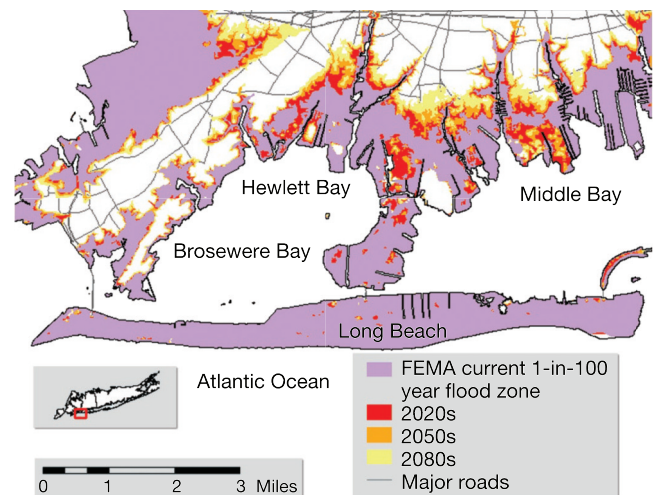


Figure 5.19 1-in-100-year flood zone for Long Beach based on the rapid-ice-melt sea level rise scenario

range forecast and a rapid ice-melt scenario. The GCM-based and rapid ice-melt scenarios are consistent with approximate 2-foot and 4-foot sea level rise by the 2080s, respectively. Corresponding 100-year floodplains for Long Beach and Great South Bay for each of the scenarios are shown in **Figures 5.16** through **5.19**.

Over the 2000–2080 forecast period, sea level rise is expected to place a growing population and increasing property at risk from flood and storm damage. These base-case analyses take as their starting point the 2000 U.S. Census estimates for population and property values within the study areas (U.S. Census Bureau Population Division, 2005). **Table 5.15** lists the base-case forecasts for the Long Beach and Great South Bay coastal regions.

## Case Study B. Modeling Climate Change Impacts in the Hudson River Estuary

The Hudson River extends unimpeded from The Battery in New York Harbor north to the Federal Dam at Troy just above Albany. The river coastline is highly populated. As the river has become cleaner over the last several decades, development pressure along its shores has increased. The goal of this case study is to describe the relative impact of sea level rise, storm surge, and large precipitation events on estuary water levels using a publicly available hydrodynamic computer model to determine which of the impacts of climate change are likely to be of greater significance to

the planners, regulators, and communities along the estuary shoreline.

The National Oceanic and Atmospheric Administration (NOAA) currently makes short-term forecasts of water levels using predictions of tides and watershed inflows. Cornell researchers used a variant of the NOAA National Weather Service model that employs the U.S. Army Corps of Engineers software HEC-RAS (Hydrologic Engineering Center-River Analysis System) to predict water level rise due to conditions outside those normally addressed by NOAA. This ClimAID assessment included three scenarios: 1) a scenario with 2 or 4 feet of sea level rise on top of tidal fluctuations, 2) high freshwater inflow scenarios, and 3) a storm surge scenario. The study also considered the relative value of improved topographic data (bathymetry, land elevation, hydraulic channel characteristics, and tributary flows) for understanding the impacts of climate change.

## Sea Level Rise and Impact on Tidal Range

Because of the low topographic gradient along the river, not counting the effect of land subsidence south of Kingston, a change in sea level at New York Harbor results in nearly the same change in water level at Albany. For example, a 3-foot increase in water level at The Battery would coincide with a roughly 3-foot increase in water levels at Albany. Thus, any change in mean water level due to sea level rise would be imposed upon the regular tidal fluctuation of 4 to 5 feet in Albany. Additionally, an increase in sea level of 2 or 4 feet will result in deeper water in the Hudson River estuary, allowing the estuary to better transmit tidal energy from The Battery to Albany. Model simulations suggested that this would effectively increase the tidal range at Albany by as much as 0.3 feet.

## Large Rainfall Events

The high freshwater inflow scenario used the 2008 annual peak flow at the Troy Dam (an approximately 5-year return period flow) and found that only water levels in the uppermost part of the tidal river above Castleton-on-Hudson changed appreciably. This conclusion is corroborated by discharge data directly measured at different points on the river. A measured 2008 peak flow of 104,000 cubic feet per second at the Troy Dam (a measure of the majority of watershed

Risk of Sea Level Rise: Long Beach Case Study Area			
	2020s	2050s	2080s
Population at risk			
GCM-based forecast	94,526	101,188	107,934
Rapid-ice-melt forecast	95,859	105,836	114,515
Property at risk (millions)			
GCM-based forecast	\$6,266	\$6,485	\$6,739
Rapid-ice-melt forecast	\$6,376	\$6,814	\$7,163
Risk of Sea Level Rise: Great South Bay Case Study Area			
	Year 2020	Year 2050	Year 2080
Population at risk			
GCM-based forecast	17,387	20,512	24,606
Rapid-ice-melt forecast	18,822	25,222	33,560
Property at risk (millions)			
GCM-based forecast	\$1,159	\$1,348	\$1,585
Rapid-ice-melt forecast	\$1,262	\$1,669	\$2,162

**Table 5.15** Population and property at risk for GCM-based and rapid ice-melt scenarios



inflows to the river) is only one-third the normal peak tidal flow in the Hudson near Poughkeepsie (300,000 cubic feet per second peak flow). The annual mean flow at Troy of 14,000 cubic feet per second is 20 times less than the 2008 peak flow. The tidal flow in the river is much larger than the largest freshwater inflows to the river. This suggests that changes in precipitation and resulting freshwater inflows to the river associated with climate change will have a more localized influence on the water levels.

## Storm Surge

A trial storm surge scenario assumed a 10-foot increase in water level on top of normal tidal fluctuations at The Battery over a 36-hour period. Storm surge is often slow relative to the dynamics of the estuary and the model indicated that the surge would travel up the river to the Troy Dam with relatively little diminishment or increase in magnitude. Thus, a storm surge can be thought of as a temporary sea level change, with all areas of the tidal Hudson affected nearly equivalently. However, Albany and the Battery are likely to have a slightly greater tidal maximum than areas at mid-river due to channel characteristics. The results indicated that these conclusions were insensitive to modest changes in the

bathymetry of shallow regions of the river or expansion of wetlands. However, finer-scale modeling along with detailed elevation and topographic data is still a critical need in order to determine which areas of which communities will be most vulnerable to the impacts of climate change on the estuary.

## Case Study C. Salt Marsh Change at New York City Parks and Implications of Accelerated Sea Level Rise

For the ClimAID assessment case study, historical aerial photographs were used to help evaluate marsh sustainability at two New York City Department of Parks and Recreation (NYCDPR) salt marshes: Udalls Cove Park Preserve (Queens) and Pelham Bay Park (Bronx). Prior evidence of New York State-wide marsh losses during the 25-year time span 1974 to 1999 was documented by NYSDEC (2004), including at these parks (Table 5.5). The current research used aerial photography obtained from 1951, 1974, 1999 (panchromatic), and 2005 (infrared) to quantify progressive marsh loss over the last half century. On-the-ground observations, sampling, and monitoring were used to gain an understanding of the observed

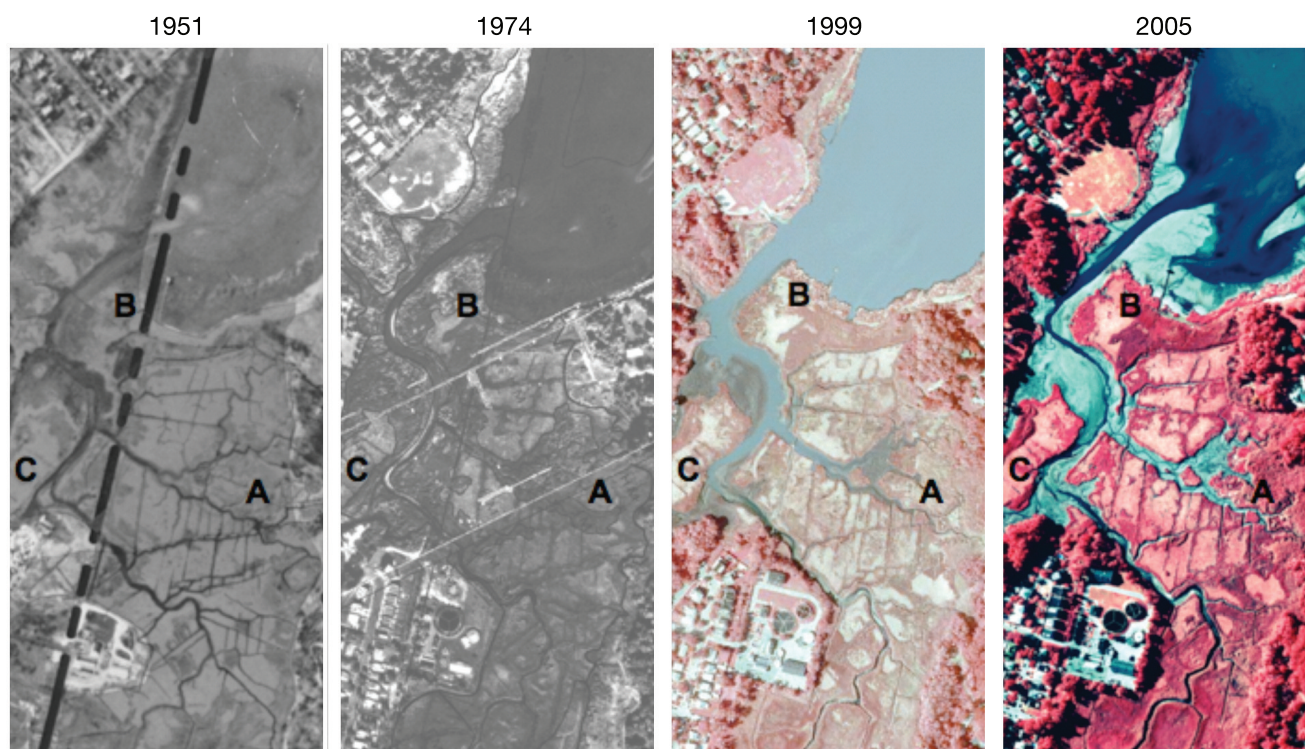


Photo credit 1951: Aero Service Corp. Photogrammetric Engineers, Phila. Pa; Photo credit 1974, 1999, 2005: NYSDEC

**Figure 5.20** Marsh loss comparisons at Udalls Cove Park Preserve, Queens



rates of loss. The results were compared with marsh loss elsewhere along the eastern United States.

For long-term monitoring, NYCDPR installed sediment elevation tables (SETs) in clusters of three at Udalls Cove Park Preserve and Pelham Bay Park in cooperation with NYSDEC and U.S. Geological Survey (USGS). These platforms have been used internationally and are effective at separating the components of surface accretion and shallow subsidence in the marshes (together with feldspar markers placed on the surface in 0.25-meter squares near the SETs). Over the next several years and decades, NYCDPR will be comparing the results from the selected parks with accretion rate data at Jamaica Bay and Fire Island, New York (Roman et al., 2007), Mashomack Preserve (Shelter Island, New York), Hackensack Meadowlands (New Jersey), and Narragansett Bay (Rhode Island).

While **Table 5.8** offers a sensitivity study on marsh survival using low, medium, and high rates of accretion in the face of projected sea level rise, on-the ground determinations of accretion and subsidence rates from SETs will offer data on how to manage specific marsh sites. The combination of aerial photo analysis and SET data from sampling stations can aid park managers, scientists, and public advocates in managing, and thereby perhaps minimizing, salt marsh loss in the coming decades.

### Udalls Cove Park, Queens

At Udalls Cove, initial analysis indicates significant land loss, including breaking up of previously contiguous marshland (see **Figure 5.20**, point A), eroding embankments (see point B), and widening of channels (see point C) (**Figure 5.20**). The amount of loss already under way was compared with projections of future loss over the next century (**Table 5.8**).

### Jamaica Bay Wildlife Refuge, Queens

Since 1998 there has been much speculation as to the cause of salt marsh deterioration and submergence at Jamaica Bay National Wildlife Refuge, part of Gateway National Recreation Area in New York City and New Jersey (Hartig et al., 2002; NYSDEC, 2006). While the exact cause is unknown, the marsh loss at Jamaica Bay

has been attributed to multiple stressors, including nutrient inputs from WPCPs (water pollution control plants for sewage treatment), deepening of navigation channels, shoreline armoring, increased tidal range (Swanson and Wilson, 2008), sea level rise, and more. Whatever the cause (or causes acting synergistically), the loss was extreme and action was taken to stem the loss.

In a pilot project at Big Egg Marsh conducted in part by local activists the Jamaica Bay Ecowatchers, the National Park Service, and many volunteers, a degraded marsh was restored by spraying sediment at a thickness of up to 3 feet and replanting with *Spartina* plugs. More recently, using sand from maintenance dredging, the U.S. Army Corps of Engineers conducted large-scale restoration at Elder's Point East for \$13 million. At both sites the artificially elevated *Spartina alterniflora* stands are thriving. A priority list has been generated through a Jamaica Bay Task Force for follow-up locations; the next restoration with sediment supplements is planned for Elder's Point West, to be followed by Yellow Bar Hassock.

## References

- Allen J.R.L. and K. Pye. 1992. "Coastal saltmarshes: their nature and importance." In *Saltmarshes: Morphodynamics, Conservation and Engineering Significance*, edited by J.R.L. Allen and K. Pye, 1-18. Cambridge, UK: Cambridge University Press.
- Aldrich, S., M. Dunkle, and J. Newcomb. 2009. "Executive Summary - Rising Waters: Helping Hudson River Communities Adapt to Climate Change Scenario Planning 2010 – 2030." The Nature Conservancy Eastern New York Chapter. Accessed January 2010. [http://www.nature.org/wherework/northamerica/states/newyork/files/rw\\_070509\\_exec.pdf](http://www.nature.org/wherework/northamerica/states/newyork/files/rw_070509_exec.pdf).
- Anisfeld, S. and J. Linn. 2002. "Wetland Loss in the Quinnipiac River Estuary: Baseline Assessment." Final Report to The Community Foundation for Greater New Haven, CT.
- Ashizawa, D. and J. Cole. 1994. "Long-term temperature trends of the Hudson River: a study of the historical data." *Estuaries* 17(1B):166-171.
- Bamber, J.L., R.E.M. Riva, B.L.A. Vermeersen, and A.M. LeBrocq. 2009. "Reassessment of the Potential Sea Level Rise from a Collapse of the West Antarctic Ice Sheet." *Science* 324 (5929): 901 doi:10.1126/science.1169335.
- Bavaro, L. 2005. "Paving Paradise." Suffolk County Department of Health Services, Peconic Estuary Program. Vol 2. Iss. 4.
- Bertness, M. D. 1991. "Zonation of *Spartina patens* and *Spartina alterniflora* in a New England salt marsh." *Ecology* 72:138-148.
- Bindoff, N. L., et al. 2007. Observations: Oceanic Climate Change and Sea Level. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change., S. Solomon, et al., Eds., Cambridge University Press, 386–432.

- Bird, E., 2008. *Coastal Geomorphology—an Introduction*. 2nd ed. Chichester, UK: Wiley & Sons, Ltd.
- Blake, E.S., E.N. Rappaport, and C.W. Landsea. 2007. "The Deadliest, Costliest, and most Intense United States Tropical Cyclones from 1851 to 2006 (and other frequently requested hurricane facts)." NOAA Technical Memorandum NWS TPC-5. [http://www.nhc.noaa.gov/Deadliest\\_Costliest.shtml](http://www.nhc.noaa.gov/Deadliest_Costliest.shtml)
- Bliss, J.D., S.J. Williams, and M.A. Arsenault. 2009. "Mineral resource assessment of marine sand resources in cape- and ridge-associated marine sand deposits in three tracts, New York and New Jersey, United States Atlantic continental shelf." In *Contributions to Industrial-Minerals Research*, Ch. N. U.S. Geological Survey Bulletin 2209-N.
- Bocamazzo, L. 2009. US Army Corps of Engineers, personal communication.
- Bolin R., M. Jackson, and A. Crist. 1998. "Gender inequality, vulnerability and disaster: issues in theory and research." In *The gendered terrain of disaster*, edited by E. Enarson and B.H. Morrow, 27-44. Westport, CT: Praeger.
- Bowman, M.J., B. Colle, R. Flood, D. Hill, R.E. Wilson, F. Buonaiuto, P. Cheng, and Y. Zheng. 2004. *Hydrologic Feasibility of Storm Surge Barriers to Protect the Metropolitan New York–New Jersey Region: Final Report to HydroQual, Inc., Marine Sciences Research Center, State University of New York, Stony Brook, NY*.
- Briggs, P. T. and J. R. Waldman. 2002. "Annotated list of fishes reported from the marine waters of New York." *Northeastern Naturalist* 9(1):47-80.
- Bullard, Robert D., ed. 2007. *Growing Smarter: Achieving Livable Communities, Environmental Justice, and Regional Equity*. Cambridge, MA: MIT Press.
- Buonaiuto, F.S. and H.J. Bokuniewicz. 2005. "Coastal Bluff Recession and Impacts on Littoral Transport: Special Reference to Montauk, NY." *Shore and Beach* 73(4): 24 – 29.
- Burger, J. and J. Shisler. 1983. "Succession and productivity on perturbed and natural *Spartina* salt marsh areas in New Jersey." *Estuaries* 6:50-56.
- Cademartori, E.A. 2000. "An assessment of salt marsh vegetation changes in southern Stony Brook Harbor: implications for future management." M.A. Thesis. Marine Environmental Science, SUNY, Stony Brook, NY, USA.
- Cahoon, D.R. and J. Lynch. 2009. "Surface Elevation Table." *Patuxent Wildlife Research Center* Accessed November 1, 2009. <http://www.pwrc.usgs.gov/set/>.
- Coch, N.K. 1993. "Hurricane hazards along the northeastern Atlantic Coast of the United States." *Journal of Coastal Research, Special Issue* 12:115-147.
- Cochran, J.K., D.J. Hirshberg, J. Wang, and C. Dere. 1998. "Atmospheric deposition to metals to coastal water (Long Island Sound, New York, USA.) Evidence from salt marsh deposits." *Estuarine, Coastal and Shelf Science* 46:503-522.
- Colle, B.A., F. Buonaiuto, M.J. Bowman, R.E. Wilson, R. Flood, R. Hunter, A. Mintz, D. Hill. 2008. "New York City's vulnerability to coastal flooding." *Bulletin of the American Meteorological Society* 89:829–841.
- Colle, B. 2009. Stony Brook University, personal communication.
- Colle, B.A., K. Rojowsky, F.S. Buonaiuto. 2010. "New York City Storm Surges: Climatology and Analysis of the Wind and Cyclone Evolution." *Journal of Applied Meteorology and Climatology* 49(1):85-101.
- Colucci, S.J. 1976. "Winter cyclone frequencies over the eastern United States and adjacent western Atlantic, 1964–1973." *Bulletin of the American Meteorological Society* 57:548–553.
- David Yang, USACE, August 2010, personal communication.
- Davis, R.E., R. Dolan, and G. Demme. 1993. "Synoptic climatology of Atlantic coast northeasters." *International Journal of Climatology* 13:171–189.
- Dean, R.G., A.R. Dalrymple, R.W. Fairbridge, S.P. Leatherman, D. Nummedal, M.P. O'Brien, O.H. Pilkey, W. Sturges III, and R.L. Wiegel. 1987. "Responding to Changes in Sea Level: Engineering Implications." Washington D.C.: National Academy Press.
- DeGaetano, A.T. 2008. "Predictability of seasonal East Coast winter storm surge impacts with application to New York's Long Island." *Meteorological Applications* 15(2): 231–242.
- DeGaetano, A.T., M.E. Hirsch, and S.J. Colucci. 2002. "Statistical prediction of seasonal East Coast winter storm frequency." *Journal of Climate* 15:1101–1117.
- DeLaune, R.D., J.A. Nyman, and W.H. Patrick, Jr. 1994. "Peat collapse, ponding and wetland loss in a rapidly submerging coastal marsh." *Journal of Coastal Research* 10:1021-1030.
- Doland, R. and R.E. Davis. 1992. "An intensity scale for Atlantic coast northeast storms." *Journal of Coastal Research* 8:352–364.
- Donnelly, J.P. and M.D. Bertness. 2001. "Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise." *Proceedings of the National Academy of Sciences* 98:14218-14223.
- Donnelly, J.P., Cleary, P., Newby, P., and Ettinger, R. 2004. "Coupling instrumental and geological records of sea-level change: Evidence from southern New England of an increase in the rate of sea level rise in the late 19th century." *Geophysical Research Letters* 31: L05203. doi:10.1029/2003GL018933.
- Downs, L.D., R.J. Nicholls, S.P. Leatherman, and J. Hautzenroder. 1994. "Historic evolution of a marsh island: Bloodsworth Island, Maryland." *Journal of Coastal Research* 10:1031-1044.
- Edinger, G.J., D.J. Evans, S. Gebauer, T.G. Howard, D.M. Hunt, and A.M. Olivero, eds. 2002. *Ecological Communities of New York State. Second Edition*. A revised and expanded edition of Carol Reschke's *Ecological Communities of New York State*. (Draft for review). New York Natural Heritage Program, New York State Department of Environmental Conservation, Albany, NY.
- Fallon D. and F. Mushacke. 1996 (unpublished). "Tidal Wetlands Trends in Shinnecock Bay, New York 1974 to 1995." Division of Fish, Wildlife and Marine Resources, New York State Department of Environmental Conservation, East Setauket, NY, USA.
- Fothergill, A., and L.A. Peek. 2004. "Poverty and disasters in the United States: a review of recent sociological findings." *Natural Hazard* 32:89–110.
- Fothergill, A., E.G.M. Maestas, and J.D. Darlington. 1999. "Race, ethnicity and disasters in the United States: a review of the literature." *Disasters* 23:156–73.
- Frumhoff, P.C., J.J. McCarthy, J.M. Melillo, S.C. Moser, and D.J. Wuebbles. 2007. "Coastal Impacts." In *Confronting Climate Change in the U.S. Northeast: Science, Impacts, and Solutions*. Report of the Northeast Climate Impacts Assessment: 15-32.
- Fuglister, F.C. 1947. "Average monthly sea surface temperatures of the Western North Atlantic Ocean." *Papers in Physical Oceanography and Meteorology*. Massachusetts Institute of Technology and Woods Hole Oceanographic Institution 10(2):25.
- Gehrels, R.W., J.R. Kirby, A. Prokoph, R.M. Newnham, E.P. Achterberg, H. Evans, S. Black, and D.B. Scott. 2005. "Onset of recent rapid sea level rise in the western Atlantic Ocean." *Quaternary Science Reviews* 24:2083-2100.

- Gornitz, V. and S. Couch. 2001. *Chapter 3. In Climate Change and a Global City: The Potential Consequences of Climate Variability and Change – Metro East Coast*, Edited by Rosenzweig, C. and W.D. Solecki. Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States. New York: Columbia Earth Institute.
- Gornitz, V., S. Couch, and E. K. Hartig. 2002. "Impacts of sea level rise in the New York City metropolitan area." *Global and Planetary Change* 32:61-88.
- Gornitz, V.M., R.C. Daniels, T.W. White, and K.R. Birdwell. 1994. "The development of a coastal assessment database: vulnerability to sea level rise in the U.S. Southeast." *Journal of Coastal Research, Special Issue* 12:327-338.
- Grosslein, M.D., and T.R. Azarovitz. 1982. "Fish distribution." Marine Ecosystems Analysis Program New York Bight Atlas Monograph 15.
- Hartig, E.K. 2001. *Chapter 5. In Climate Change and a Global City: The Potential Consequences of Climate Variability and Change – Metro East Coast*, Edited by Rosenzweig, C. and W.D. Solecki. Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States. New York: Columbia Earth Institute.
- Hartig E.K., V. Gornitz, A. Kolker, F. Mushacke, and D. Fallon. 2002. "Anthropogenic and climate-change impacts on salt marsh morphology in Jamaica Bay, New York City." *Wetlands* 22:71-89.
- Hartig, E.K. and V. Gornitz. 2005. "Salt marsh change, 1926-2003 at Marshlands Conservancy, New York." Long Island Sound Research Conference Proceedings.
- Haugan, P.M., C. Turley, H.O. Pörtner. 2006. "Effects on the marine environment of ocean acidification resulting from elevated levels of CO<sub>2</sub> in the atmosphere." OSPAR intersessional correspondence group. DN-utredning. [www.dirnat.no](http://www.dirnat.no).
- Hayden, B.P. 1981. "Secular variation in Atlantic Coast extratropical cyclones." *Monthly Weather Review* 109:159-167.
- Hildebrand, S.F., and W.C. Schroeder. 1928. "Fishes of Chesapeake Bay." *Bulletin of the Bureau of Fisheries* 43(1):1-366.
- Hirsch, M.E., A.T. DeGaetano, and S.J. Colucci. 2001. "An East Coast winter storm climatology." *Journal of Climate* 14: 882-899.
- Holgate, S.J. and P.L. Woodworth. 2004. "Evidence for Enhanced Coastal Sea Level Rise During the 1990s." *Geophysical Research Letters* 31:L07305. doi:10.1029/2004GL019626.
- Holland, D.M., et al. 2008. "Acceleration of Jakobshavn Isbrae triggered by warm subsurface ocean water." *Nature Geoscience* 1:659-664.
- Horton, R., C. Herweijer, C. Rosenzweig, J.P. Liu, V. Gornitz, and A.C. Ruane. 2008. "Sea level rise projections for current generation CGCMs based on the semi-empirical method." *Geophysical Research Letters*, 35, L02715, doi:10.1029/2007GL032486. <http://pubs.giss.nasa.gov/cgi-bin/abstract.cgi?id=ho05300q>
- Horton, R., V. Gornitz, M. Bowman, and R. Blake. 2010. "Climate observations and projections." *Annals of the New York Academy of Sciences*, 1196, 41-62, doi:10.1111/j.1749-6632.2009.05314.x. <http://pubs.giss.nasa.gov/cgi-bin/abstract.cgi?id=ho08400z>
- Howell, P., J. Benway, C. Giannini, K. McKown, R. Burgess, and J. Hayden. 2005. "Long-term population trends in American lobster (*Homarus americanus*) and their relation to temperature in Long Island Sound." *Journal of Shellfish Research* s24:849-857.
- Hu, A., G.A. Meehl, W. Han, and J. Yin. 2009. "Transient response of the MOC and climate to potential melting of the Greenland ice sheet in the 21<sup>st</sup> century." *Geophysical Research Letters* 36:L10707.
- Insurance Journal. 2007. "Agents Fear N.Y. Coast Insurance Market Worse; Pils Weigh Options". *Insurance Journal*. Accessed May 2009. <http://www.insurancejournal.com/news/east/2007/10/11/84189.htm>.
- Ishimatsu A., M. Hayashi, T. Kikkawa. 2008. "Fishes in high-CO<sub>2</sub>, acidified oceans." *Marine Ecology Progress Series* 373:295-302.
- ISO (Insurance Services Office) Property Claims Department, n.d. <http://www.isopropertyresources.com/Products/Property-Claims-Service/Property-Claim-Services-PCS.htm>.
- Kana, T.W. 1995. "A mesoscale sediment budget for long island, New York." *Marine Geology* 126:87-110.
- Kearney, M.S., A.S. Rogers, J.R.G. Townsend, E. Rizzo, D. Stutzer, J.C. Stevenson, and K. Sundborg. 2002. "Landsat imagery shows decline of coastal marshes in Chesapeake and Delaware Bays." *Eos, Transactions, American Geophysical Union* 83(16):177-178.
- Klein, R.J.T. and R.J. Nicholls. 1998. "Coastal Zones." In *Handbook on Methods for Climate Change Impact Assessment and Adaptation Strategies, Version 2.0*, edited by J.F. Feenstra, I. Burton, J.B. Smith, and R.S.J. Tol. Nairobi and Amsterdam: United Nations Environment Programme and Institute for Environmental Studies, Vrije Universiteit: 7.1-7.35.
- Kocin, P.J., and L.W. Uccellini. 1990. "Snowstorms along the Northeastern Coast of the United States: 1955-1985." *Meteorological Monograph No. 44*, American Meteorological Society.
- Kolker, A.S. 2005. "The Impacts of Climate Variability and Anthropogenic Activities on Salt Marsh Accretion and Loss on Long Island." Dissertation. Marine Sciences Research Center, Stony Brook University, Stony Brook, NY.
- Kriesel, W., C.E. Landry, and A. Keeler. 2005. "Coastal erosion management from a community economics perspective: The feasibility and efficiency of user fees." *Journal of Agricultural and Applied Economics* 37(2):451-461.
- Kurihara H. 2008. "Effects of CO<sub>2</sub>-driven ocean acidification on the early developmental stages of invertebrates." *Marine Ecology Progress Series* 373:275-284.
- Landry, C.E., A.G. Keeler, and W. Kriesel. 2003. "An economic evaluation of beach erosion management alternatives." *Marine Resource Economics* 18:105-127.
- Leatherman, S.P. and J.R. Allen, eds. 1985. *Geomorphic Analysis of South Shore of Long Island Barriers*. U.S. Army Corps of Engineers.
- Leatherman, S.P. and R.J. Nicholls. 1995. "Historic and future land loss for upland and marsh islands in the Chesapeake Bay, Maryland, USA." *Journal of Coastal Research* 11:1195-1203.
- Limburg, K.E. and R.E. Schmidt. 1990. "Patterns of fish spawning in Hudson River tributaries: Response to an urban gradient?" *Ecology* 71(4):1238-1245. Report to Hudson River Foundation. Hudsonia Limited. [http://www.hudsonriver.org/lr/reports/Schmidt\\_005\\_87R\\_peer1.pdf](http://www.hudsonriver.org/lr/reports/Schmidt_005_87R_peer1.pdf)
- Ludlum, David M. 1963. "Early American Hurricanes: 1492-1870." *American Meteorological Society*.
- Lynch, J. 2009. National Park Service, personal communication.
- MacCall, A.D. 1990. *Dynamic geography of marine fish populations*. Seattle: University of Washington Press.
- Metropolitan Transportation Authority (MTA). 2007. *August 8, 2007 Storm Report*.
- Morrow, B. H. 1999. "Identifying and Mapping Community Vulnerability." *Disasters* 23(1):11-18.



- Naparstek, A. 2005. "A history of hurricanes in New York—including the day in 1893 that Hog Island disappeared for good." *New York Magazine*, Sept. 4.
- New York City Department of Environmental Protection (NYC DEP). 2008. *Jamaica Bay Watershed Protection Plan*. [http://www.nyc.gov/html/dep/html/dep\\_projects/jamaica\\_bay.shtml](http://www.nyc.gov/html/dep/html/dep_projects/jamaica_bay.shtml)
- New York City Department of Environmental Protection (NYC DEP). 2008. *Report 1: Assessment and Action Plan - A Report Based on the Ongoing Work of the DEP Climate Change Task Force*. New York City Department of Environmental Protection Climate Change Program. With contributions by Columbia University Center for Climate Systems Research and Hydroqual Environmental Engineers & Scientists, P.C., New York, NY.
- New York City Panel on Climate Change (NPCC). 2010. *Climate Change Adaptation in New York City: Building a Risk Management Response*. C. Rosenzweig and W. Solecki, Eds. Prepared for use by the New York City Climate Change Adaptation Task Force. *Annals of the New York Academy of Sciences* 1196. New York, NY.
- New York State Department of Environmental Conservation (NYS DEC). 2006. *Welcome to Marine Habitat Protection*. Website no longer available. Portion retrieved May 12, 2008, from: <http://www.dec.ny.gov/lands/5489.html>.
- New York State Department of Environmental Conservation (NYS DEC). 2003. *Tidal Wetlands Losses in Nassau and Suffolk Counties*. Prepared by F. Mushacke. Accessed on August 7, 2003, portion retrieved May 12, 2008, website no longer available. [www.dec.state.ny.us/website/dfwmr/marine/wetlands/index.html](http://www.dec.state.ny.us/website/dfwmr/marine/wetlands/index.html).
- New York State Department of Environmental Conservation (NYS DEC). 2004. *1974 – 1999 Vegetated Tidal Wetland Trends of the New York Metropolitan Area and the Lower Hudson River*. Final report prepared by Mushacke, F. and Picard, E.
- New York State Sea Level Rise Task Force, 2010. New York State Sea Level Rise Task Force Report to the Legislature. [http://www.dec.ny.gov/docs/administration\\_pdf/slrtrfinalrep.pdf](http://www.dec.ny.gov/docs/administration_pdf/slrtrfinalrep.pdf)
- Nick, F.M., A. Vieli, I.M. Howat, and I. Joughlin. 2009. "Large-scale changes in Greenland outlet glacier dynamics triggered at the terminus." *Nature Geoscience* 2:110-114.
- NOAA. 2004. *Historic Sea Level Trends*. Accessed on September 30, 2004. <http://co-ops.nos.noaa.gov/sltrends/sltrends.shtml>
- Nordstrom, K.F. and C.T. Roman. 1996. "Environments, processes and interactions of estuarine shores." In *Estuarine Shores; Evolution, Environments and Human Alterations* 1-12. New York: John Wiley & Sons.
- Nuttle, W.K. 1997. "Conserving coastal wetlands despite sea-level rise." *EOS, Transactions, American Geophysical Union* 78: 260-261.
- Nydick, K.R., A.B. Bidwell, E. Thomas, and J.C. Varekamp. 1995. "A sea level rise curve from Guilford, Connecticut, USA." *Marine Geology* 124:137-159.
- Onishi, N. 1997. "The little island that couldn't." *New York Times*, March 18.
- Orson, R.A., W. Panageotou, and S.P. Leatherman. 1985. "Response of tidal salt marshes of the U.S. Atlantic and Gulf Coasts to rising sea levels." *Journal of Coastal Research* 1:29-38.
- Oviatt, C. 2004. "The changing ecology of temperate coastal waters during a warming trend." *Estuaries* 27:895-904.
- Pfeffer, W.T., et al. 2008. "Kinematic constraints on glaciers contributions to 21st century sea level rise." *Science* 321:1340-1343.
- Rahmstorf, S., A. Cazenave, J.A. Church, J.E. Hansen, R.F. Keeling, D.E. Parker, and R.C.J. Somerville. 2007. "Recent climate observations compared to projections." *Science* 316:709.
- Reitan, C.H. 1974. "Frequencies of cyclones and cyclogenesis for North America, 1951–1970." *Monthly Weather Review* 102:861–868.
- Reschke, C. 1990. "Ecological Communities of New York State." *New York Natural Heritage Program, NYSDEC*. Latham, NY.
- Rignot, E., et al. 2008. "Recent Antarctic ice mass loss from radar interferometry and regional climate modeling." *Nature Geoscience* 1:106-110.
- Rohling, E.J., K. Grant, C. Hemleben, M. Siddall, B.A.A. Hoogakker, M. Bolshaw, and M. Kucera. 2008. "High rates of sea level rise during the last interglacial period." *Nature Geoscience* 1:38-42.
- Roman, C.T., J.W. King, D.R. Cahoon, J.C. Lynch, and P.G. Appleby. 2007. "Evaluation of marsh development processes at Fire Island National Seashore (New York): recent and historic perspectives." *Technical Report NPS/NER/NRTR 2007/089*. National Park Service, Boston, MA.
- Root, A., L. Schintler and K.J. Button. 2000. "Women, travel and the idea of 'sustainable transport'." *Transport Reviews* 20(3):369-383.
- Rosenzweig, C. and W. D. Solecki, eds. 2001. *Climate Change and a Global City: The Potential Consequences of Climate Variability and Change*. Metro East Coast Report for the U.S. Global Change Research Program, National Assessment of the Potential Consequences of Climate Variability and Change for the United States. Columbia Earth Institute, New York. 224 pp.
- Sabine C.L., R.A. Feely, N. Gruber, R.M. Key, K. Lee, J.L. Bullister, R. Wanninkhof, C.S. Wong, D.W.R. Wallace, B. Tilbrook, F.J. Millero, T.H. Peng, A. Kozyr, T. Ono, and A.F. Rios. 2004. The oceanic sink for anthropogenic CO<sub>2</sub>. *Science* 305, 367–371.
- Salmun, H., A. Molod, F.S. Buonaiuto, K. Wisniewska, K.C. Clarke. 2009. "East Coast Cool-weather Storms in the New York Metropolitan Region." *Journal of Applied Meteorology and Climatology* 48(11):2320-2330.
- Steig, E.J., D.P. Schneider, S.D. Rutherford, M.E. Mann, J.C. Comiso, and D.T. Shindell. 2009. "Warming of the Antarctic ice-sheet surface since the 1957 International Geophysical Year." *Nature* 457:459-463.
- Swanson R. L. and R. E. Wilson. 2008. "Increased Tidal Ranges Coinciding with Jamaica Bay Development Contribute to Marsh Flooding." *Journal of Coastal Research* 24(6):1565-1569.
- Sze, J., and J.K. London. 2008. "Environmental justice at the crossroads." *Sociology Compass* 2(4):1331-1354.
- Talmage, S.C. and C.J. Gobler. 2009. "The effects of elevated carbon dioxide concentrations on the metamorphosis, size, and survival of larval hard clams (*Mercenaria mercenaria*), bay scallops (*Argopecten irradians*), and Eastern oysters (*Crassostrea virginica*)." *Limnology and Oceanography* 54(6):2072-2080.
- Tanski, J. November 2009. New York Sea Grant Cornell Extension, personal communication.
- Thieler, E.R., and E.S. Hammar-Klose. 1999. *National Assessment of Coastal Vulnerability to Future Sea-Level Rise: Preliminary Results for the U.S. Atlantic Coast*. U.S. Geological Survey, Open-File Report 99–593, 1 sheet.
- Titus, J.G. 1988. "Greenhouse Effect, Sea Level Rise and Coastal Wetlands." U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation. Washington D.C. July. EPA 230-05-86-013.
- U.S. Census Bureau Population Division. 2005. "Interim State Population Projections, 2005, Table 1: Interim Projections: Ranking of Census 2000 and Projected 2030 State Population and Change: 2000 to 2030."



- U.S. Environmental Protection Agency (EPA)/CCSP. 2009. *Coastal Sensitivity to Sea-Level Rise: A Focus on the Mid-Atlantic Region*. A report by the U.S. Climate Change Science Program and the Subcommittee on Global Change Research. J.G. Titus, K.E. Anderson, D.R. Cahoon, D.B. Gesch, S.K. Gill, B.T. Gutierrez, E.R. Thieler, and S.J. Williams. Accessed on May 5, 2010. <http://www.epa.gov/climatechange/effects/coastal/sap4-1.html>.
- Varekamp, J.C., E. Thomas, and O. Van de Plassche. 1992. "Relative sea level rise and climate change over the last 1500 years." *Terra Nova 4: Global Change, Special Issue*: 293-304.
- Waldman, J. 2006. "The diadromous fish fauna of the Hudson River: life histories, conservation concerns, and research avenues." In *The Hudson River Estuary*, edited by J.S. Levinton and J.R. Waldmans, 171-188. New York: Cambridge University Press.
- Waldman, J.R., T.R. Lake, and R.E. Schmidt. 2006. "Biodiversity and zoogeography of the fishes of the Hudson River: watershed and estuary." *American Fisheries Society Symposium* 51:129-150.
- Warren, R.S. and W.A. Niering. 1993. "Vegetation change on a northeast tidal marsh: interaction of sea level rise and marsh accretion." *Ecology* 74:96-103.
- Weiss, D. 1974. "Late Pleistocene Stratigraphy and Paleoecology of the Lower Hudson River Estuary." *GSA Bulletin*, v 85(10), 1561-1570.
- Wells, J. V. 1998. *Important Bird Areas of New York State*. New York State Office of National Audubon Society. Albany, NY.
- Wray, R.D., S.P. Leatherman, and R.J. Nicholls. 1995. "Historic and future land loss for upland and marsh islands in the Chesapeake Bay, Maryland, USA." *Journal of Coastal Research* 11:1195-1203.
- Wright, B. and R. Bullard. 2007. "Rebuilding a 'new' New Orleans," in *Growing Smarter: Achieving Livable Communities, Environmental Justice, and Regional Equity*. Cambridge, MA: MIT Press.
- Wu, S.Y., B. Yarnal, and A. Fisher. 2002. "Vulnerability of coastal communities to sea-level rise: A case study of Cape May County, New Jersey, USA." *Climate Research* 22(4): 255-270.
- Yang, D. August 2010. US Army Corps of Engineers, personal communication.
- Yang, D. May 2011. US Army Corps of Engineers, personal communication.
- Yarnal, B. 2007. "Vulnerability and all that jazz: Addressing vulnerability in New Orleans after Hurricane Katrina." *Technology in Society* 29:249-255.
- Yin, J., M.E. Schlesinger, and R.J. Stouffer. 2009. "Model projections of rapid sea level rise on the Northeast coast of the United States." *Nature Geoscience* 15:1-5. (see also Hu et al., 2009, above).
- Zappieri, J. 2003. NYS Department of State, personal communication.
- Zeppie, C.R. 1977. "Vertical profiles and sedimentation rates of Cd, Cr, Cu, Ni, and Pb in Jamaica Bay, New York." M.S. Thesis. Marine Environmental Sciences Program, State University of New York, Stony Brook, NY, USA.
- Zielinski, G.A. 2002. "A Classification Scheme for Winter Storms in the Eastern and Central United States with an emphasis on Nor'easters." *Bulletin of the American Meteorological Society* 83:37-51.
- Zishka, K.M. and P.J. Smith. 1980. "The climatology of cyclones and anticyclones over North America and surrounding ocean environs for January and July, 1950-77." *Monthly Weather Review* 108:387-401.

## Appendix A. Stakeholder Interactions

Stakeholder interaction is a key component of the ClimAID assessment design, integrating scientific knowledge with local experience and allowing the prioritization of vulnerabilities and provision of tangible adaptation strategies that decision-makers can use. The Coastal Zones Sector interacted with relevant stakeholders through meetings and phone conferences, and through a more regularly engaged focus group.

### Meetings

The Coastal Zones Sector held its first stakeholder meeting on January 9, 2009, at the City University of New York Graduate Center in New York City. The following agencies, stakeholders, and academic institutions were represented: National Park Service, Stony Brook University, New York State Department of State, Suffolk and Nassau Counties, the New York District Army Corps of Engineers, New York City Department of Parks and Recreation, Department of Environmental Conservation Hudson River Estuary Program and New York State Climate Change Office, The Nature Conservancy, New York State Emergency Management Office, and the New York Sea Grant Extension. The meeting included a presentation by the New York State Department of State on its emerging post-storm redevelopment plan.

We held our second stakeholder meeting as a webinar on February 10, 2010. The following agencies, stakeholders, and academic institutions were represented: CUNY Institute for Sustainable Cities, City University of New York, New York State Department of State, NASA Goddard Institute for Space Studies, New York City Department of Parks and Recreation, Department of Environmental Conservation Hudson River Estuary Program and New York State Climate Change Office, Suffolk County Department of Environment and Energy, The Nature Conservancy, New York State Emergency Management Office, and New York Sea Grant Extension.

### Focus Group and Related Assessment Efforts

From the initial stakeholder meeting a focus group was constructed from members of The Nature Conservancy

(point of contact [POC] Sarah Newkirk), New York Sea Grant (POC Jay Tanski), New York City Department of Parks (POC Ellen Hartig), New York State Department of Environmental Conservation (NYS DEC) Region 2 (POCs Kristin Marcell, Betsy Blair), and Stony Brook University (POC Henry Bokuniewicz). The members of the focus group served as regional experts, contributed text to the Coastal Zone chapter, and provided feedback on the overall sector assessment progress and methodology. Several of the focus group members also act as liaisons between ClimAID and related regional assessment efforts in order to coordinate work products and recommendations to policy makers.

#### *New York City Climate Change Adaptation Task Force and the New York City Panel on Climate Change*

In August 2008, Mayor Michael Bloomberg launched the Climate Change Adaptation Task Force and the New York City Panel on Climate Change (NPCC) as part of his PlaNYC 2030, to develop adaptation strategies to protect the city's infrastructure from climate change impacts (Rosenzweig and Solecki, 2010). Experts on the NPCC from academic institutions and from legal, engineering, and insurance industries advised the Adaptation Task Force in developing comprehensive and inclusive strategies to protect the city's infrastructure against the effects of climate change. Of the many products developed from the NPCC work, the sea level rise information and mapping strategies were most critical to the development of the ClimAID Coastal Zones chapter, forming the foundation of case study flood projections and illustrations.

#### *New York State Sea Level Rise Task Force*

The New York State Sea Level Rise Task Force, established by the state legislature and chaired by the NYSDEC Commissioner, was charged with providing New York State with the best available science as to sea level rise and its anticipated impacts. Its tasks were to develop inventories of at-risk assets, describe the impacts of sea level rise and prepare guidance for the

development of risk and adaptation strategies. The final report and website includes recommendations for protective standards and adaptive measures to be used by state and local governments as they move forward with planning for sea level rise and climate change. The Task Force adopted projections developed by the NPCC for sea level rise and coastal inundation (Rosenzweig and Solecki, 2010). These projections, which were also adopted for the ClimAID assessment, were refined for the Hudson River (see section 5.2.1 and Chapter 1, "Climate Risks") and included a rapid ice-melt scenario.

#### *Rising Waters*

The Rising Waters project was a multi-stakeholder scenario planning project to prepare for climate change in the Hudson Valley (Aldrich et al., 2009). The Nature Conservancy was the lead on the effort along with five major partners: the Cary Institute for Ecosystem Studies, the NYS DEC Hudson River Estuary Program, NYS DEC/NOAA Hudson River National Estuarine Research Reserve, the Cornell University Water Resources Institute, and Sustainable Hudson Valley. The process, based on a scenario planning process developed by Royal Dutch Shell aimed to develop realistic plausible scenarios or stories of the future based on the best available information today on the drivers of environmental, social, economic, and technological change and how they relate to one another (Aldrich et al., 2009). The scenarios are designed to serve as a tool to evaluate adaptation strategies that will work best across the range of possible futures. Four future scenarios were developed for the Hudson Valley for the year 2030. Two primary variables were explored in the scenarios. The first was whether the Hudson Valley opted to adapt to climate change in a way that tends to work with nature (using greener, non-structural solutions) or more engineered structural solutions. The second variable is the level of effort (large or small) in preparing for climate change. Climate information for the scenarios was based upon the best available scientific projections at the time and was the same for all four scenarios. A list of adaptation strategies was developed and evaluated based on criteria set by stakeholders and performance of the strategy in each scenario.

<sup>1</sup> Census tracts are small, relatively permanent statistical subdivisions of a county delineated by local participants as part of the U.S. Census Bureau's Participant Statistical Areas Program. A census block group is a cluster of census blocks having the same first digit of their four-digit identifying numbers within a census tract.