Near Bylot Island, Canada

Credit: Susan van Gelder

Climate Analysis

Flooding at West and Cortlandt Streets, Hurricane Donna, 1960

Credit: Allyn Baum/The New York Times

Although New York City has been hit by coastal storms before, Sandy was an historic event by many measures. Since 1900, 14 hurricanes and countless nor'easters have struck the area. Sandy, however, exceeded them all—not only in terms of storm surge height, but also in the scale and scope of the devastation it caused. *(See sidebar: Storms Through New York City History)*

Of course, Sandy was not just an historic storm. It was also idiosyncratic. As discussed in Chapter 1 (*Sandy and Its Impacts*), a set of circumstances—timing, size, and path—all came together to cause unprecedented impacts, primarily on the southern, coastal-facing areas of the city.

As devastating as Sandy was, however, not everything about the storm was unprecedented. Its 80- mile-per-hour (mph) peak wind gusts fell well short of other storms that have hit New York City, including Hurricane Carol in 1954 (up to 125-mph gusts) and Hurricane Belle in 1976 (up to 95-mph gusts). Previous storms also brought much more rain with them. Sandy dropped a scant inch in some parts of New York, far less than the 5 inches of rain dropped on the city during Hurricane Donna in 1960 or the 7.5 inches during the April 2007 nor'easter.

With greater winds and more rain, Sandy could have had an even more serious impact on the areas of Staten Island, Southern Brooklyn, and South Queens that experienced the most devastation during the storm. And while Sandy brought the full force of its impact at high tide for these southernmost areas of the city, it hit the area around western Long Island Sound almost exactly at low tide. As a consequence, parts of the Bronx, Northern Queens, and East Harlem were not as affected as they could have been.

In fact, the same storm, arriving at a slightly different time, likely would have had significant effects on New York's northernmost neighborhoods. According to modeling undertaken by the storm surge research team at the Stevens Institute of Technology, if Sandy had arrived earlier—near high tide in western Long Island Sound, rather than in New York Harbor and along the Atlantic Ocean—the peak water level in the western Sound, measured at the King's Point gauge, which hit more than 14 feet above Mean Lower Low Water, or MLLW (over 10 feet above datum NAVD88) during Sandy, instead could have reached almost 18 feet above MLLW (almost 14 feet above NAVD88). *(See maps: Sandy Inundation, Bronx and Northern Queens and Sandy Inundation Simulated 9 Hours Earlier, Bronx and Northern Queens; see sidebar: Defining Datums; see graph: Illustrative Shift in Tide Cycle)*

The result would have been devastating for infrastructure providing critical services to the rest of the city. Flooding could have overwhelmed parts of the Hunts Point Food Distribution Center in the Bronx, thereby threatening facilities that are responsible for handling as much as 60 percent of the city's produce. Meanwhile, the power plants in Astoria, Queens, which are responsible for almost one-third of the city's installed generation capacity, could have been inundated as well. At LaGuardia Airport, which was flooded to about 14 feet above MLLW (about 10 feet above NAVD88) during Sandy, this could have resulted in a water level of about 17 feet above MLLW (13 feet above NAVD88) or up to 12 feet of water above ground level. Additional, four wastewater treatments plants and 29 water pumping stations could also have been affected.

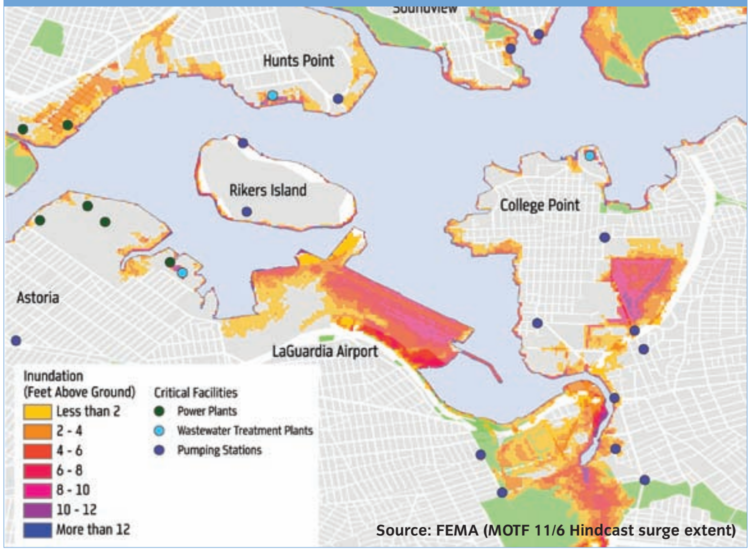
Clearly, while Sandy was historic, it was not, in fact, a worst-case scenario for all of New York

Storms Through New York City History

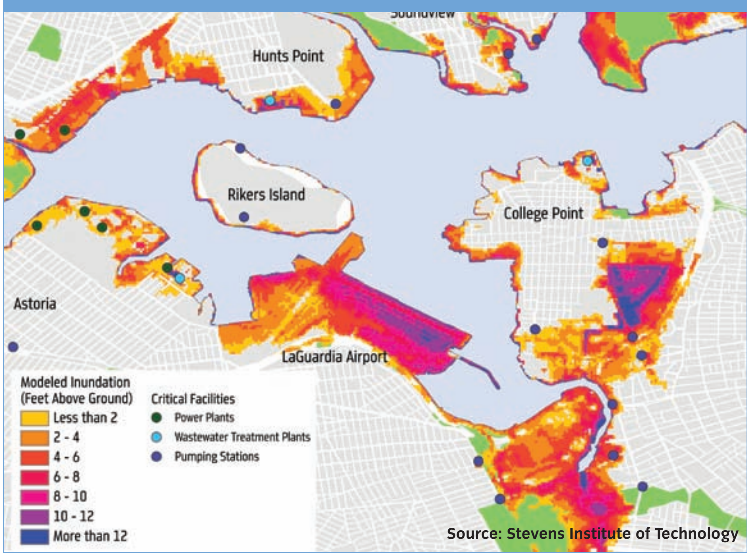
Sandy may have been the latest catastrophic storm to hit New York City, but it certainly was not the first. Throughout history, the city has suffered from hurricanes and other coastal storms, such as nor'easters. Hurricanes and tropical storms strike New York infrequently, relative to other types of coastal storms (generally arriving during hurricane season, June 1 to October 31), and can produce large surges, heavy rains, and high winds. Nor'easters, by contrast, are cold weather storms that have strong northeasterly winds blowing in from the ocean ahead of them. Compared to hurricanes, nor'easters generally bring smaller surges and weaker winds but can cause significant harm because they tend to last longer, resulting in extended periods of high winds and high water that can be sustained through one or more high tides.

In 1821, a hurricane made a direct strike on New York City, bringing winds of about 75 mph and a reported 13-foot storm surge that flooded Lower Manhattan as far north as Canal Street. In 1938, a storm known as the Long Island Express—because the fast-moving eye passed over Long Island—hit with no warning, leading to over 600 deaths, including 10 in New York City, while 100-mph wind gusts knocked out electricity north of 59th Street in Manhattan. In 1960, Hurricane Donna had wind gusts of up to 90 mph and a 10-foot (above MLLW) storm surge that caused extensive pier damage. Major storms have been showing up in the North Atlantic with greater frequency in the last few decades. Examples of recent storms having significant impacts to New York City include: Agnes in 1972, Belle in 1976, Gloria in 1985, a nor'easter in 1992, Bertha in 1996, Floyd in 1999, Isabel in 2003, Ernesto in 2006, a nor'easter in 2007, and Irene and Lee in 2011—which made back-to-back appearances just 14 months prior to Sandy.

Sandy Inundation, Bronx and Northern Queens



Sandy Inundation Simulated 9 Hrs. Earlier, Bronx and Northern Queens



Simulated estimate of flooding by the Stevens Institute of Technology's NYHOPS model. Note that these results are hypothetical.

Defining Datums

A vertical datum is a base reference point for determining heights or depths. Vertical datums set a consistent zero point so elevations can be compared with one another at different locations with different physical characteristics. For example, flood levels can be measured relative to mean sea level, or relative to ground levels that may be well above mean sea level.

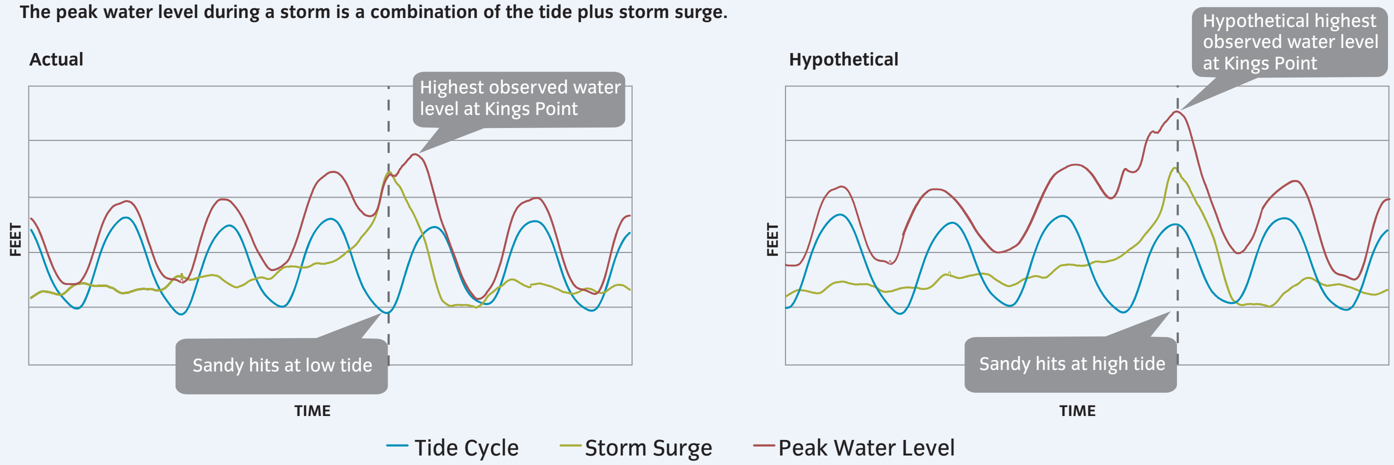
Tidal datums, such as Mean Lower Low Water (MLLW), are standard elevations defined by a certain phase of the tide. Tidal datums are used as references to measure local water levels and therefore vary over different areas. For example, the MLLW tidal datum is determined by averaging the lower of the two low waters of any tidal day for a particular tide gauge over a period of time. There are tide gauges in the New York City area at multiple locations, including at the Battery and Kings Point. MLLW is a useful datum for comparing water levels at a specific point to "normal" water levels, but is less helpful for comparing water elevations in different locations, since they may experience very different MLLW levels.

Gravity-based datums, such as the North American Vertical Datum of 1988 (NAVD88) are referenced to a fixed point in the ground. NAVD88 is the national standard, largely because it allows for comparisons of water levels across many locations that have different tidal characteristics.

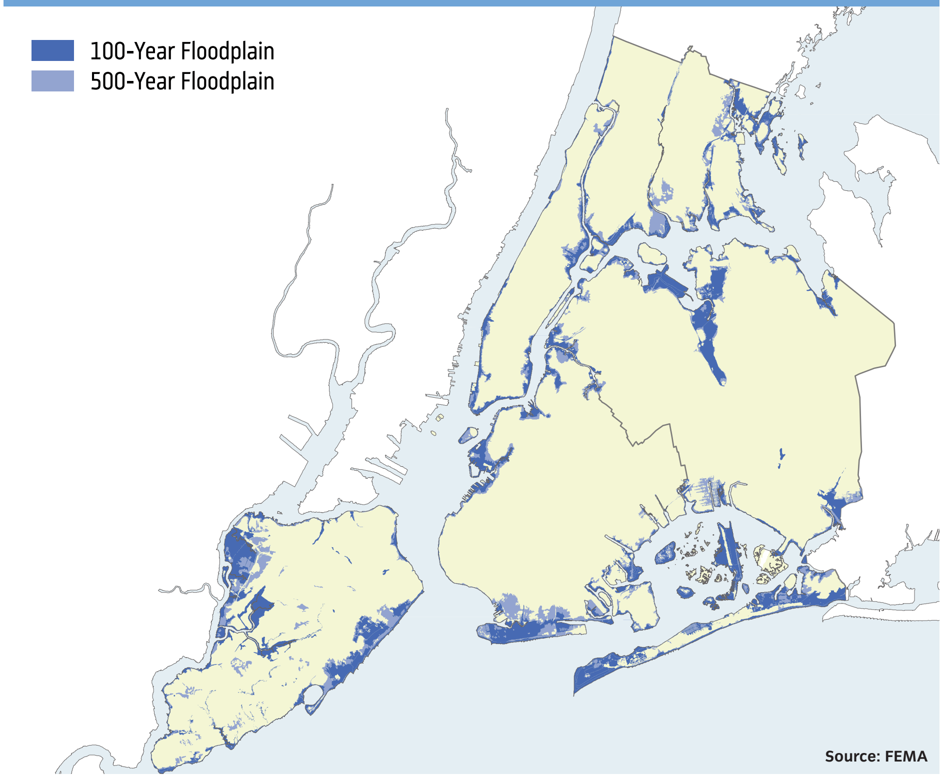
In order to facilitate comparisons across different locations, this report refers to all water elevations in NAVD88 unless otherwise specified. MLLW is used selectively to highlight location-specific water levels and typically shows higher values than NAVD88. Flood depths, which are measured from ground level and vary with terrain, also are used to describe the flooding experienced in different neighborhoods.

Illustrative Shift in Tide Cycle

The peak water level during a storm is a combination of the tide plus storm surge.



1983 FEMA Flood Insurance Rate Maps, FIRMs



City. And as the climate changes, raising the prospect of stronger storms coming more frequently, the risks that New York City faces will only intensify.

Of course storms are not the only climate threats New Yorkers face. The city is also vulnerable to other "extreme" events, such as heavy downpours, heat waves, droughts, and high winds. Chronic conditions, such as rising sea levels, higher average temperatures, and increased annual precipitation, also have direct impacts on the city and can make the effects of extreme events worse. That is why this report is not about preparing New York for the next Sandy or even the next coastal storm, but is instead about how New York can adapt to the full spectrum of future challenges posed by climate change—whatever they may be.

New York's Current Vulnerabilities

Since 1983, New York's vulnerability to coastal storms has been reflected in flood maps produced by the Federal Emergency Management Agency (FEMA), which describe the Federal government's assessment of flood risk. Called Flood Insurance Rate Maps (FIRMs) because they are used by the National Flood Insurance Program (NFIP) and trigger certain flood insurance requirements, the maps show how much land lies within the "100-year floodplain" (the area that has a 1 percent or greater chance of flooding in any given year) and the "500-year floodplain" (the area that has a 0.2 percent or greater chance of flooding any year). They also define different zones of vulnerability within the 100-year floodplain, including areas that are at risk of destructive wave action, and that generally require flood-protective construction standards (see Chapter 3, *Coastal Protection*; Chapter 4, *Buildings*; and Chapter 5, *Insurance*).

These 1983 FIRMs show that a full 33 square miles of New York City—almost half of Brooklyn—are within the equivalent of the 100-year floodplain. As of 2010, there were about 218,000 New Yorkers living in those areas. All 14 of the city's wastewater treatment plants and 12 out of 27 power plants, representing 37 percent of the city's generation capacity, are within the 100-year floodplain as reflected in the 1983 FIRMs, many of these critical facilities placed on the coast out of operational necessity. There are also vibrant neighborhoods and commercial districts in this area that contain approximately 35,500 buildings, 377 million square feet of floor area, and 214,000 jobs. *(See map: 1983 FEMA Flood Insurance Rate Maps, FIRMs)*

However, even before Sandy, the City and FEMA had known that the flood maps did not adequately reflect New York's risks. Although FEMA converted the maps to digital form in 2007, their content had not changed meaningfully since 1983. As such, this report refers to the maps as 1983 FIRMs. In the intervening three decades, many changes had been made to the city's shoreline and significant development had occurred on the waterfront. In addition, sea levels had continued to rise as they had since the beginning of the 20th century (over a foot since 1900), more accurate coastal modeling and mapping techniques had been developed, and 30 years of additional data on storms were available.

Recognizing the need for updated information on New York's flood risks, in 2007, the City formally requested that FEMA update its flood maps for New York—a multiyear process that FEMA kicked off in 2009. In 2010, to help inform FEMA's mapping process, the City acquired the most detailed elevation data ever gathered for New York, known as LiDAR (light detection and ranging) data. To collect these data, the City flew an airplane equipped with a laser scanner over the five boroughs to measure land elevations with tremendous precision. This allowed the City to create a detailed, three-dimensional picture of the shape and characteristics of New York's surface area—which in turn could be used by FEMA for substantially better flood mapping.

Hurricane Sandy demonstrated the importance of regular coastal updates to FEMA's maps. The area that flooded during the storm was more than one and a half times larger than the 100-year floodplain defined on FEMA's 1983 FIRMs. In certain communities, the areas that flooded were several times larger than the floodplains outlined on the maps. In Brooklyn and Queens, for example, the combined amount of land flooded was roughly equal to the amount of land in the entire citywide 100-year floodplain as mapped in 1983 (both about 33 square miles). Meanwhile, about 60 percent of all buildings and more than half of the residential units in areas that Sandy inundated were outside the 100-year floodplain, as were approximately 25 percent of the buildings tagged by the Department of Buildings (DOB) as having been seriously damaged or destroyed as of December 2012. In these areas, not only were residents unaware of the risks that they faced, but the buildings in which they lived and worked had not been subject to the flood-protective construction standards that generally apply within the floodplain (see Chapter 4). *(See map: 1983 FEMA FIRMs and Sandy Inundation Area Comparison)*

Just three months after Sandy, in January 2013, as part of an effort to give New Yorkers better information about their flood risks from coastal storms, FEMA issued interim maps for New York, just as it had done for other communities that did not have up-to-date maps following major storms (for example, it did so for Louisiana and Mississippi after Hurricane Katrina in 2005). These interim maps—called Advisory Base Flood Elevation maps, or ABFEs—together with a set of emergency measures enacted by Mayor Bloomberg to suspend certain zoning restrictions and modify

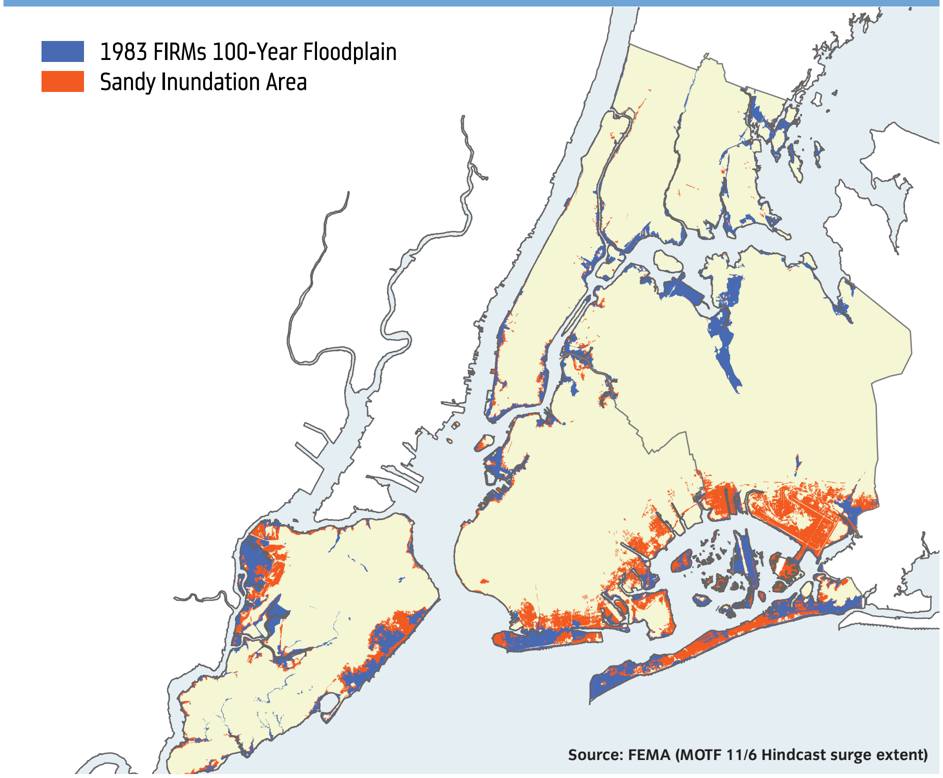
100-Year Flood

The term "100-year" flood can be misleading, and perhaps even provides a false sense of security. This report uses the term "100-year" flood or floodplain because it is the most commonly used phrase and one with which the public is familiar. Nevertheless it is important to understand what the term means. A 100-year flood is not the flood that happens once every 100 years. Rather, it is the flood that has a 1 percent chance of occurring in any given year. Experiencing a 100-year flood does not decrease the chance of a second 100-year flood occurring that same year or any year that follows.

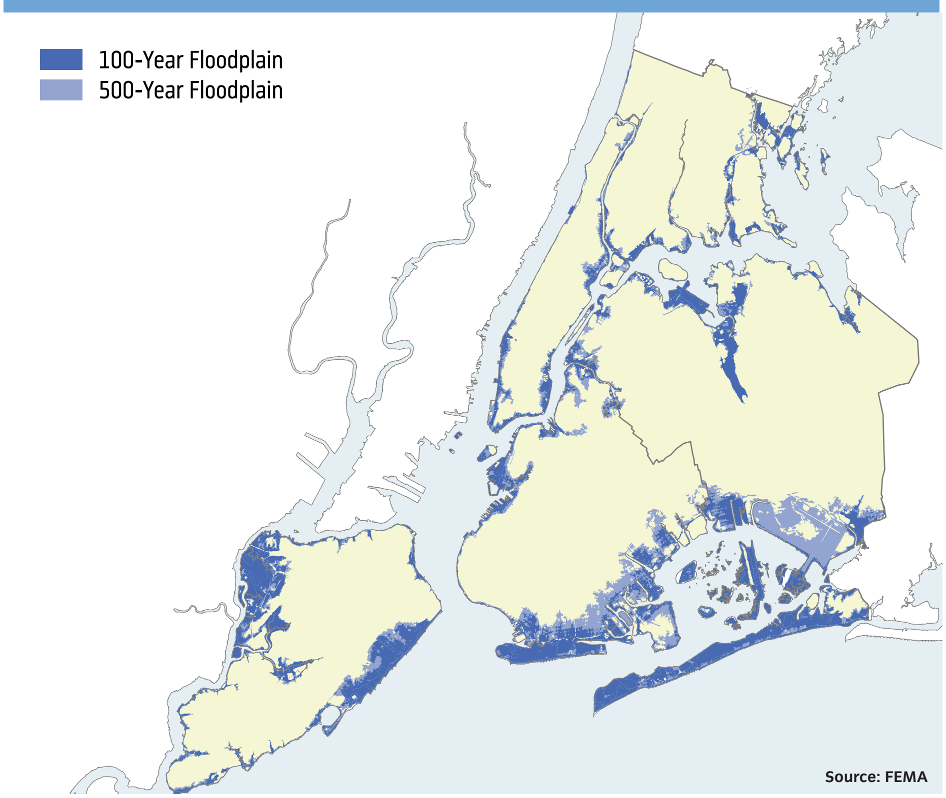
Even the 1 percent concept can be misleading—because when the years add up, so too does the probability. A 1 percent chance each year may not seem like much, but when the public or private sectors are making decisions, it matters. Determining whether to buy a particular house or where to build a power plant has long-term implications. For example, a 100-year flood today, without considering future impacts from sea level rise or climate change, has a 26 percent chance of occurring at least once over the life of a 30-year mortgage. Similarly, a 100-year flood today has a 45 percent chance of occurring over the 60-year life of a power substation.

Lest anyone think the probability of a so-called 100-year storm is too remote to worry about or plan for, consider what it means for the children of New York today. A child born today with the average life expectancy of a New Yorker (80.9 years) faces a 56 percent probability (without sea level rise) of witnessing today's 100-year flood within her lifetime.

1983 FEMA FIRMs and Sandy Inundation Area Comparison



2013 FEMA Preliminary Work Maps (PWMs)



certain building codes temporarily, allowed New Yorkers to begin rebuilding after the storm to standards that better reflected actual flood risks.

In June 2013, FEMA issued Preliminary Work Maps (PWMs) for New York City that incorporated even more accurate wave modeling. Though similar in many cases to the ABFEs released in January, the revised maps differed significantly in certain respects—they showed, for example, substantially smaller areas of the city at risk of destructive wave action. These PWMs will be considered best-available information until FEMA releases Preliminary FIRMs (by the end of 2013), the first official product of the FEMA map update process launched in 2009. After a public review and appeals period, the Preliminary FIRMs will be revised and released as new, final Effective FIRMs (replacing the 1983 maps) likely in 2015. The new FIRMs will inform a variety of flood-related requirements, including flood insurance and flood-protective construction standards. Though some adjustments may occur, it is currently believed that the new FIRMs will tell a similar story about the city's vulnerability to coastal storms as was told by the PWMs. *(See map: 2013 FEMA Preliminary Work Maps (PWMs))*

Updating FEMA FIRMs for New York City

1981
FEMA completes a Coastal Flood Study for New York City.

1983
FEMA issues the first FIRMs for New York City.

1980s

1991-2007
FEMA revises FIRMs with updated wetland and stream modeling, and minor adjustments to the floodplain.

1990s

2007
FIRMs are converted to digital form and posted online.

2007
New York City calls on FEMA to conduct a full update of the FIRMs.

2000s

Floodplain Comparison of Major American Cities

City	Population in the 100-Year Floodplain	Share of Total Population	Land Area of 100-Year Floodplain (Square Miles)	Population Density of 100-Year Floodplain (People per Square Mile)
New York	398,100	5%	48	8,300
Houston	296,400	14%	107	2,800
New Orleans	240,200	70%	183	1,300
Miami	144,500	36%	18	8,000
Fort Lauderdale	83,200	50%	21	4,000
San Francisco	9,600	1%	3	3,200

Source: NOAA's Spatial Trends in Coastal Socioeconomics, Demographic Trends (1970-2011); 2010 US Census Tiger Files, and population data; floodplain census data gathered from Miami's Chief of Community Planning, Houston's City Engineer, and Fort Lauderdale's Planning Department; New York population data was obtained from the Department of City Planning Population Division.

Overall, the story told by the PWMs is unsurprising but nonetheless troubling. The new 100-year floodplain, roughly corresponding to the areas flooded during Sandy, is larger than indicated on the 1983 maps by about 15 square miles, or 45 percent. The new floodplain includes larger portions of all five boroughs with significant expansion in Brooklyn and Queens. Citywide, there are now 67,700 buildings in the floodplain (an increase of 90 percent over the 1983 FIRMs) encompassing over 534 million square feet of floor area (up 42 percent). The number of residential units in the floodplain has increased to 196,700 (a jump of over 61 percent), with the majority of those residences in Brooklyn, Manhattan, and Queens. Almost 400,000 New Yorkers now live in the floodplain (up 83 percent)—more living in the floodplain than in any other American city (though some cities, such as New Orleans, have a much higher share of their populations in the 100-year floodplain). *(See timeline: Updating FEMA FIRMs for New York City; see table: Floodplain Comparison of Major American Cities)*

While the information contained in the PWMs has been critical for assessing current risks and informing rebuilding, the city's experience both before and after Sandy highlights areas for improvement in the current FEMA flood-mapping process. The lack of regular updates, the time involved in performing such updates, and the communication to stakeholders regarding those updates have made it challenging for governments, infrastructure operators, residents, and business owners to understand and address their coastal flood risks.

Storms are not the only weather challenges to New York City. Another is heavy downpours—which have increased over the last half-century across the Northeast. These heavy rains threaten the city's critical infrastructure, especially the water and transit systems. For example, in 2011, back-to-back Tropical Storms, Irene and Lee, produced elevated turbidity (murkiness resulting from stirred sediment) and high bacteria counts in several of the City's Upstate reservoirs that supply drinking water. During and immediately following the storms, turbidity levels remained high in the Catskill System and in the Catskill Aqueduct, which carries drinking water from the Ashokan Reservoir to the Kensico Reservoir before delivering it to the city. As a result, special treatment continued for almost nine months, the longest such treatment period ever recorded. With treatment and operational measures, the City ensured that the drinking water delivered to the public remained in compliance and safe for consumption.

2010
New York City and FEMA form a partnership. The City acquires highly accurate topographical data, known as LiDAR.

June 2013
FEMA releases PWMs for New York City.

2010s

2009
FEMA initiates New York/New Jersey Coastal Flood Study.

October 29, 2012
Sandy hits.

January and February 2013
FEMA releases ABFEs.

Mayor Bloomberg signs an executive order providing zoning relief for New Yorkers rebuilding to FEMA's new standards.

2015
New FIRMs expected to be adopted by the City after FEMA's process of public appeals and response.

Heavy downpours also present risks to the transit system. A single rainstorm in 2007 severely disrupted 19 major segments of New York City's subway system during morning rush hour, forcing much of the system to shut down and affecting as many as 2.3 million subway riders. Impacts to the subway system created further congestion and delays on flooded roadways and on the bus system, as subway riders tried to find a ways to get to work.

Meanwhile, heat waves—defined here as three or more consecutive days of temperatures at or above 90 degrees—are another extreme weather threat to New York. These events can be even more severe in New York due to the Urban Heat Island (UHI) effect that can cause the city's air temperature to be more than seven degrees warmer than in neighboring counties, particularly at night, disproportionately impacting certain neighborhoods. The UHI effect is caused in part by a greater concentration of buildings and paved areas, and affects energy use, comfort and quality of life, and exposure to heat stress. Heat waves strain the city's power grid and cause deaths from heat stroke and exacerbate chronic health conditions, particularly for vulnerable populations such as the elderly. In fact, heat waves kill more Americans each year than all other natural disasters combined. For example, a heat wave in New York in July 2006 resulted in 140 deaths. Going forward, a more severe and persistent heat wave, or one coupled with a major power outage, could cause even more deaths.

Another extreme event that impacts New York is drought. Droughts can lower reservoir levels and thus have an obvious and significant impact on the city's drinking water supply. Several droughts have occurred over the last 50 years, with the most intense lasting from 1963 to 1965, during which time residents and businesses significantly reduced water use through voluntary and mandatory restrictions. Since that

A September 2004 storm flooded 9th Street in Brooklyn.

Credit: Seth Wenig/The New York Times

Patients being treated for heat exhaustion at the Maimonides Medical Center in Brooklyn during the July 2006 heat wave

Credit: James Estrin/The New York Times

Wind damage from Sandy in Brooklyn

Credit: Earl Wilson/The New York Times

time, water demand has dropped, reducing the risk to New York from drought. However, the City continues to take steps to reduce water demand, such as identifying and repairing leaks, encouraging the use of more efficient "low flow" plumbing fixtures, and installing more than 830,000 automatic meter reading devices across the city to allow customers to manage their water use better. While these efforts have significantly increased drought resilience, the City continues to monitor and manage water demand.

Finally, New York also faces the threat of high winds—especially in connection with coastal storms. High winds can down trees and overhead utility lines, damaging property and causing power outages. At high enough speeds, winds can even damage buildings. Category 1 hurricanes come with sustained wind speeds of at least 74 mph, and Category 2 hurricanes bring sustained winds of 96 to 110 mph—far greater than Sandy's 80-mph wind speeds at landfall in New Jersey. In fact, in 1954, Hurricane Carol brought sustained wind speeds of up to 100 mph to the New York area, causing extensive damage.

New York Vulnerabilities in the Future

Although New York clearly is at risk today, long-term changes in climate will make many extreme events and chronic conditions worse. These changes have, in fact, been underway for some time. As noted earlier, over the last century, sea levels around New York City have risen by more than a foot. Temperatures, too, are climbing. In fact, the National Weather Service and National Oceanic and Atmospheric Administration (NOAA) labeled 2012 the warmest year on record in New York City and in the contiguous United States, with average temperatures in the US 3.2 degrees Fahrenheit above normal and a full degree higher than the previous warmest year ever recorded.

Globally, all signs indicate that these changes will accelerate. Atmospheric concentrations of heat-trapping carbon dioxide have reached levels that have not been seen on earth for millions of years. Since the onset of the industrial revolution, combustion of fossil fuels and land use changes have led to a roughly 40 percent increase in carbon dioxide levels. Because the key greenhouse gas, carbon dioxide, stays in the atmosphere for 100 years or longer, the climate is essentially "locked in" to some additional warming. Meanwhile, since the late 1970s, global average temperatures have increased by approximately 1 degree Fahrenheit and the volume of sea ice in the Arctic during the month of September has declined by almost 80 percent. Ocean temperatures have also warmed and the vast majority of glaciers have retreated.

Long-term changes in climate mean that when extreme weather events strike, they are likely to be increasingly severe and damaging. As sea levels rise, coastal storms are likely to cause flooding over a larger area and to cause areas already at-risk to flood more frequently than today. As temperatures get warmer, heat waves are expected to become more frequent, last longer, and intensify—posing a serious threat to the city's power grid and New Yorkers' health.

Through PlaNYC, the City has been making a concerted effort to understand the effects that climate change will have on New York. A critical part of this effort began as far back as 2008, when Mayor Bloomberg convened the New York City Panel on Climate Change (NPCC)—one of the first American cities to create a body of leading climate and social scientists charged with developing local climate projections. With representatives from leading scientific institutions, such as the NASA Goddard Institute for Space Studies and Columbia University's Earth Institute, the NPCC brought to bear state-of-the-art global climate models and local observations to analyze future local vulnerabilities.

In 2009, the NPCC released its findings in a groundbreaking report that made predictions for a set of chronic hazards and extreme events likely to confront the city in the future. The report—entitled *Climate Risk Information 2009*—described a New York that would be far more exposed to climate-related impacts going forward than it is today. For example, the NPCC projected that by mid-century New York could experience sea levels (under a "middle range" scenario) that are up to a foot higher, causing flooding from what is today a 100-year storm to occur two to three times as often. The NPCC also projected that by the 2050s New York was likely to experience more frequent heavy downpours and many more days at or above 90 degrees.

To begin addressing these risks, in 2008 the Mayor convened more than 40 public and private infrastructure operators as part of the Climate Change Adaptation Task Force, another PlaNYC initiative. Task Force members used the NPCC projections to evaluate the risks to their infrastructure and identify strategies to address them. For instance, Con Edison assessed how changes in extreme heat would impact future peak electrical load demand, to determine when additional capacity might be required.

The City also took action to strengthen its built environment. For example, the City required new waterfront development to design for the future risk of sea level rise and coastal storms, and passed regulations allowing buildings to elevate electrical equipment to their roofs without special permits. The City also launched the NYC°Cool Roofs Program to paint rooftops white, thereby minimizing heat gain.

The work of the Climate Change Adaptation Task Force and City agencies demonstrates the power of accurate information to drive thoughtful planning and decision-making. That is why the City has continued to advocate for better and more current information on the risks New York faces. As mentioned earlier, the City pushed for an update to FEMA's flood maps for New York so the City and its residents and businesses could better understand the existing risks from flooding during coastal storms. However, the City also

NPCC 2013 Climate Projections

Chronic Hazards	Baseline (1971-2000)	2020s		2050s	
		Middle Range (25th - 75th percentile)	High End (90th percentile)	Middle Range (25th - 75th percentile)	High End (90th percentile)
Average Temperature	54 °F	+2.0 to 3.0 °F	+3.0 °F	+4.0 to 5.5 °F	6.5 °F
Precipitation	50.1 in.	+0 to 10%	+10%	+5 to 10%	+15%
Sea Level Rise[1]	0	+4 to 8 in.	+11 in.	+11 to 24 in.	+31 in.

Extreme Events		Baseline (1971-2000)	2020s		2050s	
			Middle Range (25th - 75th percentile)	High End (90th percentile)	Middle Range (25th - 75th percentile)	High End (90th percentile)
Heat Waves and Cold Events	Number of days per year at or above 90°F	18	26 to 31	33	39 to 52	57
	Number of heat waves per year	2	3 to 4	4	5 to 7	7
	Average duration (days)	4	5	5	5 to 6	6
	Number of days per year at or below 32°F	72	52 to 58	60	42 to 48	52
Intense Precipitation	Days per year with rainfall exceeding 2 inches	3	3 to 4	5	4	5
Coastal Floods at the Battery[1]	Future annual frequency of today's 100-year flood	1.0%	1.2% to 1.5%	1.7%	1.7% to 3.2%	5.0%
	Flood heights from a 100-year flood (feet above NAVD88)	15.0	15.3 to 15.7	15.8	15.9 to 17.0	17.6

Source: NPCC; for more details, see *Climate Risk Information 2013*.

[1] Baseline period for sea level rise projections is 2000-2004.

Like all projections, the NPCC climate projections have uncertainty embedded within them. Sources of uncertainty include data and modeling constraints, the random nature of some parts of the climate system, and limited understanding of some physical processes. The NPCC characterizes levels of uncertainty using state-of-the-art climate models, multiple scenarios of future greenhouse gas concentrations, and recent peer-reviewed literature. Even so, the projections are not true probabilities, and the potential for error should be acknowledged.

recognized that even updated FEMA flood maps, because they are based on historic data, will not provide information about the changes that are likely to threaten New York in the future.

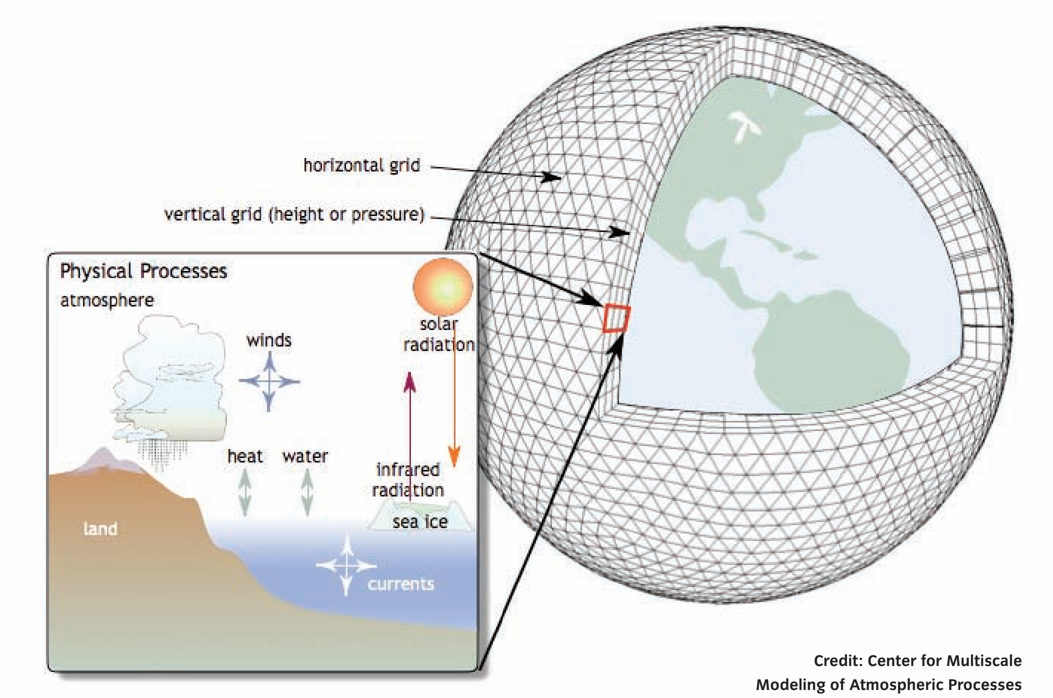
To ensure that the City would always have access to the latest information about future climate risks, in September 2012 New York City formally codified the NPCC and the Climate Change Adaptation Task Force when it wrote those two entities into law—the first bill passed by any local government in the country to institutionalize a process for updating local climate projections and identifying and implementing strategies to address climate risks. The new law requires that the NPCC meet twice a year, advise the City and the Climate Change Adaptation Task Force on the latest scientific developments, and update climate projections at least every three years, starting from March 2013.

Of course, in the wake of Sandy, waiting another three years would have been too long. That is why, in January 2013, the City reconvened the NPCC on an emergency basis to update its projections to inform planning for rebuilding and resiliency post-Sandy. NPCC members agreed to participate on an accelerated timetable, setting aside other important research to focus on updating the projections to help New York plan for the future.

Drawing on the latest climate models, recent observations about climate trends, and new information about greenhouse gas emissions, the NPCC updated its 2009 projections—in a document called *Climate Risk Information 2013*, which it has released concurrent with this report. These projections tell a dire story about New York's future. *(See table: NPCC 2013 Climate Projections; see sidebar: How New York's Climate Projections are Developed)*

The NPCC now projects that, by mid-century, sea levels could rise by more than 2.5 feet, especially if the polar ice sheets melt at a more rapid rate than previously anticipated. That magnitude of sea level rise would threaten

How New York's Climate Projections Are Developed



Credit: Center for Multiscale Modeling of Atmospheric Processes

The New York City Panel on Climate Change (NPCC) develops climate projections using global climate models. These models are mathematical representations of the earth's climate system (e.g., the interactions between the ocean, atmosphere, land, and ice). They use estimates of future greenhouse gas and pollutant concentrations to project changes in climate variables such as temperature and precipitation. Because future emissions are uncertain, scientists use a range of scenarios that can be linked to assumptions about future population and economic growth and technological change.

To develop the most recent set of climate projections, the NPCC used the latest climate models developed for the upcoming *Intergovernmental Panel on Climate Change Fifth Assessment Report*. The NPCC also used estimates of future atmospheric concentrations of greenhouse gases called Representative Concentration Pathways (RCPs), selecting two RCPs (4.5 and 8.5) for which the greatest number of climate model simulations were available and which span a range of potential future concentrations. To produce local temperature and precipitation projections, the NPCC used these two RCPs and 35 global climate models for the land-based grid box covering New York City. To generate sea level rise projections, the NPCC used 24 global climate models and the same two RCPs. For sea level rise, the NPCC also included additional global factors and local factors.

The results provide a range, or distribution, of outcomes. Local projections are presented for the "middle range" (the middle 50 percent of that distribution) and the "high end" (the 90th percentile of that distribution). The high end is presented as a more extreme outcome and would be appropriate for those with lower risk tolerances—such as critical infrastructure operators.

Source: NPCC; for more details, see *Climate Risk Information 2013*.

low-lying communities in New York with regular and highly disruptive tidal flooding, and make flooding as severe as today's 100-year storm at the Battery up to five times more likely. The NPCC also predicts it is more likely than not (more than 50 percent probability) that there will be an increase in the most intense hurricanes in the North Atlantic Basin.

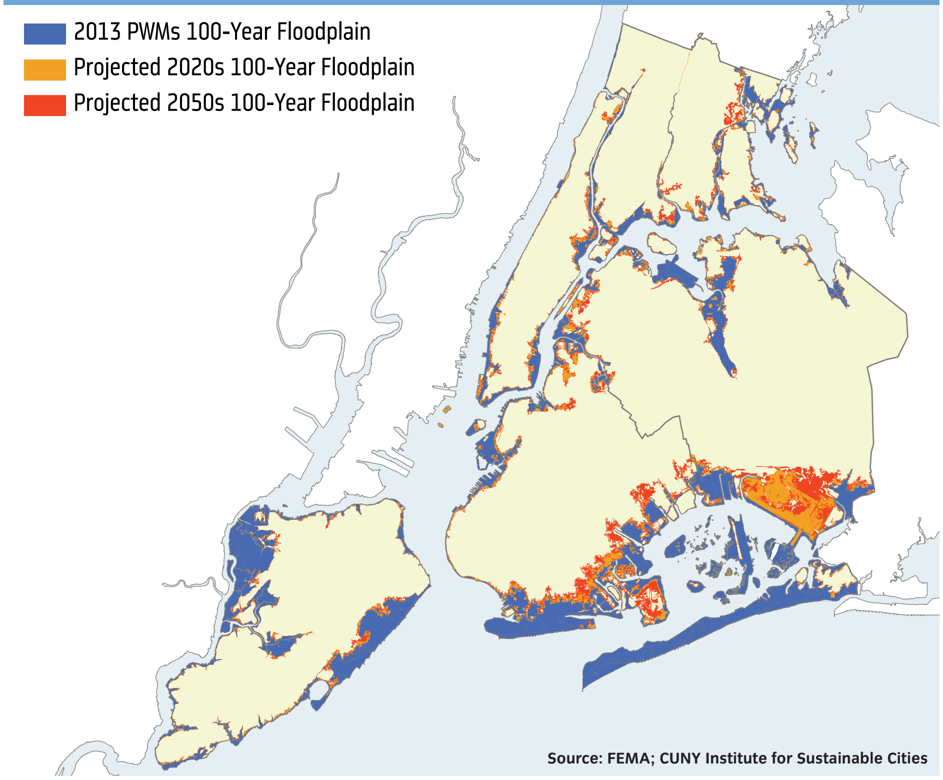
Meanwhile, the NPCC also predicts that, by the 2050s, the city could have as many days at or above 90 degrees annually as Birmingham, Alabama has today—a threefold increase over what New York currently experiences. Heat waves could more than triple in frequency, lasting on average one and a half times longer than they do today. Similarly, it is also very likely (more than 90 percent probability) that the New York City area will see an increase in heavy downpours over this time period.

These projections have been subjected to rigorous peer review, and represent the best-available climate science for New York City. However, they are not yet officially recognized by the State or Federal governments because there is no formal mechanism for them to do so. As planning for resiliency moves forward in New York, it will be necessary to make sure that all stakeholders addressing climate change in New York City are using common projections based on the work of the NPCC to avoid confusion or conflicting standards.

The City also has worked with the NPCC to develop a series of "future flood maps" for New York that will help guide the city's rebuilding and resiliency efforts. These forward-looking maps are created by using a simplified approach that combines the NPCC's "high end" sea level rise projections with FEMA's PWMs. The maps illustrate how the 100-year floodplain could increase over the next several decades with these high end projections. Because these maps were not developed using advanced coastal modeling, the accuracy of the flood projections is limited and they are not suitable for evaluating risks to individual properties. However, they are extremely useful for understanding the general extent of future flood risks. *(See map: Future Flood Maps for the 2020s and 2050s; see sidebar: Possible Links Between Sandy and Climate Change)*

The new maps show that the area that might be flooded in a 100-year storm in the 2020s could expand to 59 square miles (up 23 percent from the PWMs) and encompass approximately 88,800 buildings (up 31 percent). With more than 2.5 feet of sea level rise, New York City's 100-year floodplain in the 2050s could be 72 square miles—a staggering 24 percent or nearly a quarter of the city—an area that today contains approximately 114,000 buildings

Future Flood Maps for the 2020s and 2050s



Source: FEMA; CUNY Institute for Sustainable Cities

Like all environment-related projections and associated map products, the NPCC future flood maps have uncertainty embedded within them. In this case, uncertainty is derived from a set of data and modeling constraints. Application of state-of-the-art climate modeling, best mapping practices and techniques, and scientific peer review was used to minimize the level of uncertainty. Even so, the map product should be regarded as indicative of the general extent of future flood risks based on high end sea level rise projections and not of the actual spatial extent of future flooding.

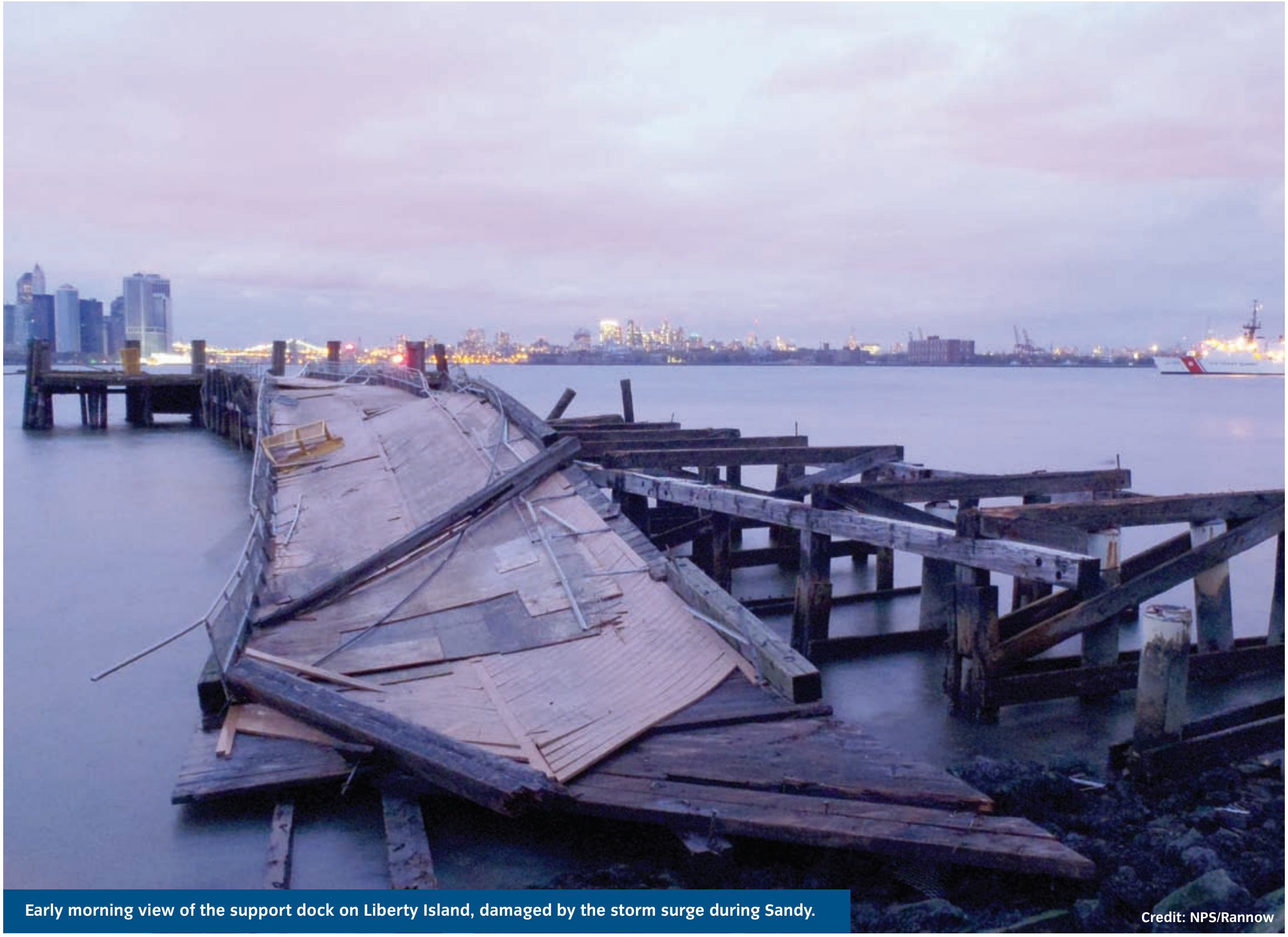
Possible Links Between Sandy and Climate Change

Sandy has brought public attention to the climate hazards of the New York area. But did climate change *cause* the storm? While it is impossible to attribute any one event such as Sandy entirely to climate change, higher sea levels certainly did increase the extent and magnitude of coastal flooding caused by the storm. Since 1900, sea levels have risen more than a foot in New York City, primarily due to climate change. As sea levels continue to rise, coastal storms will cause flooding over a larger area and at increased heights than they otherwise would have.

Sandy is also thought to have gained strength from unusually warm upper ocean temperatures in the North Atlantic. As the planet warms, upper ocean temperatures are expected to increase, which could fuel storms. Although hurricanes depend on a range of climate variables and it is not clear how these other variables will change, recent studies suggest that the most intense hurricanes may increase globally. And, it is more likely than not (greater than 50 percent probability) that such hurricanes also will increase in the North Atlantic Basin.

Loss of sea ice as the Arctic warms may possibly have influenced Sandy's path and intensity. The volume of sea ice in the early fall has decreased 75 percent since 1980, and some researchers have linked this to changes in the atmospheric steering currents known as the jet stream—changes that may be increasing the frequency and intensity of extreme weather events. The dip in the jet stream that contributed to Sandy's "westward" turn that resulted in its striking New Jersey was unusual. Whether the reduction of sea ice played a role in that particular configuration remains unknown, but climate scientists believe it is worthy of further research.

Source: NPCC; for more details, see *Climate Risk Information 2013*



Early morning view of the support dock on Liberty Island, damaged by the storm surge during Sandy. Credit: NPS/Rannow

(almost twice as many as indicated by the PWMs). This area currently accounts for 97 percent of the city's power generation capacity, 20 percent of its hospital beds, and a large share of its public housing. Over 800,000 New Yorkers, or 10 percent of the city's current population, now live in the 100-year floodplain projected for the 2050s—a number of flood-vulnerable residents that is greater than the total number of people living in the entire city of Boston.

Building on the information contained in these future flood maps, the City also commissioned an analysis of the economic impacts of projected changes in the city's vulnerability to coastal storms. This work was completed by Swiss Re, one of the world's largest reinsurers (a company that, because it provides its clients with reinsurance and insurance protection against natural catastrophe risks, has developed expertise in projecting the probability of extreme weather and the resulting damage). Unlike the risk represented in FEMA's maps, Swiss Re took into account the potential damage caused by both flooding and high winds. Their analysis shows that the combination of rising sea levels and more intense storms is expected to come with significant costs—costs that will be measured in many billions of dollars. *(See sidebar: Expected Loss Modeling and Cost-Benefit Analysis)*

With analytical tools such as the Swiss Re model, the City has yet another way of assessing the likelihood and impact of coastal storms on New York. Still the model does not assess the impact of extreme events beyond coastal storms (which include both storm surge and wind), nor does it assess potential public health impacts of coastal storms and other extreme weather events such as heat waves.

The City, however, has been working to fill this gap in understanding the public health risks posed to New York by climate change. As part of the Climate-Ready Cities and States Initiative, the City's Department of Health and Mental Hygiene (DOHMH) has been estimating health risks, identifying vulnerable populations, and developing public health adaptation strategies for extreme heat and other climate hazards. For example, without mitigation, hotter summers predicted for the 2020s (based on the NPCC 2009 projections), could cause an estimated 30 to 70 percent increase in heat-related deaths, or about 110 to 260 additional heat-related deaths per year on average in New York City compared to the baseline period for the analysis (1998–2002). Additional work will be necessary to refine these projections and identify strategies with which to respond, but this analysis is an important starting point that illustrates, in yet another way, the stakes associated with climate change.

The remainder of this report outlines specific initiatives to address the current and future climate change-related vulnerabilities faced by New York as outlined above. But these initiatives will be most effective only if they continue to be informed by the best-available science. And while New York has been a global leader in this area, there is still more that the City can do—on its own and with the Federal government—to improve the quality of the data and tools available to it.

This chapter contains a series of initiatives that are designed to strengthen the City's ability to understand and prepare for the impacts of climate change. In many cases, these initiatives are both ready to proceed and have identified funding sources assigned to cover their costs. With respect to these initiatives, the City intends to proceed with them as quickly as practicable, upon the receipt of identified funding.

Meanwhile, in the case of certain other initiatives described in this chapter, though these initiatives may be ready to proceed, they still do not have specific sources of funding assigned to them. In Chapter 19 (*Funding*), the City describes additional funding sources, which, if secured, would be sufficient to fund the full first phase of projects and programs described in this document over a 10-year period. The City will work aggressively on securing this funding and any necessary third-party approvals required in connection therewith (i.e., from the Federal or State governments). However, until such time as these sources are secured, the City will proceed only with those initiatives for which it has adequate funding.

Initiative 1

Work with FEMA to improve the flood-mapping process

The nearly three-decade gap between the introduction of FIRMs for New York in 1983 and the launch of a map update process in 2009 meant that the City and other stakeholders had to rely upon outdated and inaccurate information to assess coastal flood risks. The City will work with FEMA to improve the flood map update process—seeking to require coastal analysis updates every 10 years. To ensure that FEMA's maps are not just more current but also more accurate and informative, the City will continue to work with FEMA to review the analysis leading to the production of Preliminary FIRMs by the end of 2013. The City also will call on FEMA to implement a series of technical and process improvements—including more appropriate application of wave modeling, thorough documentation of all work, and the use of an external quality assurance contractor to review completed work. This work is technically complicated and checks should be built into the process at every step. With participation from FEMA and the Office of Long-Term Planning and Sustainability (OLTPS), this joint work can begin immediately.

Initiative 2

Work with FEMA to improve the communication of current flood risks

Despite FEMA's best efforts, many residents and business owners in vulnerable areas have found both the flood-mapping process and the maps themselves to be confusing. In fact, even today, many New Yorkers in the floodplain are not aware of the existence of FEMA's maps. The City, through OLTPS, will call on FEMA to increase the transparency of its mapping process, to improve the user experience in accessing online flood maps, and to expand efforts to make all affected property owners aware of the maps. Subject to available funding, this may include joint development of a new interactive platform for communicating flood-related risk information, insurance availability, and steps New Yorkers can take to protect themselves from flood risks.

Initiative 3

Call on the State and Federal governments to coordinate with the City on local climate change projections

Using multiple sets of climate change projections for New York City across different levels of government would cause confusion among stakeholders and would potentially lead to conflicting standards for protecting against future risks. To address this concern, the City will work with State and Federal partners to agree on a uniform set of projections for New York City and a consistent approach for presenting those projections, based on the work of the NPCC. The City, through OLTPS, also will call on the Federal government to establish a policy that would recognize local climate projections if they meet rigorous scientific standards.

Initiative 4

Continue to refine local climate change projections to inform decision-making

Although the NPCC's 2013 work represents the most current view of the risks that New York faces, there remains more work to be done, as is always the case with such efforts. The City will work with the NPCC and key stakeholders in 2013 and beyond to develop additional climate change projections and to make these projections even more useful. For example, OLTPS will work with the NPCC to include additional extreme climate events and chronic hazards, such as high winds and humidity, in the scope of the NPCC's work. OLTPS and the NPCC also will work to identify a set of metrics that can help the City and others measure actual climate changes against predicted climate change, in order to adjust policies and investment decisions in the future.

Initiative 5

Explore improved approaches for mapping future flood risks, incorporating sea level rise

Although the City and the NPCC have developed future flood maps to show how sea level rise could change flood zones going forward, the methodologies for developing these maps can be improved with better science and intergovernmental coordination. To plan for future coastal risks more effectively, the City will work with the NPCC and Federal partners to evaluate alternative approaches to mapping future risks. OLTPS will continue to develop improved future flood maps and will work with FEMA to develop recommendations for how FEMA can incorporate the future impacts of sea level rise into its ongoing non-regulatory mapping efforts.

Initiative 6

Launch a pilot program to identify and test strategies for protecting vulnerable neighborhoods from extreme heat health impacts

On average, heat waves cause more deaths than any other type of extreme weather event. Going forward, more intense, longer, and more frequent heat waves will increase this risk, especially to seniors, those with chronic disease, and those without access to air conditioning. Subject to available funding, the City will: 1) develop updated UHI models and maps to measure air temperature and evaluate landscape-based strategies to mitigate UHI effects; 2) work in two high-risk neighborhoods to identify vulnerable populations, residential facilities, walking and transit routes, existing and potential locations of UHI mitigation measures, and air conditioned spaces that could be made accessible as cooling shelters; and 3) engage with community stakeholders and City agencies to develop and implement enhanced Heat-Health Warning Systems, targeted UHI mitigation measures, and expanded access to air conditioned spaces during heat waves. The project will produce a replicable model for heat illness prevention strategies to roll out to other high-risk neighborhoods, and to inform citywide cooling messages and strategies. The project will be led by DOHMH, building upon studies and communications strategies developed as part of a Centers for Disease Control-funded Climate-Ready Cities project. DOHMH will work in coordination with OLTPS and the Department of Parks & Recreation on the development of UHI models and maps. The goal is to launch the project in late 2013 and complete it by 2015.

Expected Loss Modeling and Cost-Benefit Analysis

Overview

In setting out to define plans for strengthening New York City's resiliency to climate change, it was critical to anchor the development of those strategies in the best possible understanding of the magnitude of the risks facing New York—including its infrastructure and its neighborhoods. Moreover, in a world of finite resources and competing priorities, a properly developed resiliency strategy should assess potential initiatives in part by relating the costs of those initiatives, including capital and operating costs, to the benefits of those initiatives—namely the reduction in risk.

Although it is impossible to quantify future risks to New York or the cost-benefit ratio of any specific intervention with precision, the insurance industry has developed probabilistic models that rely on analytical techniques to provide quantitative guidance on these topics. In order to ground its work in the best-available analysis, the City engaged Swiss Re, a reinsurance company. Swiss Re uses probabilistic models to assess both the frequency and severity of an event (such as a coastal storm) as well as the magnitude of loss likely to be suffered if such an event were to occur. Working with the City, the company applied the same models used for their internal underwriting and risk analysis activities to the assessment of the risks facing New York.

Approach

The City applied Swiss Re's natural catastrophe models to New York City to help understand the potential impacts of wind and storm surge on the city (FEMA's FIRMs do not model the impacts of wind), assuming a world of rising sea levels and more intense storms. In order to do so, the City and Swiss Re combined three sets of inputs:

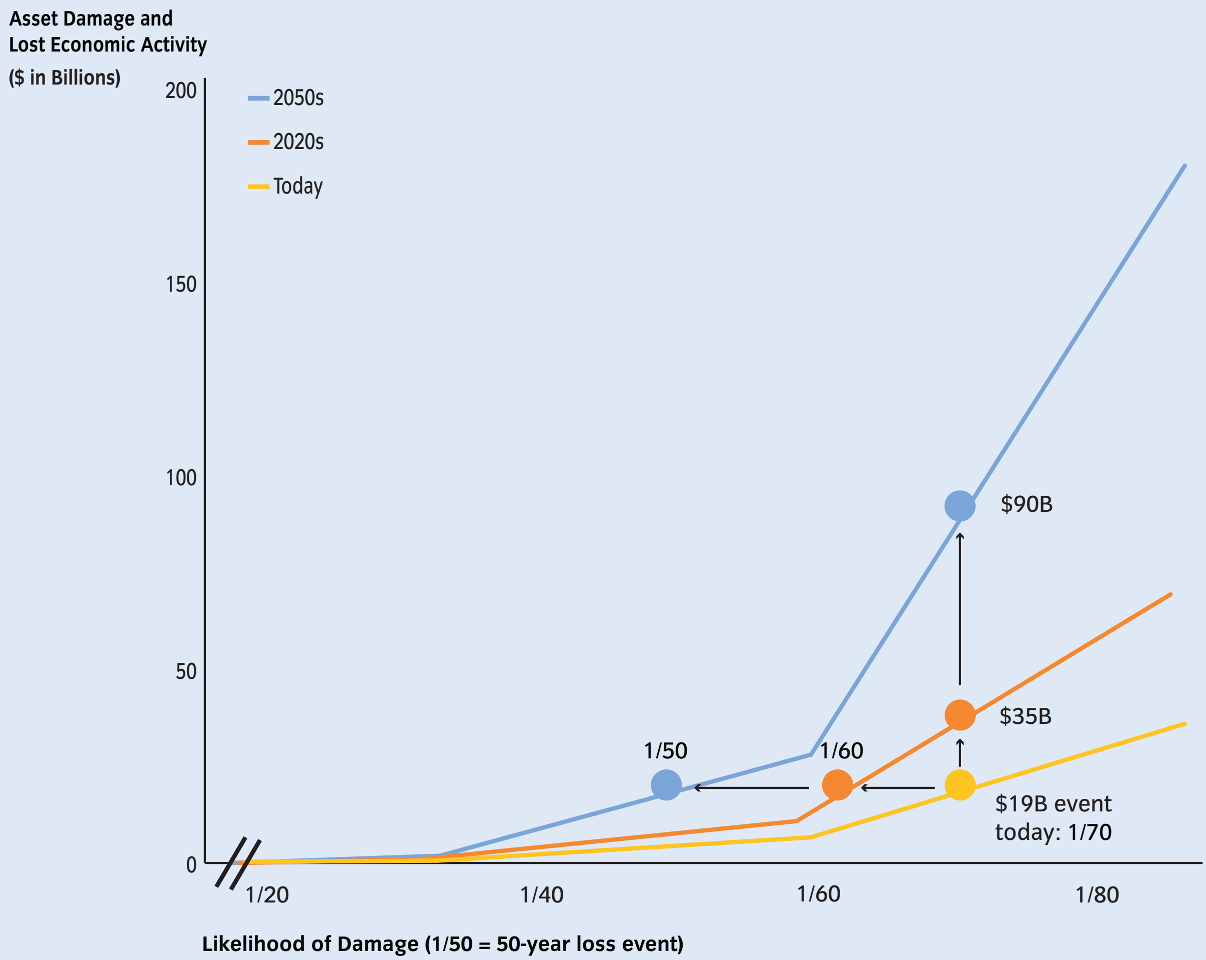
1. **Hurricane models:** As a seller of large-scale natural catastrophe reinsurance products, Swiss Re has built simulations of hurricanes based on robust historical data. Swiss Re uses data from the National Hurricane Center that includes nearly 1,200 observed tropical storms and hurricanes in the Atlantic Basin between 1851 and 2008. The Swiss Re model then "tweaks" each of these historical storms hundreds of times to create over 200,000 storms that could form in the area, and then uses established models for atmospheric pressure, speed, size, and angle of landfall to assess the resulting storm surge and wind fields.

2. **Climate change scenarios:** The City provided Swiss Re with guidance on projected sea level rise in the 2020s and 2050s, based on work of the New York Panel on Climate Change (NPCC). Specifically, the City instructed Swiss Re to assume of sea level rise by the 2020s, and the 2050s, based on the NPCC's climate projections. In addition, Swiss Re adjusted the future frequency of different categories of hurricanes (tropical storm through category 5) based on academic research.

3. **City-level asset and economic activity:** The consultants worked closely with City agencies to develop a working model of asset value divided into several categories, including, among other things, buildings, transportation, telecommunications, and utilities. These asset values were further broken down by zip code as was the city's economic activity (gross city product).

It is important to note several key limitations to this approach. First, while the Swiss Re models assess the potential impact of surge and wind resulting from coastal storms, they do not reflect the risk from other climate impacts—heat waves, drought, heavy downpours, and more. As a result, the analysis does not provide a holistic assessment of risk. Second, the analysis assumes the city as it exists today, not as it may change in the future. Thus, impacts to major new buildings or infrastructure that may exist in the 2020s or 2050s are not reflected in projected losses. Finally, and most importantly, the Swiss Re models only seek to estimate losses that can be readily measured in dollars—namely, physical damage to assets, such as buildings and tunnels, and reductions in income and loss of use due to physical damage (for example, if people in unimpacted areas could not travel to work due to transportation outages). Using this approach total losses caused by Sandy, an estimated $19 billion (according to the City's analysis provided to the Federal government), could be broken down into over $13 billion of physical damage and almost $6 billion of lost economic activity. But of course, not every potential impact can or should be quantified by such a simple metric. For example, the Swiss Re models do not predict loss of life or injury. Nor do they highlight potentially disproportionate impacts on disadvantaged populations such as the elderly or medically vulnerable. These and other non-financial impacts should be and have been critical inputs in the development of the initiatives in this report.

Loss Frequency Curves



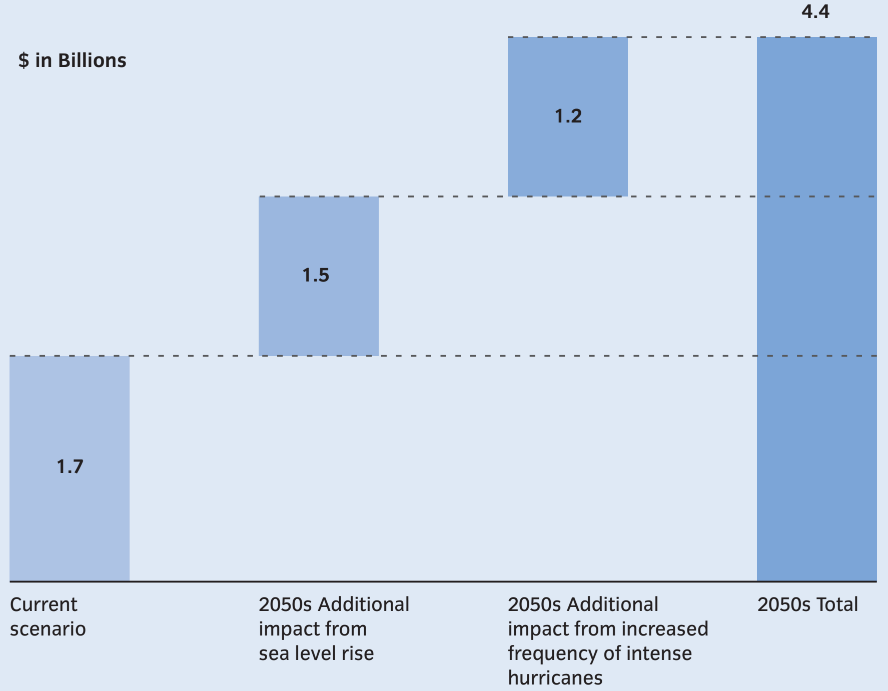
Source: Team Analysis

Based on these inputs, Swiss Re models produce a "loss frequency curve" for each of three scenarios: 2012, the 2020s, and the 2050s. Each curve indicates the probability that a given level of loss—in terms of both asset damage and lost economic activity, expressed in billions of current dollars—will be met or exceeded in any given year (known also as the "probability of exceedance"). As sea levels rise and hurricane patterns change, the loss curves move up, demonstrating both that the chance of experiencing a given level of loss grows over time and the amount of loss increases if the probability of occurrence is kept constant.

For example, according to the Swiss Re analysis, a storm today that causes the same magnitude of infrastructure and property damage and economic loss as Sandy ($19 billion) is considered a once-in-70-year "loss event" (or has a 1.4 percent chance of happening in any given year). This reflects a range of storms including those that, unlike Sandy, could result in very little damage due to flooding but major damage due to wind. With the impact of climate change (and assuming no additional development in the floodplain), the models suggest that this probability will grow—causing a $19 billion loss event (in current dollars) to become a once-in-60-year loss event by the 2020s (or an event with a 1.7 percent chance of happening in any given year), and a once-in-50-year loss event by the 2050s (or an event with a 2 percent chance of occurring in any given year).

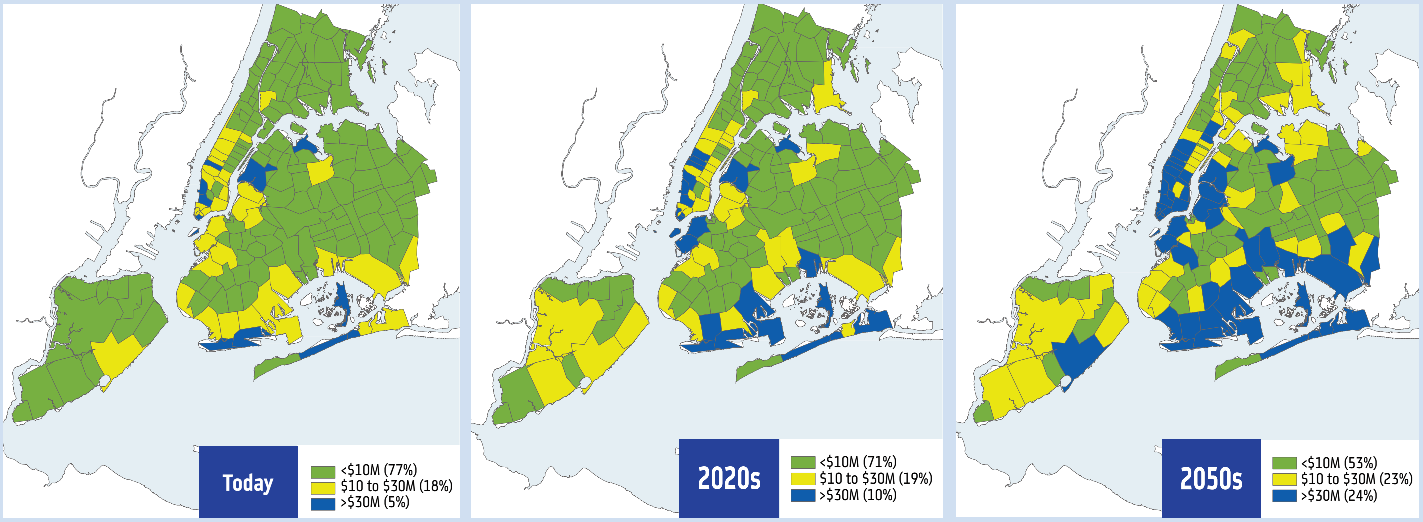
In addition, by keeping the probability of occurrence constant, the Swiss Re analysis further shows that a once-in-70-year loss event today is expected to cause in the future significantly more damage than Sandy caused. The models suggest that a storm of this frequency would cause $35 billion (in current dollars) of damage by the 2020s, an increase of 1.8 times the actual damage caused by Sandy. Meanwhile, by the 2050s, with rising sea levels and more intense storms, a once-in-70-year loss event would cause an estimated $90 billion (in current dollars) of damage, or almost five times the asset damage and economic loss caused by Sandy, even if it is assumed that no additional development happens in the floodplain.

Growth in Expected Annual Losses from Storm Surge and Wind



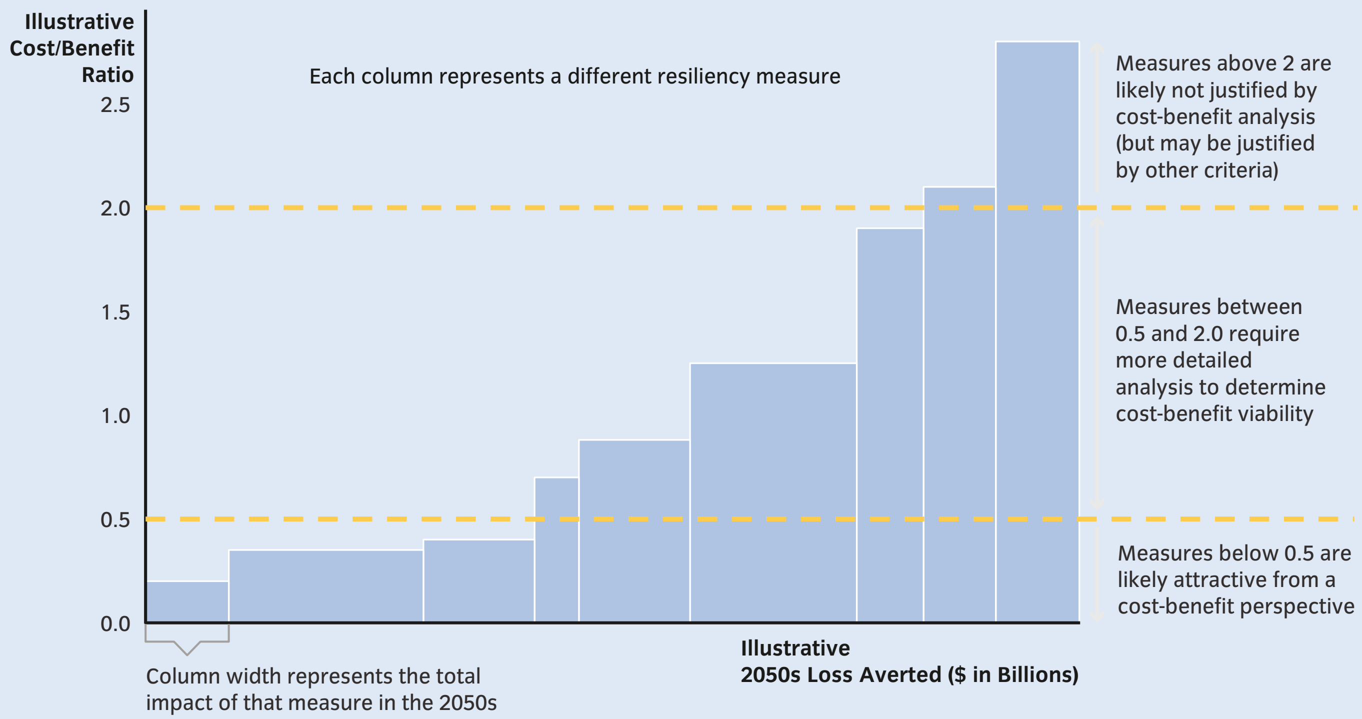
While the loss frequency curves map different levels of loss to their exceedance probabilities, another way to understand the risks to New York is to consider expected annual losses. This is generated by multiplying the different exceedance probabilities by the amounts of loss associated with them and adding up the results (or put differently, by calculating the area under the loss curve). The resulting number indicates the expected annual average impact to assets and economic activity, recognizing that in some years the actual losses may be zero (if no coastal storms strike New York) while in other years the losses may be significant (if, for example, a Sandy-level loss event were to strike). The Swiss Re models project that expected annual losses in New York City of $1.7 billion today will grow to $4.4 billion in current dollars by the 2050s. As the chart indicates, this growth in expected losses is attributable in roughly equal proportions to rising sea levels (which make flooding from coastal storms more damaging) and to the increased frequency of intense hurricanes.

Total Asset and Economic Activity Losses



Yet another way to understand the projected economic loss to the city due to sea level rise and the increased frequency of intense hurricanes is by conducting a geographical analysis, taking into account the physical locations of assets and economic activity. For example, the Swiss Re models break these losses down by zip code over time. Today, expected losses are concentrated in many of the same areas of the city that were impacted during Sandy (such as the East and South Shores of Staten Island, Southern Brooklyn, South Queens, the Brooklyn-Queens Waterfront, and Southern Manhattan), but also in other, less-impacted areas such as Northern Queens and the Bronx. In the future, the expected losses cover a significantly wider swath of the city. It is also important to note that while the maps divide the city by zip code (which may cover reasonably large areas, including inland areas), actual losses generally will be concentrated in the waterfront areas of those zip codes.

Cost-Benefit Analysis Output



In addition to calculating expected losses, the Swiss Re models also enable cost-benefit estimates of proposed interventions. Through analysis of the costs (including capital costs and ongoing operating costs) of specific interventions, the models estimate the benefit of these actions in terms of avoided (or mitigated) damage to assets and losses to economic activity. Although this model is not designed specifically to measure the costs and benefits of resiliency measures, it can provide helpful guidance. For example, in evaluating proposals, the City generally concluded that an intervention with a cost-benefit ratio of greater than two (projected costs twice as large as projected benefits) was unlikely to be attractive on a cost-benefit basis, even with refined assumptions.

By contrast, a measure with a cost-benefit ratio of less than 0.5 (projected benefits twice as large as projected costs) was considered highly likely to be an attractive investment. The chart above is an illustration of how general interventions were evaluated.

Of course, as noted earlier, certain interventions that perform well or poorly on a cost-benefit analysis might nonetheless be worthwhile public investments as a result of other, less easily quantifiable attributes (such as the protection or lack of protection provided to vulnerable populations). For this reason, cost-benefit analyses were an important tool, but not the only tool employed by the City in selecting among resiliency strategies for this report.