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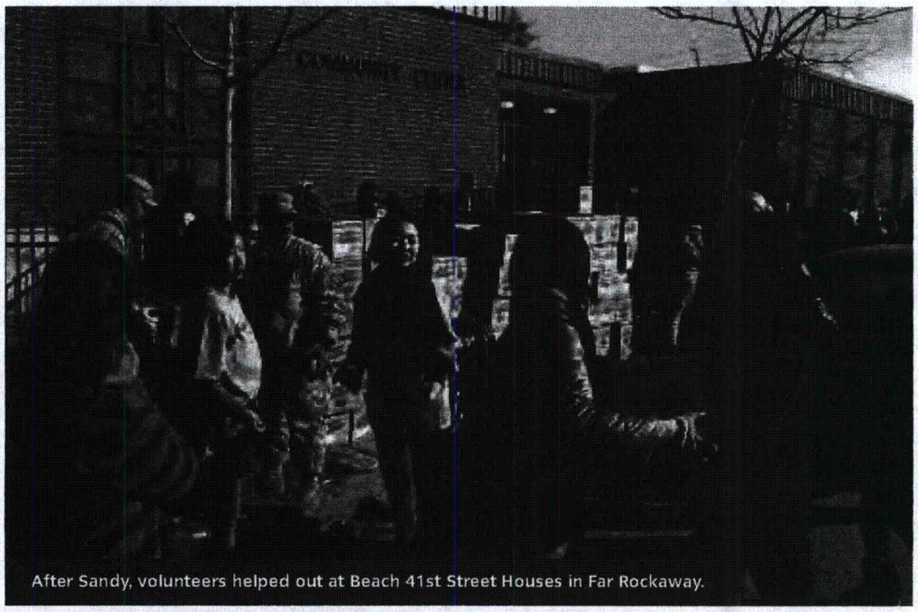
A STRONGER, MORE RESILIENT NEW YORK

The City of New York
Mayor Michael R. Bloomberg

Introduction



After Sandy, volunteers helped out at Beach 41st Street Houses in Far Rockaway.

Public Engagement

"To succeed, the plans must include the input of the people who live and work in these communities—and they will. Members of the community will assist in shaping and implementing each community plan—and that will be just the beginning of our work."

– Mayor Michael Bloomberg, announcing the Special Initiative for Rebuilding and Resiliency on December 6, 2012

Public outreach has been a priority for the Special Initiative for Rebuilding and Resiliency (SIRR) throughout the formulation of *A Stronger, More Resilient New York*. SIRR consulted elected officials, community leaders, and the general public in areas impacted by Sandy, as well as citywide organizations with a stake in sustainability and resiliency. This outreach has been conducted with numerous stakeholders:

Government Partners Engaged	30+	City, State, and Federal Agencies
Public Officials Briefed	65+	Elected Offices
	19	Community Boards
Organizations Briefed	320+	Business, Civic, Community-Based, Environmental, Faith-Based, and Labor
General Public Engagement	11	Public Workshops
	1,000+	New Yorkers Briefed In Person

Building a more resilient New York in the face of long-term climate change is work that will take years beyond the publication of *A Stronger, More Resilient New York*. Ultimately it is the public who will carry forward this plan. SIRR offers sincere thanks to those who participated in the development of the report, which we hope will benefit generations to come.

When Hurricane Sandy roared into New York on October 29, it drove the waters around our city right up to, and then over, our doorstep. Forty-three people died in the deluge and untold numbers were injured. Along the shoreline the storm surge smashed buildings and engulfed entire communities. It flooded roads, subway stations, and electrical facilities, paralyzing transportation networks and causing power outages that plunged hundreds of thousands into darkness. Fires raged. Wind felled trees. Heartache and hardship—and at least $19 billion in damage—are the storm's legacy.

An unpredictable series of meteorological phenomena combined to create this disaster—Sandy arrived during a full moon, when the Atlantic tides were at their highest; the storm was enormous and when it collided with other weather fronts, it turned sharply and made landfall in New Jersey, subjecting the city to onshore winds that drove its devastating storm surge right into our coastal communities.

When the waters receded, New York was, in many ways, a changed city. Certainly the lives of many New Yorkers had changed. Friends and loved ones were lost. Homes that families had passed down for generations were gone. Businesses that New Yorkers had started from scratch were wiped out. New Yorkers looked around and saw beloved parks and beaches in ruins. Even residents of inland areas that escaped direct storm damage were affected when workplaces and schools could not open because of power outages. The subway system was shut down. In some places, the mail could not be delivered.

New Yorkers across all five boroughs felt more vulnerable. Sandy was a cruel reminder of how destructive coastal storms can be in our dense urban environment—storms that, with climate change, are expected to increase in intensity.

Under Mayor Bloomberg's leadership, relief and recovery efforts kicked in immediately. Teams from countless City agencies fanned out across New York, removing debris and beginning the process of restoring what had been lost. The Bloomberg Administration created the Mayor's Office of Housing Recovery Operations to work with the City's Department of Housing Preservation and Development and other agencies to rebuild and repair homes and return people who had been displaced to safe, sustainable housing. It established loan and grant programs to help businesses clean up and reopen their doors.

New Yorkers themselves also rose to the occasion. People from all boroughs streamed to the Rockaways and Red Hook, to Coney Island and Staten Island, and to other hard-hit communities, bringing with them food, fuel for generators, and ready hands to help in whatever way they could. Volunteers went door-to-door in high-rise buildings to assist the elderly or those with disabilities left stranded when elevators stopped functioning. They worked with the National Guard and the Red Cross to distribute emergency supplies.

But even as the people of the city focused on Sandy and the destruction it had wrought across the five boroughs, it became clear that relief and recovery efforts alone would not be a sufficient response to this disaster. It was critical for the City also to turn simultaneously to the future and to prepare—not just for "the next Sandy," and not just for hurricanes and storm surge. It was essential to redouble the broader preparations for climate change begun with PlaNYC.

In December 2012, Mayor Bloomberg delivered a speech announcing a major new effort to ready the city for the future. *A Stronger, More Resilient New York* is the response to the Mayor's call to action. The nearly $20 billion plan contained in this report (towards which the City will contribute up to $1 billion in new funding) includes over 250 initiatives. Together these initiatives will further protect the coastline—our first defense against storms and rising sea levels—as well as strengthen the buildings in which New Yorkers live and work, and all the vital systems that support the life of the city, including our energy grid, transportation systems, parks, telecommunications networks, healthcare system, and water and food supplies. Meanwhile, for the areas of New York that Sandy hit especially hard, this plan proposes local rebuilding initiatives that will help these communities emerge safer, stronger, and better than ever.

The underlying goal of this report is resiliency. That is, to adapt our city to the impacts of climate change and to seek to ensure that, when nature overwhelms our defenses from time to time, we are able to recover more quickly.

In short, we have to be tough.

And toughness, as we all know, is one of the defining traits of New Yorkers.

In just the first few years of this century, we have been through the September 11, 2001 terrorist attacks, financial crises and blackouts, and now, Sandy. With each challenge, we have become more united as a city.

We must come together again with an even stronger commitment to slow the progress of climate change while simultaneously preparing for the changes already evident around us—and those yet to come.

If we embrace this plan today, we will be positioned to meet the challenges that climate change may bring tomorrow, and almost certainly will bring in the years and decades ahead. If we take action now, we will make New York City stronger, safer, and more resilient—not only for our own benefit, but for the benefit of future generations of New Yorkers.

The time has come to make our city even tougher.

Credit: Katie Orlinsky/The New York Times

Volunteers in New Dorp Beach in Staten Island

What Resiliency Means

It was October 30, 2012, the immediate aftermath of Sandy. Homes and businesses across the Rockaways lay in ruins, devastated by the storm's surge. Yet a new oceanfront housing development named Arverne by the Sea stood as a stalwart survivor. While planning the development, the City had required the developer to install a wide, planted dune system on the beach in front of the site and to elevate homes, incorporating special drainage features. During Sandy, the dunes absorbed the storm's destructive waves. The site's elevation and drains kept water out of most homes. All of these measures protected property and possibly saved lives.

Arverne by the Sea was minimally affected by Sandy. Credit: Gerard Romski

Over in Southern Brooklyn, meanwhile, the Shorefront Center for Rehabilitation and Nursing Care was able to remain open, despite the area's widespread inundation. Constructed to City standards intended to protect against storms just like Sandy, the facility not only was a safe haven for its residents, it also sheltered members of the wider community whose own homes were flooded.

And in Lower Manhattan, Battery Park City, too, stood strong even though it fronts directly on the Hudson River. When built, its site had been raised, and its buildings were set back behind parks and an esplanade. As a result, residents and businesses emerged from Sandy largely unscathed.

The threats of climate change are significant and growing. Others have said that the only answer to these threats—rising sea levels, powerful storms, and other chronic and extreme events—is to wall the city in, or to retreat from the shore. But the success stories above—and many other examples across the five boroughs—make clear that it is possible to build a more resilient New York.

A resilient city is not one that is shielded from climate change all of the time—because, sadly, when it comes to nature's powerful forces, that is simply not possible. But a resilient city is one that is: first, protected by effective defenses and adapted to mitigate most climate impacts; and second, able to bounce back more quickly when those defenses are breached from time to time.

It is based on these convictions that we have formulated the following resiliency principles—principles that underlie all aspects of this report. These are the principles that should also guide our city in the years and decades ahead as we all work together to create a stronger, more resilient New York:

Dunes around Arverne By The Sea absorbed the storm's destructive waves. Credit: Gerard Romski

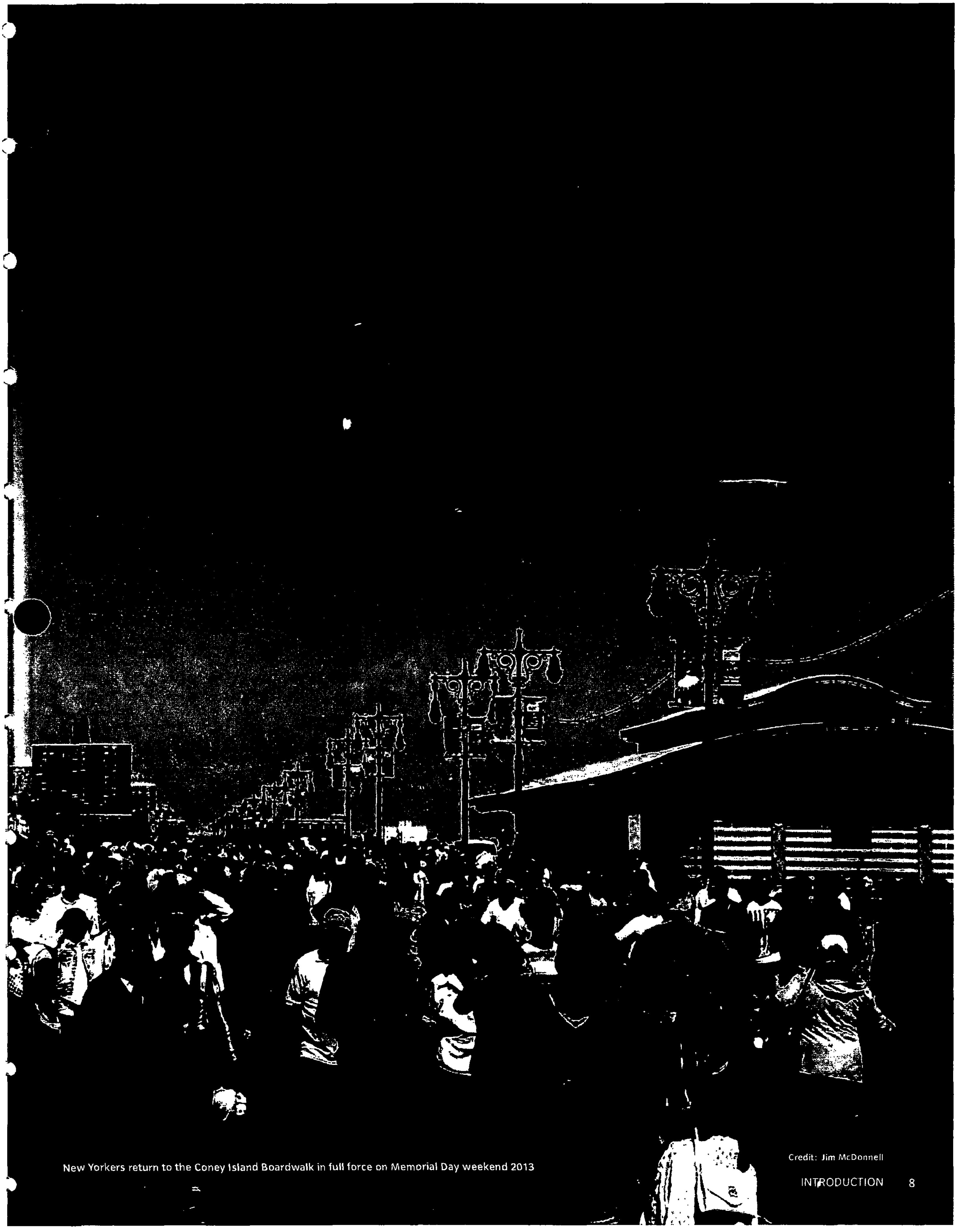
We *can* embrace our coastline. A strong coastline—with vibrant waterfront neighborhoods, critical infrastructure, and cherished natural and cultural resources—is essential to New York's present and future. We can fight for and rebuild what was lost, fortify the shoreline, and develop waterfront areas for the benefit of all New Yorkers. The city cannot, and will not, retreat.

We *must* plan ambitiously. Even with limited resources, we must make investments in smart, effective protections for our city, modifying and expanding strategies as we learn more about the threats we face and piloting projects that can be scaled up over time.

We *will* make New York a stronger, more resilient city. The city must be able to withstand the forces of climate change and bounce back quickly when extreme weather strikes. Climate change affects all New Yorkers. Not just those whose homes or businesses were flooded during Sandy, or those in the South Bronx or East Harlem or a hundred other neighborhoods that could be struck during a future storm, but every man, woman, and child who may not be able get to work or school because the subway is shut due to flooding, or whose health is at risk during a prolonged heat wave or power outage—that is, every man, woman, or child who calls New York City home.

Out of the heartbreaking catastrophe that was Sandy has come this *can*-do, *must*-do, *will*-do plan.

The time to act on this plan is now.



New Yorkers return to the Coney Island Boardwalk in full force on Memorial Day weekend 2013

Credit: Jim McDonnell

In the Lower Manhattan Financial District Post-Sandy

dit: Alexius Tan

Sandy and Its Impacts

43 deaths... 6,500 patients evacuated from hospitals and nursing homes... Nearly 90,000 buildings in the inundation zone... 1.1 million New York City children unable to attend school for a week... close to 2 million people without power... 11 million travelers affected daily... $19 billion in damage...

By any measure, Sandy was an unprecedented event for New York City. Never in its recorded history had the city experienced a storm of this size. Never had a storm caused so much damage. Never had a storm affected so many lives. As of the writing of this report, individuals, families, businesses, institutions, and, in some ways, the city itself are still recovering from this devastating natural disaster and will continue to do so for years.

As it turns out, it took an improbable set of factors coming together in exactly the worst way to give rise to the catastrophic impacts of this storm. *(See sidebar: A Brief History of Sandy)*

There was, for example, the storm's timing. Its arrival on the evening of October 29 coincided almost exactly with high tide on the Atlantic Ocean and in New York Harbor (high tide arrived at the Battery in Lower Manhattan at 8:54 p.m., and the surge peaked there at 9:24 p.m.). This meant that water levels along much of the city's southern coastline already were elevated, with typical high tides about five feet higher than water levels at low tide. And, on the night of Sandy's arrival, it was not just a normal high tide but a "spring" tide, when the moon was full and the tide was at the very peak of its monthly cycle—generally up to half a foot higher than the average high tide. *(See maps: Water Levels Around New York City on October 29)*

Then there was the storm's size. When Sandy made landfall, its tropical-storm-force winds extended 1,000 miles from end to end, making it more than three times the size of Hurricane Katrina. Storm size—the area over which strong winds blow—correlates closely with storm surge, the rise in water level caused by the storm's low pressure and the force of its winds pushing against the water. *(See graphic: Sandy Size and Wind Speed; see graphic: Katrina Size and Wind Speed)*

Because Sandy was such a massive storm, it generated a massive surge. And that surge, coming on top of the spring high tide, created a "storm tide" of over 14 feet above Mean Lower Low Water at the Battery, shattering the previous record of 10 feet, set when Hurricane Donna arrived in New York in 1960. *(See chart: High Water Events at Lower Manhattan)*

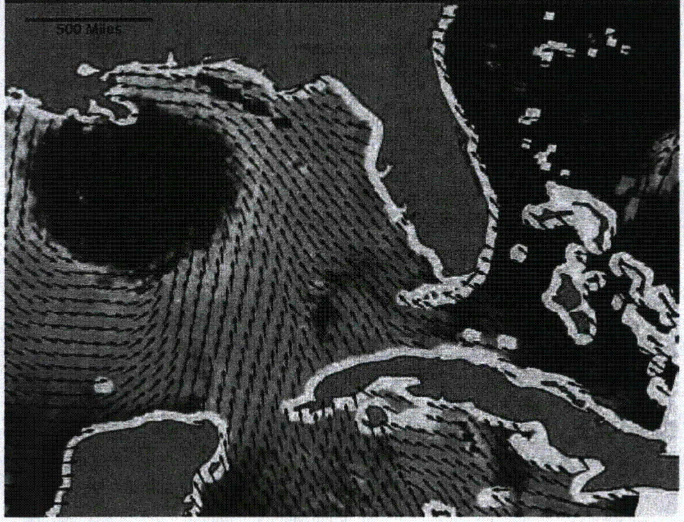
Finally, there was the unusual path Sandy took to the city's shores. Most hurricanes that approach the Northeast glance the coastline or curve east and head out to sea before they ever reach New York. But as Sandy came spinning north along the east coast of the United States, winds spiraling counterclockwise, the storm encountered weather systems that caused it to take a different course—one that would spell disaster for parts of the city. A high-pressure system to the north blocked the storm's advance. At the same time, a low-pressure system that was pushing eastward towards the Atlantic coast energized the storm and reeled it in. Steered between these two systems, Sandy made a westward turn—and headed straight for land just as it was increasing in intensity. At 7:30 p.m. on October 29, 2012, Sandy slammed into New Jersey head-on, seven miles north of Atlantic City, with maximum winds of 80 miles per hour.

The storm's angle of approach put New York City in the path of the storm's onshore winds, the worst possible place to be. The winds earlier that day had been blowing in a generally southward direction in the New York area. However, as Sandy arrived, its winds shifted, instead moving in a generally northwesterly direction. It was this shift that helped push the storm's massive surge—and its large, battering waves—directly at the south-facing parts of the city.

As a result of all of these factors, Sandy hit New York with punishing force. Its surge and waves battered the city's coastline along the Atlantic Ocean and Lower New York Bay, striking with particular ferocity in neighborhoods across South Queens, Southern Brooklyn, and the East and South Shores of Staten Island, destroying homes and other buildings and damaging critical infrastructure. Meanwhile, the natural topography of the city's coastline channeled the storm surge that was arriving from

Sandy Size and Wind Speed

Katrina Size and Wind Speed



Source: NASA

Wind Speed (miles per hour): 0 20 40 60

A Brief History of Sandy

Sandy was no ordinary hurricane. It was a meteorological event of colossal size and impact. It was a convergence of a number of weather systems that came together in a way that was disastrous for the New York area.

Sandy, however, began innocently enough—far from New York and almost three weeks before its arrival on the area's shores. It was October 11, late in the Atlantic hurricane season, when a tropical wave formed off the west coast of Africa. By October 22, the wave had evolved into a weather system in the Caribbean called Tropical Storm Sandy, the 18th named storm of the 2012 hurricane season. (*See map: Sandy Storm Path*)

A tropical storm is a cyclone—a system of clouds and thunderstorms rotating around a central "eye"—that originates in tropical waters and gets its energy from those warm waters. Sandy gained wind speed as it curled north. By October 24, it was a hurricane—a storm with wind speeds of at least 74 miles per hour (mph)—with an eye visible on satellite images. Sandy made landfall on Jamaica on October 24 as a Category 1 hurricane then intensified to a Category 3 hurricane before hitting Cuba on October 25, according to the National Hurricane Center.

While the storm moved across the Bahamas, it weakened to a Category 1 hurricane—but began to grow significantly in size. It continued to grow as it traveled north of the islands. After passing the Bahamas, Sandy turned northeast, beginning its trek through the Atlantic Ocean, paralleling the eastern coast of the United States. Its winds whirled counterclockwise, raising water levels all the way from Florida to Maine.

Although most hurricanes on a northward track along the US coast continue to hug the coast or eventually curve east and out to sea before they reach New York, Sandy encountered two other weather systems that caused it to shift direction and abruptly intensify yet again. One was a high-pressure system to the north that blocked Sandy's northward advance. The other was a low-pressure system pushing eastward over the southeastern United States that reenergized Sandy. Steered between these two weather systems, Sandy turned sharply west just as it was reaching another peak of intensity.

When Sandy made landfall in Brigantine, New Jersey, just north of Atlantic City, at 7:30 p.m. on October 29 with 80-mph winds, it was technically no longer a hurricane. Two-and-a-half hours before it had made landfall, the National Hurricane Center had reclassified Sandy as a "post-tropical cyclone" because the storm had evolved in such a way that it no longer possessed the technical characteristics of a hurricane: It lacked strong thunderstorm activity near its center; its energy did not come from warm ocean waters but from the jet stream; and it had lost its eye.

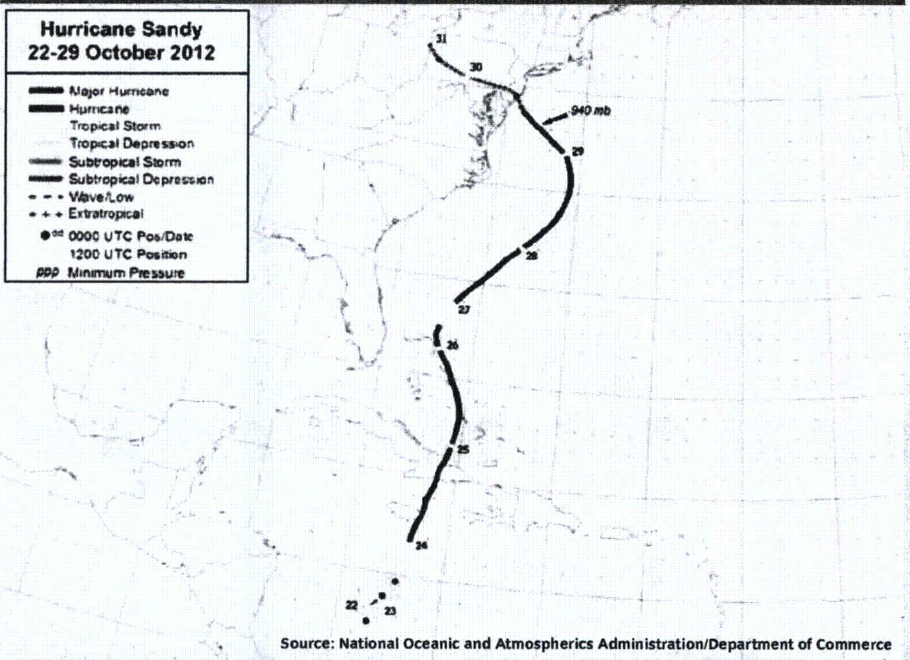
No matter what Sandy was called, though, the storm never lost its large wind field or its large radius of maximum wind (which is why weather experts still considered it a "hurricane strike" when it hit the New York region). In fact, when the storm made landfall, its tropical-storm-force winds extended 1,000 miles—three times that of a typical hurricane. It was those winds, as well as the storm's low pressure, that were responsible for its catastrophic storm surge.

The storm's angle of approach was also significant. Because Sandy came at the coast of New York at a perpendicular angle, its counterclockwise onshore winds drove the surge—and the surge's large, battering waves—directly into the city's coastline.

After landfall, Sandy slowed and weakened while moving through southern New Jersey, northern Delaware, and southern Pennsylvania. It finally lost its defined center while passing over northeastern Ohio late on October 31. For the next day or two, what remained of Sandy continued over Ontario, Canada before merging with a low-pressure area over eastern Canada and heading out to sea for good.

At that point, of course, New York still was reeling from the storm's effects—and was only beginning to cope with the extent of the damage.

Sandy Storm Path



Source: National Oceanic and Atmospherics Administration/Department of Commerce

Sandy by the Numbers

Sandy made landfall three times: at Bull Bay, Jamaica, on October 24; at Santiago de Cuba, Cuba, on October 25; and finally at Brigantine, New Jersey, on October 29

The storm's wind speed was 80 mph at landfall in New Jersey.

Its wind field extended for 1,000 miles.

In the US, $50 billion in total damages have been attributed to the storm, making it more costly than any other storm except Hurricane Andrew in 1992 and Hurricane Katrina in 2005.

the ocean northward into New York Harbor, elevating water levels in Jamaica, Sheepshead, Gravesend, and Gowanus Bays, as well as in Upper New York Harbor and the East and Hudson Rivers. At the same time, the storm surge also was pushing water into Long Island Sound, and from there south.

In short, the ocean fed bays, the bays fed rivers, the rivers fed inlets and creeks. Water rose up over beaches, boardwalks, and bulkheads. It was an onslaught of water.

In total, a staggering 51 square miles of New York City flooded—17 percent of the city's total land mass. The floodplain boundaries on the flood maps from the Federal Emergency Management Agency (FEMA) in effect when Sandy hit had indicated that 33 square miles of New York City might be inundated during a so-called "100-year" flood, or the kind of flood estimated to have only a 1 percent chance of occurring in any given year. However, Sandy's storm tide caused flooding that exceeded the 100-year floodplain boundaries by 53 percent citywide. In Queens, the area Sandy flooded was almost twice as large as the floodplain area indicated on the maps. In Brooklyn, the area that flooded was more than twice as large as the floodplain. In certain communities, flooded areas were several times the size of the floodplains on FEMA maps. *(See map: Sandy Inundation)*

The urban character of New York City magnified the impact of the flooding. More than 443,000 New Yorkers were living in the areas that Sandy flooded when the storm struck. In all, 88,700 buildings were in this inundation zone—buildings containing more than 300,000 homes and approximately 23,400 businesses. Much of the city's critical infrastructure also was within flooded areas—including hospitals and nursing homes, key power facilities, many elements of the city's transportation networks, and all of the city's wastewater treatment plants.

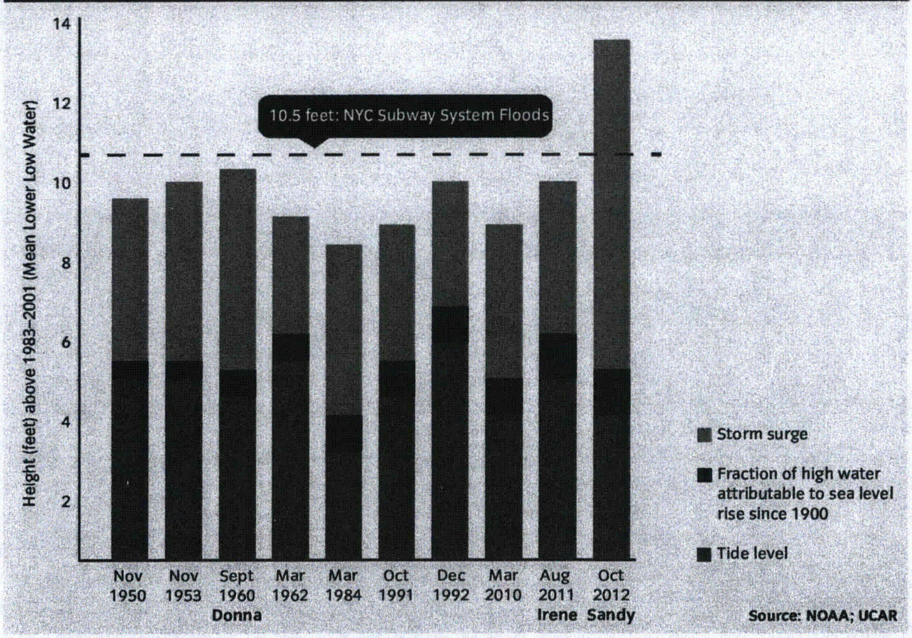
In many places, it was not only the extent of flooding that was significant; it was also the depth of floodwaters. Water heights of several feet above ground level were prevalent in many coastal areas. Near Sea Gate, on the Coney Island peninsula in Brooklyn, the water reached 11 feet above ground level, and at Tottenville on Staten Island, they rose to 14 feet.

Many storms have hit New York with higher winds than Sandy's 80-mile-per-hour peak wind gusts. Many storms have brought more rain than the half inch that Sandy dropped in parts of New York. However, Sandy's storm surge—and the devastation it caused—was unlike anything seen before. The surge, and the flooding and waves that came with it, had an enormous impact on the city.

Sandy's Impact on New York

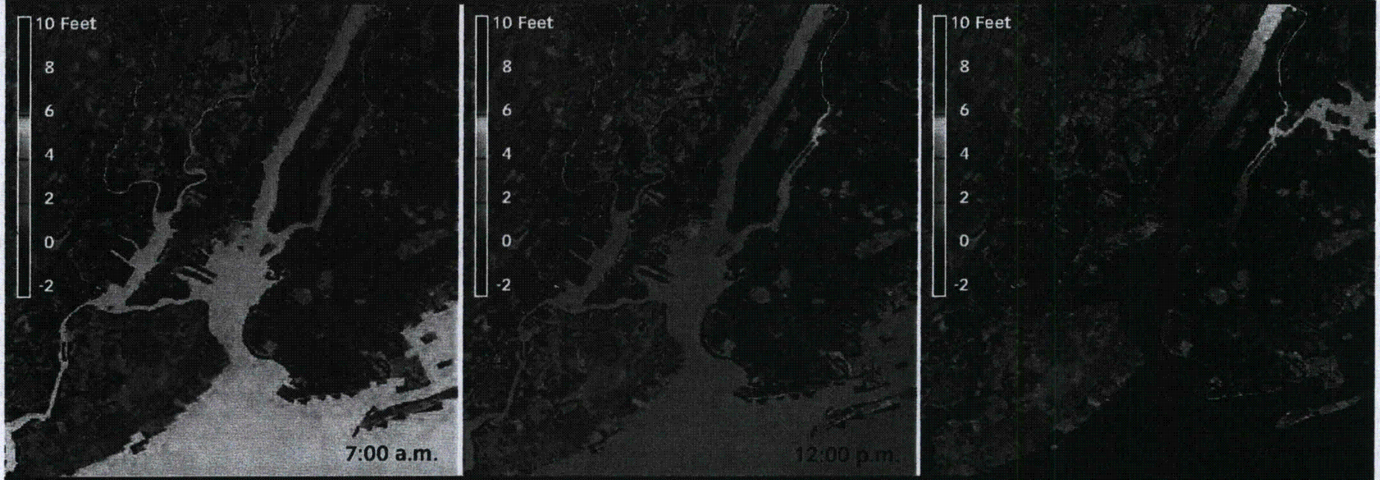
Any catalogue of the woes that Sandy brought to New York City must start with the tragic deaths of 43 people, the vast majority of whom perished from drowning in areas where waters rose rapidly as a result of the surge. Of these deaths, 23 occurred in Staten Island (including

High-Water Events in Lower Manhattan



Source: NOAA; UCAR

Water Levels Around New York City on October 29



Tidal cycles are different in different parts of the Harbor—with lower water levels in Long Island Sound coinciding with higher levels in the Lower and Upper New York Bay and vice versa. On the evening of October 29th, just before the arrival of Sandy's surge, the tidal cycle was bringing higher tides to the City's south and lower tides to its north.

Source: CMS at Stevens Institute of Technology

10 in the neighborhood of Midland Beach alone), with the remainder spread throughout Queens, Brooklyn, and Manhattan. The storm took an especially high toll on the young and old, with victims ranging from a 2-year-old boy to a man and a woman aged 90.

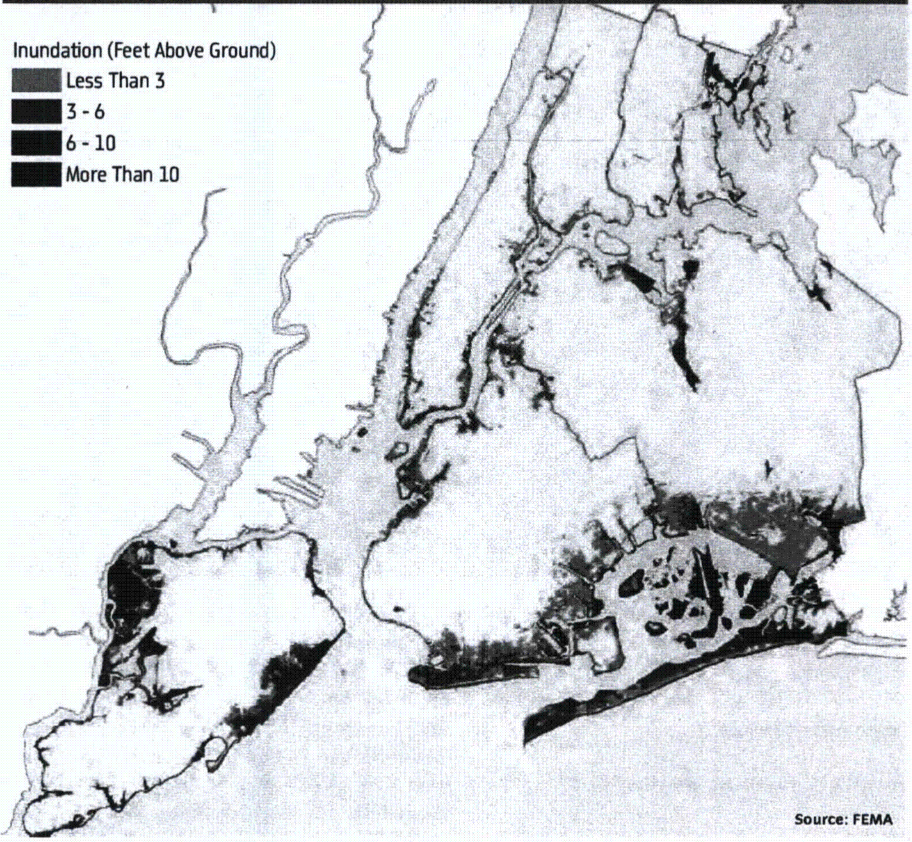
In other cases, the storm spared lives, but still turned them upside down. It destroyed homes that families had tended to over generations (of the hundreds destroyed or determined to be structurally unsound by the Department of Buildings (DOB), with over 60 percent in Queens and almost 30 percent in Staten Island). It impacted many businesses that New Yorkers had started from scratch (not just those in Sandy's inundation area, but 70,000 in areas that lost power during the storm). In some cases, it severely affected those with the fewest resources to draw on—residents of public housing developments, for example, since many of these developments are located on the coastline and were thus particularly vulnerable to extreme weather events. More than 400 New York City Housing Authority buildings containing approximately 35,000 housing units lost power, heat, or hot water during Sandy.

Meanwhile, facilities and services that are crucial to the well-being of all New Yorkers fully or partially shut down for the duration of the storm, and in some cases, for long periods afterwards. Disruptions to some systems (such as power) affected the functioning of others (healthcare, transportation, and telecommunications, among others). The trials of some communities (flooding and power outages in hubs like Southern Manhattan) created tribulations for others (those living elsewhere who could not work because their offices could not open). The storm was a reminder of how interconnected the city's systems are.

It also highlighted significant vulnerabilities in many of these systems and in certain geographic areas of the city. Below are brief summaries of some of the major impacts of the storm on the city's coastline, buildings, infrastructure, and selected neighborhoods. Further information, analysis, and initiatives can be found in the relevant chapters of the report.

Coastline and Waterfront Infrastructure
During Sandy, the coastline of the southern half of the city felt the full force of the storm. Ocean-facing areas generally experienced the destructive impact of waves reported to be 12 feet or more, along with flooding, while other coastal areas experienced only flooding, though the damage from that flooding was still serious and long-lasting.

Sandy Inundation



Source: FEMA

Although barges and other "floating" infrastructure played a key role in the city's recovery from Sandy, damage to "fixed" waterfront infrastructure was extensive. The storm damaged boardwalks, landings, and terminals. Waves and retreating waters caused coastal erosion, with New York's beaches losing up to 3 million cubic yards of sand or more citywide, including 1.5 million cubic yards on the Rockaway Peninsula alone.

Though the storm surge generally devastated areas that it touched, the city's nourished beaches, dunes, and bulkheads did help to mitigate its impact, particularly where these protections were combined to form multilayered defenses.

For more on coastal protection, see Chapter 3.

Buildings
Building damage from Sandy was widespread and in many cases severe. In some areas, storm surge and rising floodwaters pushed houses right off their foundations or caused walls to collapse. Elsewhere, floodwaters filled basements and ruined electrical and other building systems, as well as personal possessions. As of December 2012, DOB had tagged nearly 800 buildings as having been structurally damaged or destroyed across the five boroughs, with tens of thousands more impacted, including buildings containing nearly 70,000 housing units that were registered with FEMA and determined to have sustained some level of damage. Over 100 of the lost homes and businesses were destroyed by storm-related fires, which were often electrical in nature, caused largely by the interaction of electricity and seawater.

Overall, there were several predictors of how the storm impacted New York's building stock. Some of these predictors related to the characteristics of the inundation that buildings faced. Not surprisingly, shoreline areas that experienced the strong lateral forces of waves had many more damaged buildings than areas with still-water flooding only. Other predictors related to a building's physical characteristics (such as building height and construction type) as well as age, which, in turn, determined the regulations in force when the building was constructed. Overall, older, 1-story, light-frame buildings suffered the most severe structural damage—representing just 18 percent of the buildings in the areas inundated by Sandy, but 73 percent of all buildings tagged as structurally damaged or destroyed by DOB as of December 2012.

Although high-rise buildings did not generally experience as much structural damage, they

often lost mechanical building equipment housed in basements, rendering buildings uninhabitable and leaving residents stranded on upper floors and businesses closed until repairs could be made.

For more on buildings, see Chapter 4.

Insurance

For many New Yorkers, insurance issues have compounded the problem of building damage from Sandy, with the extensive flood damage from the storm focusing attention on flood insurance. Most large commercial properties obtain insurance, including flood insurance, through the private market. Although most homeowners in New York City have homeowners insurance, these policies typically do not cover flood damage, and homeowners and small business owners seeking flood coverage generally purchase policies through the National Flood Insurance Program (NFIP), which is administered by FEMA.

When Sandy struck, however, most New York City property owners affected by the storm did not have adequate flood insurance—or any flood insurance at all. This was the case for a variety of reasons. For example, more than half of all buildings and about half of the residential units in the area flooded by Sandy were outside of FEMA's 100-year floodplain—so the owners of these buildings were probably unaware of the risks that they faced and, at any rate, were not required by the terms of their mortgages to have flood insurance (since Federally backed mortgages require such coverage only for buildings in the 100-year floodplain). Even among those in the floodplain, many were not insured for flood damage (less than 50 percent of residential buildings in the pre-Sandy 100-year floodplain had flood insurance). This was either because they did not comply with, and their mortgage lenders did not enforce, the terms of their mortgages (about one-third of residential buildings with Federally backed mortgages in New York when Sandy hit did not have flood insurance), or because they did not have mortgages in the first place. Meanwhile, in many cases, those who were insured discovered, after Sandy, that they were not covered for certain losses, such as damages in basements.

Going forward, premiums in the private insurance market may increase in the near term, particularly in flood-prone areas, but the private insurance market overall, despite large losses from Sandy, is expected to remain competitive, with signs, as of the writing of this report, that the market may already be stabilizing. Because of reforms to the NFIP enacted before Sandy, however, property owners insured by the NFIP are likely to see large and permanent increases in flood insurance premiums—unless changes to the NFIP are enacted.

For more on insurance, see Chapter 5.

Utilities

Sandy dealt a serious blow to the city's utilities—particularly its electric utilities, due in part to the fact that some of the most important utility infrastructure is on the waterfront. Close to 2 million people lost power at some point during the storm, with almost a third of these customers in Manhattan. In fact, parts of Lower Manhattan and Brooklyn even lost power prior to Sandy, when Con Edison preemptively disconnected them from the city's grid to protect equipment and reduce potential downtime. Almost all areas south of the Empire State Building followed when floodwaters inundated several of the city's substations in Southern Manhattan. On Staten Island and in the Rockaways, meanwhile, 120,000 customers lost power due to substation damage, while all around the city, strong winds took down overhead lines, affecting another 390,000 customers.

Generally, damaged substations were repaired quickly, with power restored to most customers in Manhattan, for example, within four to five days. Repairing damage to the whole overhead system, though, took almost two weeks, even with the help of thousands of utility workers from other states. Damage to electrical equipment within buildings took considerably longer in many cases, leaving some places in the Rockaways and other hard-hit areas without power or heat for weeks as crews of electricians and plumbers, many of them sent by the City free of charge as part of its Rapid Repairs program, went door-to-door to check and repair equipment.

Other utility systems experienced varying degrees of disruption. Con Edison's steam system, which services 1,700 large buildings in Manhattan, including major hospitals, was unable to supply steam to one-third of its customers when the storm inundated four of the system's six plants and flooded utility tunnels. It took nearly two weeks to restore service to these customers.

The natural gas system generally performed better, although 84,000 customers lost service, mostly in Brooklyn, where National Grid shut off gas valves close to the coast to isolate flooded pipes from the rest of its distribution system. Within hard-hit areas, each affected customer had to be checked by plumbers before service was restored, which took several weeks.

For more on utilities, see Chapter 6.

Liquid Fuels

For many New York City drivers, the post-storm period might have brought back memories of the oil crises of the 1970s. For days and weeks, long lines were the norm at gas stations that still had fuel. Although initial reports suggested that stations primarily closed because they did not have the power to pump gas, in fact over 90 percent of the city's gas stations were outside of the areas of the city that experienced widespread power outages. Instead, the real problem was that the stations had no gas to pump. This was due to severe breakdowns in the supply chain serving New York caused by storm damage to fragile infrastructure in New Jersey and on the New York City waterfront.

The storm shut down refineries for several weeks, stopped marine and pipeline deliveries for three to four days, and damaged storage terminals. As a result, for four days after the storm, the system received no new supply, and for almost a month after that, supply was limited. As soon as drivers returned to the roads, long lines at gas stations followed. Within one week of Sandy's landfall, less than 20 percent of stations were able to sell fuel at any given time.

Working with the Federal government and the State National Guard, the City set up a fueling program for critical and public service fleets including emergency responders, utility vehicles, ambulances, and school buses. Regular consumers had to wait several weeks for the system to recover fully, though license plate-based rationing did reduce lines and a host of regulatory waivers helped bring supply back into balance with demand.

For more on liquid fuels, see Chapter 7.

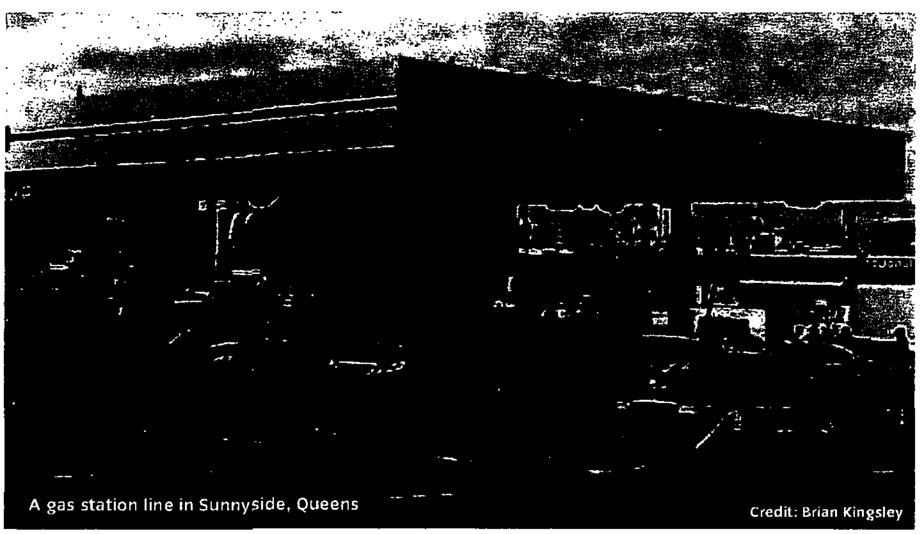
Healthcare
Sandy placed an unprecedented strain on the city's healthcare system as a whole, and disrupted services in affected communities across New York. Six hospitals closed—four in Manhattan, one in Brooklyn, and one on Staten Island—requiring City and State health officials, co-located at the City's Office of Emergency Management, to coordinate the evacuation of nearly 2,000 patients. Hospitals that remained open—frequently owing to the heroic efforts of staff, who pumped out or diverted water, repurposed lobbies to serve as inpatient rooms, and siphoned gasoline from vehicles to run generators—struggled to meet the needs of incoming patients.

Charging cell phones in the East Village
Credit: Matt Kane

Nursing homes and adult-care facilities were also affected by flooding and power outages. Twenty-six facilities closed and five partially closed, resulting in the evacuation of 4,500 patients. At the community level, flooding caused over 500 buildings with doctors' offices, clinics, and other outpatient facilities to close. Many patients who could not reach their normal providers had to postpone care or sought help at hospital emergency rooms, further straining the entire system.

For more on healthcare, see Chapter 8.

Telecommunications
Sandy caused outages across phone, wireless, cable, and Internet services. Short-term outages affected the greatest number of customers and were a direct result of power loss, which knocked out cable and Internet service in homes and businesses immediately.



A gas station line in Sunnyside, Queens
Credit: Brian Kingsley

Wireless service was also affected when backup batteries powering cell sites ran down, generally four to eight hours after grid power was lost, reducing or eliminating service to over a million cell customers in New York City. Even customers with working cell networks found that charging mobile devices was a challenge in areas without power, though many businesses and cell companies set up charging stations in affected areas.

Meanwhile, flood damage at critical facilities in Southern Manhattan, Red Hook, and the Rockaways disrupted landline and Internet service throughout the neighborhoods they served for up to 11 days. Generally, providers with modern networks and hardened facilities were able to restore service faster, while those that had not adequately protected facilities from flooding faced longer and more extensive outages.

In coastal areas, flood damage to building telecommunications equipment and cabling caused long-term outages, with some providers using flood damage as an opportunity to swap in new, more resilient equipment rather than simply fixing in-place infrastructure—a benefit to customers over the long term, but frequently at the cost of considerable short-term inconvenience. For example, in commercial buildings in part of Southern Manhattan, Verizon opted to replace corroded copper cables with fiber. The result was that in a sample of 172 buildings, nearly 60 percent did not have service fully restored 60 days after Sandy, with 12 percent still out after 100 days.

For more on telecommunications, see Chapter 9.

Transportation

During Sandy, many highways, roads, railroads, and airports flooded. At the same time, all six East River subway tunnels connecting Brooklyn and Manhattan were knocked out of service by flooding, along with the Steinway Tunnel that carries the 7 train between Queens and Manhattan, the G train tunnel under Newtown Creek, the Long Island Railroad and Amtrak tunnels under the East River and the PATH and Amtrak tunnels under the Hudson River. Major damage occurred to the South Ferry subway station in Lower Manhattan, as well as to the subway viaduct connecting Howard Beach, Broad Channel, and the Rockaways. Service also was disrupted on the Staten Island Ferry, the East River Ferry, and private ferries. The loss of ferry service during and after Sandy stranded some 80,000 normal weekday riders, while the loss of subway service stranded another 5.4 million normal weekday riders.

Exacerbating flooding was the loss of electrical power, which made it difficult to pump out tunnels, clean up damaged subway stations, and begin restoring service. The difficulty in "dewatering" the tunnels further increased the damage from Sandy, as sensitive mechanical, electrical, and electronic equipment soaked in corrosive salt water. In addition to subway tunnels, flooding closed three vehicular tunnels into and out of Manhattan, interrupting the commutes of 217,000 vehicles.

Although major bridges reopened as soon as winds dissipated and portions of the transportation network not directly flooded experienced little damage, over 500 miles of roads suffered significant damage and the subway system remained out of service in the days after the storm, even as crews worked around the clock to restore service. This led to significant gridlock on roads and bridges into Manhattan as people tried to return to work by car. The commuting challenges led City and State officials to implement temporary measures to manage travel and congestion. These measures included restrictions on single-occupant vehicles using bridges and tunnels across the Hudson and East Rivers, increased East River ferry service, and the successful "bus bridges"—an above-ground replacement for the subways that sent hundreds of buses back and forth on the bridges between Brooklyn and Manhattan. These measures enabled over 226,000 commuters to cross the East River—almost triple the number able to cross before they were in place.

One week after Sandy struck, many subway lines had been fully or partially restored, but some elements of the system remained closed much longer, with repairs projected to take months and even years. However, the opening of A train service to Broad Channel and the Rockaways just prior to the release of this report shows the strong commitment of the region's transportation agencies to the restoration of service as quickly as possible.

For more on transportation, see Chapter 10.

Parks

The Department of Parks & Recreation (DPR) closed all City parks the day before Sandy, and the parks remained closed after the storm while DPR worked continuously to complete park inspections, reopening many facilities within three days—aided by legions of volunteers who helped bag debris and gather fallen branches. However, nearly 400 parks were damaged significantly and remained closed for major repairs. Across the city approximately 20,000 street and park trees were damaged or downed. Beaches and waterfront park facilities were hard-hit by storm surge, erosion, and coastal flooding, with two miles of scenic boardwalk destroyed primarily in the Rockaways as well as in Coney Island and on the East Shore of Staten Island.

Notwithstanding this loss, many DPR facilities—including beaches, wetlands, and other natural areas—played a role in protecting adjacent communities, serving as a buffer for these areas. In addition, some newer parks, which designers had planned with extreme weather risks in mind, weathered the storm with comparatively little damage. For example, Brooklyn Bridge Park generally fared well because of its elevation and use of resilient coastal edges and plantings. Meanwhile, the new park being constructed at the center of Governors Island—on a site elevated with fill—also largely was protected from Sandy's surge.

For more on parks, see Chapter 11.

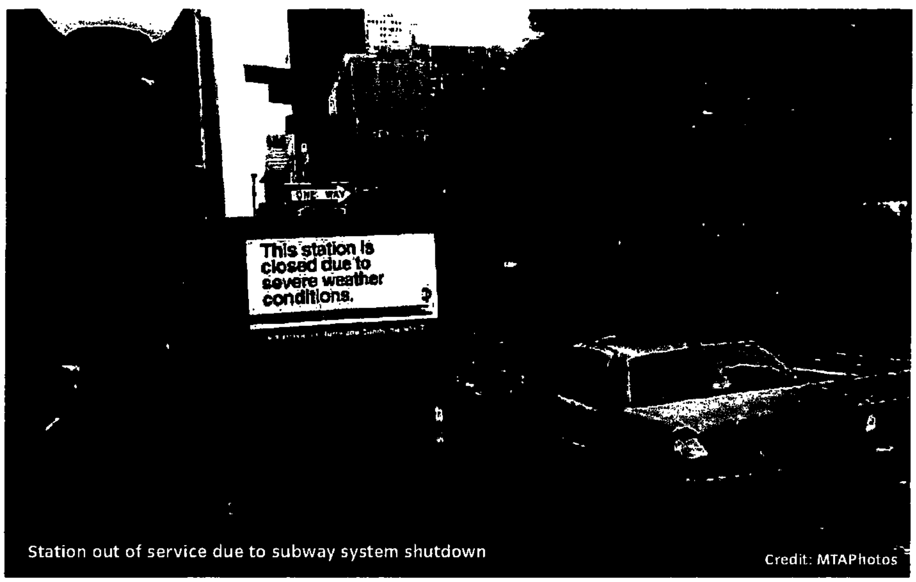
Water and Wastewater

High-quality drinking water continued to flow uninterrupted to New York City during and after Sandy. However, in areas with power outages, the pumping systems in high-rise buildings ceased to function, leaving residents on upper floors with empty taps and no way to flush toilets. Meanwhile, a fire in Breezy Point in Queens caused significant disruption to that neighborhood's private water distribution system.

By contrast, Sandy's storm surge had a major impact on the city's wastewater treatment system. Ten of 14 wastewater treatment plants operated by the Department of Environmental Protection (DEP) released partially treated or untreated sewage into local waterways (though water quality samples showed impacts to be minimal due to dilution from the enormous volume of water flowing through the Harbor from the surge). In addition, 42 of 96 pumping stations that keep stormwater, wastewater, or combined sewage moving through the system were temporarily out of service because they were damaged or lost power.

While many facilities in neighboring municipalities were impaired for several weeks, New York City was treating 99 percent of its wastewater within just four days of the storm's end, and 100 percent within 2 weeks.

As for the city's stormwater and combined sewers, though Sandy was not a major rain event and the sewers generally performed as designed during the storm, the unprecedented volume of the surge was beyond the capacity of the system to handle. As the surge finally



Station out of service due to subway system shutdown Credit: MTAPhotos receded, the system did help to drain floodwaters, though the sand and debris left by the surge did slow this process.

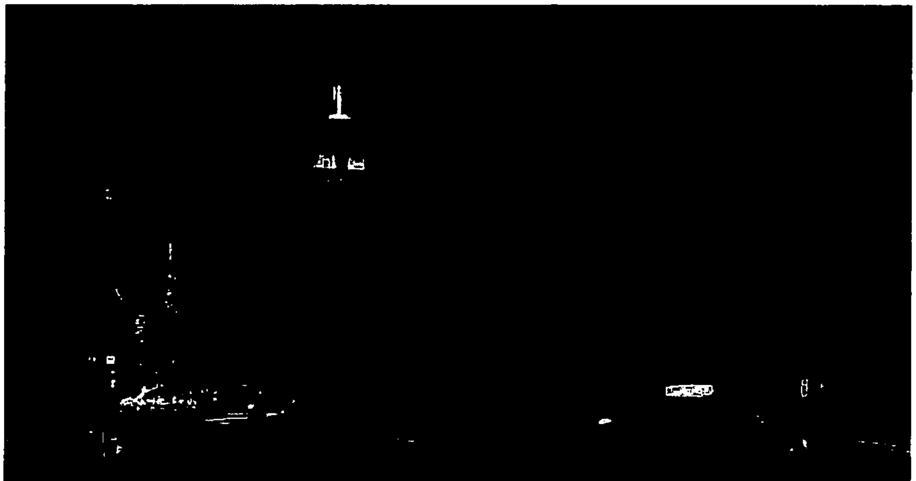
For more on water and wastewater, see Chapter 12.

Other Critical Networks
Thankfully, New York's food supply chain continued to function reasonably well during and following the storm. This supply chain is made up of wholesale distributors, which bring food to the city and often store it in warehouses, and retailers, which supply food directly to New Yorkers. The city's food distributors depend heavily on transportation networks to make deliveries and electricity for their refrigeration systems, so they experienced a slight strain when the area's bridges were temporarily closed and power outages were at their peak. Fortunately, though, Hunts Point, the city's largest food distribution center—and a key distribution point for much of the fresh food that comes into the city—largely was unaffected.

Location dictated Sandy's impact on food retailers. For example, when power went out in Southern Manhattan, many supermarkets and bodegas lost perishable food. Meanwhile, many food retailers in Coney Island and Brighton Beach (almost 30 supermarkets and 50 bodegas) and nearly all retailers in the Rockaways and Broad Channel were affected by storm surge or flooding. Unless they had generators, these retailers were also without power and also lost inventory. Many food pantries—an important source of nourishment for the city's vulnerable populations often located in the basements of churches and other buildings—similarly experienced flooding. This left some areas without access to food within a reasonable distance.

The City and FEMA stepped in and over a three-month period gave out almost 4 million meals from hot-food distribution sites in areas such as South Queens and Southern Brooklyn.

New York City's solid waste system, too, generally functioned well, despite some damage to its facilities, its vehicle fleet, and New York City's rail network. Truck-based collection resumed almost immediately after the storm, even though many Department of Sanitation workers themselves had homes damaged by the storm. In addition to diligently removing the regular daily volume of solid waste, these employees managed to cart away over 400,000 tons of excess debris from waterlogged homes and businesses—to widespread acclaim.



Blackout in Chelsea from Southern Manhattan power outage — Credit: Dan Nguyen

Because some facilities responsible for receiving New York City's solid waste were affected by the storm, the City made contingency plans for disposal—for instance, diverting over 10 percent of the city's residential and institutional solid waste from a waste-to-energy facility in New Jersey to other facilities. Rail transport of solid waste also experienced disruptions. Important lines were down for five days on Staten Island and in the Bronx, during which time solid waste was stored in containers or shipped out on transfer trailers.

For more on food supply and solid waste, see Chapter 13.

Communities
While Sandy affected neighborhoods all across New York City, the storm hit five coastal areas particularly hard—the Brooklyn-Queens Waterfront, the East and South Shores of Staten Island, South Queens, Southern Brooklyn, and Southern Manhattan. Three of the five areas (the East and South Shores of Staten Island, South Queens, and Southern Brooklyn) were directly exposed to storm surge and destructive waves along the shore, and all experienced widespread inundation. Across the five areas—which are home to 685,000 people—physical and economic damage was extensive and long-lasting.

Building damage in these areas was pervasive and in many cases devastating. Neighborhoods in South Queens, Southern Brooklyn, and along the East and South Shores of Staten Island accounted for over 90 percent of the buildings in Sandy-inundated areas citywide and over 70 percent of the buildings tagged by DOB as having been seriously damaged or destroyed citywide as of December 2012. Buildings along the Brooklyn/Queens Waterfront and in Southern Manhattan, meanwhile, often lost critical building systems, expensive mechanical equipment, and personal property and inventory located on ground floors. Residents of high-rise buildings—including elderly New Yorkers and those with physical limitations—found themselves, in many cases, stranded on upper floors when their buildings lost elevator service. Many of these impacts were felt particularly acutely by residents of public housing developments located on the waterfront.

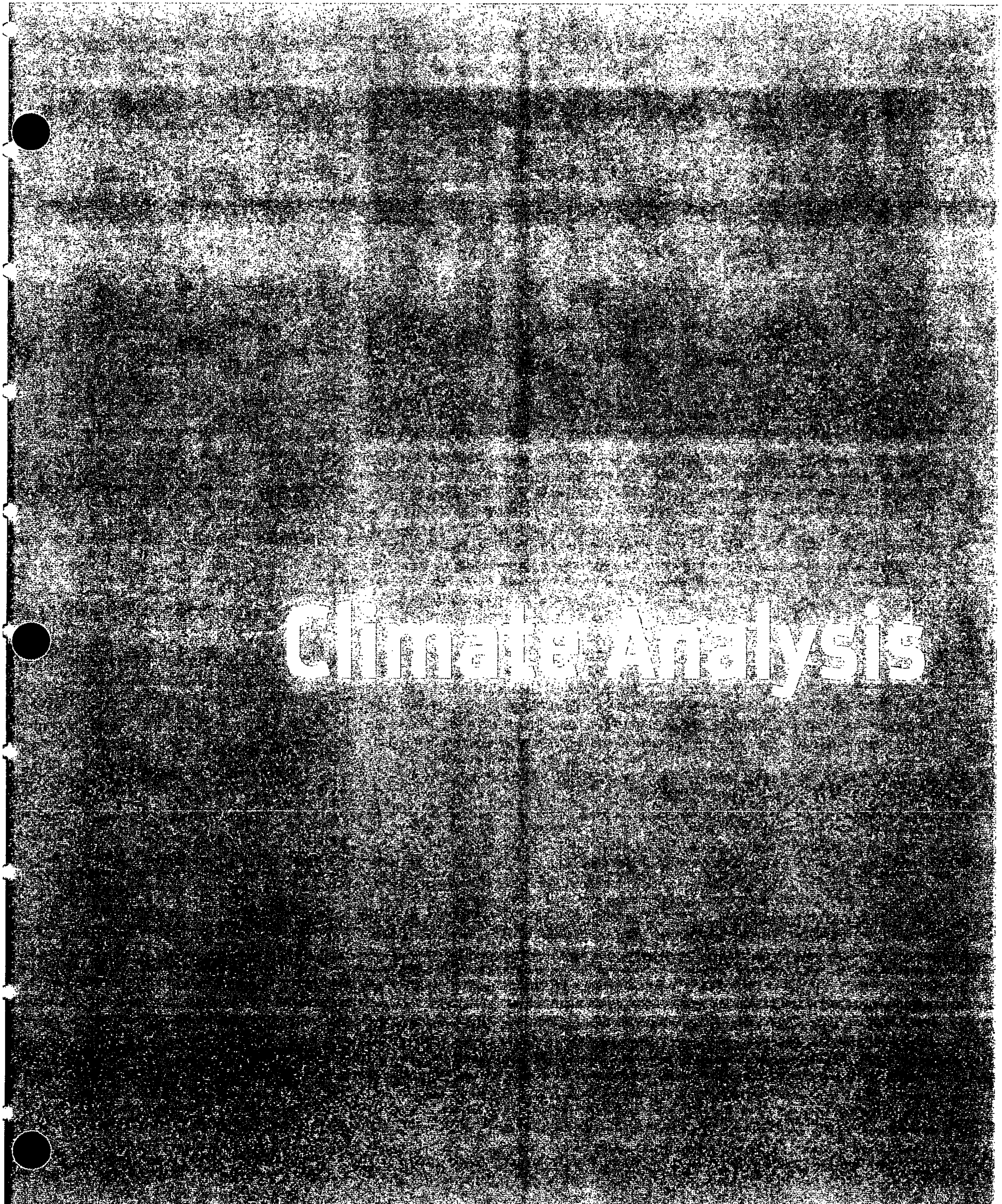
Across these communities, there was also damage done to critical infrastructure, often affecting not just these communities, but the city as a whole. For example, many of Southern Manhattan's vehicular tunnels were inundated during the storm, resulting in their closure for up to three weeks following Sandy, eliminating key connections between New York City and New Jersey and between New York's boroughs. Southern Manhattan's subway tunnels flooded as well, and most subway lines were down between three and seven days, impairing the system citywide. Wastewater treatment plants in several neighborhoods also saw flooding and damage, and all five communities experienced power outages.

The recovery of these neighborhoods is vital not only to the people who live and work in them, but to the city as a whole. This report would not be complete without plans to address the vulnerabilities that Sandy exposed in these areas and that climate change likely will exacerbate in the future. The initiatives in this report aim to help these communities stand strong again.

For the Brooklyn-Queens Waterfront, see Chapter 14. For the East and South Shores of Staten Island, see Chapter 15. For South Queens, see Chapter 16. For Southern Brooklyn, see Chapter 17. For Southern Manhattan, see Chapter 18.

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.

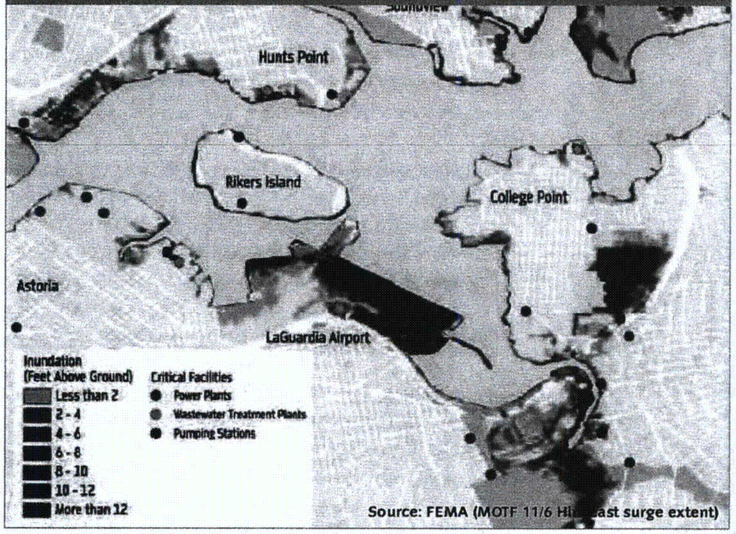
Clearly, while Sandy was historic, it was not, in fact, a worst-case scenario for all of New York

Storms Through New York City History

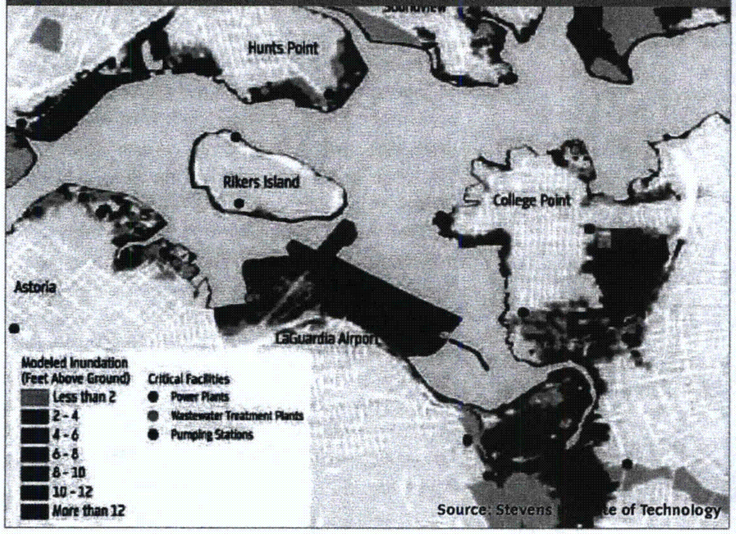
Sandy may have been the latest catastrophic storm to hit New York City, but it certainly was not the first. Throughout history, the city has suffered from hurricanes and other coastal storms, such as nor'easters. Hurricanes and tropical storms strike New York infrequently, relative to other types of 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.

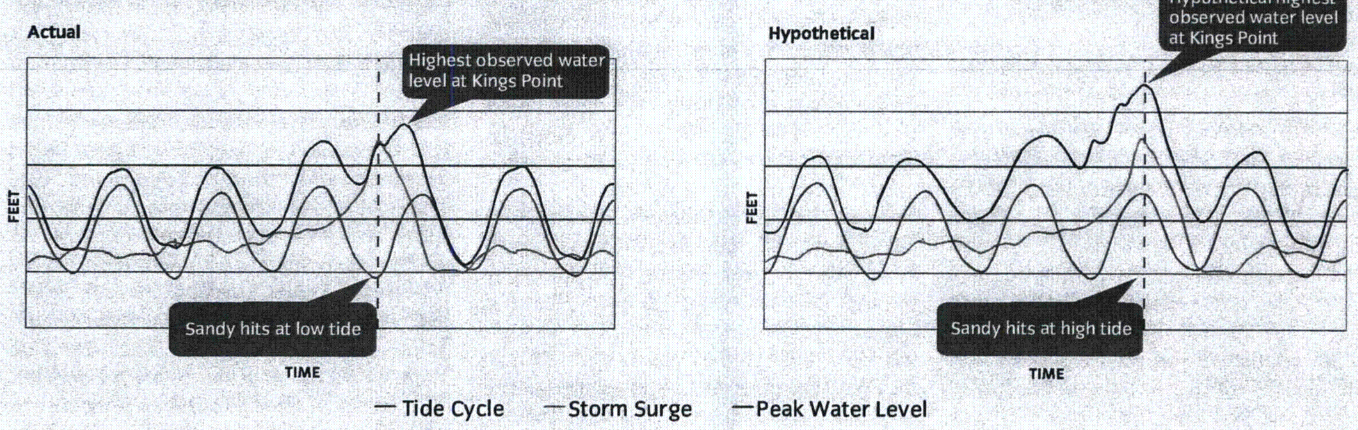
Tidal datums, such as Mean Lower Low Water (MLLW), are standard elevations defined by a certain phase of the tide. Tidal datums are used as references to measure local water levels and therefore vary over different areas. For example, the MLLW tidal datum is determined by averaging the lower of the two 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.

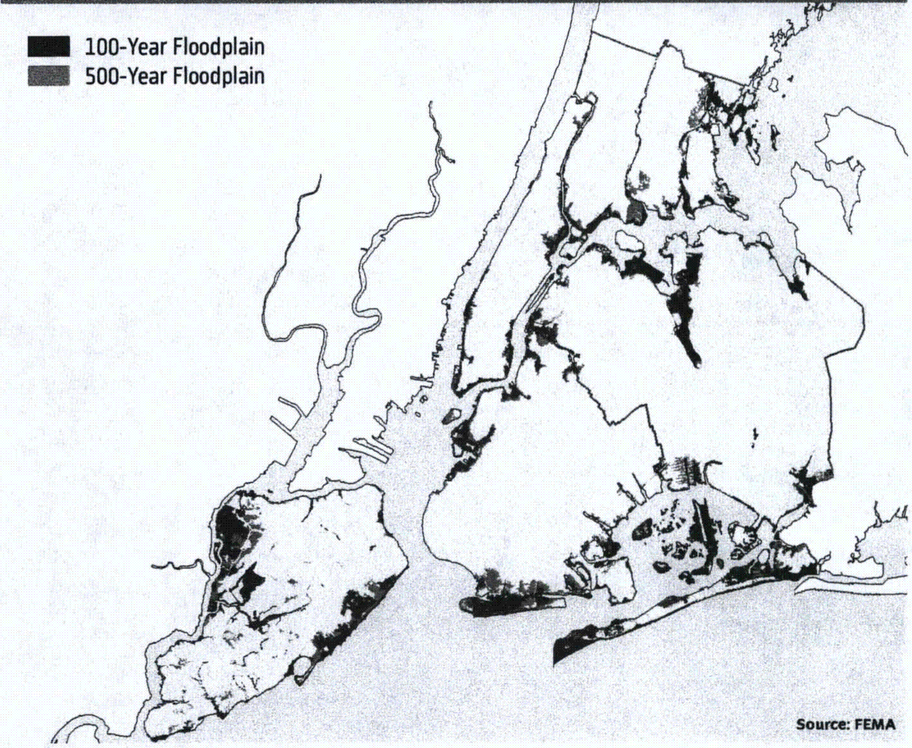
In order to facilitate comparisons across different locations, this report refers to all water elevations in NAVD88 unless otherwise specified. MLLW is used selectively to highlight location-specific water levels and typically shows higher values than NAVD88. Flood depths, which are measured from ground 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)*

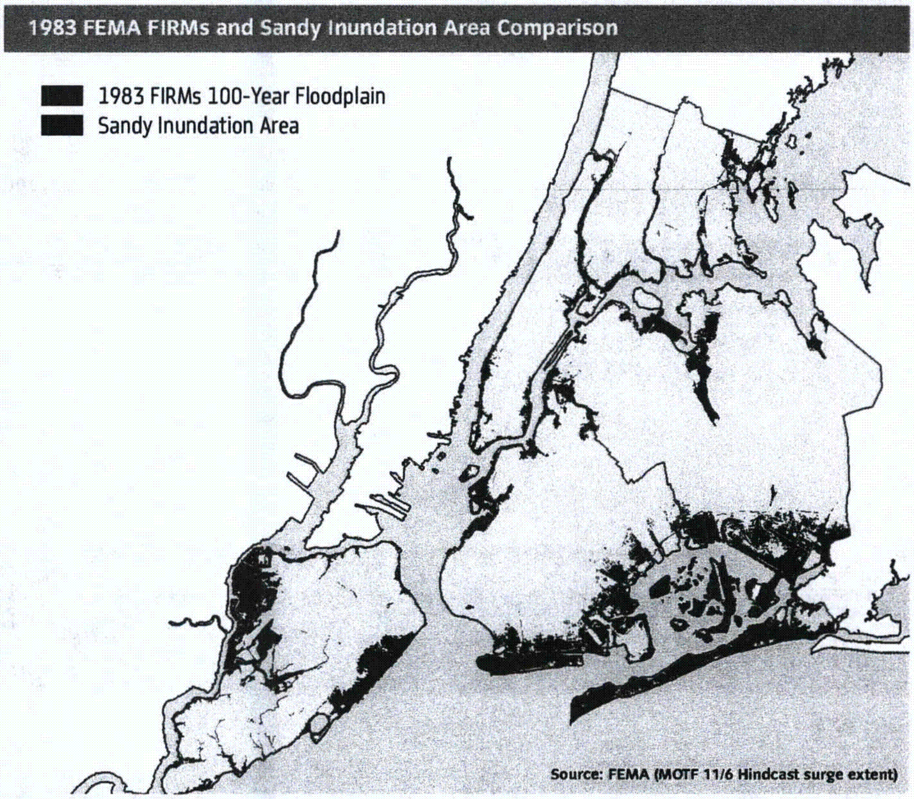
Just three months after Sandy, in January 2013, as part of an effort to give New Yorkers better information about their flood risks from coastal storms, FEMA issued interim maps for New York, just as it had done for other communities that did not have up-to-date maps following major storms (for example, 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

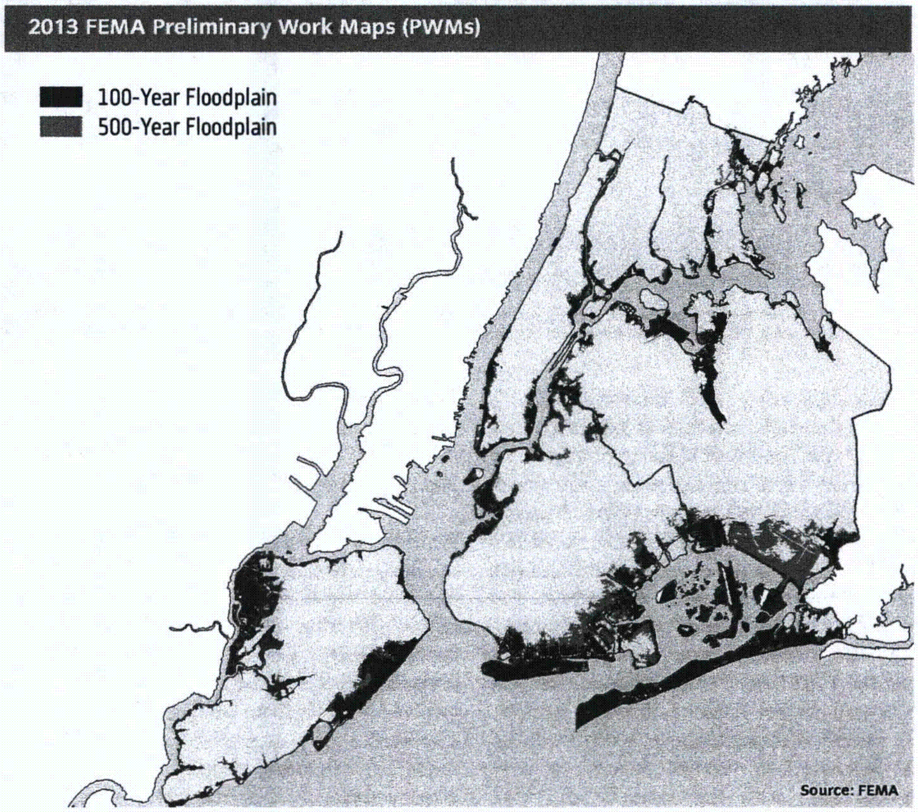
100-Year Flood

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.





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.

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

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.

1980s — 1990s — 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.

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

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

2010s

October 29, 2012
Sandy hits.

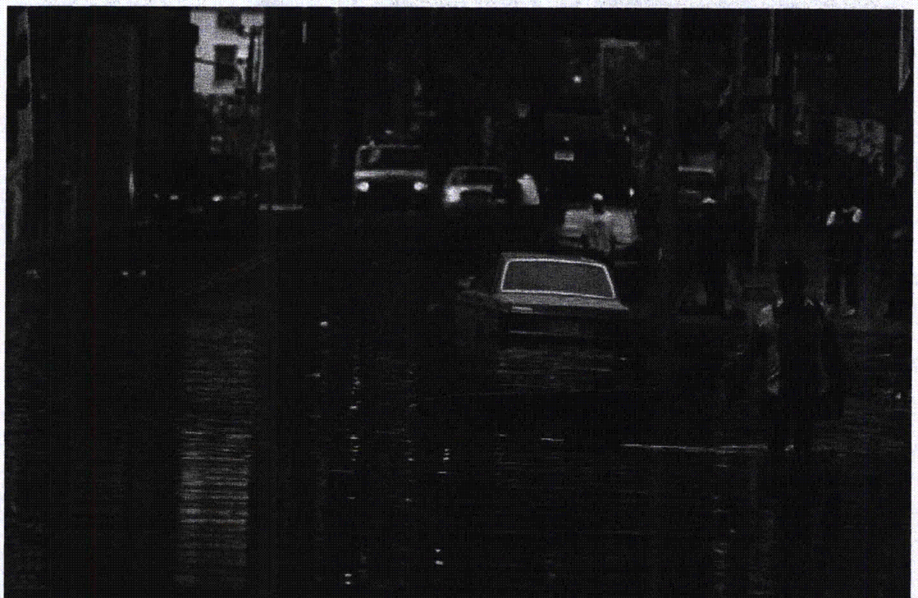
January and February 2013
FEMA releases ABFEs.

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

June 2013
FEMA releases PWMs for New York City.

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.



A September 2004 storm flooded 9th Street in Brooklyn. Credit: Seth Wenig/The New York Times

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.

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

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


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's 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 2.8 °F	+3.2 °F	+4.1 to 5.7 °F	6.6 °F
Precipitation	50.1 in.	+1 to 8%	+10%	+4 to 11%	+13%
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.

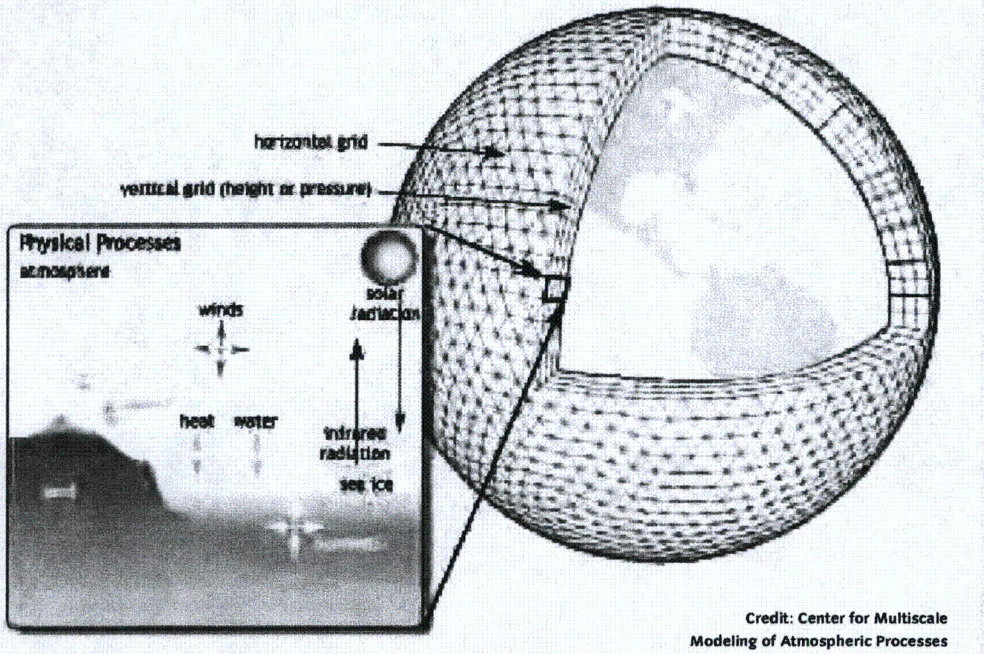
To ensure that the City would always have access to the latest information about future climate risks, in September 2012 New York City formally codified the NPCC and the Climate Change Adaptation Task Force when it wrote those two entities into law—the first bill passed by any local government in the 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.

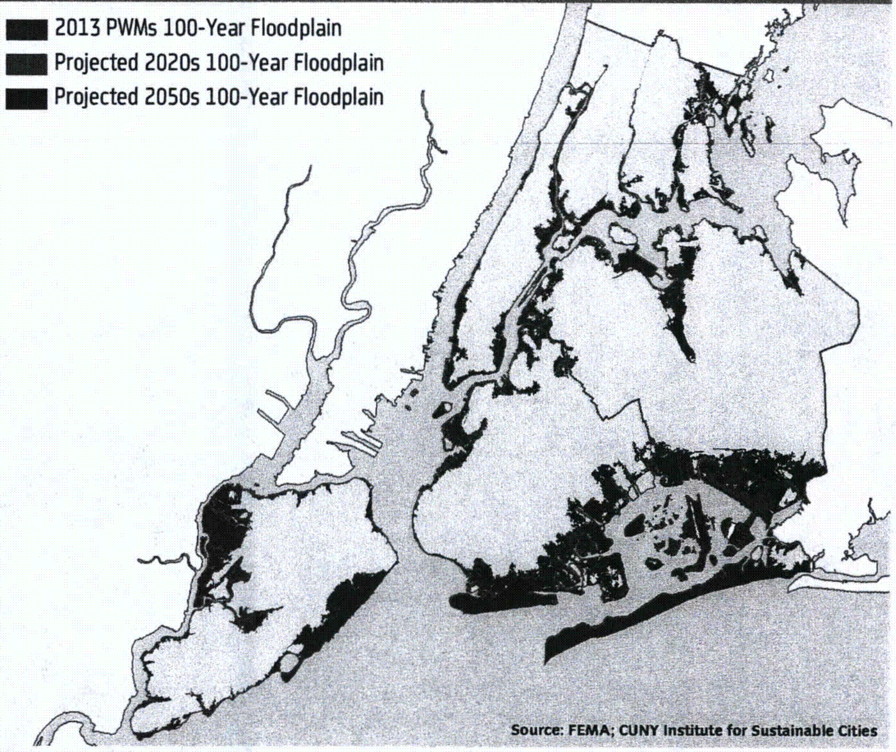
Meanwhile, the NPCC also predicts that, by the 2050s, the city could have as many days at or above 90 degrees annually as Birmingham, Alabama has today—a threefold increase over what New York currently experiences. Heat waves could more than triple in frequency, lasting on average one and a half times 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 80 percent since the late 1970s, 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:

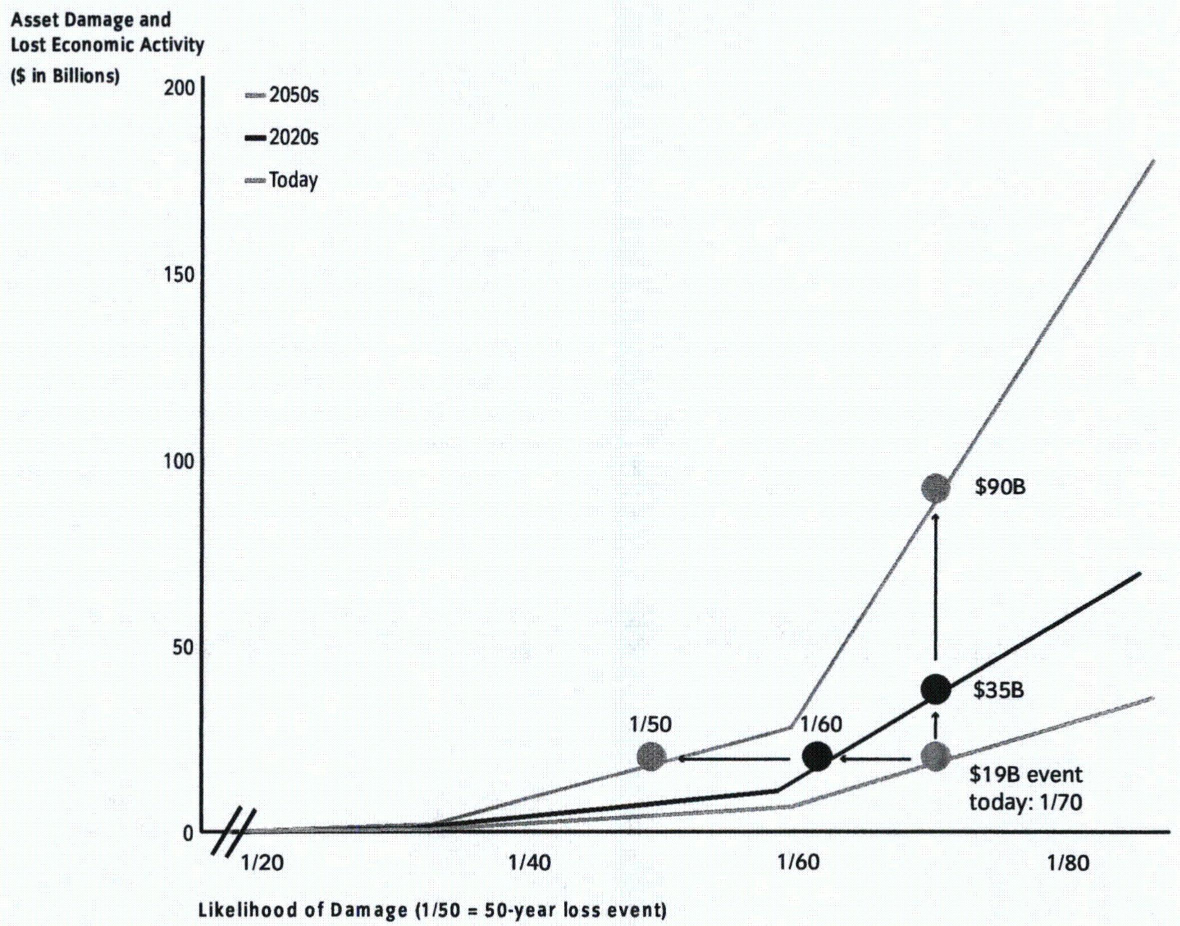
1. **Hurricane models:** As a seller of large-scale natural catastrophe reinsurance products, Swiss Re has built simulations of hurricanes based on robust historical data. Swiss Re uses data from the National Hurricane Center that includes nearly 1,200 observed tropical storms and hurricanes in the Atlantic 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

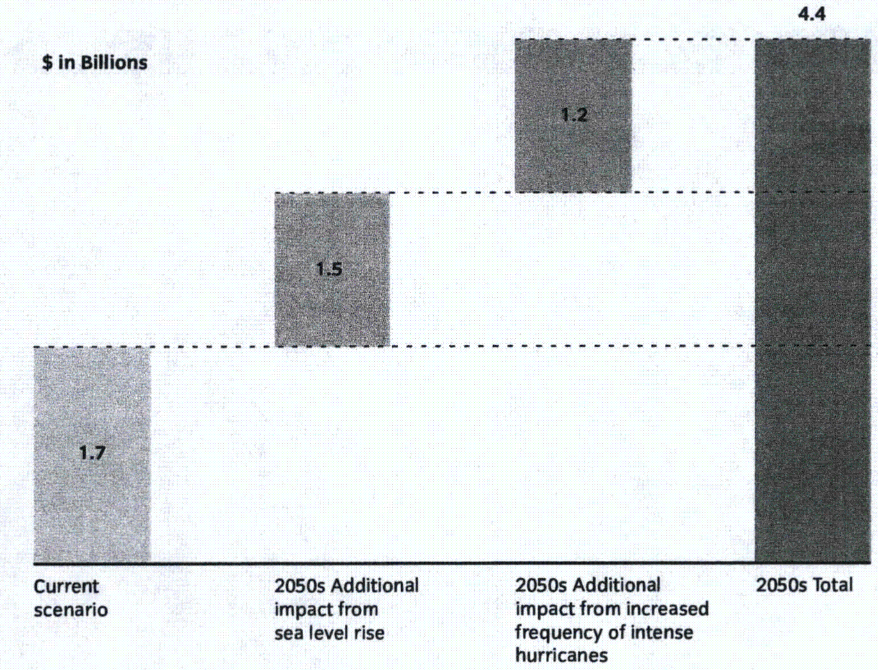
Based on these inputs, Swiss Re models produce a "loss frequency curve" for each of three scenarios: 2012, the 2020s, and the 2050s. Each curve indicates the probability that a given level of loss—in terms of both asset damage and lost economic activity, expressed in billions of current dollars—will 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.

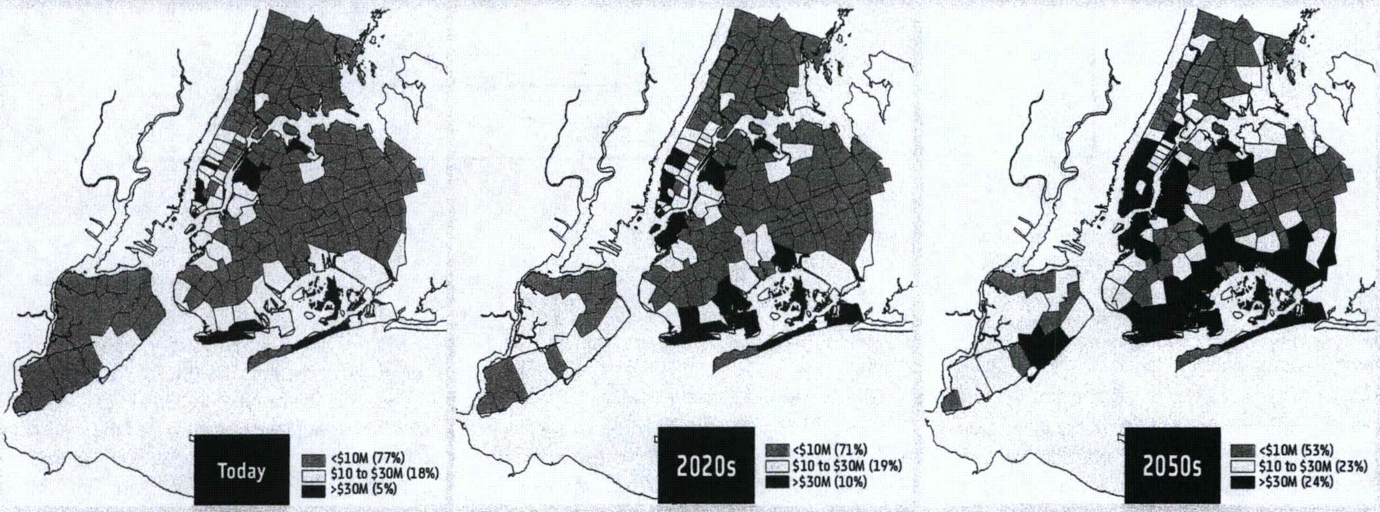
Expected Loss Modeling and Cost-Benefit Analysis (Continued)

Growth in Expected Annual Losses from Storm Surge and Wind



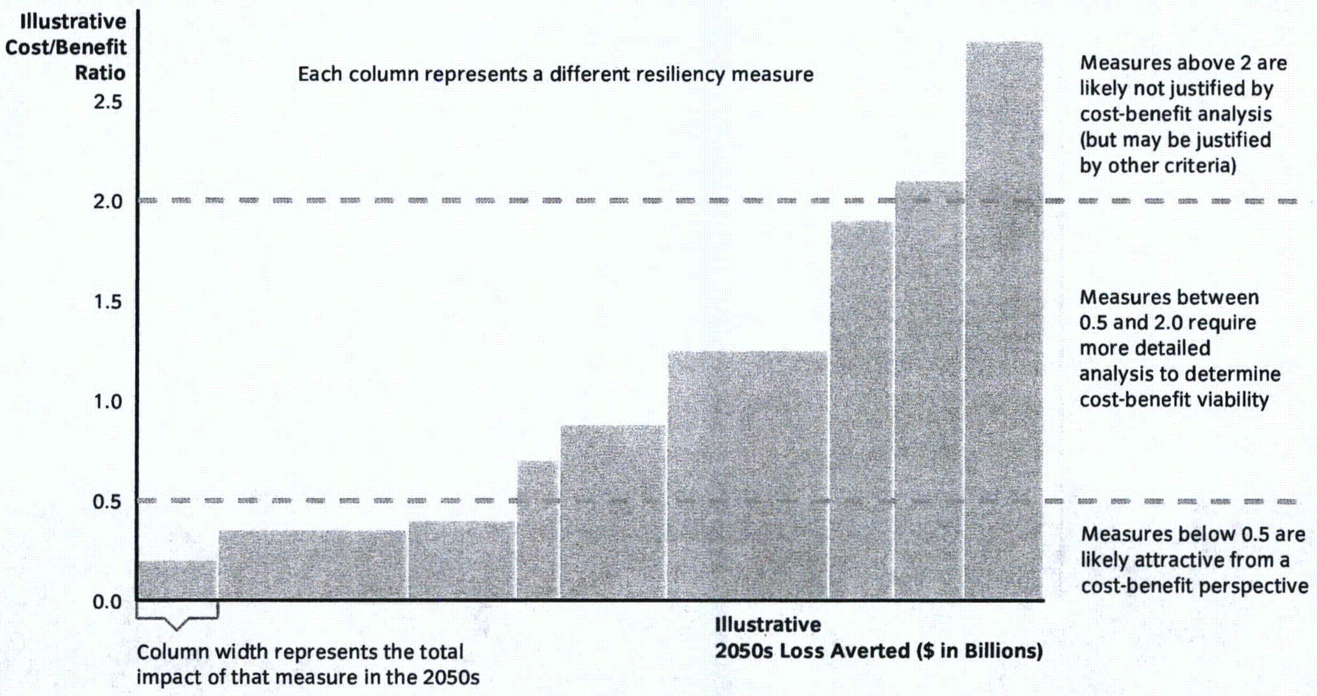
While the loss frequency curves map different levels of loss to their exceedance probabilities, another way to understand the risks to New York is to consider expected annual losses. This is generated by multiplying the different exceedance probabilities by the amounts of loss associated with them and 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.

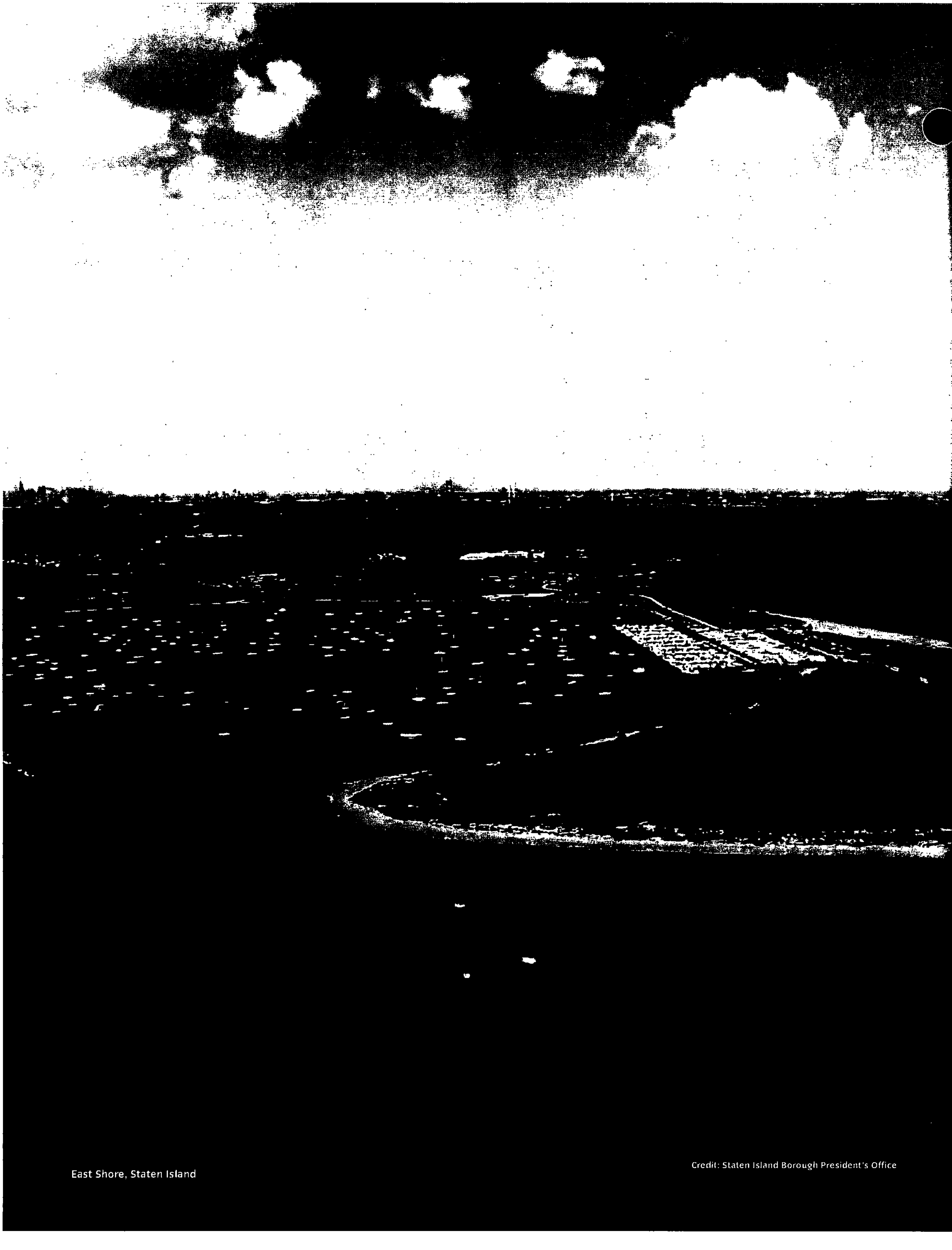
Cost-Benefit Analysis Output



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.

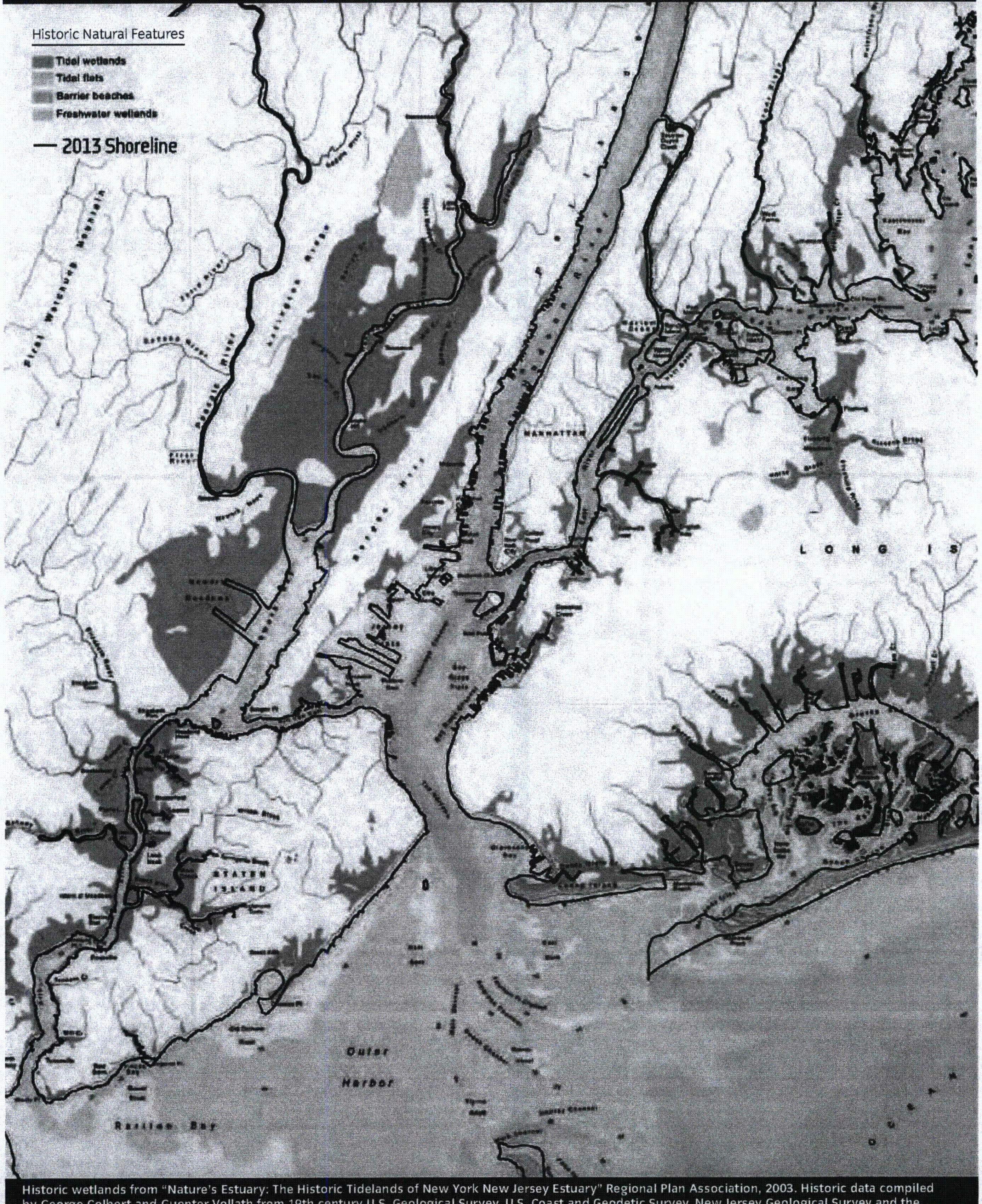


East Shore, Staten Island

Credit: Staten Island Borough President's Office

Coastal Protection

New York City's Coastline: Then and Now



Historic wetlands from "Nature's Estuary: The Historic Tidelands of New York New Jersey Estuary" Regional Plan Association, 2003. Historic data compiled by George Colbert and Guenter Vollath from 19th century U.S. Geological Survey, U.S. Coast and Geodetic Survey, New Jersey Geological Survey and the Ratzer Survey of 1776-1777.

When Henry Hudson sailed into what is now known as New York Harbor in 1609, the coastline he encountered was a wondrous place. Archipelagos of small islands dotted near-shore waters. Wetlands and oyster beds stretched for miles. Sloping beaches lay dazzling under the sun. The harbor coastline provided abundant food sources and natural protection from storms. It would prove essential to the survival and growth of the early settlement of New Amsterdam. (*See map: New York City's Coastline: Then and Now*)

This coastline is just as essential to New York City's survival and growth today.

Not surprisingly, New York City's coastline—which stretches a total of 520 miles and is longer than the coastlines of Miami, Boston, Los Angeles, and San Francisco combined—has changed dramatically since the 17th century. The inhabitants of New York City have altered its very topography in many ways, dredging waterways to ease the way for shipping, constructing piers and bulkheads, and even using fill to reshape the shoreline's contours. While some of the historic natural features that once protected what is today New York City have been lost in the process, the changes that were made have enabled commerce and industry to flourish, neighborhoods to thrive, and infrastructure to perform critical functions.

Notwithstanding the important role played by the city's waterfront through most of its history, during the last decades of the 20th century, large sections of the coastline fell into disuse and disrepair. In recent years, however, the city has begun to reconnect with this critical asset. These new connections have taken many forms, from investments in the working waterfront to new housing, parks, and ferry landings. As much as this renewed embrace of what Mayor Bloomberg has referred to as the "sixth borough" has benefitted its citizenry, New York's reengagement with its coastline has also occurred out of necessity—as the city has sought to meet the needs of a growing population and expanding economy.

However, even as the city has reconnected with its waterfront, New Yorkers have known that proximity to the water brings with it certain challenges, especially as global climate change advances—a threat discussed in detail in PlaNYC, the City's sustainability plan, in 2007. Thus, in 2011, building on PlaNYC, the City released *Vision 2020: The New York City Comprehensive Waterfront Plan*, the centerpiece of an effort known as the Waterfront Vision and Enhancement Strategy, or WAVES. This effort set forth broad goals for the shoreline of New York City, including, of course, increased climate resiliency. To this end, the report's accompanying WAVES Action Agenda put forth specific initiatives that already have helped to create a waterfront that is more productive and better prepared for the future.

In October 2012, with the arrival of Sandy, the case for increased climate resiliency—even beyond the initiatives set forth in the WAVES Action Agenda—was forcefully made to all New Yorkers. The storm scoured beaches along New York City's ocean-facing coastline, damaging buildings and infrastructure, flooding neighborhoods, causing dangerous erosion, and most seriously, killing 43 New Yorkers. Areas along the Hudson and East Rivers and the other waterways in the Upper Bay, meanwhile, experienced record-setting flooding, along with damage and destruction to building systems, business inventory, and personal property.

As the impacts of climate change accelerate over time, more damage, more flooding, and more erosion are likely in New York, with sea levels continuing to rise and more of the most intense storms expected. In response to these challenges, the City believes that it must bulk up its defenses, improving the coastline with protective measures. This will not eliminate all flooding from all conceivable storms—an impossible goal—but mitigate the effects of sea level rise where the risk is greatest and reduce the effects of storm waves and storm flooding significantly.

Reaching these resiliency goals—and protecting all of the waterfront assets along the coastline more effectively—requires a deliberate and coordinated approach. This chapter seeks to achieve this goal, presenting the City's new, comprehensive coastal protection plan.

The plan articulates a full menu of proposed coastal protection measures tailored to the specific geomorphology of (described below) and risks facing neighborhoods that are most exposed. These measures, though complementary, also can be implemented independently over time, based on available funding and relative priority. Though ultimately the city will be best served by implementing the entire suite of options, this report sets forth an initial set of projects that targets areas that have particularly large concentrations of businesses or residents (or both), areas that house critical infrastructure, and areas that shelter especially vulnerable populations. Though these projects still come at significant cost, they have been scaled in such a way that the City believes that they not only can but should get under way immediately.

Of course, the City cannot implement these new coastal protection measures alone. Implementing them will require partnerships with the Federal government, likely through the US Army Corps of Engineers (USACE), and other regional stakeholders and governmental entities. To make these new coastal measures as effective as possible, the City itself also will have to improve the way that it administers the shoreline that it controls, ensuring better management, design, and operation of its coastal assets—something that this chapter also addresses. Finally, this chapter also will call on the various regulatory bodies with responsibility for permitting along the waterfront in New York City—from the City, to the State, to the Federal government—to work together to clarify, simplify, and simultaneously make more effective the process of permitting, both in general and for critical flood-protection projects.

Over the centuries, the coastline of New York City has been a sparkling natural resource, a setting for commerce and industry, and a place for housing and recreation. Going forward, it also can reprise a role that it played ably in the early days of New Amsterdam and before. Namely, to provide protection to the people living along and behind this coastline.

The New York City Coastline

The city's 520-mile coastline—bordering the ocean, as well as rivers, bays, and inlets—is both diverse and complex. To understand this coastline, it is critical to understand its geomorphology—or the combination of its natural landforms, underlying geological conditions, and built condition. The geomorphology of today's city is largely the result of a colossal glacier that moved over what is now New York City over 20,000 years ago, combined with the coastal modifications that inhabitants have made in more recent times. This complexity is, in turn, amplified not just in the diverse uses and multiple property owners found today all along the water's edge across the city, but also by the many regulators with responsibility for the coastline's protection.

The Geomorphology of the New York City Coastline

New York City's southernmost waterfront areas—the Rockaway Peninsula, the Coney Island peninsula, and the East and South Shores of Staten Island—generally are characterized by gently sloping sandy beaches with some natural and built dunes, as well as discrete areas containing elevated bluffs. In places, groins (rock and timber structures perpendicular to beaches) and other reinforced structures have been installed to protect these beaches. Communities in these areas typically are less densely populated than other parts of New York City, though they also tend to be much more densely populated than other coastal areas along the eastern seaboard.

Within Jamaica Bay, one of the region's most important and largest natural features, there are many natural edges and marsh islands, some newly reconstituted. Here, portions of the shoreline have been filled in and hardened with bulkheads (vertical retaining walls) and revetments (shoreline protection constructed with armor stone). Many of the areas surrounding Jamaica Bay are particularly low-lying, a result of the glacial outwash plains that were formed at the end of the last Ice Age. Along and within Jamaica Bay and its tributaries, there are a wide array of neighborhoods, as well as several elements of critical city infrastructure, including transportation assets such as John F. Kennedy (JFK) Airport, marine terminals, and wastewater treatment plants.

Further north and within the Upper Bay—the areas along the Hudson and East River shorelines of Manhattan, Brooklyn, and Queens, as well as on the North Shore of Staten Island—the topography historically rose quickly to greater elevations along the coast. However, significant use of landfill to extend the coastline and the filling and development of former marshland have altered the waterfront significantly over the past three centuries, with large areas along these coasts now lying at or near the water level. Examples of these low-lying areas include the southern parts of Manhattan, East Harlem, Red Hook, and the areas adjacent to the Gowanus Canal and Newtown Creek in Brooklyn and Queens. Generally, in these areas, coastal edges have been hardened extensively over time with bulkheads, revetments, and piers supporting maritime, industrial, commercial, residential, and transportation uses.

In the northernmost waterfront areas of the city, the shorelines are quite varied. Some parts are naturally rocky, such as along City Island and Eastchester Bay. Other areas, by contrast, including Orchard Beach, have more gently sloping, sandy edges, some of which are manmade. Along the northern Queens waterfront as well as along large sections of the Harlem and Hudson Rivers in northern Manhattan and the Bronx, the topography is generally quite steep with high bluffs in some neighborhoods. Along parts of the east and south Bronx waterfront, meanwhile, land tends to slope more gently up from the water's edge. A variety of filled land and hardened edges, such as bulkheads and revetments, have been put in place throughout the area over time, with some natural areas reintroduced and restored, such as at Alley Creek in Queens. The land uses in the city's northern waterfront areas are quite diverse, ranging from key infrastructure such as LaGuardia Airport and the multiple power plants in Astoria, Queens, to the Hunts Point Food Distribution Center in the Bronx, to single-family homes on City Island and large, multi-family developments such as Co-Op City in the northeast Bronx.

Generally, New York City's coastline does not have purpose-built coastal defenses; many of the features that serve this function do so coincidentally, rather than by design. For example, recreational beaches—nourished (i.e., provided with additional sand to supplement and replace sand lost to erosion) and expanded over time in a partnership between the Department of Parks & Recreation (DPR) and the USACE—generally have been engineered with recreational goals in mind, though they also provide important protection for adjacent neighborhoods. The city's remaining wetlands and natural areas, which, until recently, often were viewed as underutilized property that could be filled and developed, also play an important protective role, serving to buffer inland areas. Meanwhile, though the coastline is dotted with many of the city's most beloved parks, it is only in recent years that the designs of these recreational areas, such as at Brooklyn Bridge Park and Governors Island, have deliberately incorporated discrete resiliency measures that could provide a model for other parks. Finally, the city's ubiquitous bulkheads also play a role in defending the city from harm, not only holding the land behind them in place—their intended purpose—but also breaking waves during storms.

Because of the uncoordinated fashion in which they were constructed over time, however, these various features, even where they do serve a defensive purpose, lack the robustness, comprehensiveness, and adaptability that the new era of climate change demands.

Regulatory Framework for the Coastline

Over a dozen City, State, and Federal agencies play a role in regulating New York City's waterfront and many waterways. In some cases, efforts by these agencies are not completely aligned. This lack of unified and coordinated regulatory oversight can lead to delayed and unpredictable waterfront activity, complicating the achievement of important public goals, including coastal resiliency.

On the City level, one organization with an important regulatory role is the City Planning Commission, which enacts zoning, reviews land use, and is the local administrator of the Waterfront Revitalization Program, a State program required under the Coastal Zone Management Act. The Department of Small Business Services (SBS), meanwhile, oversees waterfront construction activity through its dockmaster and waterfront permit units.

At the State level, a key role is played by the New York State Department of State, which monitors consistency of Federal actions against the State and City Coastal Management Program policies.

Previous Coastal Protection Studies of New York City

Although this report contains the City's first comprehensive coastal protection plan, many studies conducted in partnership with the US Army Corps of Engineers (USACE) and the State over the years have addressed the need for coastal protections. Some studies—such as those for the Rockaway Peninsula (initially authorized in 1965), Coney Island (1986), and Orchard Beach (1992)—led to beach nourishment projects that included popular recreational components. Other studies that were focused more directly on flood protection, such as the Hurricane and Storm Damage Reduction Project for the South Shore of Staten Island, authorized in 1993, were left uncompleted due to a lack of funding and consensus and have only recently been relaunched and fully funded.

By contrast, a study of Plumb Beach, Brooklyn is a notable success story. The study recommended a reconstituted beach, which was completed in 2012, just days before Sandy, providing significant protection to the Belt Parkway during the storm.

Another important study is the Hudson-Raritan Estuary Comprehensive Restoration Plan. This plan was released in May 2009 by the USACE and the Port Authority of New York & New Jersey, in partnership with the New York New Jersey Harbor Estuary Program. The plan is targeted at improving 11 ecosystem types within the estuary. Though the plan does not focus on flood protection, there is now an opportunity to leverage its findings to achieve ecosystem and flood protection benefits in the areas adjacent to the relevant ecosystems.

Notwithstanding all of the foregoing, a comprehensive flood protection study for the Upper New York Bay, one of the most densely populated and economically important waterways in the world, has never even been undertaken—let alone completed. The opportunity presented by the USACE's North Atlantic Coast Comprehensive Study, which was authorized by Congress in January 2013 and will evaluate flood risks of vulnerable coastal populations in areas affected by Sandy, must not be wasted.

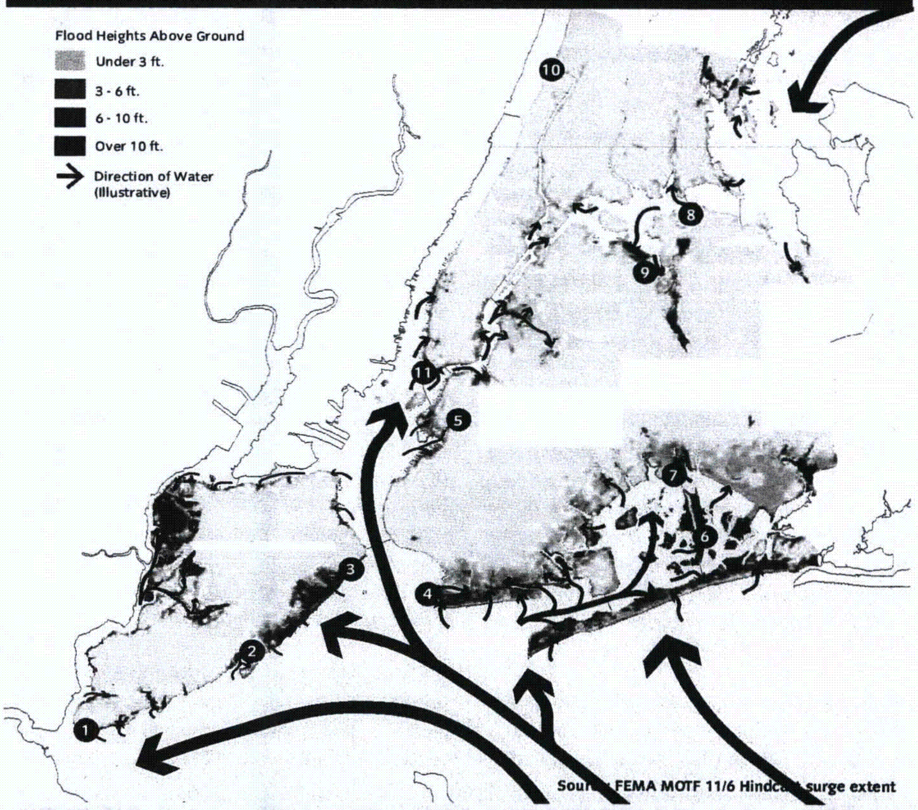
At the same time, the State Department of Environmental Conservation regulates in-water activities, wetlands, and other coastal uses by issuing permits, including water quality certifications, and enforces the Coastal Erosion Hazard Area, pursuant to which the State regulates, and generally seeks to discourage, the construction of hardened structures in areas of high erosion risk like beaches.

Finally, the Federal government's regulatory reach is distributed among many agencies, with the USACE, which has broad authority over the waters of the United States, typically serving as the coordinating body for many Federal agencies, including the US Fish and Wildlife Service and the Environmental Protection Agency. Among the USACE's responsibilities in New York Harbor are regulating its navigable waterways, implementing local public works projects, and protecting against flood risks, all as authorized by Congress. The US Coast Guard also plays a vital role in New York Harbor, regulating vessel traffic and coordinating other waterway activities.

Prior to Sandy, the City had partnered with the USACE and the State on several studies to evaluate protections for vulnerable communities in New York City. These studies typically were initiated following major storms, and some led to important projects that have been completed or are underway. In other cases, though, studies languished due to a lack of consensus on solutions. Moreover, despite the existence of many vulnerable and densely populated coastal areas in New York City, no comprehensive flood protection studies have ever been undertaken for the Manhattan, Brooklyn, Queens, and Bronx riverfronts, or for other areas of the Upper Bay. *(See sidebar: Previous Coastal Protection Studies of New York City)*

Until recently, the types of storms that have prompted studies on coastal protections have occurred infrequently. As a result, following these storms, interest in protection tended to wane, with impacted coastal communities often unable to secure the requisite funding needed to move forward with more effective protection measures. Sandy, however, has focused renewed attention on the need for such measures in New York City and brought into better focus the risks that extreme weather poses for the coast.

Sandy Inundation



Peak Storm Surge Elevations During Sandy

Location	Time Oct. 29, 2012	Water Level in Feet (NAVD88)
1. Tottenville, Staten Island	8:38 p.m.	+16.0
2. Great Kills Harbor, Staten Island	8:52 p.m.	+13.2
3. South Beach, Staten Island	8:23 p.m.	+15.0
4. Sea Gate, Brooklyn	8:23 p.m.	+13.3
5. Gowanus Canal, Brooklyn	9:04 p.m.	+11.1
6. Broad Channel, Queens	9:18 p.m.	+10.4
7. Howard Beach, Queens	9:23 p.m.	+11.2
8. Whitestone, Queens	10:06 p.m.	+10.6
9. World's Fair Marina, Queens	10:06 p.m.	+10.4
10. Inwood, Manhattan	10:06 p.m.	+9.5
11. The Battery, Manhattan	9:24 p.m.	+11.3*

*** Equivalent to 14 feet above Mean Lower Low Water (MLLW)**

Source: USGS, NOAA

Note: This chart calculates all elevations using the national reference standard known as NAVD88, which establishes a consistent base measurement point from which elevations are determined, unlike other local references to sea level. Press accounts or other sources are known to be reported using many reference standards and require conversion (see Chapter 2, *Climate Analysis*).

What Happened During Sandy

The Effects of the Storm Surge on the Coastline

Storm surge is the increase in water levels brought about by the low pressure and wind field of a coastal storm. When the surge comes into contact with a shoreline, it pushes additional water onto that shoreline, often inundating large inland areas. The impacts of surge are further amplified when entering water bodies that serve as funnels, such as New York Harbor. Overall, Sandy's surge had an incredibly destructive impact on the coastline of New York City, though different sections of the coastline experienced the storm differently and with different consequences. (*See map: Sandy Inundation*)

Generally, Sandy's coastal inundation took one of three forms. First, floodwaters came directly from the ocean, as water surged over beaches and bulkheads, flooding neighborhoods and critical infrastructure such as tunnels. Extreme water levels were seen citywide as the storm peaked in the evening of October 29, 2012. (*See chart: Peak Storm Surge Elevations During Sandy*)

In many cases, in ocean-facing areas such as Southern Brooklyn, South Queens, and the East and South Shores of Staten Island, from South Beach to Tottenville, the surge brought with it not just large volumes of water but also powerful waves that wreaked havoc on buildings and infrastructure alike. Record ocean waves of over 30 feet were measured in the ocean southeast of the Rockaway Peninsula.

Another impact of the wave action along the city's ocean-facing coastline was massive beach erosion. In fact, estimates indicate that up to 3 million cubic yards of sand, and maybe more, were lost citywide, with the Rockaway Peninsula alone losing about 1.5 million cubic yards of sand (a volume larger than the Empire State Building) and additional losses occurring in Coney Island, Orchard Beach, and the East and South Shores of Staten Island.

The second way Sandy's surge impacted the city was via less direct routes. In these cases, the city's many bays, inlets, and creeks functioned as "backdoor" channels, funneling ocean waters inland. For example, much of the flooding in Southern Brooklyn came not only over the area's beaches, but also via Coney Island Creek and Sheepshead Bay. Likewise, floodwaters from Jamaica Bay contributed to the inundation of the Rockaway Peninsula, where, as area residents explained, "the ocean met the bay." Newtown Creek, meanwhile, overflowed its banks, flooding Maspeth, Greenpoint, East Williamsburg, and Bushwick. Similarly, the Gowanus Canal overflowed its banks, flooding Red Hook and other adjacent neighborhoods.

The third way Sandy's surge impacted New York City was by overtopping the city's extensive shoreline drainage infrastructure, and in some cases infiltrating the roadway drainage and sewer system through catch basins, manholes, and storm drains in the streets, especially in low-lying areas such as in Midland Beach, Staten Island. This network of pipes and other features is designed to drain rainwater away from land and into the area's waterways and is not designed to protect against storm surge. Additionally, several tide gates and floodgates (devices that prevent water from flowing backwards through the drainage system)—including at Oakwood Beach, Staten Island—were damaged during the storm, while others, including at Flushing Meadows Corona Park, lost power and had to be operated manually during Sandy, amid the overwhelming volume of water that they were being asked to handle.

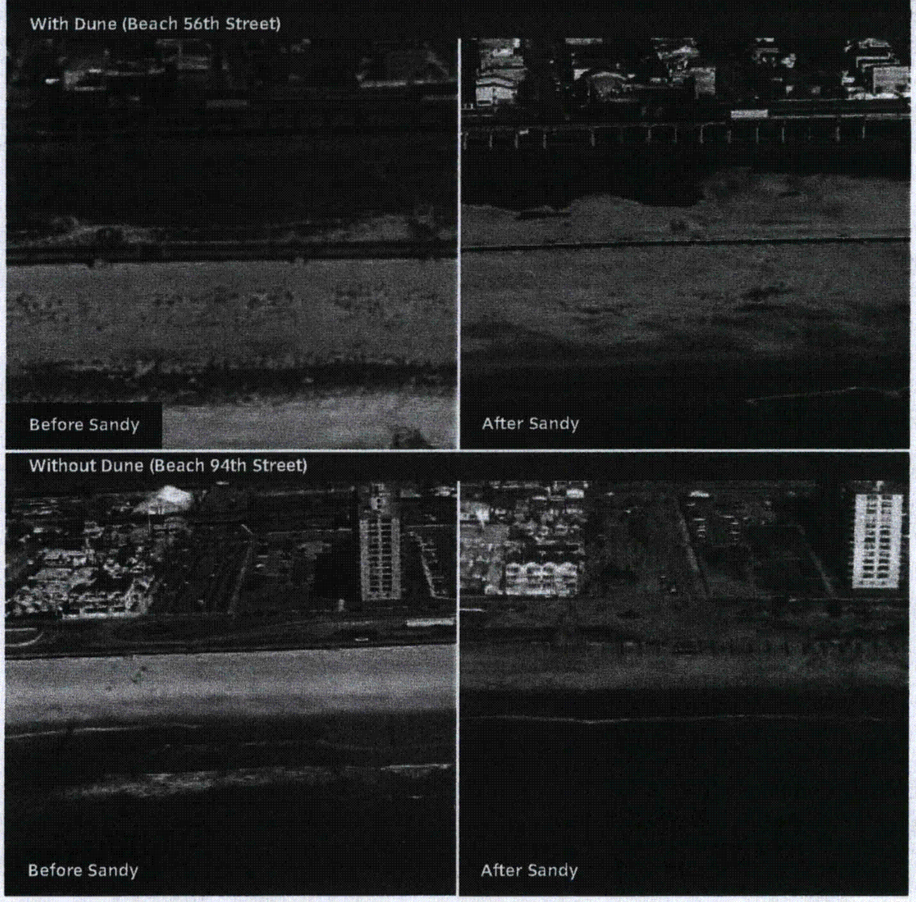
Performance of Existing Coastal Defenses

Though Sandy's surge generally devastated areas that it touched, some coastal features and strategies—such as beaches nourished with sand, dunes, wetlands, new and elevated drainage systems, site elevation, and bulkheads—did offer some protection. For example, many nourished beaches and dunes absorbed the destructive energy of waves and floodwaters, in many cases buffering adjacent neighborhoods. This was the case on the Coney Island peninsula, where the neighborhoods behind the nourished beaches of Coney Island and Brighton Beach suffered far less-destructive wave impact than did Sea Gate, where the beaches had not been nourished. In addition, areas of the Rockaway Peninsula with established dunes, such as Beach 56th Street, suffered substantially less damage and less sand migration into neighborhoods than areas without them, such as Beach 94th Street. (*See photos: Dune Protection on the Rockaway Peninsula*)

Site elevation, too, often proved effective in protecting buildings from destructive waves and flooding. Much of the city's development along the waterfront has occurred on land created by filling in historic wetlands and marshes *at-grade*, leaving them at risk of flooding. However, *elevated* developments—such as Battery Park City in Lower Manhattan and Arverne By The Sea on the Rockaway Peninsula—survived Sandy with minimal damage, particularly compared to other nearby locations that were not elevated.

Drainage systems that took advantage of local landscape and site characteristics also worked well. Though the volume of water that came with Sandy's surge was so massive that, in many cases, these systems were overwhelmed by peak water levels, areas with newer, elevated systems such as Arverne By The Sea were able to drain more quickly as floodwaters receded—sometimes immediately—allowing quicker recovery.

Dune Protection on the Rockaway Peninsula



Credit: NOAA