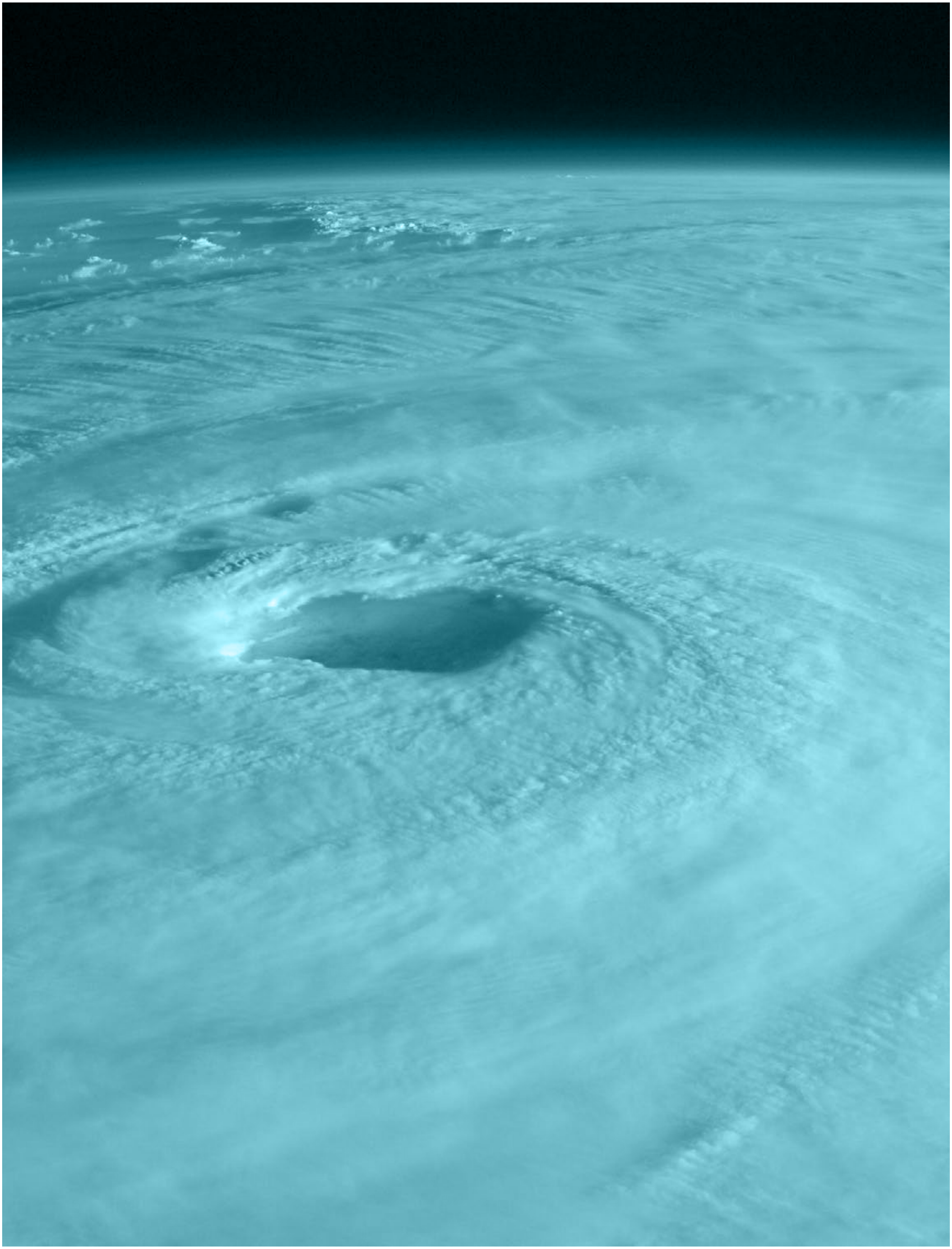


COASTAL STORMS

CHAPTER 4.1

Coastal storms are a reality for New York City, arriving as hurricanes, tropical cyclones ,and nor'easters when certain meteorological conditions converge. Not only dangerous, these storms can be deadly, sustaining destructive winds, heavy rainfall, storm surge, coastal flooding, and erosion. Climate change and rising sea levels are likely to worsen their impacts.

WHAT IS THE HAZARD?

TROPICAL CYCLONES

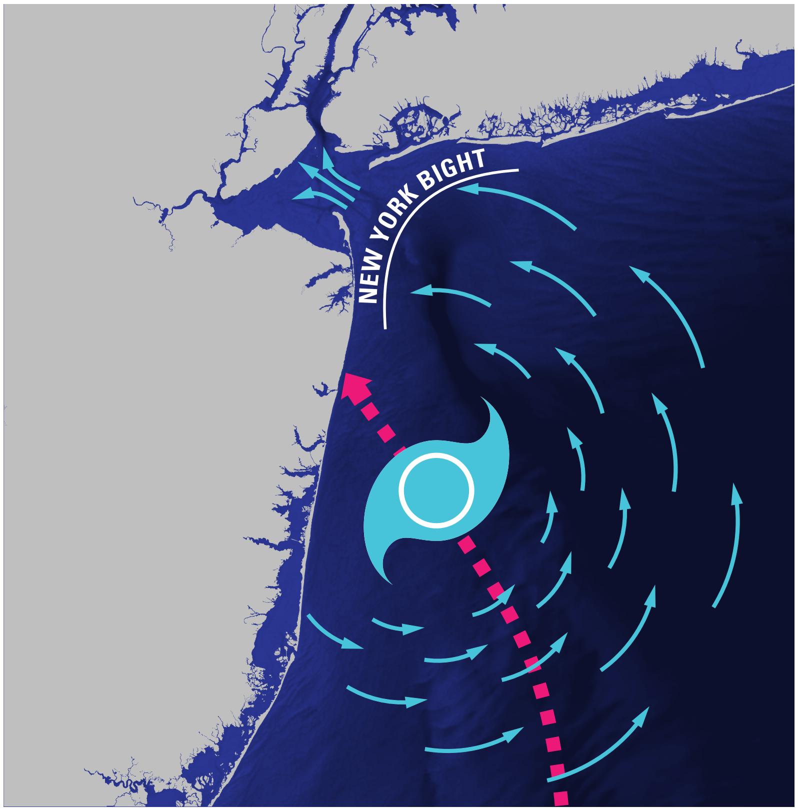
Tropical cyclones are organized areas of precipitation and thunderstorms that form over warm tropical ocean waters and rotate counterclockwise around a low pressure center. Such storms are classified as follows:

- A **tropical depression** is an organized system of clouds and thunderstorms with a defined low pressure center and maximum sustained winds of 38 miles per hour (mph) or less.
- A **tropical storm** is an organized system of strong thunderstorms with a defined low pressure center and maximum sustained winds of 39 to 73 mph.
- A **hurricane** is an intense tropical weather system of strong thunderstorms, a well-defined low pressure center ("eye"), and maximum sustained winds of 74 mph or more.

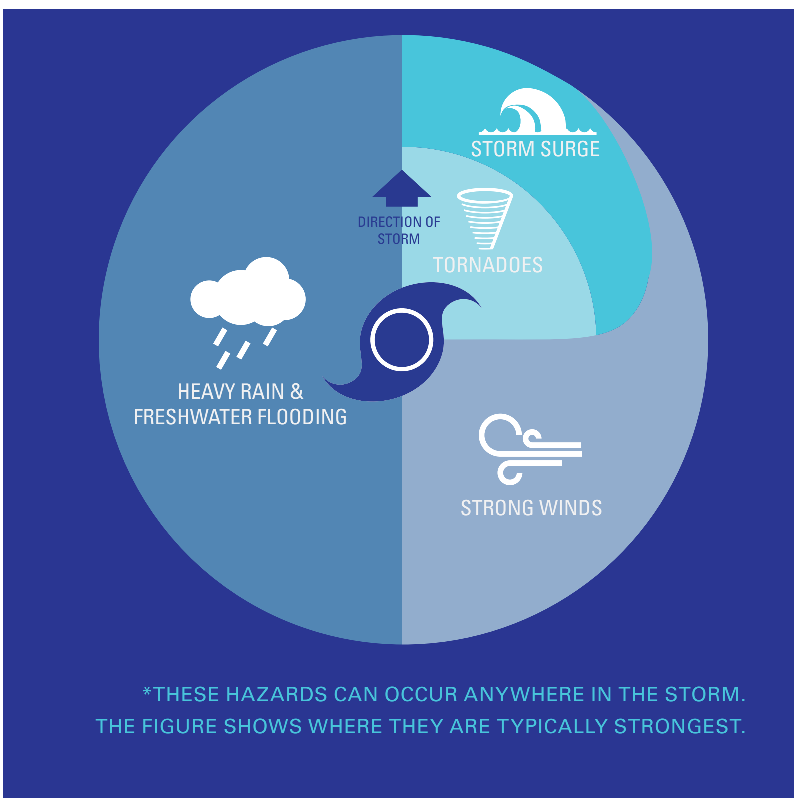
In the North Atlantic Basin—where New York City is located—tropical cyclones often form in the Atlantic Ocean between Africa and the Lesser Antilles, in the Caribbean Sea, or in the Gulf of Mexico. Typically, they first track in a westerly or northwesterly direction. They are then pushed northward and eventually eastward by the force of the Earth's rotation. They may track up the East Coast of the United States and reach New York City if water temperatures are warm enough and the prevailing winds steer them in this direction.

The Atlantic hurricane season lasts from June through November and features an average of 11 tropical storms and six hurricanes annually. New York City is at highest risk between August and October, when ocean temperatures are warmest.

The primary hazards associated with coastal storms are flooding (both inland and coastal) and wind. Inland flooding may result from heavy rain. The amount of rainfall depends on a storm's speed, size, and local geography. Heavy rain can cause freshwater flooding from rivers or in low-lying areas with poor drainage. Urban flash flooding is an acute form of the latter.



A HYPOTHETICAL STORM APPROACHING NEW JERSEY
SOURCE: NYC OEM



PRIMARY HAZARDS ASSOCIATED WITH HURRICANES
SOURCE: NYC OEM

Of all hazards associated with coastal storms, coastal flooding from storm surge causes the greatest damage and the most deaths. Storm surge is the rise in water level caused by a storm's strong winds and low pressure. The most significant storm surge typically occurs near the storm's eye wall (the region of clouds and intense thunderstorms surrounding the eye) and in the right-front quadrant of the storm, where the storm's speed of forward motion accelerates the counterclockwise rotating winds. During periods of high tide, the water levels can be even higher, causing severe flooding. The observed water level resulting from the combination of storm surge and the astronomical tide is known as the storm tide: that is, the highest water level reached during a storm. The shoreline along the open ocean and in wide estuaries is also exposed to powerful wave action in addition to flooding from rainfall, storm surge, and tides.

Wind-related hazards from coastal storms are straight-line winds and tornadoes. They are generally strong enough to snap or uproot trees and utility poles and cause structural damage to buildings. Flying debris becomes another hazard. Tornadoes are usually relatively low on the Enhanced Fujita Scale, which measures tornado strength (see "Strong Windstorms"), and are short in duration, but they may still pose a significant risk.

NOR'EASTERS

A nor'easter is a type of coastal storm that occurs most often between October and April in the Mid-Atlantic and Northeast United States, where counterclockwise circulation brings winds from a northeasterly direction. Like tropical cyclones, these storms are associated with heavy precipitation and wind. However, they form outside of the tropics (often over the Carolinas or southeast coast of the United States) during cooler months, and they can maintain their strength over land.

These storms also differ from hurricanes in that they bring the threat of heavy snow, sleet, and/or freezing rain but are rarely associated with tornadoes. Although nor'easters typically have weaker surface winds than hurricanes, they occur more often, may develop more quickly, and may affect larger geographic areas.

WHAT IS THE DIFFERENCE BETWEEN A TROPICAL STORM AND A NOR'EASTER?

TROPICAL CYCLONES	NOR'EASTERS
Form in tropics or subtropics	Form outside of the tropics
Can only form and maintain strength over warm water	Can form and maintain strength over land or water
Energy source is warm ocean water	Energy source is temperature contrasts in the atmosphere
Occur between June and November	Occur between October and April
Are often associated with bands of severe thunderstorms and possibly tornadoes	Are rarely associated with severe thunderstorms and tornadoes
Are not associated with wintry precipitation (snow, sleet, freezing rain)	Are often associated with wintry precipitation (snow, sleet, freezing rain)

NOTABLE STORMS IN THE NEW YORK CITY AREA

September 1821: A large hurricane hits Long Island with a 13-foot storm tide in parts of New York City.

September 1938: The most powerful hurricane on record to ever impact the region makes landfall near Fire Island

August 1954: Hurricane Carol makes landfall in eastern Long Island with sustained winds over 100 mph.

March 1962: Nor'easter caused extensive damage along much of the East Coast between North Carolina and southern New England.

September 1985: Hurricane Gloria makes landfall on Long Island as a Category 1.

December 1992: A powerful nor'easter causes extensive damage to structures, utilities, and roads across New York City.

September 1999: Tropical Storm Floyd dumps between 10 and 15 inches of rain causing extensive flooding and damage.

October 2012: Hurricane Sandy makes landfall in southern New Jersey, devastating New York City and much of the metropolitan area.

WHAT IS THE RISK?

STORM SEVERITY AND OUR PHYSICAL EXPOSURE

The severity of a coastal storm depends on multiple factors. Storms are formally categorized on the basis of wind speed as measured by the Saffir-Simpson Hurricane Wind Scale.

Other factors that affect a storm's severity are its size and speed of forward motion. A larger, slower-moving Category 1 storm may cause more widespread damage than a smaller, faster-moving Category 2 storm because the winds will impact the region for a longer time and total rainfall will be greater.

The storm's size determines the wind field (the area impacted by storm winds), and thus affects wave heights and storm surge. In general, larger storms produce larger waves and higher storm surge. In a fast-moving storm, winds on the right side are amplified by the storm's forward speed, but slow-moving storms will impact an area for a longer period of time, generally producing more rainfall and inland flooding. On the open coast, a faster storm will produce higher surge. However, a higher surge is produced in bays, sounds, and other enclosed bodies of water with a slower storm.

The direction that the storm is moving when it reaches New York City—its "bearing"—also contributes to its consequences. A storm moving in a westerly direction that is south of the city at landfall will put New York City on the right side, meaning stronger winds and higher storm surge for the city. If a storm is moving in an easterly direction and makes landfall east of the city, we will be on left side of the storm, which could mean higher rainfall totals but less significant winds and storm surge.

The geography of the local coastline amplifies storm surge impacts. The New York Bight—the nearly 90-degree angle formed by the shorelines of Long Island and New Jersey—can direct a storm surge into New York Harbor. The worst-case-scenario hurricane for New York City is moving in a northwest direction with landfall just to the south along the

Saffir-Simpson Hurricane Wind Scale

Category

1

74-95 mph

Very dangerous winds will produce some damage: Well-constructed frame homes could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days

Category

2

96-110 mph

Extremely dangerous winds will cause extensive damage: Well-constructed frame homes could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages that could last from several days to weeks.

coast of New Jersey. This track puts the city in the right-front quadrant of the storm and directs the highest storm surge into the New York Bight.

This is what happened during Hurricane Sandy in 2012, and it is one reason the storm had such a significant impact on the city. Tropical Storm Irene made landfall over Brooklyn the year before but was a very different storm. Its bearing at landfall was a north-northeast direction, resulting in fewer direct surge impacts on the city.

A CLOSER LOOK AT STORM SURGE

While the entire city is at risk of high winds and freshwater flooding, only locations close to tidally influenced water bodies will experience storm surge. The extent and severity of storm surge flooding also depends on local topography. Locations right on the shore are also at risk from severe wave action, which is often accompanied by debris impact. While waves are generally highest along the open ocean, also at risk are bay, sound, and wide river estuary shorelines.

To predict storm surge and help guide the City's planning for coastal storms, New York City Emergency Management Department uses a National Hurricane Center computer model called Sea, Lake, and Overland Surges from Hurricanes (SLOSH). SLOSH takes into account a number of variables for storms moving in different directions and varying in strength from Category 1 to Category 4. The model then calculates surge levels for a worst-case scenario for each storm category.

The National Hurricane Center forecasts storm tide heights for tropical storms and hurricanes on a probabilistic basis (a range of likely storm tide levels) and updates its forecasts regularly as the storm approaches landfall. The National Oceanic and Atmospheric Administration provides timely storm tide forecasts for non-tropical storms (including nor'easters) on a deterministic basis (a single value for each tide gauge location). Some academic institutions, including Stevens Institute of Technology and SUNY Stony Brook, provide similar forecasting services. While intended purely for research purposes, these forecasts can be valuable supplements to official forecasts.

Category

3

111-129 mph

Devastating damage will occur: Well-built framed homes may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.

Category

4

130-156 mph

Catastrophic damage will occur: Well-built framed homes can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

STORM FREQUENCY

According to the National Hurricane Center, on average, hurricanes winds have impacted the New York City area every 19 years, and major hurricanes (Category 3 or higher) every 74 years. A Category 5 hurricane is not expected to occur here under current climate conditions. This has no relation to the storm surge estimates produced from the SLOSH model.

New York City is typically hit by several nor'easters each year. They range in intensity. While severe nor'easters do strike the city occasionally, most nor'easters are relatively weak. But even those can produce significant rainfall or snowfall and minor-to-moderate coastal storm tides and related damage.

VULNERABILITY

Many factors make our coastal city particularly vulnerable to major coastal storms and their secondary impacts. Notably, nearly 2.5 million city residents live in storm surge inundation zones, and a great deal of valuable real estate and critical infrastructure is located in those zones.

HOW IS DEPTH OF FLOODING DETERMINED?

The amount of flooding a storm causes is one of the most important characteristics of the event. Meteorologists often report this as the amount of storm surge: that is, the additional water above mean (average) sea level that results directly from the coastal storm.

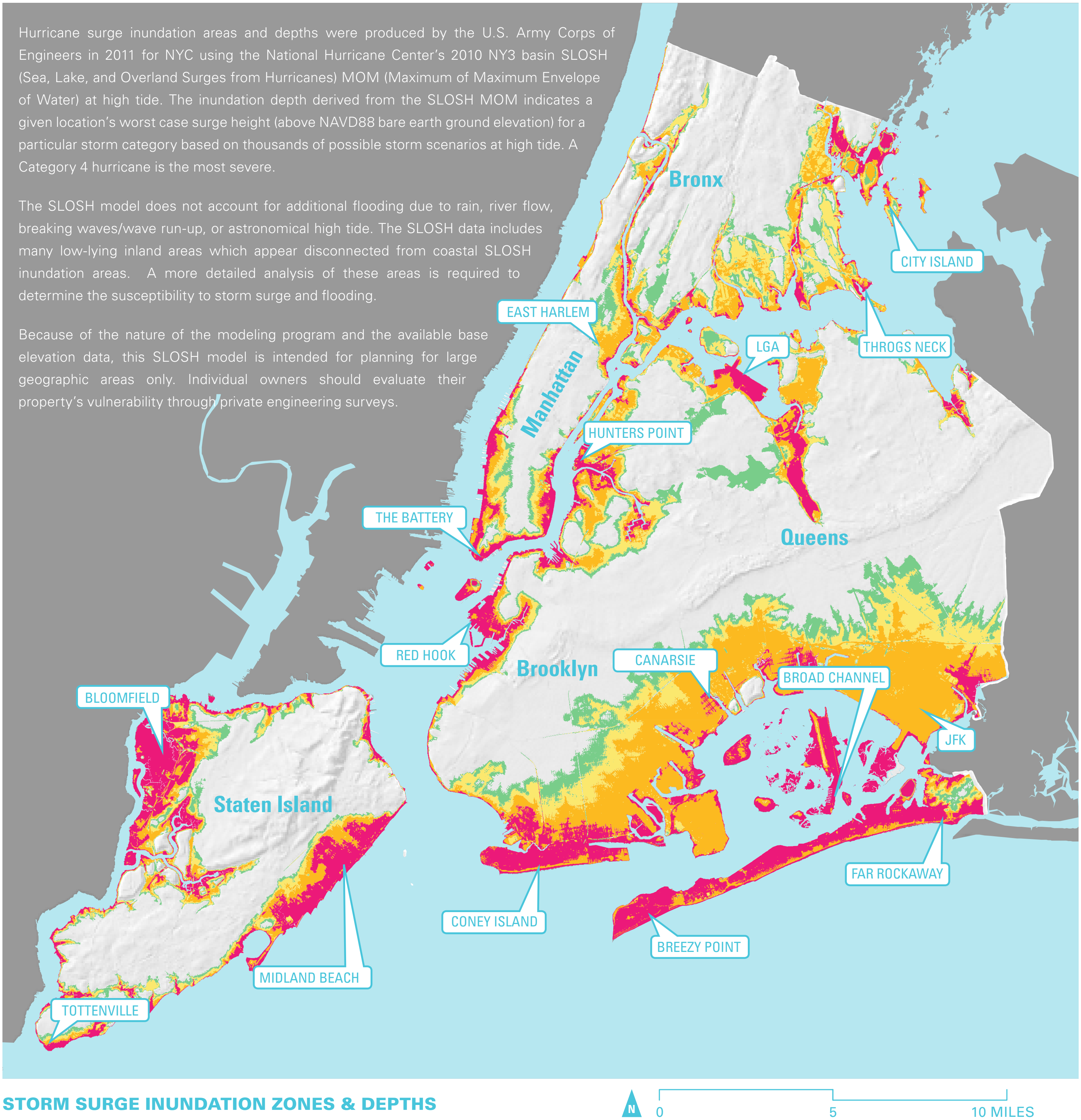
But reporting storm surge can misrepresent the amount of flooding if — for the specific location for which depth of flooding is determined — elevation above mean sea level and tide are not taken into account. That is because factors that determine the amount of flooding at a specific point include tide levels at the time of the storm's landfall, which can range up to eight feet in the New York City area, and land elevation – how high above mean sea level a location is on land. This was a point of confusion among public officials, the media, and the general public during Hurricane Sandy.

To more simply communicate information about predicted storm surge flooding, the National Hurricane Center has developed an experimental *Potential Storm Surge Flooding Map*. Launched for the 2014 hurricane season, this tool shows on a map the potential depth of flooding forecasted during a storm, taking into account uncertainties in the forecast, with periodic updates as the storm progresses.

Hurricane surge inundation areas and depths were produced by the U.S. Army Corps of Engineers in 2011 for NYC using the National Hurricane Center's 2010 NY3 basin SLOSH (Sea, Lake, and Overland Surges from Hurricanes) MOM (Maximum of Maximum Envelope of Water) at high tide. The inundation depth derived from the SLOSH MOM indicates a given location's worst case surge height (above NAVD88 bare earth ground elevation) for a particular storm category based on thousands of possible storm scenarios at high tide. A Category 4 hurricane is the most severe.

The SLOSH model does not account for additional flooding due to rain, river flow, breaking waves/wave run-up, or astronomical high tide. The SLOSH data includes many low-lying inland areas which appear disconnected from coastal SLOSH inundation areas. A more detailed analysis of these areas is required to determine the susceptibility to storm surge and flooding.

Because of the nature of the modeling program and the available base elevation data, this SLOSH model is intended for planning for large geographic areas only. Individual owners should evaluate their property's vulnerability through private engineering surveys.



STORM SURGE INUNDATION ZONES & DEPTHS

SOURCE: NHC; USACE

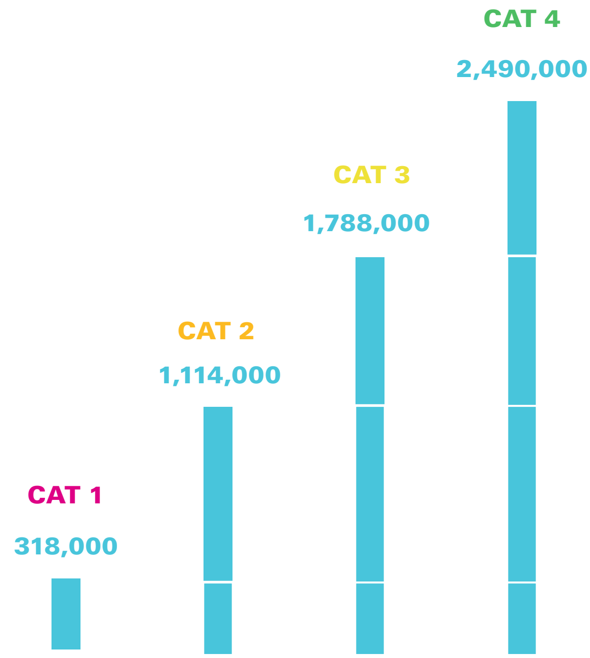
SLOSH MOM CATEGORY

CAT. 1 CAT. 2 CAT. 3 CAT. 4

INNUNDATION DEPTH (SEE MAP ON PG. 52)

SAMPLE LOCATION	CAT 1	CAT 2	CAT 3	CAT 4
The Battery	3′	10′	16′	21′
Bloomfield	8′	14′	20′	27′
Breezy Point	3′	10′	15′	21′
Broad Channel	3′	11′	17′	23′
Canarsie	2′	12′	19′	25′
City Island	4′	10′	16′	21′
Coney Island	3′	10′	16′	21′
East Harlem	0′	4′	10′	15′
Far Rockaway	2′	8′	14′	20′
Hunters Point	3′	9′	15′	20′
JFK	0′	7′	15′	22′
LGA	5′	11′	17′	23′
Midland Beach	10′	16′	23′	28′
Red Hook	3′	10′	16′	21′
Throgs Neck	3;	9′	15′	21′
Tottenville	7′	13′	20′	26′

NUMBER OF NEW YORKERS LIVING IN EACH STORM SURGE INUNDATION ZONE



* Expressed as Cumulative Total

SOURCE: NHC; USACE; US CENSUS

New York City's role as a global financial center and the fact that we are embedded in a large, complex regional economy mean damage to us can reverberate beyond our borders. Conversely, if a major storm were to primarily impact Northern New Jersey or Long Island, its secondary consequences could reverberate here.

The following presents a small sampling of the consequences of major coastal storms. Others are detailed in the Flooding and Strong Windstorms profiles in this chapter. For a more detailed account of the catastrophic damage caused by Sandy, see the chapter "Sandy and Its Impacts" in *A Stronger, More Resilient New York* and the Hurricane Sandy Retrospective Analysis in the *2014 New York City Hazard Mitigation Plan*.

PEOPLE AT RISK

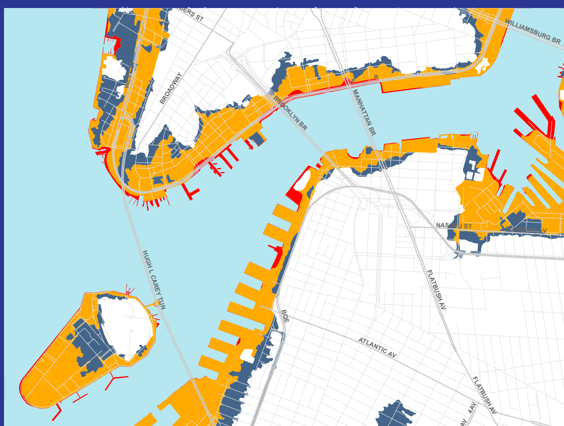
Coastal storms pose dangers to human health and safety both during and after a storm. During a storm, dangers include floodwaters in which people may drown, flying debris, downed trees and power lines, and power loss that may disrupt basic services. If people do not heed evacuation orders, sheltering in inadequate or surge-prone locations carries its own risks. Risks are compounded for vulnerable populations.

Floodwaters, debris on roadways, or damaged public transportation may leave people stranded for a long time. People who are stranded and need medical care will be at increased risk if medical personnel cannot respond promptly and if medical facilities are not operational.

Power outages can disable lighting, refrigerators, air conditioning and heating, hot water, and kitchen appliances. Without electricity, phones cannot be charged. Various types of life support equipment, such as ventilators and oxygen concentrators depend on electricity. Without working elevators, people may be stranded on upper floors of high-rise buildings. Residents stranded in flooded or otherwise damaged homes may be exposed to contaminated floodwaters and the growth of toxic mold, and to food spoilage if power is out for a long time.

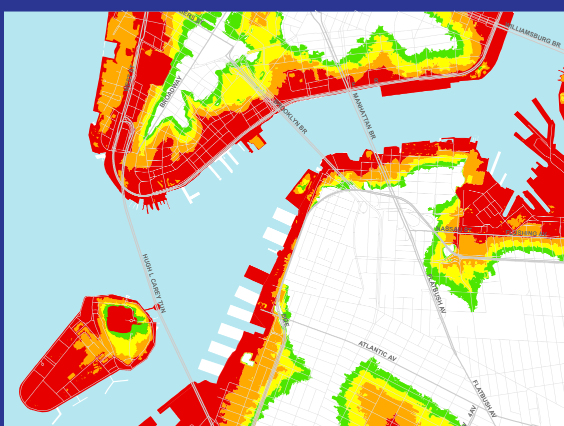
Coastal Flood Maps:
An Overview of Flood, SLOSH, and Evacuation Zones

The Federal Emergency Management Agency (FEMA) Flood Zones are different than SLOSH Storm Surge Inundation Zones and the New York City Hurricane Evacuation Zones. Each set of zones is intended to show areas at risk of storm surge, but the zones are created using different methods for different purposes. FEMA's Flood Zones are developed for flood insurance and building code requirements. SLOSH Storm Surge Inundation Zones and Evacuation Zones determine areas at risk of storm surge for life safety.



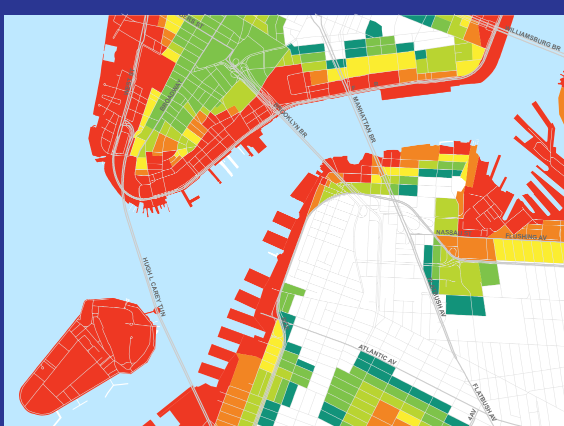
FEMA Flood Zones

FEMA creates Flood Insurance Rate Maps (FIRMs) as part of the National Flood Insurance Program (NFIP) to demonstrate flood risk and determine flood insurance requirements. FEMA models a set of storms that determine flood risk and the probability of flooding for a region. This flood risk is represented by different flood zones on a FIRM. These flood zones (V, A and Shaded X zones) inform property owners of the annual risk of flooding of their property. For example, the V and A zones (the 100-year floodplain) have a 1 percent annual chance of flooding in any given year. Properties located in this high risk area are required to carry flood insurance if the property has a federal mortgage. These maps also determine building code requirements and zoning regulations.



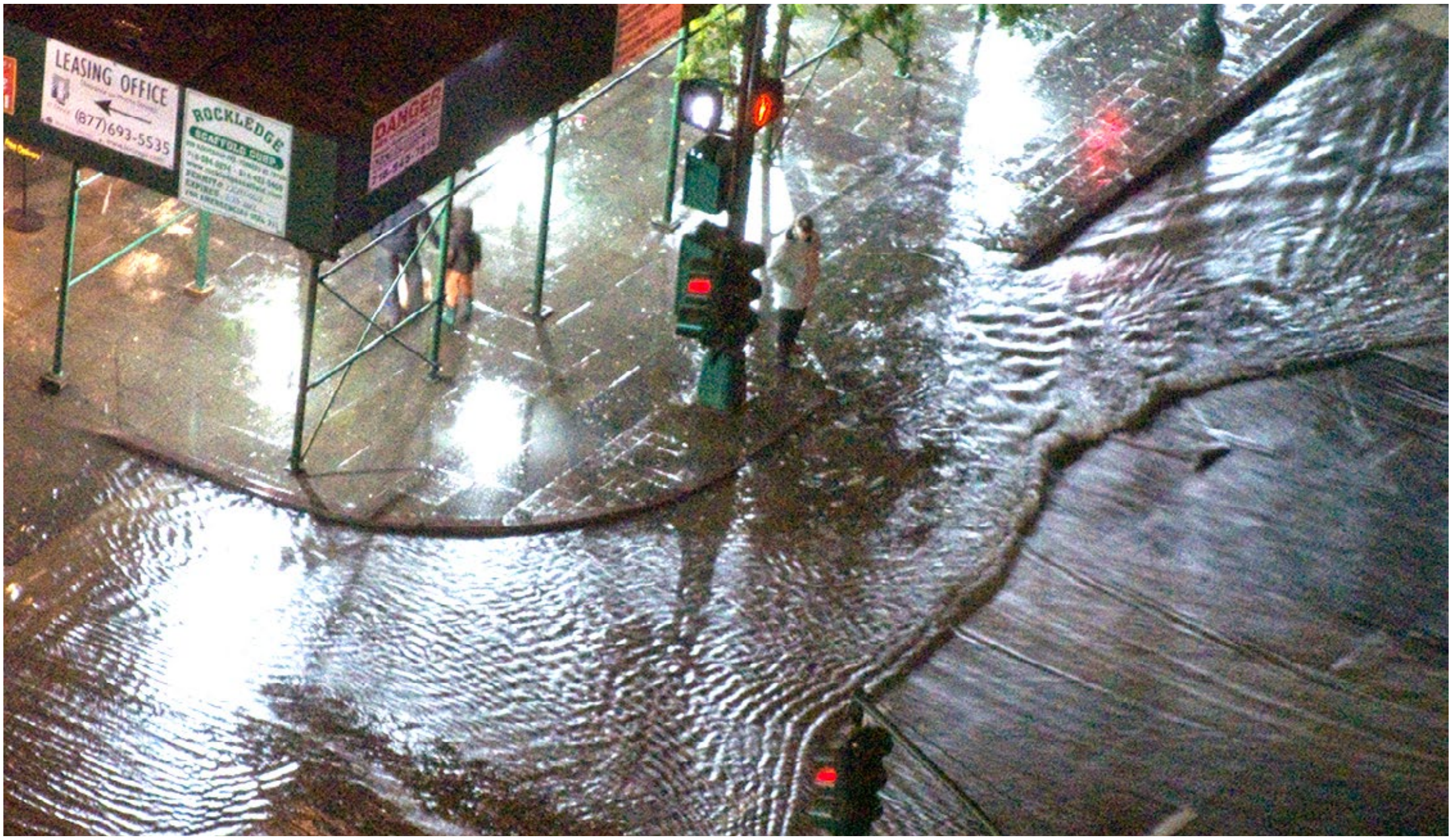
SLOSH Storm Surge Inundation Zones

The National Oceanic and Atmospheric Administration's Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model is used to calculate the risk of flooding from hurricane storm surge. SLOSH models thousands of storm scenarios for the region, creating storm surge inundation zones that show the worst case flooding for each hurricane storm category (1-4). SLOSH does not include wave action or rainfall and does not assign a probability, or likelihood, that this worst case storm surge will occur at any given location. SLOSH is used to develop evacuation zones for localities throughout the country.



New York City Hurricane Evacuation Zones

The New York City Emergency Management Department uses the storm surge inundation zones from SLOSH to create evacuation zones. New York City has six evacuation zones, zones 1-6, which were updated in 2013. These zones represent areas that may be inundated by or isolated by storm surge. The evacuation zones take into account different storm characteristics, including the bearing of the storm as it approaches the region, the storm intensity, characteristics of the community and built environment, and evacuation considerations. Hurricane Evacuation Zones are specifically used for life safety purposes and do not apply to building, zoning, or insurance regulations.



SANDY WEST ST FLOODING
SOURCE: MTA

BUILDINGS AT RISK

During coastal storms, buildings are at risk of damage from wind, flooding due to heavy rain or storm surge, and wave action. Flying or floating debris can cause additional damage. Mechanical systems, utilities such as electricity and natural gas, fire suppression systems, and telecommunications can all be compromised by flooding and wind. (For more information on vulnerable building types, see Flooding and Strong Windstorms.)

Potential wind damage to buildings resulting from various storm scenarios was calculated by New York City Emergency Management's GIS unit using the FEMA HAZUS-MH model. This analysis predicted that winds from a coastal storm that would be expected to occur on average once every 100 years would damage nearly 40,000 buildings and cause over $3.5 billion in damage. Winds from a storm that would occur on average every 1,000 years would be expected to damage nearly 450,000 buildings – almost half of the city's building stock – and result in nearly $53.6 billion in damage.

INFRASTRUCTURE AND ESSENTIAL SERVICES AT RISK

According to SLOSH model analysis conducted by NYC Emergency Management's GIS unit, nearly 40 percent of the city's critical facilities and infrastructure are located within a storm surge zone (see table 3.6.33 in the *2014 New York City Hazard Mitigation Plan*). This includes healthcare facilities, schools, power plants, wastewater treatment plants, and emergency response facilities.

Much of New York City's aging transportation and utility infrastructure is vulnerable to coastal storm damage. This includes subway tunnels and stations, bus depots in low-lying areas, bridges, and vehicle tunnels. Breakdown of public transportation could leave many people stranded, which would cause a number of secondary social and economic impacts, particularly for people who must travel to work or school, or obtain medical care.

Due to sea level rise, coastal flooding from a future Sandy-like storm is likely to cause even more extensive damage. Lesser storms will reach the same flood elevations as Sandy more readily and more often.

Shortages of liquid fuels may result if supply chains are disrupted by damage to fuel terminals, pipelines, and storage tanks. This can lead to long lines at the limited number of gas stations where fuel is available. Fuel shortages could also impede emergency response.

Vulnerable utilities include aboveground telecommunications and power distribution infrastructure, such as power lines and electric substations that are directly exposed to wind, flooding, or falling trees and debris. Underground power and telecommunications equipment is not exposed to wind but is at risk of flooding in some locations.

All of the City's 26 power generation facilities are located in storm surge inundation zones, which increases the risk of a citywide outage during a major storm.

ECONOMY AT RISK

The impacts of a major coastal storm could cause economic damage extending far beyond our city and our region. Locally, businesses could lose revenue because of damage to the buildings they occupy and the contents of those buildings, including inventories and equipment. Storm damage to energy and telecommunications systems could disrupt business operations. Employees could be stranded and unable to get to work. Customers could be forced to stay home. Tourism could suffer.

A global financial capital, New York City has tremendous assets in Lower Manhattan, home to Wall Street and two of the world's largest stock exchanges. That area is particularly vulnerable to storm surge flooding.

Huge quantities of goods enter and exit the United States through the Port of New York and New Jersey. Damage to port facilities can restrict the flow of imported goods to other parts of the country and delay U.S. exports.

THE ENVIRONMENT AT RISK

Intense storms can permanently submerge wetlands, cause barrier islands to narrow or split, and erode beaches and dunes. The loss of these natural storm barriers leaves wooded areas and parks farther inland more exposed to the impacts of wind and storm surge.

If facilities that store toxic or hazardous materials are flooded, those materials could be dispersed and threaten marine habitats.

Other environmental impacts include the loss of coastal vegetation due to saltwater flooding and tree damage due to high winds.

FUTURE RISK

In determining how to prepare for and respond to coastal storms, we must understand how climate change could affect those storms.

For the North Atlantic, climate scientists predict that warmer ocean temperatures will cause the most intense tropical cyclones to become more frequent, while the overall frequency of storms may decrease slightly. While these projections carry a significant degree of uncertainty, emergency managers and planners know that, independent of climate change's effects on storms, the fact that climate change is raising sea levels will make coastal storms' consequences more severe. This is because, as ocean water warms, it expands and increases in volume, causing the water level to rise. Global warming is also causing land glaciers and polar land-based ice caps (the Greenland and Antarctic ice sheets) to melt at a faster rate, which increases the amount of water in the oceans. This additional height boosts storm surge, and it floods some areas that would otherwise have remained dry.

Thus, as sea levels continue to rise, storm surge flooding will cause more frequent, more severe, and more extensive damage than it does today.

Since 1900, local sea level has risen over 1 foot in New York City. During Sandy, that extra foot of storm surge flooded locations that would have previously remained dry. Taking sea level at the beginning of the 21st century as the baseline, sea level rise around New York City is projected to rise as much as 2.5 more feet by the middle of the century, and possibly over 6 more feet by the end of the century. Thus, coastal flooding from a future Sandy-like storm is likely to cause even more extensive damage, while storm tides from lesser storms will reach elevations as high as Sandy more readily and more often.

Note: Selected strategies for reducing the risks identified above are discussed in the Flooding and Strong Windstorms profiles of this chapter.

HURRICANE SANDY

Hurricane Sandy, which made landfall on October 29, 2012, was not in any way a typical storm. It was a hybrid, with characteristics of both a hurricane and a nor'easter, which is very unusual. A number of factors contributed to the record storm surge experienced in parts of the city. Although its winds were only the equivalent of a Category 1 hurricane, Sandy's massive size – nearly three times that of an average hurricane – increased the height of the waves and storm surge, causing extensive damage over an extremely large area.

Never before had any storm followed a track that featured such an abrupt westward turn: it put the entire region's dense concentration of people, property, and infrastructure in harm's way. Sandy's coincidence with the full moon, and thus tides which were already higher than normal, added an additional 3 feet to the 11-foot storm surge experienced at the Battery, the southern tip of Manhattan.

Hurricane Sandy was the costliest natural disaster in New York City's history. Winds of up to 90 mph combined with a storm surge that reached more than 14 feet (as recorded at the Battery), caused 44 deaths and approximately $19 billion in economic losses. Nearly 70,000 housing units were damaged, displacing roughly 150,000 residents.

The city also suffered extensive flooding of subway, PATH, commuter train, and Amtrak tunnels; the Hugh Carey Brooklyn-Battery and Queens-Midtown vehicular tunnels; and critical facilities including power substations, hospitals, and wastewater treatment plants. Power outages affected many homes and businesses, causing significant economic losses.

The liquid-fuels supply chain experienced widespread failure, due mainly to reduced output at refineries and damaged storage tanks, terminals, pipelines, and other infrastructure.

Since Sandy, much progress has been made to restore the city, but in some areas recovery will continue for years. What has been learned from that storm is already, in many ways, making us better prepared for the next one, as evidenced in the $20 billion plan for making the city more resilient that is detailed in *A Stronger, More Resilient New York*.