6. Coastal Storms

A. Hazard Profile

i. Hazard Description

Coastal storms, both tropical cyclones and nor'easters, can and do affect New York City. In fact, the city's densely populated and highly developed coastline makes it one of the most vulnerable cities in the United States to damage from coastal storms.

Tropical Cyclones

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

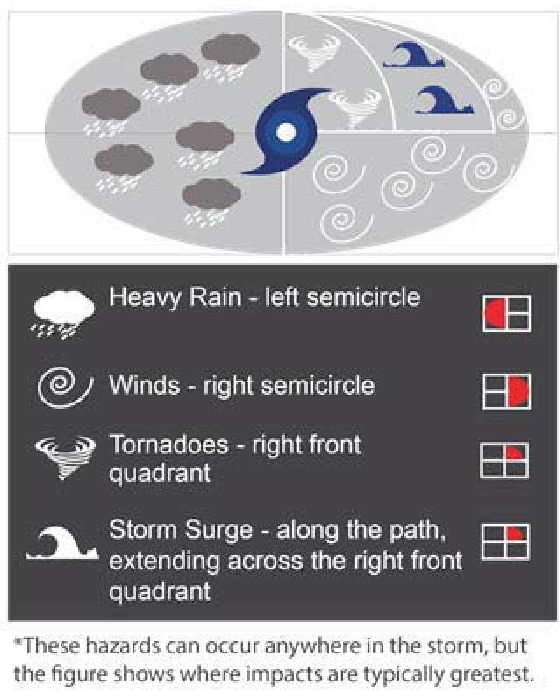
- A **tropical depression** is an organized system of clouds and thunderstorms with a defined surface circulation and maximum sustained winds of 38 miles per hour (mph) or less.
- A **tropical storm** is an organized system of strong thunderstorms with a defined surface circulation and maximum sustained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

A number of conditions must be in place for tropical cyclones to form and maintain their intensity. Most importantly, water temperatures must be greater than 80°F. In the North Atlantic Basin—where storms that affect New York City originate—these conditions are most likely to occur off the coast of Africa, in the Caribbean Sea, and in the Gulf of Mexico.

Once tropical cyclones form, they often track northward or westward until they reach the mid-latitudes (usually the northern Gulf of Mexico, southeastern United States, or the northwest Atlantic), where they turn northward or eastward due to the prevailing winds. However, when certain meteorological conditions coincide, they may track up the East Coast of the United States and reach New York City.

Hurricanes that affect New York City typically occur during what is known as the Atlantic hurricane season, which lasts from June through November. There are an average of 11 tropical storms and six hurricanes per year in the North Atlantic Basin. New York City is at highest risk between August and October when meteorological conditions in the North Atlantic Basin are most favorable for storm formation and water temperatures are warmest. Although water temperatures rarely reach 80°F as far north as New York City during this time of the year, they are generally warm enough so that strong hurricanes will not lose a significant amount of energy before making landfall. According to the National Hurricane Center (NHC), the Atlantic hurricane season is currently in a period of heightened activity that started around 1995.

Figure 3.6.49: Primary Hazards of Tropical Cyclones (Source: OEM)



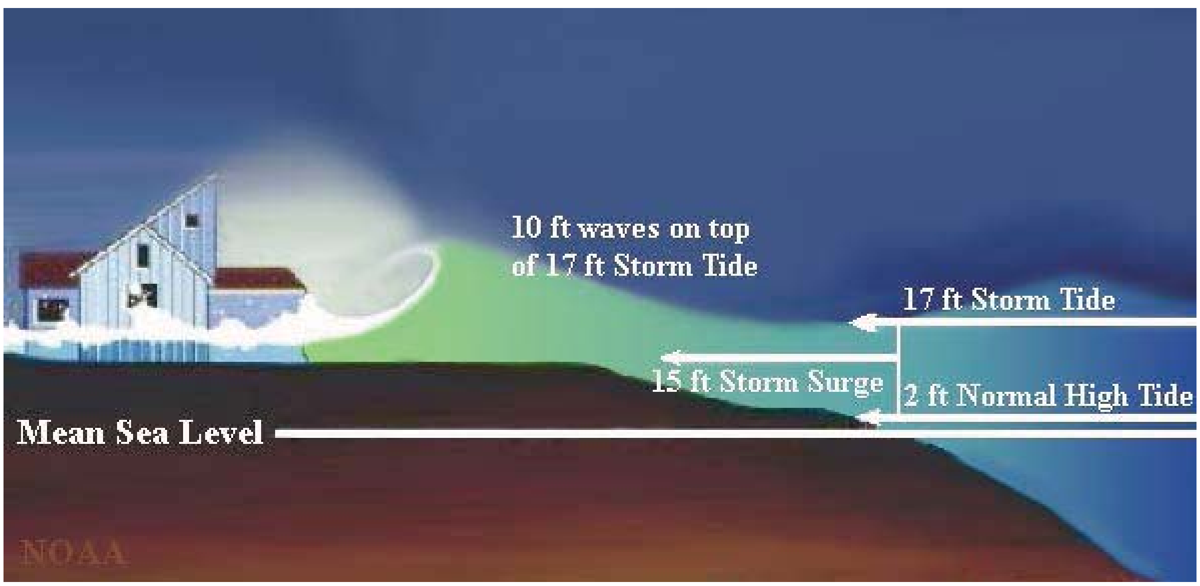
When tropical systems make landfall, the primary hazards are heavy rain, wind, tornadoes, and storm surge (see Figure 3.6.49). The most dangerous conditions typically occur near the center of circulation, or eye wall (region surrounding the eye), and in the right-front quadrant of the storm, where the speed of forward motion adds to the effect of the wind and storm surge.

Heavy rain from tropical systems can occur throughout the storm, with the highest values typically expected on the left side of the eye (left semicircle). The amount of rainfall from a particular storm is less dependent on the storm's classification than it is on its speed, size, and the geography of the area it moves over. Heavy rain can cause freshwater flooding, when rivers and streams overflow their banks, or it can cause inland (flash) flooding in low-lying areas when the rainfall rate exceeds the capacity of the ground or drainage systems to absorb the water.

Storm surge is the storm-related hazard that causes the most significant damage and greatest number of deaths. Storm surge is an abnormal rise in water level above the normal astronomical tide level as it is pushed towards the shore by the force of the winds and low pressure of a storm. It is measured as the difference between normal astronomical tide levels and observed storm water levels, or storm tide.

The intensity of the storm surge is dependent on several storm characteristics, including the maximum sustained winds, forward speed, size of the wind field, direction of the storm's track at landfall, and the geography of the coastline. The most significant storm surge typically occurs near the eye and in the right-front quadrant of the storm. This advancing surge combines with the normal tides to create the hurricane storm tide, which can raise the mean water level even higher during periods of high tide and cause severe inundation of coastal areas. Storm tide values are always referenced to a vertical datum, typically mean lower low water (MLLW). MLLW is the average height of the lowest tide (lower of the two daily low tides) recorded at a tide station each day during a recording period.

Figure 3.6.50: Combined Effects of Storm Surge, Tide, and Wave Action (Source: NOAA)



The strongest winds associated with tropical systems typically occur on the right side of the storm (right semicircle). Strong winds can knock down trees and power lines and cause structural damage to buildings and property. Flying debris carried by winds is also a threat to human life and property.

Tornadoes may form in the eye wall or in thunderstorms embedded in rain bands far away from the center, most commonly in the right-front quadrant of the storm. In general, tornadoes produced by tropical cyclones are relatively weak and short in duration, but they can still pose a significant risk.

Inundation caused by storm surge is the height (or depth) of water above ground level. This is calculated by subtracting the local land elevation (referenced to a vertical datum) from the total storm tide height. For example, a storm tide height of 20 feet at an elevation of five feet would result in 15 feet of inundation.

Beaches along the open ocean are not only exposed to stillwater flooding from the surge and tides, they are also exposed to powerful wave action, which is superimposed on the storm tide. Wave action exerts a tremendous force on the beach, local buildings, property, and infrastructure (see Figure 3.6.50).

Nor'easters

A nor'easter is a type of coastal storm that primarily affects the Mid-Atlantic and New England states, most commonly between October and April. Like tropical cyclones, these storms are associated with heavy precipitation and a counterclockwise rotation around a center of low pressure. However, unlike tropical cyclones, nor'easters form outside of the tropics, typically over the central or western United States, northern Gulf of Mexico, or northwestern Atlantic. In addition, they can originate and sustain themselves over land and form during the cooler months of the year.

When these storms reach the Northeast or Mid-Atlantic coast, the counterclockwise circulation brings winds from a northeasterly direction—hence the name nor'easters. Although nor'easters are typically weaker than hurricanes, they may be larger, have longer durations, and more widespread impacts. Furthermore, nor'easters strike the New York City area more frequently than hurricanes do. Thus, the cumulative destructive potential of nor'easters may be greater than that of hurricanes.

Nor'easters can bring heavy precipitation, inland flooding, and winds that are often strong enough to knock down trees and power lines and cause structural damage to buildings. They may also bring coastal flooding from storm surge and large waves. While nor'easters do not commonly have tornadoes associated with them, they do bring the threat of heavy snowfall (see section 15. Winter Storms). If a wintertime nor'easter moves up the coast and follows a track west of New York City, wintry precipitation will often change to rain. However, if the storm maintains a track just off the coast of the city, snow or mixed precipitation is likely to occur.

Coastal Geography and Storm Surge Risk

New York City is particularly vulnerable to storm surge because of a geographic characteristic called the New York Bight. A bight is a curve in the shoreline of an open coast that funnels and increases the speed and intensity of storm surge. The New York Bight is located at the point where the New York and New Jersey coastlines meet, creating nearly a right angle. For New York City, the worst-case-scenario hurricane track has a storm making landfall just to the south along the coast of New Jersey, putting the city in the right-front quadrant of the storm and funneling the storm surge directly into Raritan Bay and New York Harbor (see Figure 3.6.51). This, in fact, is precisely what happened during Hurricane Sandy in 2012 and a primary reason the storm had such a disastrous impact on New York City (see section 12. Hurricane Sandy Retrospective Analysis).

Figure 3.6.51: New York Bight with a Hypothetical Storm Approaching New Jersey (Source: OEM)

ii. Severity

Tropical Cyclones

Once a tropical cyclone reaches hurricane status (winds ≥74mph), the National Weather Service (NWS) uses the Saffir-Simpson Hurricane Wind Scale to classify its severity. This system, shown in Table 3.6.26, categorizes a hurricane's current intensity on a scale ranging from one to five based on the storm's maximum sustained wind speed, and it describes potential property damages for the various ratings. Hurricanes categorized 3 or higher are considered major hurricanes.

Although the Saffir-Simpson Hurricane Wind scale is a practical way of measuring hurricane strength, there are other factors that contribute to a hurricane's impact on a given location. These include the storm's size (proportional to the radius of maximum winds) and speed of forward motion. For example, a larger, slower-moving storm may cause more widespread damage than a smaller, faster-moving storm with higher sustained winds because the winds will impact a location for a longer period. Furthermore, the radius of maximum winds and forward speed determine the wind fetch (the distance the wind blows across the water surface) and duration, and thus also affect wave heights and storm surge. The greater the distance and longer the time the winds blow across a body of water, the larger the waves and higher the storm surge.

The direction a storm is moving when it reaches New York City—or bearing—also contributes to the impact it will have. A storm's bearing will determine which part of the storm hits the city and the direction of the winds, which, in turn, will also affect the height of the storm surge.

Nor'easters

Nor'easters do not have a universally recognized classification system. However, their strength and severity are influenced by factors similar to those that influence the strength and severity of hurricanes.

iii. Probability

Tropical Cyclones

The NHC has calculated return periods for both hurricanes and major hurricanes (Category 3 or higher) for various locations along the East Coast of the United States. These return periods are equal to the average amount of time between the passages of two hurricane eyes within a 50-nautical-mile (57.54-mile) radius of a given location. According to these NHC probability models, New York City is currently expected to experience a hurricane on average once every 19 years. The same models predict a recurrence interval of 74 years for major hurricanes. A Category 5 hurricane is not expected to occur in the New York City area because such a storm is not meteorologically sustainable north of Virginia. A Category 4 hurricane is also unlikely, although still possible.

Nor'easters

New York City typically experiences several nor'easters every year, and these storms can range significantly in intensity. Most of these storms are relatively weak but still have the potential to produce significant rainfall or snowfall and minor-to-moderate damage. The probability of more severe nor'easters is lower, but they do strike New York City on occasion.

iv. Location

Within New York City, vulnerability to coastal storms is highly variable, depending to a large extent on location. To predict storm surge and help guide the City's planning for coastal storms, the Office of Emergency Management (OEM) utilizes outputs from a NHC computer model called SLOSH (Sea, Lake, and Overland Surges from Hurricanes). The SLOSH model calculates surge heights for storms moving in different directions and varying in strength from Category 1 to Category 4. SLOSH is not used for nor'easters, although similar criteria will apply when estimating storm surge extent or heights from nor'easters of varying magnitudes.

The SLOSH calculations are based on differing wind speeds for Category 1-4 storms, radius of maximum winds, forward speeds, changes in pressure, and angles of approach. The SLOSH model calculates surge levels as if that location were hit by the most intense part of the storm. The culmination of these factors results in a worst-case scenario for storm surge in the SLOSH model.

Figure 3.6.52 shows the areas of the city that would experience inundation from different storm categories, based on calculations from the SLOSH model. Figure 3.6.53 shows the inundation depths from storm surge for the worst-case scenario for each hurricane category (inundation depth = storm tide height – land eleva-

Table 3.6.26: Saffir-Simpson Hurricane Wind Scale, Including Tropical Storms (Source: National Hurricane Center)

Category	Winds (mph)	Damage	Damage Description
Tropical storm	39 to 73	Minor	• Minor damage to trees, power lines, and poorly constructed homes
1	74 to 95	Moderate	• 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
2	96 to 110	Moderate-Severe	• 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
3	111 to 130	Extensive	• 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
4	131 to 155	Extreme	• 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
*5	>155	Catastrophic	• A high percentage of framed homes will be destroyed, with total roof failure and wall collapse • Fallen trees and power poles will isolate residential areas • Power outages will last for weeks to possibly months • Most of the area will be uninhabitable for weeks or months

Notes:
*Not expected to occur in the New York City area because such a storm is not meteorologically sustainable north of Virginia.

Figure 3.6.52: New York City Storm Surge Inundation Zones (Source: OEM GIS)

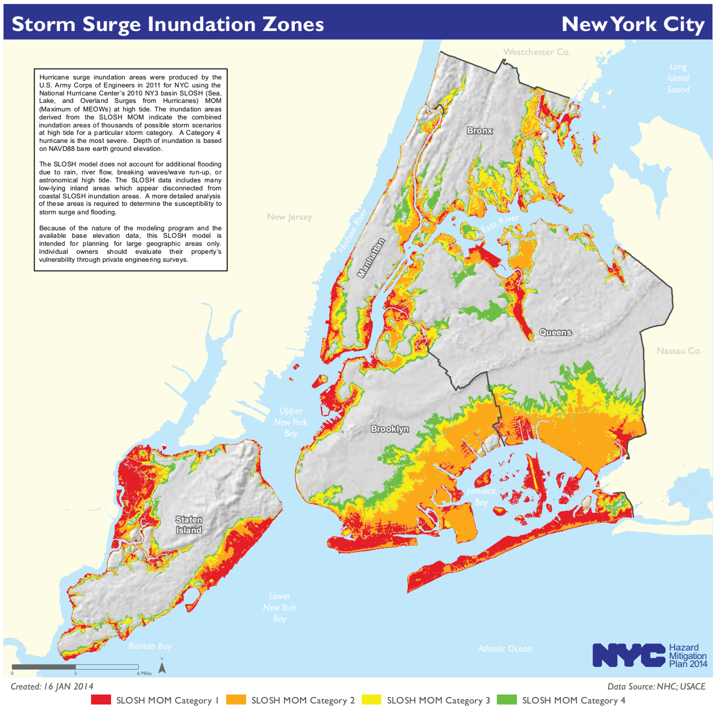
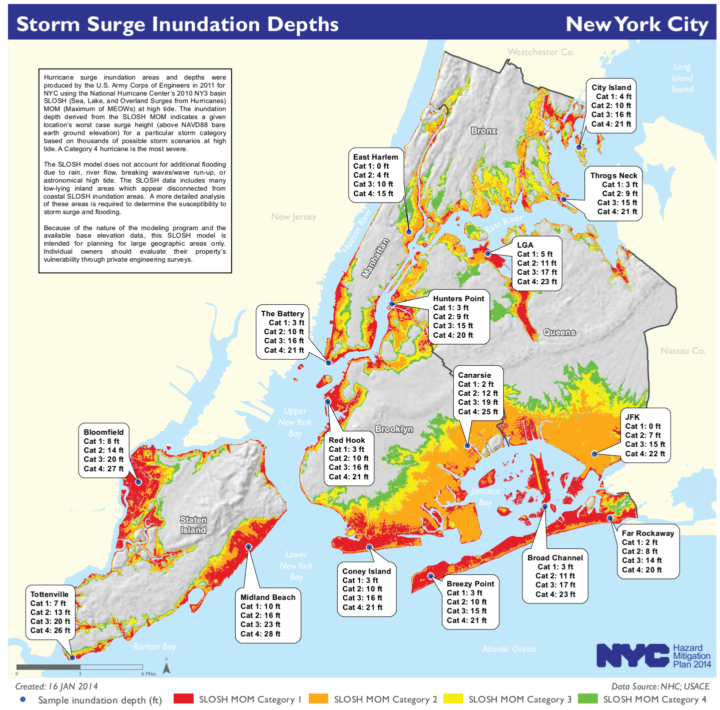


Figure 3.6.53: Storm Surge Inundation Zones with Selected Inundation Depths for Storm Categories (Source: OEM GIS)



tion), using output from the SLOSH analysis.

To prepare for coastal storms, OEM utilizes SLOSH data to develop the *New York City Coastal Storm Plan* (CSP), which defines the areas that may be required to evacuate in the event of a storm. These zones are based on a SLOSH output called Maximum Envelope of Water (MEOW). MEOWs show the maximum surge inundation from a set of hypothetical storms with fixed intensity and bearing but varied size, forward speed, and landfall locations. The evacuation zones employ a range of possible scenarios from the MEOWs, whereas the SLOSH maps only display one scenario for each category. The storm surge inundation maps represent the worst-case scenario storm surge, or MOM (Maximum of MEOWs). The City updated its evacuation zones in June 2013. Unlike the prior set of evacuation zones, which were in place when Hurricane Sandy struck in 2012, the storm's bearing is a significant input into the calculation of the new zones.

v. Historic Occurrences

Table 3.6.27, below, reviews coastal storms that have affected New York City since 1785 (details vary based on available data).

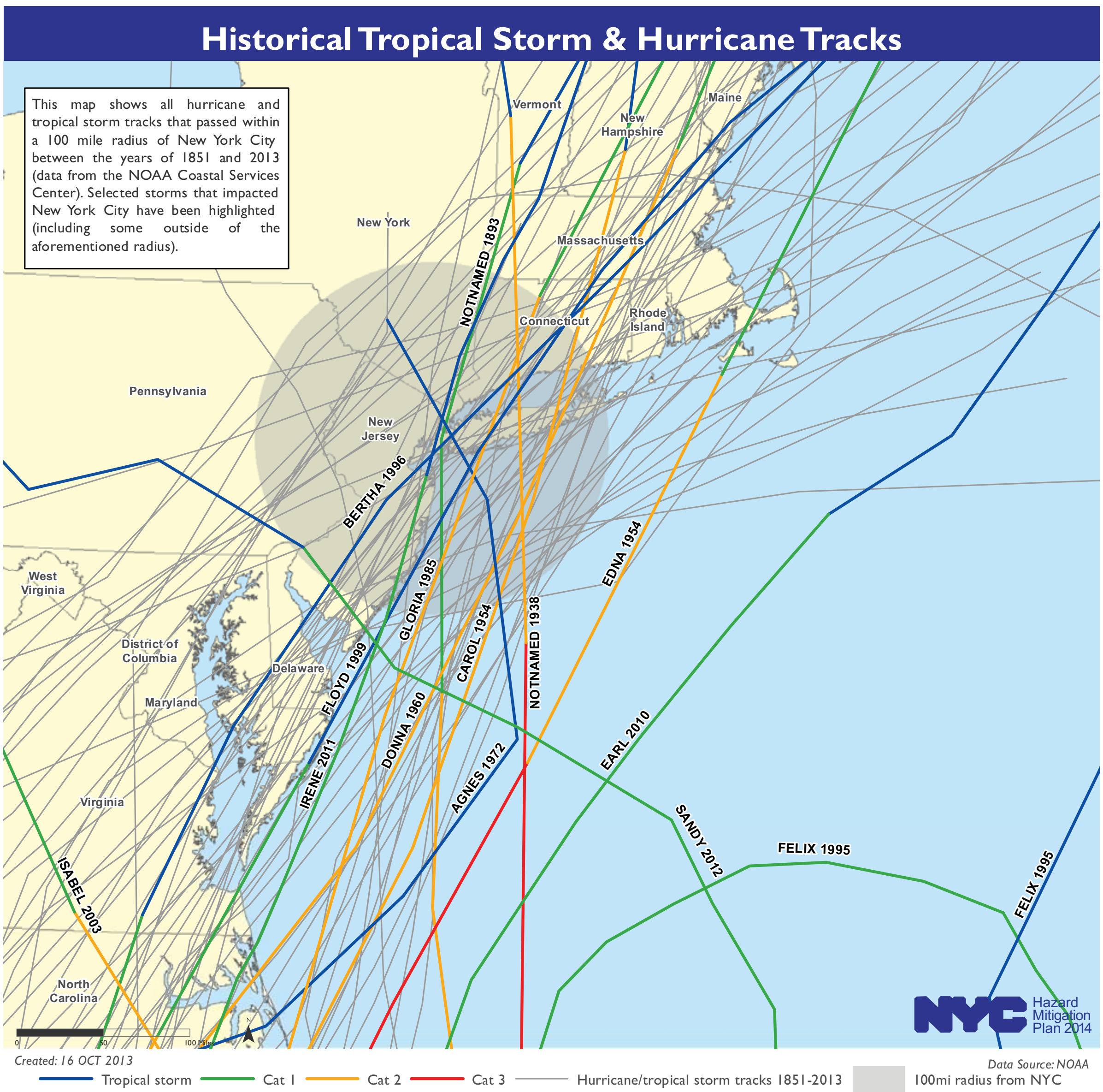
Table 3.6.27: Coastal Storms Affecting New York City 1785 to 2012

Date	Event	Location	Description
September 23, 1785	The Equinoctial Storm	Manhattan	• Large ships driven onto Governors Island
August 19, 1788	Unnamed coastal storm	Citywide	• West side of Battery "almost laid in ruins"
September 23, 1815	The Great September Gale	Citywide	• Montauk Lighthouse heavily damaged
September 3, 1821	Norfolk and Long Island Hurricane	Citywide	• Storm tide rises 13 feet in one hour and causes the East River and the Hudson River to converge across lower Manhattan • Widespread flooding as far north as Canal Street
June 4, 1825	Unnamed coastal storm	Citywide	• Ships wreck off New York coast • Some trees down
November 13, 1846	Great Havana Hurricane	Citywide	• 100 yards of the Battery wash away
October 6, 1849	Unnamed coastal storm	Citywide	• Considerable structural damage
July 18, 1850	Unnamed coastal storm	Citywide	• Coney Island bathhouses demolished
August 23, 1893	Unnamed hurricane	Citywide	• Destroys Hog Island (near the Rockaway Peninsula)
September 21, 1938	The Great Hurricane of '38, a.k.a the Long Island Express	Citywide	• Most powerful hurricane to make landfall near New York City • Eye crosses over Long Island, giving the storm its nick-name • Kills 200 to 300 people, including 10 in New York City • Electricity knocked out north of 59th Street in Manhat-tan • 100 large trees in Central Park destroyed • Shinnecock Inlet on Long Island was created
August 31, 1954	Hurricane Carol	Citywide	• Makes landfall in eastern Long Island and southeastern Connecticut • Sustained winds of more than 100 mph and gusts 115 to 120 mph • The most destructive hurricane to hit the northeast to this date
September 10, 1954	Hurricane Edna	Citywide	• Passes east of Long Island, producing 9 inches of rain
September 12, 1960	Hurricane Donna	Citywide	• Creates an 11-foot storm tide in New York Harbor and causes extensive pier damage

Date	Event	Location	Description
March 7, 1962	Ash Wednesday Nor'eas-ter	Citywide	• One of most intense winter storms to ever hit the East Coast • Wave heights reach 40 feet offshore of New York City • Significant damage reported from North Carolina to southern New England
June 22, 1972	Tropical Storm Agnes	Citywide	• Agnes fuses with another storm system in the north-eastern U.S., flooding areas from North Carolina to New York State • Causes 122 deaths and more than $6 billion in damage (adjusted for inflation)
September 27, 1985	Hurricane Gloria	Citywide	• Makes landfall on Long Island at 80 mph • Produces a modest storm surge of 4 to 7 feet above normal across the Atlantic • Could have produced a much stronger and intense surge if it had hit at high tide • Causes largest single power loss in U.S. history to date • Total damage estimated at $900 million • Some moderate beach erosion
December 21, 1992	Nor'easter	Citywide	• Flooding, coastal erosion, and debris • Damage to residential and commercial structures, utility lines, roads, and other infrastructure
August 21, 1995	Hurricane Felix	Citywide	• Lingers off the East Coast for nearly a week, menacing the northeastern United States before drifting out to sea
June 18, 1996	Hurricane Bertha	Citywide	• Weakening storm brings heavy rain to the city
January 3, 1999	Nor'easter	Citywide	• 2.42 inches of rain • 50 vehicle accidents in Queens
September 16, 1999	Tropical Storm Floyd	Citywide	• Floods subway tunnels across the city, causing service disruptions • Drops 10 to 15 inches of rain in 24 hours • Public schools close for the day
September 18, 2003	Tropical Storm Isabel	Brooklyn, Bronx, Queens, Staten Island	• A fallen tree branch in the Bronx seriously injures a man • Total damage exceeds $1 billion along East Coast
April 15, 2007	Nor'easter	Citywide	• Produces 7 inches of rain at LaGuardia Airport and 8.41 inches of rain in Central Park, with high winds and storm surge
October 28, 2009	Remnants of Hurricane Danny	Citywide	• 2.75 inches of rain in Sheepshead Bay, Brooklyn
August 24, 2011	Tropical Storm Irene	Citywide	• 6.87 inches of rain in Central Park, with wind gusts exceeding 50 mph • $1.3 billion in damage statewide

Date	Event	Location	Description
October 29, 2012	Hurricane Sandy	Citywide	• Costliest natural disaster in New York City history • Wind gusts exceed 60 mph at Central Park and LaGuardia and Kennedy Airports and reach more than 80 mph in some parts of the city • 11- to 14-foot storm tide in New York City—in some spots the highest in recorded history • 44 deaths in New York City • Widespread flooding, building damage, and power outages

Figure 3.6.54: Tropical Storm and Hurricane Tracks within a 100-mile Radius of New York City 1851 to 2013 (Source: OEM GIS)



B. Vulnerability Assessment

i. Social Environment

Coastal storms can have a significant impact on the population of New York City. Based on population figures from the 2010 Census, nearly 2.5 million New York City residents live within a storm surge inundation zone, putting them at increased risk (see Table 3.6.28).

Table 3.6.28: New York City Residents in Storm Surge Inundation Zones (Source: OEM GIS)

Storm Surge Inundation Zone	Population (2010 Census)
Category 1	318,000
Category 2	796,000
Category 3	674,000
Category 4	702,000
Total	2,490,000

New York City residents, particularly special needs populations such as the elderly, physically or mentally disabled, or people with underlying health conditions, may be exposed to significant safety and health risks during and after the passage of a storm. Health risks may result from direct exposure to storm impacts; people may drown in rising waters, get struck by flying debris and falling trees, or electrocuted by fallen power lines. People may also be forced to shelter in inadequate housing with no heat or hot water. They may be exposed to contaminated floodwaters, spoiled food or mold, or they may experience the disruption of basic services (Lane et al. 2013). Rain, wind, and runoff may also contribute to high levels of turbidity (suspended pollutants) in local reservoirs, which interferes with the disinfection of drinking water.

Risk factors that increase vulnerability to coastal storms include lack of mobility, lack of access to medical resources, lack of information, and language barriers. The elderly are among the most vulnerable groups because they often lack mobility or the means to evacuate. In addition, the elderly are most likely to be physically disabled or have pre-existing medical conditions that may make evacuation more difficult, particularly for those living in elevator buildings experiencing utility outages.

New York City has a large population of immigrants, many of whom do not speak English fluently. Language barriers may result in difficulty receiving warnings, and may further inhibit the translation of warnings to action (see section 4. New York City's Hazard Environment).

Special needs populations are also at an increased risk due to their reliance on healthcare facilities (hospitals, nursing homes, adult care facilities, and pharmacies), which may shut down or operate at reduced capacity during coastal storms. Patients and residents of such facilities are at risk due to power loss, especially people requiring life-support equipment that runs on electricity, such as ventilators. Since many of these facilities are located in storm surge inundation zones (see Table 3.6.33), they are at an increased risk if backup generators and essential equipment are located on lower floors that are more likely to flood.

Not only can coastal storms affect residents of healthcare facilities, they can strain the healthcare system as a whole. As the number of patients goes up, the amount of available space goes down, and people may be unable to receive essential medical treatment. Furthermore, evacuation of patients, especially those with critical ailments or injuries, can be particularly challenging.

People who are unable to evacuate during a storm and instead shelter in place are at increased risk during coastal storms for several reasons, including delayed response from medical personnel due to lack of transportation or access to certain areas, non-functioning medical facilities, or high volume of calls. In addition, power outages may disable systems that use electric pumps to distribute water to upper floors of high-rises, leaving people without potable water or water for washing and flushing. Residents may be stranded if they live in a high rise and lose elevator power.

When storm-related damage to essential utilities or building systems precedes hot or cold weather, health risks are increased greatly by the lack of air conditioning or space heating, respectively. If residents remain stranded in flooded or damaged homes after the storm passes, they may be exposed to secondary health hazards such as contaminated drinking water or growth of toxic mold. Additional health risks may result from food spoilage if people are without power for an extended period after the storm.

Following a major storm or other disaster, those who are significantly affected may also experience mental health problems such as post-traumatic stress disorder and other anxiety and mood disorders. These effects are most common during the months immediately following the storm, but can potentially last much longer depending on the severity of the storm, the nature of exposure, chronic stressors related to the storm (such as prolonged displacement or power disruption), pre-existing mental health issues, and access to adequate care and assistance.

ii.Built Environment

Both buildings and infrastructure are subject to significant damage during coastal storms.

Buildings

The vulnerability of buildings to storm surge and storm damage depends on building characteristics, including height, construction type, age, and location (SIRR, 2013). In general, low-rise buildings are more vulnerable to damage and destruction than mid-rise and high-rise buildings. Low-rise buildings have proportionally more floor area on or closer to the ground, and by their very nature tend to house primary uses on the ground floor. In addition, low-rise buildings are often built from combustible materials, and buildings of this type are more prone to structural damage than buildings with the steel, masonry or concrete frames characteristic of high-rise buildings (see section 4. New York City's Hazard Environment).

During Hurricane Sandy, much of the damage to buildings was due to surge force and depth of inundation. Sandy flooded an area that included 9% of the city's building stock. Much of the Sandy-related damage was non-structural in nature, largely due to flooding of building systems and electrical equipment located on the ground floors or in basements.

Building age is an important indicator of structural vulnerability. Older buildings are more likely to sustain significant damage than newer buildings, primarily due to the fact that building and zoning standards have become more stringent over time. During Hurricane Sandy, for example, structures built before New York City's 1961 Zoning Resolution and the 1983 federal standards associated with Flood Insurance Rate Maps (FIRMs) from the Federal Emergency Management Agency (FEMA) suffered more severe damage than newer buildings. This proved to be the case with many New York City Housing Authority (NYCHA) facilities.

The susceptibility of the built environment to flood damage also depends on specific characteristics of the storm itself as well as the location of buildings. For example, buildings along the coast subject to the force of wave action are much more likely to sustain serious damage than buildings subject to stillwater flooding only.

Potential Losses to Buildings from Coastal Storms

Losses to buildings in various potential storm scenarios were calculated using HAZUS-MH (see section 3. Hazard Risk Assessment Organization). The HAZUS-MH hurricane module is a wind model and does not include damages from storm surge. Damage calculations are based on the effects of wind, wind-driven rain, and other wind-related hazards such as projectile impacts. Even though the module is for hurricanes, it can apply to any coastal storms that produce wind-related damages.

The general damage classes provided by HAZUS-MH for the hurricane module are: None, Minor, Moderate, Severe, and Destruction. These classes are an attempt to simplify a range of wind-related structural damages into several basic groups. Table 3.6.29 outlines damage states for residential structures.

Table 3.6.29: Damage States for Residential Structures (Source: HAZUS-MH Hurricane Technical Manual)

Damage State	Qualitative Damage Description	Roof Cover Failure	Window Door Failures	Roof Deck	Missile Impacts on Walls	Roof Structure Failure	Wall Structure Failure
0	**No Damage or Very Minor Damage** Little or no visible damage from the outside. No broken windows, or failed roof deck. Minimal loss of roof over, with no or very limited water penetration.	≤2%	No	No	No	No	No
1	**Minor Damage** Maximum of one broken window, door or garage door. Moderate roof cover loss that can be covered to prevent additional water entering the building. Marks or dents on walls requiring painting or patching for repair.	>2% and ≤15%	One window, door, or garage door failure	No	<5 impacts	No	No
2	**Moderate Damage** Major roof cover damage, moderate window breakage. Minor roof sheathing failure. Some resulting damage to interior of building from water	>15% and ≤50%	> one and ≤ the larger of 20% & 3	1 to 3 panels	Typically 5 to 10 impacts	No	No
3	**Severe Damage** Major window damage or roof sheathing loss. Major roof cover loss. Extensive damage to interior from water.	>50%	> the larger of 20% & 3 and ≤50%	>3 and ≤25%	Typically 10 to 20 impacts	No	No
4	**Destruction** Complete roof failure and/or, failure of wall frame. Loss of more than 50% of roof sheathing.	Typically >50%	>50%	>25%	Typically >20 impacts	Yes	Yes

All of the coastal storm results are based on a probabilistic analysis because the historic record of deterministic events for our immediate area is limited. Probabilistic analysis in HAZUS-MH allows for a summary of results from seven discrete return periods: 10, 20, 50, 100, 200, 500, and 1,000 years (see Table 3.3.4 in section 3. Hazard Risk Assessment Organization). Output such as building damage counts (see Table 3.6.30) or dollar losses (see Table 3.6.31) may be analyzed for any of these return periods.

Since the New York City area does not frequently experience hurricane-level wind events, annualized losses (see section 3. Hazard Risk Assessment Organization) can also be helpful in estimating the impact over time of such events (see Table 3.6.32 and Figure 3.6.55).

Table 3.6.30: HAZUS-MH Calculation of Approximate Number of Buildings Damaged due to Wind from a Coastal Storm, by Return Period.

Return Period (years)	Minor	Moderate	Severe	Destruction	Total Damaged	% of Building Stock Damaged
10	0	0	0	0	0	**0.0%**
20	1,800	100	0	0	1,900	**0.2%**
50	8,300	800	100	0	9,200	**0.9%**
100	33,800	5,600	200	0	39,600	**3.7%**
200	95,100	20,800	900	100	116,900	**10.9%**
500	214,100	74,300	5,900	1,800	296,100	**27.6%**
1,000	278,200	139,000	22,600	8,700	448,500	**41.8%**

Notes: Output rounded to the nearest hundred buildings.

Table 3.6.31: HAZUS-MH Calculation of Economic Losses due to Wind from a Coastal Storm, by Return Period (Source: OEM GIS)

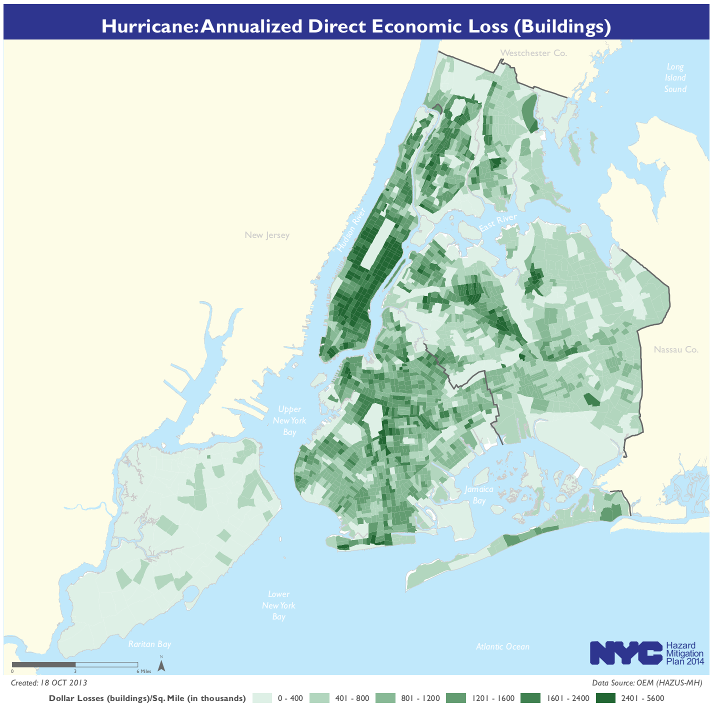
Return Period (years)	Building Damage ($)	Contents Damage ($)	Inventory Loss ($)	Income Loss ($)	Total ($)
10	0	0	0	0	**0**
20	27,764,000	1,745,000	0	332,000	**29,841,000**
50	803,789,000	50,340,000	2,000	50,998,000	**905,128,000**
100	3,061,473,000	244,777,000	420,000	256,471,000	**3,563,142,000**
200	8,088,942,000	825,247,000	3,127,000	873,512,000	**9,790,829,000**
500	22,028,575,000	3,649,592,000	25,684,000	2,859,507,000	**28,563,358,000**
1,000	38,448,295,000	9,978,726,000	56,005,000	5,077,610,000	**53,560,636,000**

Notes: Economic loss values are calculated to the nearest $1,000.

Table 3.6.32: HAZUS-MH Calculation of Annualized Economic Losses due to Wind from a Coastal Storm, by Borough (Source: OEM GIS)

Borough	Structural Damage ($)	Contents Damage ($)	Inventory Loss ($)	Income Loss ($)	Total ($)
Bronx	28,098,000	6,143,000	32,000	3,478,000	37,752,000
Kings	62,762,000	14,400,000	116,000	7,741,000	85,019,000
New York	37,748,000	6,150,000	32,000	4,733,000	48,663,000
Queens	63,918,000	15,577,000	86,000	7,327,000	86,907,000
Richmond	12,447,000	3,062,000	11,000	1,275,000	16,795,000
City Total	**204,972,000**	**45,333,000**	**277,000**	**24,555,000**	**275,136,000**

Figure 3.6.55: HAZUS-MH Results for Annualized Losses to Buildings due to Wind from a Coastal Storm, by Census Tract (Source: OEM GIS)



Infrastructure

Much of New York City's aging transportation and utility infrastructure is also highly vulnerable to significant damage from coastal storms. Within the transportation sector, at particular risk are subway tunnels, subway stations, and bus depots in low-lying, flood-prone areas, as well as bridges and passenger car tunnels. Shortages in the supply of liquid fuels may also result due to disruptions in the supply chain, as were experienced during Hurricane Sandy.

Vulnerable utilities include above-ground telecommunications and power distribution infrastructure (power lines and electric substations), which are directly exposed to wind, flooding, or falling trees and debris. Underground power and telecommunications are not as exposed, but still may be at risk of flooding in vulnerable locations. Furthermore, all of the City's 26 power generation plants are located in SLOSH zones, including eight in the SLOSH zone for a Category 1 storm (see Table 3.6.33).

Table 3.6.33 shows the total number of critical facilities and key assets located within storm surge inundation zones for Categories 1 through 4 storms. These facilities and assets are at risk from storm surge and severe damage during coastal storms.

Table 3.6.33: Critical Assets within Storm Surge Inundation Zones (Source: OEM GIS)

Asset Type	SLOSH Cat 1	SLOSH Cat 2	SLOSH Cat 3	SLOSH Cat 4	In SLOSH Zone	Not In SLOSH Zone	Total	% In SLOSH Zone
Airports (perimeter)*	1	1	0	0	2	0	2	100%
Nursing homes (FP)	13	23	14	16	66	107	173	38%
Hospitals (FP)	4	7	10	4	25	36	61	41%
Police stations (FP)	2	6	13	4	25	52	77	32%
Fire stations (FP)	17	20	16	18	71	157	228	31%
EMS stations (FP)	7	6	10	6	29	50	79	37%
Wastewater treatment plants (FP)	12	2	0	0	14	0	14	100%
Power plants (est. FP)	8	16	2	0	26	0	26	100%
DOE school facilities	51	219	177	150	597	1,216	1,813	33%
Private schools	23	63	80	74	240	608	848	28%
Colleges	4	9	10	11	34	89	123	28%
Ferry landings**	47	0	0	0	47	0	47	100%
Subway stations (point)	31	32	37	52	152	338	490	31%
Rail stations	9	2	2	2	15	27	42	36%
Cultural facilities (DCP)***	2	2	3	4	11	26	37	30%
Bus depots	6	13	2	2	23	7	30	77%
Bridges****	N/A	N/A	N/A	N/A	61	9	70	87%
Tunnels****	N/A	N/A	N/A	N/A	4	0	4	100%
Major roads (mi)****	N/A	N/A	N/A	N/A	479	408	887	54%
City total	237	421	376	343	**1,921**	**3,130**	**5,051**	**38%**

Notes:

Unless otherwise noted, a facility point was used to do a spatial calculation. This may result in some inaccuracies in category designation. Assets types with "FP" indicate that the actual facility footprint was used in the calculation (FPs were estimated for power plants).

*Based on airport perimeter—significant storm surge impact only.

**Active New York City commuter/commercial/recreational ferry landings only (including Ellis and Liberty Islands). All landings assumed to be in Category 1 slosh zone.

***Determination made by OEM and DCP on which assets to include.

****Estimated only. Based on visual review of bridge/tunnel segments with ortho photo. Considered not in a zone if all New York City approaches are fully clear of inundation. Major roads do not include bridge/tunnel spans.

iii. Natural Environment

Coastal storms can have significant impacts on natural areas and coastal ecosystems. Significant storms have the potential to permanently submerge wetlands and cause barrier islands to narrow or split. Erosion of beaches and dunes, wetland loss, and barrier island breaching are all direct impacts of coastal storms that can damage or destroy coastal habitats and disrupt migration patterns of terrestrial animals. The loss of these natural storm barriers also leaves wooded areas and parks farther inland more exposed to the impacts of wind and storm surge.

Marine and aquatic species are also vulnerable. Following the passage of a storm, contaminated runoff may lead to elevated levels of dissolved nutrients in coastal waters. This reduces the amount of dissolved oxygen in the water and may result in localized fish kills. Sources of contaminated runoff include chemical spills or leaks from commercial or industrial areas and overflow from sewers and wastewater treatment plants. Large volumes of debris in local waterways can also be hazardous to local species. Large-scale changes in the population, distribution, and migrations of marine and aquatic species are possible over the long term.

iv. Future Environment

When considering the prospect of coastal storms in the future, planners and emergency managers must understand how climate change will affect the probability of these storms for New York City and the impacts the storms will have if they do make landfall in or near the city.

As the climate continues to warm, ocean surface temperatures are projected to increase. As a result, storms may become more intense. Although it is still unclear how all of the climatic variables affecting hurricanes will change, there is a general consensus among climate scientists that the frequency of the most intense hurricanes (not the frequency of hurricanes in general) may increase globally and in the North Atlantic Basin.

Scientists are less certain as to how the probability of these storms will change at the local level, including potential changes in storm tracks. Several recent studies have found a possible link between melting Arctic sea ice and storm tracks. This evidence suggests that melting sea ice may change the pattern of the Jet Stream, which, in turn, can shift the tracks of storms in the Atlantic. However, this research is in its early stages and is still only suggestive at this point.

Although there is still uncertainty about how probability will change, scientists are fairly certain that the impacts of coastal storms will worsen in the future when combined with sea level rise due to climate change (NPCC, 2013). Climate change contributes to sea level rise in several ways. As ocean water warms, it expands and increases in volume, which in turn causes sea level to rise. Global warming is also causing land glaciers and polar ice caps to melt at a faster rate, which increases the amount of water in the oceans. Since 1900, relative sea level has risen approximately 1.1 feet in New York City owing in part to climate change and in part to local factors such as land subsidence. By the middle of the 21^{st} century, sea level around New York City could rise up to 2.5 additional feet, according to high-end projections from the New York City Panel on Climate Change. As sea levels continue to rise, coastal flooding from future storms will cause more extensive damage than from an equivalent storm today because sea level will already be higher to begin with.

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