7) Coastal Storms: Multi-Hazard Analysis for New York City

a) Hazard Profile

i) Hazard Description

Coastal storms, including nor'easters, tropical storms, and hurricanes, can and do affect New York City. New York's densely populated and highly developed coastline makes the City among the most vulnerable to hurricane-related damage.

Tropical Storms and Hurricanes

A hurricane is a type of tropical cyclone, which is a generic term for a low-pressure system that generally forms in the tropics. Thunderstorms and, in the Northern Hemisphere, a counterclockwise circulation of winds near the earth's surface accompany the cyclone. Tropical cyclones 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 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 miles per hour.
- A hurricane is an intense tropical weather system of strong thunderstorms, with a well-defined surface circulation, and maximum sustained winds of 74 miles per hour or higher.

Atlantic hurricanes form off the coast of Africa or in the southern Atlantic Ocean, Caribbean Sea, or Gulf of Mexico. Hurricanes require warm tropical oceans, moisture, and light winds above them to form. A hurricane can produce violent winds, tornadoes (primarily on the leading and trailing edges of the hurricane), powerful waves and storm surge, and torrential rains and floods.

Atlantic hurricane season lasts from June to November, averaging 11 tropical storms each year, six of which turn into hurricanes. New York City is at highest risk between August and October because water temperatures in the Northern Atlantic are most likely to reach a temperature warm enough to develop and sustain a hurricane. According to the National Hurricane Center, the Atlantic hurricane season is currently in a period of heightened activity that started around 1995 and could last at least another decade.

Heavy rain, coastal flooding, and powerful winds are commonly associated with hurricanes. Storm surge is often the greatest hurricane-related hazard.[1] Storm surge is water that is pushed toward the shore by the force of the winds swirling around the storm. This advancing surge combines with the normal tides to create the hurricane storm tide, which can increase the mean water level 15 feet or more. In addition, wind driven waves are superimposed on the storm tide. This rise in water level can cause severe inundation in coastal areas, particularly when the storm tide coincides with the normal high tides.

[1] Storm surge is measured as the difference between tide levels and observed storm water levels.

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 New York and New Jersey meet, creating a right angle in the coastline.

Figure 41: New York Bight

Nor'easters

A nor'easter is a strong low-pressure system that affects the Mid-Atlantic and New England states. It can form over land or coastal waters. These typically winter events are notorious for producing heavy snow, rain, and tremendous waves that crash onto Atlantic beaches, often causing beach erosion and structural damage. Wind gusts associated with these storms can exceed hurricane force in intensity. A nor'easter gets its name from the continuously strong northeasterly winds blowing in from the ocean ahead of the storm and over the coastal areas.

Nor'easters may occur at any time of the year but are most common from September through April. If a wintertime nor'easter moves up the coast, following a track west of New York City, wintry precipitation will often change to rain. However, if the storm maintains a track just off the eastern coast of the City, snow, or mixed precipitation is likely to occur, assuming there is enough moisture and cold air.

ii) Severity

The NWS uses the Saffir-Simpson Scale to classify hurricane severity. The scale categorizes a hurricane's present intensity on a one to five rating and provides an estimate of property damage and coastal flooding upon landfall. Wind speed determines a hurricane's Saffir-Simpson Scale rating since storm surge is greatly dependent on the coastline shape and slope of the continental shelf.

Saffir-Simpson Hurricane Scale				
Category	**Storm Surge (ft)**	**Winds (mph)**	**Damage**	**Damage Description**
1	6.1–10.5	74–95	Moderate	• Damage primarily to trees and unanchored homes • Some damage to poorly constructed signs • Coastal road flooding
2	13.0–16.6	96–110	Moderate-Severe	• Some roofing material, door, and window damage to buildings • Considerable damage to shrubbery and trees • Flooding of low-lying areas
3	14.8–25	111–130	Extensive	• Some structural damage to residences and utility buildings • Foliage blown off trees and large trees blown down • Structures close to the coast will have structural damage by floating debris
4	24.6–31.3	131–155	Extreme	• Curtainwall failures with utilities and roof structures on residential buildings • Shrubs, trees, and signs all blown down • Extensive damage to doors and windows • Major damage to lower floors of structures near the shore
5	Not predicted	>155	Catastrophic	• Complete roof failure on many residences and industrial buildings • Some complete building and utility failures • Severe, extensive window and door damage • Major damage to lower floors of all structures close to shore

Table 13: Saffir-Simpson Hurricane Scale

iii) Probability

According to hurricane probability models, there is a 2.6% chance a hurricane will impact the New York City area (New York City, Westchester, and Long Island) during any given hurricane season. During a 50-year period there is a 13.6% chance a hurricane

will impact the New York City area and a 3.3% chance an intense hurricane (Category 3 or higher) will affect the City.

iv) Location

OEM uses a computer model called SLOSH (Sea, Lake, and Overland Surges from Hurricanes) to predict the effects of storm surge and help guide the City's planning efforts for coastal storms. The SLOSH model calculates surge based on storms moving in different directions and with varying strengths. The SLOSH model analyzes storms moving northeast, northwest (the direction that will have the greatest impact), and varying in strength from Category 1 to Category 4.

The SLOSH calculations are based on the storm surge above the mean tide and the strongest potential winds for each category storm. The error is +/- three feet. Additionally, the SLOSH model calculates inundation levels for each location as if the hurricane hit that particular location head-on. The culmination of these factors results in a "worst-case" scenario for storm surge in the SLOSH model.

The SLOSH[2] map in Figure 42 shows the areas of the City that would experience inundation from storm surge based on hurricane category. The following four maps display the estimated storm surge levels for different neighborhoods throughout New York City. These maps provide a visual representation of New York City's physical vulnerability. A Category 2 storm would completely inundate the Rockaway Peninsula and a Category 3 storm could put Coney Island under 21 feet of water. With more than 21 square miles of land within a Category 4 surge zone, a significant hurricane would affect millions of New Yorkers and compromise the City's aging infrastructure.

[2] The SLOSH map represents locations that may experience flooding from hurricane storm surge. In contrast, the floodplain map represents locations that experience natural coastal flooding, which may be unrelated to hurricanes, and are within the FEMA-defined 100-year floodplain. Hurricane storm surge areas overlap many areas that are designated as the 100-year floodplain, but the hurricane storm surge areas are considerably larger and represent a different hazard.

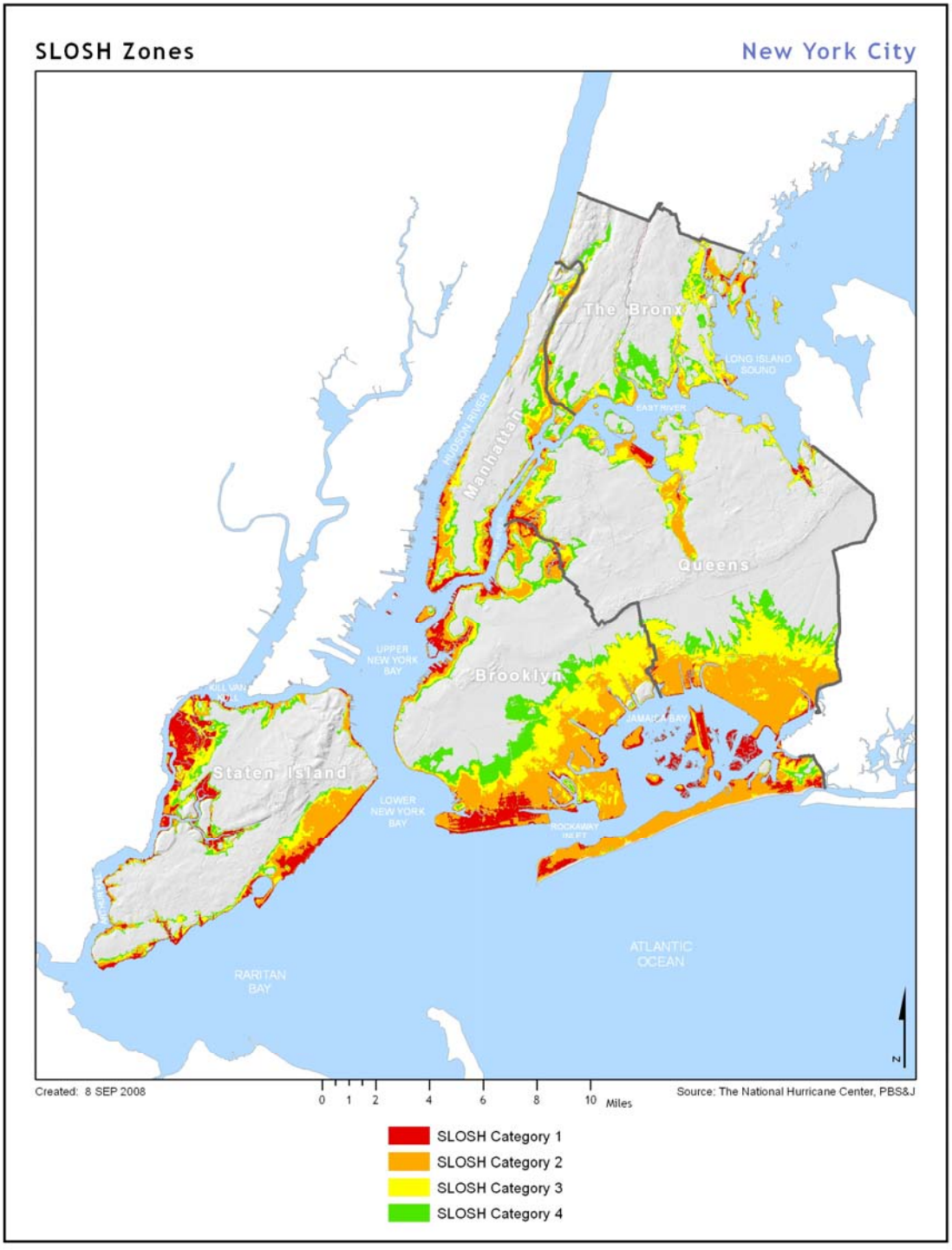

Figure 42: New York City SLOSH Model

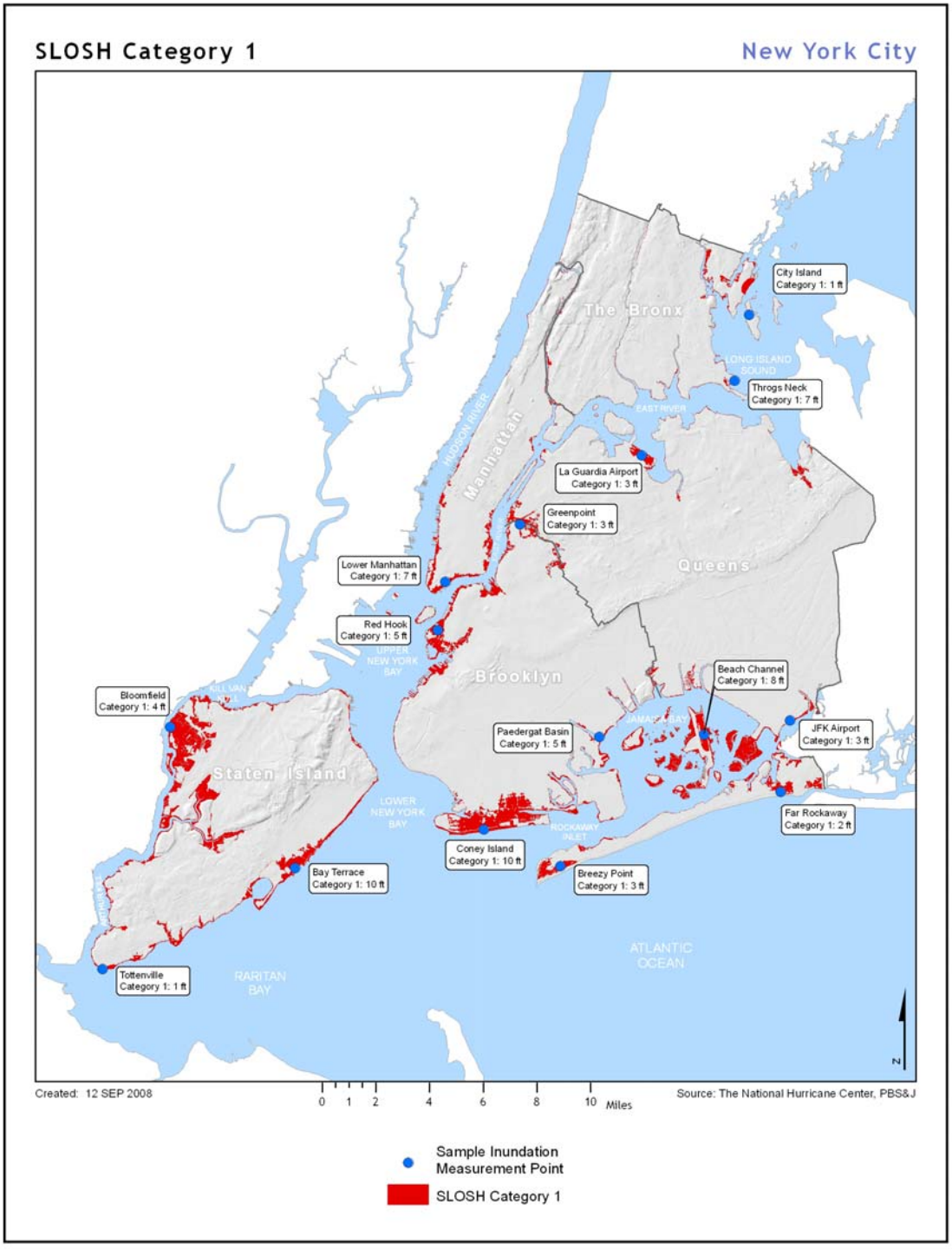

Figure 43: New York City Storm Surge for a Category 1 Hurricane

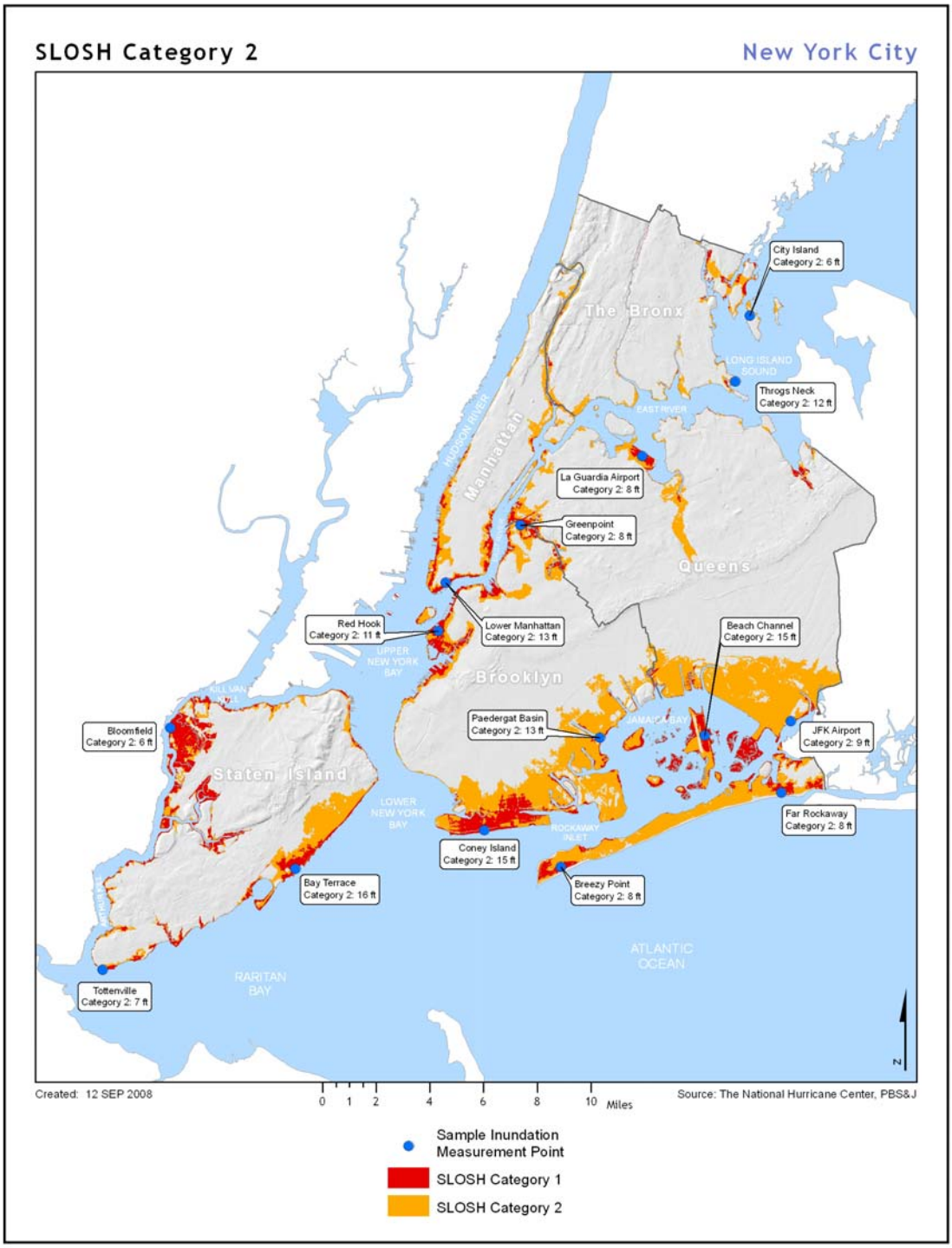

Figure 44: New York City Storm Surge for a Category 2 Hurricane

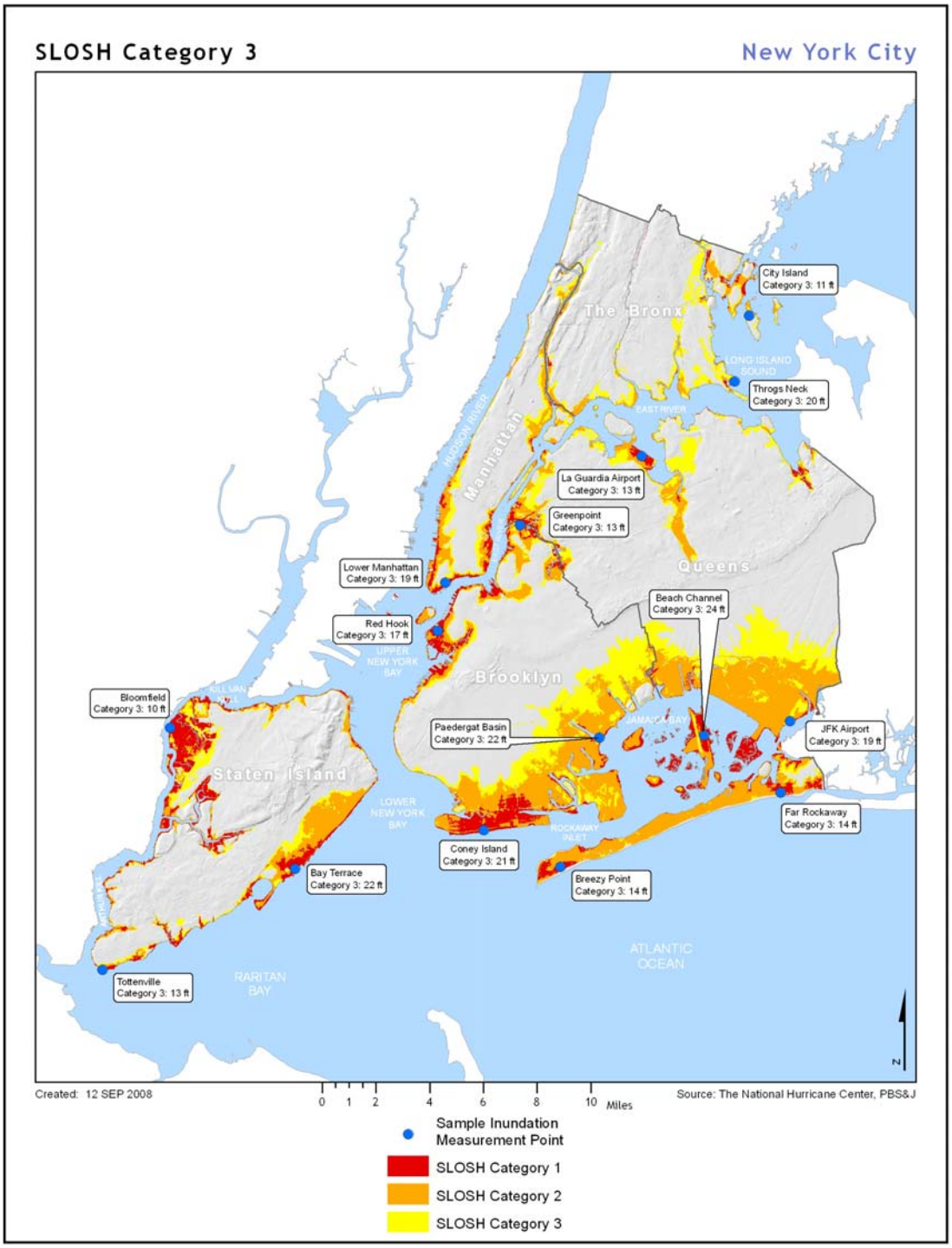

Figure 45: New York City Storm Surge for a Category 3 Hurricane

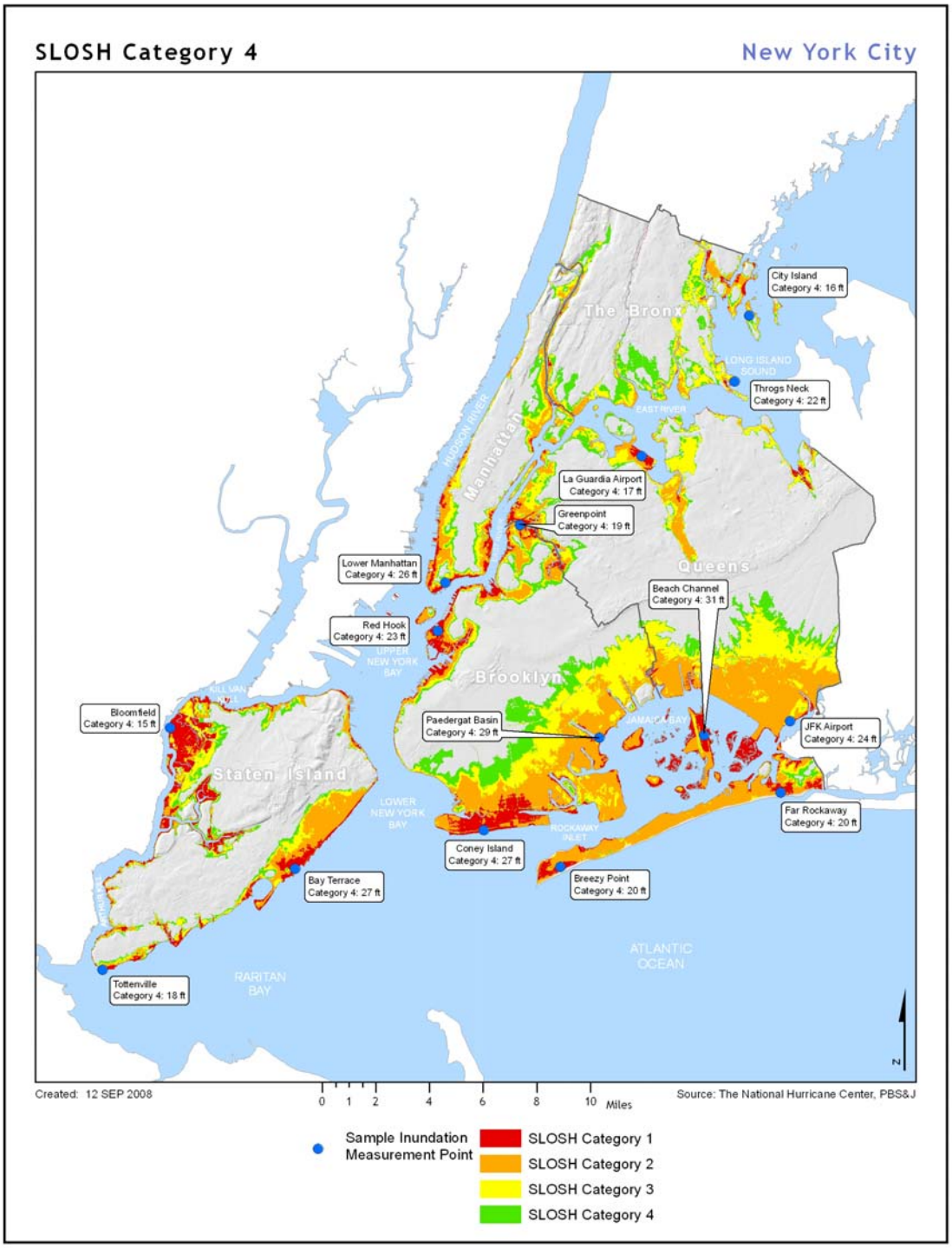

Figure 46: New York City Storm Surge for a Category 4 Hurricane

v) Historic Occurrences

Historic Occurrences of Coastal Storms in New York City			
Date	**Event**	**Location(s)**	**Description**
Sept. 3, 1821	Hurricane	Citywide	• Believed to pass directly over parts of New York City • Tides rose 13 feet in one hour and caused the East River to converge into the Hudson River across lower Manhattan along Canal Street • No deaths reported
Aug. 24, 1893	Hurricane	Citywide	• Category 1 • Destroyed Hog Island
Oct. 10, 1894	Hurricane	Citywide	• Category 1
Sept. 21, 1938	Hurricane	Citywide	• Category 3 • Most powerful hurricane to make landfall near New York City • Eye crossed over Long Island giving it its name, the Long Island Express • Killed nearly 200 people total; 10 in New York City • Electricity knocked out north of 59th Street in Manhattan • 100 large trees in Central Park were destroyed
Aug. 30, 1954	Hurricane Carol	Citywide	• Made landfall in eastern Long Island and SE Connecticut • Sustained winds more than 100 mph and gusts 115 to 125 mph • Most destructive hurricane to hit the northeast coast since the 1938 hurricane • Major flooding throughout the City
Aug. 19, 1955	Hurricanes Diane and Connie	Citywide	• Leftover rains from hurricanes dropped nearly 12 inches of rain at LaGuardia Airport • In just over one week, the remnants of 2 hurricanes passed over the City.
Sept. 12, 1960	Hurricane Donna	Citywide	• Created an 11-foot storm tide in New York Harbor and caused extensive pier damage

Historic Occurrences of Coastal Storms in New York City			
Date	**Event**	**Location(s)**	**Description**
June 22, 1972	Tropical Storm Agnes	Citywide	• Agnes fused with another storm system in the northeastern U.S., flooding areas from North Carolina to New York State • Caused 122 deaths • More than $6 billion in damage (when adjusted for inflation)
Sept. 27, 1985	Hurricane Gloria	Citywide	• Category 3 • Made landfall on Long Island at 80 mph • Produced a modest storm surge of 4-7 feet above normal across the Atlantic • Could have produced a much stronger and intense storm surge if it happened during high tide • Caused the largest single power loss in U.S. history at the time • Total damage estimated at $900 million in 1986
Dec. 21, 1992	Nor'easter	Citywide	• Flooding and coastal erosion, debris • Damage to residential and commercial structures, utility lines, roads and other infrastructure
June 17, 1995	Hurricane Felix	Citywide	• Hurricane Felix lingered off the East Coast for nearly a week, menacing the northeastern U.S. before it finally drifted out to sea
June 18, 1996	Tropical Storm Bertha	Citywide	• Weakening storm brought heavy rain to the City
Jan. 3, 1999	Nor'easter	Citywide	• 2.42 inches of rain • 50-vehicle accident in Queens
Sept. 16, 1999	Tropical Storm Floyd	Citywide	• Flooded subway tunnels across the City causing service disruptions • Dropped 10-15 inches of rain in a 24-hour period • Public schools closed for the day
Sept. 18, 2003	Tropical Storm Isabel	Brooklyn, Bronx, Queens, Staten Island	• One fatality in the NY area – a man drowned while bodysurfing off Long Beach, Long Island • A fallen tree branch in the Bronx seriously injured a man • 640 trees and 801 tree limbs were downed across the City • Total damage exceeded $1 billion along the East Coast

Historic Occurrences of Coastal Storms in New York City			
Date	**Event**	**Location(s)**	**Description**
Apr. 15, 2007	Nor'easter	Citywide	• More than 7.5 inches of rain in Central Park • More than 500 flights cancelled • Disrupted power to 18,500 customers in three states

Table 14: Historic Occurrences of Coastal Storms in New York City

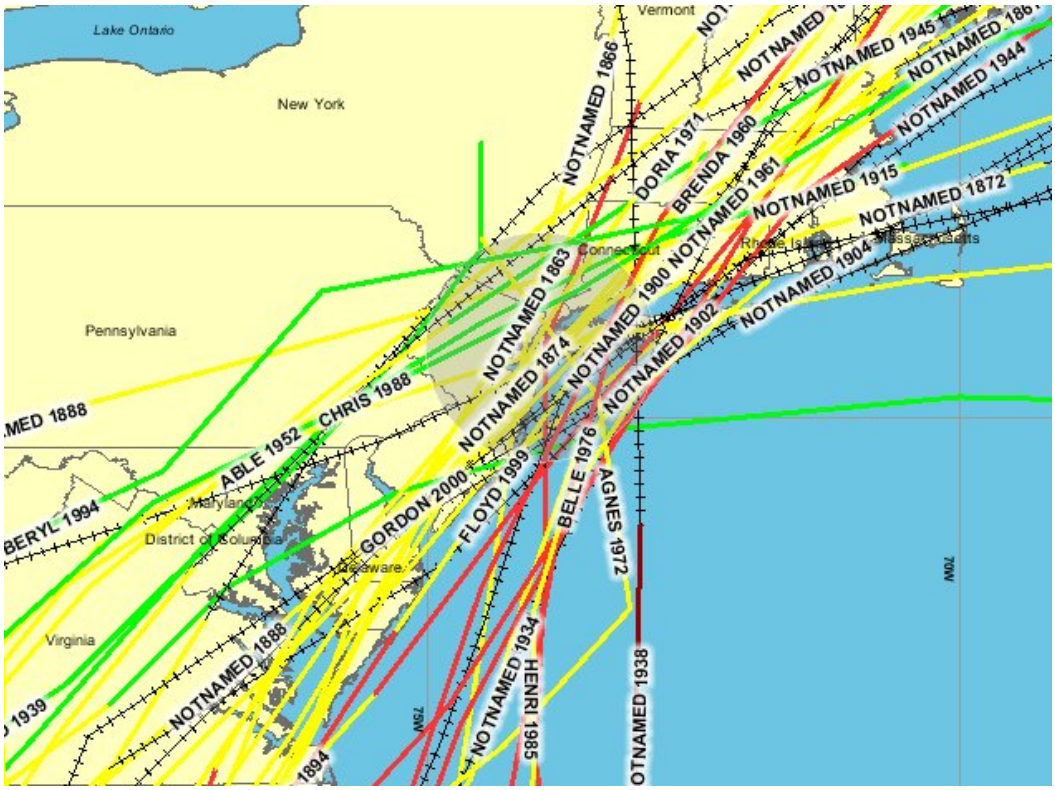

Figure 47: History of Coastal and Tropical Storms Tracks

b) Vulnerability Assessment

i) Impact to New York City

A Category 1 hurricane can cause storm surge of up to 10 feet and 95 mile per hour winds causing moderate damage to the City's foliage and unstable buildings along the coast. A Category 4 hurricane would devastate New York City with surge levels surpassing 30 feet in some areas, causing large-scale utility disruptions and damage to buildings and infrastructure. Due to the geography and climate characteristics of New York City, scientists do not predict a Category 5 hurricane would reach as far north as New York City and although possible, a Category 4 hurricane is unlikely.

The New York City Coastal Storm Plan (CSP) uses the SLOSH zones to define the areas that may be required to evacuate, called evacuation zones, based on different categories

of storms. Zone A would evacuate prior to a Category 1 hurricane, Zone B prior to a Category 2 hurricane, and Zone C prior to a Category 3 or 4 hurricane.

Depending on the severity of the hurricane, OEM estimates that between 272,000 and three million New Yorkers may have to evacuate. Most evacuees will stay with friends or family within or outside of the City. Some evacuees will go to City-provided shelters located outside the SLOSH zones. Table 15 is an estimate of total evacuees in New York City based on the evacuation zones. These numbers derive from population data, behavioral assumptions, tourist occupancy, and vehicle accessibility. "Other evacuees" refers to the shadow population that will evacuate even though they do not live in the evacuation zone.

CSP Evacuees by Zone	
Order Scope	**Evacuees**
Zone A (Category 1)	272,331
Zone B (Category 2)	677,940
Zone C (Categories 3 and 4)	1,380,388
Subtotal Zone Evacuees	2,330,659
Other Evacuees*	714,162
Total Potential Evacuees	***3,044,821***

*Other evacuees are people who will evacuate from non-flood zones

Table 15: CSP Evacuees

Density is a major concern for New York City in the context of a hurricane. More than eight million people live within 305 square miles across the five boroughs. New York City's three islands and the main land create 578 miles of coastline. Close to two million people in 743,000 households live within a SLOSH zone and as much as 38% of the City's land may experience inundation by storm surge in a coastal storm.

ii) Structural Vulnerability

The Planning Team used HAZUS-MH to estimate potential losses from hurricanes in New York City based on a probabilistic model, in which the probability is expressed as a percent chance that a hurricane of a specific magnitude will occur in any given year. For example, a hurricane with a 50-year return period, or occurrence rate, has a 2% chance of occurring in any one year.

Probabilistic Modeling	
Return Period (Years)	**Chance of Occurrence in Any Given Year (%)**
10	10
20	5
50	2

Probabilistic Modeling	
Return Period (Years)	Chance of Occurrence in Any Given Year (%)
100	1
200	0.5
250	0.4
500	0.2
1,000	0.1

Table 16: Return Periods for Probabilistic Modeling

HAZUS-MH runs were conducted for 10, 20, 50, 100, 200, 500, and 1,000-year return periods. Using a 10-year return period, HAZUS-MH predicts no buildings would experience any form of damage. At the 100-year return period, HAZUS-MH estimates three buildings would experience complete destruction from a hurricane. The 1,000-year return period estimates 407,000 structures, or more than half of the City's current building stock, would experience some type of damage.

Number of Buildings Damaged from a Hurricane					
Return Period (Years)	Minor	Moderate	Severe	Destruction	Total
10	0	0	0	0	***0***
20	2,546	84	3	0	***2,633***
50	12,473	1,729	41	0	***14,242***
100	39,111	11,119	183	3	***50,416***
200	80,043	34,514	623	52	***115,233***
500	175,907	110,079	4,966	1,672	***292,623***
1,000	219,682	170,640	12,067	5,090	***407,480***

Table 17: HAZUS-MH Calculation of Number of Buildings Damaged from a Hurricane by Return Period

Table 18 displays the total number of critical facilities and key assets located within the Category 4 SLOSH zone. These facilities and assets are at risk to storm surge and severe damage in a Category 4 hurricane.

Critical Assets Located within SLOSH Zones	
Critical Asset	#
Subway Stations	119
Rail Stations	30
Bridges and Tunnels	31
Major Roads (miles)	461
Airports	2
Ferry Landings	25
Emergency Services – Police Stations	22
Emergency Services – Fire Stations	56

Critical Assets Located within SLOSH Zones	
Critical Asset	**#**
Emergency Services – EMS Stations	10
Educational – Colleges	19
Educational – Public Schools	343
Educational – Private Schools	215
Healthcare – Hospitals	23
Healthcare – Nursing Homes	57
Cultural Facilities	11
Infrastructure – Power Plants	17
Infrastructure – Wastewater Treatment Plants	13

Table 18: Critical Assets within SLOSH Zones

iii) Potential Loss Estimate

Table 18 and Figure 48 highlight the key findings from the HAZUS-MH probabilistic run. In total, the City has $826 billion of buildings exposed to hurricanes of any or all categories. Residential buildings account for $583 billion, or 70%, of this total. The annualized loss, or long-term average losses in a given year, is $276 million for total building structures. More than 80% of the annualized capital loss results from damage to buildings, while less than 0.5% is derived from inventory loss.

Annualized Capital Stock Loss for Hurricanes ($1,000s)				
County	**Building Damage**	**Contents Damage**	**Inventory Loss**	**Total**
Brooklyn	58,862	12,143	439	***71,444***
Bronx	32,284	6,940	199	***39,423***
Manhattan	70,276	14,476	125	***84,877***
Queens	53,880	12,217	315	***66,412***
Staten Island	10,914	3,148	30	***14,092***
Total	***226,216***	***48,924***	***1,108***	***276,248***

Table 19: HAZUS-MH Results for Hurricanes

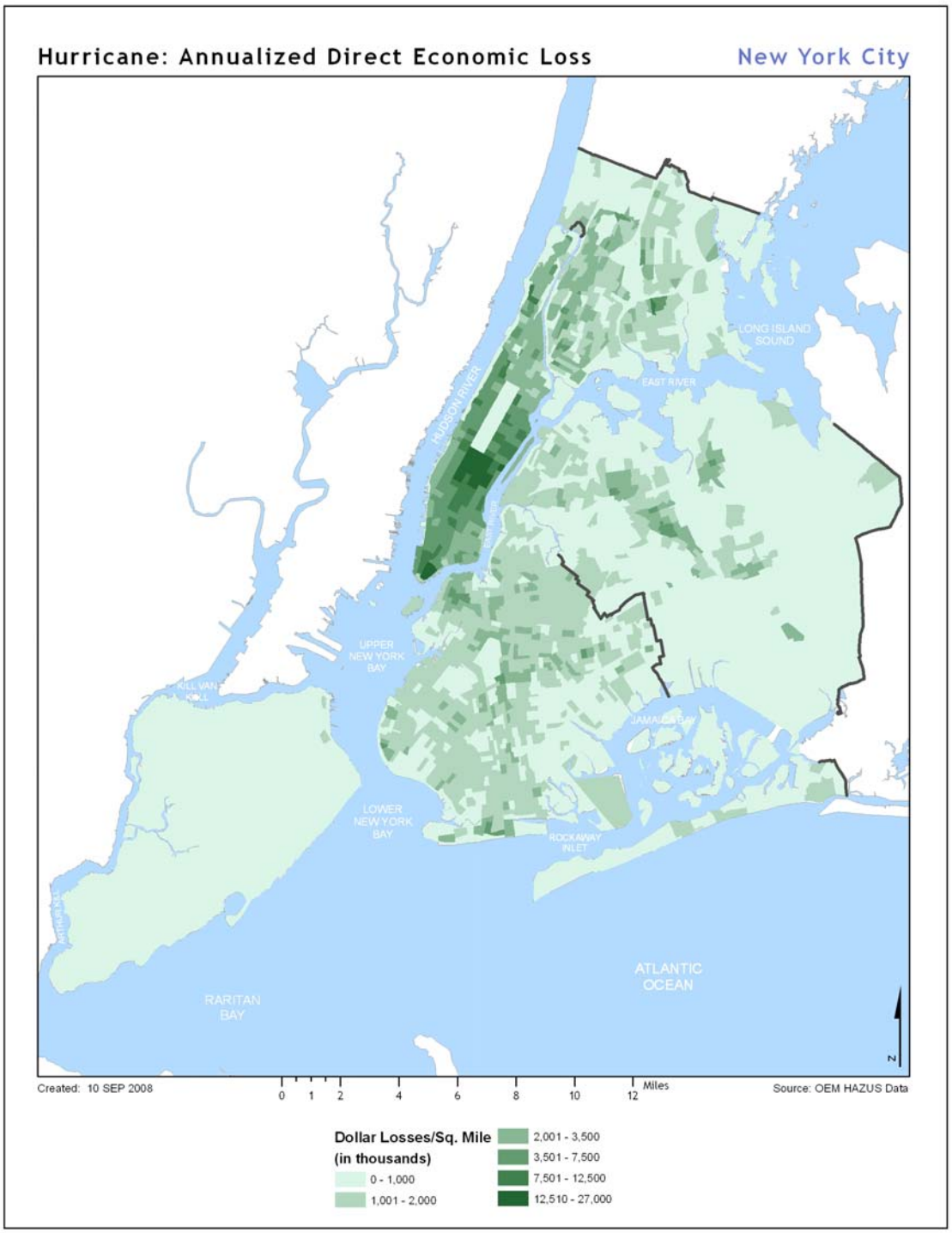

Figure 48: HAZUS-MH Results for Annualized Losses from a Hurricane