

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

A. SUMMARY

Hurricane Sandy, which made landfall on October 29, 2012, was an unprecedented storm in many respects as well as the costliest natural disaster in New York City's history. Much progress has been made to rebuild and restore the City since the storm. However, many of the hardest-hit areas are still in the midst of recovery—a process that will likely continue for years to come. As the recovery continues, the City is also looking to the future and planning ahead to prevent another disaster of this magnitude. Sandy prompted City officials, businesses, academics and residents to think more seriously about and move forward with strategies to protect New York City as it becomes increasingly vulnerable in the face of climate change.

B. STORM CHARACTERISTICS

i. Formation and Evolution

Sandy was first classified as a tropical storm in the central Caribbean on October 22, 2012, strengthening into a hurricane on October 24th before making initial landfalls in Jamaica, eastern Cuba and the Bahamas (see Figure 1). From there, Sandy continued on a northerly path paralleling the Eastern Seaboard of the United States. As Sandy continued to track northward, the weather forecast models came into agreement that the storm would take an unusual westward turn and make landfall in southern New Jersey. To make matters worse, Sandy was interacting with a frontal system which was moving eastward at the time, causing the storm to morph into an incredibly dangerous hurricane/nor'easter hybrid.



Figure 1: Sandy's Path (source: NOAA).

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

ii. Unique Characteristics

From a meteorological standpoint, Hurricane Sandy was an anomaly. For one thing, the storm was massive, stretching nearly 1,000 miles across at its peak (see Figure 2). The storm generated waves and storm surge that were significantly larger than would have been expected from a Category 1 storm in select locations; this is because tropical storm-force or higher winds were spread across such a large area. Before Sandy made landfall, its wind field stretched from the Atlantic to as far west as Chicago and produced large waves on the Great Lakes.

Sandy's track was another unusual characteristic. Most storms in the western Atlantic either move east out to sea or move north-northeast, paralleling the east coast of the United States. However, a blocking high pressure system over the northern Atlantic, combined with a pronounced southerly dip in the Jet Stream caused Sandy to make an unprecedented sharp westward turn before it made landfall.

The same weather pattern facilitated the interaction between Hurricane Sandy and the weather system moving eastward, producing a storm with an unusual combination of tropical and non-tropical characteristics. In fact, Sandy marked the first time in recorded history in which snow (experienced in parts of the interior Northeast and Mid-Atlantic) was associated with a tropical cyclone. Just prior to landfall, Sandy's minimum central pressure, another indicator of storm strength, set a record for any east coast storm north of Cape Hatteras, NC at 940 millibars.



Figure 2: Satellite Image Showing Sandy Engulfing Much of the Eastern United States and Southern Canada.

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

C. PRE-STORM PREPARATIONS IN NEW YORK CITY

When computer forecast models began to suggest a possible landfall in the region, New York City activated its Coastal Storm Plan (for more information, see Mitigation Strategy Section 6: Emergency Planning and Operations). Many pre-storm preparations were related to transportation. Several days before the storm, City agencies fueled vehicles and generators in anticipation of possible fuel shortages. At 7 p.m. on October 28 (the day before the storm), the Metropolitan Transportation Authority (MTA) began a citywide shutdown of buses, subways, and commuter rails (Metro North and Long Island Railroads). At 12 a.m. on October 29, The Port Authority of New York and New Jersey (PANYNJ) suspended all PATH service between New York and New Jersey. The MTA and PANYNJ also closed bridges and tunnels as conditions warranted. Airlines cancelled all scheduled flights into and out of area airports.

At the same time, the City issued mandatory evacuation orders for Zone A (evacuation zones have since been revised; see Risk Assessment Section 6: Coastal Storms), plus the Rockaway Peninsula and Hamilton Beach in Queens and City Island in the Bronx. The Mayor's Office, in coordination the Office of Emergency Management (OEM) and the Department of Homeless Services (DHS), opened emergency shelters throughout the city. The Department of Parks & Recreation (Parks) closed all City parks. All New York City residents who were not evacuated, other than authorized government personnel and essential emergency personnel, were advised to stay home. In anticipation of power outages, utility crews were brought in from other states. Utility providers also erected temporary storm barriers around their facilities.

D. IMPACTS ON NEW YORK CITY

i. Landfall

On October 29, shortly after transitioning from a Category 1 hurricane to an extra-tropical storm, Sandy made landfall near Atlantic City, New Jersey. This was a worst-case scenario storm track for New York City (see "Coastal Storms" Hazard Analysis). Sandy's track, combined with its massive size and coincidence with an astronomical high tide (up to half a foot higher than normal high tide), produced surge that well exceeded what would typically be expected from a Category 1 hurricane. Storm surge reached all-time record levels at various locations throughout New York City, including the Battery in lower Manhattan, which experienced a 9.40 foot storm surge and a 14.06 foot storm tide. Figure 3 shows the extent of the storm surge inundation throughout New York City. In addition to the unprecedented storm surge, massive waves crashed into ocean-facing beaches. One buoy south of New York Harbor measured a wave height of 32.5 feet.

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

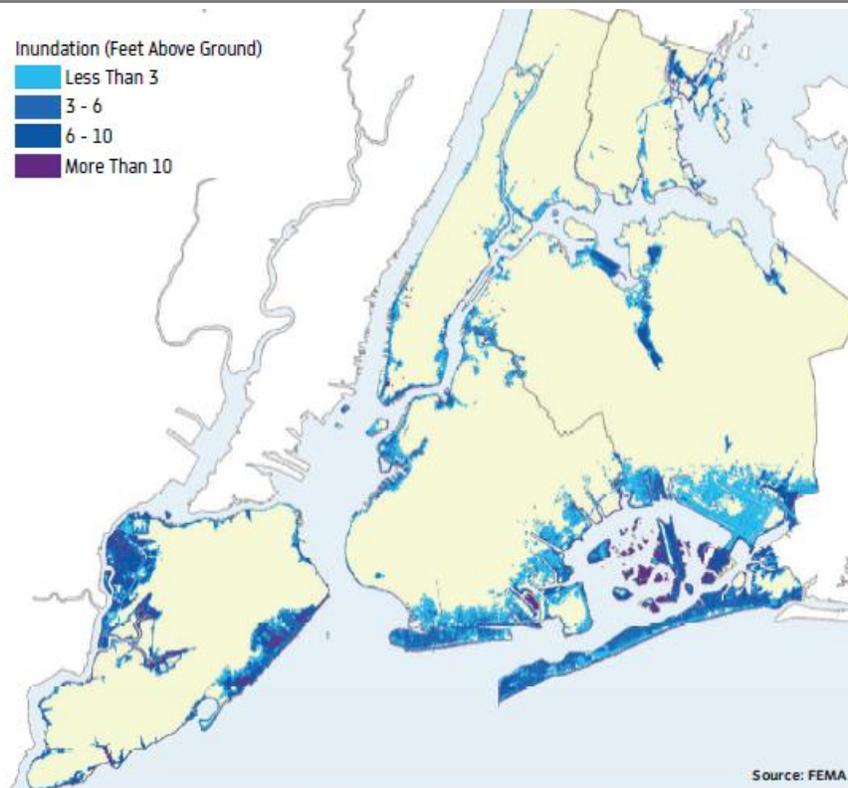


Figure 3: Sandy Storm Surge Inundation in New York City (source: FEMA)

Although Sandy did not produce a significant amount of rain in New York City (less than one inch), the majority of the Tri-State Area experienced repeated wind gusts over 60 mph for at least several hours, including at both LaGuardia and Kennedy Airports. Downed trees and power lines blocked roadways. A number of fires also resulted where saltwater came into contact with electrical wires. One massive fire in the Queens community of Breezy Point destroyed over 100 homes.

ii. Aftermath

When Sandy finally moved out of the area, it left significant damage in its wake. As a result of the storm, there were 44 deaths in New York City (the 44th death was confirmed by the New York City Office of the Chief Medical Examiner – OCME – in June, 2013), 23 of which were in Staten Island and the remainder of which were spread across Queens, Brooklyn and Manhattan. The majority of these deaths were attributed to drowning in areas where storm surge rose rapidly.

In total, Sandy flooded 51 square miles of New York City—17% of the City's total land mass (see Figure 3), and caused approximately \$20 billion in damage to the City's building stock and infrastructure. The most affected areas were the eastern and southern shores of Staten Island, the Brooklyn/Queens waterfront, Southern Queens, Southern Brooklyn, and Lower Manhattan.

Various methods have been employed to calculate the amount of building stock and exposed population within the inundation zone, each resulting in slightly different estimates. Depending

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

on the methodology used for calculation, there are an estimated 70,000 to 90,000 buildings and roughly 450,000 residents within the inundation zone. Approximately 150,000 residents were displaced from their homes and forced to seek temporary housing or immediate home repairs.

Building damage from Sandy was widespread and in many cases severe. As of December 2012, DOB had tagged 800 buildings as being destroyed or structurally unsound, with tens of thousands more suffering at least minor damage. Nearly 70,000 housing units were registered with FEMA as having sustained at least some level of damage. Residents in New York City Housing Authority (NYCHA) developments were hit particularly hard, with roughly 80,000 residents in 423 buildings significantly impacted.

Overall, there were several indicators of how the storm impacted New York City's building stock. Shoreline areas that experienced the force of waves sustained more damage to buildings than areas with still-water flooding only. Other factors related to physical characteristics (such as building height and construction type) as well as age (which defined the regulations in force when the building was constructed) were also important determinants. Overall, older, 1-story, light-frame buildings suffered the most structural damage.

Sandy caused significant damage to the City's critical infrastructure, disrupting services and damaging facilities essential to the well-being of the City's residents. Table 1 displays the number of critical facilities that were inundated during Sandy, categorized by facility type (thus satisfying New York State Hazard Mitigation Planning Requirement No. 2). The City's power distribution systems suffered a particularly heavy blow. Inundation of five Con Edison substations and four LIPA substations, combined with damage to overhead power lines, resulted in the loss of power to nearly two million residents.

ASSET TYPE	IN SANDY INUNDATION AREA	NOT IN SANDY INUNDATION AREA	TOTAL
Airports (perimeter)*	2	0	2
Nursing Homes (FP)	15	158	173
Hospitals (FP)	6	55	61
Police Stations (FP)	2	75	77
Fire Stations (FP)	18	210	228
EMS Stations (FP)	8	71	79
WWTP (FP)	10	4	14
Power Plants (est. FP)	9	17	26
DOE School Sites	77	1213	1290
Private Schools	30	818	848
Colleges	7	116	123
Ferry Landings**	N/A	N/A	47
Subway Station (point)	31	459	490
Rail Station	9	33	42

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

ASSET TYPE	IN SANDY INUNDATION AREA	NOT IN SANDY INUNDATION AREA	TOTAL
Cultural Facilities (DCP)***	1	36	37
Bus Depots	6	24	30
Bridges****	29	41	70
Tunnels*****	3	1	4
Major Roads (mi)*****	235	652	887
Total	497	3984	4528
Percentage	11%	88%	100%

DISCLAIMERS:

Note that asset counts are NOT based on facility field reports from the event. Hindcast data may contain inaccuracies. Unless otherwise noted, a facility point was used to do a spatial calculation. This may result in some inaccuracies in Category designation. FEMA MOTF Hindcast data was produced using the SLOSH model. It is the best available data but note that it may not reflect actual ground conditions in all areas. Assets that fall within the Hindcast extent but appear to be the result of DEM (terrain data) anomalies were excluded from the inundation area. Where possible, facility footprints were used for the analysis. When this data was not available, point locations were used. May not always reflect actual conditions on the ground. Asset types with "FP" indicate that the actual facility footprint was used in the calculation (for power plants FPs were estimated).

*Hindcast data shows inundation for both LGA & JFK but field reports indicated only LGA was definitively impacted by surge

**Active NYC commuter/commercial/recreational ferry landings only (includes Ellis & Liberty Island). Hindcast data clipped to shoreline - cannot accurately determine impact to ferry landings.

***Determination made by OEM/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.

Table 1: Critical Assets in Sandy Inundation Zone (Source: OEM; Analysis based on FEMA MOTF Hindcast data).

The City's transportation infrastructure was severely impacted by Sandy (see Figure 4). The Metropolitan Transportation Authority (MTA) suffered an estimated \$5 billion in damage, half of which was attributed to the inundation of subway and commuter rail tunnels, including seven subway tunnels and two LIRR tunnels beneath the East River which needed to be pumped. Significant flooding also occurred in the PATH train and Amtrak tunnels beneath the Hudson River connecting Manhattan and New Jersey. Corrosion from saltwater flooding caused severe damage to the electrical equipment at the South Ferry subway station (Subway service has since been restored to the old South Ferry station, but the new station remains closed indefinitely due to damage sustained during the storm). Additionally, one subway bridge, three subway yards, and six city bus facilities were flooded.

More than 500 miles of roads suffered significant damage. Roads were littered with trees and debris, and the Brooklyn-Battery and Queens-Midtown passenger car tunnels were inundated by storm surge. While subway service was out—it took days to restore—there was gridlock on city roads and bridges.

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

Both LaGuardia and Kennedy Airports remained closed for days after the storm (although field reports indicated that only LaGuardia was definitively inundated by storm surge). Over 12,000 flights scheduled into and out of the three New York City area airports were cancelled.

Sandy Inundation: Transportation

New York City

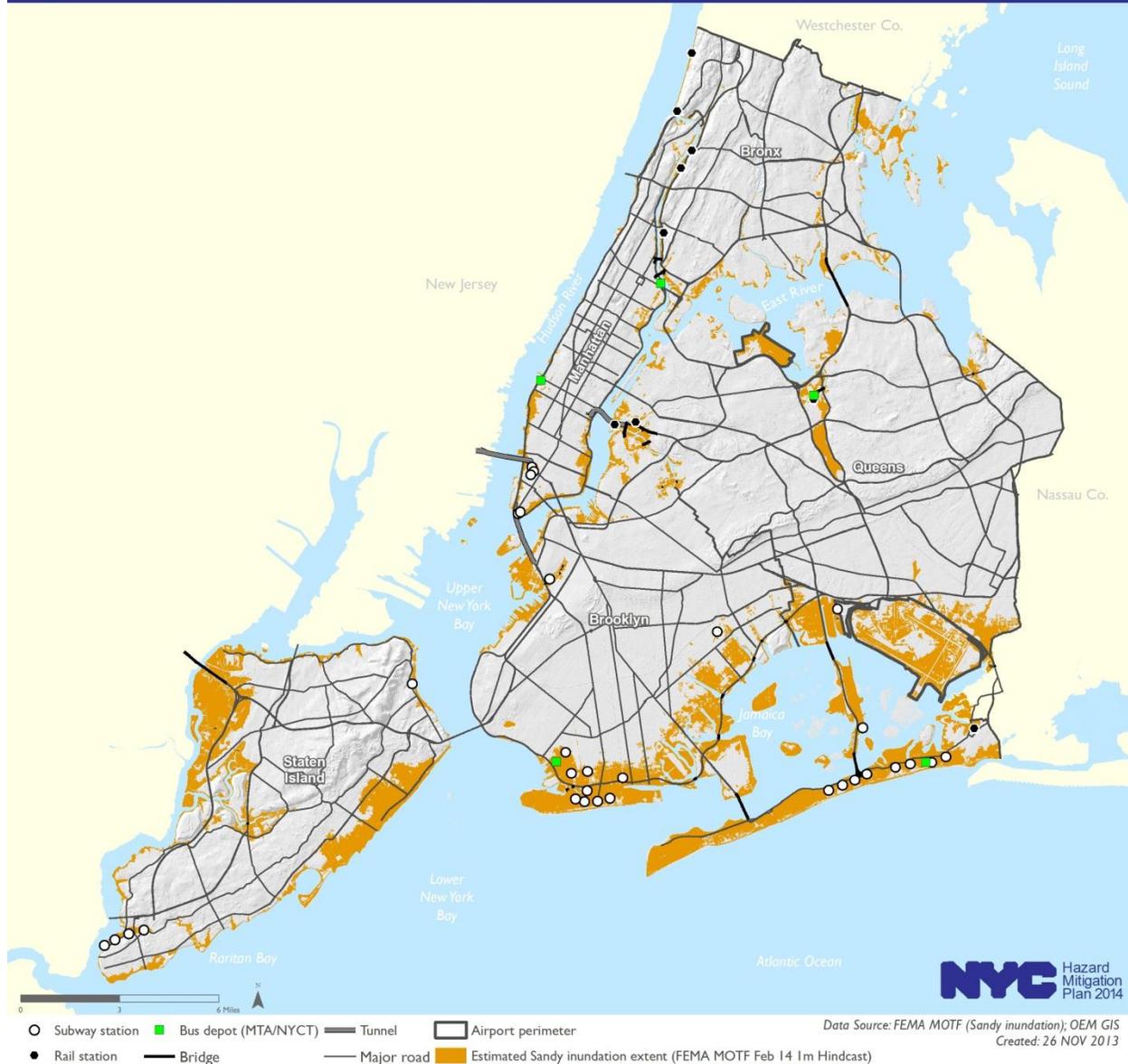


Figure 4: Transportation Infrastructure Inundated During Sandy.

Sandy also severely impacted the City's supply of liquid fuels. The storm shut down refineries for several weeks, stopped marine and pipeline deliveries for three to four days, and damaged storage terminals. For four days after the storm, the system received no new supply, and for almost a month after that, supply was limited. As a result, many gas stations closed, and many of the ones that remained open had significant fuel shortages.

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

Sandy placed a significant strain on the City's healthcare system (see Figure 5). In total, six hospitals were forced to close, which required City and State health officials to coordinate the evacuation of nearly 2,000 patients. Sandy also forced the closure or partial closure of 31 nursing homes and adult care facilities, from which 4,500 additional patients required evacuation. Many of these facilities were forced to close due to flood damage to the backup power generators.

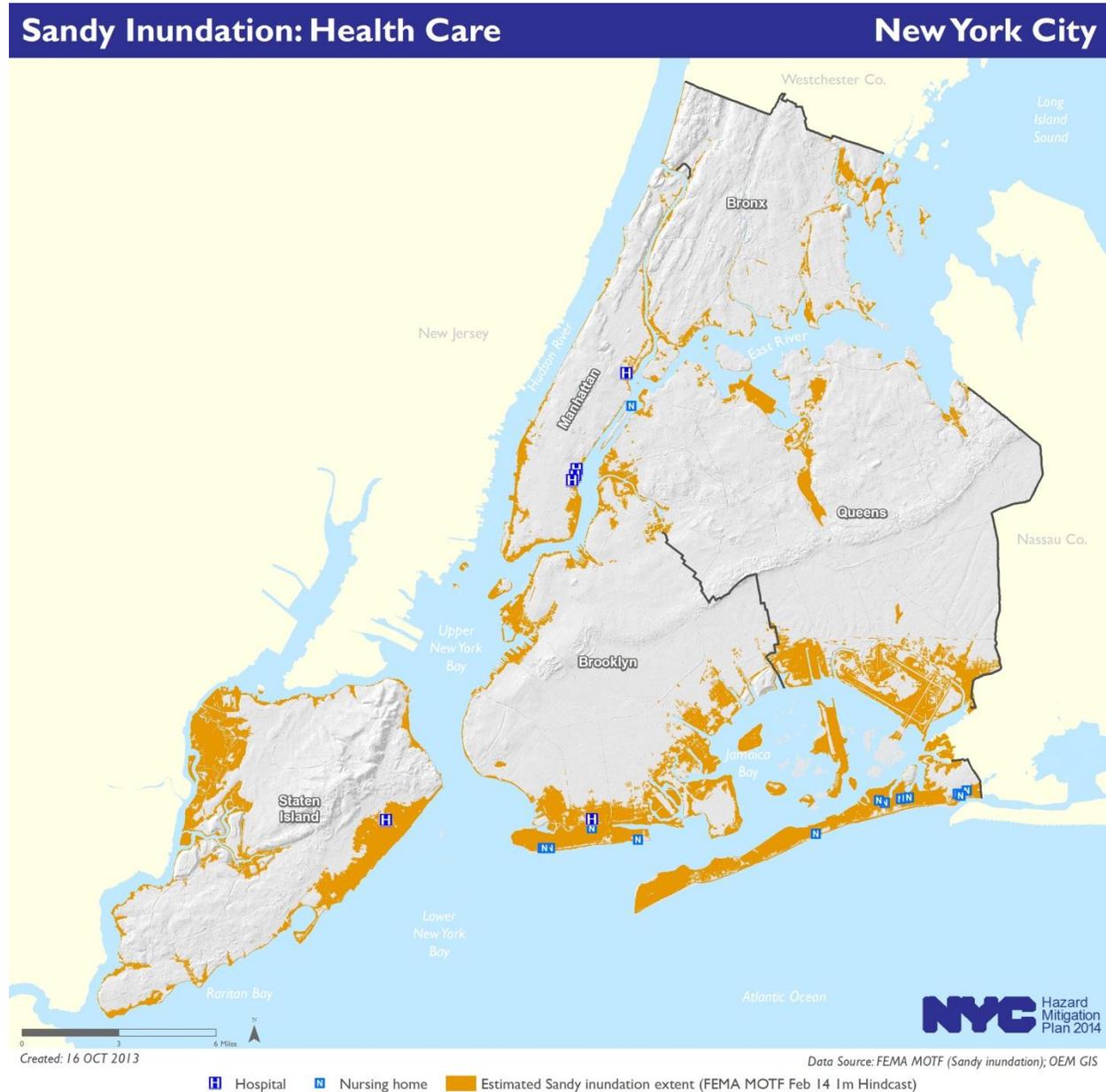


Figure 5: Healthcare Facilities Inundated During Sandy.

The City's telecommunications system also experienced significant outages during Sandy. Short-term outages to wireless and cell service generally occurred as a direct result of power loss, while flood damage at critical facilities—in Lower Manhattan, Red Hook in Brooklyn, and the

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

Rockaway Peninsula in Queens—disrupted landline and Internet service for up to 11 days. Flood damage to building telecommunications equipment caused even longer outages in some coastal areas.

Damage to City schools resulted in over one million children being unable to attend school for at least a week. Some schools which suffered severe damage were forced to close for the remainder of the year (see Figure 6).

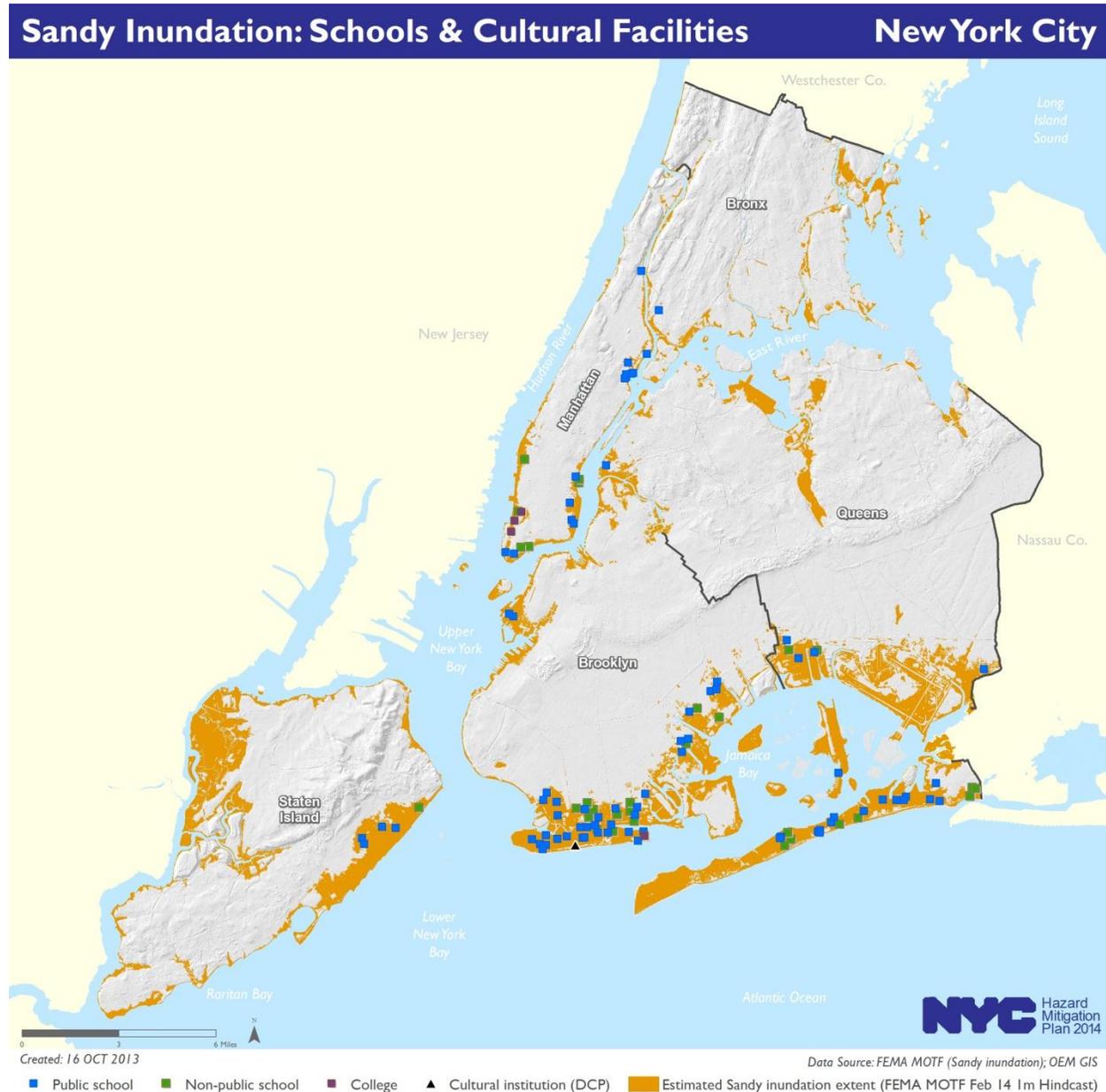


Figure 6: Schools and Cultural Facilities Inundated during Sandy.

Sandy also had a significant impact on the environment and on recreational areas. When storm surge inundated wastewater treatment plants it caused 10 of the 14 plants operated by the

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

Department of Environmental Protection (DEP) to release untreated or partially treated sewage into local waterways. Due to loss of power, 42 of the 96 pumping stations, which facilitate the movement of combined sewage through the system, were temporarily out of service. The city's stormwater and combined sewer systems were simply unable to handle the unprecedented volume of storm surge.

City parks and natural areas remained closed or inaccessible for several days after the storm as crews worked to remove downed trees and debris. City beaches suffered severe damage and erosion from storm surge and battering waves, including nearly three miles of boardwalk on the Rockaway Peninsula. Storm surge also inundated and damaged coastal wetland ecosystems.

Loss Estimates

Loss estimates from Sandy were calculated using the same HAZUS-MH methodology as was used for flooding (see Built Environment section of Flooding Hazard Analysis) over the Sandy storm surge inundation zone, provided by FEMA MOTF. This hazard boundary was used to produce a depth grid to perform a HAZUS-MH coastal flood analysis. Note that this is not a true storm surge model as it does not account for the impacts of fast-moving surge. Over 50% of all buildings within the Sandy storm surge inundation zone were flooded (Table 2), amounting to roughly \$20 billion in total damages (Table 3).

Borough	% of Buildings Damaged
Bronx	41
Kings	42
New York	39
Queens	54
Richmond	73
City Total	53

Table 2: Percentage of buildings in Sandy inundation zone damaged due to flooding, by borough.

Borough	Capital Stock Loss (\$)	Income Loss (\$)	Total Loss (\$)
Bronx	405,881,000	2,533,000	408,414,000
Kings	5,123,469,000	62,542,000	5,186,011,000
New York	7,006,110,000	70,448,000	7,076,558,000
Queens	5,238,726,000	87,869,000	5,326,595,000
Richmond	1,998,276,000	10,594,000	2,008,870,000
City Total	19,772,462,000	233,986,000	20,006,448,000

Table 3: Direct economic losses due to flooding from Sandy, by borough.

E. POST-STORM RECOVERY

Although it will likely take years for New York City to fully recover from Sandy, much progress has already been made. In the days and weeks following the storm, roads were reopened, flooded tunnels were de-watered, public transportation resumed, power was restored, and the

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

airports gradually returned to normal flight schedules. One week after Sandy struck, many subway lines were fully or partially restored, but some elements of the system remained closed for a longer period, with repairs projected to take months or even years. However, the opening of A train service to Broad Channel and the Rockaway Peninsula in May 2013 shows the strong commitment of the City's transportation agencies to the restoration of service as quickly as possible.

In the months following Sandy, thousands of City employees and service volunteers worked tirelessly to clear 700,000 tons of debris and rebuild neighborhoods. Relief money, food, and supplies were brought in to help the hardest-hit communities. The Mayor's Office of Housing and Recovery Operations (HRO) was established to rebuild and repair homes and return displaced residents to safe and sustainable housing. The City worked with FEMA to create and implement the federal Sheltering and Temporary Essential Power (STEP) program as NYC Rapid Repairs, a free program to restore power, heat, and hot water to private homes. When the program concluded in April 2013, it had repaired approximately 11,500 homes representing more than 20,000 units. Many of the residents displaced by Sandy have since returned to their homes.

HRO also developed loan and grant programs to help businesses clean up and reopen. By mid-March 2013, 82% of the 11,295 businesses that were inundated had reopened. Additionally, the City has been working with the United States Army Corps of Engineers (USACE) to restore miles of damaged or eroded beach, boardwalk, and waterfront. This work has been occurring in areas including the Rockaway Peninsula, Coney Island, and the southern shore of Staten Island. Many beaches in these areas were open for business again during the summer of 2013.

In January 2013, President Obama signed the Disaster Relief Appropriations Act of 2013, which provides \$15.1 billion in Community Development Block Grant Disaster Recovery (CDBG-DR) funds to repair and restore areas affected by Sandy. New York City has received two allocations of funding of CDBG-DR funding: \$1.77 billion from the first round of CDBG-DR grants and \$1.447 billion from the second round of CDBG-DR grants. HUD has approved the City's action plan for the first round of funding and the City is moving forward with using these funds for rebuilding and recovery-based housing programs, business programs, infrastructure, resiliency programs, and citywide administration and planning. The City is in the process of updating this action plan to reflect the additional funding received from the second round of CDBG-DR funding.

After Sandy, FEMA issued interim mapping and elevation products to provide New Yorkers a better understanding of flood risks since the current Flood Insurance Rate Maps (FIRMs) were out of date. This included the Advisory Base Flood Elevations (ABFEs) and Preliminary Work Maps (PWMs). The City has also since revised its hurricane evacuation zones to take into account different characteristics of storms (see Coastal Storms Hazard Analysis).

A number of citywide and community-level resiliency initiatives have come about in the wake of Sandy. The most comprehensive of these is the Special Initiative for Rebuilding and Resiliency (SIRR), initiated by Mayor Bloomberg in December 2012 to explore what happened during

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

Sandy and how to prepare for and protect New York City from the impacts of climate change. The most significant accomplishment of this initiative was a report released in June 2013 entitled “A Stronger, More Resilient New York”, a comprehensive plan with actionable recommendations for rebuilding the communities impacted by Sandy and increasing the resiliency of buildings and infrastructure citywide. The report includes community rebuilding and resiliency plans for the areas most affected by Sandy: the Brooklyn-Queens waterfront, the East and South Shores of Staten Island, southern Queens, southern Brooklyn, and southern Manhattan. Many of the actions incorporated in the Hazard Mitigation Plan are from this report.

Additional city resiliency actions are included in the Hurricane Sandy After Action Report to Mayor Bloomberg, with recommendations on how the City's response capacity and performance can be strengthened in the future. In collaboration with SIRR, the City also reconvened the New York City Panel on Climate Change (NPCC), a team of climate science experts who make climate projections for New York City and offer recommendations for how the city can adapt to a changing climate. The NPCC released its second report in June 2013, coinciding with the release of the A Stronger, More Resilient New York report.

F. LESSONS LEARNED

Prior to Sandy, New York City's vulnerability to hurricanes and climate change had been well established, but few people anticipated the devastation that such a coastal storm could bring. Moreover, although New York City had already been factoring climate change into its planning, and undertaking resiliency initiatives, Sandy revealed that these efforts should be expanded and accelerated. Although a direct link between Sandy and climate change cannot be proven, sea level rise will continue to exacerbate the impacts of storm surge in the future.

A number of city needs that Sandy brought to light are outlined in the Hurricane Sandy After Action report, which groups its recommendations according to seven themes:

- I. Improved evacuation, including updated evacuation zones and better, clearer communication to help New Yorkers understand how to protect themselves from the risk of severe weather.
- II. Improved accessibility of all coastal storm-related information and services to make them available to all New Yorkers, including persons with disabilities or special medical needs, homebound populations, non-English speakers, and undocumented immigrants.
- III. Better integration of the City's data across platforms and agencies to increase situational awareness and allow more targeted, efficient response and recovery operations.
- IV. Additional capacity to respond to large-scale building inundation and loss of power, including pre-storm identification of the equipment and skilled resources likely to be needed for building restoration and better coordination with private building owners.

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

- V. Better coordination of relief to affected areas and to vulnerable or homebound populations, including more efficient deployment of volunteers and donations to residents and business owners.
- VI. The development of a mid- to long-term housing plan for New Yorkers displaced by damage from coastal storms.
- VII. Partnership with the federal and state authorities that regulate and enforce standards for private companies and utilities that provide essential services to New York City residents.

The Analysis of Sandy's impacts emphasized the need for updated FEMA flood zones and new hurricane evacuation zones. Sandy also underlined the need to rethink how to build or rebuild in vulnerable coastal areas by promoting more flood -resistant building designs and encouraging land uses that can accommodate periodic flooding. The importance of accurate weather and climate forecasting and warnings was another lesson to come out of the City's experience with Sandy. Along with this comes the need to improve coordination amongst weather experts, emergency management officials, and the general public.

12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

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12. HURRICANE SANDY RETROSPECTIVE ANALYSIS

Section III: Natural Hazard Risk Assessment

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