12. Hurricane Sandy Retrospective Analysis

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 recovering—a process that will likely continue for years. As recovery continues, the City is making plans to lessen the risk and impact of another disaster of this magnitude in the future.

B. Storm Characteristics

i. Formation and Evolution

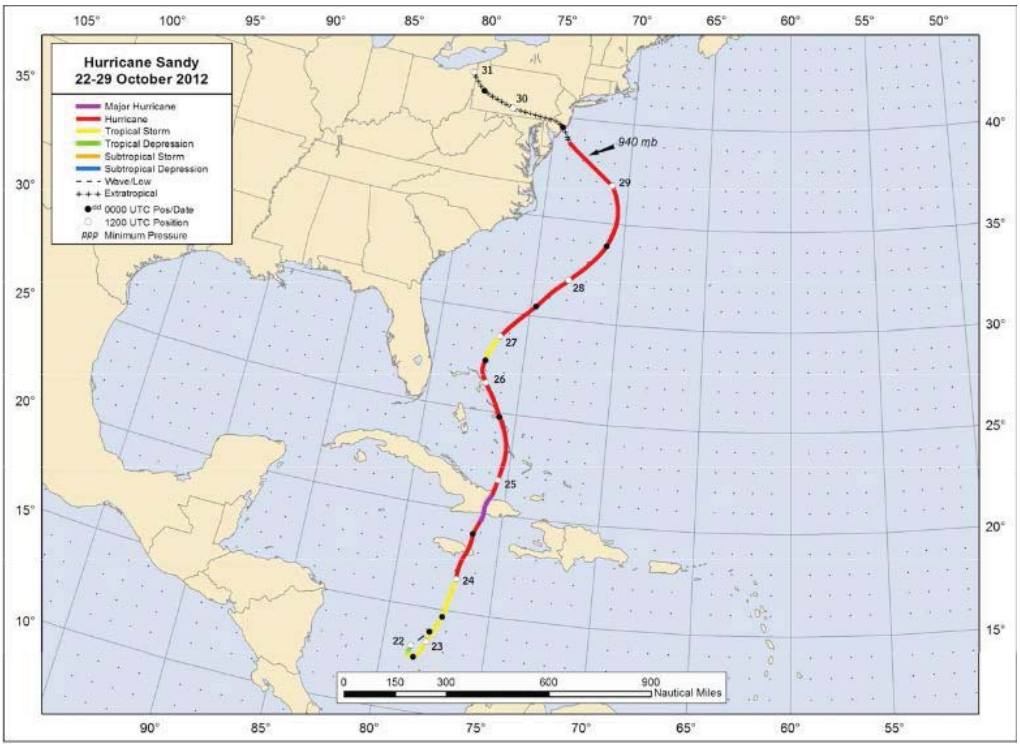
Sandy was first classified as a tropical storm in the central Caribbean on October 22, 2012, strengthening into a hurricane on October 24 before making initial landfalls in Jamaica, eastern Cuba, and the Bahamas (see Figure 3.12.88). From there, Sandy continued on a northerly path paralleling the Eastern Seaboard of the United States. As the storm tracked northward, 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 that was moving eastward at the time, causing it to morph into an incredibly dangerous hybrid storm with both tropical and non-tropical characteristics.

ii. Unique Characteristics

From a meteorological standpoint, Sandy was an anomaly. For one thing, the storm was massive, stretching nearly 1,000 miles across at its peak (see Figure 3.12.89). The storm generated waves and storm surge that were larger than what 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 this storm to make an unprecedented sharp westward turn before it made landfall.

Figure 3.12.88: Hurricane Sandy's Path (Source: NOAA).



The same weather pattern facilitated the interaction between 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, North Carolina, at 940 millibars.

and New Jersey. MTA, DOT, 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 (based on New York City's old evacuation zone for a worst-case scenario Category 1 storm) plus the Rockaway Peninsula and Hamilton Beach in Queens and City Island in the Bronx. The Mayor's Office, in coordination with the Office of Emergency Management (OEM) and the Department of Homeless Services, opened emergency shelters throughout the city. The Department of Parks & Recreation (DPR) 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.

Figure 3.12.89: Satellite Image Showing Hurricane Sandy Engulfing Much of the Eastern United States and Southern Canada (Source: Phys.org).

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 Chapter 4: 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 PM 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 AM on October 29, the Port Authority of New York and New Jersey (PANYNJ) suspended all PATH service between New York

D. Impacts on New York City

i. Landfall

On October 29, shortly after transitioning from a Cat-

egory 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 section 6. Coastal Storms). The storm'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 a storm tide that exceeded what would typically be expected from a Category 1 hurricane in some locations. Storm surge reached record levels at various points throughout New York City, including the Battery in Lower Manhattan, which experienced a 9.4-foot storm surge (see Figure 3.12.90) and a storm tide of 14.06 feet above mean lower low water (MLLW).

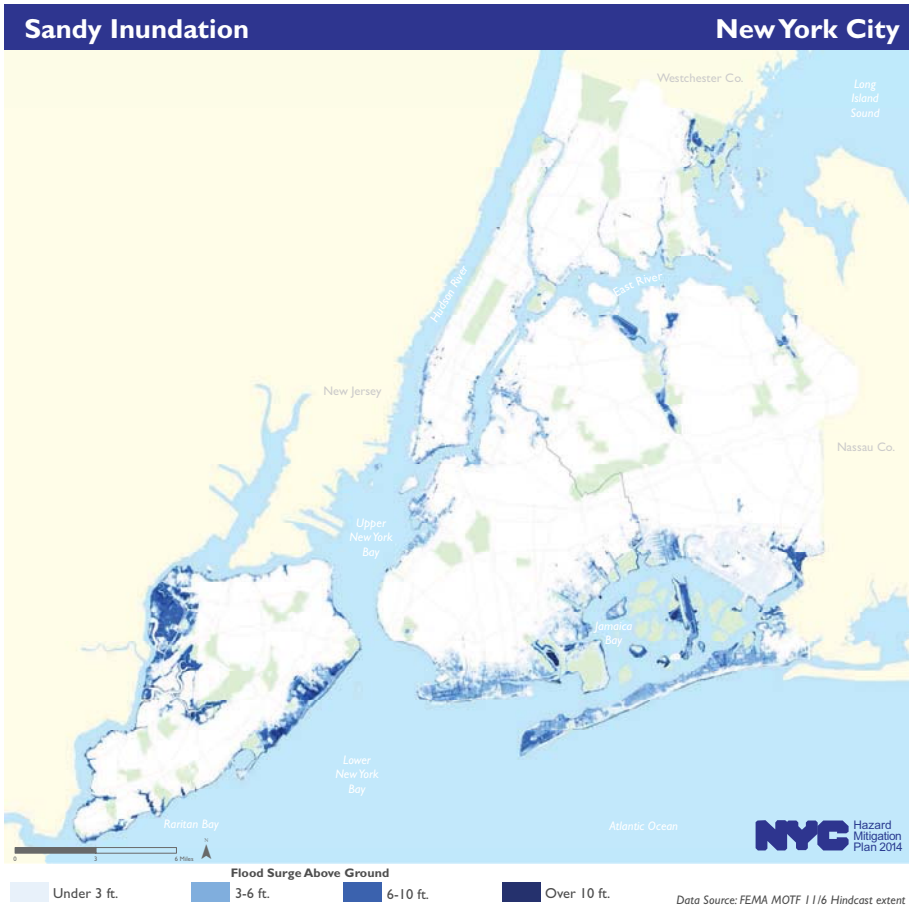
In addition to the unprecedented storm surge, massive waves crashed into ocean-facing beaches. One buoy south of New York Harbor measured a wave height of 32.5 feet.

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. In total, the storm flooded 51 square miles of New York City—17% of the city's total land mass (see Figure 3.12.90). The most affected areas were the eastern and southern shores of Staten Island, the Brooklyn/Queens waterfront, southern Queens, southern Brooklyn, and Lower Manhattan.

Figure 3.12.90: Hurricane Sandy Inundation in New York City (Source: DCP GIS)



Impacts on Social Environment

As a result of Hurricane Sandy, there were 44 deaths in New York City (the 44th death was confirmed by the New York City Office of the Chief Medical Examiner 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. Nearly half of the fatalities were among adults aged 65 or older, most due to drowning.

Approximately 450,000 New York City residents were living in areas that were inundated. Approximately one-third of these residents were displaced from their homes and forced to seek temporary housing or immediate home repairs following the storm. According to *A Stronger, More Resilient New York* (website link provided at the end section 12) (see Post-Storm Recovery, below), 27% of households in the surge area were seniors, of which 12.1% were living alone. Also disproportionally impacted were low-income residents—New Yorkers who would have difficulty covering losses despite the availability of Federal Emergency Management Agency (FEMA) assistance. Residents in New York City Housing Authority developments were hit particularly hard, with roughly 80,000 residents in 423 buildings significantly impacted.

Impacts on Built Environment

Sandy caused nearly $20 billion in damage to the city's building stock and infrastructure. Various methods have been employed to calculate the number of buildings within the inundation area, each resulting in slightly different estimates. Depending on the methodology used for calculation, there were an estimated 70,000 to 90,000 buildings within the inundation zone.

Building damage from Sandy was widespread and in many cases severe. By 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.

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 the structural characteristics of buildings (such as height and construction type) as well as age (which defined the regulations in force when the buildings were constructed) were also important determinants. Overall, older (constructed before 1961), one-story, light-frame buildings, such as bungalows originally intended for seasonal use along the immediate ocean shoreline, suffered the most structural damage. High-rise buildings generally experienced less structural damage, but they did sustain damage to generators and electrical equipment housed in basements or otherwise insufficiently elevated. Repairing this damage was in many cases costly and disruptive.

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. Power distribution systems suffered a particularly heavy blow. Inundation of five Con Edison substations and four Long Island Power Authority substations, combined with damage to overhead power lines, resulted in the loss of power to nearly two million residents.

Table 3.12.63 identifies critical facilities that were inundated during Sandy, thus satisfying New York State Office of Emergency Management (NYS OEM) Requirement F2. (For more detailed information on how these critical facilities were impacted, see *A Stronger, More Resilient New York*.)

Table 3.12.63: Critical Assets in Hurricane Sandy Inundation Area (Source: OEM GIS; analysis based on FEMA MOTF Hindcast data)

ASSET TYPE	IN INUNDATION AREA	NOT IN INUNDATION AREA	TOTAL
Airport (perimeter)*	2	0	2
Nursing home (FP)	15	158	173
Hospital (FP)	6	55	61
Police station (FP)	2	75	77
Fire station (FP)	18	210	228
EMS station (FP)	8	71	79
Wastewater treatment plant (FP)	10	4	14
Power plant (est. FP)	9	17	26
DOE school organization	94	1,719	1,813
Private school	30	818	848
College	7	116	123
Ferry landing**	N/A	N/A	47
Subway station (point)	31	459	490
Rail station	9	33	42
Cultural facility (DCP)***	1	36	37
Bus depot	6	24	30
Bridge****	29	41	70
Tunnel****	3	1	4
Major road (mi)****	235	652	887
Total	**515**	**4,489**	**5,051**
Percentage	**10%**	**89%**	**100%**

Notes:

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 Modeling Task Force (MOTF) Hindcast data was produced using the SLOSH model. It is the best available data, but 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. Data 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).

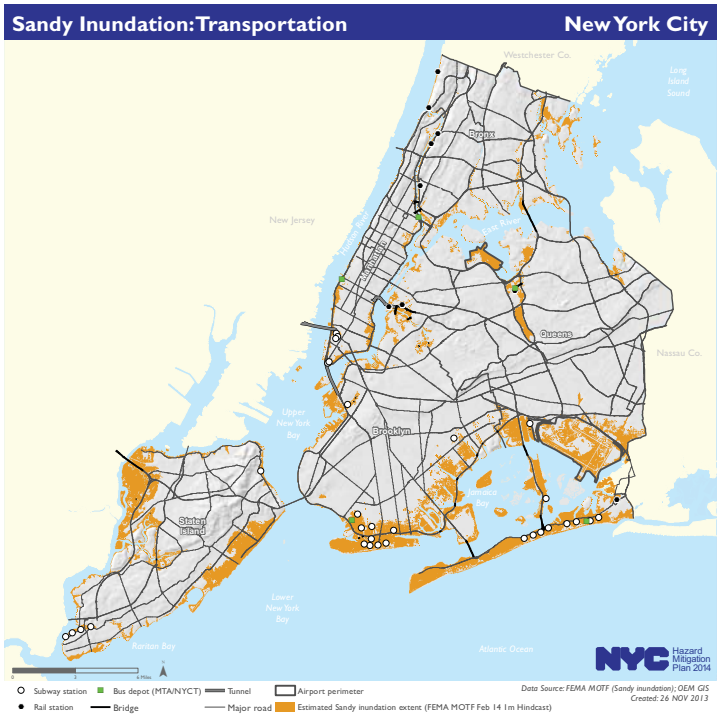
*Hindcast data shows inundation for both LGA and JFK airports, but field reports indicated only LGA was definitively impacted by surge.

**Active commuter/commercial/recreational ferry landings only (includes Ellis and Liberty Islands). Hindcast data clipped to shoreline—cannot accurately determine impact to ferry landings.

***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.

Figure 3.12.91: Transportation Infrastructure Inundated during Hurricane Sandy (Source: OEM GIS).



New York City's transportation infrastructure was severely impacted by Sandy (see Figure 3.12.91), affecting 8.5 million public transit riders and 4.2 million drivers. The MTA suffered an estimated $5 billion in damage, half of which was attributed to the inundation of subway and commuter rail tunnels. All six East River subway tunnels connecting Brooklyn and Manhattan were knocked out of service by flooding, along with the Steinway Tunnel that carries the 7 train between Queens and Manhattan, the G train tunnel under Newtown Creek, the Long Island Railroad and Amtrak tunnels under the East River, and the PATH and Amtrak tunnels under the Hudson River. 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.

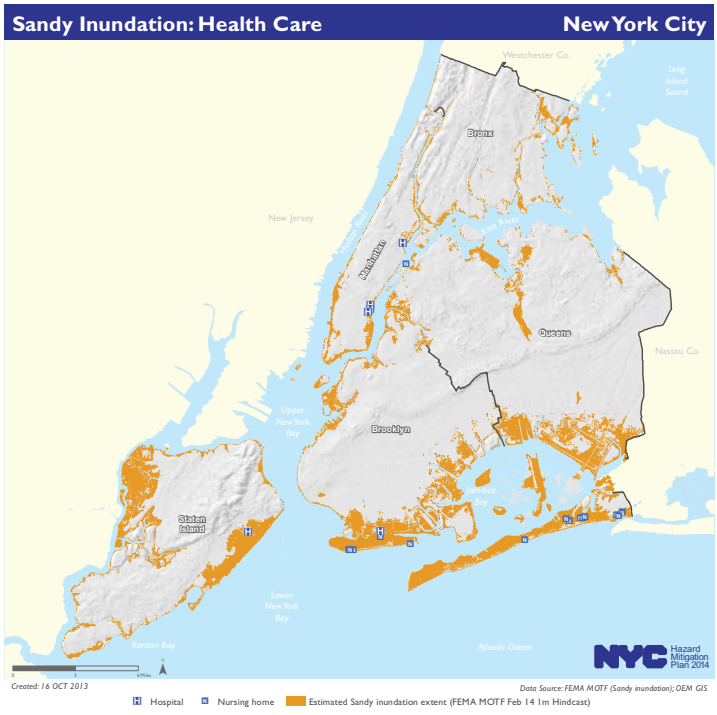
More than 500 miles of city roads suffered significant damage. Roads were littered with trees and debris, and the Brooklyn-Battery and Queens-Midtown passenger car tunnels were inundated by storm surge. While subway service was out—it took days to restore—there was gridlock on city roads and bridges.

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 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, a number of gas stations closed, and many of the ones that remained open had significant fuel shortages.

The storm placed a significant strain on the city's healthcare system (see Figure 3.12.92). In total, six hospitals were forced to close (four in Manhattan, one in Brooklyn, and one on Staten Island), which required City and State health officials, co-located at OEM, to coordinate the evacuation of nearly 2,000 patients.

Figure 3.12.92: Healthcare Facilities Inundated during Hurricane Sandy (Source: OEM GIS).



The storm 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 backup power generators.

The city's telecommunications system also experienced significant outages. 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 Rockaway Peninsula in Queens—disrupted landline and Internet service for up to 11 days. Flood damage to telecommunications equipment in buildings 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 that suffered severe damage were forced to close for the remainder of the year (see Figure 3.12.93).

Loss Estimates

Loss estimates from Sandy were calculated using the same HAZUS-MH methodology that was used for flooding (see section 3. Hazard Risk Assessment Organization and section 11. Flooding) of the Sandy storm surge inundation zone, provided by the FEMA Modeling Task Force (MOTF). This hazard boundary was used to produce a depth grid to perform a HAZUS-MH coastal flood analysis (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 storm surge inundation zone were flooded (Table 3.12.64), amounting to nearly $20 billion in total damages (Table 3.12.65).

Figure 3.12.93: Schools and Cultural Facilities Inundated during Hurricane Sandy (Source: OEM GIS).

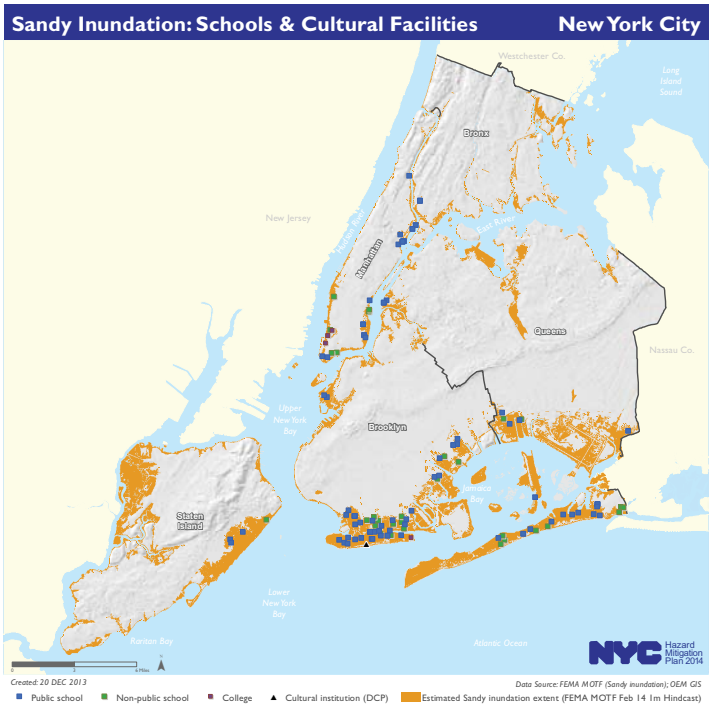


Table 3.12.64: Percentage of Buildings in Hurricane Sandy Inundation Zone Damaged due to Flooding, by Borough (Source: OEM GIS, FEMA)

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

Table 3.12.65: Direct Economic Losses due to Flooding from Hurricane Sandy, by Borough (Source: OEM GIS, FEMA)

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**

Notes: Damage estimates are calculated to the nearest $1,000.

Impacts on the Natural Environment and Recreation

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

During Sandy, 5,700 acres of New York City's park system were inundated by floodwaters, causing $800 million in damages. City parks and natural areas remained closed or inaccessible for days after the storm as crews worked to remove downed trees and debris.

The city's beaches bore the brunt of the storm's wave action, with significant impacts on the Rockaway Peninsula, Coney Island and adjacent areas of southern Brooklyn, and along the east and south shores of Staten Island. The storm damaged beachfront infrastructure and facilities. On the Rockaway Peninsula, storm surge destroyed whole sections of nearly three miles of the boardwalk, scattering wood planks into neighboring communities. Meanwhile, erosion displaced approximately 3 million cubic yards of sand. In some places, beachfronts retreated by as much as 70 feet. Sandy also pushed water over bulkheads on waterfront sites, damaging these critical coastal defenses.

Storm surge inundated and damaged coastal wetland ecosystems. However, salt marshes located in Jamaica Bay and its tributary systems remained largely clear of floating debris, with much vegetation surviving.

Flooding from storm surge also affected city marinas and piers, including the 79th Street Boat Basin in Manhattan, the World's Fair Marina in Queens, the Sheepshead Bay Piers in Brooklyn, and the Lemon Creek Marina on Staten Island. Docks, pilings, and piers were damaged, and buildings supporting these marinas were inundated, causing damage to equipment and electrical and plumbing systems.

E. Post-Storm Recovery

Although it will likely take years for New York City to fully recover, much progress has already been made. In the days and weeks following the storm, roads were reopened, flooded tunnels were "dewatered," power was restored, public transportation resumed, and the airports gradually returned to normal flight schedules. One week after the storm 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.

In the months following the storm, 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 residential structures representing more than 20,000 housing units. Many residents displaced by the storm 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.

The City has made beach restoration a priority and has been working with the United States Army Corps of Engineers to restore miles of damaged and eroded beach and coastal flood risk management structures. 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 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 CDBG-DR funding: $1.77 billion from the first round and $1.447 billion from the second round. The United States Department of Housing and Urban Development has approved the City's action plan for the first round of funding, and the City is using these funds for rebuilding and recovery-based housing programs, business programs, infrastructure, resiliency programs, and citywide administration and planning. The City is updating its action plan to incorporate the second round of CDBG-DR funding.

After Sandy, FEMA issued interim mapping and elevation products to provide New Yorkers with a better understanding of flood risks because the Flood Insurance Rate Maps (FIRMs) in effect at the time of the storm were out of date. These products included Advisory Base Flood Elevations and Preliminary Flood Insurance Rate Maps (Preliminary FIRMs). The City also revised its hurricane evacuation zones, placing a greater focus on the varying angles of approach for different storms (see section 6. Coastal Storms).

A number of resiliency initiatives have come about in the wake of the storm. 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 Sandy and how to prepare for and reduce New York City's risk from the impacts of climate change. In June 2013 SIRR released a report 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 Brooklyn-Queens waterfront, the East and South shores of Staten Island, southern Queens, southern Brooklyn, and southern Manhattan. Many of the actions in the 2014 Hazard Mitigation Plan related to coastal storms and flooding are adapted from this report.

In collaboration with SIRR, the City 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. In 2010 the NPCC had released its first publication, *Climate Change Adaptation in New York City: Building a Risk Management Response*. In June 2013 the NPCC released its second publication, *Climate Risk Information: Observations, Climate Change Projections, and Maps*, (website link provided at the end of section 12) coinciding with the release of *A Stronger, More Resilient New York*.

Additional city resiliency actions are included in the *Hurricane Sandy After Action* (website link provided at the end of section 12) report to Mayor Bloomberg, with recommendations on how the City's response capacity and performance can be strengthened in the future. The report groups its recommendations according to seven themes:

- 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.
- 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.
- Better integration of the City's data across platforms and agencies to increase situational awareness and allow more targeted, efficient response and recovery operations.
- 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.
- 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.

- The development of a mid- to long-term housing plan for New Yorkers displaced by damage from coastal storms.
- Partnership with the federal and state authorities that regulate and enforce standards for private companies and utilities providing essential services to New York City residents.

F. Lessons Learned

Sandy brought a number of city needs to light. The analysis of the storm's impacts emphasized the necessity for updated FEMA flood zones and new hurricane evacuation zones. Sandy 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. Sandy also highlighted the need to ensure access to critical services for older adults, populations with disability, and other vulnerable communities. 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 among weather experts, emergency management officials, and the general public.

The storm also 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. 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.

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Website Links:

A Stronger, More Resilient New York:

http://www.nyc.gov/html/sirr/html/report/report.shtml

Climate Risk Information: Observations, Climate Change Projections, and Maps:

http://www.nyc.gov/html/planyc2030/downloads/pdf/npcc_climate_risk_information_2013_report.pdf

Hurricane Sandy After Action:

http://www.nyc.gov/html/recovery/downloads/pdf/sandy_aar_5.2.13.pdf