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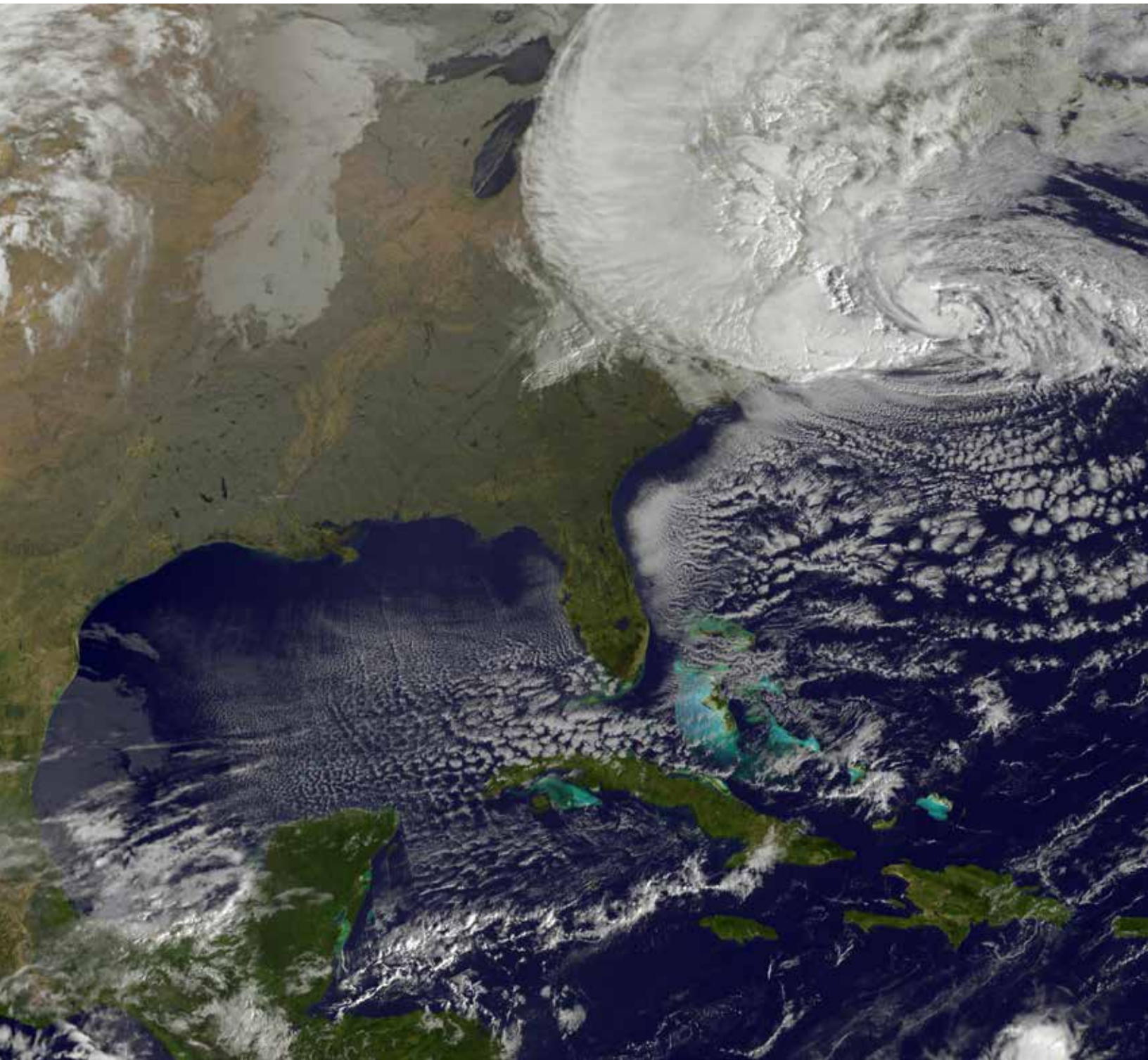
# **Preparing for Climate Change:** Lessons for Coastal Cities from Hurricane Sandy

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## **ABOUT NRDC**

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## EXECUTIVE SUMMARY

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Scientists warn that the damage wreaked by Hurricane Sandy is a glimpse of what is to come with future storms as climate change fuels rising seas and more powerful extreme weather events. NRDC's analysis of the damage, in human terms, finds New York City woefully unprepared for this future. NRDC's new mapping analysis estimates that nearly 290,000 New Yorkers in the five boroughs of New York City were unexpectedly flooded by Sandy's stormwaters. The Federal Emergency Management Agency (FEMA) flood zone maps in effect when Sandy struck were nearly 30 years out of date, leaving hundreds of thousands of people less prepared for the disastrous flooding than they might have been. Flooding covered 46.2 square miles, an area 65 percent larger than the flood-vulnerable area identified by FEMA's outdated maps; the agency's "100-year flood zone" left out an estimated 21.4 square miles of the flooded city. This unexpectedly flooded area is home to tens of thousands of people highly vulnerable to flooding's harmful health effects; these include more than 16,000 children under 5 years old and 43,000 people 65 years and older, who must rely on others to help them get safely out of harm's way in emergencies; and nearly 90,000 people whose economic means to recover are especially limited. More than 121,000 New Yorkers lived in public housing developments that were flooded or lay within the flood risk zones. Fifty-two such buildings were impacted by flooding, and over 61,000 people in 28 of those NYCHA buildings, were outside FEMA's 100-year flood risk area.

Projections suggest that the extent of flooding New York City experienced with Sandy could become a regular occurrence (every two years) by 2100 if rapid sea level rise occurs. New York City is not alone, and the impact of Sandy highlights the vulnerability of coastal cities nationwide. To improve coastal resiliency, FEMA has an important opportunity to include the effects of climate change in its future flood-zone mapping efforts, in New York City

and across the nation. Without this action by FEMA, large numbers of storm-vulnerable communities will be less than fully prepared for climate change's effects and are likely to find themselves in harm's way. At the same time that communities take steps to help reduce the worst future effects for coastal communities, action is also needed to limit heat-trapping carbon pollution that is fueling climate change and the sea level rise that heightens storm surge.

## 1. WHAT HAPPENED DURING HURRICANE SANDY?

On October 29, 2012, Hurricane Sandy made landfall and wreaked havoc across the northeastern United States. At 1,000 miles in diameter, Hurricane Sandy was the largest storm ever recorded in the Atlantic Ocean and affected states from Maine to Florida, causing 234 deaths in eight countries.<sup>1</sup> Because of its huge size, and unusual trajectory as it barreled into New York and New Jersey at high tide,<sup>2</sup> Sandy drove a record high storm surge into the coast.<sup>3</sup> At the Battery in lower Manhattan, the water level reached a record-high of 13.88 feet, which included a 9.23-foot storm surge, an all-time record at that location.<sup>4</sup> Although peak wind speeds were not similarly record-breaking, the storm's extent was notable: Sandy combined tropical storm-force winds that extended out 900 miles from its center with extremely low air pressure, which generally makes for stronger storms.<sup>5,6</sup>

## 2. WHAT DID SANDY DO IN THE NEW YORK CITY REGION?

In New York and New Jersey, more than 375,000 housing units were damaged or destroyed.<sup>7</sup> Sandy's winds and flooding knocked out electricity for more than 8.5 million people<sup>8</sup> and the loss of power was crippling, shutting down heating systems, knocking out elevator service in high-rise buildings, and interrupting life-support and other crucial systems. Some people were trapped for days and even weeks on upper floors of buildings, needing prescription medicines or medical care yet unable to get it.

Hurricane Sandy caused an estimated \$75 billion in damages in the United States, with only half of that covered by insurance.<sup>9</sup> In New York City's five boroughs, hundreds of thousands of people were affected by Sandy's floodwaters, winds, rains, and longer-term disruptions to infrastructure, businesses, and lives.

Besides the immediate effects of Sandy's storm surge on public health—fatalities, injuries, fires from short-circuited electrical systems—many components of critical public health infrastructure were devastated. Work, school, and medical care were all interrupted by flooding and loss of power. More than 1,000 patients were evacuated from New York City hospitals.<sup>10</sup> Longer-term health effects from flood damage became apparent among New Yorkers in the weeks that followed Sandy. Waterborne illness risks increased

from contact with sewage- and chemical-contaminated floodwaters on city streets and beachfronts. Moisture and mold damage to water-logged homes and schools created serious indoor air quality problems. Respiratory complaints soared, not only for residents but also among relief workers exposed to debris dust and other particulates. People forced to leave their homes and move into temporary shelters were at risk of contracting respiratory and other infections in close quarters. Among those trying to find temporary power sources, improper use of generators or space heaters led to carbon monoxide poisonings.<sup>11</sup> The experience of the storm, displacement, and cleanup disrupted hundreds of thousands of people's lives and increased the number of people in need of counseling for stress as well as longer-term psychosocial impacts.<sup>12</sup>

The effects of flooding were felt far beyond the areas identified as flood-vulnerable by FEMA. FEMA—the Federal Emergency Management Agency—is in charge of creating and issuing flood risk zone maps. The maps are applied in the National Flood Insurance Program (which is why they are sometimes called FIRMs, or Flood Insurance Rate Maps). These maps also are used by state and local governments to identify vulnerable areas; to help drive preparation, evacuation, and response planning; and to help developers and homeowners understand the risks associated with a property. Community officials use the flood maps to administer flood management regulations and reduce flood damage; lending institutions and federal agencies apply the maps when making loan decisions or providing grants for safe building construction.<sup>13</sup> Homeowners and businesses must make informed decisions about a location's relative chances of being flooded, and they assume that being outside FEMA's flood zone gives some assurance that they are beyond the high-risk areas.<sup>14</sup>

When Sandy struck the Northeast on October 29, 2012, the flood zone maps in use were out of date by nearly 30 years. Last updated in 1983, the FEMA flood zone maps then in use did not include the latest data on flood elevations or the current science about local sea level changes, which increase coastal flood risks. The record-breaking flood height and storm surge that accompanied Sandy was on par with the New York City Panel on Climate Change projections for the 2050s. This single incident reached levels then projected to occur 35 years from now.<sup>15</sup> By relying on FEMA's outdated maps and not taking advantage of the best available science on local climate change impacts, vast areas of the city did not know they were at risk. ProPublica reported that state and city

officials had been asking for map revisions for years, to apply “technology and modeling methods that didn’t exist when they were first drawn in the 1980s.” But FEMA “ignored state and city officials’ appeals to update the maps with better data until it was too late.”<sup>16</sup>

Here’s what we know about climate change and why it makes the East Coast more vulnerable to Sandy-level flooding: Climate change is one of the main factors causing sea level rise globally, as warmer oceans thermally expand and land-based ice melts.<sup>17</sup> This raises the risk for flooding in coastal cities. Sea level rise along the mid-Atlantic coast between 1950 and 2012 has already increased the probability of Sandy-like flooding by one-third to two-thirds. According to a recent government report, “Coastal communities are facing a looming SLRrel [relative Sea Level Rise] crisis, one that will manifest itself as increased frequency of Sandy-like inundation disasters in coming decades along the mid-Atlantic and elsewhere.”<sup>18</sup> FEMA’s practice of estimating flood risk by looking backward (i.e., using historical flood levels) rather than forward (i.e., considering projections of climate change) significantly underestimates both current and future flooding risks facing the nation’s coastal communities.

### 3. WHO IN NEW YORK CITY WAS IMPACTED BY SANDY’S FLOODWATERS: NRDC’S NEW MAPPING ANALYSIS

The goal of NRDC’s analysis was to get a clearer picture of the human cost of underestimation of flooding risks. We wanted to identify the inundated areas beyond FEMA’s 100-year flood zone and understand who and what were unexpectedly flooded there during Hurricane Sandy. We worked with experts in GIS (Geographic Information Systems) mapping to compare publicly available data on how much of New York City was actually flooded by Sandy, versus FEMA’s 1983 flood zone maps; then we superimposed information about the vulnerable people, health facilities, and schools that were in the areas not expected to flood. [See the Methods sections of the Appendix for more details on data sources and analyses.]

The total area flooded was 46.2 square miles in area. Of that total, the area outside FEMA’s then-defined 100-year flood zones and therefore unexpectedly flooded, estimated at 21.4 square miles in NRDC’s new map analysis, was 65 percent larger than the 33 square miles mapped by FEMA in 1983 as being within the 100-year flood zone. NRDC’s analysis shows that, in the 21.4-square-mile area that flooded but was not identified as being at risk of flooding, tens of thousands of people lived, worked, and attended school, potentially underprepared for Hurricane Sandy.

People and institutions in unexpectedly flooded areas	
Total residents	289,719
Children under age 5	16,456
People age 65 and older	43,286
People living in poverty*	89,953
New York City Housing Authority (NYCHA) public housing residents:	
Those in areas unexpectedly flooded	61,052
Those within FEMA flood zone or unexpectedly flooded	121,560
Hospitals and nursing homes	18
Residential medical facilities and senior centers	31
Schools	
Daycare or Head Start facilities	74
Elementary or secondary schools	80
Wastewater Treatment Plants (WWTPs)	4

\* Defined here for NYC as people whose income is less than twice the federal poverty level (FPL). See Methods.

**Figure 1** shows that in 2012 when Sandy struck, hundreds of thousands of New Yorkers were unexpectedly inundated: an estimated 289,719 residents. This estimate included tens of thousands of New Yorkers who are among those most vulnerable to flooding: more than 16,000 children under 5 years of age, more than 43,000 people age 65 and older, and nearly 90,000 people living in poverty.

**Figure 2** shows that, of the nearly 302,000 housing units flooded in New York City, approximately 12 percent were rental units owned and run by the New York City Housing Authority (NYCHA), the city's public housing organization.<sup>19</sup> NRDC estimates that 121,560 NYCHA residents lived either in the FEMA flood zone area or in NYCHA units unexpectedly flooded by Sandy (i.e., beyond FEMA's mapped 100-year flood zone). These people lived either in one of the 28 NYCHA developments unexpectedly flooded (61,052 residents in these buildings, or 54 percent of NYCHA's flooded buildings), or in one of the 34 NYCHA developments within FEMA's mapped areas.

Home to more than 400,000 New York City residents in total, NYCHA housing is often plagued by mold and water intrusion as a result of significant building disrepair. This will only be exacerbated by the consequences of climate change—more frequent storms, sea level rise, increased flooding—without the necessary building repairs and upgrades.

**Figure 3** shows that 18 hospitals, inpatient units, or nursing homes, 22 residential medical facilities, and 9 senior centers were located in areas unexpectedly flooded by Sandy. Storm response strategies, such as rapid evacuation or sheltering in place, present health risks to patients or elderly residents. While New York City hospitals saw some heroic evacuations of more than 1,000 patients as floodwaters rose, storm surge crippled outpatient services and flooded scores of nursing homes, especially in the Rockaways area of Queens. Safe evacuation of frail or medically incapacitated people requires advance planning, adequate staffing, and technical expertise and is especially challenging when power outages mean failure of medical equipment and elevators and patients risk exposure to cold or floodwaters.<sup>20</sup>

**Figure 4** shows that 74 daycare or Head Start facilities and 80 elementary or secondary schools were in areas of unexpected inundation. Since schools are often used as neighborhood shelters and relief centers, this flooding not only displaced students but hampered relief efforts. Flooding of school buildings also increases the chances of moisture and mold damage, which poses significant long-term health risks, especially for children.

**Figure 5** shows that, of the 14 municipal wastewater treatment plants in New York City, four were flooded unexpectedly by Sandy because they stood outside the 100-year flood zone area in effect at the time. When such plants are inundated by floodwaters, untreated sewage can overflow into storm sewers and neighborhood streets. The Rockaway facility in Queens was completely submerged. The Oakwood Beach plant on Staten Island was effectively an island, as the surrounding community was flooded by the storm surge.<sup>21</sup> From these four WWTPs, 600 million gallons of partially treated or untreated sewage overflowed into area waterways.<sup>22</sup>

More detailed information can be found in the Methods and associated data (see Tables 1-4) in the Appendix.

**FIGURE 1**

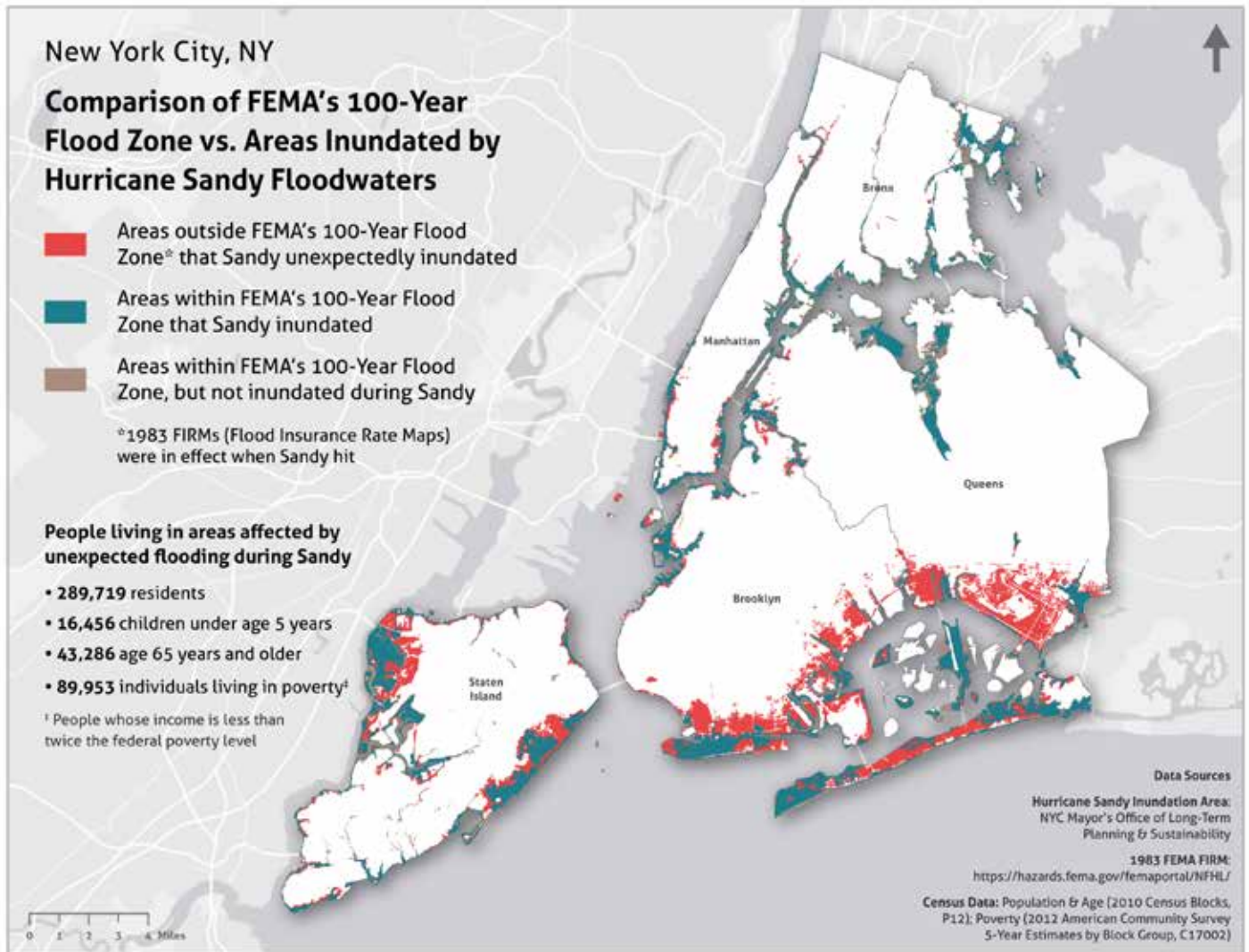
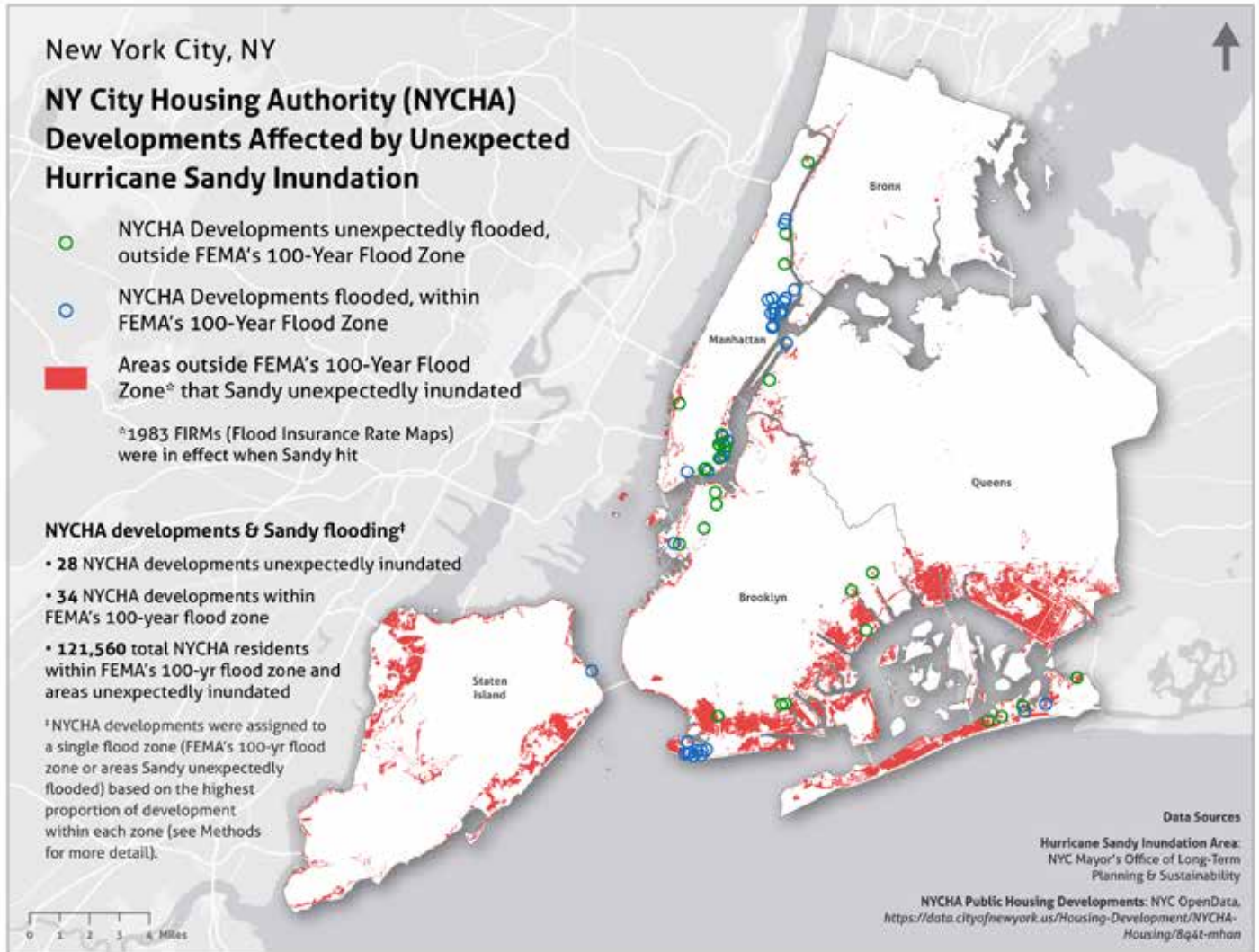
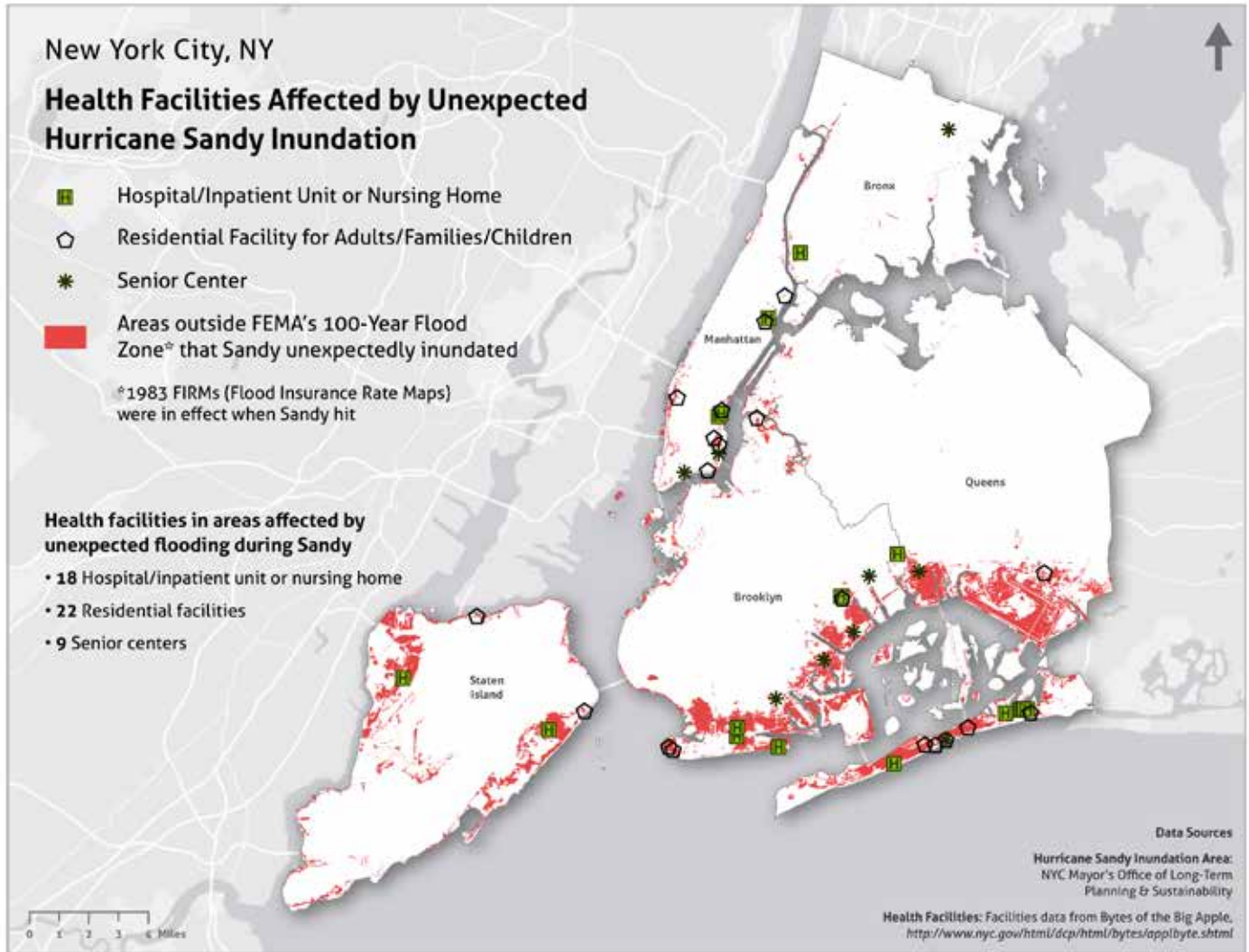




FIGURE 2



**FIGURE 3**



**FIGURE 4**

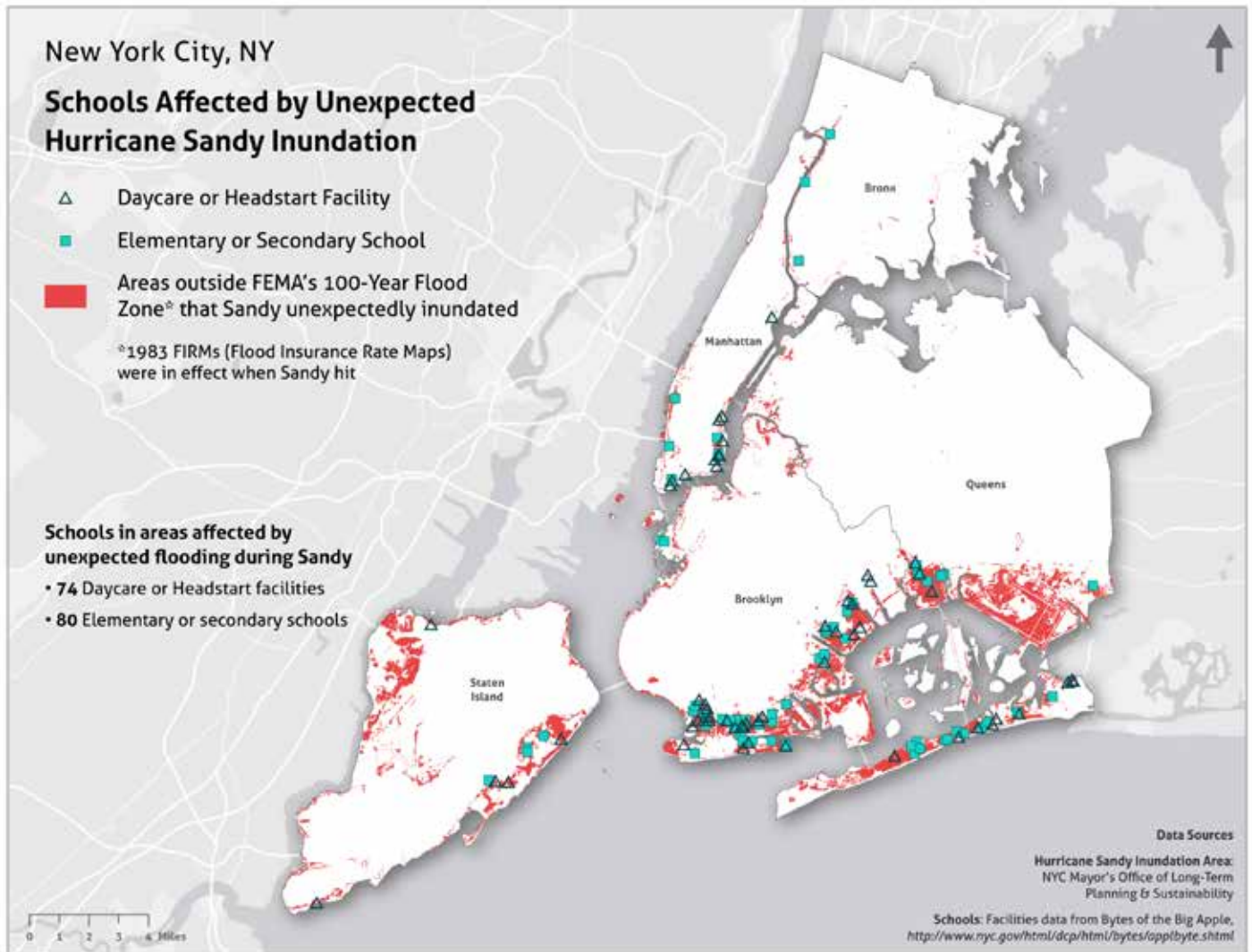
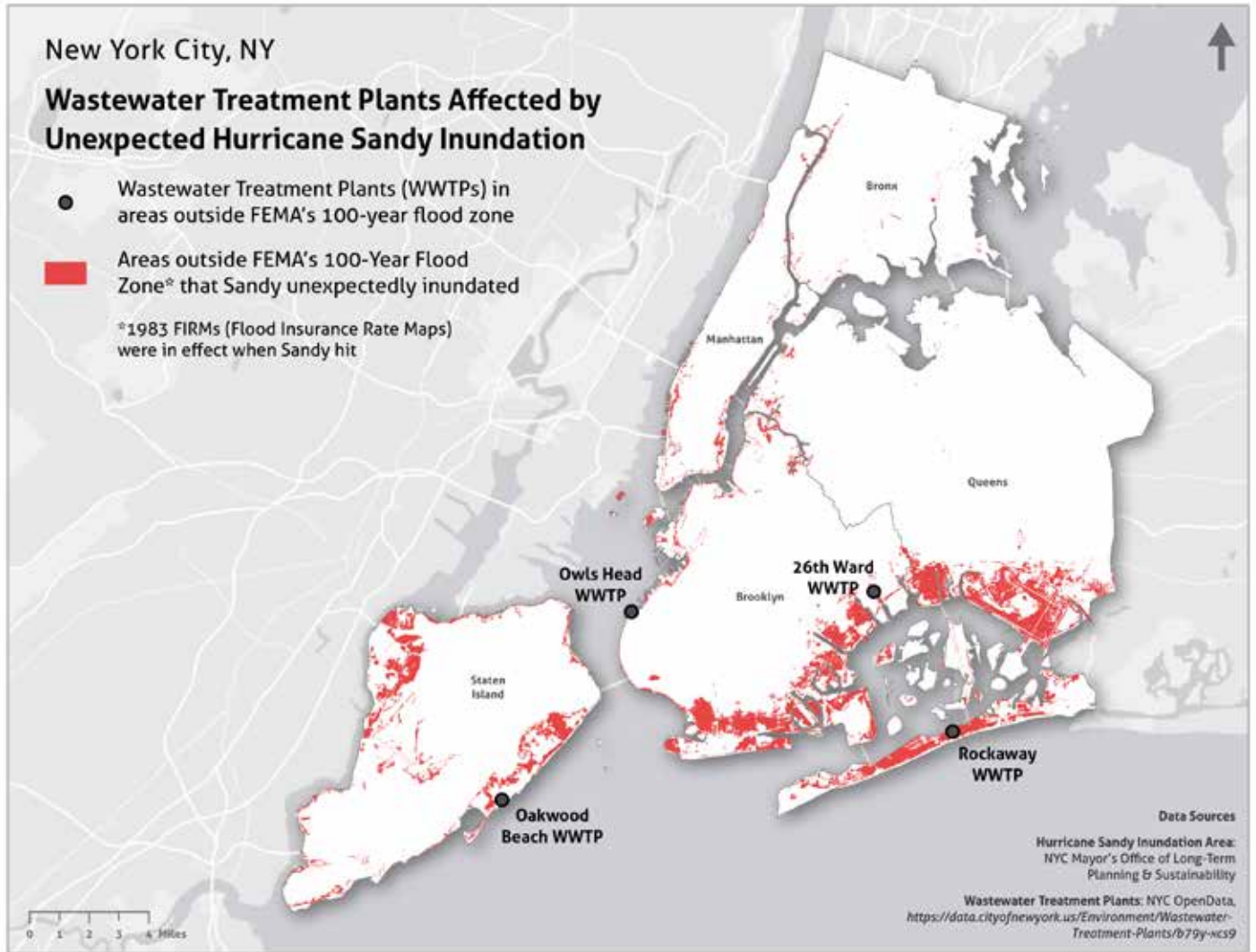


FIGURE 5



#### 4. WHAT DID WE LEARN ABOUT PUBLIC HEALTH PREPAREDNESS FROM HURRICANE SANDY?

##### **Coastal cities are increasingly flood-vulnerable because of climate change.**

Climate change is fueling more intense coastal flooding in part because sea level rise in turn amplifies storm surge heights. Sea level has already risen in New York City by about 13.2 inches (1.1 feet) since 1900, nearly twice the observed global rate of sea level rise, according to the New York Panel on Climate Change (NPCC2), which reconvened in 2013 after Hurricane Sandy struck.<sup>23</sup> Sea levels in the Northeast from Cape Hatteras, North Carolina, to Long Island are rising faster than average, according to two recent studies that suggest New York City is in a “hot spot” of relatively rapid sea level rise.<sup>24</sup> In decades to come, the effects of sea level rise and associated storm surge flooding could create immense challenges for New Yorkers and other coastal communities in the Northeast. If a storm of a size similar to Sandy’s—or even a storm of lesser intensity—were to strike the Northeast again, it could cause even more damage because sea levels are projected to rise another 7 to 31 inches by 2050 (11 to 24 inches is the midrange estimate).<sup>25</sup> A recent study from the National Oceanic and Atmospheric Administration found that flooding and storm surges similar to those experienced during Sandy could strike Lower Manhattan and Sandy Hook, New Jersey, every 20 to 50 years, assuming an “intermediate high” sea level rise (3.9 feet), by the year 2100. If sea levels rise 6.6 feet (the “high” projection), a level of coastal flooding similar to Sandy’s could happen every year or two by 2100.<sup>26</sup>

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***Sea level at the Battery in New York City has already risen a little over a foot since 1900. Climate change will speed this effect in years to come: in 40 years, sea level in NYC is likely to rise another 11 to 24 inches, with 31 inches possible by the 2050s.***

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##### **Current flood preparedness policies are not adequate, in part due to FEMA’s outdated process for flood risk mapping.**

The flood zone maps that FEMA began updating for the New York–New Jersey region in 2013 still don’t consider future vulnerability from climate change.<sup>27</sup> Moreover, they use old information sources, and they do not take into account the actual areas affected by Sandy flooding. Federal law under the Biggert-Waters Flood Insurance Reform Act of 2012 requires FEMA to factor in climate change, yet this is not happening as yet. These new New York City maps, due for finalization by 2015, will soon be out of date, leaving people with a false impression of flood risks. They will put people in harm’s way and encourage development and redevelopment in areas that have a higher risk of flooding than is actually portrayed.<sup>28</sup> And the preparedness issues that New York City faces with its flood zone maps also apply in coastal cities across the country.

##### **Especially in densely-populated cities, the impacts of coastal flooding can be huge.**

Hurricane Sandy serves as a wake-up call for the whole country. An estimated 53 percent of Americans live in coastal counties now, and that number is expected to climb to 75 percent by 2025.<sup>29</sup> From 1970 to 2010, the U.S. population living in coastal areas increased by 39 percent.<sup>30</sup>

##### **Vulnerable populations are especially in need of heightened flood preparedness.**

During coastal storms, some populations are more vulnerable than others. The impact of flooding, lack of power and water, and disrupted medical care can be more devastating, and recovery more difficult. Especially storm-vulnerable groups include older adults, young children, and people living in low-income households, along with people with physical or mental health problems, members of disadvantaged racial or ethnic groups, and people without strong social-support networks.<sup>31</sup> Two weeks after Sandy struck, The New York Times reported that nearly half of the 43 people who died in New York City the storm were 65 or older, many from drowning at home; others died from storm-related injuries, hypothermia, and other causes.<sup>32</sup> Social isolation affects many aging people today, as families become more widely dispersed geographically, among other reasons. The issue is growing along with the size of this population. The proportion of older Americans in the U.S. population is increasing at the fastest rate in a century: In 2010, about 13 percent of the population was 65 or older, but by 2030 that segment will have risen to nearly 20 percent. Older New Yorkers living in waterfront assisted-living facilities were

heavily impacted by Sandy, as were retirees attracted to beach homes and the elderly poor who lived in flood zones. Older people may be among those least likely to evacuate if they can't drive or find it difficult to take public transit.<sup>33</sup>

### **For cities to be more climate-resilient, greater preparedness is urgently needed.**

FEMA needs to include the effects of climate change in flood zone mapping in order to give individual homeowners, communities, and city and state agencies the most up-to-date available information to prepare for coastal flooding. New, actionable policies at the federal, state, and local levels to incorporate the lessons learned from Hurricane Sandy are important steps to better protect residents of New York City and coastal communities across the nation, who will continue to be threatened as climate change continues. Otherwise, an opportunity to improve preparedness and create healthier, more secure communities will be squandered.<sup>34</sup>

## **5. WHAT NEEDS TO BE DONE: RECOMMENDATIONS TO ENHANCE CLIMATE-HEALTH PREPAREDNESS AND COASTAL FLOOD RESILIENCE.**

We must increase the climate resilience of communities across the United States. A growing number of sources can help planners estimate how climate change will affect the extent of storm-related flooding. Opportunities are available to protect public health at a number of levels.

### **AT THE LOCAL LEVEL**

■ **Public housing.** The maps in this report show that more of NYCHA's public housing residents are at risk from flooding than was originally thought. NYCHA should be paying attention to this and acting to protect its residents, especially vulnerable kids, elders, and people with respiratory illnesses like asthma. By taking actions to make its buildings more climate-resilient, NYCHA has a role to play in flood preparedness and in NYC's climate-health preparedness, and a responsibility to alert its residents of ways to reduce flooding-related health risks. The post-Sandy priorities detailed by NRDC on Sandy's one-year anniversary<sup>35</sup> include "establishing environmental health protections, resiliency planning, and recovery programs aimed specifically at protecting those most vulnerable to flooding, including environmental justice communities, people with pre-existing medical conditions, and persons without the financial resources to fully protect their families' health." Some of the specific steps that could be taken include alerting residents with pre-existing medical conditions to secure additional

prescription refills, locating possible food distribution centers in advance, and sharing information on safe use of generators to avoid carbon monoxide poisoning.<sup>36</sup> These priorities can be applied by NYCHA to develop enhanced plans for rapid response after storms, engaging community leaders and social networks to develop better-targeted responses that take into account flooding's disproportionate effects on public housing residents. Conducting flood emergency drills and practices can provide important insights before another wake-up call like Sandy.

■ **Schools.** Since schools often serve as community shelters and relief locations, conducting vulnerability assessments of schools' flood risks under changing climate conditions can bolster community resilience. Baseline surveys of neighborhood health risks, such as waste storage facilities that are in close proximity to schools, playgrounds, and other critical community service sites, can provide more detail on possible post-flood health hazards. Establishing decentralized power sources for schools, such as solar, and upgrading schools' emergency generators will offer protections both to students and to the surrounding community.

■ **Health care facilities and senior centers.** Conducting storm and flood vulnerability assessments for both public and private health care facilities will help determine which ones need the most advance planning in order to provide continued physical and mental health care and medications when storms strike. Determining whether evacuation or sheltering in place is most appropriate and then conducting drills with staff and residents can help establish systems that will be better prepared to respond to the health challenges of storms and flooding. Newly proposed federal regulations<sup>37</sup> to prepare healthcare facilities nationwide for climate change could offer health benefits to cities and states that far outweigh the costs.

■ **Critical infrastructure, like wastewater treatment plants.** Critical infrastructure, including energy generation and distribution systems, drinking water and wastewater treatment facilities, and public transportation and emergency response systems, must be protected and made more resilient to future disasters. Raising the level of critical equipment at WWTPs well above the elevations that are at risk of future flooding, with the projected effects of climate change taken into account, can help protect them from more flooding. Increasing the amount of investment in cost-effective green infrastructure can help absorb stormwater runoff and mitigate storm surge-related flooding in ways that also beautify both coastal and inland communities.<sup>38</sup>

The NPCC2 report on ways to enhance New York City's resilience to major climate change risks, including coastal flooding, is scheduled for release in the spring of 2014. This panel was reconvened by the city on an emergency basis after Hurricane Sandy "to update its projections to inform planning for rebuilding and resiliency post-Sandy."<sup>39</sup> The recommendations from NPCC2 could serve as useful guidelines for identifying and prioritizing strategies to increase the City's resilience to coastal flooding that take climate change's effects into account, via infrastructure and administrative improvements, and monitoring that the city can undertake.

## AT THE STATE LEVEL

The post-Sandy priorities for government action detailed by NRDC on Sandy's one-year anniversary include not only establishing environmental health protections for the communities most vulnerable to flooding, but also the reform of state and federal environmental review procedures "so that proposed projects fully analyze resilience and energy efficiency alternatives in light of climate change realities."

## AT THE NATIONAL LEVEL

■ **FEMA has an important role to play in establishing climate-resilient flood zone mapping.** The agency has an opportunity in New York City to revise its Preliminary Flood Risk maps to factor in climate change impacts before releasing the final versions in 2015. Biggert-Waters actually requires FEMA to incorporate climate change impacts when updating flood maps (see Section 216).<sup>40</sup> FEMA now has an opportunity and an obligation to incorporate the effects of climate change—higher sea levels, greater storm surge heights, and more areas at risk of inundation—into the next set of maps being developed.

As described above, FEMA's preliminary flood risk maps fail to take into account future climate impacts, like sea level rise and changing precipitation patterns; and fail to reflect any sea level rise that occurred in the past decade because they use data only from 1983 to 2001. This could cause the agency to underestimate current sea levels by as much as 3 inches. The maps have been calibrated to historic flooding/storm events but do not include information from Hurricane Sandy.<sup>41</sup>

In New York City, the agency has time to revise the updated maps to include the latest local climate change impact estimates, before the maps are finalized in 2015.

It is essential that FEMA incorporate the most current climate change science and modeling on coastal storm surge and flooding into its Flood Map Program nationwide, to help address gaps in storm preparedness. Its actions will promote health equity in nationwide flood preparedness and response activities, increase public health protection, and help reduce damage costs.

■ **To limit the worst effects of climate change and lessen risks to coastal cities,** we must take action to reduce the pollution fueling climate change and weather-related disasters. The U.S. Environmental Protection Agency has proposed the first-ever limits on carbon pollution from new power plants, with rules for existing plants expected in 2014 – combined, the sources of nearly 40% of carbon pollution emissions in the U.S.<sup>42</sup> Significantly scaling up energy efficiency and increasing the use of renewable energy sources also act to limit heat-trapping carbon pollution, helping to create healthier and more secure communities.

Paying attention to climate change and how it affects flooding has a payoff: The costs of flood preparedness measures are outweighed by the benefits of reduced flood damage by a factor of five to one.<sup>43</sup> The lessons learned in New York City from Hurricane Sandy reach far beyond the city's five boroughs. The best available science must be applied to help protect coastal residents' health and welfare nationwide. Every state with coastal residents needs to be acutely aware that FEMA's flood maps don't yet include climate change's projected effects. Until the agency's practices change, each state must on its own include projected sea level rise, higher storm surge heights, and new areas at risk of flooding in its flood-preparedness plans.

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## APPENDIX: METHODOLOGY USED IN DEVELOPING MAPS AND FACILITY ANALYSIS

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To create the map series for the Issue Brief analysis, NRDC consultants accessed publicly-available map files that described the locations of existing infrastructure that was critical to the health and lives of New Yorkers: health facilities, schools, and wastewater treatment plants. Furthermore, we tallied the numbers of some of the most flood-vulnerable residents of New York City—older adults, young children, public housing residents, or people living in poverty—who lived in areas that Sandy’s unexpectedly flooded. Below we detail the data sources used to develop each map, and the methods used to assemble the data layers.

### FIGURE 1: BASE MAP

#### Method

The base map was created using FEMA’s 1983 Flood Insurance Rate Map and the Mayor’s Office of Long-Term Planning and Sustainability Hurricane Sandy Inundation Area from February 2013. The FEMA layer was filtered to include only those areas having a 1 percent chance of being equaled or exceeded in any given year (i.e. 100-year flood zones), also known as Special Flood Hazard Areas or SFHAs ([www.fema.gov/floodplain-management/flood-zones](http://www.fema.gov/floodplain-management/flood-zones)); for more specific information, see: [msc.fema.gov/webapp/wcs/stores/servlet/info?storeId=10001&catalogId=10001&langId=-1&content=flood zones&title=FEMA+Flood+Zone+Designations](http://msc.fema.gov/webapp/wcs/stores/servlet/info?storeId=10001&catalogId=10001&langId=-1&content=flood%20zones&title=FEMA+Flood+Zone+Designations).

The final FEMA/Sandy layer was created by overlaying the FEMA flood layer and the Sandy inundation layer (using the union tool in our GIS software). This provided us with three unique categories:

1. Areas outside FEMA’s 100-year flood zone that Sandy unexpectedly flooded
2. Areas within FEMA’s 100-year flood zone that Sandy flooded
3. Areas within FEMA’s 100-year flood zone that were not flooded during Sandy

For each flood area we calculated the total area in square miles, total resident population, proportion of the population under age 5, proportion of the population age 65 or over, proportion of the population who were nonwhite, and proportion of population living in poverty, defined here as individuals whose income is less than two times the federal poverty level. The Census variable that was used is “C17002,” defined as ratio of income to poverty level in the past 12 months, from the population for whom poverty status is determined. See Appendix Table 1.

#### Data sources

- Hurricane Sandy Inundation Area: New York City Mayor’s Office of Long-Term Planning and Sustainability
- 1983 FEMA FIRM: [hazards.fema.gov/femaportal/NFHL/](http://hazards.fema.gov/femaportal/NFHL/)
- Census data: Population & Age (2010 Census Blocks, P12); Nonwhite (2010 Census Blocks, P5); Poverty (2012 American Community Survey 5-Year Estimates by Block Group, C17002)

### FIGURE 2: NEW YORK CITY HOUSING AUTHORITY (NYCHA)

We included all NYCHA group housing developments in the five boroughs of New York City, except those designated “FHA Repossessed Housing.” We also tallied data on numbers of people residing in the NYCHA developments as of 2011. Once filtered, we selected all developments that were within or partly within the FEMA flood zone or Sandy inundation zone and calculated the proportion of each NYCHA development within each of the FEMA/Sandy zones. Note that some developments were located in a single zone while others were located in multiple zones. Using the calculated proportions, we assigned NYCHA developments to a final zone based on the highest proportion of development within each zone. As an example, if 25 percent of Development X was located in the FEMA 100-year flood zone and flooded (FEMA flooded, shown in blue), and 40 percent of Development X was flooded yet not located in the FEMA 100-year flood zone (unexpectedly flooded, shown in red), we assigned the entire Development X to the red area.



The map shows NYCHA developments located in the two flooded zones (unexpectedly flooded and FEMA flooded). Appendix Table 2 lists the flood zone status of all NYCHA developments for all three zones (flooded, in FEMA flood zone; not flooded, in FEMA flood zone; and unexpectedly flooded).

#### **Data source**

- NYCHA, New York City OpenData: [data.cityofnewyork.us/Housing-Development/NYCHA/tqep-rn2w](https://data.cityofnewyork.us/Housing-Development/NYCHA/tqep-rn2w)

### **FIGURE 3: HEALTH FACILITIES**

#### **Method**

We intersected the New York City facilities data with the FEMA/Sandy layer and filtered to the following types of health-related facility:

1. Hospital/Inpatient unit or nursing home
2. Residential facility for adults/families/children
3. Senior center

The map shows health facilities located in the unexpectedly flooded zone. Appendix Table 3 lists all health facilities located in the three zones flooded, in FEMA flood zone; not flooded, in FEMA flood zone; and unexpectedly flooded).

#### **Data source**

- Facilities, Bytes of the Big Apple: [www.nyc.gov/html/dcp/html/bytes/applbyte.shtml](http://www.nyc.gov/html/dcp/html/bytes/applbyte.shtml)

### **FIGURE 4: SCHOOLS**

#### **Method**

We intersected facilities data with the FEMA/Sandy layer and filtered to the following types of school-related facilities:

1. Daycare or Head Start facility
2. Private elementary or secondary school (combined with #3 to make “Elementary or Secondary School”)
3. Public elementary or secondary school (combined with #2 to make “Elementary or Secondary School”)

The map shows schools located in the unexpectedly flooded zone. Appendix Table 4 lists all schools located in the three zones (flooded, in FEMA flood zone; not flooded, in FEMA flood zone; and unexpectedly flooded).

#### **Data source**

- Facilities, Bytes of the Big Apple: [www.nyc.gov/html/dcp/html/bytes/applbyte.shtml](http://www.nyc.gov/html/dcp/html/bytes/applbyte.shtml)

### **FIGURE 5: WASTEWATER TREATMENT PLANTS (WWTPS)**

#### **Method**

We accessed data on the locations of municipal WWTPs in New York City from New York City OpenData. The data was intersected with the FEMA/Sandy layer and filtered to show WWTPs located in the unexpectedly flooded zone.

#### **Data source**

- Wastewater Treatment Plants, New York City OpenData: [data.cityofnewyork.us/Environment/Wastewater-Treatment-Plants/b79y-xcs](https://data.cityofnewyork.us/Environment/Wastewater-Treatment-Plants/b79y-xcs)

## MAPPING ANALYSIS DATA TABLES

**Table 1. Areas of New York City's five boroughs, by Flood Zone status relative to the FEMA 1983 FIRM Maps, with tallies of select flood-vulnerable populations**

Type	Map Color	Flood Zone Status	Area (Sq Mi)	Total Resident Population	Population Under Age 5	Population 65 or Older	Population Living Below 2x Federal Poverty Level
FEMA & surge	blue	flooded, in FEMA flood zone	24.761	206,054	11,862	30,805	90,071
FEMA only	tan	not flooded, in FEMA flood zone	8.265	50,499	2,722	6,175	21,658
Surge only	red	unexpectedly flooded	21.399	289,719	16,456	43,286	89,953

Census variables were calculated at the block level.

**Table 2. NYCHA Developments in New York City, by Flood Zone Status relative to the FEMA 1983 FIRM Maps., and with numbers of residents in each development (as of 2011)**

Borough	Flood Zone Status*	NYCHA Development
Brooklyn	flooded, in FEMA flood zone	Red Hook West
Brooklyn	flooded, in FEMA flood zone	Surfside Gardens
Brooklyn	flooded, in FEMA flood zone	Coney Island
Brooklyn	flooded, in FEMA flood zone	Coney Island I (site 1b)
Brooklyn	flooded, in FEMA flood zone	Coney Island I (site 8)
Brooklyn	flooded, in FEMA flood zone	Coney Island I (sites 4 & 5)
Brooklyn	flooded, in FEMA flood zone	Gravesend
Brooklyn	flooded, in FEMA flood zone	Haber
Brooklyn	flooded, in FEMA flood zone	O'dwyer Gardens
Brooklyn	flooded, in FEMA flood zone	Carey Gardens
Brooklyn	unexpectedly flooded	Red Hook East
Brooklyn	unexpectedly flooded	Sheepshead Bay
Brooklyn	unexpectedly flooded	Farragut
Brooklyn	unexpectedly flooded	Gowanus
Brooklyn	unexpectedly flooded	Ingersoll
Brooklyn	unexpectedly flooded	Marlboro
Brooklyn	unexpectedly flooded	Nostrand
Brooklyn	unexpectedly flooded	Bay View
Brooklyn	unexpectedly flooded	Breukelen
Brooklyn	unexpectedly flooded	Boulevard
Manhattan	flooded, in FEMA flood zone	Riis
Manhattan	flooded, in FEMA flood zone	Smith
Manhattan	flooded, in FEMA flood zone	Two Bridges Ura (site 7)
Manhattan	flooded, in FEMA flood zone	East River

**Table 2. NYCHA Developments in New York City, by Flood Zone Status relative to the FEMA 1983 FIRM Maps., and with numbers of residents in each development (as of 2011)**

<b>Borough</b>	<b>Flood Zone Status*</b>	<b>NYCHA Development</b>
Manhattan	flooded, in FEMA flood zone	Isaacs
Manhattan	flooded, in FEMA flood zone	Lavanburg Homes
Manhattan	flooded, in FEMA flood zone	Metro North Plaza
Manhattan	flooded, in FEMA flood zone	Baruch
Manhattan	flooded, in FEMA flood zone	Campos Plaza I
Manhattan	flooded, in FEMA flood zone	Wilson
Manhattan	not flooded, in FEMA flood zone	Rangel
Manhattan	not flooded, in FEMA flood zone	Clinton
Manhattan	not flooded, in FEMA flood zone	Holmes Towers
Manhattan	not flooded, in FEMA flood zone	Polo Grounds Towers
Manhattan	not flooded, in FEMA flood zone	Jefferson
Manhattan	not flooded, in FEMA flood zone	Lehman Village
Manhattan	not flooded, in FEMA flood zone	Wagner
Manhattan	not flooded, in FEMA flood zone	Washington
Manhattan	not flooded, in FEMA flood zone	335 East 111th Street
Manhattan	not flooded, in FEMA flood zone	White
Manhattan	unexpectedly flooded	Riis Ii
Manhattan	unexpectedly flooded	Dyckman
Manhattan	unexpectedly flooded	Fulton
Manhattan	unexpectedly flooded	Harlem River
Manhattan	unexpectedly flooded	La Guardia
Manhattan	unexpectedly flooded	La Guardia Addition
Manhattan	unexpectedly flooded	Lincoln
Manhattan	unexpectedly flooded	Lower East Side Ii
Manhattan	unexpectedly flooded	Lower East Side Iii
Manhattan	unexpectedly flooded	Lower East Side Rehab (group 5)
Manhattan	unexpectedly flooded	Wald
Manhattan	unexpectedly flooded	Baruch Houses Addition
Manhattan	unexpectedly flooded	Campos Plaza Ii
Queens	flooded, in FEMA flood zone	Ocean Bay Apartments (oceanside)
Queens	flooded, in FEMA flood zone	Astoria
Queens	flooded, in FEMA flood zone	Beach 41st Street-beach Channel Drive
Queens	unexpectedly flooded	Queensbridge South
Queens	unexpectedly flooded	Redfern
Queens	unexpectedly flooded	Hammel
Queens	unexpectedly flooded	Ocean Bay Apartments (bayside)
Queens	unexpectedly flooded	Carleton Manor
Staten Island	flooded, in FEMA flood zone	New Lane Area

**Table 3. Health Facilities in New York City, by Flood Zone status relative to the FEMA 1983 FIRM Maps**

<b>Borough</b>	<b>Flood Zone Status</b>	<b>Facility Type</b>	<b>Facility Name</b>
Bronx	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	Willow Shelter Next Step
Bronx	not flooded, in FEMA flood zone	Hospital/Inpatient Unit or Nursing Home	Providence Rest, Inc.
Bronx	not flooded, in FEMA flood zone	Senior Center	City Island Senior Center
Bronx	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Lincoln Medical & Mental Health Center
Bronx	unexpectedly flooded	Senior Center	Dreiser Senior Center
Brooklyn	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	Ocean View Manor Home For Adults (ah)
Brooklyn	flooded, in FEMA flood zone	Hospital/Inpatient Unit or Nursing Home	Saints Joachim & Anne Nursing And Rehabilitation Center
Brooklyn	flooded, in FEMA flood zone	Hospital/Inpatient Unit or Nursing Home	Sea-crest Health Care Center
Brooklyn	flooded, in FEMA flood zone	Hospital/Inpatient Unit or Nursing Home	Shorefront Jewish Geriatric Center
Brooklyn	flooded, in FEMA flood zone	Senior Center	Haber Houses Senior Center
Brooklyn	flooded, in FEMA flood zone	Senior Center	Surf Solomon Senior Center
Brooklyn	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	Surf Manor Home For Adults
Brooklyn	flooded, in FEMA flood zone	Senior Center	Jasa Scheuer House Of Coney Isl Sr Ctr
Brooklyn	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	Mermaid Manor Home For Adults (ah/alp)
Brooklyn	flooded, in FEMA flood zone	Senior Center	Jasa Manhattan Beach Senior Center
Brooklyn	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	Bay Family Center
Brooklyn	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	The Waterford On The Bay (ah)
Brooklyn	flooded, in FEMA flood zone	Senior Center	Red Hook Senior Center
Brooklyn	not flooded, in FEMA flood zone	Senior Center	Jasa Luna Park Senior Center
Brooklyn	unexpectedly flooded	Residential Facility for Adults/Families/Children	Abraham Residence li
Brooklyn	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Menorah Home & Hospital For Aged & Infirm
Brooklyn	unexpectedly flooded	Residential Facility for Adults/Families/Children	Abraham Residence l
Brooklyn	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Shoreview Nursing Home
Brooklyn	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Coney Island Hospital
Brooklyn	unexpectedly flooded	Senior Center	Young Israel Bedford Bay Senior Center
Brooklyn	unexpectedly flooded	Senior Center	Jasa Mill Basin Center
Brooklyn	unexpectedly flooded	Senior Center	Jasa Hes Senior Center
Brooklyn	unexpectedly flooded	Residential Facility for Adults/Families/Children	Amber Court Of Brooklyn (ah/ alp)
Brooklyn	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	River Manor Care Center
Brooklyn	unexpectedly flooded	Senior Center	Boulevard Senior Center
Brooklyn	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Brooklyn-queens Nursing Home
Brooklyn	unexpectedly flooded	Residential Facility for Adults/Families/Children	Brc Mcguinness Assessment
Manhattan	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	Urban Family Center
Manhattan	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	Greenhope Housing
Manhattan	not flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	Life

**Table 3. Health Facilities in New York City, by Flood Zone status relative to the FEMA 1983 FIRM Maps**

<b>Borough</b>	<b>Flood Zone Status</b>	<b>Facility Type</b>	<b>Facility Name</b>
Manhattan	not flooded, in FEMA flood zone	Senior Center	Roosevelt Island Senior Center
Manhattan	not flooded, in FEMA flood zone	Senior Center	Stanley Isaacs Senior Center
Manhattan	not flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	East River - Win
Manhattan	not flooded, in FEMA flood zone	Senior Center	Gaylord White Senior Center
Manhattan	unexpectedly flooded	Senior Center	Smith Houses Senior Center
Manhattan	unexpectedly flooded	Residential Facility for Adults/Families/Children	Gouverneur Court
Manhattan	unexpectedly flooded	Senior Center	Ujc Lillian Wald Houses Senior Center
Manhattan	unexpectedly flooded	Residential Facility for Adults/Families/Children	Avenue D
Manhattan	unexpectedly flooded	Residential Facility for Adults/Families/Children	Huntington House Shelter
Manhattan	unexpectedly flooded	Residential Facility for Adults/Families/Children	Huntington House
Manhattan	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Va Ny Harbor Healthcare System - Manhattan Campus
Manhattan	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Bellevue Hospital Center
Manhattan	unexpectedly flooded	Residential Facility for Adults/Families/Children	30th St. Intake
Manhattan	unexpectedly flooded	Residential Facility for Adults/Families/Children	30th Street Shelter
Manhattan	unexpectedly flooded	Residential Facility for Adults/Families/Children	30th St. Assessment Program
Manhattan	unexpectedly flooded	Residential Facility for Adults/Families/Children	Frederick Fleming House (ah)
Manhattan	unexpectedly flooded	Residential Facility for Adults/Families/Children	Carnegie East House (ehp)
Manhattan	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Metropolitan Hospital Center
Manhattan	unexpectedly flooded	Residential Facility for Adults/Families/Children	Encampment House
Queens	flooded, in FEMA flood zone	Hospital/Inpatient Unit or Nursing Home	Resort Nursing Home
Queens	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	Rockaway Manor Hfa (ah)
Queens	flooded, in FEMA flood zone	Hospital/Inpatient Unit or Nursing Home	West Lawrence Care Center, Llc
Queens	flooded, in FEMA flood zone	Hospital/Inpatient Unit or Nursing Home	Brookhaven Rehabilitation & Health Care Center Llc
Queens	flooded, in FEMA flood zone	Hospital/Inpatient Unit or Nursing Home	Oceanview Nursing & Rehabilitation Center, Llc
Queens	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	Borden Avenue Veterans Residence
Queens	flooded, in FEMA flood zone	Residential Facility for Adults/Families/Children	River View Gardens Ny Found. Ehp #8 (ehp)
Queens	not flooded, in FEMA flood zone	Senior Center	Jasa Brookdale Senior Center
Queens	not flooded, in FEMA flood zone	Senior Center	Jasa Roy Reuther Senior Center
Queens	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Neponsit Health Care Center
Queens	unexpectedly flooded	Residential Facility for Adults/Families/Children	New Gloria's Manor Home For Adults (ah)
Queens	unexpectedly flooded	Residential Facility for Adults/Families/Children	Belle Harbor Manor (ah)
Queens	unexpectedly flooded	Residential Facility for Adults/Families/Children	St. John's Residence & School For Boys
Queens	unexpectedly flooded	Senior Center	Ccns Seaside Rockaway Senior Center
Queens	unexpectedly flooded	Residential Facility for Adults/Families/Children	Surfside Manor Home For Adults Llc (ah/alp)
Queens	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Horizon Care Center

**Table 3. Health Facilities in New York City, by Flood Zone status relative to the FEMA 1983 FIRM Maps**

Borough	Flood Zone Status	Facility Type	Facility Name
Queens	unexpectedly flooded	Residential Facility for Adults/Families/Children	Seaview Manor Llc
Queens	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Peninsula Hospital Center
Queens	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Lawrence Nursing Care Center, Inc
Queens	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Rockaway Care Center
Queens	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Peninsula Center For Extended Care And Rehabilitation
Queens	unexpectedly flooded	Residential Facility for Adults/Families/Children	Springfield Gdn Resp
Queens	unexpectedly flooded	Senior Center	Howard Beach Senior Center
Staten Island	flooded, in FEMA flood zone	Senior Center	New Lane Senior Center
Staten Island	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	The Heart Institute
Staten Island	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Staten Island University Hosp-north
Staten Island	unexpectedly flooded	Residential Facility for Adults/Families/Children	New Broadview Manor Home For Adults (ah/alp)
Staten Island	unexpectedly flooded	Hospital/Inpatient Unit or Nursing Home	Pax Christi Hospice
Staten Island	unexpectedly flooded	Residential Facility for Adults/Families/Children	Buckingham House

**Table 4. Schools in New York City, by Flood Zone status relative to the FEMA 1983 FIRM Maps**

*See table at:* <http://www.nrdc.org/globalwarming/files/hurricane-sandy-coastal-flooding-Table4.pdf>

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