Mitigation Assessment Team Report

Hurricane Sandy in New Jersey and New York

Building Performance Observations, Recommendations, and Technical Guidance

FEMA P-942 / November 2013

FEMA

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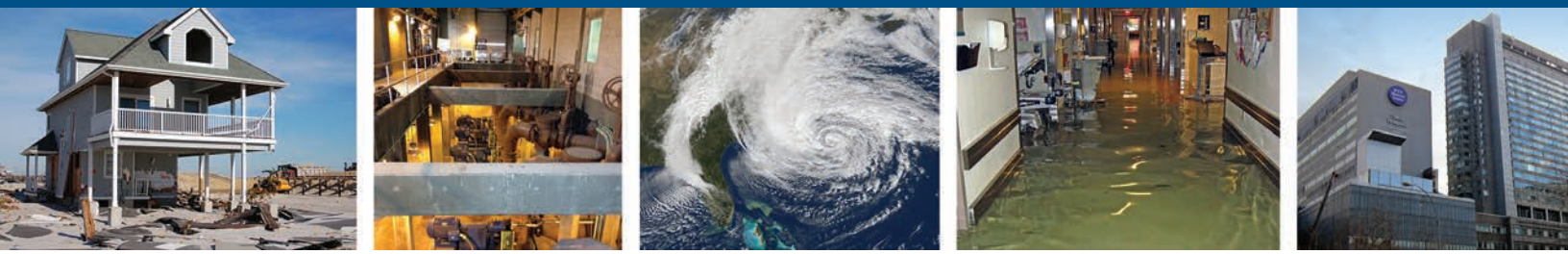
MITIGATION ASSESSMENT TEAM REPORT

In response to Hurricane Sandy, the Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) to evaluate damage from the hurricane, document observations, and based on these, offer conclusions and recommendations on the performance of buildings and other structures affected by flood and wind forces. The MAT included FEMA Headquarters and Regional Office engineers, representatives from other Federal agencies, local government officials, academia, and experts from the design and construction industry. The conclusions and recommendations in this report are intended to provide decision makers, designers, contractors, planners, code officials, industry groups, government officials, academia, homeowners, and business owners and operators with information and technical guidance that can be used to reduce future hurricane damage.

DEDICATION

FEMA and the Hurricane Sandy Mitigation Assessment Team dedicate this report to the memory of the victims of Hurricane Sandy, their families, friends, and communities suffering from their loss. The Mitigation Assessment Team hopes this report will help others avoid similar losses in the future.

Photographs that appear across the top of the first page of each chapter (from left to right): Residential building with failed column due to floating debris and failed connection between the column and column footing (Ortley Beach, NJ); Subgrade motors at sewage treatment plant for effluent pumping with power and electronic controls in conduits (Bay Park, NY); Satellite image of Hurricane Sandy on Oct. 28 (Source: NOAA GOES Project); Flood levels approximately 6 inches above the finished floor inside the Hoboken University Medical Center (Hoboken, NJ) (photo courtesy of Hoboken University Medical Center); NYU Langone Medical Center with Tisch Hospital on the left (New York, NY)



HURRICANE
SANDY
IN NEW JERSEY
AND NEW YORK

Executive Summary

On October 29, 2012, Hurricane Sandy made landfall on the East Coast of the United States. Hurricane Sandy was the deadliest and most destructive hurricane of the 2012 Atlantic Hurricane Season and the third-costliest hurricane in United States history (New York City 2013b; NHC 2013b).

Hurricane Sandy made landfall near Brigantine, NJ, as a 1,000-mile-wide post-tropical cyclone. It had an estimated sustained wind speed of 80 miles per hour and a minimum pressure of 945 millibars. Although the wind speed was on the lower end of a Category 1 hurricane,[1] the pressure was typical of a Category 3 hurricane. Hurricane Sandy approached the East Coast at a perpendicular angle and coincided with a spring high tide that was higher than normal because of a full moon. All of these factors combined to generate a massive surge that caused flooding and wind damage in 24 states across the northeastern and mid-Atlantic United States (Hurricane Sandy Rebuilding Taskforce 2013). New Jersey and New York were the most severely damaged. Nearly 2 million energy users lost power, contributing to the widespread impact of the storm. Total economic losses across the United States from Hurricane Sandy are estimated to be $50 billion (New York City 2013b).

1 According to the Saffir Simpson Hurricane Scale http://www.aoml.noaa.gov/general/lib/laescae.html.

Mitigation Assessment Team Deployment and Observations

In December 2012, in response to a request for technical support from their Joint Field Offices in New Jersey and New York, Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) composed of national and regional experts to assess the performance of buildings in New Jersey and New York. The MAT conducts forensic engineering analyses of buildings and related infrastructure to determine causes or structural failure and success, and to recommend actions that Federal, State, and local governments; the construction industry; and building code organizations can take to reduce future damage and protect lives and property in hazard-prone areas.

The MAT deployed to New Jersey and New York assessed high-, mid-, and low-rise buildings; municipal buildings; historic buildings; transportation facilities; schools; coastal residential properties; data centers; and critical facilities such as hospitals, police, emergency medical service facilities, and fire stations.

MAT observations indicated that the wind speed of Hurricane Sandy was below a design wind event. However, the flooding caused by Hurricane Sandy was in excess of the 1-percent-annual-chance flood event across much of the area visited by the MAT. The 1-percent-annual chance flood event is used as the minimum NFIP design requirement by those communities that have adopted the NFIP. The storm caused significant flooding and erosion in most of the areas the MAT visited. Flooding caused widespread damage to structures, critical facilities, and infrastructure. Most damage to low-rise buildings resulted from inundation, and oceanfront low-rise buildings were damaged by wave action, erosion, and scour. Many low-rise one- and two-family dwellings in coastal areas were of older construction that pre-dates community adoption of floodplain regulations. Very few of these homes were elevated to the appropriate base flood elevation (BFE). Most damage to mid- and high-rise buildings resulted from the inundation of mechanical, electrical, plumbing, and other critical systems. Many of these systems were not elevated to or above the BFE. In addition to building damage, utility outages were widespread.

MAT Recommendations

The recommendations for disaster-resistant practices in hurricane-prone regions presented in this report are presented as potential resolutions to the conclusions based on the MAT's field observations. The recommendations are applicable to planners; decision makers; designers; contractors; building officials; Federal, State, and local government officials; building owners and operators; emergency managers; and homeowners. The following summarizes some of the key recommendations.

Climate Change and Sea Level Rise

All community reconstruction and mitigation decisions should consider the impact of climate change and sea level rise on the coastal environment and the structures in these areas.

Building Codes and Standards

■+ ***Ordinances.*** FEMA is developing its model floodplain management ordinance specifically to coordinate with building codes. The New Jersey Department of Environmental Protection (NJDEP) and the New York State Department of Environmental Conservation should evaluate the FEMA model ordinance and consider its merits related to reducing duplicate and potentially conflicting requirements. The two agencies should adopt a coordinated ordinance to enhance local enforcement.

■+ ***Inspections.*** Given the number of buildings damaged by Hurricane Sandy and the extent of Special Flood Hazard Areas (SFHAs) in the five boroughs of New York City, the New York City Department of Buildings should establish a mechanism to supplement inspections with a "flood zone compliance special inspection" to be conducted and certified by special inspectors or special inspection agencies, as proposed in pending legislation. The New Jersey Department of Community Affairs and NJDEP, in cooperation with FEMA, should develop one or more courses specifically on the flood provisions of the NJDEP rules and the New Jersey Uniform Construction Code and include inspection of SFHA development.

Flood Protection

■+ ***Mapping.*** FEMA should review the mapping procedures used to identify flood hazards landward of erosion control structures, such as bulkheads, seawalls, and revetments, and revise the procedures where Hurricane Sandy data and application of new simulation techniques indicate better guidance can be developed.

■+ ***Subgrade connections.*** In buildings that share subgrade connections (e.g., access tunnels, basements, underground parking), flood prevention measures should be implemented to prevent flooding from spreading to connected areas or to other buildings.

■+ ***Elevation.*** Local communities should require that new structures and structures undergoing Substantial Improvement or that have sustained Substantial Damage should be elevated in accordance with Table ES-1, and associated building systems elevated in accordance with Table ES-2. The elevation recommendations in Table ES-1 and ES-2 should also be applied, to the extent practical, to existing buildings that are undergoing repair or retrofit, and that do not meet Substantial Improvement/Damage criteria.

Residential Construction

■+ ***Elevation.*** Existing one- and two-family houses and other existing low-rise buildings should be elevated when possible, and the foundation should be replaced with a type suitable to the construction environment if needed. Recommended elevations for new buildings, those determined to have Substantial Damage, and those that will undergo Substantial Improvement are shown in Table ES-1.

■+ ***Below-grade spaces.*** Existing homes with first-floor framing at or below the BFE should be retrofitted by elevating higher and strengthening continuous load paths to resist both the uplift and shear loads associated with combined flood and wind loads. Below-grade garages or

basements are common in older construction in New Jersey and New York. The local community should consider that below-grade garages or basements in the SFHA should be filled and flood openings installed in any remaining enclosure that is above grade, but below the lowest floor.

■+ ***Addition of freeboard.*** Designers of new homes should consider the likelihood and consequences of flood levels that exceed the BFE and mitigate this risk by adding at least 2 feet of additional elevation (freeboard) for structures in all flood hazard areas.

Table ES-1: Recommended Elevations for New and Substantially Damaged or Substantially Improved Buildings

New and Substantially Damaged or Improved Construction, Building Type[a]	Minimum Recommended Elevation and Floodproofing Level (select highest)
• One- and two-family structures • Other Risk Category II residential structures • Risk Category II non-residential structures	• Effective BFE + 2 feet, or Preliminary BFE + 2 feet,[b] or State/local DFE
• Risk Category III structures housing occupants or residents with limited mobility • Risk Category III structures that a community considers essential	• Risk Category IV elevation, see below
• Risk Category III structures not included above	• Effective BFE + 2 feet, or Preliminary BFE + 2 feet,[b] or State/local DFE
• Risk Category IV structures	• Effective BFE + 2 feet, or Preliminary BFE + 2 feet,[b] or State/local DFE, or 0.2-percent-annual-chance (500-year) flood level • Where the design flood is associated with coastal flooding, add 1 additional foot of freeboard to account for future sea level rise.

a. See ASCE 7 (2010 Edition), Table 1.5-1 for Building Category explanation.

b. Use Advisory Base Flood Elevation (ABFE) where Preliminary Work Maps have not been released, but where ABFE is more than 2 feet above the Effective BFE.

BFE = base flood elevation

DFE = design flood elevation

Table ES-2: Recommended Elevations for Utility Systems

Risk Category(a)	Minimum Recommended Elevation and Floodproofing Level (select highest)
Risk Category II structures, and Risk Category III not treated like Risk Category IV	At structure elevation
Risk Category IV structures, and certain Risk Category III structures (see Table 7-1)	1 foot above the structure elevation from Table ES-1
Existing structures (where practicable)	Corresponding elevation for new construction; if not practicable, elevate/floodproof as high as practical

a. See ASCE 7 (2010 Edition), Table 1.5-1 for Building Category explanation.

Critical Facilities and Key Assets

- ***New buildings, existing buildings, and critical functions.*** New buildings, repairs to existing buildings, and systems that support critical functions should be designed to be more resistant to disruption by flood events. Owners and operators should provide emergency power systems or temporary connections to reduce outages when utilities are disrupted.

- ***Healthcare facilities.*** Healthcare facilities should plan for extended complete power loss and associated loss of other utilities by developing emergency plans that include emergency operations, training exercises, and procurement of emergency systems and supplies. Appropriate supplies may include headlamps for staff, backup communication systems with batteries, and battery-powered lighting.

- ***Essential utilities and ventilation equipment at maintenance facilities and associated transit facilities.*** Facility owners should consider elevating or protecting key utilities and ventilation equipment at maintenance facilities and the associated transit facilities to the 0.2-percent-annual-chance flood level, consistent with design guidance for critical facilities. Since there is a potential for seepage after the flood event to continue for several weeks, facility owners should consider protecting equipment from this seepage.

Mechanical, Electrical, and Plumbing Systems

- ***Fuel tanks.*** Fuel tanks located in below-grade spaces should be in dry-floodproofed enclosures per American Society of Civil Engineers 24, *Flood Resistant Design and Construction*, or be able to resist buoyancy, and crushing pressures.

- ***Critical building systems.*** When possible move mechanical and electrical systems to above the elevation specified by ASCE 24. When elevation is not possible, protect these critical building systems with wet or dry floodproofing.

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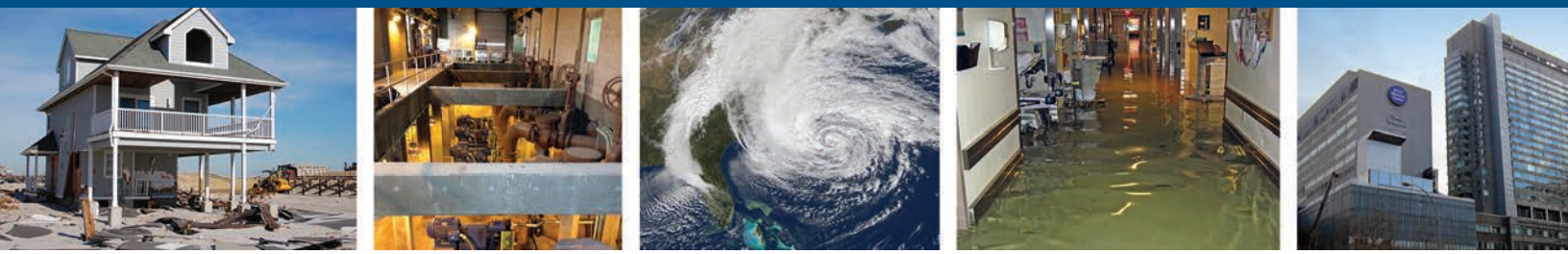
Acronyms and Abbreviations

ABFE	Advisory Base Flood Elevation
ASCE	American Society of Civil Engineers
BFE	base flood elevation
CFR	Code of Federal Regulations
CMU	concrete masonry unit
CRS	Community Rating System
CT	computed tomography (scan)
DCEA	Division of Code Enforcement and Administration (New York State)
DFE	design flood elevation
DHS	Department of Homeland Security
DOB	Department of Buildings (New York City)
DOI	Department of the Interior
FDNY	New York City Fire Department
FEMA	Federal Emergency Management Agency
FGI	Facility Guidelines Institute
FHADFE	Flood Hazard Area Design Flood Elevation
FIMA	Federal Insurance and Mitigation Administration
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
GIS	geographic information system
HSIP	Homeland Security Infrastructure Program
HVAC	heating, ventilation, and air conditioning
HWM	high water mark
IBC	International Building Code
ICC	International Code Council
I-Codes	International Code Series
ICU	intensive care unit
IEBC	International Existing Building Code
IFC	International Fire Code
IFGC	International Fuel Gas Code
IMC	International Mechanical Code
IPC	International Plumbing Code
IPMC	International Property Maintenance Code
IRC	International Residential Code for One- and Two-Family Dwellings
IS	intermediate school
IT	information technology
JCFD	Jersey City Fire Department
JFO	Joint Field Office
kW	kilowatt(s)
LEED	Leadership in Energy and Environmental Design
LiMWA	Limit of Moderate Wave Action
LIPA	Long Island Power Authority
MAT	Mitigation Assessment Team
MEP	mechanical, electrical, and plumbing
MOTF	FEMA Modeling Task Force
mph	miles per hour
MRI	magnetic resonance imaging
MTA	Metropolitan Transit Authority
MWFRS	main wind force resisting system
NAVD88	North American Vertical Datum of 1988
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
NHC	National Hurricane Center
N.J.A.C.	New Jersey Administrative Code
NJDCA	New Jersey Department of Community Affairs
NJDEP	New Jersey Department of Environmental Protection
NOAA	National Oceanic and Atmospheric Administration
NYCHA	New York City Housing Authority
NYPD	New York City Police Department
NYSDEC	New York State Department of Environmental Conservation
NYU	New York University
OEM	Office of Emergency Management
PATH	Port Authority Trans-Hudson
PS	primary school
PSEG	Public Service Enterprise Group
RSF	Recovery Support Function
SCADA	supervisory control and data acquisition
SFHA	Special Flood Hazard Area
SIRR	Special Initiative for Rebuilding and Resiliency
STP	Sewage Treatment Plant
UCC	Uniform Construction Code
UPS	uninterruptible power supply
USGS	U.S. Geological Survey
WWTP	wastewater treatment plant
YMCA	Young Men's Christian Association



HURRICANE
SANDY
IN NEW JERSEY
AND NEW YORK

1 Introduction

When Hurricane Sandy made landfall on the coast of New Jersey in October 2012, it was 1,000 miles wide and one of the largest diameter hurricanes on record (NOAA 2013b).

Hurricane Sandy caused an estimated 147 fatalities and damage in 24 States, from Florida to Maine and as far west as Wisconsin (NOAA 2013a). The hurricane heavily damaged portions of the Caribbean and the Mid-Atlantic and northeastern United States, where New Jersey and New York were the hardest hit. The Centers for Disease Control and Prevention conducted an analysis of fatalities using data from the Red Cross and published a report on the causes and locations of deaths that were directly related to Sandy (CDC 2013). As part of the response to the disaster, the Federal Insurance and Mitigation Administration (FIMA) of the U.S. Department of Homeland Security's (DHS's) Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) composed of national and regional building science and other types of experts to assess the damage in New Jersey and New York (see Section 1.2.3).

The MAT began to deploy on December 4, 2012, and completed its field investigative work in February 2013. The mission of the MAT was to assess the performance of residential buildings and representative infrastructure affected by Hurricane Sandy in New Jersey and New York and to describe the lessons learned to help communities, property owners, and others more successfully mitigate damage from future natural hazard events.

The primary purpose of this MAT report is to improve the natural hazard resistance of buildings by evaluating the key causes of building damage and failure and recommending solutions. This report describes the MAT's observations during the field investigations in New Jersey and New York and the conclusions and recommendations that are based on the observations. The purpose of this report is to provide information that will assist communities, businesses, design professionals, and individuals to rebuild safer, more robust structures, thereby minimizing loss of life and injuries, and reducing property damage resulting from future natural hazard events.

This MAT report focuses on several construction and floodplain issues not previously observed in other MAT damage investigations. These issues include:

- The effect of the storm on a heavily urbanized area
- The damage to buildings where continuous load path systems were not present, either because of the age of the building or because of additions to the original structure
- The interconnectivity of buildings through underground spaces and how those spaces affected the movement of floodwater
- The effect of saltwater intrusion, which heavily damaged electrical transmission systems in buildings throughout Lower Manhattan
- The protection provided by manmade shoreline erosion control structures and wide beaches and high dunes, which reduced the effect of storm surge on properties located behind them in portions of New Jersey and New York

1.1 Organization of Report

This chapter recounts events and damage caused by Hurricane Sandy, describes the MAT background and process, and summarizes flood hazard information. Floodplain management regulations and building codes and standards that affect construction in New Jersey, New York City, and New York State are discussed in Chapter 2. Chapter 3 contains a basic assessment and characterization of the structural and envelope performance of low-rise buildings affected by Hurricane Sandy. Chapter 4 provides a similar assessment as in Chapter 3, but focuses on mid- and high-rise buildings affected by the event. Chapter 5 presents damage to and functional loss of critical facilities and key assets affected by Hurricane Sandy. Chapter 6 discusses damage to historic structures. Chapter 7 presents the MAT's conclusions and recommendations intended to help guide the reconstruction for hurricane-resistant communities. Chapter 8 presents the references used in developing this report. In addition, the following appendices are included:

Appendix A: Acknowledgements

Appendix B: Glossary

Appendix C: Recovery Advisories and Fact Sheets for Hurricane Sandy

Appendix D: Mapping and Geographic Information System Data

Appendix E: History of Sandy and Hurricanes in the Northeast

Appendix F: Background of the National Flood Insurance Program (NFIP), the International Code Series (I-Codes), and Referenced Standards

Appendix G: Background on Floodplain Management and Building Codes in New Jersey, New York State, and New York City

Appendix H: Facility-Specific Descriptions of Critical Facilities and Key Assets

Appendix I: Definitions of Critical Facilities and Risk Categories

Appendix J: Crosswalk of Recommendations with National Disaster Recovery Framework Goals

1.2 Background

This section presents background information, including:

- The meteorological events that led to the formation of Hurricane Sandy (Section 1.2.1)
- Regional preparedness actions taken in New Jersey and New York (Section 1.2.2)
- Information on the FEMA MAT and its process, including selection of damaged areas and buildings to be visited by the MAT, team composition and the involvement of State and local agencies, structure types assessed by the MAT, and deployment (Section 1.2.3)

1.2.1 Hurricane Sandy – The Event

Hurricane Sandy formed as a ***tropical wave*** that emerged off the west coast of Africa on October 11, 2012.[1] On October 27, as Sandy moved over the Gulf Stream, the radius of maximum winds extended over 100 nautical miles from the center, making Sandy one of the largest hurricanes ever recorded in the Atlantic. By 5 p.m. Eastern Daylight Time on October 29, Sandy was approximately 45 nautical miles southeast of Atlantic City and was declared post-tropical. The center of post-tropical cyclone Sandy made landfall at Brigantine, NJ, with estimated sustained winds of 80 miles per hour (mph) and a minimum pressure of 945 millibars. The pressure at landfall was typical of Category 3 hurricanes, but the observed wind speed was on the lower end of Category 1 hurricane intensity. For more information on the timeline and history of Hurricane Sandy, refer to Appendix E.

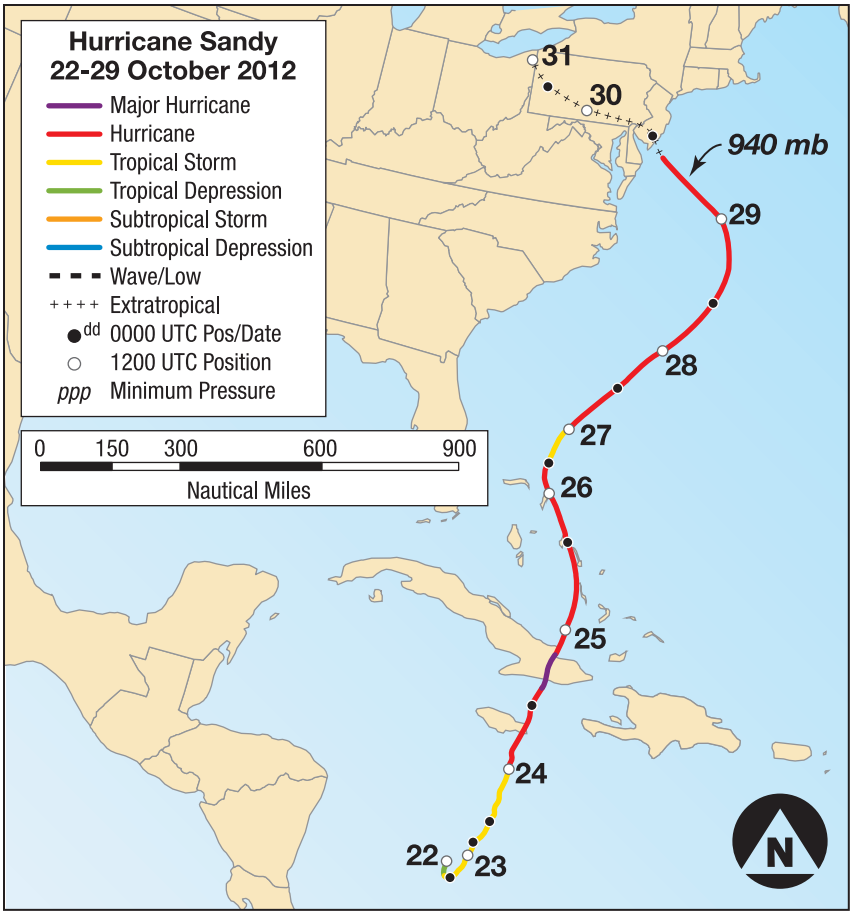
Sandy's Track

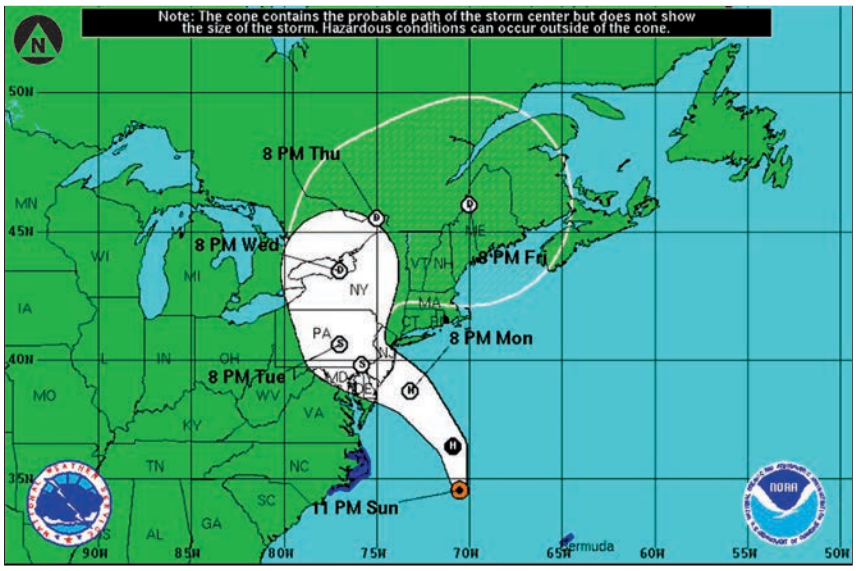
The track of Hurricane Sandy was unusual for an East Coast storm. It is uncommon for a tropical or extratropical cyclone to make landfall nearly perpendicular to the eastern coast of the United States above 35°N latitude, as depicted in Figure 1-1. The tracks of 20 recorded hurricanes prior to Sandy passing within 100 nautical miles of Atlantic City, NJ, are depicted in Figure 1-2. Since 1870, only one other hurricane has made a direct landfall in New Jersey without previously encountering land; all other hurricane tracks have paralleled the coastline.

1 All information about the life cycle and evolution of Hurricane Sandy was obtained from The Hurricane Sandy Tropical Cyclone Report from the National Hurricane Center (NHC 2013b).

Figure 1-1:
National Oceanic and Atmospheric Administration's (NOAA's) National Hurricane Center, Hurricane Sandy's track (top) and Hurricane Sandy's track as it approached the United States (bottom)

SOURCE: TOP IMAGE, MODIFIED FROM NOAA; BOTTOM IMAGE, NOAA





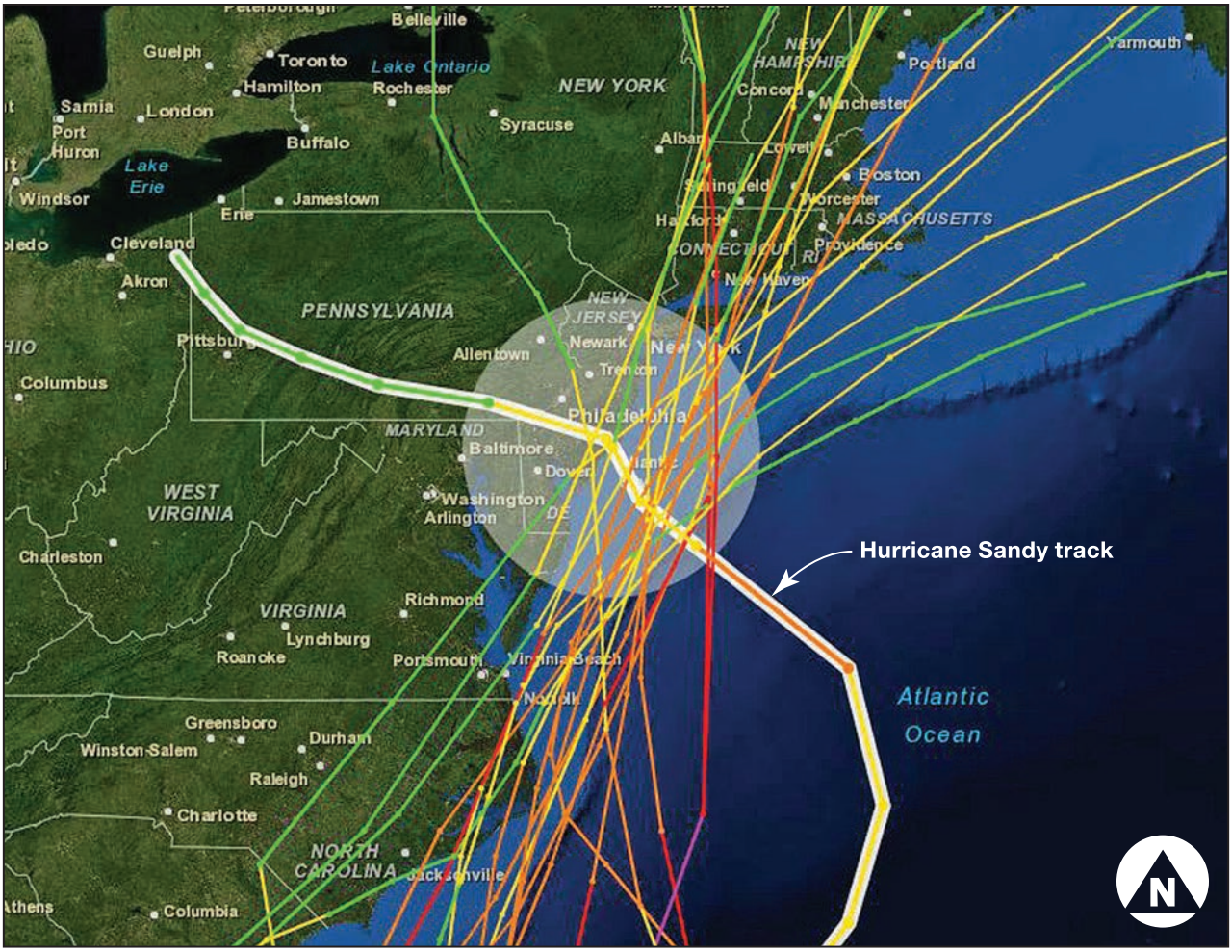


Figure 1-2: Historical hurricane tracks passing within 100 nautical miles of Atlantic City, NJ

SOURCE: DATA FROM THE NOAA COASTAL SERVICES CENTER HURRICANE TRACK DATABASE AT HTTP://CSC.NOAA.GOV/HURRICANES

Meteorological Hazards

The large size of Sandy resulted in a relaxed pressure gradient over a large storm diameter. The maximum sustained winds decreased, though the wind field at or near hurricane force (74 mph) was very wide.

The most prevalent damage associated with Sandy came from ***storm surge***. Sandy was a very large hurricane/post-tropical cyclone, with a very rapid forward speed of over 20 knots just before landfall. However, the surge associated with Sandy behaved more like that associated with a slow-moving, large hurricane with

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Storm surge: An abnormal rise of water, over and above the astronomical tide, caused by a severe storm such as a tropical cyclone or nor'easter.

Storm surge is one of the main causes of coastal inundation. Large waves also raise coastal water levels and ride on top of the storm surge, and can cause extreme damage.

Storm surge is expressed in terms of feet above predicted astronomical tides.

localized areas of peak surge. The highest surge values were recorded well north of the storm center, near the New York City lower bay and harbor. This phenomenon can be partially attributed to the concave shape of the shoreline there, the direction of the storm landfall, and the timing of the storm, which coincided with a spring high tide that was higher than normal because of a full moon.

In and adjacent to New Jersey, surge levels of 5.16 feet in Cape May, 6.29 feet at the Delaware River, and 5.82 feet in Atlantic City were recorded. In New York, a surge level of 12.65 feet above tidal predictions was recorded at King's Point on Long Island Sound, 9.56 feet on the northern end of Staten Island, and 9.4 feet at the Battery in Lower Manhattan.

Inundation was another major component of the flood hazard associated with Sandy. Coastal inundation levels were recorded across New Jersey and New York. Coastal inundation levels recorded in New Jersey include 4 to 9 feet in Monmouth and Middlesex Counties, 3 to 7 feet in Union and Hudson Counties, 3 to 5 feet in Ocean County, and 2 to 4 feet in Essex, Bergen, Atlantic, Burlington, and Cape May Counties. Coastal inundation levels recorded in New York include 4 to 9 feet in Staten Island and Manhattan, 3 to 6 feet in Brooklyn and Queens, 3 to 6 feet in Nassau and Suffolk Counties, 3 to 5 feet in the Hudson River Valley, and 2 to 4 feet in the Bronx and Westchester County.

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Inundation: Represents the total water level that occurs on normally dry ground as a result of a storm tide.

Inundation levels are expressed in terms of height above ground level.

1.2.2 Regional Preparedness Actions

News and weather reports provided plenty of advance notice of the arrival of Hurricane Sandy, allowing the region to prepare. Regional pre-event planning was performed by cities, counties, and State emergency management agencies.

In New York, Governor Cuomo ordered evacuations for several areas and announced that public transportation systems in New York City, including subway, bus, commuter rail, and tunnels, would be shut down at 7 p.m. on Sunday, October 28, 2012 (Weisenthal 2012). Evacuation was mandatory for some areas of Suffolk and Nassau Counties and recommended for portions of Westchester and Rockland Counties. Following the Governor's announcement, Mayor Bloomberg of New York City announced a mandatory evacuation of low-lying areas in the city identified as Evacuation Zone A.[2] Evacuation Zone A is the area of New York City that is most prone to flooding; for Manhattan, it begins at 39th Street and 1st Avenue, continues down the East River through the financial district, and then up the West Side Highway to 60th Street (Figure 1-3). After Hurricane

REPORT FINDINGS
CENTERS FOR DISEASE CONTROL AND PREVENTION

Despite the advance notice and mandatory evacuations, most of the deaths directly related to Sandy were caused by drowning, with the majority occurring within homes (CDC 2013).

2 In this context, "Evacuation Zone A" is referring to the zone used for New York City inundation and evacuation mapping purposes, not "Zone A" as used on Flood Insurance Rate Maps (FIRMs).

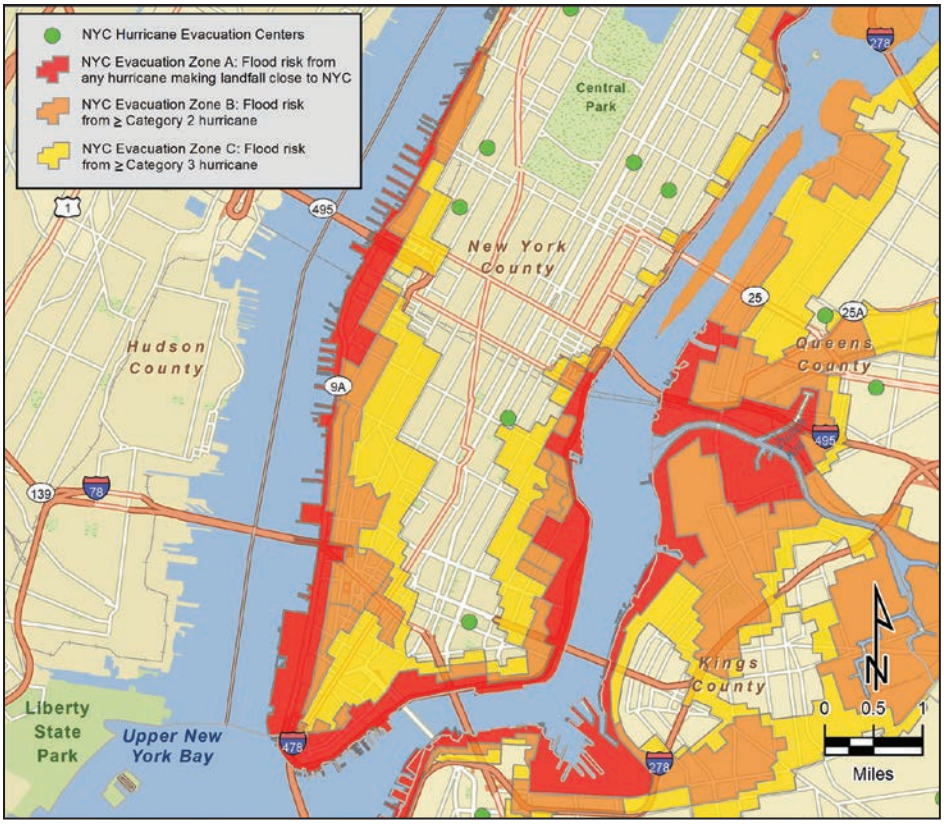


Figure 1-3: Map of New York City Evacuation Zones in effect in Manhattan at the time Hurricane Sandy made landfall

SOURCE: FEMA MOTF FROM HTTP://WWW.ARCGIS.COM/EXPLORER/?URL=HTTP://SERVICES.ARCGIS.COM/OFH668NDRN7TBJH0/ARCGIS/REST/SERVICES/SANDYNYCEVACMAP/FEATURESERVER/0&SOURCE=SD, ACCESSED 10-10-2013

Sandy, New York City updated its evacuation maps.[3] The new maps have extended evacuation areas to reflect the hazard risk.

In New Jersey, Governor Christie declared a state of emergency in advance of the storm and issued a mandatory evacuation order for the barrier islands, from Sandy Hook to Cape May, by 4 p.m. on October 28, 2012. On October 28, Hoboken Mayor Zimmer and Jersey City Mayor Healy both ordered the evacuation of all basement and street-level residential units. All New Jersey Transit service (bus, rail, and light rail systems) were preemptively closed on October 29, along with most schools throughout the State.

Electric power companies located in areas of expected flooding planned to de-energize their systems before the arrival of the storm surge. This step was taken to allow facilities that rely on utility power to transfer to generator power before the arrival of storm surge.

- In New York, Con Edison preemptively shut down some of their electrical power and steam systems around 7 p.m. on Monday, October 29, 2012, in Lower Manhattan. They also tried to protect their facilities with flood barriers, including sand bags and plywood sheathing. However, the storm surge exceeded predictions by 3 feet, and much of the underground electrical and steam distribution system, including several key substations, was inundated (New York City 2013b).

3 To see the updated evacuation map for New York City, visit http://maps.nyc.gov/hurricane.

- In New Jersey, Public Service Enterprise Group (PSEG) turned off power to facilities between 8 p.m. and 10 p.m. on Monday, October 29, 2012.

1.2.3 FEMA Mitigation Assessment Team

FEMA conducts building performance studies after unique or nationally significant disasters to better understand how natural and manmade events affect the built environment. A MAT is deployed only when FEMA believes the findings and recommendations derived from field observations will provide design and construction guidance that will improve the disaster resistance of the built environment in the affected State or region and will be of national significance to other disaster-prone regions. FEMA bases its decision to deploy a MAT on preliminary information such as:

- Magnitude of the expected hazards
- Potential type and severity of damage in the affected areas
- Pre-storm site conditions, such as the presence of older housing stock and aging infrastructure
- Potential value of study results to the rebuilding effort
- Strategic lessons that can be learned and applied, potentially on a national level, related to improving building codes, standards, and industry guidance
- Possibility that the field investigation would reveal pertinent information regarding the effectiveness of (1) certain FEMA grants and (2) key engineering principles and practices that FEMA promotes in published guidance and best practices documents

The MAT studies the adequacy of current building codes, local construction requirements, building practices, and building materials in light of the damage observed after a disaster. Lessons learned from the MAT's observations are communicated through Recovery Advisories, Fact Sheets, and a comprehensive MAT report available to communities to aid their rebuilding effort and enhance the disaster resistance of building improvements and new construction.

Sandy Team Composition

The Sandy MAT included many experts including:

- FEMA Headquarters and Regional Office engineers and experts
- Other Federal agencies including:
  - Department of Housing and Urban Development
  - National Institute of Standards and Technology
  - National Oceanic and Atmospheric Administration (NOAA)
- Federal Alliance for Safe Homes, Inc.

- International Code Council, Inc. (ICC)
- Association of State Floodplain Managers
- Construction and building code industry experts
- Academia
- Design professionals
- Home builders
- FEMA specialists who joined the New Jersey and New York Joint Field Offices (JFOs)

Team members included structural, civil, mechanical, coastal, and electrical engineers; floodplain management, building code, materials, historical, critical facilities, urban floodproofing, housing, mechanical, electrical, and plumbing (MEP) experts; healthcare specialists; architects and architectural historians; and floodplain mappers. The members of the MAT are listed in the front matter.

The Hurricane Sandy MAT was divided into four units: Coastal; Hospitals and Other Critical Facilities; High-Rise, Police, Fire, and School; and Historical. Each unit visited several locations in New Jersey and New York to assess the performance of specific building and facility types.

Involvement of State and Local Agencies

FEMA encouraged the participation of State, county, and local government officials and locally based experts in the assessment process. Their involvement was critical and resulted in:

- Improving the MAT's understanding of local construction practices
- Encouraging the MAT to develop recommendations that were both economically and technically feasible for the communities involved
- Facilitating communication among Federal, State, and local governments and the private sector
- Improving the State and local understanding of the MAT's observations and recommendations to enable them to better effect change in their communities

The MAT met with local emergency management and government officials in many of the areas they visited. The officials gave an overview of the damage in their area and helped to identify key sites to visit. The MAT also coordinated with the FEMA JFOs that had been set up in the area shortly after Hurricane Sandy. Appendix A lists these and other individuals who assisted with the MAT in its field operations and report development.

Site Selection

Before deploying the MAT, FEMA deployed a reconnaissance team and a Pre-MAT. The reconnaissance visit was conducted on November 6, 2012, in New Jersey coastal communities in Atlantic, Cape May, Ocean, and Monmouth Counties. The reconnaissance team made observations on damage levels to help identify locations for the Pre-MAT and MAT to visit.

Three Pre-MAT subteams were deployed from November 15, 2012, to November 18, 2012. The subteams visited coastal urban areas of New Jersey and New York and heavily urbanized areas of New Jersey and New York City. The members of the Pre-MAT created a list of sites deemed valuable for the MAT to observe. The locations listed by the Pre-MAT included areas with a high concentration of damage and areas with damage not typically observed by previous MATs.

Damage observations collected by the reconnaissance team and the Pre-MAT subteams, as well as observations made by two MAT members from an aerial flyover of New Jersey, New York, and New York City on November 26, 2012, were used to establish locations for the MAT to assess in more detail. The FEMA Region II JFOs, State and local government agencies, and the MAT members identified potential sites for the MAT to visit. The potential sites were then compared to other types of data, listed below, in order to select the final site list:

- Depth grids and flood extents produced by the FEMA Modeling Task Force (MOTF)
- Water surface elevation data compiled from the U.S. Geological Survey (USGS), recorded high water marks (HWMs), and surge sensor data
- Homeland Security Infrastructure Program (HSIP) Gold critical infrastructure data[4]
- Data on FEMA Hazard Mitigation Assistance grant projects
- ImageCAT assessment data[5]

Please see Appendix D for more information on how mapping and geographic information system (GIS) data were used during site selection.

FEMA MODELING TASK FORCE (MOTF)

Both the Pre-MAT and MAT relied on GIS products and data developed and provided by the MOTF. The MOTF played an important role in the response and recovery for Hurricane Sandy by coordinating hazard and modeling information from a variety of sources, including other Federal agencies, universities, the National Labs, and State and local agencies, to develop consensus for best estimates of impacts before, during, and after the storm. The MOTF information was used to "ground-truth," verify, and enhance impact assessments.

The MAT received invaluable support from home, business, and critical facility owners and managers in New Jersey and New York. These individuals accompanied the MAT through many of the affected areas and provided valuable insights into local communities and their experiences before, during, and after Hurricane Sandy.

4 More information on the HSIP can be found on the DHS Web site here: http://www.dhs.gov/infrastructure-information-partnerships.

5 More information about ImageCAT assessment data can be found here: http://www.imagecatinc.com/.

Structure Types Selected by the MAT

The structures selected by the MAT for damage assessment included: residential, non-residential, and mixed use low-rise buildings; mid- and high-rise buildings; critical facilities and key assets; and historic structures. Buildings were located in both coastal and riverine floodplains, as well as in urban areas.

Field Deployment

FEMA deployed the four MAT units to New Jersey and New York beginning on December 4, 2012. The MAT units conducted site visits and recorded observations along the New Jersey and New York shorelines, as well as within the urban areas of New Jersey and New York (Figure 1-4). The deployment was staggered to improve the efficiency and effectiveness of the MAT. Staggering the unit deployments allowed certain MAT members with specific skill sets to be assigned to more than one unit, thereby reducing the overall team costs, minimizing the size of each unit, and reducing logistical needs, such as housing, in the disaster area.

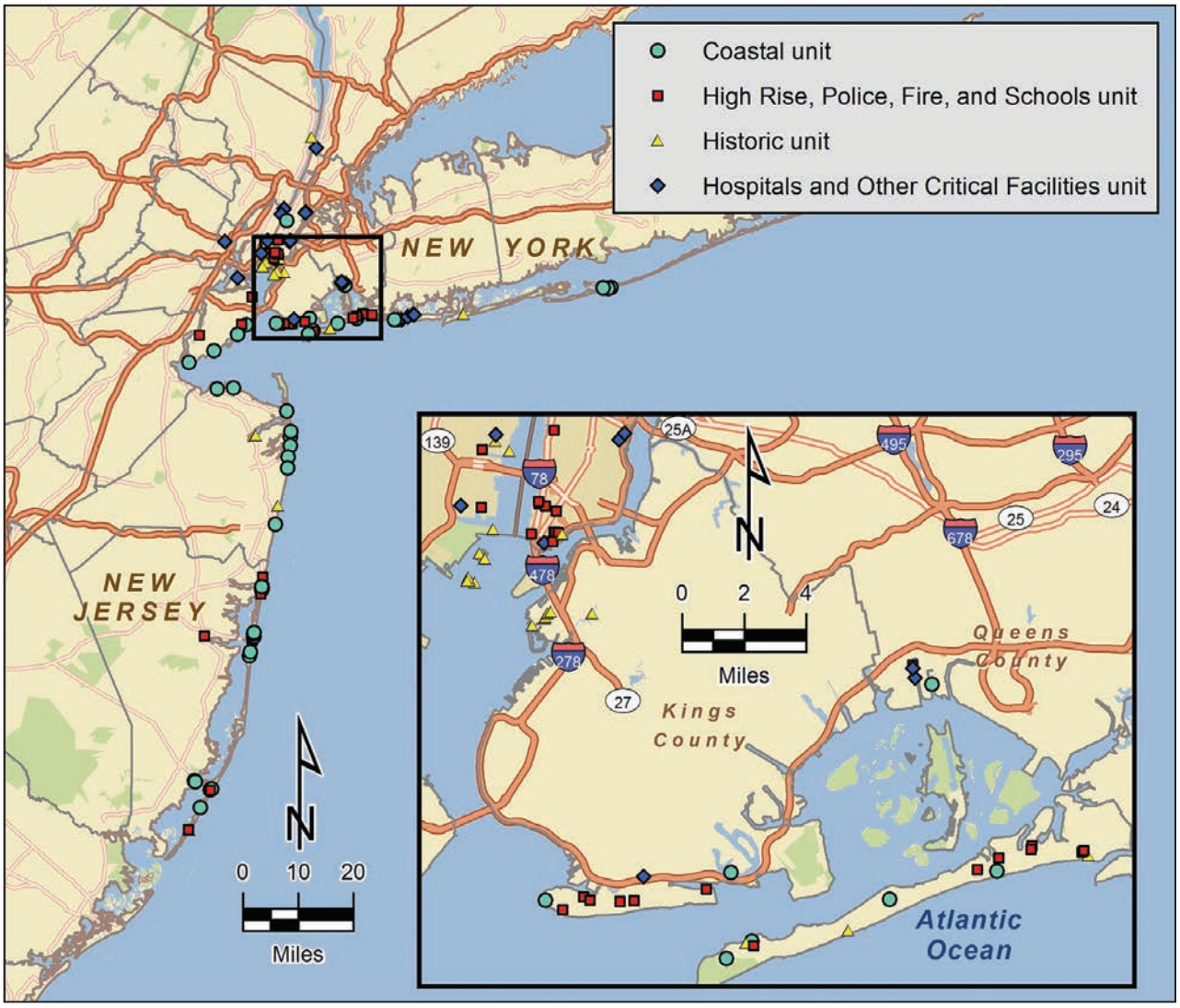


Figure 1-4: Locations visited by the four MAT units after Hurricane Sandy

- The ***Coastal*** unit observed low-rise structures located along coastal and riverine areas of New Jersey and New York. The buildings observed were primarily residential, low-rise buildings, though some schools and fire and police stations were also included.

- The ***Hospitals and Other Critical Facilities*** unit observed healthcare facilities, senior care centers, police and fire stations, schools, transportation centers, data centers, and municipal facilities across New Jersey and New York.

- The ***High-Rise, Police, Fire, and School*** unit observed mid- to high-rise residential and commercial buildings located in urban areas of New Jersey and New York.

- The ***Historical*** unit observed historic buildings across New Jersey and New York.

When possible, building or facility owners were interviewed to gain insight into how their buildings and/or facilities withstood Hurricane Sandy and how their recovery efforts were progressing. The MAT spent considerable time assessing partially damaged buildings to determine why certain buildings performed better than others. The MAT took note of any technique used that they considered a ***best practice***.

TERMINOLOGY

Best practice: A construction technique that, though not required by the building code in the area, has proven to minimize damage from natural hazards.

1.3 Summary of Damage Observed

Hurricane Sandy caused widespread damage to buildings across the entire affected area, as well as widespread power outages and interruptions in utility service. Hurricane Sandy brought large-scale flooding to coastal and riverine residential and urban areas, particularly concentrated along the New Jersey and New York coastlines. Although the effects of Sandy were felt along much of the northeast coast, New Jersey and New York sustained the worst impacts from the storm and are the focus of this report. Most of the damage observed was caused by flooding (hydrostatic, hydrodynamic, buoyancy, and wave loads). Observations of damage caused by wind were rare, and wind damage was much less significant than the flooding damage.[6]

The flood damage observed was a result of inundation, erosion and scour, and wave action. Although inundation alone was a significant source of damage, some of the more dramatic structural failures observed were a result of the added force of wave action. Many buildings, both residential and non-residential, were inundated at the basement and first floor levels, which disrupted operations and damaged utilities, causing significant repair costs and extensive loss of income. The MAT noted:

- Many of the low-rise and residential buildings in coastal areas were of older construction that pre-dates the NFIP.

6 This does not include the consequential effects of wind damage, such as tree fall, which in turn caused extensive power outages and damages to the electrical distribution grid.

- Many of the high-rise buildings and hospitals had underground vehicle access and subgrade tunnels between buildings to distribute utilities that were inundated during the storm, commonly resulting in damaged utility systems and power outages.

- Flood damage to many of the high-rise and critical facility structures was typically a result of inundated mechanical, electrical, plumbing, and other utility systems where these systems were located below the base flood elevation (BFE).

- Most of the damaged historic buildings were in areas subject to inundation and wave impact and had first floor elevations below the BFE.

1.4 Flood Zones and Issuance of Updated Flood Hazard Information

Congress requires FEMA to update the Nation's Flood Insurance Rate Maps (FIRMs) periodically so they remain current and accurately reflect local flood hazards. FIRMs delineate special flood hazard zones (e.g., Zone VE, Zone AE) and BFEs that reflect the nature of the flood conditions expected during the base flood (see Section 1.4.1). Flood risk can change over time. Natural changes, such as beach erosion, subsidence, accretion within floodways, climate change, sea level rise, and manmade structures, such as bridges or sea walls, may affect flood hazards for a given area.

The New Jersey/New York coast is one of the most highly populated and developed coastlines in the United States, and the area has undergone heavy development since it was last mapped by FEMA. The coastal flood studies underway use the best available data and the most current and accepted methods for modeling storm surge and coastal flood hazards.

ELEVATIONS

Unless otherwise noted, all elevations in this report are relative to mean sea level and reported as North American Vertical Datum of 1988 (NAVD88) elevations.

1.4.1 FIRMs and Flood Zones

FIRMs delineate flood hazard zones (e.g., Zone VE, Zone AE) that reflect the nature of the flood conditions expected during the base flood. The base flood is the flood that has a 1 percent annual chance of occurrence (frequently referred to as the 100-year flood). FIRMs show the base flood elevation, or BFE. The area designated as subject to inundation from the 1-percent-annual-chance flood is called the Special Flood Hazard Area (SFHA).

Areas delineated as Zone V on FIRMs are subject to inundation as well as wave heights of 3.0 feet or higher. The Limit of Moderate Wave Action (LiMWA) that is delineated in new FIRMs occurs in Zone A at the limit of the 1.5-foot base flood wave height. The area of Zone A that is seaward of the LiMWA is known as a Coastal A Zone. Wave heights between 1.5 and 3.0 feet are expected during the base flood in Coastal A Zones.

FIRMs also show shaded Zone X areas that are outside the SFHA but that are subject to flooding with a 0.2 percent annual chance of occurrence (frequently referred to as the 500-year flood). Unshaded Zone X areas are land areas that are at a higher elevation than the SFHA and shaded Zone X areas.

TERMINOLOGY

Coastal A Zone: The portion of the coastal SFHA referenced by building codes and standards, where base flood wave heights are between 1.5 and 3 feet, and where wave characteristics are deemed sufficient to damage many NFIP-compliant structures on shallow or solid wall foundations.

Limit of Moderate Wave Action (LiMWA): A line indicating the limit of the 1.5-foot wave height during the base flood. FEMA requires new flood studies in coastal areas to delineate the LiMWA.

Zone V: Under the NFIP, an area of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high-velocity wave action from storms or seismic sources. This area is subject to inundation by the base flood, where wave heights or wave runup depths are 3.0 feet or higher.

Zone A: Under the NFIP, area subject to inundation by the 1-percent-annual-chance flood where wave action does not occur or where waves are less than 3.0 feet high.

Zone X: Under NFIP, areas where the flood hazard is lower than that in the SFHA (Zone V and Zone A).

Communities that participate in the NFIP adopt Flood Insurance Studies (FISs) and associated FIRMs, which are then used by the communities to regulate floodplain development. FISs are prepared using specified models and the physical, hydrologic, and climate conditions in effect at the time the studies were conducted. The resulting FIRMs are drawn incorporating the FIS data. FIRMs and FISs are thus a "snapshot" of flood risk at a certain time, and can become outdated as topographic, hydrologic, or climate conditions change, or as engineering methods and models improve. The FIS, FIRM, and associated flood data adopted by the community is referred to as "Effective" until replaced by a new FIRM. Only Effective FIRMs are used for insurance rating and NFIP regulatory purposes.

1.4.2 Advisory Base Flood Elevation Maps

After severe floods, FEMA may issue Advisory Base Flood Elevation (ABFE) maps for areas where the existing FIRMs no longer adequately represent the actual base flood risk. ABFE maps are based on ***in-progress*** or ***approximate*** studies. They are intended to offer guidance to community officials and property owners as they plan reconstruction. ABFE maps do not represent the "Effective" data for insurance rating and regulatory purposes, but they do provide interim information for reconstruction efforts and can be used until the new FISs and Effective FIRMs are adopted by the community. Use of ABFE maps for post-flood reconstruction is mandatory only if the maps are adopted by a State or community. ABFEs are not used for insurance rating or NFIP regulatory purposes. ABFE maps for portions of New Jersey and New York are available at http://www.region2coastal.com/sandy/abfe. For more information about the best available floodplain management data, please see FEMA Floodplain Management Bulletin 1-98 at http://www.fema.gov/media-library/assets/documents/7401?id=2231.

New Jersey ABFE Maps

ABFE maps were released for 10 New Jersey counties (Atlantic, Bergen, Burlington, Cape May, Essex, Hudson, Middlesex, Monmouth, Ocean, and Union) on December 14, 2012. On January 24, 2013, the New Jersey Department of Environmental Protection (NJDEP) issued an Emergency Rule that adopted the ABFE maps for the purpose of State permits that are issued for new construction, reconstruction, and mitigation. In addition, flood elevations established by the NJDEP will be used to enforce the State's building code.

FEMA GUIDANCE DOCUMENTS

Over the past few decades, FEMA has provided guidance on building practices to improve hazard resistance. FEMA highly recommends that designers, architects, builders, home and business owners, government, and planning and code officials, among others, in hurricane-prone areas refer to these publications. The publications are downloadable for free at the FEMA Web site: http://www.fema.gov/building-science-publications.

New York ABFE Maps

ABFE maps were released for seven New York counties (Bronx, Kings, New York, Richmond, Queens, Rockland, and Westchester). ABFE maps were released for Westchester County and portions of New York City on January 28, 2013. The remaining New York City ABFE maps were released on February 25, 2013. ABFE maps were not produced for Nassau and Suffolk Counties because their FIRMs are up-to-date and based on current models and technical studies.

In New York State, flood maps are adopted at the local level. As of January 31, 2013, New York City requires that reconstruction projects add ***freeboard*** above the Effective BFE for certain building types, but allows relief from this requirement for some reconstruction projects if owners build to the ABFE (if the ABFE is higher than the Effective BFE plus freeboard).

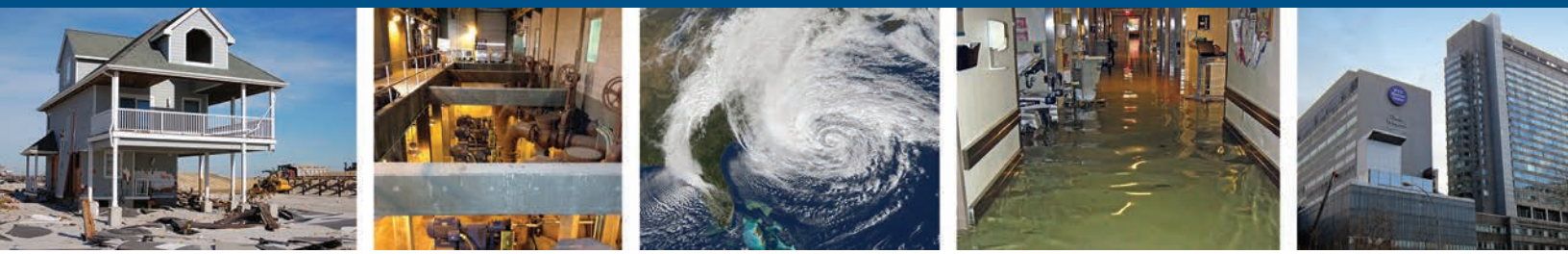
TERMINOLOGY

Freeboard: Under the NFIP, a factor of safety usually expressed in feet above a flood level for purposes of floodplain management.

1.4.3 New FIRMs

The ABFE maps are being superseded by Preliminary FIRMs. The revised preliminary flood hazard information will be posted on FEMA's Geoplatform[7] for public review and use as it becomes available. Preliminary FIRMs will undergo a public review period and statutory appeal period prior to being adopted by communities as the Effective FIRM. The new Effective FIRMs, once adopted, will be used for insurance rating and regulatory purposes. In certain locations, the new FIRMs may result in higher BFEs or higher risk zone designations than are shown on current FIRMs. These new BFEs and flood risk zones will affect the minimum building requirements.

7 Available at: http://www.Region2Coastal.com.



HURRICANE
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2 Building Codes, Standards, and Regulations

The MAT performed research on existing codes and standards adopted by New Jersey, New York, and New York City.

The floodplain management regulations of the NFIP and the flood provisions of the family of model codes developed and maintained by the ICC are related. Since 1998, FEMA has participated in the code development process for the I-Codes. Every 3 years, the family of model codes is modified through a formal, public consensus process.

The flood provisions in the 2009 and 2012 I-Codes are consistent with NFIP requirements for buildings and structures, and the 2006 I-Codes are

THE I-CODES AND THE NFIP

FEMA compiled excerpts of the flood provisions of the 2009 and 2012 I-Codes and prepared additional documents that identify the differences between each edition. FEMA also prepared a checklist that compares the requirements of the NFIP to the flood provisions of the 2009 and 2012 editions of the I-Codes and ASCE 24-05 (a standard referenced by the I-Codes), and *Highlights of ASCE 24-05 Flood Resistant Design and Construction* (FEMA 2010c). These resources are accessible at http://www.fema.gov/building-science/building-code-resources.

essentially consistent. Consequently, as long as no flood provision has been modified to weaken the requirements, communities can rely on the I-Codes to fulfill the requirements for buildings and structures that they must enforce to participate in the NFIP.

Unless constrained by State requirements, communities that enforce building codes with NFIP-consistent provisions have two primary tools to regulate development in flood hazard areas: (1) building codes that govern the design and construction of buildings and structures and (2) either Appendix G of the International Building Code (IBC) or local floodplain management regulations. These tools are designed to work together to result in buildings, structures, and all other development that are resistant to flood loads and flood damage.

This chapter contains separate sections for New Jersey, New York State, and New York City to highlight each jurisdiction's programs and authorities related to floodplain management and building codes, including amendments to the I-Codes. An additional section summarizes guidelines and standards that are referenced by New Jersey and New York State for healthcare facilities.

BIGGERT-WATERS FLOOD INSURANCE REFORM ACT OF 2012 (BW-12)

As a requirement of BW-12, FEMA is tasked with assessing the impact, effectiveness, and feasibility of including nationally recognized building codes as part of the NFIP's floodplain management criteria. The results of the evaluation are summarized in the 2013 FEMA report titled, *Including Building Codes in the National Flood Insurance Program* (FEMA 2013e).

Overall, the study found there would be positive impacts that would help to reduce damage from floods. The most significant benefits would arise from the use of the elevation requirements of the codes, which exceed the NFIP minimum requirements.

The appendices for this report include additional pertinent information. Appendix F contains summaries of:

- The NFIP, including the program's relationship with NFIP State Coordinating Agencies, the program's general performance requirements for buildings, the minimum requirements for buildings in Zone A and Zone V, and the NFIP Community Rating System
- The flood provisions of the I-Codes that apply to buildings and structures
- How the NFIP and the I-Codes treat historic structures
- American Society of Civil Engineers (ASCE), *Flood Resistant Design and Construction* (ASCE 24), a design standard that is referenced by the I-Codes
- The flood provisions of the Facility Guidelines Institute (FGI) *Guidelines for Design and Construction of Health Care Facilities* (FGI Guidelines)
- The flood provisions of the National Fire Protection Association (NFPA) *Standard for Health Care Facilities* (NFPA 99)

Appendix G of this report contains summary descriptions of the floodplain management programs and buildings codes of New Jersey, New York State, and New York City. This appendix includes the background for jurisdiction-specific conclusions and recommendations in Section 7.3.

2.1 State of New Jersey

Two departments of the State of New Jersey have statutory authorities and programs that affect floodplain management at the local jurisdiction level: the NJDEP establishes flood elevation data and manages a State permit program, and the New Jersey Department of Community Affairs (NJDCA) is charged with adopting and maintaining the State's building code, known as the New Jersey Uniform Construction Code (UCC) (N.J.A.C. 5:23).[1]

Floodplain management has a long history in New Jersey. In 1929, the legislature authorized a State agency to regulate structures "within the natural and ordinary high water mark." In 1962, a second law was adopted authorizing the study and delineation of floodplain areas. In 1972, the legislature adopted a third statute to amend the 1962 Act to authorize the adoption of regulations for floodplain areas. The Act, as amended, is known as the Flood Hazard Area Control Act. Since the 1970s, many local jurisdictions have regulated flood hazard areas in order to participate in the NFIP.

New Jersey and many of its local jurisdictions also have long histories with building codes. Many communities had been enforcing codes for many years before the statutory authority for a statewide building code was enacted in 1975.

Appendix G, Section G.1, contains the following: (1) descriptions of the NJDEP's flood hazard area mapping and community assistance programs, model local flood damage prevention ordinance, and flood hazard area rules and permits; (2) a recommendation made by a commission appointed to address flooding in the Passaic River Basin; (3) descriptions of NJDCA's programs for administering the State building code and amendments made to the flood provisions of the model I-Codes; and (4) a description of New Jersey's unique "prior approval" process through which local construction officials and local floodplain administrators are to coordinate on such matters as Substantial Improvement determinations. The appendix also notes that New Jersey maintains its own register of historic places.

2.2 New York State

Two departments of the State of New York have statutory authorities and programs that affect floodplain management at the local jurisdiction level: the Department of Environmental Conservation (NYSDEC) has a number of programs that have bearing on floodplain management, and the Department of State is charged with adopting and maintaining the State's building code.

Floodplain management has a long history in New York. Many local jurisdictions have regulated flood hazard areas since the early 1970s in order to participate in the NFIP. Building codes also have a long history in New York. The legislative action that authorized a statewide uniform code found

1 http://www.state.nj.us/dca/divisions/codes/codreg/ucc.html.

that a "multiplicity" of codes had been adopted at various levels of State and local government, which indicates that many communities had enforced building codes for many years before the first statewide building code was enacted in 1984.

Appendix G, Section G.2, contains descriptions of the NYSDEC's floodplain management program, model local law for flood damage prevention, and the State's programs for administering the State building code and amendments made to the flood provisions of the model I-Codes. The appendix also notes that New York State maintains its own register of historic places.

2.3 New York City

The history of New York City's construction regulations is summarized in the 2011 Construction Codes Revision Handbook (NYC DOB 2011). Rules that affect building locations, public safety, and sanitary needs in the area that is now incorporated as New York City date back to 1674. Today, New York City comprises the Boroughs of Manhattan (New York County), Queens (Queens County), Brooklyn (Kings County), The Bronx (Bronx County), and Staten Island (Richmond County).

The first document to be called a "Building Code" was published in 1899 and significantly updated in 1916. Significant changes were made in 1938 and, in the face of the Stock Market Crash of 1929, efforts were made to remove costly, outdated provisions, resulting in the 1938 Code. By the 1950s, criticisms that the 1938 Code did not embrace the latest technology led to efforts to revise the code, culminating in the 1968 Code.

By State law, the City is authorized to adopt and maintain its own code, rather than enforce the New York State Uniform Fire Prevention and Building Code. The current version of the New York City Construction Code,[2] based on the 2003 edition of the I-Codes, became effective on July 1, 2008, and has been subject to numerous amendments.

The Construction Codes consist of five technical volumes: the Building Code, Plumbing Code, Mechanical Code, Fuel Gas Code, and the Energy Conservation Code. The same codes apply to all new buildings, whether state-of-the-art skyscrapers or one- and two-family dwellings. The City maintains a separate Administrative Code that contains administration, enforcement, permitting, licensing, fees, and other provisions that apply to the five technical volumes.

The New York City Department of Buildings (DOB)[3] ensures the safe and lawful use of over 975,000 buildings and properties by enforcing the Construction Code, Electrical Code, Zoning Resolution, New York State Labor Law, and New York State Multiple Dwelling Law. The DOB examines construction plans, issues construction permits, inspects properties, issues Certificates of Occupancy, and licenses trades.

The Construction Code is maintained, administered, and enforced by the DOB. The City is required to develop revisions every 3 years to maintain consistency with the I-Codes. The DOB uses a consensus-based approach, involving extensive participation from the architectural and

2 http://publicecodes.cyberregs.com/st/ny/ci-nyc/YC-P-2008-000006.htm.

3 http://www.nyc.gov/html/dob/html/about/about.shtml.

engineering community, industry, labor, and government. Using a committee structure, new code texts are evaluated and debated. Technical committees reach agreement on the majority of changes. Issues not resolved by committees are mediated by the Department.

The DOB's multi-phase code revision process to produce the next edition of the Construction Code began in 2011. Revisions to bring it up to date with the 2009 I-Codes were introduced to City Council in May 2013 (Int. No. 1056).[4] Among the many revisions throughout the code to incorporate modifications that are unique to New York City are numerous amendments to the flood provisions, which are found primarily in Appendix G, Flood-Resistant Construction, of the Construction Code (see Appendix G, Section G.3.1, of this report).

Appendix G, Section G.3 of this report, contains descriptions of New York City's program for administering the City's building code and amendments made to the flood provisions of the model I-Codes and ASCE 24. The appendix also highlights how the DOB responded to Hurricane Sandy, including passing emergency rules, and notes that the City maintains a list of historic properties, structures, objects, and archaeological sites.

2.4 Guidelines and Standards for Healthcare Facilities

Healthcare facilities are required to be designed and constructed in accordance with building codes and any additional specifications adopted by the applicable jurisdiction. This section describes the flood provisions and emergency power requirements contained in the FGI Guidelines and a standard produced by the NFPA. Both documents are cited by building codes and other regulations in New Jersey and New York State.

The FGI Guidelines are not referenced by the IBC but are referenced by both New Jersey and New York:

- New Jersey requires the construction and rehabilitation of healthcare facilities to be in accordance with the UCC building subcode and the FGI Guidelines, providing that the more restrictive shall govern (§ 5:23-3.2(b), N.J.A.C.).

NEW YORK STATE HOSPITAL CODE

The State Health Commissioner is authorized (but not required) to specify certain requirements for healthcare facilities in floodplains, including:

- No floors located below the "100-year flood crest level" unless specifically approved
- Surgical suites, medical records storage, or medical records libraries above the "100-year flood crest level"
- Helicopter landing pads to evacuate patients and staff
- Capability to provide services necessary to maintain the life and safety of patients and staff, including electrical service and emergency power, heating, ventilation, sterilization, communications, food service, emergency department, and x-ray service
- Alternate water supply and alternate means to store or dispose of sewage, garbage, and biological waste

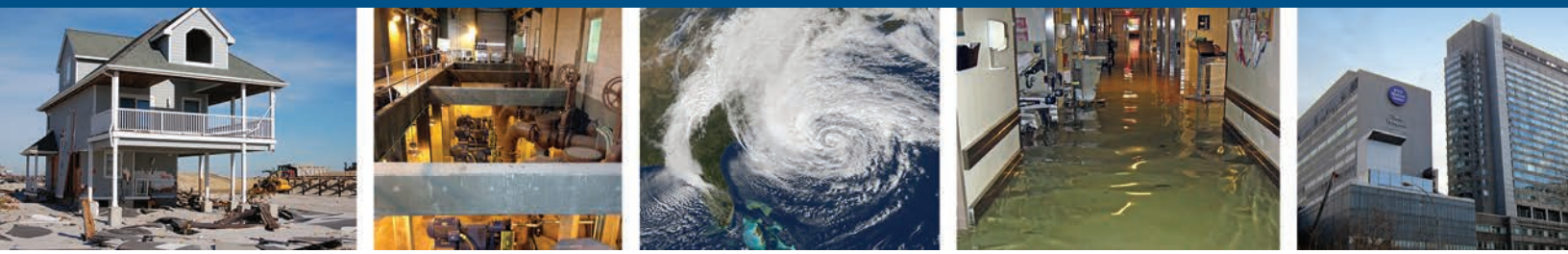
SOURCE: SEC. 711.3, NEW YORK STATE HOSPITAL CODE

4 http://council.nyc.gov/html/committees/legislation.shtml (search for "1056" for 2013).

- New York State requires all health facilities to comply with building codes and the more restrictive requirements of numerous technical standards cited in regulations applicable to the construction of medical facilities, including the 2010 edition of the FGI Guidelines (Title 10, New York Codes, Rules and Regulations, Subchapter C State Hospital Code, s. 711.2).

NFPA 99 is adopted by reference in IBC and cited only in Section 407.10, which applies only to hyperbaric facilities. NFPA 99 is referenced in the FGI Guidelines. New York State also references NFPA 99 (1999 edition) in regulations that apply to the construction of medical facilities.

Appendix F, Section F.5, contains descriptions of the flood provisions of the FGI Guidelines and NFPA 99.



HURRICANE
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3 Performance of Low-Rise Buildings

Most of the buildings structurally damaged or destroyed by Hurricane Sandy were one- and two-family low-rise buildings.

In New York City, more than 70 percent of the structurally damaged or destroyed buildings were low-rise, combustible structures constructed before 1961 of lighter, stud-frame (wood joist) materials (New York City 2013c). The MAT visited select one- and two-family low-rise buildings across New Jersey and New York that were impacted by Hurricane Sandy. Based on their observations, the performance of these buildings during Hurricane Sandy was similar to the performance of similar building types in previous MAT investigations in which the flood and erosion conditions were comparable.

Flood information accompanying the figures within this chapter includes what is shown on FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). The information includes the FIRM and ABFE zone designations for the sites pictured and the FIRM/ABFE 1-percent-annual-chance elevation presented in parentheses. The approximate maximum stillwater elevations resulting from Hurricane Sandy are also presented. Refer to Section 1.4 for more information about FIRM and ABFE maps. All elevations are presented in NAVD88 unless otherwise noted.

Summary of General Observations

Other MAT observations on the performance of low-rise buildings during Hurricane Sandy are as follows:

- Buildings on strong foundations elevated above the flood level performed well, but those below the flood level either sustained inundation damage (inland and sheltered water shoreline areas) or were damaged by hydrodynamic, wave, or floating debris loads associated with high-energy storm surge (buildings near the oceanfront).

- Although dune erosion was widespread throughout the region, the presence of wide beaches and tall, wide dune fields reduced damage to buildings and infrastructure situated landward of the dunes, both low-rise buildings and other buildings. Low and narrow beaches and dunes were completely eroded in many areas, and buildings and infrastructure landward of the dunes were subject to damaging wave action and/or high-velocity flow.

EROSION CONTROL STRUCTURES DO NOT ALWAYS WITHSTAND STORM FORCES

Erosion sometimes occurs during storms despite the presence of erosion control structures such as dunes, seawalls, revetments, and toe protection. Storm waves frequently overtop, damage, or destroy poorly designed, constructed, or maintained erosion control devices. Land and buildings behind an erosion control device are not necessarily safe from coastal flood forces and storm-induced erosion or scour.

- The effectiveness of erosion control structures (e.g., bulkheads, seawalls, revetments) varied widely, depending on the height, age, and condition of the structures, and on the beach condition seaward of the structures.

Summary of Observations in New Jersey and New York

The MAT observed several issues that were more common after Hurricane Sandy in New Jersey and New York than in other recent storms investigated by MATs:

- Many buildings affected by flooding from Hurricane Sandy had basements with finishes, contents, and MEP systems that were damaged.

- Many older buildings did not have continuous load paths because of the original construction or because the load paths had been modified or had degraded. This issue was the result of the fact that a large portion of the building stock was several decades old.

- The use or modification of pre-existing foundations in the buildings observed by the MAT added to load path continuity problems because the old foundations were not constructed to newer codes that provide better resistance to hazard forces and risks associated with the sites of the buildings.

- Load path connection failures between the foundation and the building were common in both New Jersey and New York. Older and newer homes both typically lacked a designed load-path connection. Failures of older homes that had load path connectors were the result of insufficient connection points, undersized connections, or significant corrosion.

- Many of the strap connections hindered only uplift and did not address the shear loads. When the houses with load paths constructed to resist primarily uplift were subjected to shear forces during the storm event, they were susceptible to failures from connectors rolling and fasteners pulling out, failure of the connection, or beams failing from insufficient strap length.

- Many buildings were located within 10 to 20 feet of a shore-parallel erosion control structure (e.g., seawall, bulkhead, revetment), many of which were overtopped by storm waves and/or surge during Hurricane Sandy. The overtopping resulted in flood and/or erosion damage to nearby buildings even when the erosion control structure survived. The proximity of the buildings to the erosion control structures is apparently a result of the age of the waterfront communities, many of which are more than 100 years old. Shoreline erosion has been ongoing during this time, resulting in the construction of many erosion control structures.

- Wind damage to buildings was observed even though Hurricane Sandy was not a design wind event. Most of the damage was to building envelopes and was related to the presence of multiple layers of building siding that appeared to have been added over time. Although most of the damage was minor, envelope damage such as this can create wind-borne debris and allow water intrusion into the building.

- There were burned residences in some of the communities visited. Other MATs deployed over the past few decades have only rarely observed fire damage after a storm event. The causes of the fires are outside of the MAT's purview, but the prevalence of older, densely packed buildings likely contributed to the spread of fire once a fire was initiated.

3.1 Performance Relative to Flood and Erosion

Several building characteristics determined the nature and extent of flood and erosion damage: the location of the building (siting), elevation of the lowest floor, building foundation, load-path connections, presence or absence of subgrade areas, and location of MEP systems.

3.1.1 Effect of Siting on Building Performance

Building location plays a major role in determining the type and severity of flood hazards to which buildings may be subjected. The MAT observed examples where each of the following siting parameters was an important contributor to building damage:

- Building location and wave exposure
  - Location of the building relative to the flood source
  - Exposure to storm-generated waves
- Beach and dune condition
  - Beach and dune conditions seaward of the building (for buildings near the open coast)
- Barrier island breaches

- Location of the building relative to potential barrier island breaches and overwash areas

- Features and structures that focus flow
  - Location of the building relative to natural features, buildings, or structures that could focus or channel flow toward the building

- Proximity to erosion control structures
  - Location of the building relative to an erosion control structure, and the characteristics and condition of that structure

- Proximity to flood-borne debris sources
  - Location of the building relative to flood-borne debris sources (e.g., other buildings, boardwalks, marinas, boats)

3.1.1.1 Building Location and Wave Exposure

For buildings with similar elevations, the location of the building relative to the shoreline and its exposure to storm-generated waves determine the severity of wave forces that impact a building or building site.

In general, buildings close to the ***ocean*** shoreline are subject to more wave, velocity flow, and erosion damage (Figure 3-1) than buildings far from the shoreline (Figure 3-2), where inundation is the dominant flood hazard.

Figure 3-1: Wave, storm surge, and erosion damage to oceanfront house at Belle Harbor, Rockaway, NY

Flood Hazard Data: FIRM = Zone X
ABFE = Zone A (11 feet)
Sandy floodwater elevation = 11 feet NAVD88

Flood Hazard Data: FIRM = Zone AE (13 feet)
ABFE = Not available. ABFEs were not released for Nassau County because the FIRMs are up to date.
Sandy floodwater elevation = 11 feet NAVD88

Figure 3-2: Inland flood inundation resulted in damaged contents but no structural damage to this house in Long Beach, NY

Buildings close to ***bay and sheltered water*** shorelines can be damaged by locally generated waves even when those buildings are protected from ocean waves. However, wave damage in these locations is usually limited to those buildings closest to the shoreline.

The MAT observed some wave damage on bay shorelines not subject to ocean waves. However, on very small or narrow water bodies, the wave heights are small and the wave periods short, which typically causes inundation-type damage with water sloshing against a building rather than wave-action damage.

This distinction between wave and inundation damage was confirmed by the DOB, whose personnel examined building damage and identified the cause and severity of flood damage by general location (New York City 2013c):

- Areas along Staten Island, the Rockaways, Coney Island, and the south shore of Long Island in Brooklyn and Queens were subject to damage caused by inundation and wave action
- Areas in Manhattan, the Bronx, and the north shore of Brooklyn and Queens were more likely subject to damage caused by floodwater inundation

Of the buildings that were identified as suffering severe damage (red tagged[1] or destroyed), 97 percent of the damage was from surge and wave action.

1 "Tagged" refers to the following designations: red tag = damage (often structural) that prohibits re-entry or re-occupancy; yellow tag = damaged, restricted re-entry, or reuse.

3.1.1.2 Beach and Dune Condition

All other factors being equal, beach and dune condition plays a central role in the degree of wave and flood damage to landward and upland buildings. The presence of wide beaches and tall, wide dunes prior to a storm are often the best defense, whereas narrow beaches and smaller dunes provide little protection against design-level coastal flood events. Dune volume above the 1-percent-annual-chance and seaward of the primary dune crest is a critical factor in determining the protective capacity of a dune. Two examples are discussed below, one in New Jersey and one in New York.

Two New Jersey beachfront communities separated by approximately 1 mile from each other—Seaside Park and Ortley Beach—illustrate the role that beaches and dunes play in damage reduction. Ortley Beach had a relatively narrow beach and low dune and sustained some of the most severe wave and erosion damage observed by the MAT (Figure 3-3). In contrast, Seaside Park had a wide beach and large dunes that protected landward areas, and observed damage was caused mostly by inundation (Figure 3-4). The Richard Stockton College Coastal Research Center report (2012) summarizes damage to the two dune systems and communities (see text box on page 3-7).

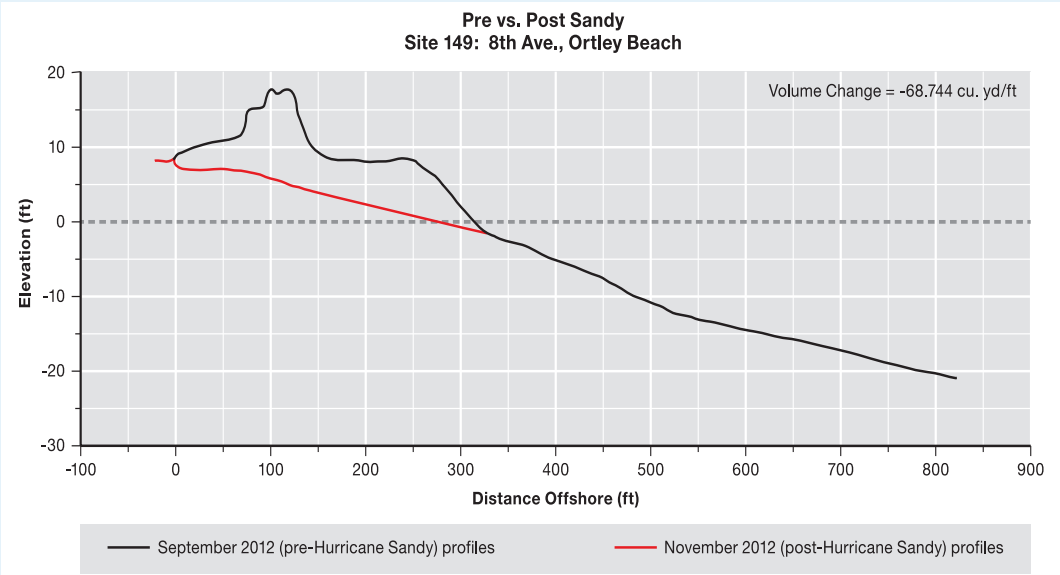
Flood Hazard Data: Sandy floodwater elevation = 8 feet NAVD88

Figure 3-3: Post-Sandy photograph of Ortley Beach, NJ, in the vicinity of 8th Avenue and New Jersey Beach that shows the loss of a dune, boardwalk, and road and severe damage to homes

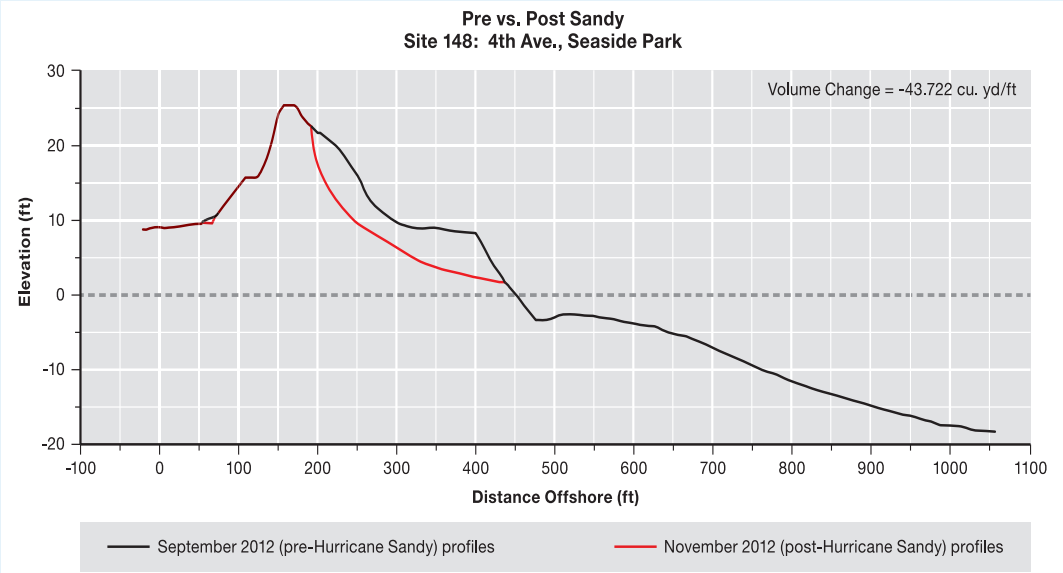
RICHARD STOCKTON COLLEGE COASTAL RESEARCH CENTER REPORT

Taken from Richard Stockton College, Coastal Research Center report (2012) on Hurricane Sandy damage to Northern Ocean County, NJ.

Ortley Beach: "Ortley Beach had a 25-year history of shoreline retreat and sand volume loss as determined by the Coastal Center's 8th Avenue survey site. Ocean Avenue, the boardwalk and many homes were completely destroyed in this segment. Site #149 located at 8th Avenue showed a sand volume loss of 68.7 yds^3/ft with over 10 feet of dune removed and pushed landward in overwash deposits. Everything was stripped away leaving a flat, featureless beach sloping into the sea. This was the site of the worst and most widespread structural damage in Northern Ocean County."



Seaside Park: "The pre- and post-storm analysis for site #148 at 4th Avenue showed that a portion of the fore-dune was removed during the storm; however, the remainder of the dune provided protection to the landward structures. No overwash occurred at the profile location. The dune's approximate 25-foot elevation (NAVD88) and 150-foot width (at the base) combined with a 150-foot wide beach provided adequate protection from tidal surge and wave action… While homes sustained flood damage in this segment from Barnegat Bay, loss of infra-structure and homes was minimized due to the larger beach-dune system hindering waves crossing over land."



Flood Hazard Data: Sandy floodwater elevation = 6 feet NAVD88

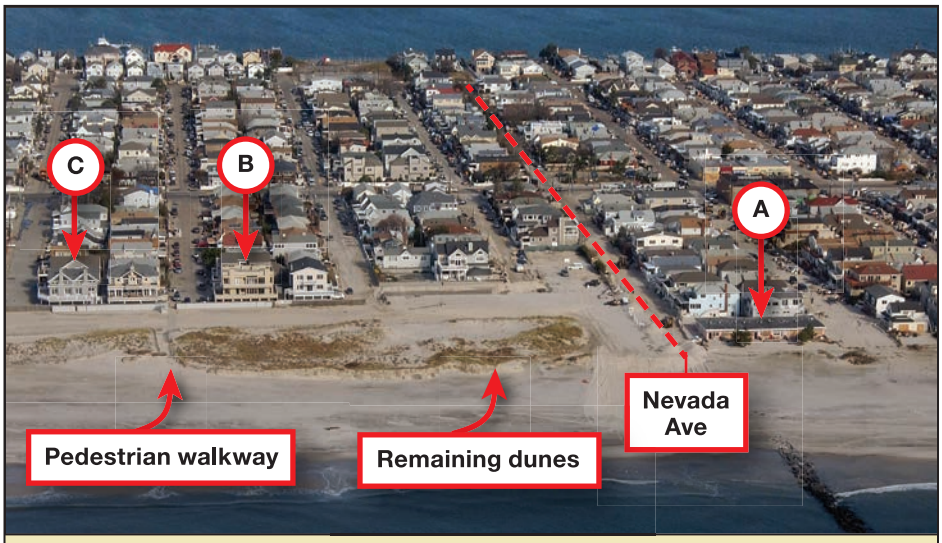
Figure 3-4: Post-Sandy photograph of Seaside Park, NJ, in the vicinity of 6th Avenue and two blocks south of New Jersey Beach. Note the intact dune with scarping, which protected the boardwalk, road, and homes.

The second example of the value of wide and tall dunes—and siting buildings farther from the shoreline—is from New York near the Village of East Atlantic Beach, located west of Nevada Avenue and east of the City of Long Beach. Figure 3-5 shows a pre-storm photograph of the area and Figure 3-6 is a photograph of the area after the storm.

Three buildings are marked on Figures 3-5 and 3-6. Building A is a one-story motel between the seaward ends of Nevada Avenue and Ohio Avenue in Long Beach, NY, and Buildings B and C are houses at the seaward ends of Rochester Avenue and Buffalo Avenue in East Atlantic Beach, NY. Building A is situated approximately 200 feet seaward of Buildings B and C. All buildings had seaward dunes prior to Hurricane Sandy, but the dunes in front of Buildings B and C were wider and located farther from the water line.

Flood Hazard Data: Building A: FIRM = Zone AE (15 feet)
Buildings B and C: FIRM = Zone AE (14 feet)
Buildings A, B, and C:
ABFE = Not available. ABFEs were not released for Nassau County because the FIRMs are up to date.
Sandy floodwater elevation = 11 feet NAVD88

Figure 3-5:
Area near Village of East Atlantic Beach, NY, showing beach and dune conditions before Hurricane Sandy
SOURCE: GOOGLE EARTH



Flood Hazard Data: Building A: FIRM = Zone AE (15 feet)
Buildings B and C: FIRM = Zone AE (14 feet)
Buildings A, B, and C:
ABFE = Not available. ABFEs were not released for Nassau County because the FIRMs are up to date.
Sandy floodwater elevation = 11 feet NAVD88

Figure 3-6:
Post-Sandy dune loss near Village of East Atlantic Beach, NY, including the near-complete loss of dunes in front of Building A
SOURCE: USGS

Figure 3-6 shows a post-storm photograph of the area. The dune seaward of Building A was largely removed by Hurricane Sandy, and sand overwash penetrated several hundred feet up Nevada Avenue. In December 2012, the MAT observed flood HWMs indicating that flood and overwash levels reached approximately 3 to 4 feet near Building A, which sustained surge and inundation damage that necessitated replacing some doors, a window, and interior walls (Figure 3-7). As shown on Figure 3-6, the seaward side of the dune in front of Buildings B and C eroded, but the landward section remained and offered substantial protection to houses landward of the dune. There was no evidence of significant flood or overwash near Buildings B and C (Figure 3-8), although pedestrian pathways through the dunes were weak points where erosion, landward flooding, and overwash were focused.

Figure 3-7:
Building A (location shown in Figure 3-6) lost doors and a window; interior repair work shown in inset (East Atlantic Beach, NY)

3.1.1.3 Barrier Island Breaches

Some barrier islands were breached by Hurricane Sandy, most notably, Mantoloking, NJ (Figure 3-9); Fire Island, NY; and Westhampton, NY. Almost all of the houses in and near the Mantoloking breach were heavily damaged or destroyed. One house in the center of the breach survived, presumably because of its pile foundation and elevation. The breach at Mantoloking, NJ, has been repaired by the New Jersey Department of Transportation.

Figure 3-8:
View east past Building C (location shown in Figure 3-6) toward Building B shows no evidence of Sandy flood damage or sand overwash (East Atlantic Beach, NY)

Two breaches occurred across the Fire Island National Seashore area near Smith Point and Old Inlet, NY, and one breach occurred at Westhampton Beach. One building near a breach survived Sandy but a subsequent storm knocked the building off its foundation. Two of the breaches (one at Westhampton Beach and another at Smith Point Beach) were repaired by the State and the U.S. Army Corps of Engineers, while one of the breaches at Fire Island remains open as of October 2013.

Flood Hazard Data: FIRM = Zone AE (5 feet)
ABFE = Zone A (8 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-9: Breach at barrier island, Mantoloking, NJ; note house that survived at the center of the breach
SOURCE: USFWS

3.1.1.4 Features and Structures That Focus Flow

Gaps in dunes, streets, and areas between buildings or other structures often channel floodwater flow. This process tends to be highly localized, and seemingly small obstructions or changes in elevation can facilitate flow channelization. Figure 3-10 shows an area approximately 0.8 mile north of the Mantoloking breach shown in Figure 3-9 that illustrates this effect. The MAT observed many significant flow channels in this area and four are discussed here (labeled channels A through D). Flow channel A was the largest and resulted in a house being washed into the bay (Figure 3-11). Flow channels B and C developed to the south and north of a house, and exited into the bay across a bulkhead that was at a lower elevation than neighboring bulkheads. The low bulkhead elevation apparently focused the flow coming across the island and between the houses, leading to scour around the shallow foundation of the house (Figure 3-12). Flow channel D developed where a bulkhead failed just north of a house that was undermined and collapsed (Figure 3-13). The house was on a shallow foundation, while its surviving neighbor to the north was on a piling and grade beam foundation.

3.1.1.5 Proximity to Erosion Control Structures

Many New Jersey and New York coastal communities were settled more than100 years ago. Shoreline erosion has been ongoing during much of this period, and the shorelines are highly armored with bulkheads, seawalls, rock revetments, groins, and breakwaters. Many beachfront areas have undergone periodic beach nourishment over the past several decades. In fact, Coney Island was the site of the first large-scale beach nourishment project in the United States in 1922–1923, when over 1 million cubic yards of sand was dredged from offshore and placed along the shoreline (Dornhelm 1995).

Figure 3-10:
Flow channels A–D (dashed lines) formed between buildings on the bayward side of the barrier island at Mantoloking, NJ, and washed sand into the bay at their ends
SOURCE: NASA

Flood Hazard Data: FIRM = Zone AE (5 feet)
ABFE = Zone V (10 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-11: House washed from the barrier island into the bay at the site of flow channel A (see Figure 3-10) (Mantoloking, NJ)

Flood Hazard Data: FIRM = Zone AE (5 feet)
ABFE = Zone V (10 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-12: Undermined house with damaged foundation between flow channels B and C (see Figure 3-10) (Mantoloking, NJ)

Flood Hazard Data: FIRM = Zone AE (5 feet)
ABFE = Zone V (10 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-13: Undermined house south of flow channel D (see Figure 3-10) (Mantoloking, NJ)

The convergence of old development and shoreline erosion means that buildings and infrastructure are often situated immediately landward of shore-parallel erosion control structures (seawalls, bulkheads, revetments). These structures may or may not be effective in protecting upland development during a severe coastal flood event, and the closer the development is to the structure, the greater the likelihood that flood or erosion damage will affect that development.[2] Even when erosion control structures remain intact, they can be overtopped by waves (and sometimes surge) if their elevation is low.

The MAT observed many instances of damage to buildings where erosion control structures were damaged or failed, and many instances of damage to buildings where intact erosion control structures were overtopped. Failed erosion control structures observed by the MAT included those with displaced vertical wall sections (Figure 3-14) and those where rocks from revetments were cast landward (Figure 3-15). The timber bulkhead in Figure 3-16 was overtopped, backfill was lost, and the adjacent house was damaged. The damaged houses shown in Figures 3-15 and 3-16 were both approximately

Figure 3-14:
Concrete seawall failed, resulting in damage to the house situated approximately 15 feet landward of the wall (Seagate, Coney Island, NY)

Flood Hazard Data: FIRM = Shaded Zone X
ABFE = Zone V (16 feet)
Sandy floodwater elevation = 13 feet NAVD88

Figure 3-15:
Rocks and rubble from a revetment were thrown and/or washed approximately 50 to 150 feet landward onto lawns and against houses at Manhattan Beach, Coney Island, NY

Flood Hazard Data: FIRM = Zone X
ABFE = Zone A (11 feet)
Sandy floodwater elevation = 11 feet NAVD88

2 NJ Coastal Zone management rule for Coastal High Hazard Areas at N.J.A.C. 7:7E-3.18(a) defines the "V zone" as that shown on the FIRM, plus areas within 25 feet of oceanfront erosion control structures. This provision was adopted based on post-storm damage surveys by the State that documented the impact of wave runup and overtopping of structures on landward development.

Flood Hazard Data: FIRM = Zone AO (flood depth 1 foot above ground surface)
ABFE = Zone A (7 feet)
Sandy floodwater elevation = 9 feet NAVD88

Figure 3-16: Timber bulkhead was overtopped, resulting in lost backfill and damage to the house situated approximately 15 feet landward of the bulkhead (Lavallette, NJ)

15 feet landward of vertical wall erosion control structures. The houses observed by the MAT that were within 20 feet of erosion control structures and exposed to ocean waves during Hurricane Sandy had almost always sustained significant flood and/or erosion damage.

3.1.1.6 Proximity to Flood-Borne Debris Sources

Flood-borne debris was plentiful during Sandy and generally consisted of pieces of destroyed buildings, floating (intact) homes, sections of boardwalks, vehicles, and small debris. The larger debris items caused structural damage in some cases. Two representative examples are provided here: a house that washed off its foundation and into an adjacent house in Lindenhurst, Long Island, NY, and a section of boardwalk in Ortley Beach, NJ, that became flood-borne debris.

The house that washed off its foundation was an older house on the south shore of Long Island, not well-connected to its foundation piers, that was exposed to storm surge and waves generated in Great South Bay (Figure 3-17). The house washed off its foundation and caused damage to the exterior walls of the neighboring house.

The second example, the boardwalk debris from Ortley Beach, NJ, is illustrated in Figure 3-18. The house shown in Figure 3-18, which had a wood column knocked out, was near a damaged boardwalk. Large debris noted by the MAT in the vicinity of the house included pieces of the boardwalk, asphalt pavement, and floating pieces of houses. Which particular piece of debris caused the column failure at the house is not known, but large debris similar to the boardwalk debris or another piece of large debris (which could have been asphalt pavement lifted by the flow, or a floating house or large section thereof) likely caused the damage.

Figure 3-17:
Bayfront house washed off its foundation and into its neighbor (Lindenhurst, NY)

Flood Hazard Data: FIRM = Zone VE (8 feet)
ABFE = Not available. ABFEs were not released for Suffolk County because the FIRMs are up to date.
Sandy floodwater elevation = 7 feet NAVD88

Flood Hazard Data: FIRM = Zone VE (10 feet)
ABFE = Zone V (14 feet)
Sandy floodwater elevation = 8 feet NAVD88

Figure 3-18:
Wood column knocked out, probably by floating debris, such as a section of boardwalk (shown in bottom inset). Top right inset shows the failed column and middle right inset shows the failed connection between the column and the column footing (Ortley Beach, NJ).

3.1.2 Elevation and Freeboard

Building floor elevation relative to the flood level was one of the principal determinants of flood damage. Houses whose lowest floors were below the flood level were inundated at best or heavily damaged or destroyed by waves and debris at worst.

Depending on location, Hurricane Sandy flood levels ranged from near the Effective BFE to several feet above the BFE. In the latter case, houses constructed with freeboard above the BFE had less flood damage to the building (refer to Section 1.4 for definition of freeboard). Figures 3-19 and 3-20 show a side-by-side example of two canal-front homes in Beach Haven West, NJ. The house on the left is a pre-FIRM house on a raised slab foundation. The Hurricane Sandy flood level was approximately 2 feet above the slab, and estimated to be less than 1 foot above the BFE. The house on the right was under construction at the time of Hurricane Sandy (only the foundation had been installed), but 2 feet of freeboard was included in the design, and the floor would have been at least 1 foot above the flood level.

Figures 3-21, 3-22, and 3-23 show houses across the street from each other in Beach Haven, NJ. Most of the oceanfront homes are elevated one story above grade on pile foundations (garage level is at grade) and the houses across the street are elevated approximately 2 feet above grade on a pile foundation.

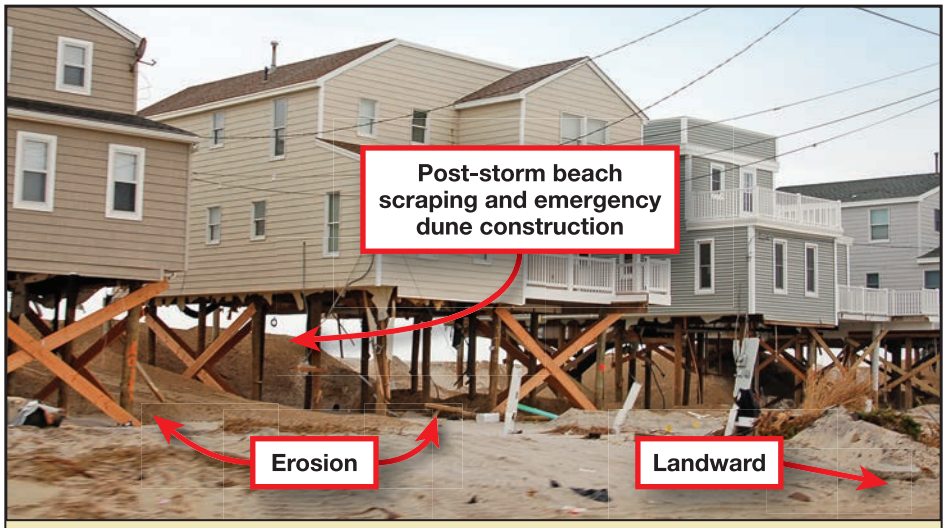
Flood Hazard Data: FIRM = Zone AE (8 feet)
ABFE = Zone V (10 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-19: Pre-FIRM house and adjacent elevated house under construction (Beach Haven West, NJ)

Figure 3-20:
Side-by-side view of houses shown in Figure 3-19;the Hurricane Sandy flood level was approximately 2 feet above the slab of the house on the left and below the floor level of the house under construction on the right (Beach Haven West, NJ)

When the dune was lost, as much as 5 feet of erosion occurred around the seaward pile foundations of the oceanfront homes (Figure 3-22). Much of that sand washed across the street and buried lots and roads. The house across the street washed off its foundation and into a neighboring home (Figure 3-23).

Figure 3-21:
Dune was lost and there was several feet of erosion around the pile foundations of oceanfront homes (see Figure 3-22) (Beach Haven, NJ). A lower elevation house across the street (circled) washed off its pile foundation and into a neighboring home (Figure 3-23).



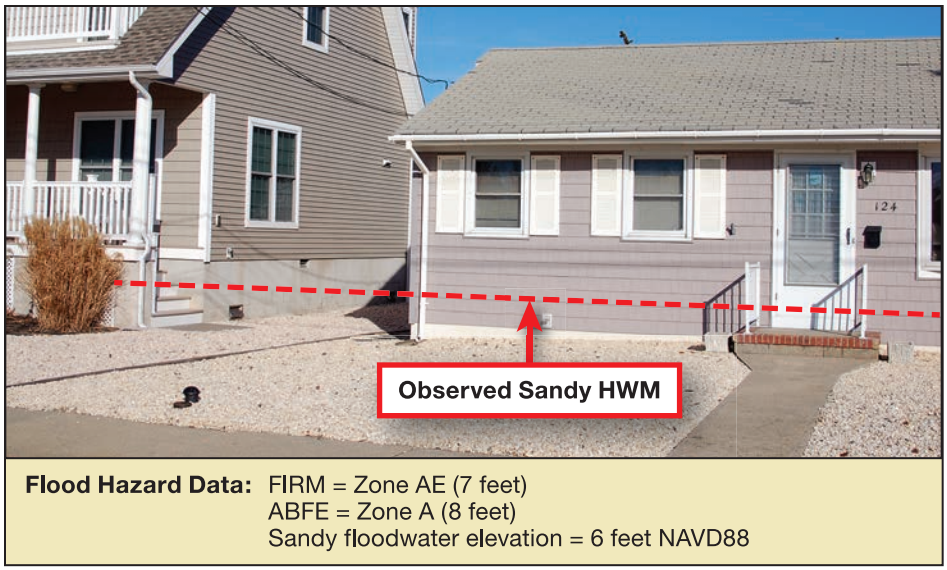
Flood Hazard Data: FIRM = Zone VE (10 feet)
ABFE = Zone V (14 feet)
Sandy floodwater elevation = 8 feet NAVD88

Figure 3-22: Dune next to these oceanfront houses was lost and an estimated 5 feet of erosion was observed under the seaward ends of the pile-supported buildings; cross-bracing for pile foundations shown in photograph was placed following the storm to prevent foundation collapses (Beach Haven, NJ)

Flood Hazard Data: FIRM = Zone AE (8 feet)
ABFE = Zone A (9 feet)
Sandy floodwater elevation = 8 feet NAVD88

Figure 3-23: House across the street from the pile-supported houses in Figure 3-22 was washed off its low pile foundation and shifted landward into a neighbor (Beach Haven West, NJ)

The final example of the value of freeboard is a house in Seaside Park, NJ. The house was elevated on a crawlspace foundation with 2 feet of freeboard (chosen by the owner). Hurricane Sandy floodwater entered the crawlspace via flood vents as expected, but the elevated house remained dry. The adjacent homes were not elevated, and floodwater inundated those homes above the floor (Figure 3-24).



Flood Hazard Data: FIRM = Zone AE (7 feet)
ABFE = Zone A (8 feet)
Sandy floodwater elevation = 6 feet NAVD88

Figure 3-24:
The house on the left was constructed with 2 feet of freeboard and remained dry during Hurricane Sandy; the house on the right was flooded above the floor level (Seaside Park, NJ)

3.1.3 Foundation Performance

The MAT observed a variety of foundation types, from wood to masonry to concrete, and with varying embedment depths, from shallow to deep. As expected, older, shallow foundations were observed to fail more frequently from erosion and local scour, regardless of the foundation material used. Deep foundations performed better in situations where erosion and scour occurred. Open foundations, such as piles or columns, performed better than solid wall foundations where waves or water moved at apparently high velocities.

The MAT also observed something not usually seen in post-storm inspections: reuse of old foundations for elevating old buildings or constructing new buildings. In some cases, the old foundations appeared largely unchanged, while in others, the new foundation elements were placed on top of or adjacent to old elements. As-built drawings and calculations were not available, so the degree of attention to design of these foundations is unknown, but the use and modification of pre-existing foundations appear to have led to additional load-path continuity problems.

Shallow versus Deep Foundations. Figures 3-25, 3-26, and 3-27 show the effect of foundation type on building performance in the area near the main breach at Mantoloking, NJ. Figure 3-25 shows the locations of two houses: House A, approximately 500 feet south of the main breach, and House B, approximately 500 feet north of the main breach. The MAT observed secondary flow channels near each of the houses, and flow depths above ground elevations near the houses were probably shallow (in the range of 2 to 3 feet), but flow velocities were probably quite high (several nearby homes in the area were swept off their foundations). Figure 3-26 looks north (toward the breach) past House A; House A was on a shallow masonry foundation and tipped into the secondary channel that formed on the north side of the house. House B shown in Figure 3-27 was constructed on a pile foundation with concrete grade beams. Although some of the columns supporting the deck on House B failed, the main foundation of the house remained in place despite scour around the foundation.

Figure 3-25:
Locations of two houses, House A (see Figure 3-26) and House B (see Figure 3-27), near the main breach at Mantoloking, NJ
SOURCE: NOAA

Flood Hazard Data: FIRM = Zone AE (5 feet)
ABFE = Zone V (10 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-26:
View looking north past House A toward the main breach, Mantoloking, NJ, shows the house tipped into the secondary scour channel that formed on the north side of the house. The area around the east and north sides of the house had been backfilled by the time photograph was taken.

Figure 3-27:
House B was under construction at the time of Hurricane Sandy; although the porch on the southeast corner collapsed into the secondary channel that formed on this side of the house, the main house survived because of its deep foundation. Inset shows grade beam supported by pilings (Mantoloking, NJ).

Many other shallow-versus-deep comparisons were evident in the Mantoloking area, where the Sandy damage was some of the worst seen by the MAT. In the area between the Mantoloking main breach and 1 mile to the north, there were approximately 55 oceanfront homes before Hurricane Sandy. After Hurricane Sandy, more than half were destroyed or had been heavily damaged by erosion. Almost all of the surviving houses—and few of the collapsed houses—were built on pile foundations. Figures 3-28 and 3-29 show pre- and post-Hurricane Sandy photographs of two adjacent oceanfront homes just north of Lyman Avenue (0.8 mile north of the main breach). House A was on a shallow foundation, and House B was on a pile foundation; House A was destroyed, but House B survived.

Figure 3-30 shows a house in a hard-hit neighborhood on the east side of Union Beach, NJ. The house was approximately 400 feet from Raritan Bay. The one-story house looked no more than a few years old and was elevated on a masonry wall foundation. The wall failed, and the house washed off the foundation (the order is uncertain).

Figure 3-31 shows a third-row house (approximately 300 feet from the Raritan Bay shoreline) in the Tottenville neighborhood of southwest Staten Island, NY. The habitable space is elevated over a garage. The garage walls are composed of a short masonry or concrete wall ("knee" wall) that extends approximately 4 feet above grade, and a wood-frame cripple wall atop the knee wall. The MAT observed many buildings with similar construction in this neighborhood. In many cases, the surge washed through the cripple wall section.

Flood Hazard Data: FIRM = Zone VE (12 feet)
ABFE = Zone V (14 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-28:
Pre-Hurricane Sandy photograph showing the area near House A and House B, approximately 0.8 mile north of the main breach at Mantoloking, NJ
SOURCE: USGS

Figure 3-29:
View looking across the former location of House A toward House B; inset shows remnant of a shallow footing for masonry pier at House A (Mantoloking, NJ)

Flood Hazard Data: FIRM = Zone AE (11 feet)
ABFE = Zone A (14 feet)
Sandy floodwater elevation = 13 feet NAVD88

Figure 3-30:
House washed off its masonry wall foundation, which collapsed (Union Beach, NJ)

Flood Hazard Data: FIRM = Zone VE (11 feet)
ABFE = Zone V (16 feet)
Sandy floodwater elevation = 13 feet NAVD88

Figure 3-31:
House elevated on a concrete or masonry knee wall and a wood-frame cripple wall was damaged when storm surge washed through the cripple wall section (side wall of house faced the bay) (Staten Island, NY)

Combinations of Foundation Systems. The MAT observed several instances where combinations of foundation systems were used under a single building, possibly a result of reusing old foundations when buildings were repaired, rebuilt, expanded, or elevated. The ages of the buildings are unknown, but many are apparently pre-FIRM buildings that have been modified over the years. Although the reasons for the foundation configurations are unknown, these foundations—and/or the connections to them—often failed to withstand the loads and conditions to which they were subject. Buildings were damaged in some cases and collapsed in others. The MAT observed several examples of these combined foundation systems over a short stretch of beach in Normandy Beach, NJ.

One example is an oceanfront house, constructed behind a dune, with a combination of masonry walls and timber piles used to support the house. The dune eroded, and the foundation elements were exposed to surge and waves. Figure 3-32 shows that the shore-parallel masonry wall collapsed, and the red circles show the failed connections between the timber piles and floor beam.

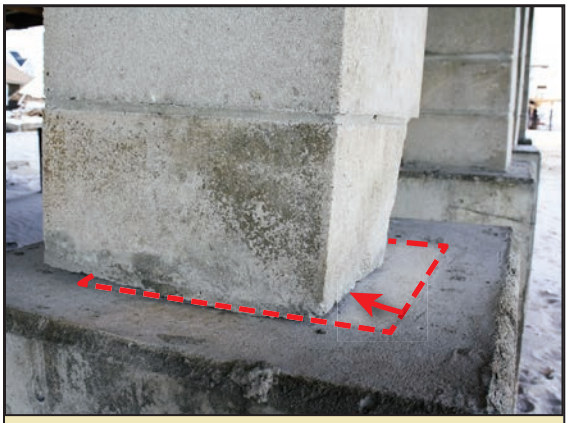
The second example is another oceanfront house in Normandy Beach elevated over a garage set into the back of the dune. The house was mostly supported by a deep, open foundation. The landward portion of the house was supported by piles with a concrete grade beam, steel pipe columns, and masonry (garage) walls above. The seaward portion of the house was supported by timber piles with concrete pile caps and masonry columns above the caps (Figure 3-33). The pile caps varied in depth from approximately 1 foot to 5 feet. The MAT observed movement of some of the masonry columns (Figure 3-34), indicating a lack of ties between the columns and pile caps or insufficient ties between the two.

Flood Hazard Data: FIRM = Zone AO (flood depth 2 feet above ground surface)
ABFE = Zone V (14 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-32: View of seaward side of the house shows combination foundation of masonry walls and timber piles; red circles indicate failed connections (Normandy Beach, NJ)

Flood Hazard Data: FIRM = Zone VE (10 feet)
ABFE = Zone V (14 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-33: Seaward side of house supported by an open foundation (Normandy Beach, NJ)



Flood Hazard Data:
FIRM = Zone VE (10 feet)
ABFE = Zone V (14 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-34: Movement of masonry columns where they join the pile caps (Normandy Beach, NJ)

The third example is an oceanfront house in Normandy Beach, NJ, that was elevated on a combination of timber piles, with wood beams and steel beams above. A timber bulkhead with a masonry wall above was attached to the perimeter piles (Figures 3-35 and 3-36). The seaward wall was pushed in, probably by waves and surge, and caused the failure of several timber piles and beams.

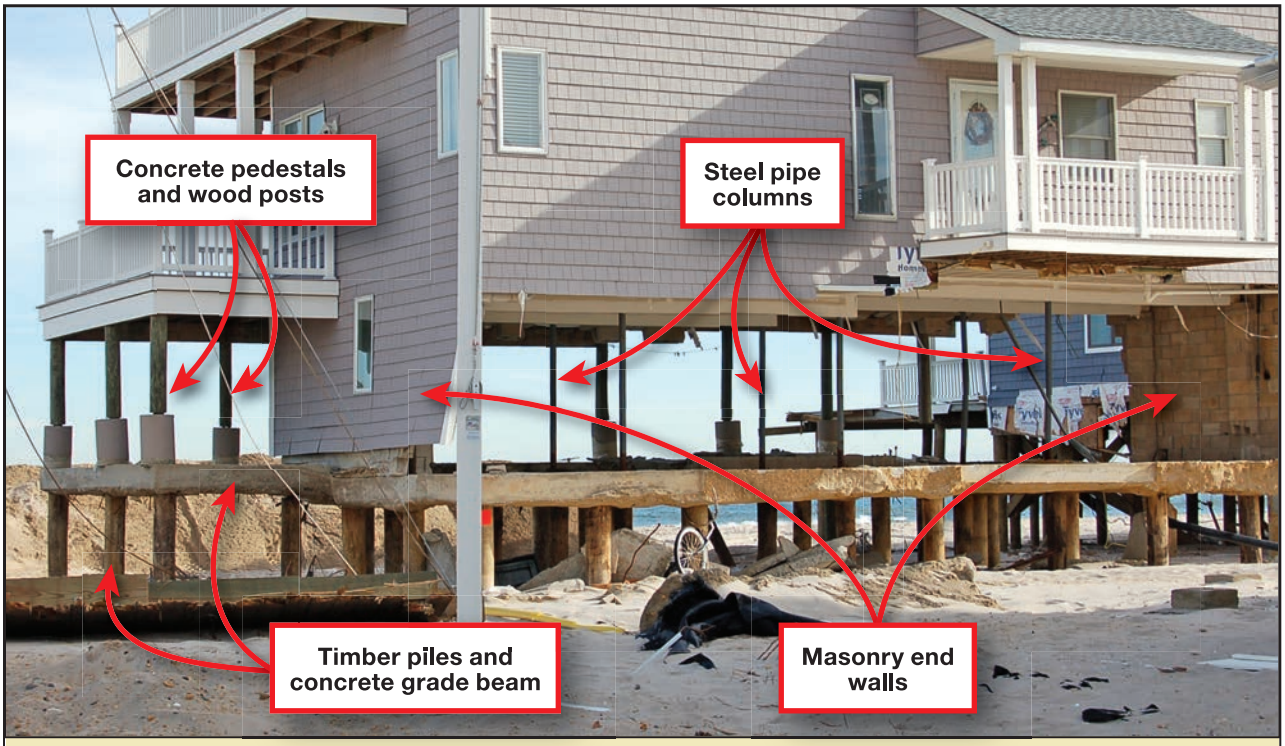
Flood Hazard Data: FIRM = Zone AO (flood depth 2 feet above ground surface)
ABFE = Zone V (14 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-35:
Elevated house supported by timber piles with a perimeter timber and masonry wall attached (Normandy Beach, NJ)

Flood Hazard Data: FIRM = Zone AO (flood depth 2 feet above ground surface)
ABFE = Zone V (14 feet)
Sandy floodwater elevation = 7 feet NAVD88

Figure 3-36:
Seaward piles and beams failed, probably when the seaward wall was pushed in by surge and waves (Normandy Beach, NJ)

The final example is a two-story residential building elevated above ground-level parking in Lavallette, NJ (Figure 3-37). The foundation of the elevated building is a combination of concrete grade beams atop timber piles, with three types of vertical structural elements above the grade beam: cast concrete pedestals with wood posts supporting elevated decks; masonry walls supporting the ends of the building; and steel pipe columns supporting the interior of the building. The timber piles and grade beams were exposed by approximately 5 feet of erosion. The masonry end walls were damaged (Figure 3-38), and one of the concrete pedestals was dislodged (Figure 3-39). Load path continuity from the foundation piles to the concrete pedestals to wood posts was compromised, and the masonry end walls were clearly inadequate for the flood loads encountered during Hurricane Sandy.



Flood Hazard Data: FIRM = Shaded Zone X
ABFE = Zone V (14 feet)
Sandy floodwater elevation = 9 feet NAVD88

Figure 3-37: Looking seaward through the parking level of a building elevated on multiple types of foundation elements (Lavallette, NJ)

Figure 3-38:
Damaged masonry end wall (north wall) of the building shown in Figure 3-37 (Lavallette, NJ)

Figure 3-39:
Failed concrete pedestal on the seaward side of the building shown in Figure 3-37 (Lavallette, NJ)

3.1.4 Connections between Foundation and Building

In many instances, the MAT observed insufficient connections between foundations and the buildings above. Although the load path to resist uplift and shear was not visible for every structure observed, the framing inspections revealed that, in most cases, the primary connection between the building and the foundation was accomplished through straps connecting the floor joists to the foundation beams. Load paths using hold-down anchors at the corners of shear walls were rarely observed. In most cases, the strapping used did not appear to be designed for both shear and uplift, and the straps were either insufficiently sized or there were not enough connectors. In several cases, the MAT observed significant corrosion of the connectors, which severely compromised the overall load path of the building. Foundation elements in several cases were not tested during Hurricane Sandy because there was an insufficient load path associated with the foundation-to-building connection. Poor load path connections in many of the buildings observed by the MAT allowed the buildings to become disconnected from their foundation. When struck by flood forces, these houses either moved entirely off their foundation, destroying the buildings, or allowed them to float off their foundation. Although some foundation failures were observed in situations where the building loads were not transferred to the foundation, most of the piles and beams remained in place even after being exposed to storm surge, and even when the surge overtopped the foundation elements.

The MAT observed numerous instances where the connections between the foundation and the building failed. The following examples are representative of the types of failures observed.

Seaside Heights, NJ – Connector Length

Figure 3-40 shows houses from the beachside community of Seaside Heights, NJ. Two houses, labeled House A and House B, were subjected to similar flood forces with different outcomes. The houses were at approximately the same elevation and similarly protected from storm surge by another row of houses along the shoreline. House A completely slid off its foundation and was resting against another house farther inland, while House B remained in place.

The foundation for House A consisted of timber piles with wood beams, on top of which the wood-frame house was attached. The house was attached to the foundation using small clips typically used to connect rafters to top plates and used only three nails at each end to make the connection. That MAT observed that many of the connections at House A appeared to have either sheared, or the nails withdrew from the floor joists they were attached to as the connector rotated (Figure 3-41). The failure of the connections allowed the house to slide off its foundation.

Although directly across the street from House A, House B remained in place. House B sustained some damage, but remained on top of its foundation. Although House A was framed with dimensional lumber floor joists rather than the engineered floor joists used for House B, the primary observed difference between the two houses with respect to the load path was the length of the load path connectors between the foundation beam and the floor framing. The load path connectors at House B were significantly longer than those across the street at House A (Figure 3-42). The House B connectors extended more than half the depth of the floor joists and more than half the depth of the foundation beam. Although the House B straps did not have the proper total number of nails in many of the connectors observed, the additional length of the connector improved the load distribution along the beam and floor joist. Neither House A nor House B appeared to have visible corrosion on the straps.

Flood Hazard Data: FIRM = Zone VE (10 feet)
ABFE = Zone V (14 feet)
Sandy floodwater elevation = 8 feet NAVD88

Figure 3-40:
Two houses (labeled A and B) near Harding Avenue in Seaside Heights, NJ, that experienced similar exposure to storm surge with different results

Figure 3-41:
In House A, a series of connectors failed due to withdrawal when the building was subjected to uplift and shear (Seaside Heights, NJ)

Figure 3-42:
In House B, a series of longer strap connectors (inside red circle) between the beam and floor joist maintained connection during Hurricane Sandy (Seaside Heights, NJ)

Beach Haven, NJ – Connector Length

Figure 3-43 shows a foundation beam that split because of a compromised load path connection. The connectors were too short, and the alignment of the connectors, combined with the uplift loads associated with high winds and flood levels exceeding the floor system, caused the foundation beam to split. Connector straps along one side of the beam were nailed into only the upper third of the beam depth, resulting in the nails splitting the grain of the wood; the beam split and failed, allowing the house to float back into an adjacent house. Although assessing whether the uplift on the house would have exceeded the capacity of the connectors would be difficult, the beam would probably not have split with longer load path connector straps.

Figure 3-43:
Beam failed due to a series of short connectors installed near the top of the beam, allowing it to split along the grain (Beach Haven, NJ)

Flood Hazard Data: FIRM = Zone AE (8 feet)
ABFE = Zone A (9 feet)
Sandy floodwater elevation = 8 feet NAVD88

Driftwood Beach Club, Sea Bright, NJ – Corroded Connectors

Many homes on Harding Avenue in the Driftwood Beach Club community of Sea Bright, NJ, experienced uplift from flood loads, with some contribution from wind loads. Wave loads likely knocked out windows, doors, and walls along the front (ocean side) of the buildings, and then, as flood heights increased, the buildings slid landward off their foundations until large sections of the foundations detached from the back. An inspection of remaining foundation systems of buildings on Harding Avenue revealed several instances of corroded connectors that no longer provided uplift or shear resistance for the foundation; an example is shown in Figure 3-44. Some of the remaining connectors observed in the nearby community of Seaside Heights exhibited similar failures where connectors had twisted, causing withdrawal of the nails.

Staten Island, NY – Older Homes

The MAT observed numerous houses constructed in low marshy areas on Staten Island, primarily between 1920 and 1960, with either minimal or no foundation-to-building connections. Several houses floated off their foundation during the storm event. The condition of many of the foundations

indicates that the crawlspaces flooded, and the buoyant forces lifted the houses off their foundations. Masonry foundations in this area are common, and the connections to houses were either highly corroded bolts or, in some cases, wooden sill plates embedded into mortar (Figure 3-45).

Flood Hazard Data: FIRM = Zone AE (9 feet)
ABFE = Zone A (8 feet)
Sandy floodwater elevation = 10 feet NAVD88

Figure 3-44:
Corroded connectors (red circle) between the foundation beam and floor joists did not provide uplift and shear resistance to withstand flood loads (Sea Bright, NJ)

Flood Hazard Data:
FIRM = Zone AE (10 feet)
ABFE = Zone V (16 feet)
Sandy floodwater elevation = 13 feet NAVD88

Figure 3-45:
A foundation with corroded connection bolts (shown in red circles); the house was lifted off the foundation because of an insufficient number of connectors (Staten Island, NY)

Fire Island, NY – Compromised Connectors

Houses along the beachfront on Fire Island were situated directly behind the dune system before Hurricane Sandy struck. Many of these houses had foundation-to-building connections, but the connectors were corroded either completely or to a degree that uplift and shear resistance would have been compromised. In some cases, the connectors had been replaced, and in others, the houses lacked a continuous load path. Figure 3-46 is an aerial photograph showing two homes, labeled House A and House B, before and after Hurricane Sandy. Figure 3-47 shows a close-up of these same two houses. House A did not have a continuous load path, and the house slid off its wooden pile foundation onto the sand (Figure 3-48). Although much of the damage observed to House A was likely from floodwater that exceeded the elevation of the house, the house next door (House B), which was similar in construction, remained in place. The MAT observed that House B had more load path connectors still intact after the storm event.

Flood Hazard Data: FIRM = Zone VE (16 feet)
ABFE = Not available. ABFEs were not released for Suffolk County because the FIRMs are up to date.
Sandy floodwater elevation = 14 feet NAVD88

Figure 3-46: Pre- and post-Hurricane Sandy aerial photographs of two Fire Island, NY, houses visited by the MAT; floodwater rose to 14 feet at this location

SOURCE: USGS

Figure 3-47: House A was unable to maintain a continuous load path because of significant corrosion of the connections between the foundation beams and floor joists (see Figure 3-48). House B had some corroded connections, but several had been replaced, and the continuous load paths were sufficient to enable relatively good performance (Fire Island, NY).

Figure 3-48:
In House A (shown on Figure 3-47), the corroded foundation beam-to-floor joist connections failed to maintain a continuous load path (Fire Island, NY)

3.1.5 Basements and Subgrade Areas

Though rarely observed by the MAT in the coastal areas of New Jersey, basements and below-grade garages are common in the New York City metropolitan area. Structurally, the basements and subgrade areas of the low-rise buildings the MAT evaluated performed well. Buildings that were constructed primarily for residential use, such as multi-family dwellings, sustained damage consistent with single-family construction. Most of the damage observed by the MAT was to interior finishes and contents. Few major structural issues related to basements and subgrade areas were encountered in the areas the MAT inspected.

The MAT observed many instances of driveways that sloped down toward a garage, often as much as 4 feet below grade. In most cases, houses had one-car garages and below-grade basement areas that housed MEP systems. These spaces are usually pumped out during normal rain events using a standard residential sump pump. However, during Hurricane Sandy, water from either the rain event or storm surge overwhelmed these sump pumps. Some of the sump pumps may have been rendered inoperable due to a loss of power or an extended outage whose duration exceeded the battery capacity of sump pumps with small backup power supplies. In most cases observed by the MAT, the water exceeded the curb and sidewalk elevation and filled the below-grade garage and basement area to the outside flood elevation. In most of these instances the main house did not sustain flood damage, but equipment and contents in the garage and basement were destroyed.

The following examples are representative of the types of damage observed by the MAT in low-rise residential buildings.

Manhattan Beach, NY – Storm Surge and Sand Damage

Although the flooding of garages in Manhattan Beach, NY, was due in most cases to high flood levels in the streets, houses along the shoreline were inundated directly by storm surge. Floodwater appeared to reach the garage height in many of the houses the MAT visited. Figure 3-49 depicts a typical below-grade garage in the New York City area. Houses subject to such flooding were not only subjected to floodwater but also to sand conveyed by the surge. Many of the sand-damaged properties may have otherwise been resistant to floodwater alone but required sand removal to restore the property to its pre-storm condition.

Figure 3-49:
A below-grade garage typical in the New York City area that was inundated by storm surge (Manhattan Beach, NY)

Flood Hazard Data: FIRM = Shaded Zone X
ABFE = Zone A (11 feet)
Sandy floodwater elevation = 11 feet NAVD88

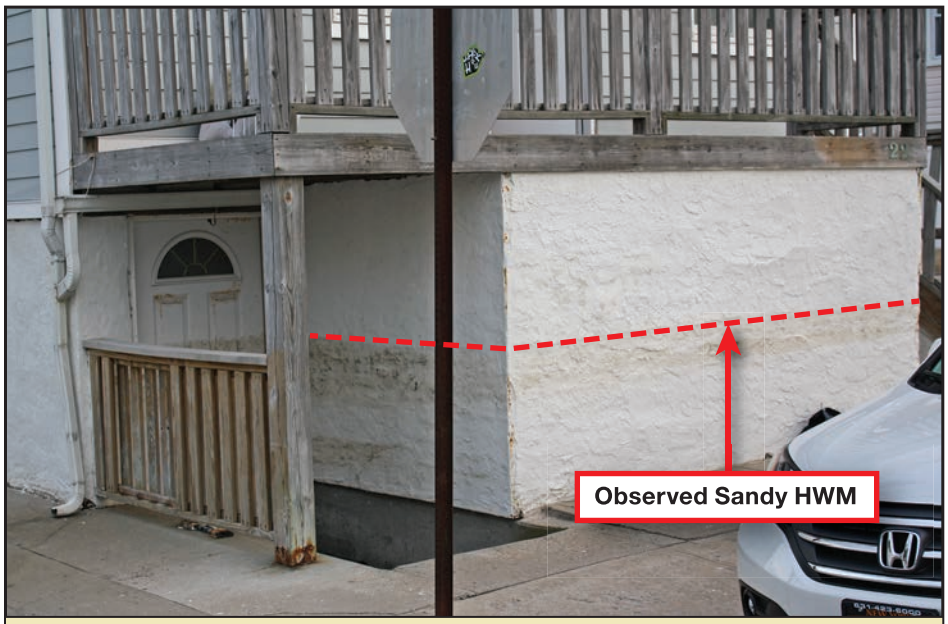
Long Beach, NY – Basement Apartments

There were numerous basement apartments where the MAT observed marks made by sand deposited approximately 2½ to 3 feet above grade. Based on the height of the HWMs above the doors and on exterior walls, the floodwater reached a height of 5 to 6 feet inside the basements (Figure 3-50). Although the flooding may not have caused enough damage for it to be determined as Substantial Damage to the structure, the damage to the finished area and contents in basement apartments was significant.

Long Branch, NJ – Use of Lowest Level for Parking

The condominium shown in Figures 3-51 and 3-52 appropriately used the lowest level as a parking garage. Although storm surge penetrated the beachside face of the building, breaching windows and doors, it did only minimal damage inside the building. Gypsum wrapping over structural

steel beams was damaged, but the beams themselves were not damaged. Lines along the exterior concrete masonry unit (CMU) walls of the structure indicated that a significant amount of sand was deposited inside the building, but it had been cleared before the MAT arrived.



Flood Hazard Data: FIRM = Zone AE (14 feet)
ABFE = Not available. ABFEs were not released for Nassau County because the FIRMs are up to date.
Sandy floodwater elevation = 14 feet NAVD88

Figure 3-50: Example of a basement apartment flooded by storm surge (Long Beach, NY)

Flood Hazard Data: FIRM = Zone X
ABFE = Zone AE (9 feet)
Sandy floodwater elevation = 12 feet NAVD88

Figure 3-51: Exterior view of an at-grade parking area for a condominium (Long Branch, NJ)

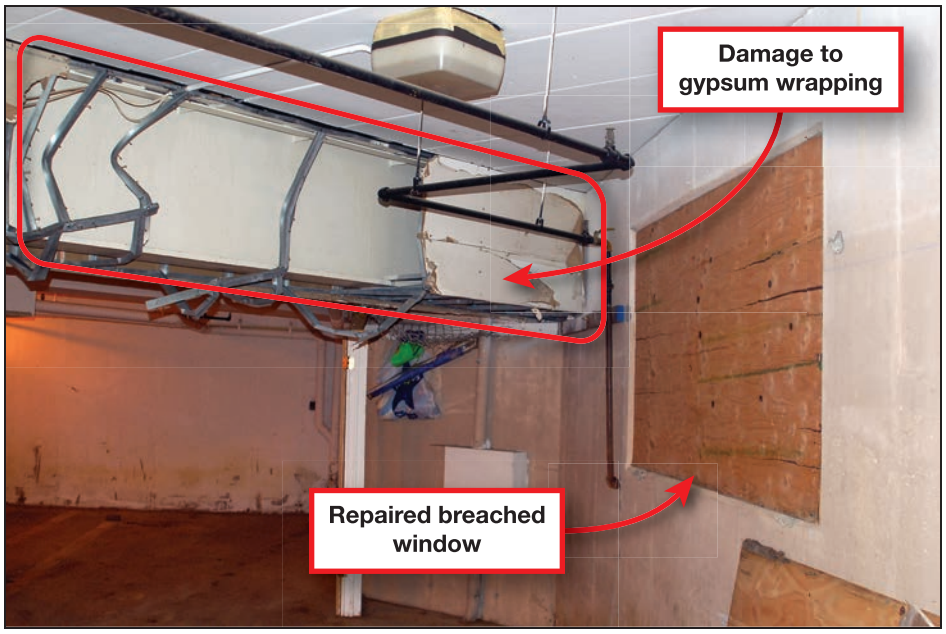


Figure 3-52:
Interior view of the at-grade parking area showing signs of storm surge and sand damage; note damage to the gypsum wrapping over the structural beam (red circle) (Long Branch, NJ)

3.1.6 Mechanical, Electrical, and Plumbing Systems

In many homes, the MEP systems are located on the lowest level of the building. These spaces were often below the BFE and subjected to significant flooding during Hurricane Sandy. Furnaces, boilers, water heaters, electrical panels, and other equipment were damaged beyond repair in many of the buildings the MAT visited. The systems were located in below-grade garages or basements, or utility rooms in at-grade floors that were inundated by floodwater or displaced sand. Other houses were flooded to an elevation above the height of the electric meter. Even when the main portion of the house was not damaged by floodwater, the owners were still displaced because of loss of power. In other cases, equipment such as air-conditioning units was elevated on exterior platforms, but was damaged by flood-borne debris dislodging support piles for the elevated platforms.

Damage to MEP systems in other low-rise buildings was consistent with that observed in single-family residential construction. In many locations, the similarities with single-family dwelling damage were particularly apparent for small multi-family dwellings with four and five apartments (Figure 3-53). These units often had basement apartments that were significantly damaged. Even occupants in units well above the reach of floodwater were displaced because of the lack of electricity and other services. Other buildings, such as some low-rise condominiums, appeared to have had their services restored before the MAT arrived (Figure 3-54), and the remaining damage was primarily to the lowest levels.

The following examples are representative of the types of damage observed in low-rise residential buildings.

Figure 3-53:
Damaged electrical meters at a multi-family dwelling (Far Rockaway, NY)

Figure 3-54:
A new transformer beside a low-rise apartment building replaced one that was damaged by storm surge (Far Rockaway, NY)

Beach Haven, NJ – Damage to At-Grade Equipment

The MAT observed numerous houses with MEP equipment in at-grade enclosures (Figures 3-55 and 3-56). These systems either were directly damaged by floodwater or sand was deposited inside the equipment. Although floodwater did not appear to have caused significant damage to the homes, the lack of power or air circulation from the inoperative heating, ventilation, and air conditioning (HVAC) system may have resulted in mold damage from even minimal water intrusion.

Flood Hazard Data: FIRM = Zone VE (11 feet)
ABFE = Zone V
Sandy floodwater elevation = 8 feet NAVD88

Figure 3-55: Electrical panels and water heaters installed in the lowest level of this beachfront house were damaged during Hurricane Sandy (red circles) (Beach Haven, NJ)

Figure 3-56: Water heater and furnace system installed in an at-grade enclosure underneath a beachfront house were damaged by floodwater (Beach Haven, NJ)

3.2 Performance Relative to Wind

Although Hurricane Sandy was primarily a flood event, the MAT observed some wind damage to low-rise buildings. Based on the MAT review of the wind data, the wind speeds during Hurricane Sandy did not exceed the ASCE 7 design wind speeds (approximately 100-120 mph) in any location across the affected area (Figure 3-57). In New Jersey, where Hurricane Sandy made landfall, maximum sustained wind speeds of approximately 80 mph or less were measured (NHC 2013b),

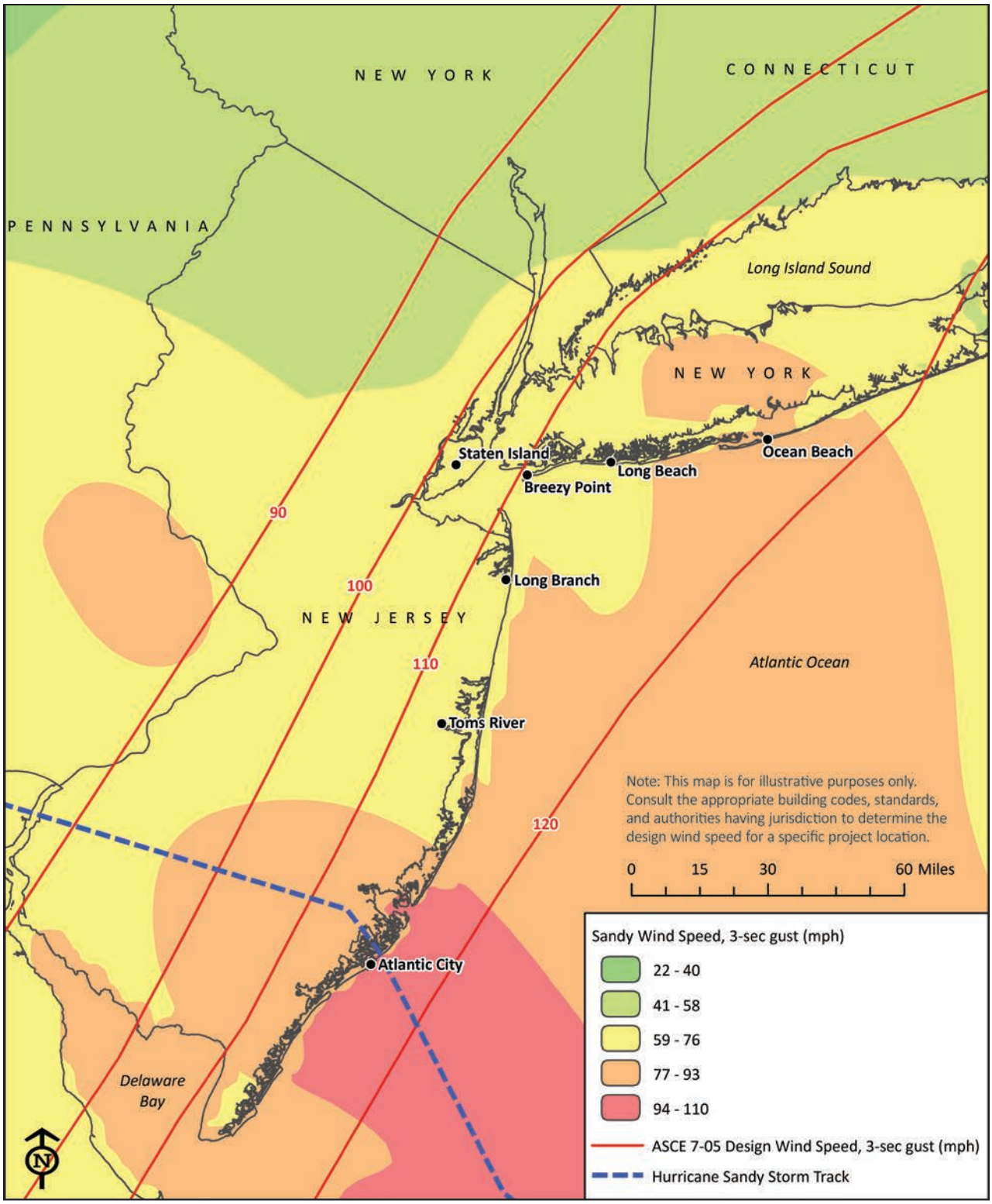


Figure 3-57: Wind speed data gathered by NOAA for Hurricane Sandy adjusted to the 3-second gust and compared with ASCE 7-05 design wind speeds.

SOURCE: ASCE 7 WIND SPEED INFORMATION USED WITH PERMISSION FROM ASCE

which is at the low end of the wind range for a Category 1 hurricane. The minimum sustained wind speed for a hurricane is 74 mph. For more information, refer to the Saffir-Simpson Hurricane Wind Scale shown in Appendix B.

Few buildings sustained wind damage, and much of the damage observed was confined to the building envelope. Where envelope damage was observed, it was typically on older buildings that had multiple layers of exterior cladding that were not appropriately attached to each other or to the building framing. Some roof losses were observed on tall buildings with sloped roofs and a few one- to two-story buildings; however, this type of damage was not frequently observed. Broken glazing was observed, but it was mostly confined to lower floors, and much of it was from flood-borne debris, not wind.

3.2.1 Main Wind Force Resisting System

Although the MAT observed no wind-related damage to the main wind force resisting system (MWFRS) of buildings, exposed building framing was inspected where present. In many cases, the buildings had no clear load paths or the load paths appeared insufficient based on wind speeds used in modern codes and standards for their location. However, because the wind speeds experienced during Hurricane Sandy were below the design wind speed for houses constructed under the building codes, the load paths present in these buildings—typically consisting of either nailed-only connections or undersized metal connectors—were mostly not tested by this wind event. If a design wind event had occurred, many additional structural failures would be expected.

Seaside Heights, NJ

Figure 3-58 shows a two-story house that was one of the few buildings observed to sustain wind damage. The fascia on the seaward side of the building appeared to be nailed to short sections of dimensional lumber, which were spaced similarly to the roof rafters and held in alignment with sections of oriented strand board running parallel to the ridge line. It was difficult to determine how this architectural extension to the roof system was attached to the roof framing, but it appeared that the entire extension section rolled up onto the roof system because of the small overlap of the roof sheathing section onto the main roof trusses. The loss of roof sheathing opened up the building to wind-driven rain and potentially internal pressurization. The lack of other damage to the siding, trim, and windows suggests that wind speeds were well below the design wind speed.

Although damage to the components and cladding of some buildings was observed, the damage was likely caused by incomplete load paths, which could result in additional loads on the MWFRS than were accounted for in the building design.

Figure 3-58:
Failure of a roof rafter fascia due to wind loads; loss of the fascia allowed water to enter the building (Seaside Heights, NJ)

3.2.2 Building Envelope Damage

Damage to building envelopes (components and cladding) was more common than to the MWFRS. This was particularly true for older structures. Many older structures with multiple layers of siding added during various remodeling efforts were observed. Consequently, the fasteners for the outermost layer of siding typically had insufficient embedment into an appropriate solid material, such as wood studs. Although vinyl siding nailed into older wood siding was observed, it probably did not meet the manufacturer's installation recommendations for attachment.

The building envelope damage was primarily to older buildings as noted below.

- + Loss of inadequately attached siding or windows that may not have been properly anchored to the building framing (Figure 3-59).

Figure 3-59: Commercial building on Staten Island, NY, with siding loss due to wind damage

- + Several older buildings that had multiple layers of exterior cladding and insulation. These buildings lost significant areas of the cladding material because the fastener length was insufficient or fasteners were attached to older cladding that had decayed (Figure 3-60).

- + Minimal loss of roof covering; roof damage observed was typically associated with older roof systems (Figure 3-61).

There were a few instances where siding material was lost from some newer construction (Figure 3-62). The nature of the siding loss indicated that the siding may not have been a high-wind vinyl siding capable of withstanding wind in an Exposure Category C as defined in ASCE 7-05.

Figure 3-60:
A multi-family low-rise building in Belmar, NJ, was damaged by wind; note multiple layers of siding

Figure 3-61:
Shingle loss on a beachfront restaurant; note that surrounding roofs do not appear to be damaged (Belmar, NJ)

Issues such as insufficient fastener length, overdriving or underdriving of fasteners, or improper fastener spacing all contributed to premature siding failure.

The following examples are representative of the types of wind damage observed in low-rise residential buildings.

Figure 3-62:
Vinyl siding on this recently constructed multi-family dwelling was damaged by wind during Hurricane Sandy (Union Beach, NJ)

S. Bay Avenue in Beach Haven, NJ – Multiple Sheathing Layers

Numerous houses along S. Bay Avenue in Beach Haven sustained various degrees of envelope damage. Many houses had four or more layers attached to the exterior sheathing. These consisted of several layers of siding, felt, and exterior insulation (Figure 3-63). Whether the additional layers of vinyl siding were purely aesthetic upgrades or intended to replace existing siding in disrepair was unclear. The poor or decayed condition of the original exterior siding, insulation, felt, and sheathing appeared to allow windblown rain to penetrate the building envelope once these layers were pulled off the building.

Figure 3-63:
Damaged siding on house with felt, exterior insulation, and two layers of exterior siding (red arrows show various layers) (Beach Haven, NJ)

Fane Court in Gerritsen Beach, NY – Improperly Fastened Siding

The MAT observed damaged siding on several older homes in Gerritsen Beach, several of which had vinyl siding installed over older materials. In many cases, insulation was added to the original siding and the vinyl siding was attached to the outside of the insulation. Fasteners were presumably not long enough to resist the wind loads.

In one case, insulation was attached to the outside of brick veneer (Figure 3-64). The insulation and vinyl siding were not installed with a symmetrical nail pattern, and not enough fasteners were used. In fact, large sections of insulation did not appear to have any fasteners. The vinyl siding was attached with fasteners that were likely not long enough to pass through the insulation and penetrate the brick veneer. Much of the loss of siding was on an open wall area where the vinyl was not restrained by fascia or window trim.

Figure 3-64: Damage to exterior siding with newer vinyl siding installed over insulation and brick veneer (Gerritsen Beach, NY)

Staten Island, NY – Wind-Borne Debris

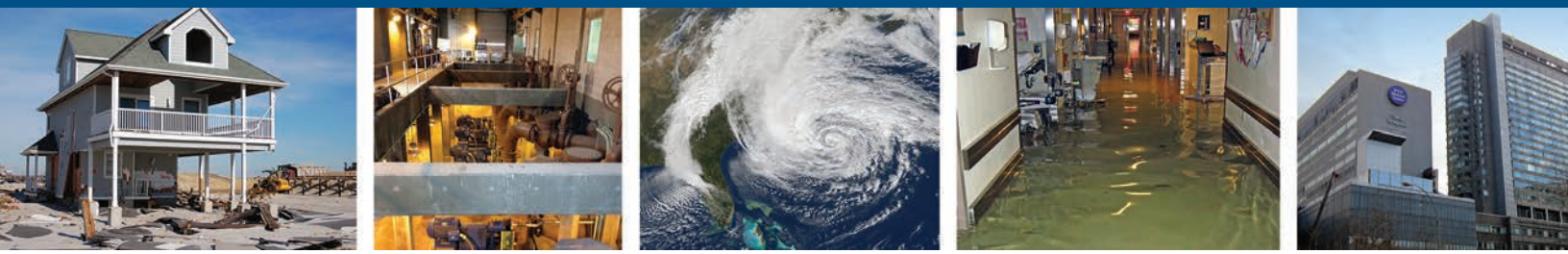
Several beachfront houses experienced roof and window damage during the storm. Whether this damage was from wind-borne debris or just wind pressures is unclear. Damage to gutters suggests that some of the damage may have been the result of wind-borne debris. Houses, such as the one shown in Figure 3-65, had window damage that started at lower level windows, which was probably caused by floodwater and flood-borne debris rather than wind. The windows that spanned the full height of the building up to the roof covering and skylights were more likely damaged by wind-borne debris, since the elevation exceeded storm surge heights. Anchorage systems or attachment points for shutters were not visible on the houses the MAT visited.

Figure 3-65: Beachfront house with damaged windows, skylights, gutters, and siding (Staten Island, NY)

3.3 Mold

Mold contamination is always a potential issue after a major flooding event. Mold is an issue for all of building types observed by the MAT, but particularly damaging to the one- and two-story residential buildings. Many residents were not able to immediately return to their homes to remove and replace flooded materials. Although there was little evidence of mold contamination during field investigations, the thousands of buildings with at-grade or below-grade living areas that were inundated by floodwater had finishes that needed to be cleaned after Hurricane Sandy or replaced following contact with potentially contaminated floodwater and to prevent the occurrence of mold.

Even though homeowners may have cleaned or replaced materials that were below the flood level, the materials above the flood level may have remained intact for a long time after the flooding. These materials may harbor mold or other contaminants. The low temperature and humidity after Hurricane Sandy gave property owners time to dry out their homes; the climate was especially helpful in homes without power because the interior of the home was kept cool and in a condition not conducive to mold growth. However, mold would have become more obvious in areas that were not properly cleaned or on finishes that were not replaced as house interiors became warmer after power, and thus heat, was restored, and during the warmer months in the spring and summer of 2013.



HURRICANE
SANDY
IN NEW JERSEY
AND NEW YORK

4 Performance of Mid- and High-Rise Buildings

The MAT observed commercial and residential mid- and high-rise buildings in the New Jersey and New York metropolitan areas affected by Hurricane Sandy.

Mid-rise buildings are defined in this MAT as having four to seven stories, and high-rise are defined as having eight or more stories.[1] Mid- and high-rise buildings are commonly used for residential and commercial use in densely populated urban areas. These buildings typically are designed to have robust structural systems; however, good structural performance alone does not ensure adequate protection from flood damage. Hurricane Sandy demonstrated that mid- and high-rise buildings do not have to be severely damaged or collapse to be rendered inoperable.

Observed damage to mid- and high-rise buildings was similar for the sites visited and caused by inundation from the high surge levels. Flood damage was predominantly to the critical building

1 The MAT definition for high-rise is adapted from the definition in the IBC: *"A building with an occupied floor located more than 75 feet above the lowest level of fire department vehicle access."* There is no definition in the IBC or other standards for mid-rise buildings; therefore, the MAT defined mid-rise as a building between four and seven stories.

systems of these structures, the failure of which crippled building operations and affected thousands of occupants. Residential units in most mid- and high-rise buildings are located above flood elevations and were not inundated inside the dwelling units. However, damage to building systems delayed recovery after the flooding and prevented people from reoccupying their homes and reopening their businesses quickly after the storm. Interruptions of businesses and temporary relocation of the residents of these highly occupied buildings increased the total financial loss to these facilities. The cost of returning building functions back to normal included both the direct costs of repairing the damaged equipment and contents as well as the cost of lost rent and business income.

TERMINOLOGY

Critical building systems: Includes any building system essential to the functioning of a building. May include MEP, emergency power, gas installations, communications, conveyance, and fire suppression.

4.1 Mid-Rise Buildings

The MAT visited seven mid-rise buildings that are part of public housing developments operated by the New York City Housing Authority (NYCHA). The housing developments visited are located throughout the Boroughs of Brooklyn and Queens and in various flood zones. All but one of the mid-rise residential buildings sustained significant damage to their mechanical and electrical systems as a result of water inundation from the storm surge. The MAT visited mid-rise buildings at the following developments:

- Carleton Manor
- Hammel Houses
- O'Dwyer Gardens
- Ocean Bay Apartments – Bayside
- Ocean Bay Apartments – Oceanside
- Red Hook West Houses
- Surfside Gardens

The mid-rise buildings highlighted in this chapter are a mix of buildings located inside and outside the SFHA. The buildings were all built in the 1950s and 1960s. Occupancy types were exclusively multi-family residential. All structures visited had subgrade spaces, almost all of which housed the building systems except for one development. The following observations are representative of the damage to mid-rises in the New York area that were inundated by storm surge.

4.1.1 Siting Effects on Building Performance

The location of each of the mid-rise developments was an important factor in the amount of flood damage they received. Table 4-1 lists each of the mid-rise developments visited along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations, and the level of storm surge experienced during Hurricane Sandy. The flood zones in Table 4-1 include those

shown on FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

Three of the developments visited in Queens, NY, are in Zone X yet experienced flood inundation. The other four sites visited in Queens and Brooklyn are in the SFHA. All seven of the mid-rise developments were subject to storm surge and inundation inside the building as a result of Hurricane Sandy. In the case of the properties on the Rockaway Peninsula and Coney Island, the flooding was a result of storm surge from the Atlantic or Jamaica Bay (to the north of the Rockaway Peninsula). The Red Hook development reportedly received flooding from a canal off Gowanus Bay that runs to the north of the property.

Table 4-1: BFEs, ABFEs, and Sandy Floodwater Elevations for Mid-Rise Buildings

Facility Name	Location (New York)	Relevant FEMA Flood Maps	Flood Zone on Map[a]	1-Percent-Annual-Chance Elevation (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[c]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
Carleton Manor	Rockaway (Queens)	Effective FIRM	Unshaded X	n/a	n/a	11
		ABFE	A	11	15	
Hammel Houses	Rockaway (Queens)	Effective FIRM	Unshaded X	n/a	n/a	10
		ABFE	V	11	15	
O'Dwyer Gardens	Coney Island (Brooklyn)	Effective FIRM	AE	9	n/a	12
		ABFE	A	13	18	
Ocean Bay Apartments, Bayside	Rockaway (Queens)	Effective FIRM	Shaded X and AE	n/a and 8	n/a	10
		ABFE	A	10	13	
Ocean Bay Apartments, Oceanside	Rockaway (Queens)	Effective FIRM	Shaded X and AE	n/a and 7	10	10
		ABFE	A	11	15	
Red Hook West Houses	Red Hook (Brooklyn)	Effective FIRM	AE	9	n/a	11
		ABFE	A	11 and 12	17	
Surfside Gardens	Coney Island, (Brooklyn)	Effective FIRM	AE	9	n/a	12
		ABFE	A	13	18	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the Tropical Cyclone Report, Hurricane Sandy (AL182012) (NHC 2013b).

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the Flood Insurance Rate Map [FIRM]). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

4.1.2 Structural Performance

The mid-rise residential developments are large and are constructed of heavy building materials and suffered no structural damage from inundation of floodwater or high winds.

Hammel Houses. The development opened in 1955, consists of 14 buildings with 708 total units, and houses a population of approximately 1,900 people. The buildings are six- and seven-story concrete-frame structures with brick façades.

The MAT observed consolidation of saturated soils at the Hammel Houses development (Queens, NY) as a result of Hurricane Sandy (Figure 4-1). The consolidation appeared to be caused by the saturation of under-compacted soils and did not affect the structural performance of the buildings.

Figure 4-1: Consolidated soils at Hammel Houses (Queens, NY)

4.1.3 Critical Building Systems

All but one of the mid-rise residential developments the MAT visited housed equipment for MEP systems in below-grade spaces. Where floodwater entered the structure and inundated the basement, these building systems were severely damaged or destroyed. Boilers, controls, electrical panels, switchgear assemblies, fuel tanks, and other mechanical systems were damaged. The MAT did not observe damage to utility company equipment, but all the sites visited lost municipal power from the service provider for a short duration. Outages extended past the restoration of the electrical grid (approximately less than 10 days) because of floodwater damage to electrical systems at the developments. Residents in buildings with damage to MEP equipment were without power, heat, and hot water until temporary equipment was obtained and installed (Bres 2012). Buildings were repaired later. According to reports from NYCHA, approximately 80,000 residents in 423 buildings were affected by lost power, heat, and/or hot water as a result of the storm. By November 18, heat, power, and hot water were completely restored (by either repair or replacement or the installation of temporary equipment) to all NYCHA buildings affected by the storm (New York City 2013a). The Ocean Bay developments and Red Hook West Houses are representative case studies of damage to critical building systems in mid-rise residential buildings.

Ocean Bay Apartments. Ocean Bay Apartments consists of two developments—the Bayside and Oceanside developments—separated by Beach Channel Drive on the Rockaway Peninsula in Queens (Figure 4-2). The Bayside development, constructed in 1961, consists of 24 buildings with a total of 1,378 units and houses a population of approximately 3,600 people. The Oceanside development was constructed in 1951 and consists of seven buildings with a total of 417 units that house a population of approximately 850 people. The buildings in both developments are mainly six- to nine-story concrete-frame structures with brick façades.

Figure 4-2: Aerial view of Ocean Bay Apartments, comprising Oceanside (yellow) and Bayside (red dashed), shows the location of Building 4 and Building 22, which house the central boiler plants (Queens, NY)

Damage to the two Ocean Bay Apartments developments differed based on the elevation of the central boiler plant and other mechanical and electrical equipment. The MAT observed significant damage to boilers, control systems, and electrical equipment in the basement of Building 22 of the ***Bayside development*** (Figures 4-3 to 4-5). Floodwater surrounding the building was approximately 2 feet deep; the floodwater entered the basement through several at-grade vented louvers and through exterior doors that opened to staircases leading to the basement (Figure 4-6). The basement was inundated with approximately 18 feet of floodwater. Residents at the Bayside development were without electricity and heat for several days after the storm until temporary electrical equipment was installed. Large portable generators were installed outside the buildings to provide electrical service while equipment was replaced and the electrical grid was repaired. In addition, temporary boilers were installed and expected to be used for an extended period because of the time required for repair or replacement of the damaged boilers.

The adjacent ***Oceanside development*** performed much better than the Bayside development because the boiler room was located on the ground level in Building 4. Less than 1 foot of water entered the building, and none of the mechanical or electrical equipment was damaged (Figure 4-7). The boilers at the Oceanside development were brought online as soon as utility service was restored to the facilities. According to NYCHA representatives, the Oceanside development, which is older than the Bayside development, was likely built without basements because of site design criteria or construction costs.

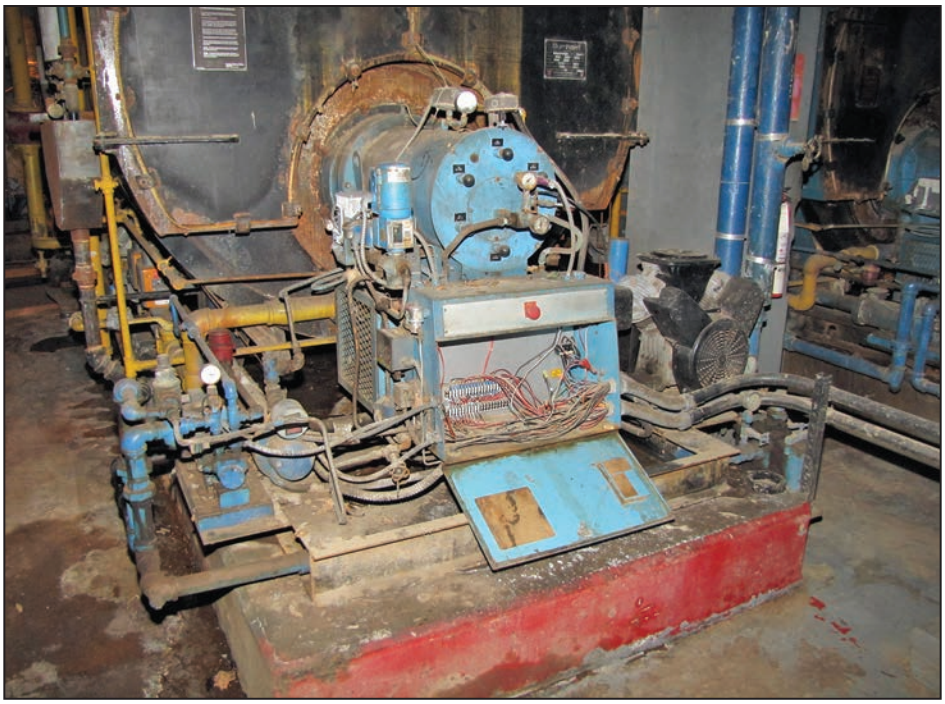


Figure 4-3:
A damaged boiler burner at the Bayside development (Ocean Bay Apartments; Queens, NY)

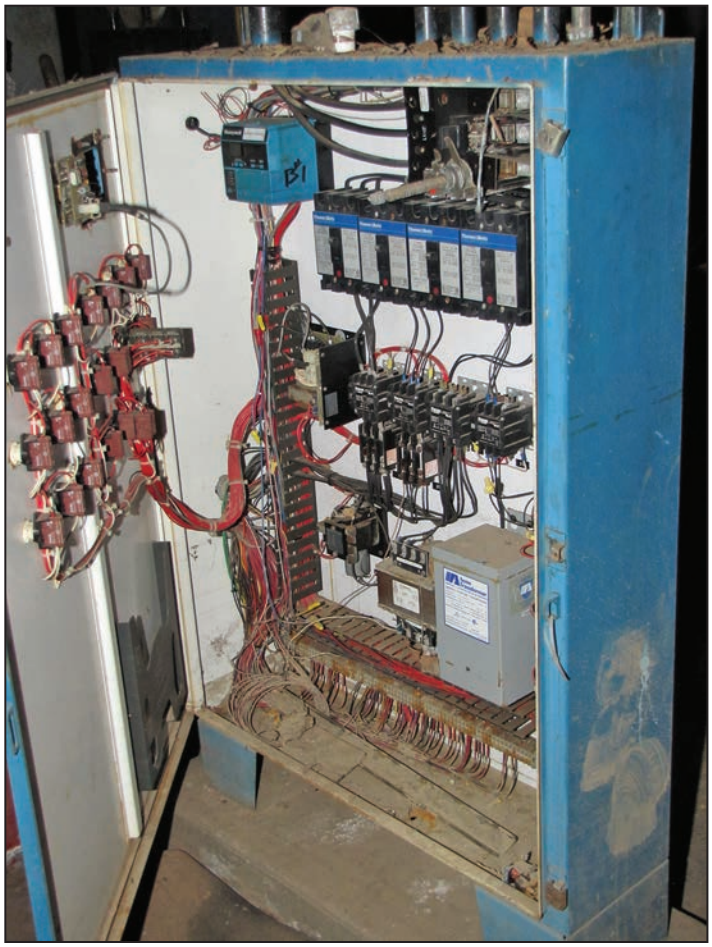


Figure 4-4:
Control equipment for a boiler that was inundated at the Bayside development (Ocean Bay Apartments; Queens, NY)

Figure 4-5: Electrical panels and switchgear system all had to be replaced after the basement was inundated at the Bayside development (Ocean Bay Apartments; Queens, NY)

Figure 4-6: Floodwater entered the basement of the Bayside development through exterior doors with staircases leading into the basement and several at-grade louvers (inset) (Ocean Bay Apartments; Queens, NY)

Figure 4-7: Boiler room at the Oceanside development, located slightly above ground level with a street level entrance (left), was not damaged by shallow floodwater (approximate flood depth indicated by dashed yellow line on right photograph) (Ocean Bay Apartments; Queens, NY)

Red Hook West Houses. The Red Hook West Houses is the largest NYCHA-owned property in Brooklyn. The development opened in 1955, consists of 14 buildings with a total of 1,470 units, and houses a population of approximately 3,330 people. The buildings are 3- to 14-story concrete-frame structures with brick façades.

Four boiler rooms in the basements of Buildings 1, 17, 19, and 25 provide heat and hot water to all buildings in the development (Figure 4-8). Furthermore, these spaces include electrical systems. The Hurricane Sandy storm surge flooded the basements (approximately 12 feet below grade) to the ceiling, causing extensive damage to boilers, control systems, electrical service and distribution equipment, and other mechanical equipment (Figures 4-9 and 4-10). Floodwater entered primarily through exterior ramps that provided access to the boiler rooms (Figure 4-11). The exterior doors at the base of the ramps failed because of floodwater forces that allowed floodwater to enter freely. Several interior partitions and doors also collapsed as a result of inundation (Figure 4-12). The heavy damage to electrical equipment resulted in the housing units being without power even after the electrical grid was restored. Residents were without electricity, heat, and hot water for several weeks after the storm until temporary equipment (generators and boilers) was installed.

4.1.4 Conveyance/Elevators

The MAT assessed only the elevators that NYCHA reported as having been damaged. Most of the elevator cabs observed by the MAT were not flooded, as they had been raised well above street level during the storm. The elevator systems included a hoisting system and motors that were located on the building roofs, so the elevator systems were largely protected from flooding. Mechanical and electrical equipment in the elevator pits, however, was damaged in the buildings that flooded. This damage, combined with the loss of utility service power, resulted in lengthy and costly repairs. Residents were therefore unable to use the elevators, which was a substantial hardship for many elderly and mobility impaired residents.

Figure 4-8: Aerial view of Red Hook West Houses; arrows indicate Buildings 1, 17, 19, and 25; boiler rooms in the basements of these buildings were inundated during Sandy (Brooklyn, NY)

Figure 4-9: Extensive flood damage to boilers, pumps, and control systems in the basement of Building 19 (Red Hook West Houses; Brooklyn, NY)

Figure 4-10: Floodwater damaged this electrical service and distribution equipment in the basement of Building 19 (Red Hook West Houses; Brooklyn, NY)

Figure 4-11: Floodwater entered the Building 25 basement through a ramp entrance to the boiler room; the approximate floodwater depth of 2 to 3 feet above grade is shown by the red line (Red Hook West Houses; Brooklyn, NY)

Figure 4-12:
Interior door of Building 19 collapsed when basement was inundated (Red Hook West Houses; Brooklyn, NY)

4.2 High-Rise Buildings

High-rise buildings suffered widespread damage and service losses from Hurricane Sandy storm surge inundation. The damage and service losses affected buildings throughout the New Jersey and New York metropolitan areas. The MAT visited nine high-rise buildings in New Jersey and New York, including one residential building in New Jersey (Jersey City condominium high-rise) and four commercial and four residential high-rise buildings in New York (includes Coney Island residential high-rise in Brooklyn).

All of the high-rise buildings highlighted in this chapter are located in SFHAs. The buildings range in age from 10 years to close to 100 years old. Occupancy types include residential, commercial, and mixed-use. All structures visited have subgrade spaces, with most of the subgrade spaces housing the building systems. The following observations are representative of the damage to high-rises in the New Jersey and New York area that were inundated by storm surge. The flood damage observed by the MAT was similar to the damage observed at the mid-rise buildings.

4.2.1 Siting Effects on Building Performance

The location of the high-rise buildings in an urban environment near the river and bay subjected all of the buildings to the Hurricane Sandy storm surge. All of the sites visited are located inside the SFHA in Zone AE, based on the Effective FIRM.

Table 4-2 lists each of the high-rise buildings visited, along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations for sites located in Zone A, and the level of storm

surge during Hurricane Sandy. The flood zones in Table 4-2 include those shown on FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

Table 4-2: BFEs, ABFEs, and Sandy Floodwater Elevations for High-Rise Buildings

Facility Name	Location	Relevant FEMA Flood Maps	Flood Zone on Map[a]	1-Percent-Annual-Chance Elevation (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[b]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
Jersey City condominium high-rise	Jersey City, NJ	Effective FIRM	AE	9	n/a	10-11
		ABFE	A	12	18	
Coney Island residential high-rise	Coney Island (Brooklyn), NY	Effective FIRM	AE	9	n/a	12
		ABFE	A	12	17	
Manhattan commercial high-rise (1)	Manhattan, NY	Effective FIRM	AE	9	n/a	11-12
		ABFE	AE and V	13 and 14	16	
Manhattan commercial high-rise (2)	Manhattan, NY	Effective FIRM	Shaded X and AE	n/a and 9	n/a	10-11
		ABFE	A	11 and 12	15	
Manhattan commercial high-rise (3)*	Manhattan, NY	Effective FIRM	AE	9 and 10	n/a	11-12
		ABFE	A and V	13 and 14	16	
Manhattan residential high-rise (4 and 5)	Manhattan, NY	Effective FIRM	AE	10	n/a	11-12
		ABFE	A	11	15	
Manhattan residential high-rise (6)*	Manhattan, NY	Effective FIRM	AE	10	n/a	11-12
		ABFE	A	11	15	
Manhattan commercial high-rise (7)*	Manhattan, NY	Effective FIRM	AE	9	n/a	11-12
		ABFE	A and V	13 and 14	16-17	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the Tropical Cyclone Report, Hurricane Sandy (AL182012) (NHC 2013b).

* Not described further in this report.

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the Flood Insurance Rate Map [FIRM]). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

All of the properties visited by the MAT had storm surge flooding and some amount of inundation as a result of Hurricane Sandy. In addition to being flooded because of their proximity to a flood source, the complexity and interconnectivity of typical buildings in the New York City urban environment influenced building performance. Shared subgrade areas allowed floodwater to travel between buildings, contributing to the flooding throughout a complex. This effect was observed in two high-rise residential buildings that shared a below-ground parking garage and basement where no measures were in place to prevent floodwater from entering the shared subgrade spaces.

4.2.2 Structural Performance

Most of the high-rise buildings visited by the MAT had no structural damage from either floodwater inundation or wind. Physical damage observed was limited to the collapse of nonstructural concrete block partition walls in basements. However, the parking garage slab in a Jersey City condominium the MAT visited was damaged by floodwater inundation.

Jersey City Condominium. Constructed in 2006, the condominium is a 12-story, rigid concrete-frame structure with 500 residential units and an interconnected two-level parking garage (Figures 4-13 and 4-14). The parking garage for the Jersey City Condominium is shared with an adjacent residential high-rise building, and is partially underneath the footprint of both condominium buildings.

Figure 4-13:
A Jersey City condominium and adjacent interconnected building (Jersey City, NJ)

Figure 4-14:
Aerial view of a Jersey City condominium and adjacent building where the highlighted region shows the approximate location of the two-level parking garage located partially beneath both buildings (Jersey City, NJ)
SOURCE: GOOGLE EARTH

The Hurricane Sandy storm surge flooded the first floor of the garage and building lobby with approximately 3 feet of water and submerged the basement of the garage. Water entered the first floor through the main lobby entrance sliding doors, damaging interior finishes. Water then moved through the lobby doors into the garage. In the garage basement, elevator equipment and a trash compactor were damaged. However, the mechanical equipment was housed on the twelfth floor and electrical equipment was elevated between the first and second floor; because the equipment was all elevated above the floodwater depth it was not damaged. One of the elevator bays was temporarily out of service due to flooding in the elevator pit (see Section 4.2.4).

The building would have been able to continue functioning immediately following the storm, except the storm surge inundation caused structural damage in the interconnected garage, requiring residents of both buildings to be evacuated. According to interviews, rapidly rising floodwater flooded the first floor of the garage before the basement level of the garage was fully inundated, so the floor slab had to support water that accumulated on the upper floor. This created a loading condition that may have exceeded the design loads (Figure 4-15) and caused the slab to spall and crack at the column hinges (Figure 4-16).

City engineers ordered the evacuation of the Jersey City condominium and the adjacent high-rise building sharing the garage because of concerns that the slab might collapse and compromise one or more of the columns, potentially causing progressive collapse of the buildings. During repair, tension cables were installed to provide additional support to the damaged slab from above while floodwater was pumped out of the basement (Figure 4-17). After the floodwater was pumped out, temporary shoring was installed in the basement (Figure 4-18). Subsequent inspections established that the structure was stable, and residents of the buildings were allowed to return. The adjacent high-rise building that shared the garage was still closed during the MAT visit (approximately 45 days after the storm) because of extensive damage to the electrical and fire systems in the basement.

Figure 4-15:
Ramp leading from the first floor of the Jersey City condominium garage to the basement level; the garage suffered structural damage when storm surge flooded the first floor of garage (Jersey City, NJ)

Figure 4-16:
First floor slab of the Jersey City condominium garage cracked and spalled at column hinges due to unbalanced flood loading (Jersey City, NJ)

Figure 4-17:
Tension cables provided additional support from above when floodwater was pumped out of garage basement (Jersey City, NJ)

Figure 4-18: Temporary shoring installed in the Jersey City condominium parking garage basement to support damaged slab above (Jersey City, NJ)

4.2.3 Critical Building Systems

Critical building systems (MEP, telecommunications, and emergency power) were located in the subgrade spaces of all but one of the high-rise buildings the MAT visited. Where the building systems were located in the subgrade spaces and unprotected, inundation badly damaged the equipment. Where the equipment was located on the upper floors of the building, no damage occurred. Building functionality varied depending on the extent of damage to critical building systems. Some buildings were able to continue operations after the storm with limited or full functionality after repairs or installing temporary equipment. However, the MAT observed two buildings with extensive damage that caused residents to be evacuated for several months. Manhattan commercial high-rise (1), Manhattan commercial high-rise (2), Manhattan residential high-rises (4 and 5), and Coney Island residential high-rise described in this section are representative case studies of damage to critical building systems in high-rise buildings.

Coney Island Residential High-Rise. The Coney Island residential high-rise is a multi-family residential development owned and operated by the NYCHA. The development opened in 1957, consists of five 14-story high-rise buildings with a total of 534 units, and houses a population of approximately 1,300 people. The buildings are concrete-frame structures with brick façades. The development has a central boiler plant in the basement of Building 3 (Figure 4-19). The site is less than 400 feet from the Atlantic Ocean waterfront.

Floodwater surrounding the properties was approximately 3 feet deep during Hurricane Sandy (Figure 4-20). The basement of Building 3, where the central boiler plant was located, was inundated. According to interviews with the building engineer, floodwater entered the basement through vented louvers and an emergency exit stairwell. Boilers, control systems, electrical panels, switchgear, and other mechanical equipment in the basement were damaged (Figures 4-21 and 4-22) and in some cases displaced (Figure 4-23). Temporary utilities were installed immediately after the storm to restore electricity and heat to residents while the equipment was repaired or replaced.

Figure 4-19: Aerial view of the five 14-story Coney Island residential high-rise (Brooklyn, NY)

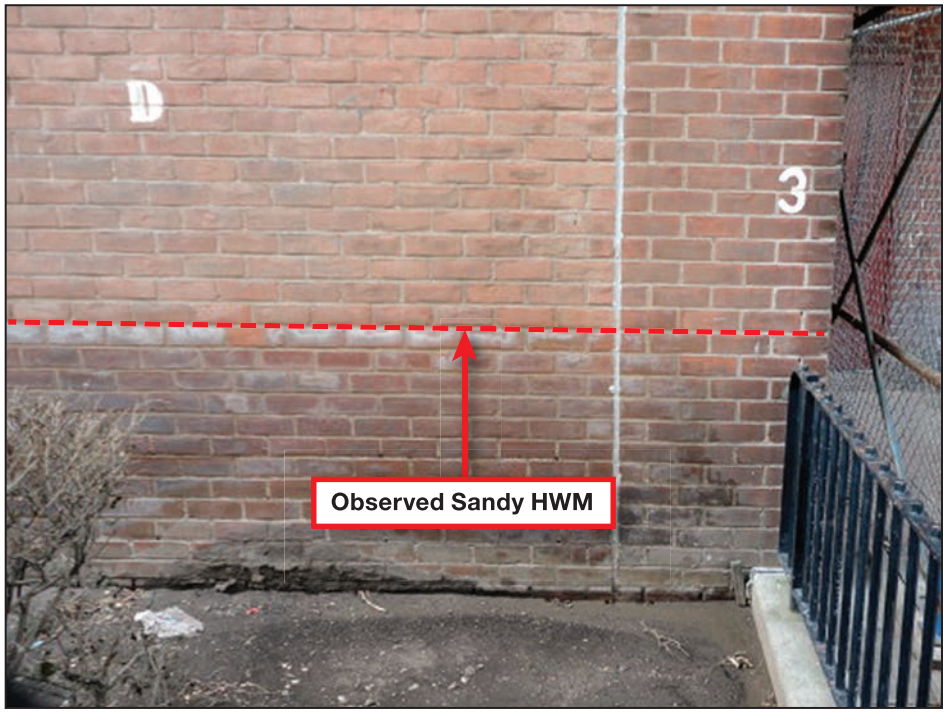


Figure 4-20:
HWM (red dashed line) 3 feet above grade on one of the Coney Island residential high-rise Houses buildings (Brooklyn, NY)

Figure 4-21:
Central boiler plant room in basement of Building 3 was inundated (Brooklyn, NY)

Figure 4-22:
Electrical distribution panel in the Building 3 basement was destroyed by corrosion due to seawater inundation (Brooklyn, NY)

Figure 4-23:
Some equipment in the central boiler plant room in the Building 3 basement was displaced by the floodwater entering the basement from an emergency exit stairwell (Brooklyn, NY)

Manhattan Commercial High-Rise (1). Manhattan commercial high-rise (1) is a 24-story building in Lower Manhattan. The high-rise, built in 1971, is two blocks from the East River near the South Street Seaport. The high-rise is a steel frame structure with masonry infill walls. Based on an interview with the building's chief engineer, water entered through the lobby doors as well as the loading dock, and the first floor of the building was inundated with more than 4 feet of water (Figure 4-24). Floodwater spread throughout the first floor and inundated the basement, primarily through the elevator shaft (Figure 4-25).

Figure 4-24:
HWM (red dashed line) along first floor electrical room wall (New York, NY)

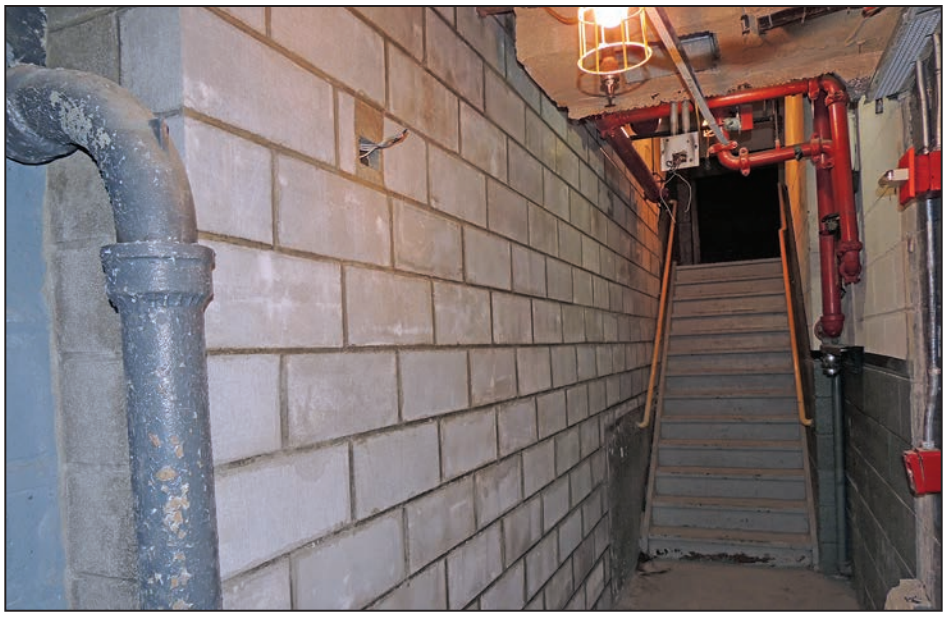


Figure 4-25:
Floodwater from the first floor lobby entered the basement through the elevator shaft; the elevator shaft walls had to be replaced after Hurricane Sandy (New York, NY)

The electrical service equipment, transfer switch, generator, and other equipment located in the first floor electrical room were all damaged. In the basement, the steam distribution system, water booster pumps, and other equipment in the mechanical room were damaged, leading to the building's loss of functionality.

The heating system for the building was repaired relatively quickly once steam service was back online from the utility provider. Telecommunications for the building were also repaired relatively quickly because telephones for the building were primarily supplied through a fiber optics network. Restoring electrical power to the building took considerably longer; approximately 45 days after Hurricane Sandy, the building was still operating on generator power (Figure 4-26). The building remained closed to tenants until repairs were made and re-opened in February 2013.

Figure 4-26:
Generator providing temporary power to Manhattan commercial high-rise (1) (New York, NY)

Manhattan Commercial High-Rise (2). An 11-story commercial and office building built in 1914, Manhattan commercial high-rise (2) is on the banks of the Hudson River near the southwest corner of the Chelsea District. The building suffered minor flood damage during Hurricane Sandy. Flood inundation was approximately 1 to 2 feet above street level. The HWM at a nearby pier was 12.3 feet.[2]

The electrical room (electrical service equipment, transfer switch, etc.) and chillers are located on the first floor, and the furnace and most other mechanical equipment are on the top floor. Flood depths on the first floor were minor and did not cause much damage.

More than 40,000 gallons of fuel was stored in four tanks in the basement that service more than 10 generators spread throughout the facility for various tenants. The fuel tanks and pumps distributing fuel to the generators are inside a floodproofed enclosure (Figures 4-27 and 4-28). In addition, the basement has six pumps (minimum capacity of 100 gallons per minute) to drain the basement in case of flooding. Prior to Hurricane Sandy, only two of the six pumps were connected to the emergency generator, but as an emergency protective measure, the other four were added to an emergency power circuit just before the storm.

Based on an interview with the building's chief engineer, water initially entered the basement through a telecommunications utility point of entry on the Hudson River side of the building. The six pumps successfully controlled flood levels in the basement, keeping the water below 3 inches throughout the basement. Generators throughout the building remained operational during the storm and after, until power service was restored by the utility provider.

Figure 4-27: Successful floodproofed fuel pump enclosure in basement of Manhattan commercial high-rise (2) (New York, NY)

2 USGS HWM-NY-NEW-003 from USGS Sandy Storm Tide Mapper http://water.usgs.gov/floods/events/2012/sandy/sandymapper.html.

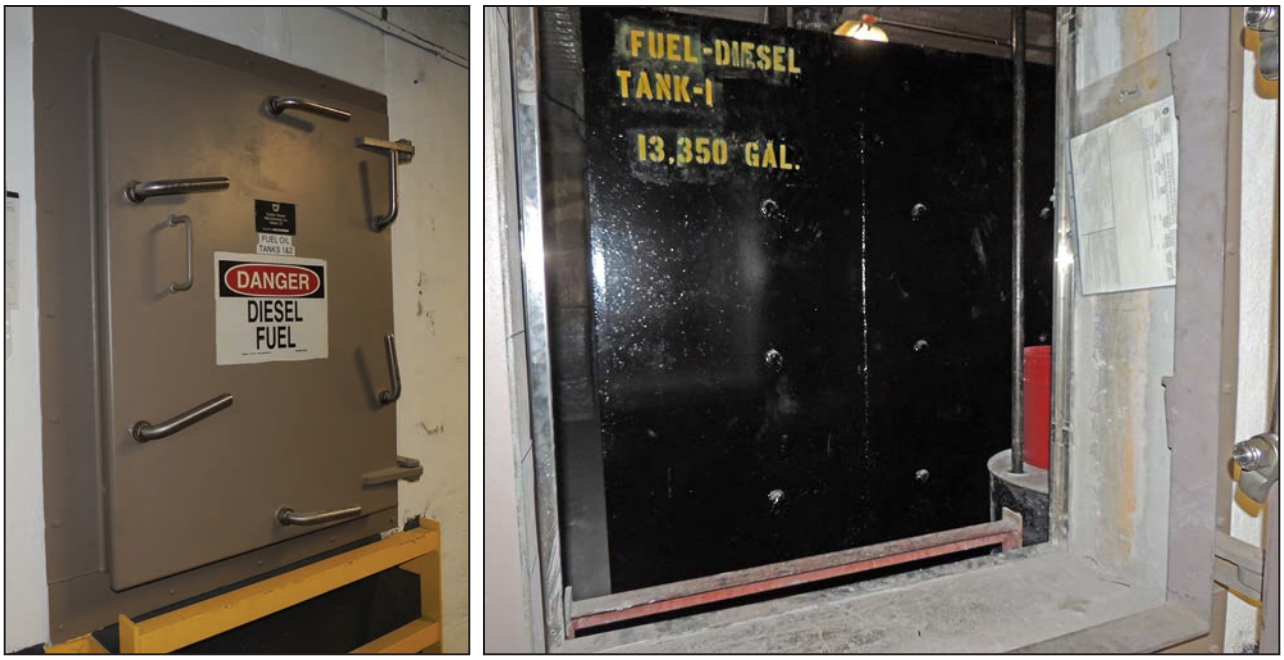


Figure 4-28: Successful floodproofed fuel tank enclosure in basement of Manhattan commercial high-rise (2) (New York, NY)

In contrast, the adjacent building had MEP equipment in the basement; it received over 1 foot of flooding in the basement and was closed for 2 weeks after Hurricane Sandy.

Manhattan Residential High-Rises (4 and 5). Manhattan residential high-rises (4 and 5) are a 28-story luxury apartment building built in 2009 and an adjacent 51-story residential building built in 2005. The buildings are mixed-use and have retail spaces on the first floors. The buildings are 3 blocks from the East River in Manhattan's Financial District and suffered significant flood damage during Hurricane Sandy. The residential buildings are interconnected through a shared basement, parking garage, and utility rooms. The 51-story building had floodgates that were 42 inches high above the ground surface, which was the BFE. The floodgates were installed at the ground-level parking garage entrance and the storefronts on the first floor (Figure 4-29). Flood depths along the first floor were minimal and did not cause much damage. However, a HWM at the loading docks indicates that the floodgates were overtopped, allowing water to enter the subgrade levels. Flood inundation levels from Hurricane Sandy were at approximately the same height as the top of the floodgate, but there was an additional 1 to 2 feet of wave action. Consequently, the subgrade areas of the buildings were inundated with approximately 30 feet of water.

The electrical room (electrical service equipment, transfer switch, etc.), chillers, mechanical equipment, and fuel storage were located in the subgrade space that is shared by the two buildings (Figure 4-30). Over 20,000 gallons of fuel is stored in tanks in the basement. A building engineer reported to the MAT that the fuel tanks were crushed by the high volume of water in the subgrade areas. The tanks released fuel into the basement areas, which mixed with the seawater and produced fumes that permeated the residential units. The building was not equipped with an emergency generator and remained closed until mid-February 2013.

Figure 4-29: Installed 42-inch-high floodgates (red arrow) were overtopped by storm surge, allowing inundation of subgrade levels (New York, NY)

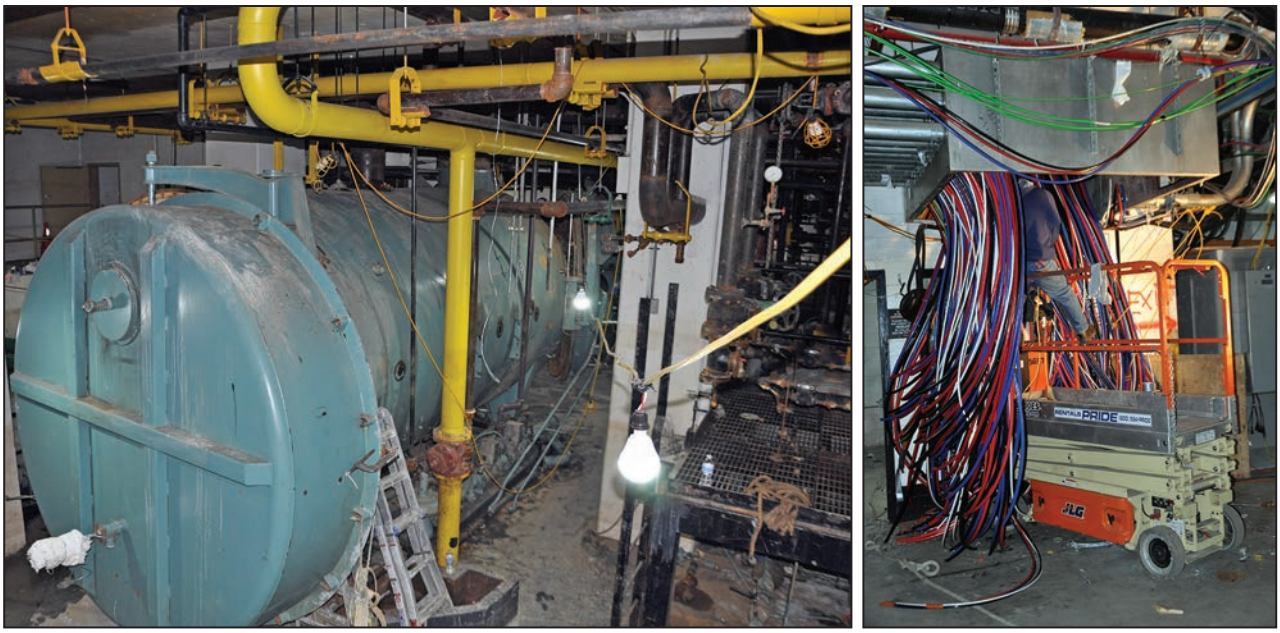


Figure 4-30: Mechanical room (left) was inundated when the 42-inch-high floodgate was overtopped by floodwater; electrical conduit throughout subgrade level (right) was replaced after being submerged in saltwater (New York, NY)

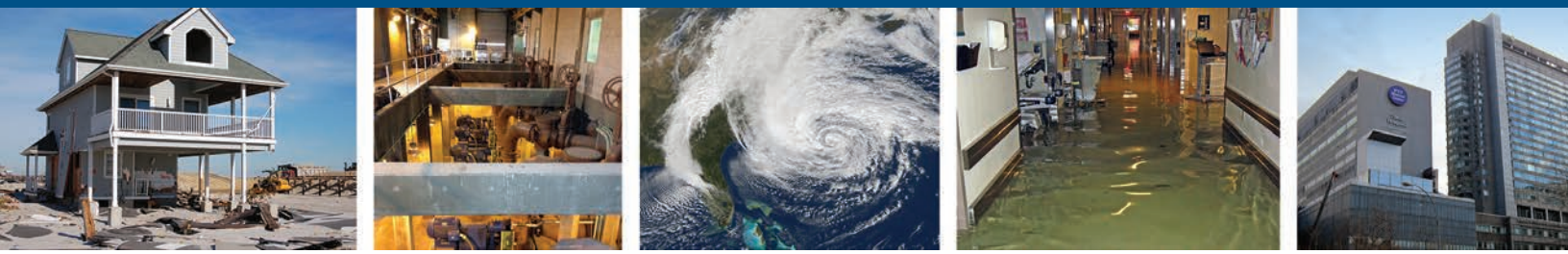
4.2.4 Conveyance/Elevators

Elevator systems in three of the high-rise residential buildings the MAT visited were damaged by Hurricane Sandy. The elevator pits and shafts extending below grade were inundated by floodwater, which damaged shaft walls, controls, and equipment. Loss of elevator service in the high-rises hindered vertical building access and adversely affected building service and operations.

- + One of the elevator bays of the Jersey City condominium building (see also Section 4.2.2) that connected the parking garage to the residential tower was temporarily out of service after equipment and controls in the elevator pit were inundated.

- + The CMU walls of the elevator shafts at both Manhattan commercial high-rise (1) and Manhattan residential high-rise (4) collapsed because of the hydrostatic pressure of floodwater in the basement (Figure 4-31).

Figure 4-31: Hydrostatic flood forces destroyed CMU walls around elevator shaft (red dashed lines) when elevator pit was inundated (Manhattan residential high-rise (4); Manhattan, NY)



HURRICANE SANDY IN NEW JERSEY AND NEW YORK

5 Performance of Critical Facilities and Key Assets

Widespread flood damage to all types of critical facilities in dense urban settings prompted the MAT to compare and contrast performance of selected critical facilities. Typical critical facilities include hospitals, fire stations, police stations, storage rooms for critical records, and similar facilities.

The MAT visited selected critical facilities affected by Hurricane Sandy across New Jersey and New York. These included healthcare facilities (hospitals and senior care centers), first responder (police and fire) stations, mass transit facilities, data centers, and wastewater treatment plants (WWTPs). Schools and gas stations were also visited because schools are

CRITICAL FACILITIES DEFINITION

FEMA defines "critical facilities" as those buildings and facilities that are essential for the delivery of vital services or protection of a community (FEMA 2007a).

sometimes used for shelters or emergency response efforts, and gas stations provide critical fuel supply for emergency systems and transportation.

5.1 Background

Critical facilities are those that carry out essential community functions during and immediately after a disaster (refer to Appendix I for additional definitions of critical facilities). ***Hospitals and healthcare facilities*** treat injuries and provide medical life support to the community. ***Police and fire stations*** are needed for response and recovery operations after an event, as well as for maintaining their core community protection duties. ***Mass transit facilities, data centers, and WWTPs*** are all vital for access to and provision of healthcare and public sanitation, for post-disaster operations, and to resume business operations for community recovery. ***Electric power*** is also vital to recovery and post-disaster operations.

The MAT assessed the effect of power loss on critical facilities, as it drastically affected their operations, but the MAT did not assess the performance of the power grid beyond the facility level as it was not within the scope of the MAT study. The MAT evaluation of critical facilities is also adopted in the June 2013 New York City Special Initiative for Rebuilding and Resiliency recovery planning report, *plaNYC, A Stronger More Resilient New York*, which includes specific recovery initiatives for each facility type.

The inundation from Hurricane Sandy significantly affected many critical facilities, severely reducing or interrupting their functionality and the services they provide to the community. Some of the observed facilities were damaged by floodwater that did not rise to the BFE. Damage to critical facilities reduced available emergency services, affected recovery times to regaining full functionality, and placed additional operational and economic burdens on communities.

5.1.1 Critical Facilities Visited by the MAT

All of the critical facilities visited were in areas inundated by Hurricane Sandy. Table 5-1 lists the type and total number of critical facilities visited by the MAT. This chapter describes the performance of representative critical facilities during and after Hurricane Sandy as observed by the MAT. Detailed descriptions of selected buildings are provided in Appendix H.

The facilities described in this chapter and in Appendix H are representative of the types of damage and lessons learned, both positive and negative, that the MAT observed during the field investigation. The selected facilities illustrate the effectiveness of various mitigation measures, vulnerabilities due to siting locations, and the effect of locating utilities and emergency equipment below design flood levels. The damage to the facilities is summarized in Chapter 5 and details of each structure are provided in Appendix H.

Table 5-1: Number of Critical Facilities Visited by the MAT

Facility Type	Building Risk Category[a]	New Jersey	New York and New York City	Total Number Visited by the MAT	Total Number of Facilities Described in MAT Report (Report Section)[b]
Healthcare – Hospitals	IV	4	4	8	5 (Section 5.1)
Healthcare – Senior Care Centers	III	1	3	4	3 (Section 5.1)
First Responders – Police	IV	7	5	12	3 (Section 5.2)
First Responders – Fire	IV	15	9	24	9 (Section 5.2)
Schools	III	2	10	12	4 (Section 5.3)
Data Centers	III	0	2	2	2 (Section 5.4)
Wastewater Treatment Plants	III	1	2	3	3 (Section 5.5)
Transportation Facilities	III	2	5	7	7[c] (Section 5.6)
	Total	**32**	**40**	**72**	**36**

a. ASCE 7-10, Section 1.2, Table 1.5-1

b. Facility-specific write-ups for these facilities are included in Appendix H.

c. Includes gas stations (4), subway (2), and maintenance yard (1).

5.1.2 General Preparedness

New Jersey

On October 27, 2012, Governor Christie declared a state of emergency in advance of the storm and issued a mandatory evacuation order for the barrier islands, from Sandy Hook to Cape May, by 4 p.m. on October 28, 2012. On October 28, Hoboken Mayor Zimmer and Jersey City Mayor Healy both ordered the evacuation of all basement and street-level residential units. All New Jersey Transit service (bus, rail, and light rail systems) were preemptively closed on October 29, along with most schools throughout the State.

The electric power companies in areas expected to have flooding prepared to de-energize their systems before the storm surge arrived. PSEG turned off power to facilities between 8 p.m. and 10 p.m. on Monday, October 29, 2012. PSEG services one-third of New Jersey's population in an area stretching across the State from Bergen to Gloucester Counties.

New York

On Sunday, October 28, 2012, New York City Mayor Bloomberg ordered suspension of mass transportation services and mandatory evacuation of New York's designated Evacuation Zone A (shown in Figure 1-3). This created unexpected difficulties for businesses that needed to maintain continuity of operations. Hotel room reservations were cancelled, and many hotels outside of the evacuation zone also closed. The hotels and other businesses outside of the evacuation zone that

remained open did not have emergency power for elevators or stairwell lighting, and in some cases, relief staff were unable to travel into Manhattan, resulting in the need for onsite staff to remain at the office for an extended period.

NEW YORK CITY'S EVACUATION ZONE A

Evacuation Zone A is the area of New York City prone to flooding; it begins at 39th and 1st Avenue in Manhattan, continues down the East River through the financial district, and then up the West Side Highway to 60th Street.

By Tuesday, October 30, 2012, five of seven Metropolitan Transit Authority (MTA) bridges were reopened, but reduced public transportation and fuel shortages made vehicular travel slow and difficult. Although the city bus system was able to reopen after the storm, the subway system was not, leaving many commuters walking, riding bicycles, and taking auxiliary buses chartered under emergency agreements (Graybow and Gellar 2012). Fuel supplies were scarce following Sandy because of inoperable fuel terminals and lack of power for fuel pumps at gas stations. In addition, floating debris and port infrastructure damage prevented access for fuel barges.

5.2 Healthcare Facilities

Healthcare facilities in the New Jersey and New York metropolitan area suffered widespread damage and service losses from Hurricane Sandy. The following observations are based on site visits to eight hospitals and four senior care facilities in the New Jersey and New York area that were flooded by storm surge. The locations are shown in Figure 5-1. In addition to collecting data on the performance of these facilities, the MAT interviewed facility staff regarding emergency planning, response during the event, and operations and level of functionality after the storm surge event.

Figure 5-1: Locations of healthcare facilities visited by the MAT

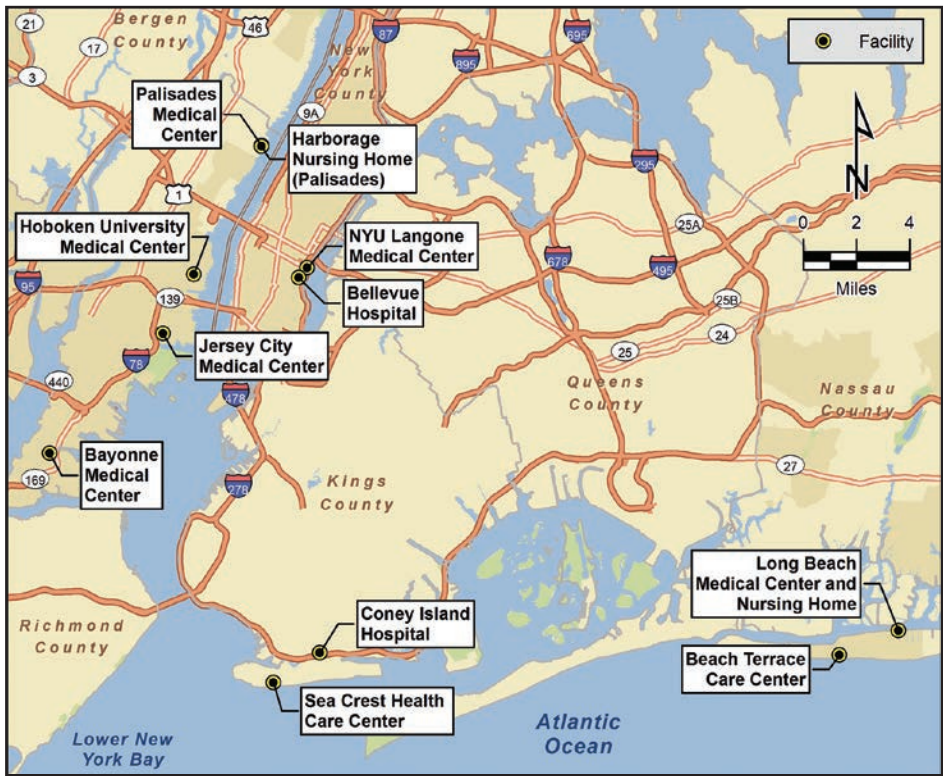


Table 5-2 lists each of the healthcare facilities visited, along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations for sites located in Zone A, and the level of storm surge during Hurricane Sandy. The flood zones in Table 5-2 include those shown on FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

Table 5-2: BFEs, ABFEs, and Sandy Floodwater Elevations for Healthcare Facilities Visited by the MAT

Facility Name	Location	Relevant FEMA Flood Maps	Flood Zone(s) on Map[a]	1-Percent-Annual-Chance Elevation(s) (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[c]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
Bayonne Medical Center	Bayonne, NJ	Effective FIRM	X	n/a	n/a	12
		ABFE	n/a	n/a	n/a	
Hoboken University Medical Center	Hoboken, NJ	Effective FIRM	AE	9	n/a	11
		ABFE	A	12	18	
Jersey City Medical Center	Jersey City, NJ	Effective FIRM	AE	9	n/a	11
		ABFE	A	12	18	
Palisades Medical Center	North Bergen, NJ	Effective FIRM	AE	8, 10	n/a	10
		ABFE	A, V	12, 14	16	
Bellevue Hospital	New York, NY	Effective FIRM	X, AE	n/a, 9	n/a	11
		ABFE	Shaded X, A	n/a, 13	n/a	
Coney Island Hospital	Brooklyn, NY	Effective FIRM	Shaded X	n/a	n/a	11
		ABFE	A	11	15	
Long Beach Medical Center	Long Beach, NY	Effective FIRM	AE	8	n/a	13
		ABFE	n/a	n/a	n/a	
NYU Langone Medical Center	New York, NY	Effective FIRM	AE	9	n/a	11
		ABFE	A, V	13, 15	18	
Harborage Nursing Home (Palisades)	North Bergen, NJ	Effective FIRM	AE	8, 10	n/a	10
		ABFE	A, V	12, 14	16	
Beach Terrace Care Center	Long Beach, NY	Effective FIRM	VE	16	n/a	11
		ABFE	n/a	n/a	n/a	
Long Beach Nursing Home (Komanoff Center)	Long Beach, NY	Effective FIRM	AE	8	n/a	13
		ABFE	n/a	n/a	n/a	
Sea Crest Health Care Center	Brooklyn, NY	Effective FIRM	AE	9	n/a	12
		ABFE	A	13	8	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the *Tropical Cyclone Report, Hurricane Sandy* (AL182012) (NHC 2013b).

NYU = New York University

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the Flood Insurance Rate Map [FIRM]). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

5.2.1 Facility Location and Construction

Four of the hospitals the MAT visited are located along or within a few blocks of either a river or bay, and all but one of the hospitals are in an SFHA. Most hospitals visited by the MAT have a complex of "pre-FIRM" and "post-FIRM" structures (refer to Appendix B, Glossary, for explanation of terms) built in flood zones with construction dates ranging from the early 1900s through 2009. Of the senior care facilities the MAT visited, two have oceanfront locations and two are located along either a river or bay.

The hospitals and senior care centers visited in New York have basements and subgrade tunnels between buildings on their campuses to distribute utilities (electrical power, steam, water, communications, and data) and house mechanical equipment, such as boilers, HVAC, and pumps. These subgrade garages and tunnels also have access openings for utility conduits and ramps for parking and vehicular access. Sump pumps are used to dewater these spaces from normal seepage and groundwater conditions, but none of the pumps were sized to handle the large, sudden inundation. When floodwater filled the subgrade tunnels and basements during Hurricane Sandy, the sump pumps were rapidly overwhelmed (in less than an hour in some cases) and the utility systems and mechanical equipment located in those subgrade spaces were inundated (Figure 5-2).

The hospitals and senior care centers visited in New Jersey do not have tunnels or extended basement areas, though one hospital has a small basement area for mechanical equipment. The damage incurred at these facilities from the storm surge primarily affected utility systems and equipment below the flood elevations.

Figure 5-2: Flood-damaged emergency generator (Long Beach, NY)

5.2.2 Preparing for Hurricane Sandy

Hospitals

All of the hospitals visited by the MAT used active flood protection measures prior to the storm surge, including sandbagging doorways and electrical rooms, protecting outside air intakes and windows located below expected flood levels with plywood, and stationing pumps and staff to handle seepage in subgrade spaces. Some passive flood mitigation efforts were also implemented. Dry floodproofing measures had been installed around tanks and pumps at some hospital facilities prior to Hurricane Sandy, but several of these efforts failed. For instance, fuel pumps and a large fuel tank in the basement of Bellevue Hospital were flooded when a seal around the submarine door failed (Figure 5-3).

PASSIVE AND ACTIVE RETROFITTING

Retrofitting measures can be passive or active in terms of human intervention. Passive retrofitting measures do not require human intervention, such as flood vents that automatically open. Active retrofitting measures require human intervention, such as the installation of sand bag barriers. Active emergency retrofitting measures are effective only if there is enough warning time to mobilize labor and equipment needed to implement the measures.

Some hospitals that had experienced flooding during previous storms evacuated their entire facility ahead of Hurricane Sandy. Most of the hospitals visited by the MAT had discharged and transferred patients prior to the arrival of the storm, canceled elective procedures, stopped accepting non-emergency patients, and made plans for the remaining patients to shelter in place with appropriate support staff and equipment.

Electrical power companies in areas that expected flooding de-energized their systems before the arrival of the storm surge (refer to Section 5.1.2 for additional information). All but one hospital reported receiving calls from the power company of the impending electrical power shut-down. The notices came only about an hour before the shut-downs.

Figure 5-3: Submarine door (left) that was installed to protect the fuel pump room (right) failed to keep floodwater out of the enclosure (New York, NY)

Once the storm struck, many hospitals were entirely without power as their emergency power systems were damaged by the floodwater. As a result, some hospitals that planned to shelter in place were forced to evacuate patients during the storm. This put tremendous stress on the remaining hospitals, ambulances, and the Web-based system that provides information on available hospital beds. Some hospitals evacuated during the storm and had difficulty locating available beds and transportation vehicles, and had to carry critically ill patients down the stairs of darkened facilities. These issues were particularly difficult for hospitals caring for at-risk populations such as children, intensive care patients, and those with mental health needs.

Senior Care Facilities

The two oceanfront facilities were located on wide beaches with city-maintained berms. The other two facilities did not have any emergency flood protective measures, such as barriers or sandbags, in place. Only one of the four facilities visited by the MAT had power equipment, such as electrical switchgear systems or generators, that was elevated above floodwater levels. Other facilities had portions of the electrical system elevated (Figure 5-4).

All of the senior care facilities planned to shelter their residents in place. Such decisions are based on balancing safety and stability for the residents. The facilities initiated disaster plans, brought in extra staff and supplies, and anticipated that sufficient power would be available from emergency generators during the time that utility power might be lost.

Figure 5-4: Floodwater inundated the electrical switchgear box at the Beach Terrace Care Center (Long Beach, NY)

5.2.3 Level of Flooding and Resulting Damage

Hospitals

The Hurricane Sandy storm surge greatly exceeded any previous flood event at these facilities in the New Jersey and New York area. Each hospital stated that there had been no event of similar magnitude in its history, and some of the hospitals have been in their current location since the 1800s or early 1900s. Modern building codes and standards require designs relative to the 1-percent-annual-chance flood event, but older facilities likely had more limited or less informed flood elevation standards at the time of their construction.

The hospitals visited by the MAT typically had 2 to 4 feet of flooding (Figure 5-5). Five of the facilities had basements that were flooded. There was extensive damage to utilities, medical equipment, communications equipment, and fuel storage tanks, which were typically located below the BFE.

Figure 5-5: Flood levels rose to approximately 6 inches above the finished floor inside the Hoboken University Medical Center (Hoboken, NJ)

SOURCE: HOBOKEN UNIVERSITY MEDICAL CENTER

Senior Care Facilities

All of the senior care facilities the MAT visited are located in Zone AE, with BFEs ranging from 8 to 10 feet. The facilities had 2 to 4 feet of flooding. Power and emergency generator systems and other MEP systems were typically located on the first floor level or basement levels and were inundated during Hurricane Sandy. The Sea Crest Health Care Center also had approximately 10 feet of sand deposited by the storm.

5.2.4 Effect on Operations and Functionality

Flood inundation at healthcare facilities during Hurricane Sandy resulted in physical damage and loss of utilities that disrupted services to existing patients and the facilities' capability to respond to medical needs after the storm. Healthcare facilities resumed operations in stages as utilities and services were repaired, replaced, or temporary measures were employed, depending on the degree of damage and the type of equipment that needed to be replaced.

Hospitals

Many hospitals were forced to close after the storm on October 29, 2012, with the time of recovery reflecting the degree of damage sustained and how quickly utilities were restored. Disruption to healthcare operations and functionality were primarily because of the loss of utilities and mechanical equipment, especially electrical power (municipal and emergency), and loss of medical equipment (computed tomography [CT] scanners and other radiology equipment) due to flooding. Medical supply chain issues, if any occurred, were not identified by the facilities visited. Refer to the summary tables in Appendix H for details related to service disruptions and additional information associated with the hospitals visited by the MAT.

Diminished healthcare capacity after a disaster event reduces the capacity of the medical community to treat patients affected by the disaster, provide emergency care, and meet the ongoing healthcare needs of the patients they serve. The immediate effect of the storm on healthcare in New York City in particular was dramatic. New York University (NYU) Langone Medical Center, Bellevue Hospital, and Coney Island Hospital treat approximately 1.5 million patients per year, and their healthcare capacity was seriously diminished after Hurricane Sandy. For example, NYU Langone Medical Center and Bellevue Hospital combined lost not only 1,700 beds for patient care, but also their ability to provide their estimated normal 1,000 daily emergency department visits for months in the aftermath of Sandy. To help meet the community need while NYU Langone Medical Center's Emergency Department remained closed, it established an Urgent Care Center. All of Bellevue Hospital's 320 psychiatric beds and 100 prisoner beds were unavailable.

Physical damage to healthcare facilities was generally limited to basements, tunnels, and rooms on lower floors that were inundated by floodwater. There was little structural damage in flooded areas, but significant damage to utilities, mechanical equipment, and medical equipment and supplies. Damaged areas included pharmacies, laboratories, radiology departments, emergency departments (Figure 5-6), out-patient clinics, kitchens, laundries, administration offices, and medical records areas. Hospital treatment areas located on higher floors, such as non-intensive care unit (ICU) and ICU beds, did not suffer physical damage.

The hospitals the MAT visited in New York had longer downtimes than the hospitals in New Jersey because flood damage to basements and tunnels in the New York facilities was more extensive. Bellevue Hospital, NYU Langone Medical Center, and Long Beach Medical Center were closed for in-patient admissions for approximately 2 months.

The absence of basements in the New Jersey facilities helped to reduce the level of damage, since utility systems and equipment were often above flood elevations. In New Jersey, the hospitals the MAT visited reopened within 1 week, except for the Hoboken University Medical Center, where the

Figure 5-6:
Hospital emergency room on ground floor (below grade) that was flooded during Sandy (New York, NY)

first floor was flooded. The damage to the first floor disrupted its emergency department, outpatient clinics, and surgical services for 2 weeks.

Senior Care Facilities

Although all of the senior care facilities visited by the MAT had originally planned to shelter in place, floodwater inundation of the basements and/or first floor levels resulted in loss of power, heat, communications, and associated functions, such as fire protection, elevators, food services, and laundry facilities. As a result, three of the four facilities had to evacuate their residents to other facilities after the storm surge receded and transportation was arranged. Residents were transferred to a number of facilities, depending on availability of beds. Some residents had to be transferred to temporary locations because there were no beds available.

5.2.5 Recovery Actions and Issues

Hospitals

Opening hospitals requires State Health Department approval. Recovery and reopening occurred in stages at the hospitals visited by the MAT, with the hospitals focusing on providing essential medical services to their communities. To streamline restoration of services while repairs were being made, most of the hospitals used temporary measures, including outsourcing food and laundry services, renting medical equipment, and supplementing utility power with generators. Outpatient services were restored in some cases by renting alternative spaces and offices in the area.

- New Jersey hospitals in-patient services:
  - Bayonne Medical Center reopened within 1 week
  - Hoboken University Medical Center reopened after 2 weeks

- Jersey Medical Center reopened within 1 week
- Palisades Medical reopened within 1 week

- New York hospitals in-patient services:
  - Bellevue Hospital reopened in February 2013
  - Coney Island Hospital reopened in March 2013
  - Long Beach Medical Center completed repairs in July 2013. As of October 2013, the facility is working with the New York Health Department to gain approval for reopening.
  - Portions of NYU Langone Medical Center reopened in late December 2012

Facility owners and managers reported considering permanent mitigation actions such as:

- Elevating critical utility systems, such as emergency power, electrical and steam power, communication and information technology (IT)/data, as well as medical and mechanical equipment, above the design flood elevation (DFE)
- Installing passive floodproofing measures in sections that cannot be elevated
- Moving elevator equipment above the DFE
- Expanding emergency power distribution systems to key areas of the hospital, including sections that house CT scanners and magnetic resonance imaging (MRI) machines, pharmaceutical and chemotherapy facilities, and research laboratories
- Elevating water pumps or adding more pumps to the backup system
- Adding emergency connections for mobile boilers to allow distribution of steam to provide heat and hot water
- Increasing capacity and creating redundancy between emergency generators

Senior Care Facilities

Similar to hospitals, opening senior care facilities requires State Health Department approval. A potential consequence of extended closure of senior care centers is the permanent loss of patients. After 30 days, transferred patients are no longer considered residents of the original facility, which can adversely affect the economic viability of a facility. To restore functionality as soon as possible while repairs were being made, the facilities used temporary measures, such as boilers and generator power, and outsourced functions such as laundry.

BEACH TERRACE CARE CENTER (LONG BEACH, NY)

A number of windows at this facility failed on the ocean side due to storm surge. The facility elected to replace the windows with windows rated for 180 mph winds as a mitigation measure to minimize future window failures during storm events, though the facility recognizes the windows are not designed for flood events.

Facility owners and managers reported considering permanent mitigation actions such as:

- Elevating emergency generators and fuel pumps at a facility instead of planning to rent emergency generators after a disaster event
- Replacing generators that use natural gas with fuel-oil-based generators for emergency power, since natural gas supplies are often turned off before major events to avoid gas leaks
- Replacing blown out windows with windows rated for 180 mph winds

5.3 First Responders: Police and Fire

The MAT visited 24 fire stations, 12 police stations, and 2 emergency medical services stations throughout New Jersey and New York that were affected by flooding during Hurricane Sandy (Figure 5-7). First responder facilities, including fire, police, and emergency medical service stations, are considered lifelines in communities. If these facilities cannot remain operational during or immediately following an event, the community loses a valuable and important part of its emergency response capability because an interruption in their operation may prevent rescue operations, evacuation, assistance delivery, or general maintenance of law and order.

Table 5-3 lists each of the first responder facilities visited, along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations, and the level of storm surge during

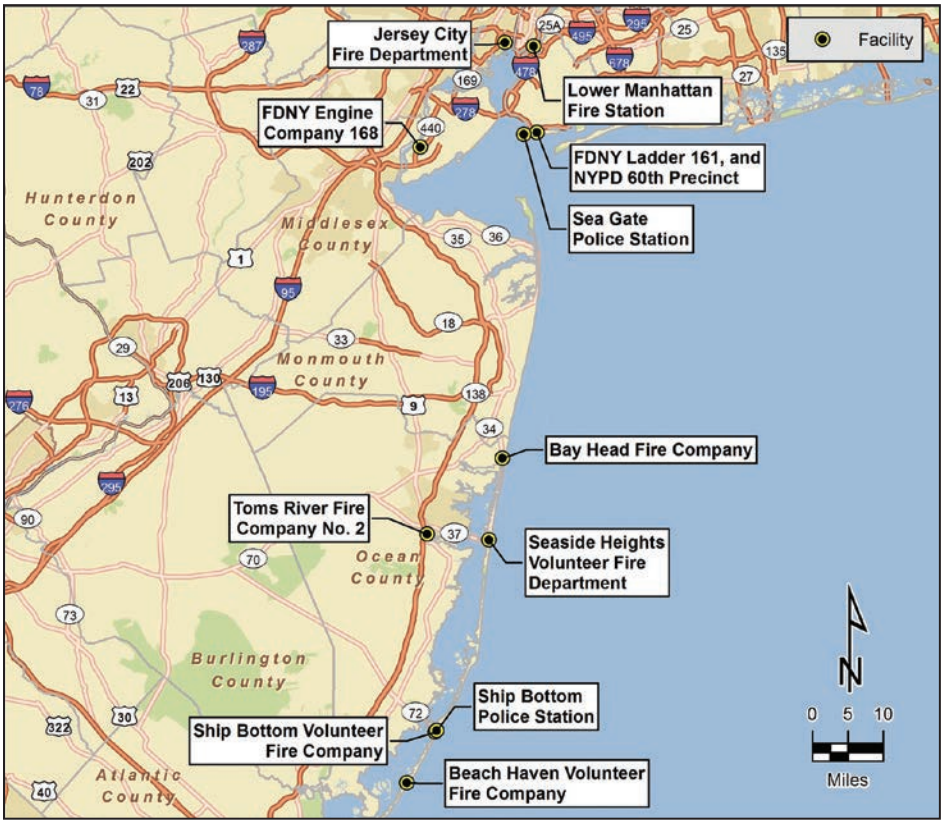


Figure 5-7: Locations of first responder facilities visited by the MAT

Table 5-3: BFEs, ABFEs, and Sandy Floodwater Elevations for First Responder Facilities Visited by the MAT

Facility Name	Location	Relevant FEMA Flood Maps	Flood Zone(s) on Map[a]	1-Percent-Annual-Chance Elevation(s) (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[c]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
Bay Head Fire Company No. 1 Station 14	Bay Head, NJ	Effective FIRM	AE	5	n/a	7
		ABFE	V	10	14	
Beach Haven Volunteer Fire Company No. 1	Beach Haven, NJ	Effective FIRM	AE	9	n/a	8
		ABFE	A	9	13	
Jersey City Fire Department (JCFD) Engine Two	Jersey City, NJ	Effective FIRM	X, AE	n/a, 9	n/a	11
		ABFE	A	12	18	
Seaside Heights Volunteer Fire Department Station 44	Seaside Heights, NJ	Effective FIRM	AE	8	n/a	8
		ABFE	A	7	11	
Ship Bottom Police Station	Ship Bottom, NJ	Effective FIRM	AE	7	n/a	6
		ABFE	A	9	13	
Ship Bottom Volunteer Fire Company 1	Ship Bottom, NJ	Effective FIRM	AE	7	n/a	6
		ABFE	A	9	13	
Toms River Fire Company No. 2	Toms River, NJ	Effective FIRM	AE	5	n/a	7
		ABFE	A	8	12	
43rd Battalion, Engine 245, FDNY Ladder 161, NYPD 60th Precinct	Brooklyn, NY	Effective FIRM	AE	9	n/a	11
		ABFE	A	12	17	
FDNY Engine Company 168 and Emergency Medical Service 23	Rossville, NY	Effective FIRM	X	n/a	n/a	14
		ABFE	n/a	n/a	n/a	
Lower Manhattan Fire Station Housing FDNY Engine Company 4 and Ladder Company 15	New York, NY	Effective FIRM	AE	9	n/a	10-11
		ABFE	V	15	18	
Sea Gate Police Station	Brooklyn, NY	Effective FIRM	AE	9	n/a	12
		ABFE	A	12	17	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the *Tropical Cyclone Report, Hurricane Sandy* (AL182012) (NHC 2013b).

FEMA = Federal Emergency Management Agency

NYPD = New York City Police Department

FDNY = New York City Fire Department

FIRM = Flood Insurance Rate Map

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the FIRM). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

Hurricane Sandy. The flood zones in Table 5-3 include those shown on all FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

5.3.1 Facility Location and Construction

The first responder facilities visited by the MAT are located along or within several blocks of a river, creek, or a bay, and all but one are in SFHAs. The facilities were constructed between the early 1900s and 2002.

The facilities the MAT visited have first floors below the BFE and one facility has a basement. The facilities that received the most damage housed mechanical equipment, such as fuel tanks, HVAC, and pumps, below the BFE. The damage to these facilities from the storm surge was mostly to the utility systems and equipment located below the Hurricane Sandy flood levels.

5.3.2 Preparing for Hurricane Sandy

Command and response personnel at all police and fire stations were organized before the event and remained on duty to be in full readiness for action both during and in the aftermath of the storm. Some sheltered in place, others had to relocate to nearby facilities.

5.3.3 Level of Flooding and Resulting Damage

Most of the first responder facilities visited by the MAT are in Zone AE, with BFEs ranging from 5 to 9 feet. The facilities typically had from 2 to 6 feet of flooding during Hurricane Sandy. Most of the facilities had power and other MEP systems below the BFE that sustained severe damage from inundation.

5.3.4 Effect on Operations and Functionality

Damage to facilities was primarily caused by flooding, with the extent varying based on the level of flooding, especially with respect to the critical building systems. In facilities that were flooded, all equipment in basements or un-elevated on the first floor was damaged. Damaged elements included electrical service equipment, distribution panels, generators, transfer switches, boilers/furnaces, and hot water heaters (Figure 5-8). When these vulnerable critical elements failed, the systems were rendered inoperative, and the functionality of the critical facilities suffered as a result.

Loss of municipal electrical power during and after Hurricane Sandy affected all first responder facilities and was evident at all the sites visited. Most of the fire and police facilities visited had emergency generators designed to provide power for full functionality during utility power outages. Facilities with functional generators were better equipped to continue operations after the storms than those that were left completely without power. At facilities where emergency power was not available or generators failed as a result of inundation, mechanical, electrical, and communications systems became partially or completely unusable. At some locations, generators were elevated but still failed because components of the emergency power system—transfer switches or pumps—were located below flood levels.

Figure 5-8: Water entered the mechanical room in the lower basement through the doorway to the ventilation well (looking up to the street level) (Brooklyn, NY)

5.3.5 Recovery Actions and Issues

The facilities most successful in maintaining operations were either sited on higher elevations or had functioning generators and minimal mechanical and electrical damage. In contrast, facilities that did not have emergency generators, or had generators that failed or sustained extensive mechanical and electrical damage, experienced the longest downtimes. Fire rescue and police facilities that were significantly damaged were forced to evacuate and relocate, which affected their operations on many levels. In some cases, facilities had to use mobile command trailers or other local accommodations, such as a local motel, for operations because of damage to the primary facility. Facilities with functioning generators and minimal mechanical and electrical damage were mostly able to remain operational during or immediately after the floodwater receded.

5.4 Schools

The MAT visited 12 educational facilities in New Jersey and New York, including early child development centers, elementary schools, middle schools, and high schools. Schools are not only centers for educating children, but also provide community employment and often serve as shelters for citizens, emergency responders, and/or logistics during an incident. Thus, loss of use can greatly affect a community's ability to rapidly respond to the needs of disaster victims. At-risk children also depend on schools for health and social services, so the loss of use has negative impacts on these youths.

Of the 12 educational facilities visited, four were selected as representative of the damaged incurred by Hurricane Sandy. The locations of these representative facilities are shown on Figure 5-9. Table 5-4 lists each of the schools visited, along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations for sites located in Zone A, and the level of storm surge during Hurricane Sandy. The flood zones in Table 5-4 include those shown on all FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

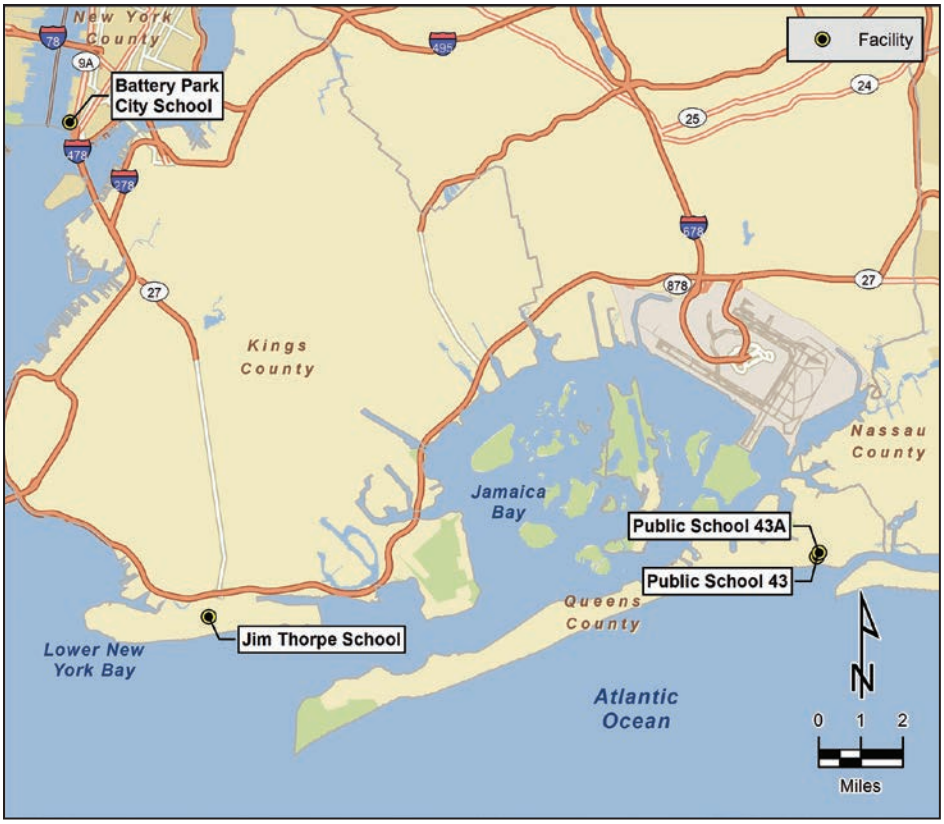


Figure 5-9: Locations of schools described in this report

Table 5-4: BFEs, ABFEs, and Sandy Floodwater Elevations for Schools Described in Report

Facility Name	Location	Relevant FEMA Flood Maps	Flood Zone(s) on Map[a]	1-Percent-Annual-Chance Elevation(s) (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[c]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
Battery Park City School	Manhattan, NY	Effective FIRM	X, AE	n/a, 9	n/a	11
		ABFE	Shaded X, A	n/a, 12	n/a	
Jim Thorpe School	Brooklyn, NY	Effective FIRM	AE	9	n/a	11
		ABFE	A	11	15	
Public School 43	Far Rockaway, NY	Effective FIRM	AE	9	n/a	10
		ABFE	A	11	15	
Public School 43A	Far Rockaway, NY	Effective FIRM	AE	9	n/a	10
		ABFE	A	11	15	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the *Tropical Cyclone Report, Hurricane Sandy* (AL182012) (NHC 2013b).

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the Flood Insurance Rate Map [FIRM]). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

5.4.1 Facility Location and Construction

The school facilities visited by the MAT are located along or within several blocks of a river, a bay, or the coastline, and all are located in flood zones. The facilities were constructed between 1920 and 2009. These were representative of dozens of schools impacted by Sandy.

Most of the school facilities the MAT visited have first floors below the BFE. The facilities that received the most damage housed mechanical equipment, such as emergency generators, fuel tanks, pumps, boilers, and electrical switchgear on the ground floor below the BFE. The damage incurred at these facilities from the storm surge primarily affected utility systems and equipment below the flood elevations. One school had mechanical equipment located on the ninth floor and received relatively little damage.

5.4.2 Preparing for Hurricane Sandy

All of the schools in New Jersey and most of the schools in New York City, and Nassau and Suffolk Counties, NY, were closed Monday, October 29, 2012, before Hurricane Sandy arrived. Most schools were also closed the following day, Tuesday; all schools in New York City were closed the remainder of the week. Most facility managers for the schools took precautionary measures, including placing temporary barriers such as sandbags at doors and other locations to prevent water infiltration.

5.4.3 Level of Flooding and Resulting Damage

All of the schools visited by the MAT are in Zone AE, with BFEs of 9 feet. The facilities typically had from 2 to 4 feet of flooding during Hurricane Sandy. The facilities that had power and other MEP systems located below the BFE sustained severe damage from inundation. Two of the schools (PS43A and Battery Park City School) have elevated MEP systems located well above flood levels and experienced little damage.

5.4.4 Effect on Operations and Functionality

Damage from Hurricane Sandy was primarily caused by floodwater inundation. Only minimal wind damage was observed at the schools visited by the MAT. Critical building systems (MEP and emergency power systems) were generally located on the ground floor level or in the basement in the schools (Figure 5-10). The MAT observed this arrangement at several school buildings affected by Hurricane Sandy where utilities were damaged. Schools without basement and elevated systems were much less affected by the storm.

5.4.5 Recovery Actions and Issues

For the most part, school buildings that suffered damage to critical building systems were forced to either relocate students or run on temporary equipment for an extended period until repairs were completed. Schools that did not have heavy damage to critical building systems were operational once schools were re-opened the week following the storm, allowing parents to focus on other recovery needs during school hours.

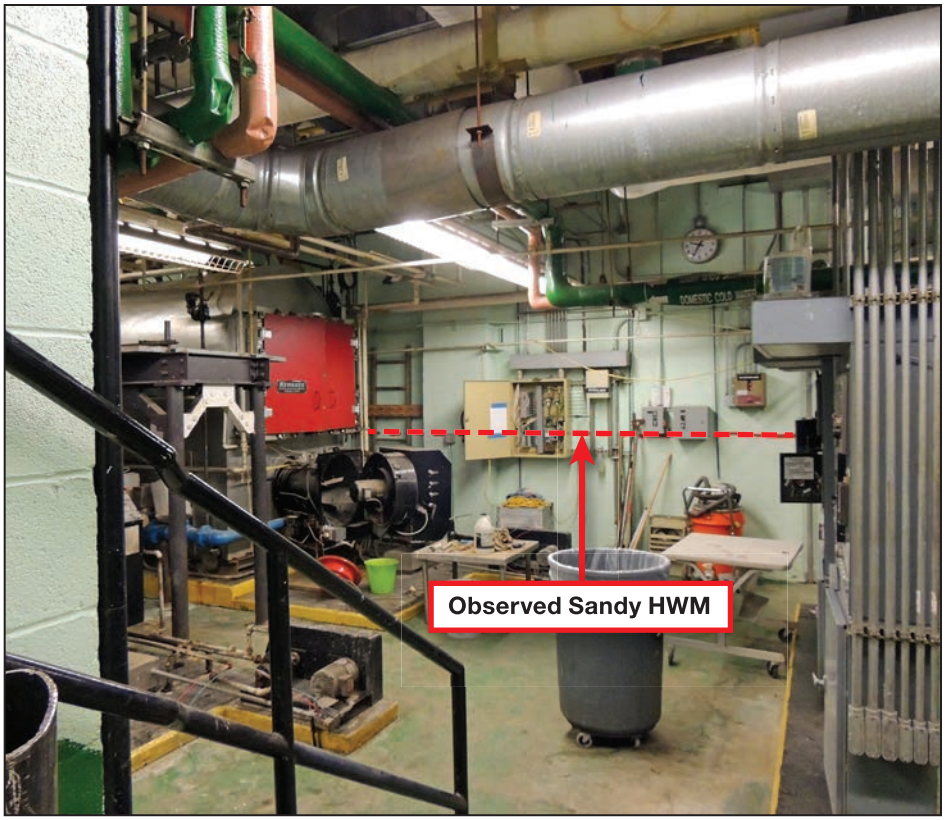


Figure 5-10: The basement of PS43 was inundated with approximately 5 feet of water (Queens, NY)

5.5 Data Centers

Data centers are centralized locations housing computer systems and associated components, such as telecommunications and storage systems. Data centers are critical to business continuity, as information and communication systems are relied on for everyday operations (e.g., telecommunications, Internet, entertainment, etc.). The MAT visited two large data centers in Manhattan, NY—Verizon and Internap—that were damaged by flooding during Hurricane Sandy (Figure 5-11).

Table 5-5 lists each of the data center facilities visited, along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations for sites located in Zone A, and the level of storm surge during Hurricane Sandy. The flood zones in Table 5-5 include those shown on all FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

Figure 5-11:
Locations of the data centers visited by the MAT

Table 5-5: BFEs, ABFEs, and Sandy Floodwater Elevations for Data Centers Visited by the MAT

Facility Name	Location	Relevant FEMA Flood Maps	Flood Zone on Map[a]	1-Percent-Annual-Chance Elevation (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[c]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
Internap Data Center	Manhattan, NY	Effective FIRM	AE	9	n/a	11
		ABFE	A	12	16	
Verizon Data Center	Manhattan, NY	Effective FIRM	AE	9	n/a	11
		ABFE	A	13	17	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the *Tropical Cyclone Report, Hurricane Sandy* (AL182012) (NHC 2013b).

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the Flood Insurance Rate Map [FIRM]). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

5.5.1 Facility Location and Construction

Internap is located in a building on Broad Street in Lower Manhattan and occupies the 14th floor of a 33-story building with two basement levels and has its emergency generators on the second floor. An adjacent building was built in 1928 and expanded in 1930 to encompass the entire block.

Fuel tanks for the building generators, as well as a 10,000-gallon fuel tank for Internap's emergency generators on the second floor, were located on the lowest basement level.

Verizon is the sole occupant of a 17-story building constructed in 1918, also on Broad Street, with three subgrade levels. Con Edison provides power and steam to the building through street access to vaults in the subgrade levels. Fuel tanks for the building generators were on the lowest basement level.

5.5.2 Preparing for Hurricane Sandy

Both data centers sustained considerable flood damage that affected their operations. Given the companies' experiences with flooding, standard operating procedures for the buildings included the management of water infiltration.

The building owners prepared by installing emergency power for building functions, such as stairwell lighting. Because of the multiple street access points to utilities in the basement levels, it was not possible to employ effective floodproofing measures. Tenant emergency action plans were based on industry-specific emergency preparedness practices to have backup or redundant operational capacity, elevate equipment where possible, and put supply chain agreements in place. Prior to Sandy, the building owners and data center tenants each followed their respective pre-event planning and flood protection measures largely independent of each other.

5.5.3 Level of Flooding and Resulting Damage

Both buildings are in Zone AE, with a BFE of 9 feet. The storm surge floodwater filled the basement levels of both buildings and rose to approximately 3 feet on the first floor level. Floodwater filled the basements through all available openings, including stairwells, elevator shafts, and access openings for the utilities. Seepage through the basement walls continued even after the storm.

5.5.4 Effect on Operations and Functionality

The day tank for Internap's generators on the second floor provided power after Con Edison turned off power to the area. When the generators were shut down, critical equipment remained in operation on battery systems. A fuel truck was on the site to provide fuel to generators, so Internap could resume its 24-hour business.

The Verizon building did not have power from Con Edison for 3 weeks, and even then only a portion of their power was restored because of flood damage to the electrical vaults in the basement. The remaining power needs were provided by emergency generators.

The biggest problem at the data centers was extensive damage to building systems and supporting equipment located in basement levels. Both facilities lost municipal power from the electrical service provider when Con Edison preemptively shut down electrical power in New York; however, mechanical and electrical equipment in the basement were submerged and rendered inoperable, resulting in long durations of disrupted building services (Figure 5-12).

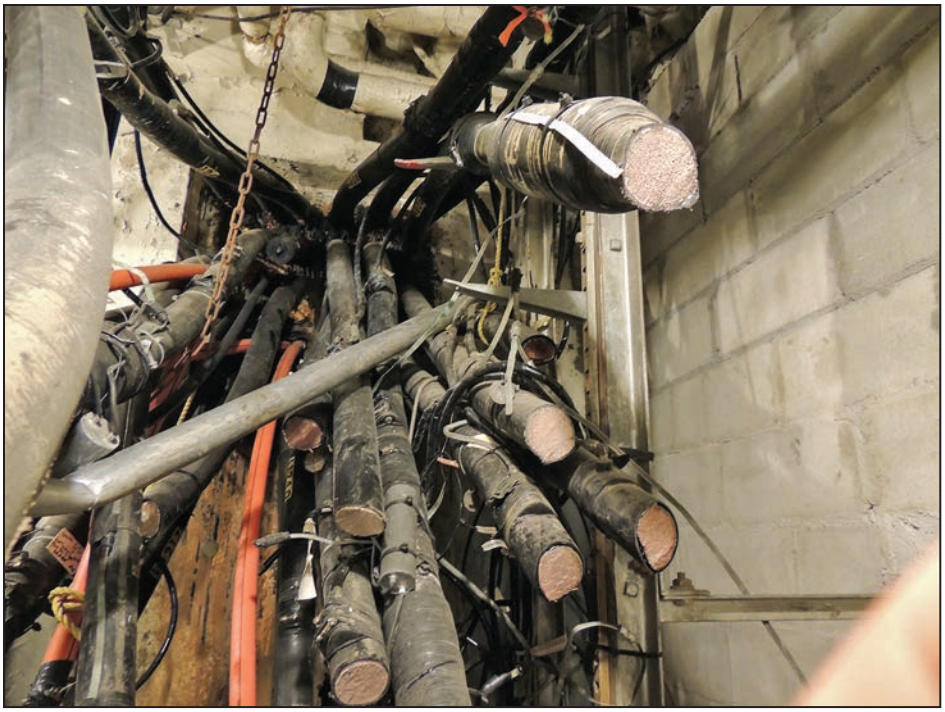


Figure 5-12: Copper communication cables that were damaged by water intrusion into the cable sheathing; positive gas pressure that kept the cables dry was lost when the equipment in the basement was flooded at this data center (Manhattan, NY)

Performance of the emergency power systems was dependent on the elevation of equipment and availability of fuel. Elevated generators with fuel in day tanks and uninterruptible power supply systems provided temporary power for one data center. The elevated generators were fueled by a 10,000-gallon tank in the basement. However, the tank broke free of its anchors as buoyant forces from 20 feet of floodwater exceeded their strength.

Both data centers had some business service disruption, with the duration depending on the extent of damage and availability of fuel for emergency power. Because of the extensive damage to building systems, the facilities had to operate on emergency power and temporary utilities for several weeks after the storm, even after electricity was restored by the service provider (Figure 5-13). A continuous fuel supply to generators was established from fuel trucks, as power was crucial to continued business operations. Issues that also affected business operations included loss of elevator service, potable water, and emergency lighting.

5.5.5 Recovery Actions and Issues

At the time of the MAT visit, both buildings were operating on temporary utilities. The following mitigation plans are being considered for business operations in floodprone regions:

- Strengthening fuel storage tanks and their anchorage for flood design-level hydrostatic submersion forces.
- Elevating fuel pumps above the DFE.
- Developing contingency plans for obtaining generator fuel.

Figure 5-13: Truck-mounted generator power brought in to replace failed basement generators at a data center (Manhattan, NY)

- Installing a fuel filter and/or a fuel clarification system to remove debris from emergency generator fuel.
- Keeping fuel hose connection to the day tank in place for rapid connection to a fuel pumper truck.
- Revising staff safety protocols to reduce the possibility of injuries from flooding, electrical hazards in a flood, navigating dark stairwells, etc.
- Developing procedures for financial and administrative staff to make unexpected purchases, such as with new vendors or at significant costs (e.g., fuel trucks with equipment to pump to elevated tanks).
- Considering satellite phones as an alternative to cell phones.
- Clarifying tenant and building owner/operator roles and responsibilities during emergencies.
- Installing submersible fuel pumps. However, if installed, plans must consider whether the elevation between a basement-level tank and generators several floors above the tank may be too great since many submersible pumps provide a low head for pumping.
- Considering hydraulic or pneumatic fuel pumps with compressors located above DFEs.
- Installing remote cameras to basement areas to monitor flooding around electrical/power areas to provide information without sending personnel down into potentially flooded spaces where they face the risk of electrocution, contamination, etc.

5.6 Wastewater Treatment Plants

WWTPs are essential to public health. Their failure to operate can result in consequences such as untreated wastewater pouring into rivers and bays and sewage backing up into homes and businesses, with associated human health and ecosystem hazards. The MAT visited three WWTP facilities to determine the effect of storm surge on their operations and the communities they serve (Figure 5-14).

Table 5-6 lists each of the WWTP facilities visited, along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations for sites in Zone A, and the level of storm surge during Hurricane Sandy. The flood zones in Table 5-6 include those shown on all FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

Figure 5-14: Locations of the WWTPs visited by the MAT

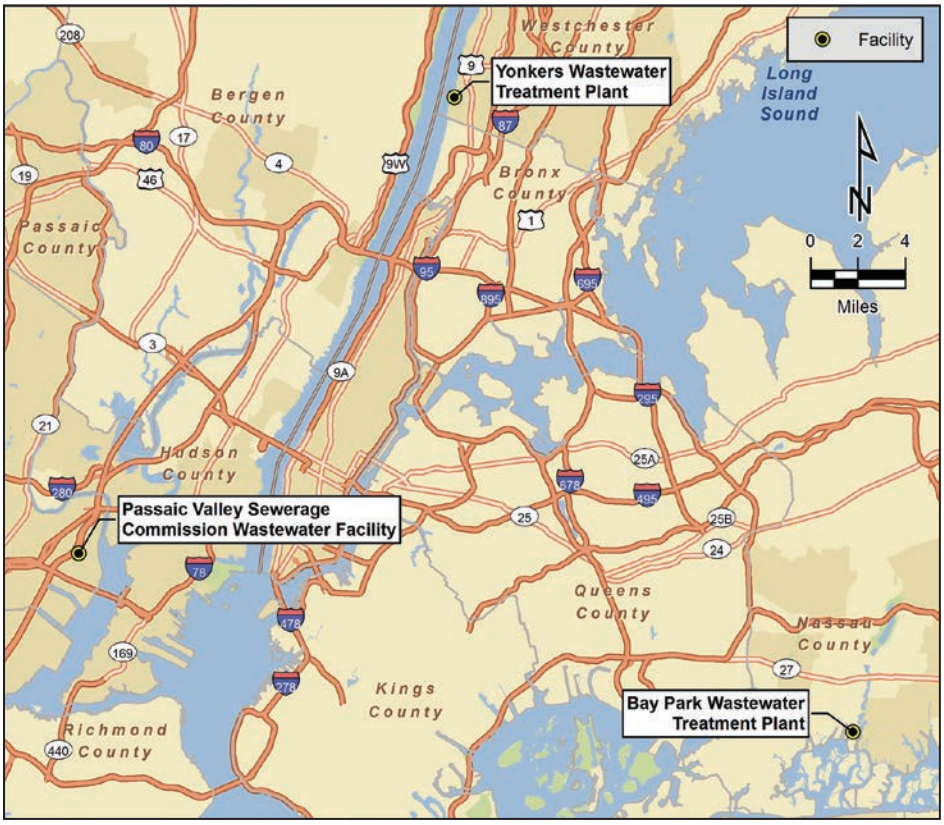


Table 5-6: BFEs, ABFEs, and Sandy Floodwater Elevations for WWTPs Visited by the MAT

Facility Name	Location	Relevant FEMA Flood Maps	Flood Zone(s) on Map[a]	1-Percent-Annual-Chance Elevation(s) (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[b]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
Passaic Valley Sewerage Commission Wastewater Facility	Newark, NJ	Effective FIRM	X, AE	n/a, 9	n/a	12
		ABFE	A	12	17	
Bay Park Sewage Treatment Plant	East Rockaway, NY	Effective FIRM	X, AE	n/a, 9	n/a	11
		ABFE	n/a	n/a	n/a	
Yonkers Wastewater Treatment Plant	Yonkers, NY	Effective FIRM	X, AE	n/a, 7	n/a	9
		ABFE	A, V	10, 12	15	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the *Tropical Cyclone Report, Hurricane Sandy* (AL182012) (NHC 2013b).

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the Flood Insurance Rate Map [FIRM]). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

5.6.1 Facility Location and Construction

WWTPs are typically built next to bodies of water to allow return of large volumes of treated water into the adjacent river, bay, or ocean. By being adjacent to the local water level, treated water can return primarily by gravity flows back into the body of water, thus reducing power needs and operating costs. This also poses special flood hazard exposure.

The Yonkers WWTP is located on the Hudson River in Yonkers, NY, approximately 20 miles north of Manhattan. It was built in the 1930s and renovated in 1978, and provides primary and secondary sewage treatment. The primary treatment system has emergency generators. The Yonkers facility serves a population of over 500,000.

The Passaic Valley WWTP, located on the Passaic River in Newark, NJ, is one of the largest sewage treatment facilities in the nation. The plant started operations in 1902 and was enlarged in 1924, and again in 1980, when secondary treatment was added. The Passaic Valley facility serves a population of over 2,000,000.

The Bay Park WWTP is located on Hewlett Bay in East Rockaway, NY. The plant started operations in 1949, and was upgraded in the 1960s and 1980s. It provides primary and secondary sewage treatment.

All three sites have utility tunnels and galleries beneath the facilities.

5.6.2 Preparing for Hurricane Sandy

Because of their low-lying proximity to large bodies of water, WWTPs in the New Jersey and New York metropolitan area were highly susceptible to storm surge inundation. However, significant storm surge events had not occurred over the last century, and other flood events had not previously inundated the plants. None of the facilities were flooded during Hurricane Irene in 2011. Given this history, WWTPs did not expect significant flooding during Hurricane Sandy. Facility preparations were similar to those for Hurricane Irene and included plans for breaching, evacuation, and de-energizing plant systems as floodwater gradually rose. Preparation activities included staging emergency generators from other locations at the WWTP site, sandbagging, and installing barrier covers to protect air intakes, switchgear, and other critical systems.

5.6.3 Level of Flooding and Resulting Damage

All three WWTPs were in a Zone AE with a BFE between 7 and 9 feet. A 12-foot storm surge traveled up the Hudson River and inundated both the Passaic Valley and Yonkers WWTP facilities. The first floor levels in buildings at the Yonkers facility received 2 to 3 feet of water. Although the roads and properties surrounding the Passaic Valley facility had frequently flooded in the past, the plant had never been flooded. Clarifying tanks located in a basin with a height of 13 feet above grade were overtopped. The Bay Park WWTP site had flood levels of 2 to 5 feet above ground level, depending on the site elevation.

5.6.4 Effect on Operations and Functionality

During Hurricane Sandy, storm surge rapidly inundated all three of the WWTP sites the MAT visited. The rapid rise prevented some of the planned actions, such as de-energizing plant systems at two of the WWTPs. De-energizing plant systems prior to inundation greatly reduces flood-induced damage and recovery time. Employees that were onsite were ordered to move to safe locations on elevated floors.

Storm surge flowing through openings and entrances flooded the basements and tunnels at all three WWTPs. Without emergency power to keep sump pumps operating, seepage from overcharged soil also contributed to the water levels in the basements and tunnels until power was supplied. In all three plants, temporary measures were still in place at the time of the MAT visit as permanent equipment was still being repaired, evaluated, and replaced.

Local power companies were able to restore power to the WWTPs within hours to 2 days. However, the plants with damaged power systems experienced recovery delays, and had to use prolonged emergency power when it was available. Related system recovery delays affected transformers, switchgear, and distribution systems (Figure 5-15) before power could be restored to the plant. With backup generators brought onsite, primary treatment of sewage using auxiliary power or components was restored within 1 to 2 days at two of the plants, and within 1 week at the third plant. In general, all inundated electrical components had to be replaced, including electronic controls and SCADA (supervisory control and data acquisition) systems. Other equipment and systems damaged by floodwater included boilers, communication systems, fire protection systems, settling tanks, and biological systems for treatment. In one case, the plant operator was able to de-energize the plant when floodwater threatened to inundate the electrical switchgear; this action facilitated

Figure 5-15: Subgrade electric system damaged by floodwater at the Passaic Valley Sewerage Commission wastewater facility (Newark, NJ)

recovery and restart of the plant. Other reports identify improvised procedures that allowed rapid restoration of facility functions.

The visited WWTPs had backup power generators for a few critical systems, but the power demand for other equipment exceeded what could be provided by available generator systems. Temporary generators were installed at some of the facilities.

5.6.5 Recovery Actions and Issues

Plant operators are repairing some equipment and putting others back into service with a planned replacement schedule (which could change due to unexpected component failures). Some pieces of equipment that failed during Hurricane Sandy require a long lead time to manufacture and replace, and temporary solutions have been developed to allow restoration of plant operations.

Each WWTP is separately examining its flood-induced damage and identifying key issues for maintaining plant functionality for future flood or other disaster events. The following issues have been identified:

- The 1-percent-annual-chance flood hazard standards for design are inadequate.
- Consistent floodproofing measures across the WWTPs visited was lacking, as was clear documentation of how code provisions for flooding hazards were applied to each critical facility component during design and construction.
- Power to critical systems was interrupted. Alternate systems are being considered depending on tradeoffs of reliability and cost.
- Backup emergency power and/or backflow valves for pumps conveying wastewater into or out of the plant was not available. Improved pumping capability and backup power for sump pumps is needed.

- Essential equipment and key assets for critical system functions were not located above the DFE, floodproofed, or hardened. Such equipment includes switchgear, motors and electronic controls, and emergency power. Water entry points, such as air vents (Figure 5-16) and door seals were not floodproofed.

Figure 5-16:
Air vents (red arrow) along walkway over subgrade utility tunnel adjacent to settling tanks on the left were overtopped by approximately 2 feet of floodwater, flooding the basement areas below at the Yonkers Wastewater Treatment Plant (Yonkers, NY)

- Flood barriers, such as berms and floodgates, were not designed consistently to or above the DFE, and many were breached.

- Access roads to the plants were flooded.

- Regional impacts from wastewater failures were significant, and coordination between States and jurisdictions was lacking.

- The requirement that wastewater plants be sited in low-lying area vulnerable to flood was not adequately addressed in site design and risk mitigation coordination between buildings, infrastructure, and surrounding natural water resources.

- Environmental impacts of untreated sewer discharge from flood-induced plant failures were not adequately evaluated or mitigated.

5.7 Transportation Facilities

The New Jersey and New York metropolitan area relies on public transportation for conducting all aspects of daily life. Some key facilities and tunnels for subways, buses, and trains were damaged by the storm surge, which severely reduced the means of transportation that residents, commuters, and businesses rely on. Immediately after the storm, fuel shortages occurred, resulting in long lines at gas stations. Most transportation facilities incurred substantial flood damage and were unable to resume operations after utility services were restored. This had significant impacts on the metropolitan area, including losses in revenue and disruption for commuters.

For subways with damaged substations and transformers, activation of utility power took days to weeks, following massive pumping efforts. Flood-damaged subway stations required extensive MEP repairs and cleaning before resuming operations. The MAT visited subway stations, maintenance facilities, and gas stations. Figure 5-17 shows the location of the facilities visited by the MAT.

Table 5-7 lists each of the transportation facilities visited, along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations for sites in Zone A, and the level of storm surge during Hurricane Sandy. The flood zones in Table 5-7 include those shown on all FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

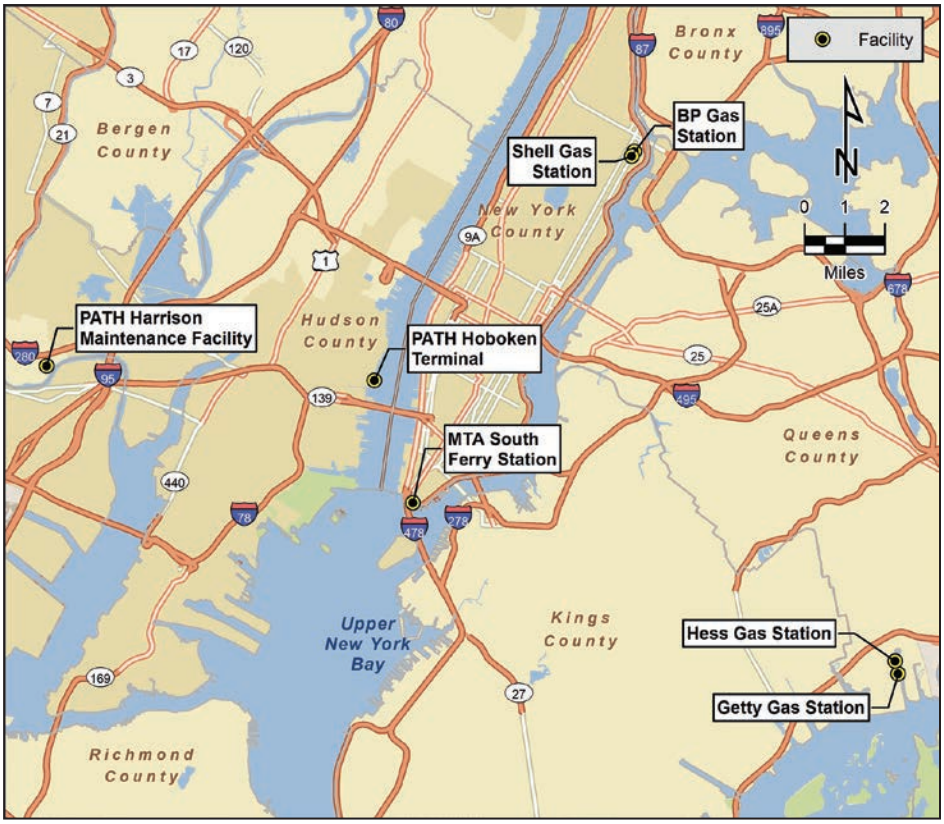


Figure 5-17: Locations of the transportation facilities visited by the MAT

Table 5-7: BFEs, ABFEs, and Sandy Floodwater Elevations for Transportation Facilities

Facility Name	Location	Relevant FEMA Flood Maps	Flood Zone on Map[a]	1-Percent-Annual-Chance Elevation (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[c]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
PATH Harrison Maintenance Facility	Harrison, NJ	Effective FIRM	AE	9	n/a	11
		ABFE	A	11	15	
PATH Hoboken Terminal	Hoboken, NJ	Effective FIRM	AE	9	n/a	11
		ABFE	V	15	20	
MTA South Ferry Station	Manhattan, NY	Effective FIRM	AE	9	n/a	11
		ABFE	A	13	17	
BP Gas Station	Harlem, NY	Effective FIRM	AE	12	n/a	10
		ABFE	A	12	14	
Getty Gas Station	Queens, NY	Effective FIRM	Shaded X	n/a	n/a	11
		ABFE	A	11	15	
Hess Gas Station	Queens, NY	Effective FIRM	Shaded X	n/a	n/a	11
		ABFE	A	11	15	
Shell Gas Station	Harlem, NY	Effective FIRM	AE	12	n/a	10
		ABFE	A	12	14	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the *Tropical Cyclone Report, Hurricane Sandy* (AL182012) (NHC 2013b).

MTA = Metropolitan Transit Authority

PATH = Port Authority Trans-Hudson

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the Flood Insurance Rate Map [FIRM]). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

5.7.1 Facility Location and Construction

The MAT visited transportation facilities to determine the effect of Hurricane Sandy on their operations and the communities they serve. The following observations are based on visits to two subway stations—the Port Authority Trans-Hudson Corporation (PATH) Hoboken station and the MTA South Ferry station—the PATH Harrison Rail Car Maintenance Facility, and four gas stations. These facilities are described in more detail in Appendix H.

The PATH Hoboken station was established in 1962 and is located on the Hudson River just north of the Holland Tunnel. The station is part of an intermodal facility connecting New Jersey Transit rail and bus lines, Metro-North Railroad, Bergen Light Rail, PATH, and the New York Waterway ferries that is used by 50,000 people daily. Parts of the facility date back to the 1900s. The MTA South Ferry station is the southernmost point of the MTA in Manhattan. It was built in 2009, and the rail track is approximately 50 feet below grade.

The PATH Harrison Rail Car Maintenance Facility is located along the Passaic River in Harrison, NJ. The facility opened in 1990 to maintain and repair approximately 300 PATH rail cars. The facility has 20 tracks and inspection and service areas with subgrade mechanical pits.

The MAT visited two gas stations in Manhattan and two in Queens, NY. They were all typical facilities with underground fuel tanks, fuel pumps and dispensers, and a small service building for customers.

5.7.2 Preparing for Hurricane Sandy

None of the transportation facilities the MAT visited anticipated the severity of flooding that occurred with Hurricane Sandy. Preparation for Hurricane Sandy varied from facility to facility. Some facilities installed floodgates (Figure 5-18) and/or used sand bags and shut down facility power to protect mechanical and electrical equipment. Other facilities made no preparations. The flood levels during Hurricane Sandy were much higher than previous flood levels at these facilities, and the inundation overwhelmed planned flood protection actions (e.g., pumping out water that overtopped floodgates).

When Con Edison proactively shut down power in Manhattan, the subway stations and some gas stations lost power. Facilities with high power usage, such as maintenance facilities, de-energized their rail and plant electrical systems before flooding began (Figure 5-19). The most damaging effects transportation facilities suffered after Hurricane Sandy was the loss of power and damage to utility equipment. Utility power to all of the visited facilities was lost for a period raging from hours to 2 weeks.

Figure 5-18:
Flood barriers (red arrow) at top of stairs into the PATH subway station (left); at the bottom of the stairs is another set of stairs leading down to the rails (right) (Hoboken, NJ)

Figure 5-19:
Repair facility with numerous work pits with subgrade power, motors, and specialized equipment was flooded with approximately 18 inches of water at a PATH facility (Harrison, NJ)

5.7.3 Level of Flooding and Resulting Damage

The PATH Hoboken station is in Zone AE with a BFE of 9 feet. The maximum floodwater elevation at the station was 11 feet. The floodwater overtopped the floodgates installed at the station stairways and poured through an elevator kiosk that failed at the street level. The floodwater flowed through the station into the subway tunnels so that the water depths were on the order of several feet.

The MTA South Ferry station is in Zone AE with a BFE of 9 feet. The storm surge completely submerged the platform and filled other areas to levels varying from 3 to 8 feet. The floodwater carried debris from streets and public trash containers. One system had submersible pumps that successfully pumped water during the flood event until they were damaged by debris, such as plastic bags and trash.

The PATH Harrison Maintenance Facility is in Zone AE with a BFE of 9 feet. The site had not been previously flooded. The storm surge reached 4 to 5 feet on the property. The flood level inside the buildings was approximately 1.5 to 2 feet.

The gas stations in Manhattan were not flooded. However, the two gas stations in Queens were flooded, one by several inches and the other by several feet.

5.7.4 Effect on Operations and Functionality

Subway Stations

Because subway systems in dense urban environments have a large portion of their facilities below grade, water management is an important part of maintaining the infrastructure system. The subway stations had flood damage to their electrical systems (transformers, switchgear, distribution panels, etc.), communication and data/IT systems, and electronic controls and equipment. Damage to these systems affected escalators, elevators, signal and fare control systems, emergency lighting, HVAC systems, and other systems necessary to facility operations (Figure 5-20).

Figure 5-20: Elevator kiosk at street level that failed under surge inundation loads (left) and became a significant source of flooding in the Hoboken Station of the PATH rail system (right) (Hoboken, NJ)

SOURCE OF PHOTO ON RIGHT: THE PORT AUTHORITY OF NEW YORK AND NEW JERSEY

Subway station personnel reported to the MAT that preliminary inspections found that electrical power and control equipment, signal equipment, communication equipment (fire alarm, public address, fare collection, etc.), and air conditioning equipment and controls must all be replaced. Emergency ventilation fans, escalators, elevators, architectural finishes, ductwork, piping, and conduit must be rehabilitated.

Subway stations required significant cleanup and recovery efforts. All flooded components and supplies had to be checked for damage, and it had to be determined whether to repair or replace them. The MAT observed corrosion on metal components (escalator chains, electrical connections, piping, etc.) and mold on porous surfaces (drywall, furniture, etc.).

Gas Stations

Although many of the City's gas stations were located outside of the areas affected by power outages, they were unable to obtain gas supplies because of breakdowns in the supply chain caused by damaged marinas, pipelines, and storage terminals. The regional failure in the fuel supply system resulted in adverse impacts, including fuel shortages, long lines at operational gas stations, lost revenue, and lack of transit options.

The four gas stations the MAT visited were all typical facilities with underground fuel tanks, fuel pumps and dispensers, and a small service building for customers. Two of the four gas stations were inundated and lost power during Hurricane Sandy. They all had adequate fuel supplies prior to the flood event, but without a generator, the two stations that lost power had no means to pump fuel. The fuel storage at one station, which did not lose power and was not flooded, became as

low as 4,000 gallons before the station was resupplied, which did not occur until 8 to 10 days later. Hurricane Sandy caused significant disruption to the fuel distribution infrastructure, and numerous emergency generators in use only increased demand.

Fuel tanks were sealed and protected from flood damage at the two flooded stations, but subgrade fuel pumps needed to be replaced. One station brought in a generator and was pumping fuel within the week. Another gas station had 8,000 gallons of fuel following the storm event but was out of service for 1 month while repairing damaged equipment.

At the two gas stations where the fuel pumps were damaged by floodwater, the facilities were closed for 7 and 30 days, respectively, according to staff. At one flooded gas station, personnel who talked with the MAT said that because their fuel company required a data link for all sales transactions, cash sales could not have been completed even if they had generator power for the fuel pumps.

5.7.5 Recovery Actions and Issues

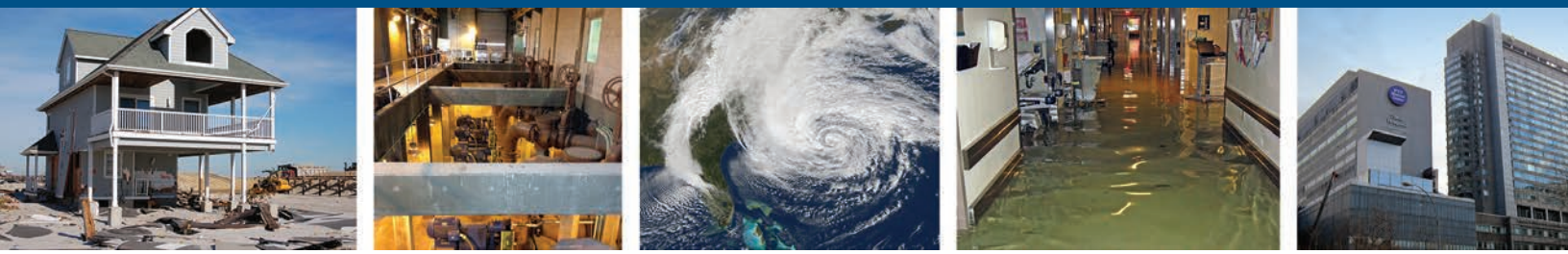
The MAT spoke with facility managers and found that transportation facilities are considering the following options as part of their recovery plans:

- Instituting improved flood protection measures, including flood barriers and elevating systems such as communication, data/IT, electrical systems, including switchgear and transformers to at least design flood levels (Figure 5-21).

- Using emergency generators or pre-wired connections for emergency generators to support pumping systems.

Figure 5-21: Subway entrance in flood zone that had its 4-foot flood barriers overtopped by the storm surge at the MTA South Ferry Station (Manhattan, NY)

- + Providing separate large-capacity pumps to handle flood volumes, versus everyday seepage maintenance, and filters to ensure that pumps are not clogged by debris.
- + Anchoring oil storage drums to prevent flotation and release of contents, or elevating them above anticipated flood levels.
- + Moving rail cars away from flood sources or to elevations above flood levels.
- + Monitoring for potential adverse corrosion effects of saltwater on steel reinforcement and other system components.



HURRICANE SANDY IN NEW JERSEY AND NEW YORK

6 Historic Properties

Historic buildings are a tangible link to a community's past and often form the core of a community's identity.

Historic districts and downtowns are often a vital part of a community's economy that attract businesses and tourists and increase surrounding property values. Unfortunately, once a historic building is lost, it cannot be replaced; therefore, mitigation and recovery strategies for historic buildings and structures should be designed to preserve the historic features and character of those properties.

Hurricane Sandy affected many historic properties, and even though wind damage was observed throughout the declared disaster areas, most of the damage to the properties appeared to be flood-related. Most of the damaged historic properties were in exposed locations (e.g., open spaces), were near the water and therefore vulnerable to storm surge and wave impact, and had floor elevations that were much lower than the Hurricane Sandy flood elevations. The historic buildings and historic districts that escaped the heavier flood damage were inland. The MAT chose eight facilities that represented the typical damage observed after Hurricane Sandy. The locations of the properties are presented in Figure 6-1.

Figure 6-1: Locations of the historic facilities visited by the MAT

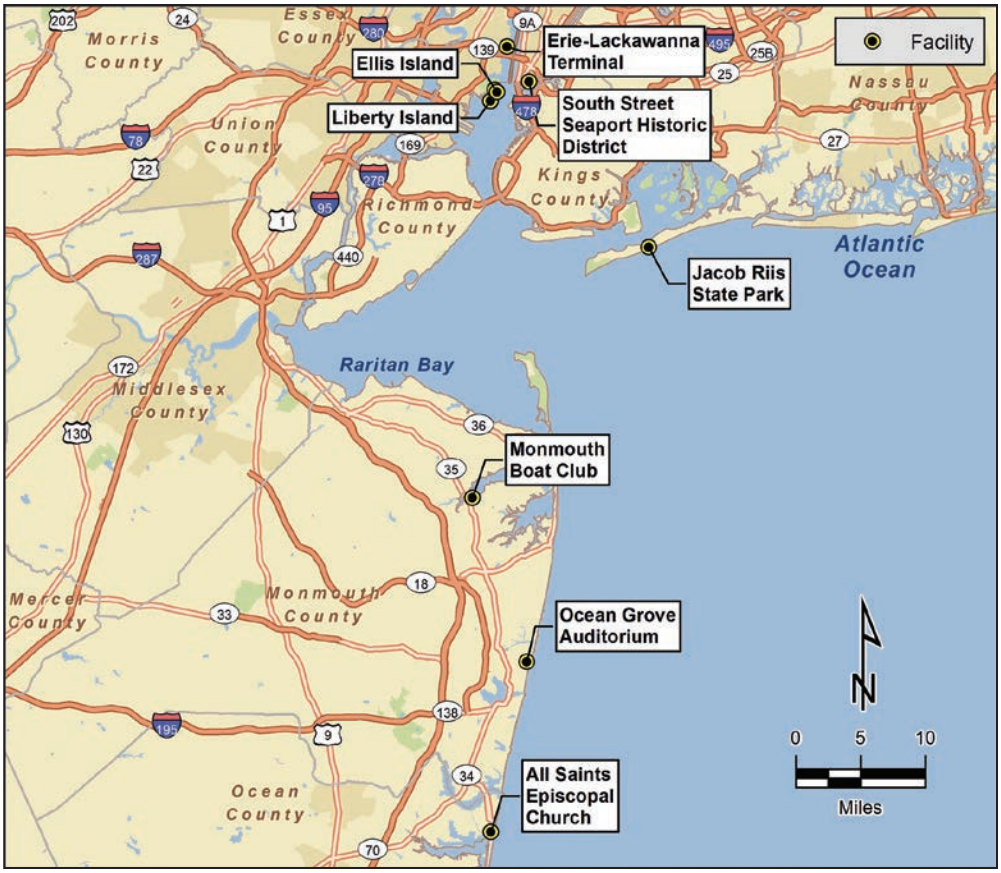


Table 6-1 lists each of the historic facilities visited, along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations for sites in Zone V and Zone A, and the level of storm surge during Hurricane Sandy. The flood zones in Table 6-1 include those shown on all FEMA flood maps relevant to the site location: the Effective FIRM and the ABFE map (where applicable). Refer to Section 1.4 for more information about BFE and ABFE maps.

Two of the eight historic facilities visited were located entirely in Zone X, outside the SFHA; the remaining six facilities were in the SFHA. All of the historic sites visited by the MAT suffered storm surge and inundation damage from Hurricane Sandy.

Europeans came to the New Jersey and New York area in the 1600s. New Jersey's historic and cultural resources include more than 74,000 historic properties and more than 6,000 archaeological sites (NJDEP 2013). Appendix G describes the regulations for repair and rehabilitation of historic structures in the State of New Jersey. New York State's historic and cultural resources include more than 5,000 national and State register listings, with more than 90,000 properties (NYS OPRHP 2009). Appendix G describes the regulations for repair and rehabilitation of historic structures in the State of New York as they relate to Substantial Improvement and Substantial Damage.

Table 6-1: BFEs, ABFEs, and Sandy Floodwater Elevations for Historic Structures

Facility Name	Location	Relevant FEMA Flood Maps	Flood Zone on Map[a]	1-Percent-Annual-Chance Elevation (feet)[b]	0.2-Percent-Annual-Chance Elevation (feet)[c]	Approximate Maximum Water Surface Elevation During Hurricane Sandy (feet)[b,c]
All Saints Episcopal Church	Bay Head, NJ	Effective FIRM	AE	5	n/a	7
		ABFE	V	10	14	
Erie-Lackawanna Terminal	Hoboken, NJ	Effective FIRM	AE	9	n/a	11
		ABFE	V	15	20	
Monmouth Boat Club	Red Bank, NJ	Effective FIRM	AE	8	n/a	11
		ABFE	V	12	15	
Ocean Grove Auditorium	Ocean Grove, NJ	Effective FIRM	Unshaded X	n/a	n/a	11
		ABFE	Unshaded X	n/a	n/a	
Ellis Island Ferry Building	New York Harbor	Effective FIRM	AE	9	n/a	11
		ABFE	V	16	22	
Ellis Island Immigration Museum	New York Harbor	Effective FIRM	AE	9	n/a	11
		ABFE	AE	12	n/a	
Statue of Liberty Concessions Building	New York Harbor	Effective FIRM	Shaded X	n/a	n/a	11
		ABFE	V	16	21	
Statue of Liberty Visitors Building	New York Harbor	Effective FIRM	Shaded X	n/a	n/a	11
		ABFE	V	16	21	
Jacob Riis State Park	Queens, NY	Effective FIRM	AE	10	n/a	11
		ABFE	A	12	17	
South Street Seaport Historic District	Manhattan, NY	Effective FIRM	AE	10	n/a	11
		ABFE	V	15	18	

a. Information related to the Effective FIRM and ABFE maps are based on current data available during the development of this report. Information is expected to change.

b. Elevations are reported as North American Vertical Datum of 1988 (NAVD88).

c. Data from Table 5 of the *Tropical Cyclone Report, Hurricane Sandy* (AL182012) (NHC 2013b).

n/a = Not applicable (base flood elevations [BFEs] do not exist for Zone X or 0.2-percent-chance elevation and are not included on the Flood Insurance Rate Map [FIRM]). Advisory Base Flood Elevation (ABFE) maps were not produced for Nassau and Suffolk Counties in New York because their FIRMs are up to date and based on current models and technical studies.

6.1 All Saints Episcopal Church (Bay Head, NJ)

Facility Description. The All Saints Episcopal Church located on Lake Avenue in Bay Head, NJ, is a contributing resource to the Bay Head Historic District (Figure 6-2). The church complex includes the sanctuary, Bristol Hall, parish office, and the rectory (located on the east side of Lake Avenue). The church falls under the governance of the New Jersey State Uniform Construction Code Act.

Figure 6-2: All Saints Episcopal Church (Bay Head, NJ)

All Saints Episcopal Church was constructed in 1889 and is the oldest church in Bay Head. Constructed in the Shingle style, the church complex and its multiple additions are clad in cedar shingles. Bristol Hall, a social hall just south of the church, was built in 1980 in a compatible style to that of the church (NPS 2005a).

Severity of Flooding and Damage to Facility. Hurricane Sandy caused severe damage to All Saints Episcopal Church and its surrounding landscape; stormwater reached approximately 7 feet (Table 5 of NHC 2013b). The rectory, the sanctuary, Bristol Hall, and the parish office sustained extensive damage. More than 4 feet of water inundated the church, destroying the main floor support in the sanctuary. The swiftly rising waters of the bay destroyed the bulkhead at the rear of the property (Figure 6-3). At the time of the MAT site visit, this bulkhead had been replaced. The rectory, located on the east side of Lake Avenue at a lower elevation, was destroyed by the combined storm surge from the ocean and the bay.

Recovery Actions. Part of the recovery efforts for this property involved cleaning and drying the buildings. Recovery efforts were well underway at the time of the MAT visit in the immediate aftermath of the storm. The hardwood floors and subfloors in Bristol Hall, the kitchen, and the entire first floor of the parish office building were removed. All of the drywall and insulation from floor level to 4 feet were removed from Bristol Hall, the kitchen, and the entire first floor of the parish office building. To preserve the interior woodwork in the sanctuary, the exterior cedar shake siding, sheathing, and insulation were removed from the foundation to 4 feet around the perimeter of the sanctuary to allow the building to dry slowly, using natural ventilation (Figure 6-4).

Figure 6-3:
Replacement bulkhead behind the narthex of All Saints Episcopal Church (Bay Head, NJ)

Figure 6-4:
Exterior cedar shake siding, sheathing, and insulation removed around the exterior of All Saints Episcopal Church for the purpose of drying the historic interior wood paneling (Bay Head, NJ)

6.2 Erie-Lackawanna Terminal (Hoboken, NJ)

Facility Description. The terminal complex in Hoboken, NJ, includes joined ferry and railroad buildings, the train shed, the baggage building/Young Men's Christian Association (YMCA) Building, and the former Pullman Building and Immigrant Station. The terminal complex falls under the governance of the New Jersey State Uniform Construction Code Act.

Completed in 1907, the Erie-Lackawanna Terminal links rail, ferry, subway, and pedestrian traffic. New Jersey Transit began rehabilitation activities at the terminal in 1978. The style of the buildings is an eclectic mix of English High Victorian in massing and French Beaux-Arts in ornamentation (Figure 6-5).

Except for the baggage building / YMCA Building and train shed, the complex is constructed on a concrete platform supported by 80-foot to 90-foot yellow pine piling set into the bed of the Hudson

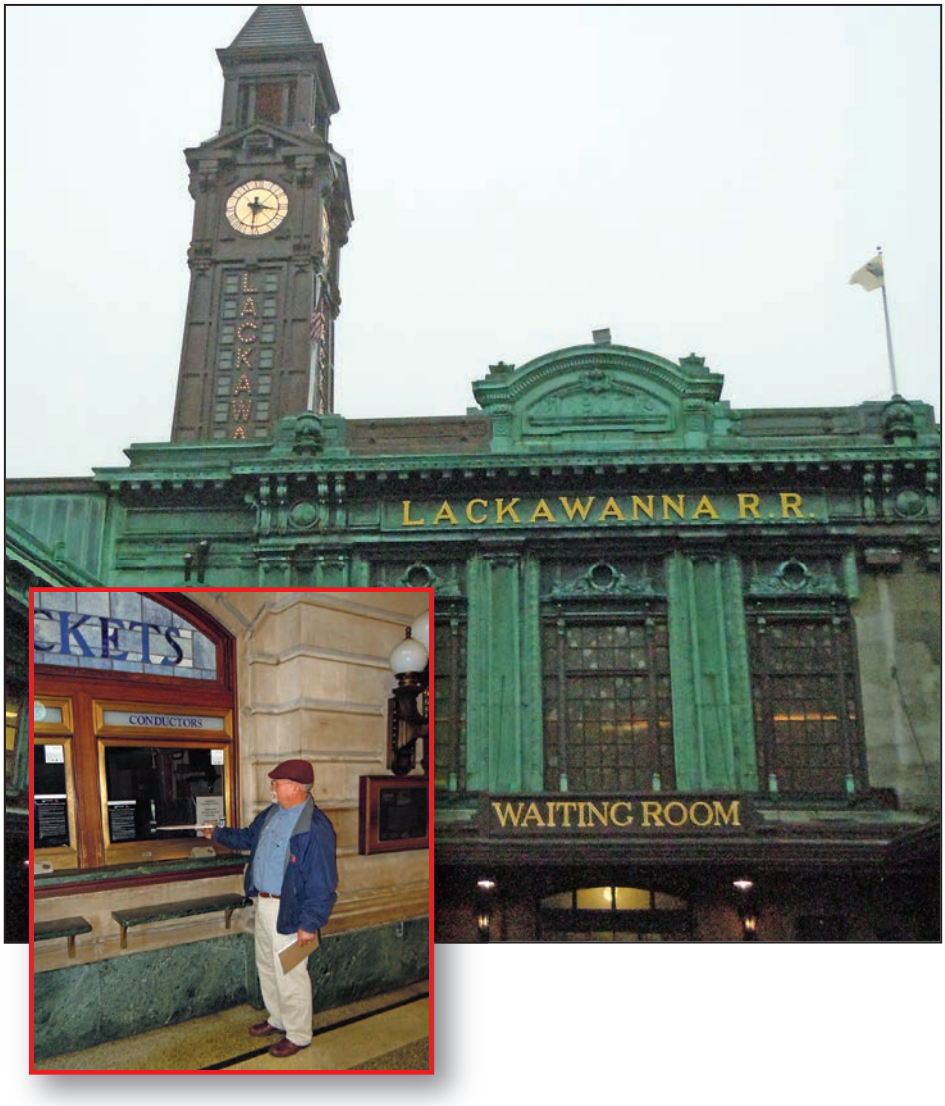


Figure 6-5:
Entrance to the waiting room of the Erie-Lackawanna Terminal; storm surge inundated the waiting room to a depth of 4 feet. Stations and Terminal Manager, Everett Lopes, indicates the HWM level in the waiting room (inset) (Hoboken, NJ).

River with a base of alternating 12-inch by 8-inch and 12-inch by 12-inch timbers laid atop the piling. Concrete footings reinforced with steel were poured on top of the timber base (NPS 2005b). The almost exclusive use of concrete in the construction of the terminal and its buildings was a fireproofing measure.

Severity of Flooding and Damage to Facility. The ferry operations section of the terminal complex suffered extensive flooding and damage, including damage to the ticketing area, locker rooms, electrical distribution equipment, transformers, and fire suppression equipment. Stormwater rose to approximately 11 feet NAVD88, which came to approximately 4 feet in the waiting area, exposing the wooden benches and the marble wainscot to saltwater intrusion (Figure 6-5 inset). Water remained in the building for over 24 hours. In the lower level of the building, some areas were inundated by 7 feet of water.

Damage to the train station section affected ticketing operations, vendor spaces, trainmaster offices, and fire suppression equipment. The engine house and wheel truing facility, electrical substations, boiler house, rail operations, and equipment were also damaged, as were some metal sheathing panels on the clock tower.

Recovery Actions. Because the wood pilings supporting the terminal complex may have been affected by hydrodynamic pressure and buoyancy, a structural assessment will be contracted by facilities management to ascertain the condition of the pilings.

6.3 Monmouth Boat Club (Red Bank, NJ)

Facility Description. The Monmouth Boat Club in Red Bank, NJ, is in Monmouth County and encompasses two conjoined buildings. The boat club falls under the governance of the New Jersey State Uniform Construction Code Act.

Constructed in 1895, the Monmouth Boat Club is the last surviving 19th-century building on the waterfront in Red Bank (NPS 1993). The original structure is a wood-frame building sheathed in hand-split cedar shingles in the Shingle style (Figure 6-6). A 1930 third-story addition exhibits more of a Colonial Revival style influence. The building is supported on five rows of pilings driven into the ground.

Of the two conjoined buildings, one is original to the site and one was moved to the site. The exterior is clad in unpainted cedar shingles with wood-frame double-hung windows and exterior doors. The heart pine strip flooring is nailed directly to the wood floor joists.

Severity of Flooding and Damage to Facility. The Monmouth Boat Club building (Figure 6-7) was inundated by storm surge and high tides, and the MAT observed HWMs at approximately 74 inches above the first floor. The building's heating and electrical systems, located below the BFE, were destroyed. In addition to flood damage to the building, the slate roof on the original building sustained minor wind damage. Some windows were damaged by either wind or wind-borne debris.

Recovery Actions. Repairs that the MAT observed to have been completed at the time of the site visit included replacement of the damaged finishes and elevation of electrical and heating equipment.

Figure 6-6:
Monmouth Boat Club's three tiers of porches overlooking the Navesink River; note exposed location on the water (Red Bank, NJ)

Figure 6-7:
Toilet room floor and subfloor had been removed prior to the MAT visit (indicated by red arrows); the river water (blue arrow) and foundation (yellow arrow) are visible below (Red Bank, NJ)

6.4 Ocean Grove Auditorium (Ocean Grove, NJ)

Facility Description. The Ocean Grove Auditorium is located in Ocean Grove, NJ, in Monmouth County three blocks west of the Atlantic Ocean and one block south of Wesley Lake. The auditorium falls under the governance of the New Jersey State Uniform Construction Code Act.

The Ocean Grove Auditorium was constructed in 1894 and is a contributing resource to the Ocean Grove Camp Meeting Association Historic District. The auditorium is a variant of the Ruskinian Gothic style (NPS 1975b). The design of the auditorium is notable for its application of 19th-century acoustical science and an innovative ventilation system that channels sea breezes through the floor and out the roof via circular ducts.

Severity of Flooding and Damage to Facility. Although the MAT observed no flood damage to the auditorium, they did observe notable wind damage. A reported 89 mph wind gust uplifted a 4,000-square-foot section of the auditorium's roof, which consisted of plywood sheathing underlayment, wood furring, and a stainless steel metal roof finish. The roof had recently been replaced in 2007. The removed roofing section composed approximately 20 percent of the entire roof. Emergency measures were taken to temporarily cover the roof to protect the interior of the auditorium. Photographs provided by the Ocean Grove Camp Meeting Association show that roof framing members, a few windows, and plywood decking were also damaged (Figure 6-8).

Recovery Actions. Repairs were underway at the time of the MAT visit, including re-roofing of damaged sections and hardening of the roof's structural members.

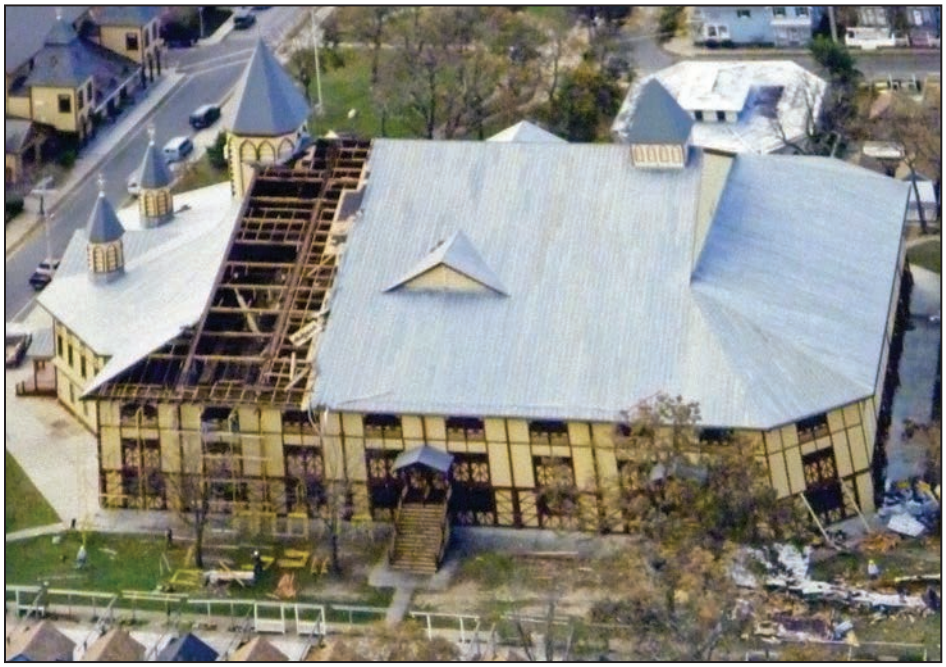


Figure 6-8: Aerial view of the wind-damaged and exposed roof of the Ocean Grove Auditorium (Ocean Grove, NJ)

SOURCE: OCEAN GROVE CAMP MEETING ASSOCIATION

6.5 Statue of Liberty National Monument (New York Harbor)

The Statue of Liberty National Monument includes Liberty Island, with the Statue of Liberty and Ellis Island, which are located in New York Harbor.

6.5.1 Ellis Island

Facility Description. Ellis Island is in New York Harbor close to Liberty State Park, NJ. Ellis Island consists of three islands, but is effectively one island because the areas between the islands have been filled in. Ellis Island is within the territorial jurisdiction of both New York State and New Jersey; the main building, which houses the Ellis Island Immigration Museum, is in New York State (NPS 2013a). There are 32 buildings on Ellis Island.

The 32 buildings were constructed of brick and stucco circa 1890 to 1930 and are distributed across Ellis Island. The buildings that date to the earlier phase of construction (late 19th to early 20th centuries) are masonry in the Beaux Arts style, and buildings dating to the last phase of construction (mid-1930s) are masonry structures in the Art Moderne style (New York City Landmarks Preservation Commission 1993). These facilities pre-date the NFIP, and many have their first floors below the BFE. Restoration and stabilization work has been ongoing since the National Park Service acquired the island in 1965.

Severity of Flooding and Damage to Facility. The storm brought water levels to approximately 11 feet at Ellis Island, destroying boilers and electrical systems below the flood level (Table 5 from NHC 2013b). The National Park Service closed Ellis Island in the aftermath of Hurricane Sandy. The main building of the Ellis Island Immigration Museum suffered significant damage to its infrastructure, mechanical systems, and fire suppression systems. There was also standing water in the basement of the building, where the concessioner's supplies are stored. Doors and windows in the Ferry Building were severely damaged, as were exhibits in the building (Figure 6-9).

Although the museum collection sustained little damage, maintaining a climate-controlled environment in the aftermath of the storm became extremely difficult because of the power loss. As a result, more than 1 million historical artifacts and documents from the Ellis Island Immigration Museum had to be relocated to storage facilities. Ellis Island was partially reopened to the public on October 28, 2013, but some buildings will remain closed until at least 2014.

6.5.2 Liberty Island

Facility Description. Liberty Island is in the New York Harbor opposite Liberty State Park, New Jersey (Figure 6-10). Once known as Bedloe's Island, Liberty Island was officially renamed in 1956. The island, along with the rest of the monument, is owned by the Federal Government and under the administration of the National Park Service.

Construction of the statue was completed in France in 1884, and the statue was shipped to the United States for reassembly and installation (NPS 1980). The statue was designated as a National Monument in 1924. Fort Wood on Liberty Island was chosen as the site for the statue because of its prominent harbor location and robust construction. Built in 1811, Fort Wood is an 11-point-star shaped fort with 24-foot-high, 30-foot-thick stone walls. The statue underwent restoration work from

Figure 6-9: Ferry Building on Ellis Island with boarded-up front doors because of damage from the hurricane (New York Harbor)

Figure 6-10: Aerial photograph showing key facilities on Liberty Island (New York Harbor)
SOURCE: GOOGLE EARTH

1984 to 1986. During the renovation, iron structural elements were replaced with steel, and a new torch was constructed (NPS 2013b).

Severity of Flooding and Damage to Facility. The Statue of Liberty itself did not receive any damage from the storm. The statue's 126-year-old, sturdy iron framework allowed it to withstand the storm's winds. However, when Hurricane Sandy hit, Liberty Island was overwhelmed with stormwater that reached approximately 11 feet. Several ancillary buildings on the north end of Liberty Island were destroyed, including storage garages, staff offices, the park police barracks, and the superintendent's house. All of the island's utilities, backup generator, and power systems were destroyed by water that was more than 5 feet deep in some parts of the 12-acre area. Additionally, the island's passenger and auxiliary docks were severely damaged.

Moderate damage was observed in all areas of a brick promenade that was built for foot traffic around Liberty Island and extends east, south, and west of the statue; large areas of paving were washed out. Stone copings and ornamental steel guardrails associated with a low stone wall that follows the edge of the island suffered moderate damage because of their exposure to the elements. Below-grade electrical floodlighting for the statue, installed in 1986, was inundated and damaged beyond repair (Figure 6-11). Liberty Island was reopened to the public on July 4, 2013.

Figure 6-11: Temporary lighting at the Statue of Liberty, installed because of damage to below-grade fixtures (New York Harbor)

6.6 Jacob Riis Park (Queens, NY)

Facility Description. Jacob Riis Park Historic District is on the Rockaway Peninsula in Queens, NY, on Jamaica Bay (Figure 6-12). The historic district comprises three main buildings: a bathing pavilion, two central mall buildings, and several miscellaneous buildings (e.g., the First Aid building). The park is part of the Gateway National Recreation Area and is under the care of the National Park Service. Although it is located in a borough of New York City, the park is a federally owned property and subject to Federal codes and regulations.

Figure 6-12: Jacob Riis Park (Queens, NY)
SOURCE: GOOGLE EARTH

Jacob Riis Park was constructed between 1932 and 1937 (NPS 1975a), which pre-dates the NFIP. These buildings were constructed of unreinforced masonry block with a brick façade. The bathing pavilion (i.e., bathhouse) is an Art Deco masonry structure that includes bathing facilities, concessions, and refreshment bars on the first floor and a sun deck and chair rental on the second floor (Figure 6-13). The eastern-central mall building houses a cafeteria, and the western building houses offices, restrooms, and a small bathhouse. Renovation on the buildings began in the 1990s, but was never completed because of lack of funding (Foderaro 2012).

Severity of Flooding and Damage to Facility. Water rose to approximately 11 feet in the historic district of Jacob Riis Park during the storm (Table 5 of NHC 2013b). The hydrostatic and hydrologic forces generated by combined effects of the inundation, repeat wave action, and sand deposition affected shoreline park buildings, building systems, roads, boardwalks, parking lots, fences, walls, and benches, causing significant structural damage because the buildings were sited so close to the coastline. Utilities were located on the first floor of the bathhouse and were destroyed, and flood forces were strong enough to demolish sections of unreinforced masonry and brick walls (Figures 6-14 and 6-15). Additionally, wide swaths of the park's beach were severely eroded from the storm surge.

Figure 6-13:
Jacob Riis bathhouse (Queens, NY)

Figure 6-14:
Flood forces destroyed masonry and brick walls; utilities located below the BFE were inundated (Queens, NY)

The combination of inundation and wave action resulted in extensive damage to lower-level openings, both windows and doors, and also caused extensive damage to the interior of the building and its contents (Figure 6-16). The Police and First Aid buildings, also located in the historic district, sustained similar damage (Figure 6-17). Sand blanketed acres of Riis Park, and waves toppled part of a brick garden wall behind the historic Art Deco bathhouse.

Figure 6-15:
Cross-section of a damaged exterior wall (Queens, NY)

Figure 6-16: Windows, walls, and doors on the Jacob Riis bathhouse destroyed by storm surge and wave action; the original windows were replaced in the 1990s during a restoration project (Queens, NY)

Figure 6-17:
Solid brick walls at the Jacob Riis First Aid building destroyed by storm surge and wave action (Queens, NY)

6.7 South Street Seaport Historic District (Manhattan, NY)

Facility Description. The South Street Seaport Historic District is located along the eastern waterfront of the East River in Manhattan, NY, and includes portions of Beekman Street, Dover Street, Front Street, Fulton Street, John Street, Pearl Street, Peck Slip, South Street, and Water Street (Figure 6-18). The historic district is under the jurisdiction of New York City and subject to the City's building codes and regulations.

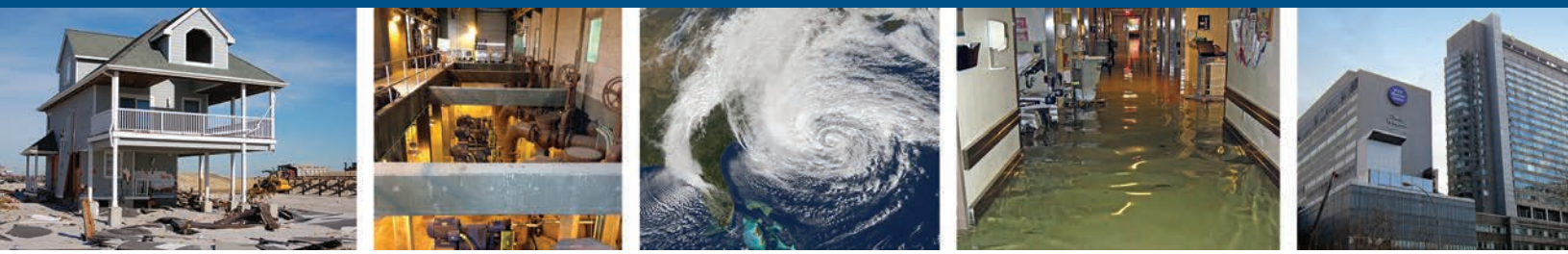
Although the buildings in the district span a construction period of almost 200 years, the majority of structures date to the first half of the 19th century and pre-date the NFIP. The buildings comprise a mix of commercial and residential structures and encompass a variety of architectural styles indicative of the early commercial development of New York City (New York City Landmarks Preservation Commission 1977). The buildings are primarily constructed with brick or brownstone and have basements and first floors below the BFE; therefore, many of the MEP systems for these buildings were below the BFE. Many of the historic properties in this section of Lower Manhattan have been converted to retail shops, restaurants, and offices.

Severity of Flooding and Damage to Facility. Located in Zone AE along the East River at the southern tip of Manhattan Island, some areas of the South Street Seaport Historic District received 5 to 8 feet of flooding as stormwater reached approximately 11 feet (Table 5 of NHC 2013b). At the historic waterfront along the banks of the East River, seven historic ships at the South Street Seaport Museum rode out the storm without damage. Farther inland, commercial tenants who remained during the storm observed a "river of water" rising and flowing through the streets. First floor and

Figure 6-18: Map of the sites visited in the South Street Seaport Historic District in Manhattan, NY

basement flooding was widespread. At the South Street Seaport Museum, water surged to 6 feet at the lobby entrance, destroying the building's electrical systems, cafe, and gift shop. A HWM above 6 feet was observed at a building addressed as 24 Peck Slip, which is approximately one block inland from the waterfront. As is evident throughout affected areas of Lower Manhattan, first floor and basement flooding was the most typical cause of damage. For example, a HWM was visible on a brick wall inside Meade's Restaurant at 22 Peck Slip (Figure 6-19). Repairs at the South Street Seaport Museum were underway at the time of the MAT visit.

Figure 6-19:
HWM (red dashed line) identified in Meade's Restaurant in the South Street Seaport Historic District (Manhattan, NY)



HURRICANE SANDY IN NEW JERSEY AND NEW YORK

7 Conclusions and Recommendations

This chapter presents the MAT's conclusions and recommendations related to their observations of various buildings in the aftermath of Hurricane Sandy.

In contrast to Chapters 2 through 6, the conclusions and recommendations are organized by function rather than structure type. As such, this chapter starts by providing general conclusions and recommendations that are applicable to all facility types, followed by recommendations related to codes and standards, and lastly, building functional aspects: siting, structural, building systems and continuity of operations. Continuity of operations is organized by facility type. The last section provides conclusions and recommendations specific to historic structures.

7.1 Summary of Building Performance

According to preliminary analyses, 53 percent of the areas flooded by Hurricane Sandy in New York City had water levels that exceeded the BFEs (New York City 2013b). Flood effects extended beyond

the inland extent of the mapped SFHAs in most communities the MAT visited, and many buildings both inside and outside the SFHAs were heavily damaged or destroyed by floodwater. In contrast, there was minimal wind damage from Hurricane Sandy. Although Hurricane Sandy's pressure at landfall was typical of a Category 3 hurricane, the observed wind speed was on the lower end of Category 1 hurricane intensity, per the Saffir-Simpson Hurricane Wind Scale.[1]

In New Jersey, the storm surge inundated barrier islands, forced its way into back bay areas, and drove sea water up into Newark Bay, the Passaic and Hackensack Rivers, Kill Van Kull, and Arthur Kill (NHC 2013b).

Areas in New York State experienced higher than expected storm surge that pushed up the Hudson River and caused flooding as far north as Albany. In New York City, a storm tide (the combination of the storm surge and astronomical tide) of over 14 feet above the Mean Lower Low Water was measured at the Battery Park, breaking the previous record of 10 feet that was set when Hurricane Donna hit New York in 1960 (New York City 2013b). In Queens and Brooklyn, the area flooded by Sandy was almost twice as large as the floodplain area on FEMA's Effective FIRMs. Long Island flooded 3 to 6 feet above ground level along the Atlantic Coast, with a HWM of 4.6 feet above ground level recorded at Freeport and a storm surge elevation of 5.6 feet above normal tide levels recorded by a gauge in Montauk (NHC 2013b). See Appendix D for examples of inundation levels observed in New Jersey and New York.

Inundation of building systems was the most prevalent form of building damage from Hurricane Sandy. This damage was observed primarily in buildings with unprotected systems located below the Sandy flood levels, especially in subgrade enclosures. Floodwater rendered building systems inoperable, which slowed recovery considerably. Other types of damage varied by building type.

Low-Rise Buildings. Inundation of basements in low-rise buildings caused system damage as well as isolated basement wall failures in some buildings. Recently constructed low-rise buildings generally suffered less flood damage because they complied with modern building codes and floodplain ordinances. The MAT observed both new and older construction that lacked adequate load path connections to resist simultaneous uplift from flood sources and lateral forces from wind.

Mid- and High-Rise Buildings. The majority of mid- and high-rise buildings suffered no structural damage from floodwater inundation. When equipment was located on the upper floors of the structure, building systems incurred no damage.

BUILDING SYSTEMS

Building systems include components such as the MEP systems, gas installations, communications systems, and fire suppression systems.

Healthcare Facilities. Healthcare facilities were mainly affected by disrupted functionality of building systems, including emergency power systems with components located below grade. Interruption of elevator service limited the ability to transport patients between floors, while loss of communications undermined the ability to coordinate transportation to and from the facilities.

1 http://www.nhc.noaa.gov/aboutsshws.php.

Other Critical Facilities. Damage to first responder facilities and schools was primarily to building systems and not structural. Facilities outside the areas flooded by Sandy or that had equipment elevated above flood levels were successful at maintaining continuity of operations after Sandy.

Damage to other facilities visited by the MAT (data centers, WWTPs, transportation facilities, and gas stations) was commensurate with that of similar building types. Damage to building systems was the primary effect of the flooding:

- Both data centers the MAT visited were in high-rise buildings with building systems located in basements. Failure of the building systems caused significant disruption to service.

- WWTPs were shut down when building systems and emergency power equipment located in subgrade areas and tunnels below the plants were flooded and damaged. WWTPs were closed for days to weeks while the facilities were drained and building systems were cleaned, repaired, or replaced.

- Transportation facilities, mainly transit facilities, most were below ground, and were inundated by floodwater and had varying degrees of damage to facility building systems. Facilities with emergency power systems located above flood elevations were operable shortly after the event, but those with flood-damaged systems required extensive repairs before they were operational again.

Historic Structures. Damage to historic structures was largely a function of their location and whether or not the buildings had subgrade or basement areas. Damage to historic structures was similar to that observed for other building types. Isolated wind damage was observed in historic buildings.

7.2 General Conclusions and Recommendations

Conclusion 1. Vulnerability Assessment: The quality of planning and preparedness for Hurricane Sandy at the many buildings visited by the MAT varied greatly. This variance of planning may have been due to the information sources used to identify the risks, as well as local government recommendations about whether to close the facilities during the flood event. Many building managers and owners may not have been aware of their risks from a severe flood event.

> ***Recommendation 1a. Perform vulnerability assessments:*** Facility owners should have vulnerability assessments conducted by a team of knowledgeable professionals to help determine options available to mitigate hazards and risks for high-rise and mid-rise buildings, critical facilities and key assets, and other structures that may be heavily impacted by a flooding event. Facility owners and operators should work with key internal staff and design professionals to analyze their facilities, key systems and components, operational assumptions, and operations plans to determine a path forward for developing project priorities and funding capital improvements that maximize facility and operational resiliency. See Hurricane Sandy Recovery Advisory No. 5, *Designing for Flood Levels Above the BFE After Hurricane Sandy* (FEMA 2013e) for selecting the appropriate flood elevation for design.

Recommendation 1b. Perform vulnerability assessments for all critical facilities: The vulnerability assessments conducted for facility owners and operators (Federal, State, and local governments and the private sector) should identify all critical and essential facilities that are subject to flooding and recommend mitigation goals that address current building code compliance, local floodplain ordinances, preparedness and mitigation, continuity of operation, and measures to minimize damage and recovery efforts. Further guidance can be found in FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds* (FEMA 2007b) and FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and Winds* (FEMA 2007c).

7.3 Codes and Standards

This section presents conclusions and recommendations based on the MAT review of floodplain management and building code programs and regulations in the State of New Jersey, New York State, and New York City that are summarized in Appendix G. It also presents conclusions and recommendations based on the MAT review of guidelines and a standard pertaining to healthcare facilities, which are summarized in Appendix F, Section F.5.

7.3.1 New Jersey

Conclusion 2. Flood Hazard Area Control Act: In January 2013, the NJDEP issued emergency amendments and concurrent proposed amendments to the Flood Hazard Area Control Act Rules. The emergency rules were adopted in May 2013 without change. The rules contain a number of requirements specific to the design and construction of buildings that are inconsistent with minimum requirements of the NFIP and inconsistent with the flood provisions of the New Jersey UCC. For background, see Appendix G, Section G.1.1.

Recommendation 2. NJDEP, NJDCA, and FEMA should coordinate review: The NJDEP, in coordination with the NJDCA and FEMA, should review the Flood Hazard Area Control Act rules that apply specifically to buildings and other structures to identify and resolve inconsistencies, except those where the NJDEP is intentionally requiring a higher standard than required by the UCC and NFIP. Instead of establishing requirements for buildings and other structures, the NJDEP rules should refer to the requirements of the UCC.

Conclusion 3. Model Flood Damage Prevention Ordinance: The NJDEP Community Assistance Program Unit provides a model flood damage prevention ordinance that contains complete requirements for regulating development in flood hazard areas, including requirements that are, for the most part, duplicative with the flood provisions of the UCC. Local officials in New Jersey and the regulated public are expected to resolve the differences between three sets of rules: the Flood Hazard Area Control Act rules, the flood provisions of the UCC, and locally adopted flood damage prevention ordinances. For background, see Appendix G, Section G.1.1.

Recommendation 3. NJDEP should evaluate FEMA model floodplain management ordinance: The NJDEP should evaluate the model floodplain management ordinance that is being developed by FEMA that is specifically written to coordinate with building codes and

consider its merits related to reducing duplicative and potentially conflicting requirements. Adopting a coordinated ordinance will enhance local enforcement.

Conclusion 4. Code Officials and Continuing Education: Code officials and inspectors are required to be licensed and to maintain qualifications through continuing education. Having flood provisions incorporated into the UCC generates a need for training that specifically addresses those provisions. For background, see Appendix G, Sections G.1.1 and G.1.2.

Recommendation 4. Develop training on flood provisions of New Jersey building code: The NJDCA and NJDEP, in cooperation with FEMA, should develop one or more courses specifically addressing the flood provisions of the NJDEP rules and the UCC. The training should include inspection of SFHA development, with particular attention to the Substantial Improvement and Substantial Damage requirements and how the local floodplain administrator and code enforcement officers work together to fulfill these requirements. This recommendation is similar to one put forth by the Passaic River Basin Flood Advisory Commission's 2011 report to the Governor. Excerpts of the flood provisions of the UCC should be prepared and made available to local floodplain administrators and local code officials.

Conclusion 5. State Review of Buildings in Flood Hazard Areas: The NJDCA performs plan reviews for State-owned buildings and many other buildings, including certain healthcare facilities and public school facilities. Although communities use the "prior approval" process (see Chapter 2, Section 2.1.5 of this report) to coordinate specification of the flood elevation to be enforced in the building code as well as Substantial Damage and Substantial Improvement determinations, NJDCA does not have an equivalent relationship with the NJDEP. For background, see Appendix G, Section G.1.2.

Recommendation 5. Establish formal consultation process: The NJDCA and NJDEP should establish a formal consultation process for identifying flood elevations and flood zones and for making Substantial Damage and Substantial Improvement determinations so that buildings in SFHAs for which the NJDCA performs plan reviews will meet the flood-resistant requirements of the UCC and the NFIP.

Conclusion 6. Building Code Amendments to the New Jersey UCC: The MAT review of the flood provisions of the New Jersey UCC identified a number of opportunities to improve consistency with the NFIP, while also increasing resiliency of construction in flood hazard areas. For background, see Appendix G, Section G.1.3.

Recommendation 6. Amend the UCC: FEMA recommends that the NJDCA amend the UCC to:

- Explicitly link the rehabilitation subcode to the prior approval process under which local floodplain administrators make Substantial Damage and Substantial Improvement determinations

- Specifically refer to local floodplain management regulations where FISs and FIRMs are adopted

- ■+ Modify UCC Section R322.3 (coastal high hazard area) to refer to ASCE 24, *Flood Resistant Design and Construction*

7.3.2 New York State

Conclusion 7. Model Local Law for Flood Damage Prevention: The NYSDEC Floodplain Management Section provides a model local law for flood damage prevention that contains complete requirements for regulating development in flood hazard areas, although some requirements use language that differs from the flood provisions in the New York State Uniform Code. Local officials in New York and the regulated public are expected to resolve the differences between the local laws and the flood provisions of the building code. For background, see Appendix G, Section G.2.1.

> ***Recommendation 7. NYSDEC should evaluate FEMA model floodplain management ordinance:*** The NYSDEC should evaluate the model floodplain management ordinance that is being developed by FEMA that is specifically written to coordinate with building codes and consider its merits related to reducing duplicative and potentially conflicting requirements. Adopting a coordinated ordinance will enhance local enforcement.

Conclusion 8. Model Local Law for Administration of the Building Codes: The New York State Uniform Code does not include the administrative chapters of the model I-Codes. The Division of Code Enforcement and Administration (DCEA) promulgates rules for administration and enforcement that are used by all entities that enforce the code. DCEA provides a model local law with provisions for administration of the codes. Currently, neither the rules nor the model local law include administrative provisions for flood hazard areas. For background, see Appendix G, Section G.2.2.

> ***Recommendation 8. Develop optional provisions for model local law:*** The DCEA should, in coordination with NYSDEC, develop optional provisions based on the flood provisions of the I-Codes for inclusion in the model local law for administration and enforcement to facilitate compliance and enforcement of the flood provisions.

Conclusion 9. Site Requirements of the New York State Hospital Code: Hospitals in New York State were heavily damaged by flooding. Some facilities remained inoperative months after the event. Section 711.3, *Site Requirements*, of the New York State Hospital Code authorizes the State Health Commissioner to require specific additional flood-resistant provisions when healthcare facilities are considered for construction in flood hazard areas. Although not specifically stated, those provisions could allow hospitals to continue to function during and after a design flood event. However, the regulations only allow, but do not require, the State Health Commissioner to require the additional specific flood provisions. For background, see Chapter 2, Section 2.4 of this report.

> ***Recommendation 9. Modify the hospital code to make flood provisions mandatory:*** Revise Section 711.3, Site Requirements, of the New York State Hospital Code so that the additional specific flood provisions contained in Section 711.3 are mandatory for all hospitals located in flood hazard areas except those explicitly exempted by the State Health Commissioner.

Conclusion 10. Code Officials and Continuing Education: Local code enforcement officials are required to complete basic training requirements and complete 24 continuing education credits

each year. Having flood provisions incorporated into the State building code generates a need for training for code officials that specifically addresses those provisions. For background, see Appendix G, Section G.2.2.

> ***Recommendation 10. Develop training on flood provisions of New York building code:*** The DCEA and NYSDEC, in cooperation with FEMA, should develop one or more courses specifically addressing the flood provisions of the State building code and inspection of SFHA development. Excerpts of the flood provisions of the building code should be prepared and made available to local floodplain administrators and local code enforcement officials.

Conclusion 11. Technical Bulletin on "Flood Venting": The DCEA 2003 technical bulletin on "flood venting" is out of date and inconsistent with FEMA's guidance in the 2008 edition of FEMA NFIP Technical Bulletin 1, *Openings in Foundation Walls and Walls of Enclosures,* and inconsistent with ASCE 24. For background, see Appendix G, Section G.2.2.

> ***Recommendation 11. Update DCEA technical bulletin on flood venting:*** The DCEA and NYSDEC should determine whether FEMA's guidance is adequate. If New York-specific guidance is necessary, the DCEA should update its technical bulletin on flood venting.

Conclusion 12. Building Code Amendments to the New York State Uniform Code: The MAT review of the flood provisions of the New York State Uniform Code identified a number of opportunities to improve consistency with the NFIP, while also increasing resiliency of construction in flood hazard areas. For background, see Appendix G, Section G.2.3.

> ***Recommendation 12. Amend New York State code:*** The DCEA should consider code amendments to:
>
> - + Modify the building code to require Risk Category II buildings (primarily non-residential buildings) to be elevated or protected to or above the BFE plus 2 feet (equivalent to on New York State amendment to residential code)
> - + Specifically refer to local laws for flood damage prevention where FISs and FIRMs are specifically adopted by title and date
> - + Modify R324.3 (coastal high hazard area) to refer to ASCE 24
> - + Restore the I-Code language for historic buildings in flood hazard areas to ensure they are treated as required by the NFIP

7.3.3 New York City

Conclusion 13. Building Code Amendments to the New York City Building Code: The MAT review of the flood provisions of the New York City Building Code, including amendments proposed in bill Int. No. 1056 that was pending before City Council in July 2013, identified a number of opportunities to improve consistency with the NFIP, clarity, and enforceability. For background, see Appendix G, Section G.3.1.

Recommendation 13. Modify proposed New York City code amendments: The NYC DOB should modify the proposed code amendments to:

- Improve consistency with the NFIP requirements for enclosed areas below elevated buildings
- Restore the ASCE 24 definitions for "residential" and "nonresidential," or clarify the New York City definitions to be consistent with FEMA guidance specifically for institutional facilities where people are cared for or live on a 24-hour basis in a supervised environment

Conclusion 14. Substantial Damage and Substantial Improvement Determinations: The NFIP expects communities to determine whether alterations, additions, repairs, and other improvements meet the definitions for Substantial Damage and Substantial Improvement (the same definitions are in the building code). For existing buildings in SFHAs, New York City requires applicants to provide documentation of costs and market value and to state whether the work is or is not Substantial Improvement. For background, see Appendix G, Section G.3.1.

Recommendation 14. The DOB should establish protocol to verify data: Guidance in FEMA P-758, *Substantial Improvement/Substantial Damage Desk Reference* (FEMA 2008e), recommends that communities carefully evaluate submitted data when the comparison of costs to market values yields a ratio that is close to 50 percent. The DOB should establish a protocol so that applicant-submitted data and statements are verified when the indicated ratio is between 40 and 50 percent.

Conclusion 15. Inspection of Construction in Flood Hazard Areas: With more than 80,000 buildings affected by Hurricane Sandy, the DOB's resources for inspection of issued permits may be strained. The building code has provisions for special inspections to be conducted by special inspectors and special inspection agencies. For background, see Appendix G, Section G.3.2.

Recommendation 15. Establish mechanism for special inspections: Given the number of buildings damaged by Hurricane Sandy and the extent of SFHAs in all five boroughs, the DOB should establish a mechanism to supplement inspections with a "flood zone compliance special inspection" to be conducted and certified by special inspectors or special inspection agencies, as proposed in pending legislation.

Conclusion 16. Dry-Floodproofed Buildings: Buildings that are designed to be dry floodproofed, with measures that require action by building managers or occupants in order to function as intended, are not protected if those actions are not carried out properly. New York City Building Code, Appendix G, Section G105.4 requires a "flood shield inspection" during construction. For background, see Appendix G, Section G.3.1 of this report.

Recommendation 16. Amend Appendix G of New York City Building Code: The DOB should consider amending Appendix G of the New York City Building Code to require owners of buildings that rely on human intervention to implement dry floodproofing measures to submit periodic inspection reports (e.g., every 3 years) to document:

- Installation and maintenance of flood shields or flood control devices

- + Posting of the emergency plan required by ASCE 24, Section 6.2.3
- + Performance of periodic practice of shield installation
- + That other permit requirements are satisfied

Conclusion 17. New York City School Construction Authority Design Standards: The New York City School Construction Authority Design Standards that are used for planning, design, and construction of public schools contain narrative descriptions of building code requirements that are not consistent with the New York City Building Code Appendix G and the requirements of the NFIP. In addition, the description of work that triggers compliance is described as only applying to repairs for which the cost is "more than 50% of the cost of replacement of the building." For background, see Appendix G, Section G.3.1 of this report.

Recommendation 17. Revise New York City School Construction Authority Design Standards: The New York City School Construction Authority should revise the narrative in Design Requirements 1.3.1.11 to be consistent with the New York City Building Code Appendix G. The description of work for which compliance is required should be expanded to include improvements and additions, and should be consistent with the building code definitions for market value, Substantial Damage, and Substantial Improvement.

7.3.4 Healthcare Facility-Specific Standards

Conclusion 18. NFPA 99: NFPA 99, *Standard for Health Care Facilities,* contains flood provisions for protecting emergency power systems and communication systems. However, NFPA 99 is only referenced in IBC Section 407.10 "Hyperbaric Facilities." For background, see Appendix F, Section F.5.2.

Recommendation 18. Revise IBC to reference NFPA: Revise the IBC to reference NFPA 99 for other portions of hospitals that serve or support critical functions.

Conclusion 19. NFPA 99 and ASCE 24 Consistency: The flood provisions of NFPA 99 are not consistent with ASCE 24, and ASCE 24 is not listed in NFPA 99 Chapter 2, "Referenced Publications." For background, see Appendix F, Section F.5.2.

Recommendation 19. Revise NFPA to reference ASCE 24: Revise NFPA 99 to include ASCE 24 as a referenced publication and revise the flood criteria to be consistent with or more restrictive than ASCE 24.

Conclusion 20. Facility Guidelines Institute: Floodwaters damaged several healthcare facilities in New Jersey and New York. Some facilities remained inoperative months after the event. The FGI Guidelines (FGI 2010) are referenced by both New Jersey and New York as a requirement for hospitals. The FGI Guidelines contain numerous references to flood risk but most of the flood references are qualitative and non-enforceable. Section 1.1 – 4.3, "Flood Protection," references Executive Order 11988, *Floodplain Management,* but lacks specific language that describes how and when Federal agencies apply the Executive Order to healthcare facilities. Section 1.1 – 4.3, "Flood

Protection" and Section 1.1 – 5.5, "Referenced Codes and Standards" both lack reference to ASCE 24. For background, see Appendix F, Section F.5.1.

> ***Recommendation 20. Revise FGI to reference ASCE 24:*** The FGI should revise Section 1.1 – 4.3, "Flood Protection" and Section 1.1 – 5.5, "Referenced Codes and Standards" of the FGI Guidelines to reference the most recent edition of ASCE 24 and properly characterize the role of Executive Order 11988.

Conclusion 21. Building System Damage and FGI: Floodwaters damaged utilities and interrupted services (such as power, steam, and water) to several hospitals. The interruption of these utilities prevented the hospitals from functioning.

Requirements for utilities and systems are contained in Section A1.2 – 6.5, "Provisions for Disasters" in the FGI Guidelines. Those guidelines state that special design is required for facilities that "must remain operational in the aftermath of a disaster." Essential services are defined as: "power, water, medical gas systems, and, in certain areas, air conditioning." The guidelines further state that special consideration "be given to the likelihood of temporary loss of externally supplied services like power, gas, water, and communications." The guidelines do not list criteria for determining which facilities must remain operational or what systems and utilities are needed for functionality. For background, see Appendix F, Section F.5.1.

> ***Recommendation 21. Revise FGI to provide specific guidance:*** The FGI should revise the FGI Guidelines to provide specific guidance on determining which facilities must remain operational in the aftermath of a disaster and what services must be provided by those facilities. The MAT acknowledges that many factors need to go into such a determination, including proximity to other hospitals, services provided by the hospital, size of the facility, presence (or absence) of redundant utilities supplying the facility, and the reliability of utilities serving the facility.

7.3.5 FEMA

Conclusion 22. International Code Series Amendments: FEMA participates in the triennial code development process to propose changes to the codes based on experience gained through post-flood investigations that are documented in MAT reports. The nature of damage observed after Hurricane Sandy and documented in this MAT report, combined with similar observations after other flood disasters, reinforces the benefits that can be gained by additional changes to the I-Codes.

> ***Recommendation 22. Propose changes to I-Codes:*** FEMA should propose changes to the I-Codes:
>
> ***IRC:***
>
> - +Incorporate additional height (freeboard) of 1 foot above BFE for dwellings in all flood hazard areas.
>
> - +Require Coastal A Zones, where a LiMWA is delineated on a FIRM or if otherwise designated by a community, to be regulated using the same requirements for Zone V, with

an exception for filled stemwall foundations that that are designed to account for wave action, debris impact, erosion, and local scour.

- ■+ Include specific requirements for underground and above-ground tanks.
- ■+ Clarify that in Zone V, where stairs are enclosed by walls designed to break away under flood loads, a door that meets the requirements for exterior doors is installed at the top of the stairs.
- ■+ Remove prescriptive provisions allowing unreinforced masonry foundation walls for new construction in Zone A.

IBC:

- ■+ Add a definition of Coastal A Zone to clarify such areas are present if the LiMWA is delineated on a FIRM or if otherwise designated by a community. This change would achieve consistency with the next edition of ASCE 24.

7.4 Siting

Several of the waterfront communities affected by Hurricane Sandy are more than 100 years old. Shoreline erosion has been ongoing during this time, and many shoreline protection structures (e.g., seawalls, bulkheads, revetments) have been built to combat erosion. In other cases, land was created by filling former marsh or shallow water areas and stabilized with erosion control structures. As a result, many low-rise buildings in these communities are situated within 10 to 20 feet of an erosion control structure.

Long-term changes, such as sea level rise, can magnify the risks faced by waterfront communities. Existing FEMA guidance, such as FEMA P-55, *Coastal Construction Manual* (2011a), and Hurricane Sandy Recovery Advisory 5, *Designing for Flood Levels Above the BFE After Hurricane Sandy* (FEMA 2013e), address some mitigation options and consideration for future sea level rise. However, FEMA's FIRMs and other mapping products depict only today's flood risk. Addressing flood risk based on current conditions does not account for the increased flood risk that may result from sea level rise.

Conclusion 23. Siting of Buildings Relative to Erosion Control Structures: The effectiveness of erosion control structures (e.g., bulkheads, seawalls, revetments) varied widely during Hurricane Sandy, depending on the height, age, construction, and condition of the structure; the beach/shoreline condition seaward of the structure; and the proximity of an upland building to the erosion control structure. Many erosion control structures failed and subjected nearby buildings to undermining and flood damage. Other erosion control structures remained intact but were overtopped by storm waves and/or surge, and many buildings near the overtopped structures sustained flood damage. In a few instances, the erosion control structures remained intact and were high enough or strong enough to prevent or reduce landward erosion and flood damage.

FEMA's guidance for mapping flood hazards landward of erosion control structures (e.g., area of wave overtopping [splash zone], Zone VE) is based, in large part, on studies and analytical tools

dating to the 1980s. No systematic review of these mapping procedures has been undertaken. The existing mapping guidance would benefit from a review of data and photographs documenting Hurricane Sandy building damage landward of these structures. Also, newer simulation techniques may be useful in evaluating the existing guidance and developing new guidance.

Recommendation 23a. Document performance of erosion control structures: FEMA should document the successes and failures of erosion control structures (e.g., bulkheads, seawalls, revetments) and damages to buildings situated landward of these structures. Use this information to develop educational materials related to building siting and design near erosion control structures.

Recommendation 23b. Review mapping procedures: FEMA should review the mapping procedures used to identify flood hazards (including Zone VE splash zones) landward of erosion control structures, such as bulkheads, seawalls, and revetments, and revise the procedures where Hurricane Sandy data and application of new simulation techniques indicate better guidance can be developed.

Recommendation 23c. Conduct detailed evaluation of damage behind erosion control structures: FEMA should conduct a detailed evaluation of building damage behind erosion control structures. This would allow FEMA to validate or revise its Zone VE overtopping splash zone criteria contained in the *Atlantic Ocean and Gulf of Mexico Coastal Mapping Guidelines Update* (FEMA 2007d).

Conclusion 24. Protection Afforded by Beaches and Dunes: Low and narrow beaches and dunes were completely eroded in many areas, and buildings and infrastructure landward of the dunes were subject to damaging wave action and/or high-velocity flow. By comparison, the MAT observed that the presence of wide beaches and tall, wide dune fields reduced damage to buildings and infrastructure situated landward of the dunes. Cuts across or through dunes (e.g., for pedestrian access) appeared to have provided pathways for high-velocity flow in some cases. FEMA flood mapping regulations have recognized this general fact since the mid-1980s, and use a particular criterion to predict dune loss during base flood events (< 540 square feet of dune cross-section above 100-year stillwater level and seaward of dune peak).

Recommendation 24a. Review dune loss criterion: FEMA should review the 540-square-foot criterion used in coastal FISs to predict base flood dune loss, and should validate or revise this criterion based on data collected during Sandy and other recent storm events.

Recommendation 24b. Develop siting and design guidance for Sandy-affected coastal areas: FEMA should review available data and any forthcoming studies of dune loss or breaching, or overwash and high-velocity flow across coastal landforms. Using information from these studies, FEMA should develop specific siting and design guidance for coastal areas affected by Hurricane Sandy. The effects of pedestrian and vehicular access paths on dune breaching should be included in the review. Guidance for dune walkovers and beach access structures should be distributed by New Jersey and New York and their communities.

Recommendation 24c. Identify barrier islands with history of breaching: States and communities should identify those barrier islands and barrier spit areas with a history of

breaching or high velocity flow during Sandy or other severe coastal storms. This information should be distributed to designers and others involved in planning, siting, and designing coastal buildings and infrastructure.

7.5 Structural

Although Hurricane Sandy did not result in widespread damage to building foundation and below-grade areas, flooding events similar to Hurricane Sandy have done so. Damage to foundations can result in cascading damage to buildings and infrastructure. Hurricane Sandy affected a very dense, urban population, and these communities face unique challenges as they rebuild. The following section presents conclusions and recommendations based on the MAT's observations and review of structural issues encountered in New Jersey, New York, and New York City areas visited by the MAT.

Conclusion 25. Effect of Foundation on Building Survival: One- and two-family houses and other low-rise buildings on foundations elevated above Sandy's flood level performed well. Many undermined, shallow building foundations collapsed while deep foundations typically survived. Few older structures (some as old as 100 years) along the New Jersey and New York coast were constructed to accommodate scour and erosion and the MAT observed many of these structures collapsed. Those that survived had very robust foundations or deep pile foundations, but these significant foundations are not common.

Recommendation 25a. Reference FEMA guidance regarding foundations for new construction: Design professionals and builders should consult FEMA guidance, such as FEMA P-55, *Coastal Construction Manual* (2011) and FEMA P-550, *Recommended Residential Construction for Coastal Areas: Building on Strong and Safe Foundations* (2009), to specify foundations for new one-and two-family houses and other new low-rise buildings in coastal areas. The information in FEMA P-55 on determining site-specific loads will help design professionals develop foundations that are sufficiently deep to withstand flood loads despite scour and erosion and will also help designers determine the appropriate elevation for a building located in an area subject to flooding.

Recommendation 25b. Elevate existing low-rise buildings where possible: Local communities should ensure that existing low-rise buildings are elevated where possible and the foundations are replaced where needed. Although numerous buildings were determined to have incurred Substantial Damage or were destroyed, many buildings sustained only minor structural damage. Even those buildings that do not meet the Substantial Damage threshold should be mitigated. At a minimum, these buildings should be brought to the current codes and standards for new construction adopted by the community. Where possible, a design professional may be able to assess an existing foundation and provide a design capable of withstanding future flood loads. The Hurricane Sandy Recovery Advisory No. 5, *Designing for Flood Levels Above the BFE After Hurricane Sandy* (FEMA 2013e), provides guidance to help design professionals and homeowners understand NFIP and building code requirements and how design and construction practices can minimize damage to buildings.

Recommendation 25c. Fill below-grade areas of buildings in the SFHA: Below-grade garages or basements are common in older construction in New Jersey and New York. For residences

in the SFHA, owners should consider filling these below-grade areas and installing flood openings in any remaining enclosure that is at or above grade, but below the lowest floor. Communities, States, and FEMA should help educate owners on the benefits of these measures that can reduce damage to equipment and reduce flood insurance premiums. Information provided to communities should discourage the improper use of space below the BFE. Additionally, the Hurricane Sandy Recovery Fact Sheet No. 2, *Foundation Requirements and Recommendations for Elevated Homes* (FEMA 2013e), describes options for elevating houses on small lots where deep foundations are required, where it is not possible to move houses to implement mitigation actions.

Recommendation 25d. Develop mitigation guidance for existing residential buildings: FEMA should develop guidance on mitigation solutions for existing residential buildings in order to minimize damage to buildings and reduce flood insurance premiums, taking into consideration the unique challenges faced when rebuilding in dense urban settings. The Hurricane Sandy Recovery Advisory No. 7, *Reducing Flood Risk and Flood Insurance Premiums for Existing Residential Buildings in Zone A* (FEMA 2013e), provides information on potential mitigation measures for existing residential buildings.

Conclusion 26. Insufficient Load Path Continuity: A large portion of the coastal residential and other low-rise light-frame building stock in the area affected by Hurricane Sandy is many decades old. Many failures occurred as a result of a lack of a continuous load path, a lack of maintenance on the load path, or a load path that was not sized to address the loads applied to the building during the storm event. Many continuous load paths were further altered on buildings because repairs and additions were made over time.

Many one- and two-family houses and other low-rise light-frame buildings failed at the floor-to-pile foundation connection as a result of insufficient connectors. Load path failures observed were primarily due to buildings having first-floor framing at or below the floodwater elevation and the combined flood and wind loads exceeding the capacity of the load path connections. The floor-joist-to-foundation load paths typically consisted of either a simple nailed connection or a system of load path connectors or blocking. In several instances, where a system of load path connectors was used, the strap connectors utilized were those more commonly used to make a truss-to-top-plate connection; this type of strap does not have sufficient capacity to resist both the shear and uplift forces encountered during flood inundation. In other instances, whether connectors may have provided sufficient uplift and shear resistance is unknown because connectors were corroded, which significantly reduced the capacity of the connectors.

Existing construction with a first floor system at or below the BFE is at significant risk of being severely damaged or destroyed by future events unless it is elevated or load path improvements are made to resist the combined flood and wind loads. New construction should be elevated high enough to prevent floodwater from entering the building envelope during future events.

Recommendation 26a. Retrofit existing homes to improve load paths: To address both the uplift and shear loads associated with combined flood and wind loads, existing homes with first-floor framing at or below the BFE should be retrofitted with either additional elevation or stronger, continuous load paths. The foundations of existing homes within the SFHA should be evaluated by local building officials to verify they maintain sufficient load path continuity.

Hurricane Sandy Recovery Advisory No. 1, *Improving Connections in Elevated Coastal Residential Buildings* (FEMA 2013e), provides details on suggested improvements for both existing and new construction for strengthening elevated floor-to-pile foundation connections and protecting metal connectors and brackets from corrosion.

Recommendation 26b. Perform regular inspections for compromised connections: Load path connections should be periodically inspected by owners or their designees to verify that the load path has not been compromised by the coastal environment. Repairs and reconstruction should use flood damage-resistant materials per NFIP Technical Bulletin 2, *Flood Damage-Resistant Materials Requirements for Buildings Located in Special Flood Hazard Areas* (FEMA 2008b), and Technical Bulletin 8, *Corrosion Protection for Metal Connectors in Coastal Areas for Structures Located in Special Flood Hazard Areas* (FEMA 1996).

Recommendation 26c. New home designs should adequately address flood risk: Designers of new homes should consider the likelihood and consequences of flood levels exceeding the BFE, and designs should address this risk. This risk is commonly addressed by either incorporating additional elevation above the minimum requirements or meeting the minimum elevation requirements and incorporating a sufficient continuous load path to resist the combined uplift and shear loads associated with flood and wind loads.

Hurricane Sandy Recovery Advisory No. 5, *Designing for Flood Levels Above the BFE After Hurricane Sandy* (FEMA 2013e), should be used by design professionals to determine an appropriate elevation for design purposes for both existing homes and new homes. Proper elevation can reduce the potential for flood loads to impact the first-floor framing and can reduce the required size of the load path connectors.

Recommendation 26d. Publish prescriptive load path details: Prescriptive load path details and connections suitable for the Hurricane Sandy-affected area should be compiled and published for use by designers, building officials, and contractors. Although building codes indicate the requirement for a load path, the codes do not prescriptively address the connections. Load path details specifically addressing foundation-to-floor framing connections should be developed by manufacturers and trade organizations related to wood framing.

Recommendation 26e. Require plans and specifications to show load path connections: Local building departments should require that load path connections be clearly shown and described in building plans and specifications. A design professional should evaluate the number, size, corrosion protection, and type of load path connectors necessary to resist all the applicable building loads. Identifying load path connectors on the plans and specifications will improve incorporation of sufficient load path connectors and improve verification of their presence. Describing and identifying load path connections in building plans and specifications should apply to both new construction and existing construction that is either being repaired or renovated. The Hurricane Sandy Recovery Advisory No. 1, *Improving Connections in Elevated Coastal Residential Buildings* (FEMA 2013e), provides details of elevated floor-to-pile connections using a variety of methods and materials and includes a list of FEMA documents that have important information related to load path connections in residential buildings.

Conclusion 27. Insufficient Siding Installation: In many instances, exterior siding was not sufficiently connected to the building. Multiple layers of siding were most commonly observed on older buildings (one- and two-family houses and other low-rise buildings). Rather than removing all of the existing siding, new siding appeared to have been installed over older siding and insulation layers. The fasteners for the outermost siding typically did not have sufficient embedment into an appropriate material, such as wood studs, to resist the wind loads. In contrast, there was little damage to buildings with properly installed siding.

Recommendation 27. Install siding properly: To withstand wind loads, siding should be installed and attached in accordance with the manufacturer's guidelines using appropriate fasteners attached to the appropriate substrate material to achieve the design wind pressures. Additionally:

- All existing exterior siding should be removed before installing new siding
- The fasteners should be corrosion resistant, have sufficient length to resist withdrawal from wind pressures, and be attached to the appropriate substrate materials. Installers should ensure proper fastener size, length, spacing, and depth of embedment in the substrate material
- Local building departments should require contractors/builders to certify that siding was installed according the manufacturer's instructions

7.5.1 Flood Protection

Conclusion 28. Flood Protection of Critical and Essential Facilities: Facilities such as WWTPs, transit facilities, and data centers that provide data and communication capabilities are not identified as "essential" or "critical" (Risk Category IV) by building codes and therefore may not be required to meet higher standards than typical non-residential buildings. However, the failure of these facilities can cripple recovery from a disaster event by incapacitating the critical infrastructure systems they support.

Recommendation 28. Local jurisdictions should determine what facilities are critical and essential: In addition to those facilities identified by the building code, the local jurisdiction should determine which facilities are critical or essential and should meet flood resistance design criteria, performance goals, and governing standards for Risk Category IV buildings. Occupied critical facilities should meet criteria recommended in ASCE 24 for Risk Category IV facilities and be coordinated with design criteria and performance goals for other system components or key assets with the respective critical infrastructure system. This includes associated siting mitigation measures, such as flood barriers, and supporting functional operations assets/facilities that are not listed as examples in ASCE 24-05, but require consideration as critical facilities; such facilities include data centers, WWTPs, and public transportation facilities, and their critical supporting substations or emergency power facilities.

Conclusion 29. Flooding in Subgrade Areas between Buildings: Subgrade areas shared between buildings are convenient for locating shared utilities. Some buildings that experienced no surface

water flooding during Sandy had subgrade areas and basements that flooded as a result of water entering through slab or wall penetrations, tunnels, vaults, or connections to basements or subgrade areas in adjacent buildings. A strict reading of FIRMs will not pick up these vulnerabilities unless a designer knows what spaces and components are underground.

In general, the MAT did not observe preventive measures in place to prevent floodwater from entering shared subgrade spaces. Inter-building flooding occurred because either preparation had not been made to prevent floodwater transmission, or installed preventive measures failed. In locations where flood doors were installed, either the doors failed or the walls surrounding the doors failed. Subgrade flooding was observed at hospital complexes with shared access tunnels and/or basements, in two high-rise residential buildings that shared a below-ground parking garage and basement, and in two WWTPs.

Recommendation 29a. Develop educational materials on below-grade flooding vulnerabilities: FEMA should develop educational materials to emphasize below-grade building vulnerabilities to flooding. Designers and building operators should understand how to identify such vulnerabilities and how to mitigate flood damage in basements and subgrade areas. A discussion of dry- and wet-floodproofing techniques should be included in the educational materials, including cautions about potential structural failures if dry-floodproofed areas cannot withstand the flood loads that will result from dry floodproofing (particularly in existing buildings).

Recommendation 29b. Protect against flooding across subgrade connections: Owners of buildings that share subgrade connections (e.g., access tunnels, basements, or underground parking) should implement flood protection measures to ensure that flooding from one area does not damage other areas or other buildings. Protection could be accomplished by implementing a dry floodproofing system, where structurally feasible, that includes barriers or watertight doors and is augmented by sump pumps with emergency power to remove any floodwater where seepage occurs. Alternatively, wet floodproofing techniques can be used if the connected spaces would not be damaged by inundation and could be cleaned up and placed back in service after flooding. FEMA P-936, *Floodproofing Non-Residential Buildings* (2013d), contains guidance on floodproofing.

7.5.2 Elevating Structures and Freeboard

Conclusion 30. Poor Performance of Buildings and Building Systems: Many non-elevated or low elevation buildings and building systems sustained flood damage due to inundation and/or wave damage. Buildings elevated above the Hurricane Sandy flood level on strong foundations sustained no such damage. Systems elevated above the flood level or protected by floodproofing measures also performed well.

TERMINOLOGY

Preliminary Work Maps: FEMA is in the process of releasing updated maps showing coastal flood hazard data in certain communities in New Jersey and New York. The updated maps (called Preliminary Work Maps) are an interim product created as part of the process of developing new FIRMs. The information on these Preliminary Work Maps is made available to applicable communities to use as the best available data for rebuilding and recovery efforts in the aftermath of Hurricane Sandy.

Recommendation 30a. Elevate new and Substantially Damaged/Improved structures to protect from flooding: Local communities should require new buildings, those determined to have Substantial Damage, and those that will undergo Substantial Improvement be elevated in accordance with Table 7-1, and associated building systems in accordance with Table 7-2. The recommendations differ from the next edition of ASCE 24 in two ways: 1) one additional foot of freeboard is added for Risk Category II structures, and 2) some Risk Category III structures are treated like Risk Category IV. All structures should have at least 2 feet of freeboard relative to detailed flood study results (not including ABFEs), and some Risk Category III structures warrant treatment like Risk Category IV for flood resistance purposes.

Table 7-1: Recommended Elevations for New and Substantially Damaged or Substantially Improved Buildings

New and Substantially Damaged or Improved Construction, Building Type[a]	Minimum Recommended Elevation and Floodproofing Level (select highest)
• One- and two-family structures • Other Risk Category II residential structures • Risk Category II non-residential structures	• Effective BFE + 2 feet, or Preliminary BFE + 2 feet,[b] or State/local DFE
• Risk Category III structures housing occupants or residents with limited mobility • Risk Category III structures that a community considers essential	• Risk Category IV elevation, see below
• Risk Category III structures not included above	• Effective BFE + 2 feet, or Preliminary BFE + 2 feet,[b] or State/local DFE
• Risk Category IV structures	• Effective BFE + 2 feet, or Preliminary BFE + 2 feet,[b] or State/local DFE, or 0.2-percent-annual-chance (500-year) flood level • Where the design flood is associated with coastal flooding, add 1 additional foot of freeboard to account for future sea level rise

a. See ASCE 7 (2010 Edition), Table 1.5-1 for Building Category explanation.

b. Use ABFE where Preliminary Work Maps have not been released, but where ABFE is more than 2 feet above the Effective BFE.

ABFE = Advisory Base Flood Elevation

BFE = base flood elevation

DFE = design flood elevation

Table 7-2: Recommended Elevations for Building Systems

Risk Category[a]	Minimum Recommended Elevation and Floodproofing Level (select highest)
Risk Category II structures, and Risk Category III not treated like Risk Category IV	At structure elevation
Risk Category IV structures, and certain Risk Category III structures (see Table 7-1)	1 foot above the structure elevation from Table 7-1
Existing structures (where practicable)	Corresponding elevation for new construction; if not practicable, elevate/floodproof as high as practical

a. See ASCE 7 (2010 Edition), Table 1.5-1 for Building Category explanation.

Recommendation 30b. Elevate existing structures to protect from flooding: The elevation recommendations in Tables 7-1 and 7-2 should also be applied, to the extent practical, to existing buildings that are undergoing repair or retrofit, and that do not meet substantial damage/substantial improvement criteria.

Recommendation 30c. Building designs should account for flood conditions: In addition to the freeboard recommendations in Recommendations 30a and 30b, building designs should be based on flood conditions that will accompany floods associated with freeboard elevations (see Figure 7-1). Specifically:

- Enforce Zone A design and construction standards in the area between the Effective/ SFHA landward limit, and a ground elevation equal to the adjacent Zone A BFE plus freeboard. This will mandate flood-resistant design and construction in some areas shown as Zone X on the Effective/ FIRMs.
- Enforce Coastal A Zone design and construction requirements in the area between the LiMWA and the LiMWA associated with the recommended freeboard.
- Enforce Zone V design and construction standards in the area between the Effective Zone V limit and the Zone V limit associated with the recommended freeboard.

Recommendation 30d. Improve protection of subgrade areas outside the SFHA: In addition to expanding the area over which freeboard is required as described in Recommendation 31 communities and States should address the vulnerability of basements and subgrade spaces in buildings outside the SFHA. To adequately protect these spaces from flooding, designers need to consider more than just location relative to the SFHA limit. NFIP Technical Bulletin 10-01, *Ensuring That Structures Built on Fill In or Near Special Flood Hazard Areas Are Reasonably Safe From Flooding* (FIA-TB-10) (2001), contains guidance that can be applied. Although it was written for buildings on fill, its content relating to measures that will mitigate buildings to be "reasonably safe from flooding" applies outside the SFHA as well.

Conclusion 31. Accounting for Future Conditions: Coastal erosion has occurred for many years throughout much of the area affected by Sandy, and is likely to continue into the future. Records also indicate that sea levels have been rising relative to the land across the area; future projections of sea level rise range from simple extrapolation of historical trends, to accelerated rates of rise. While future erosion rates and rates of relative sea level rise are subject to debate, both processes can increase flood hazards at a site, and it is prudent to incorporate these future conditions into planning, design, construction, and mitigation projects. Some regions are already responding to changing conditions. New York City recently released revised evacuation maps that extended the evacuation area to account for greater hazard risks.

Recommendation 31. Designers should consider the potential impacts of sea level rise: Sources for information on this topic include:

- Hurricane Sandy Recovery Advisory 5, *Designing for Flood Levels Above the BFE After Hurricane Sandy* (FEMA 2013e)
- Chapter 3 of FEMA P-55, *Coastal Construction Manual* (2011a)
- Technical Factsheet 1.6 in FEMA P-499, *Home Builder's Guide to Coastal Construction* (2010d)

- FEMA study titled *The Impact of Climate Change and Population Growth on the National Flood Insurance Program Through 2100* (AECOM 2013)

Information regarding potential increases in BFEs resulting from sea level rise in New Jersey and New York can be found at the U.S. Global Change Research Program Web site.[2] This Web site contains interactive maps that display the projected future areal extent of SFHAs. Calculators on the Web page allow the user to project an estimated future BFE resulting from sea level rise.

Taking sea level rise into account is similar to how freeboard affects flood zones (pushes the zones landward). Figure 7-1 illustrates how higher flood levels shift flood zones landward. Element A-1 shows a cross-section of an existing ABFE, Preliminary, or Effective FIRM. Element A-2 shows how recommended flood hazard zones shift as flood levels increase or higher freeboard is considered.

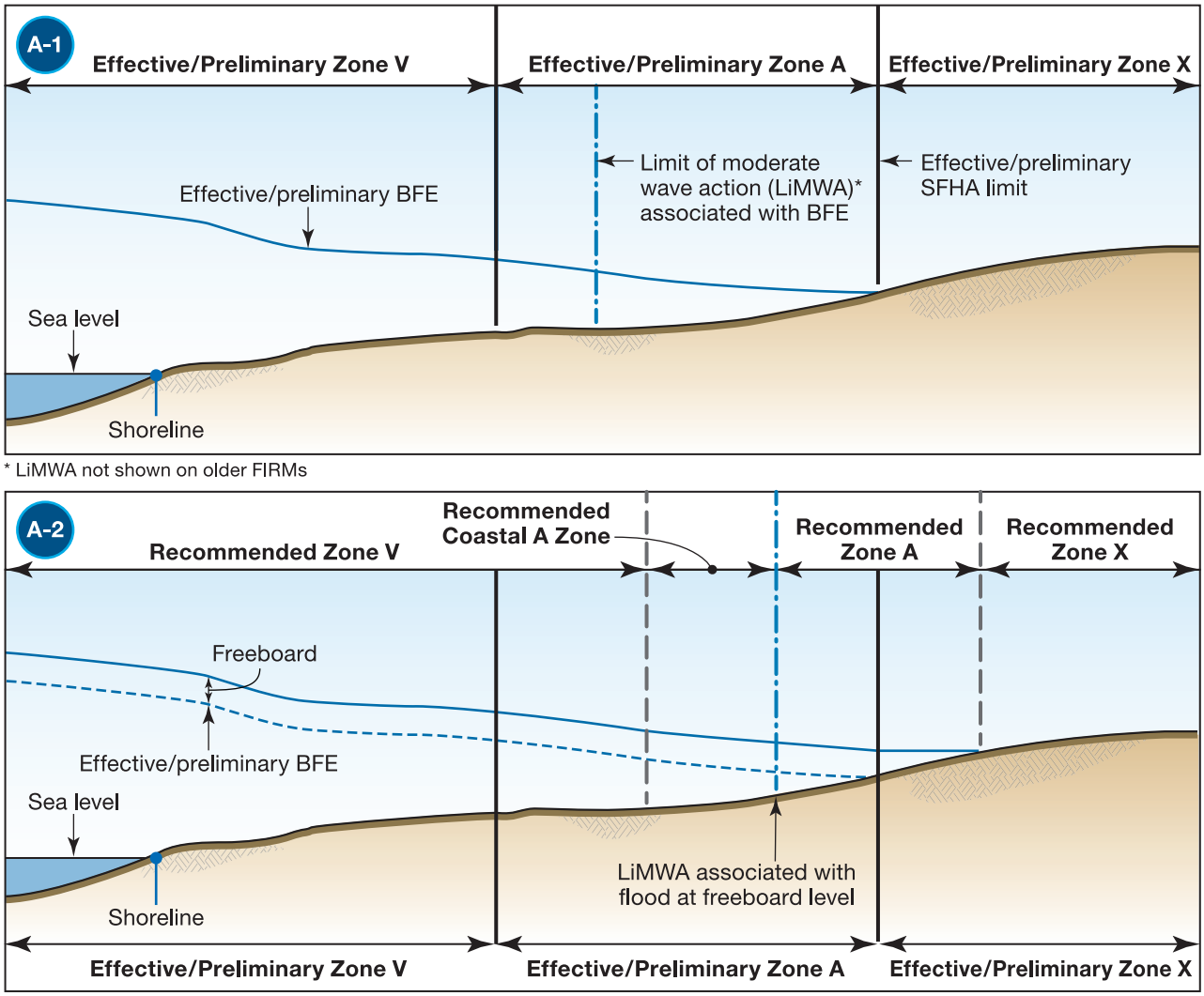


Figure 7-1: Higher flood levels shift flood zones landward

2 http://www.globalchange.gov/component/content/article/87-assessment/902-coastal-resilience-resources.

7.6 Building Systems

Building systems are essential to the functionality of all facility types. Even when flooding does not cause structural damage to a building, the inundation of building systems can cause the building to be uninhabitable or to have limited functionality for weeks or months. Building systems include MEP systems, as well as elevators, emergency power systems, fuel tanks, sump pumps, and other related equipment.

7.6.1 General Protection

Conclusion 32. Protection of Building Systems: Building systems such as the MEP systems were often insufficiently protected to prevent damage from floodwater. Most buildings did not incur Substantial Damage, but many of their critical building systems such as furnaces, boilers, water heaters, and electrical panels were located on floors at or below grade and were inundated and damaged. For basements and below-grade garages, sump pumps, that under normal conditions would keep these areas from flooding, were overwhelmed by the severe rain or storm surge entering through doorways, windows, and vents. Other equipment such as air conditioners were elevated, but damaged by flood-borne debris knocking out support piles.

IMPORTANCE OF CRITICAL BUILDING SYSTEMS

Critical building systems, those deemed essential by a community or the building code, are important for community resilience.

Recommendation 32. Building owners should elevate, relocate, or protect building systems above the BFE: Systems such as air conditioning compressors, which are often located on exterior platforms, should be elevated above the BFE and either cantilevered off the building or on a foundation designed to resist flood loads, including debris impact. Any exterior mounted equipment should be properly anchored to resist wind loads (and seismic loads, if necessary) using corrosion resistant anchorage straps. Additional information is available from several FEMA publications:

- ■+ Hurricane Sandy Recovery Advisory No. 3, *Restoring Mechanical, Electrical, and Plumbing Systems in Non-Substantially Damaged Residential Building* (FEMA 2013e)
- ■+ FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings* (FEMA 2007b)
- ■+ FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings* (FEMA 2007c)
- ■+ FEMA P-424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* (FEMA 2010a)

Conclusion 33. Emergency Power Systems: Flood protection systems that rely on electrical power were rendered ineffective when power was lost. Emergency power systems protected from flood damage would have allowed the flood protection systems to remain functional.

Recommendation 33a. Submit a proposal to modify ASCE 24, Section 7.1 commentary: A proposal should be submitted to the ASCE 24 *(Flood Resistant Design and Construction)* Standard Committee to modify the commentary of Section 7.1 to state it is the intent of standard Section 7.1 to include emergency power systems.

Recommendation 33b. Determine minimum required emergency power duration and capacity: Facility owners should conduct a critical review of existing and future conditions that could impact a building during a storm event. The minimum required emergency power duration and capacity should be determined.

Conclusion 34. Protection of Building System Components: Some components of building systems are required by New York City building code to be located on the lowest level of the building, which generally equates to a basement or subgrade area. However, high-rise residential buildings and critical and essential facilities had building systems located in basements or subgrade areas in both New Jersey and New York City. The location of building systems is important in maintaining building operations: facilities with elevated building systems resulted in a functioning building, post-event.

Recommendation 34. Protect critical building systems in subgrade areas: Building owners with building systems in basement or subgrade areas susceptible to flooding should protect these systems from coming into contact with floodwater. These systems can be protected by a variety of methods used singly or to greater effect, in conjunction with one another. Recommendations for general building systems are described in the Hurricane Sandy Recovery Advisories Nos. 2, 3, and 4. The following recommended actions apply to critical systems, those determined to be essential to the function of the building:

1) Relocate

- + Relocate building systems and/or components in accordance with the recommendations in Table 7-2
- + Relocate utility equipment to a higher floor or build an elevated addition to use as a utility room
- + Relocate systems to a higher elevation per ASCE 24

2) Elevate

- + Elevate critical building systems components in accordance with the recommendations in Table 7-2
- + Elevate damaged building systems during repair or replacement
- + Elevate to the BFE or higher even if it is not required; if elevating to the BFE or relocating the equipment is not feasible, raise the equipment as high as possible in place
- + Pay attention to specific vulnerabilities, characteristics, and restrictions on equipment placement that can affect the ability to elevate or relocate it

- ■+ Install platforms on the floor to elevate equipment in place

3) Dry Floodproof

- ■+ Seal building systems penetrations
- ■+ Install backflow prevention devices on plumbing equipment
- ■+ Require emergency power for floodproofing system components (e.g., sump pumps)
- ■+ Protect building systems through integrated floodproofing by using a combination of wet and dry floodproofing techniques

4) Install System and Component Redundancy

- ■+ Require emergency power to support critical facility functions
- ■+ Establish redundancies

Conclusion 35. Facilitate the Connection of Temporary Building Systems: Many buildings had temporary equipment installed in flooded areas to replace damaged connections and restore function to building systems. After other flood disasters, the MAT has observed buildings where temporary connections in floodprone areas were converted to permanent connections. In many instances these converted temporary connections were not protected by being relocated above the BFE or being dry floodproofed before their conversion to permanent connections and thus were vulnerable to damage by flooding.

> ***Recommendation 35. Establish points for temporary power connection:*** In order to reduce service outages, building owners should establish and maintain points of temporary power connection for mechanical and electrical service components. Building owners should consider long-term recovery when selecting the locations for temporary power, heat, and other building systems connections since the temporary connection may become permanent. New permanent connections for critical building systems should be located as indicated according to the Risk Category shown on Table 7-2 or otherwise protected from floodwater through dry floodproofing.

7.6.2 Elevators

Loss of elevator service created hardship for many building tenants in both critical facilities and non-critical facilities.

Conclusion 36. Protect Below-Grade Elevator Equipment: Below-grade sections of elevators (i.e., elevator pits) are extremely vulnerable to inundation. Many elevator shaft walls collapsed and related equipment was destroyed.

> ***Recommendation 36a. Emergency plans should address the possibility of elevator failure:*** Building owners and operators should recognize the impact of elevator failure on

evacuation, emergency operations, and normal operations and plan accordingly. Elevate and/or floodproof elevator system components to minimize flood damage in accordance with FEMA Technical Bulletin 4, *Elevator Installation for Buildings Located in Special Flood Hazard Areas in accordance with the National Flood Insurance Program* (FEMA 2010b).

Recommendation 36b. Facilities should protect elevator service, especially when it is essential to function: Building owners should know that power outages occur and make preparations for them. There should be a clear understanding of what to expect and how to prepare. Protecting elevator service may include:

- Relocating essential controls above the DFE
- Dry floodproofing essential elevator systems
- Providing a water sensor in the elevator pit to recall elevator to DFE

Additional guidance can be found FEMA Technical Bulletin 4, *Elevator Installation for Buildings Located in Special Flood Hazard Areas* (2010b).

7.6.3 Fuel Tanks and Emergency Pumps

Conclusion 37. Protection of Fuel Storage Tanks: The MAT observed numerous fuel storage tanks used to supply emergency generators and other equipment that were not designed to be protected against flood hazards. Large fuel storage tanks in New York City are located at the lowest occupied grade, often at basement level, in accordance with the building code and because of concerns related to fire risk and efficient use of available space. During the flood event, some tanks broke their anchorage and damaged other building systems within the compartment, while other tanks were crushed and released fuel oil into the floodwater.

Recommendation 37a. Design installation of large fuel storage tanks to resist flotation and implosion: Building owners and operators, including WWTPs, should install large fuel storage tanks that are designed to resist flotation forces and implosion for the design flood level. To meet business continuity requirements, redundant emergency power systems should be considered. Facility owners should understand that full tanks or those that are nearly full are inherently less buoyant, better resist uplift, and are less susceptible to crushing. Therefore, facility owners should considering filling tanks prior to a flooding event (depending on advance warning). See Hurricane Sandy Recovery Advisory No. 6, *Protecting Building Fuel Systems from Flood Damage* (FEMA 2013e) for more information on protecting building fuel systems.

Recommendation 37b. Protect tanks in subgrade areas from flood damage: Building owners with fuel tanks located in below-grade spaces should locate tanks in dry-floodproofed enclosures per ASCE 24 or ensure that tanks are able to resist buoyance and crushing pressures. When possible, move mechanical and electrical systems associated with the tanks to above the elevation specified by ASCE 24. When elevation is not possible, protect these critical building systems with wet or dry floodproofing. Any electrical or mechanical equipment required to operate a dry floodproofing enclosure should have emergency power. Guidance

can be found in Hurricane Sandy Recovery Advisory No. 4, *Reducing Interruptions to Mid- and High-Rise Buildings during Floods* (FEMA 2013e). Some recommendations from the Hurricane Sandy Recovery Advisories Nos. 4 and 6 include:

- Elevate the tank above flood levels
- Use tanks that can withstand pressure
- Anchor tanks to resist buoyancy
- Dry floodproof the tank room and use normal (not high-pressure resistant) tanks
- Do not use oil as a fuel source in below-grade areas, use natural gas boiler instead
- Filling the tank is a failsafe/emergency measure to be done pre-event

Conclusion 38. Protection of Associated Utilities Equipment: Many of the utilities and building systems observed by the MAT were not designed and protected against flood hazards. Utilities and equipment located in the basement levels, including electric switchgears, pumps, and chillers, as well as copper cables and elevators, were completely submerged and heavily damaged.

Recommendation 38. Install fuel pumps in large storage tanks to maintain operations: Facility owners should install fuel pumps for large storage tanks that are designed to operate during flood conditions. Depending on the relative location of the large storage tank and the generators, submersible pumps, elevated pumps, and/or flood protection measures may be required to maintain operation.

Facility owners should also elevate electric power systems and cooling systems 1 foot above the structure elevation shown in Table 7-1. This also applies to switchgear and transformer vaults often hosted by the local electrical utility.

Conclusion 39. Sump Pumps: Water continued to seep into basements for several weeks after the flood event as the groundwater level slowly receded. Inadequate groundwater protection systems and emergency pumping of subgrade levels resulted in ongoing seepage that slowed cleanup and recovery efforts throughout the affected area.

Recommendation 39. Install sump pumps to remove seepage from subgrade areas: To address ground saturation and increased seepage into basements during and following a flood event, facility owners should install sump pumps that are tied to emergency power systems to remove seepage and/or floodwater.

7.7 Continuity of Operations in Critical Facilities and Other Key Assets

Protecting critical infrastructure from natural hazards is vital not only to minimizing damage, but also to minimizing down-time. Prolonged down-times place a heavy burden on the community.

Continuity of operations is particularly important for critical facilities and other key community assets. The following conclusions and recommendations are primarily for critical and essential facilities, though owners and operators of other facilities may also find them useful.

7.7.1 Planning for Continuity of Operations

Conclusion 40. Need for Holistic Approach to Building Systems and Planning: Many of the emergency preparedness plans for critical and essential facilities visited by the MAT did not consider damage from a hazard in combination with system failures and similarly, building systems were not designed with this consideration. For example, many facilities were not prepared for concurrent flooding and power loss. This lack of detailed planning had a large effect on those facilities that decided to "defend in place." For instance, some facilities had to unexpectedly evacuate when emergency power was lost and access to the lower floors was made difficult by the presence of floodwater.

Some examples of the types of damage that occurred because of the combined failures of building systems include:

- The MAT found that most of the damage observed was related to the placement of **mechanical and electrical systems in basements and first stories**. When systems were directly inundated or intentionally shut down to reduce damages, a wide range of building services was interrupted. Electrical switchgear and mechanical systems were destroyed and boilers inundated. The MAT observed that transformer vaults and unit substations were often placed on lower levels; when this equipment flooded, it prevented the facility from receiving utility power until the vault transformers or the unit substations were replaced, typically after the utility company energized its distribution lines.

- **Fuel supplies** for emergency power systems (i.e., main fuel tanks, pumping systems, day tanks, and tank vents) and electrical supplies for emergency power (generator and distribution equipment, supplies to vulnerable equipment, and power configuration) were not considered holistically. The result was that floodwater entered many buildings via the numerous entry points where floors and walls were penetrated by mechanical piping and electrical conduits.

- In data centers, older style **communication cables** consisted of multi-pair copper conductors with paper insulation. Outside of the facility, the cables were pressurized to prevent water entry. However, floodwater disrupted power to the compressors that supplied the cables. The loss of pressurization allowed floodwater to enter the communication cables, destroying the paper insulation and damaging the cables beyond repair. Newer style fiber optic cable, on the other hand, was mostly undamaged.

Recommendation 40a. Building owners should provide emergency power systems for facilities: This is particularly important for healthcare and other critical facilities. Specifically, facility owners should:

- Examine emergency power systems holistically to evaluate not only the emergency power system, but other systems that rely on emergency power such as the electrical system and mechanical system. Mutually dependent systems should be evaluated together to design a

resilient system that includes redundancies. Facility owners should evaluate combinations of hazards, such as fire and flood.

- Elevate or dry floodproof critical emergency power equipment.

- Protect fuel supplies for emergency power systems. The focus should be on protecting liquid fuels (i.e., diesel and oil) and system components (i.e., day tanks, pumping systems, main fuel tanks, and tank vents). Refer to Hurricane Sandy Recovery Advisory No. 6, *Protecting Building Fuel Systems from Flood Damage* (FEMA 2013e), for additional details and also see recommendations in Hurricane Sandy Recovery Advisory No. 4, *Reducing Interruptions to Mid- and High-Rise Buildings During Floods* (FEMA 2013e), for general building systems.

- Mitigate electrical systems for emergency power. For instance, elevate generator and distribution equipment and transfer switches, isolate supplies to vulnerable equipment, and reconfigure emergency power systems to be less vulnerable to flooding.

Recommendation 40b. Adhere to Presidential Preparedness Directive 21: As the recent Presidential Preparedness Directive 21 states, critical infrastructure needs to withstand and rapidly recover from all hazards. Lower floors of buildings should be floodproofed, evacuated, and preparedness plans should include a contingency for lack of access to or from the building post-event.

Further guidance can be found in FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds* (FEMA 2007b). See also the Hurricane Sandy Recovery Advisory Numbers 2, 4, and 5 for information on floodproofing and limiting building interruptions.

Recommendation 40c. Facility owners and operators should develop holistic plans to limit disruption of critical functions: New buildings, repairs to existing buildings, and systems that support critical functions should be designed to be more resistant to disruption by flood events. Owners and operators should provide emergency power systems or temporary connections to reduce outages when utilities are disrupted. Recommendations described in other parts of this chapter should be applied to protect such systems, specifically by:

- Establishing and maintaining connection points for temporary facilities (refer to Recommendation 35)

- Establishing and maintaining redundancies (refer to Recommendations 21, 34, 37a, 40a, 41, and 45c)

- Prioritizing which electrical systems will use back-up power or emergency generators (refer to Recommendation 33b)

- Protecting elevator service (refer to Recommendation 36b)

- Using flood damage-resistant materials (refer to Recommendation 26b)

- Limiting use of lower floors (refer to Recommendations 25c and 30d)

- ■+ Elevating temporary equipment (refer to Recommendation 35)

7.7.2 Healthcare Facilities

Conclusion 41. Prepare for Emergency Evacuation: Emergency evacuation of a healthcare facility either during or immediately after an event is difficult and dangerous. Complete loss of power, including back-up systems, is common following these events. Healthcare facilities struggled after Hurricane Sandy to provide care or evacuate in the dark.

Recommendation 41. Healthcare facilities should develop a comprehensive plan for complete power loss: Healthcare facilities should take steps to prepare for disaster events, such as:

- ■+ Include in preparedness plans the details of an emergency evacuation during or immediately after an event; such plans should include internal and external resources and agreements
- ■+ Elevate or dry floodproof mechanical and electrical service components per ASCE 24
- ■+ Elevate electrical systems for utility power (elevate main switchgear, utility transformers, and distribution equipment; isolate supplies to vulnerable equipment)
- ■+ Install and maintain redundancies in building systems to speed post-disaster recovery
- ■+ Install or maintain quick connects for temporary power and other systems (i.e., power, potable water, heat) for use in future storm events if needed and appropriate measures to protect the backup emergency equipment should be taken

Conclusion 42. Loss of Power: Most of the hospitals observed by the MAT experienced complete loss of power, including back-up systems, during Hurricane Sandy. Hospitals struggled to provide care, perform evacuations in the dark, and start up quickly after the event. Hospitals and long-term healthcare facilities were forced to transfer patients and long-term residents to other facilities with few or no accompanying records. Emergency evacuation of a hospital either during or immediately after a flood event is difficult and potentially dangerous.

Recommendation 42. Develop emergency plans that cover complete power loss for extended periods: Healthcare facilities should plan for extended complete power loss and associated loss of other utilities by developing emergency plans that include emergency operations, training exercises, and procurement of emergency systems and supplies. Appropriate supplies may include provision of headlamps for staff, back-up communication systems with batteries, and battery-powered lighting.

Conclusion 43. Vulnerable Healthcare Equipment: Key equipment on lower floors is vulnerable to flooding. Key equipment includes hospital equipment (i.e., CT scanner, MRI machines, refrigeration equipment for blood banks, etc.), communications equipment, and vital records.

Recommendation 43a. Prepare key records before a significant storm event: Healthcare facilities should prepare key records in advance of a storm to aid continuity of patient care in

the event of power loss or evacuation. For example, NYU Langone Medical Center pre-printed patient summaries that greatly aided the receiving hospitals when patients were evacuated.

Recommendation 43b. Protect critical function areas from flooding: Facility owners should dry floodproof and/or place critical functions (i.e., emergency room and radiology) on upper floors, and wet floodproof or place non-critical functions (i.e., laundry and food service) on lower floors more prone to flooding. Facilities should identify back-up spaces for critical functions that cannot be moved, such as their Emergency Department. They may also want to consider subcontracting non-critical functions, such as laundry and food service, as part of their planning process. Some medical imaging equipment is located on subgrade floors due to shielding requirements and may not be moveable.

For additional details in reducing flood effects, including guidance in regard to medical and compressed gas storage tanks, refer to Hurricane Sandy Recovery Advisory No. 2, *Reducing Flood Effects in Critical Facilities* (FEMA 2013e).

7.7.3 Gas Stations

Conclusion 44. Fuel Shortages: The availability of fuel for generators and vehicles, as well as the ability to deliver it, was sharply reduced in the affected areas after Hurricane Sandy (New York City 2013b). The fuel shortage affected hospitals, fire and police stations, and other critical facilities, as well as recovery efforts and employees of businesses not directly affected by the power outage.

Recommendation 44a. Prepare a plan for maintaining fuel supplies: Critical facilities or those that must be functional during and immediately after a disaster event should develop plans for maintaining fuel supplies during emergency situations. The plans should include fuel for generators, emergency employees, and work vehicles and should specify coordination with a fuel supplier.

Recommendation 44b. Protect subgrade fuel pumps from flooding: To remain operational during and immediately after a flood event, gas stations in SFHAs should protect subgrade fuel pumps from flood damage and make arrangements for emergency power, particularly for stations that require IT and telecom systems to dispense fuel. If emergency generators are not installed, a dedicated circuit to rapidly connect portable generators may be useful.

7.7.4 Transit Facilities (Maintenance Facilities, Entry Stations)

Conclusion 45. Insufficient Flood Protection of Transit and Maintenance Facilities: The transit facilities and their related maintenance facilities were inadequately protected from flood hazards. Floodwaters flooded system tunnels where access points to the subways and rail systems, such as elevator kiosks at street level and stairway entrances, were inadequately protected from flood inundation.

Recommendation 45a. Protect key utilities and ventilation equipment to the level applicable for critical facilities: Facility owners should consider elevating or protecting key utilities and ventilation equipment at maintenance facilities and the associated transit facilities to the 0.2-percent-annual-chance flood level, consistent with design guidance for critical facilities

(refer to Recommendation 34). The potential for seepage after the flood event may continue for several weeks and protection from this seepage should be considered for facilities. Facility and transit protection should consider the potential for multiple subsurface seepage penetration points from adjacent buildings, utility system entry points, and proximate remnant or relic urban underground systems and should also be coordinated with protection and recovery plans along the transit alignments.

Recommendation 45b. Prepare a plan to protect critical assets: Transit facility owners and operators should develop and execute a more robust plan for moving critical assets such as rail cars and subway cars out of high hazard areas in advance of a hazard event.

Recommendation 45c. Install barriers to prevent floodwater entering transit stations: Transit facility owners should consider installing barriers and floodgates to prevent floodwater entry into transit stations at key points. Inflatable barriers could be installed as a redundant measure to provide intermediate pressure relief at pumping locations or to prevent or divert surface flow runoff. Where inflatable barriers are used, facility owners should consider filling them with salt water, as opposed to fresh water, to ensure that density is not an issue. If possible, floodproofing measures should protect to the DFE or 0.2-percent-annual-chance flood event elevation, whichever is higher. The design of floodgates and barriers should consider existing structural capacity, interconnectivity of underground tunnels, and the flood resistance of supporting structures.

Conclusion 46. Insufficient Preparedness of Transit Facilities: Many transit facilities in flood zones have systems for pumping street drainage from rainfall and snow melt, but do not have emergency power systems for flood events. One system had submersible pumps that successfully pumped water during the flood event until they were damaged by debris, such as plastic bags and trash, carried by the floodwater from streets and public containers.

Recommendation 46. Install submersible pumps: Transit facility owners should consider installing submersible pumps for flood events with safeguards against debris, such as plastic bags and trash.

7.7.5 Wastewater Treatment Plants

Conclusion 47. Insufficient Below-Grade Flood Protection of Wastewater Treatment Plants: The WWTP observed by the MAT did not have adequate flood protection of their below-grade areas. The lack of effective flood barriers outside of or within the tunnel system allowed floodwater to fill the utility tunnels and connected facility basements. Specifically, flooded utility tunnels resulted in extended downtime while the utility systems were being repaired.

Recommendation 47. Protect utility tunnels from flooding: WWTP owners and operators should consider protecting utility tunnels by installing barriers and/or partitions. Depending on the flood elevation and location, berms and floodgates around the utility tunnel should be considered in conjunction with structural flood barriers within the tunnel system that create partitions. In order for any structural barriers to be effective, however, the original structure must be carefully evaluated before implementing any floodproofing measure to ensure its structural capacity to resist DFE flood loads. To address ground saturation and increased

seepage into utility tunnels during and following a flood event, sump pumps tied to emergency power systems that have adequate capacity for removing seepage and/or floodwater should be provided.

7.8 Historic

Protecting historic structures and preserving stored artifacts are in the best interest of our Nation. Therefore, protecting these historic structures and artifacts from natural hazards should be included in community hazard mitigation plans. The following conclusions and recommendations are based on the MAT's observations and review of the historic structures and properties it visited in New Jersey, New York, and New York City.

Conclusion 48. Hazard Planning: The majority of the historic structures visited by the MAT lacked site-specific hazard mitigation plans. While historic structures and other cultural resources are usually included as part of a local jurisdiction's hazard mitigation plan, these plans do not delve into each historic property in detail and instead provide general mitigation strategies.

Recommendation 48a. Develop site-specific multi-hazard mitigation plans for landmark buildings: Whether publically or privately owned, historic property owners should develop a site-specific multi-hazard mitigation plan for landmark buildings and their associated landscape features. While specifically written for State and local governments, FEMA 386-6, *Integrating Historic Property and Cultural Resource Considerations into Hazard Mitigation Planning: State and Local Mitigation Planning How-To Guide* (FEMA 2005), is also useful for building owners, as it describes the four steps of developing a mitigation plan: (1) organize resources, (2) assess risks, (3) develop a mitigation plan, and (4) implement the plan and monitor progress.

Recommendation 48b. Protect historic structures that cannot be elevated: Where elevation is not feasible or would be an adverse effect, floodproofing might be a viable alternative. Floodproofing measures could include:

- Relocating critical building systems components such as electrical systems, HVAC, furnaces, and boilers out of the basement to a higher floor
- Wet floodproofing basement areas
- Using flood-resistant materials below the BFE
- Where structurally feasible, bracing and reinforcing walls to withstand hydrostatic forces
- Where structurally feasible, installing exterior watertight shields for doors and windows or using interior watertight shields over windows and doors where the use of exterior shields may adversely affect the historic designation
- Where structurally feasible, using membranes and other sealants in basement areas to reduce water seepage through walls

- Installing sump pumps or a drainage collection system in basement areas
- Where possible, elevating or relocating appliances to elevated areas

Conclusion 49. Integrate N.J.A.C. 5:23-6 and the NFIP: The New Jersey Rehabilitation subcode (N.J.A.C. 5:23-6, 2013) and the NFIP are not integrated. Both documents provide favorability to historic structure elevation requirements provided by the building code and the NFIP.

Recommendation 49. Develop mitigation guidance for historic structures: FEMA should work with the NJDCA to provide mitigation guidance about a broad range of mitigation options to make historic structures more resilient by retrofitting historic structures with wet floodproofing techniques as opposed to traditional elevation techniques.

Conclusion 50. Retention of Historic Designation: The Federal government encourages the retention of historic designation through incentives such as not having to meet the floodplain management requirements of the NFIP as long as they maintain their historic structure designation, and through tax credits for the rehabilitation of historic structures.

Recommendation 50. Evaluate retrofit options for historic buildings: Owners of historic structures should evaluate if the structure can be retrofitted with flood mitigation measures without loss of historic designation. If retrofitting without loss of historic designation is possible, a registered design professional with experience rehabilitating historic structures should be used when designing and installing flood mitigation retrofits to a historic structure.

Conclusion 51. Protection of Climate-Controlled Artifacts: Museums and historic structures need temporary power to maintain climate-control in locations where artifacts are stored and to protect historic fixtures and finishes. Without a climate-controlled environment, fragile artifacts and building elements are vulnerable to damage by humidity. The MAT observed that critical building systems were damaged and rendered non-functional by storm surge and floodwater, and temporary power systems either did not exist or failed, placing artifacts and interior fixtures/furnishings at risk due to heightened moisture levels.

Recommendation 51. Protect critical building systems of historic structures: The recommendations for protecting critical building systems components and continuity of operations (see Section 7.7) are also applicable to museums and historic structures. However, the design must ensure that protective measures do not compromise the building's historic designation or eligibility for historic designation. Protective measures may include:

- Elevating critical building systems and components
- Dry floodproofing critical building systems and components if unable to elevate them
- Storing artifacts and other fragile items in areas above BFE

If located outside the building, temporary power generators installed at a historic building should be placed so as to not adversely affect character-defining features of the building and surrounding landscapes and view sheds, but should still ensure the equipment is protected from floodwater and high wind.

Conclusion 52. Unshielded Subgrade Windows and Doors: The MAT observed many instances of damage that resulted from unshielded subgrade basement windows and unshielded doors that failed and allowed water to enter the first floor and basement areas of historic structures.

> ***Recommendation 52. Protect subgrade windows and doors:*** Building owners should protect subgrade basement windows and unshielded doors by installing flood shields to cover openings to protect the structure from low-level flooding (less than 3 feet deep). A registered design professional should be consulted to determine whether or not the building will be able to resist the loads imposed by the level of flooding. Any mitigation measures should be incorporated in such a way as not to cause loss of historic designation or obscure existing significant historic features.

7.9 Summary of Conclusions and Recommendations

Table 7-3 is a matrix showing a list of the conclusions and recommendations cross referenced to the sections of the report that describe the supporting observations. Note that while some recommendations may be applicable to all building types, only the buildings for which the recommendations are most applicable are indicated on this table.

Table 7-3: Summary of Conclusions and Recommendations

Observations	Conclusions	Recommendations	Low-Rise	Mid- and High-Rise	Healthcare Facilities	First Responders	Schools	Data Centers	Wastewater Treatment Plants	Transportation Facilities	Historic Structures
Sections 4.1.3, 4.1.4, 4.2.3, and 4.2.4	**1:** Vulnerability Assessment	**1a**: Perform vulnerability assessments		✔							
Section 5.2.2, 5.5.2, 5.6.2, and 5.7.2		**1b**: Perform vulnerability assessments for all critical facilities			✔	✔	✔	✔	✔	✔	
Appendix G, Section G.1.1	**2:** Flood Hazard Area Control Act (New Jersey)	**2:** NJDEP, NJDCA, and FEMA should coordinate review	✔	✔	✔	✔	✔	✔	✔	✔	
Appendix G, Section G.1.1	**3:** Model Flood Damage Prevention Ordinance (New Jersey)	**3:** NJDEP should evaluate FEMA model floodplain management ordinance	✔	✔	✔	✔	✔	✔	✔	✔	
Appendix I, Section G.1.1, Section G.1.2	**4:** Code Officials and Continuing Education (New Jersey)	**4:** Develop training on flood provisions of New Jersey building code									
Appendix G, Section G.1.2	**5:** State Review of Buildings in Flood Hazard Areas (New Jersey)	**5:** Establish formal consultation process	✔	✔		✔					

Table 7-3: Summary of Conclusions and Recommendations (continued)

Observations	Conclusions	Recommendations	Low-Rise	Mid- and High-Rise	Healthcare Facilities	First Responders	Schools	Data Centers	Wastewater Treatment Plants	Transportation Facilities	Historic Structures
Appendix G, Section G.1.3	**6:** Building Code Amendments to the New Jersey UCC (New Jersey)	**6:** Amend the UCC	✔	✔	✔	✔	✔	✔	✔	✔	
Appendix G, Section G.2.1	**7:** Model Local Law for Flood Damage Prevention (New York State)	**7**: NYSDEC should evaluate FEMA model floodplain management ordinance	✔	✔	✔	✔	✔	✔	✔	✔	
Appendix G, Section G.2.2	**8:** Model Local Law for Administration of the Building Codes (New York State)	**8:** Develop optional provisions for model local law	✔	✔	✔	✔	✔	✔	✔	✔	
Section 2.4	**9:** Site Requirements of the New York State Hospital Code (New York State)	**9**: Modify the hospital code to make flood provisions mandatory			✔						
Appendix G, Section G.2.2	**10:** Code Officials and Continuing Education (New York State)	**10**: Develop training on flood provisions of New York building code									
	11: Technical Bulletin on "Flood Venting" (New York State)	**11**: Update DCEA technical bulletin on flood venting	✔	✔	✔	✔	✔	✔	✔	✔	✔
Appendix G, Section G.2.3	**12:** Building Code Amendments to the New York State Uniform Code (New York State)	**12**: Amend New York State Code	✔	✔	✔	✔	✔	✔	✔	✔	
Appendix G, Section G.3.1	**13:** Building Code Amendments to the New York City Building Code (New York City)	**13**: Modify proposed New York City code amendments	✔	✔	✔	✔	✔	✔	✔	✔	
	14: Substantial Damage and Substantial Improvement Determinations (New York City)	**14:** The DOB should establish protocol to verify data	✔	✔	✔	✔	✔	✔	✔	✔	
Appendix G, Section G.3.2	**15:** Inspection of Construction in Flood Hazard Areas (New York City)	**15**: Establish mechanism for special inspections	✔	✔	✔	✔	✔	✔	✔	✔	

Table 7-3: Summary of Conclusions and Recommendations (continued)

Observations	Conclusions	Recommendations	Low-Rise	Mid- and High-Rise	Healthcare Facilities	First Responders	Schools	Data Centers	Wastewater Treatment Plants	Transportation Facilities	Historic Structures
Appendix G, Section G.3.1	**16:** Dry-Floodproofed Buildings (New York City)	**16:** Amend Appendix G of New York City Building Code		✔	✔	✔	✔	✔	✔	✔	
	17: NYC School Construction Authority Design Standards (New York City)	**17**: Revise NYC School Construction Authority Design Standards					✔				
Appendix F, Section F.5.2	**18:** NFPA 99	**18:** Revise IBC to reference NFPA			✔						
	19: NFPA 99 and ASCE 24 Consistency	**19:** Revise NFPA to reference ASCE 24			✔						
Appendix F, Section F.5.1	**20:** Facility Guidelines Institute	**20**: Revise FGI to reference ASCE 24			✔						
	21: Building System Damage and FGI	**21**: Revise FGI to provide specific guidance			✔						
Sections 3.1, 4.1, 4.2, Chapter 5, and Chapter 6	**22:** International Code Series Amendments	**22:** Propose changes to I-Codes	✔	✔							
Sections 3.1.1 and 6.1	**23:** Siting of Buildings Relative to Erosion Control Structures	**23a:** Document performance of erosion control structures									
Sections 3.1.1		**23b:** Review mapping procedures									
Sections 3.1.1, 4.1.1, 4.2.1, 6.1 Appendix J, Sections J.1.3, J.6.2		**23c:** Conduct detailed evaluation of damage behind erosion control structures	✔	✔							
Sections 3.1.1, 4.1.1, 4.2.1, 6.6, Appendix J, Sections J.1.3, J.6.2	**24:** Protection Afforded by Beaches and Dunes	**24a:** Review dune loss criterion									
		24b: Develop siting and design guidance for Sandy-affected coastal areas	✔	✔	✔	✔	✔	✔	✔	✔	
		24c: Identify barrier islands with history of breaching	✔	✔	✔	✔	✔	✔	✔	✔	
Section 3.1.3	**25:** Effect of Foundation on Building Survival	**25a**: Reference FEMA guidance regarding foundations for new construction	✔								

Table 7-3: Summary of Conclusions and Recommendations (continued)

Observations	Conclusions	Recommendations	Low-Rise	Mid- and High-Rise	Healthcare Facilities	First Responders	Schools	Data Centers	Wastewater Treatment Plants	Transportation Facilities	Historic Structures
Section 3.1.3	25: Effect of Foundation on Building Survival	**25b**: Elevate existing low-rise buildings where possible	✔								
		25c: Fill below-grade areas of buildings in the SFHA	✔								
		25d: Develop mitigation guidance for existing residential buildings	✔								
	26: Insufficient Load Path Continuity	**26a**: Retrofit existing homes to improve load paths	✔								
		26b: Perform regular inspections for compromised connections	✔								
		26c: New home designs should adequately address flood risk	✔								
		26d: Publish prescriptive load path details	✔								
		26e: Require plans and specifications to show load path connections	✔								
Section 3.2	27: Insufficient Siding Installation	**27:** Install siding properly	✔								
Chapter 5, Appendix J	28: Flood Protection of Critical and Essential Facilities	**28**: Local jurisdictions should determine what facilities are critical and essential			✔	✔	✔	✔	✔	✔	
Sections 4.2.1, 5.2.1, 5.5, 5.6, 5.7	29: Flooding in Subgrade Areas Between Buildings	**29a:** Develop educational materials on below-grade flooding vulnerabilities		✔	✔	✔	✔	✔	✔	✔	
		29b: Protect against flooding across subgrade connections		✔	✔	✔			✔	✔	
Sections 3.1.6, 4.1.3, 4.2.3, 5.2.3, 5.3.3, 5.4.3, 5.5.3, 5.6.3, 5.7.3	30: Poor Performance of Buildings and Building Systems	**30a**: Elevate new and Substantially Damaged/ Improved structures to protect from flooding	✔	✔	✔	✔	✔	✔	✔	✔	
		30b: Elevate existing structures to protect from flooding	✔								
		30c: Building designs should account for flood conditions	✔	✔	✔	✔	✔	✔	✔	✔	
		30d: Improve protection of subgrade areas outside the SFHA	✔	✔	✔	✔	✔	✔	✔	✔	✔

Table 7-3: Summary of Conclusions and Recommendations (continued)

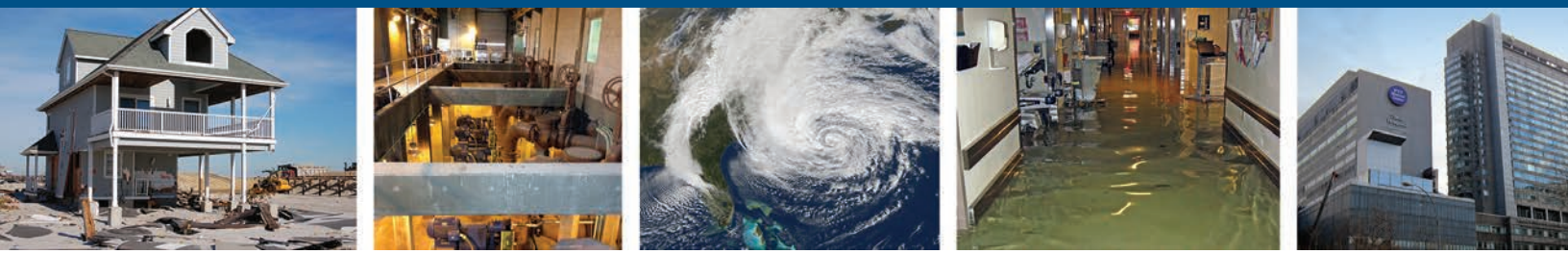
Observations	Conclusions	Recommendations	Low-Rise	Mid- and High-Rise	Healthcare Facilities	First Responders	Schools	Data Centers	Wastewater Treatment Plants	Transportation Facilities	Historic Structures
Sections 1.2.2, 1.4	**31:** Accounting for Future Conditions	**31**: Designers should consider the potential impacts of sea level rise	✔	✔	✔	✔	✔	✔	✔	✔	
Sections 3.1.6, 4.1.3, 4.2.3, Chapter 5	**32:** Protection of Building Systems	**32:** Building owners should elevate, relocate, or protect building systems above the BFE	✔	✔	✔	✔	✔	✔	✔	✔	✔
	33: Emergency Power Systems	**33a:** Submit a proposal to modify ASCE 24, Section 7.1 commentary		✔	✔	✔	✔	✔	✔	✔	
		33b: Determine minimum required emergency power duration and capacity		✔	✔	✔	✔	✔	✔	✔	
	34: Protection of Building System Components	**34:** Protect critical building systems in subgrade areas		✔	✔	✔	✔	✔	✔	✔	
	35: Facilitate the Connection of Temporary Building Systems	**35:** Establish points for temporary power connection		✔	✔	✔	✔	✔	✔	✔	
Sections 4.1.4, 4.2.4, 5.2, 5.5, 5.7	**36:** Protect Below-Grade Elevator Equipment	**36a:** Emergency plans should address the possibility of elevator failure		✔	✔	✔	✔	✔	✔	✔	
		36b: Facilities should protect elevator service, especially when it is essential to function		✔	✔	✔	✔	✔	✔	✔	
Sections 4.1.3, 4.2.3, Chapter 5	**37:** Protection of Fuel Storage Tanks	**37a:** Design installation of large fuel storage tanks to resist flotation and implosion		✔	✔	✔	✔	✔	✔	✔	
		37b: Protect tanks in subgrade areas from flood damage		✔	✔	✔	✔	✔	✔	✔	
Sections 3.1.6, 4.1.3, 4.2.3, Chapter 5	**38:** Protection of Associated Utilities Equipment	**38:** Install fuel pumps in large storage tanks to maintain operations		✔	✔	✔	✔	✔	✔	✔	
	39: Sump Pumps	**39:** Install sump pumps to remove seepage from subgrade areas		✔	✔	✔	✔	✔	✔	✔	
Chapter 5	**40:** Need for Holistic Approach to Building Systems and Planning	**40a:** Building owners should provide emergency power systems for facilities			✔	✔	✔	✔	✔	✔	

Table 7-3: Summary of Conclusions and Recommendations (continued)

Observations	Conclusions	Recommendations	Low-Rise	Mid- and High-Rise	Healthcare Facilities	First Responders	Schools	Data Centers	Wastewater Treatment Plants	Transportation Facilities	Historic Structures
Chapter 5	**40:** Need for Holistic Approach to Building Systems and Planning	**40b:** Adhere to Presidential Preparedness Directive 21			✔	✔	✔	✔	✔	✔	
		40c: Facility owners and operators should develop holistic plans to limit disruption of critical functions			✔	✔	✔	✔	✔	✔	
	41: Prepare for Emergency Evacuation	**41:** Healthcare facilities should develop a comprehensive plan for complete power loss			✔						
Section 5.2	**42:** Loss of Power	**42:** Develop emergency plans that cover complete power loss for extended periods			✔						
	43: Vulnerable Healthcare Equipment	**43a:** Prepare key records before a significant storm event			✔						
		43b: Protect critical function areas from flooding			✔						
Section 5.7	**44:** Fuel Shortages	**44a:** Prepare a plan for maintaining fuel supplies								✔	
		44b: Protect subgrade fuel pumps from flooding								✔	
	45: Insufficient Flood Protection of Transit and Maintenance Facilities	**45a:** Protect key utilities and ventilation equipment to the level applicable for critical facilities								✔	
		45b: Prepare a plan to protect critical assets								✔	
		45c: Install barriers to prevent floodwater entering transit stations								✔	
	46: Insufficient Preparedness of Transit Facilities	**46**: Install submersible pumps								✔	
Section 5.6	**47:** Insufficient Below-Grade Flood Protection of Wastewater Treatment Plants	**47:** Protect utility tunnels from flooding							✔		
Chapter 6	**48:** Hazard Planning	**48a:** Develop site-specific multi-hazard mitigation plans for landmark buildings									✔

Table 7-3: Summary of Conclusions and Recommendations (concluded)

Observations	Conclusions	Recommendations	Low-Rise	Mid- and High-Rise	Healthcare Facilities	First Responders	Schools	Data Centers	Wastewater Treatment Plants	Transportation Facilities	Historic Structures
Chapter 6	**48:** Hazard Planning	**48b:** Protect historic structures that cannot be elevated									✔
	49: Integrate N.J.A.C. 5:23-6 and the NFIP	**49:** Develop mitigation guidance for historic structures									✔
	50: Retention of Historic Designation	**50:** Evaluate retrofit options for historic buildings									✔
	51: Protection of Climate-Controlled Artifacts	**51:** Protect critical building systems of historic structures									✔
	52: Unshielded Subgrade Windows and Doors	**52:** Protect subgrade windows and doors									✔



HURRICANE
SANDY
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