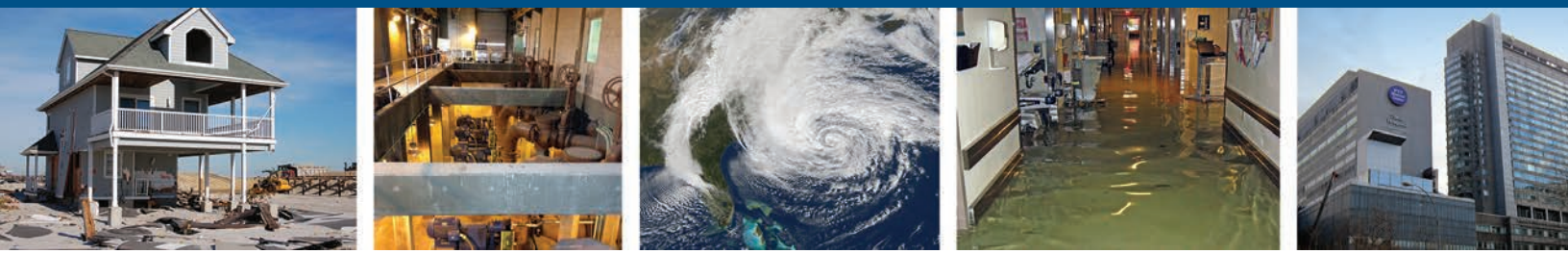

HURRICANE SANDY IN NEW JERSEY AND NEW YORK

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

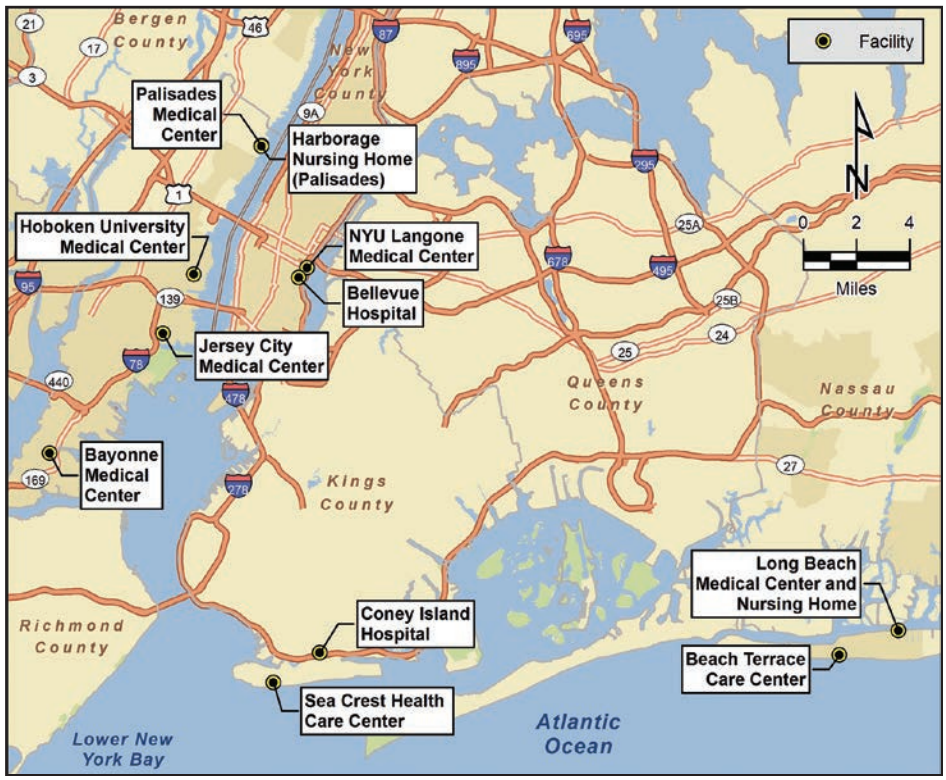

Table 5-2 lists each of the healthcare facilities visited, along with the applicable flood zones, 1-percent- and 0.2-percent-annual-chance flood elevations for sites located in Zone A, and the level of storm surge during Hurricane Sandy. The flood zones in Table 5-2 include those shown on FEMA flood 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

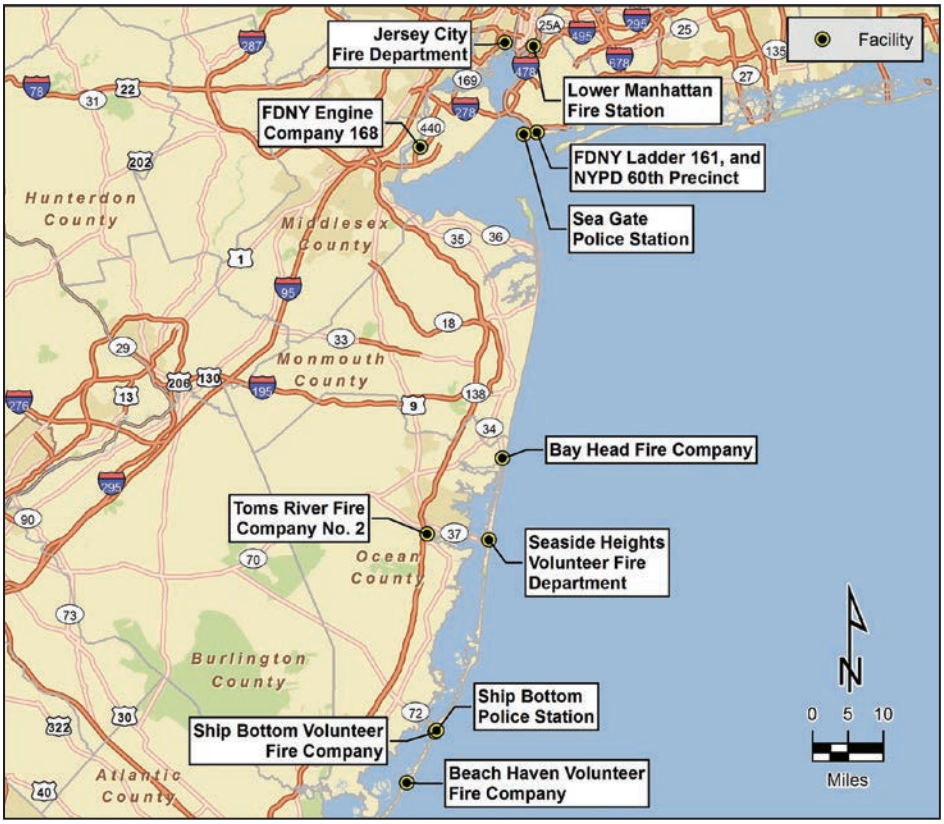

Figure 5-7: Locations of first responder facilities visited by the MAT

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.

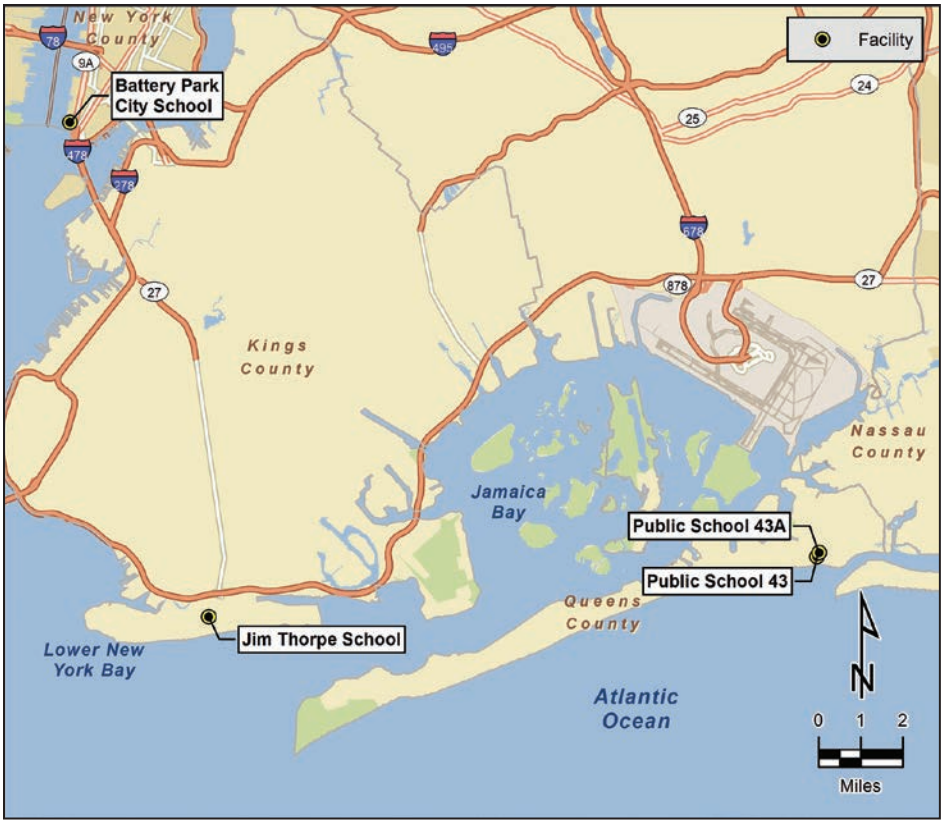

Figure 5-9: Locations of schools described in this report

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.

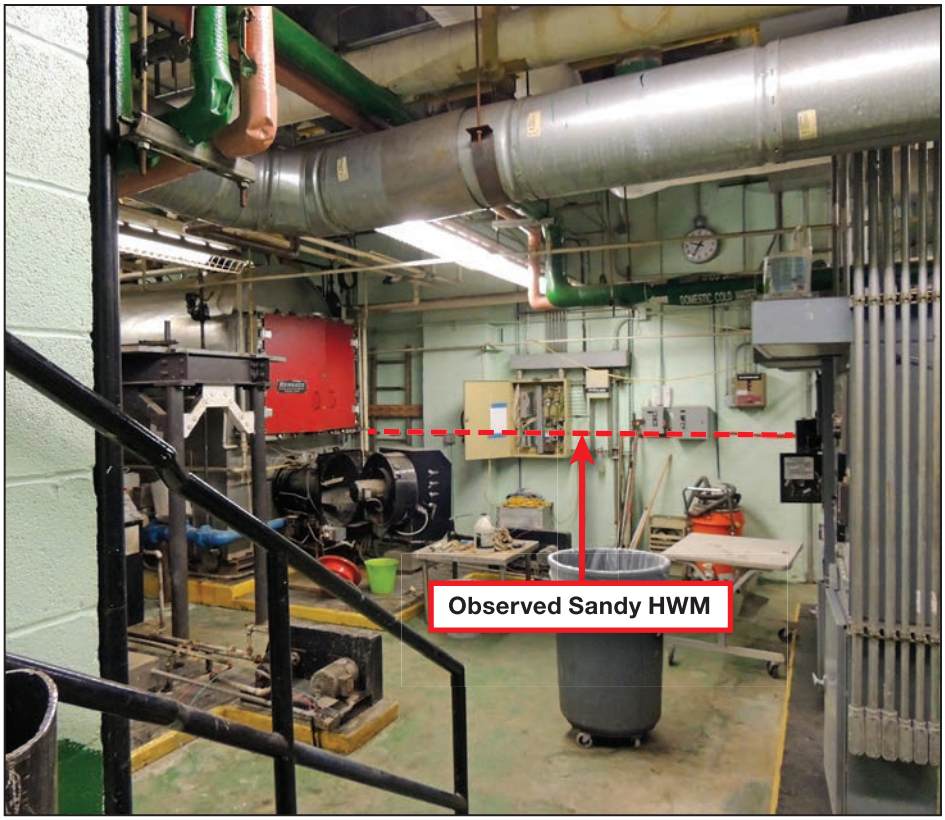

Figure 5-10: The basement of PS43 was inundated with approximately 5 feet of water (Queens, NY)

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).

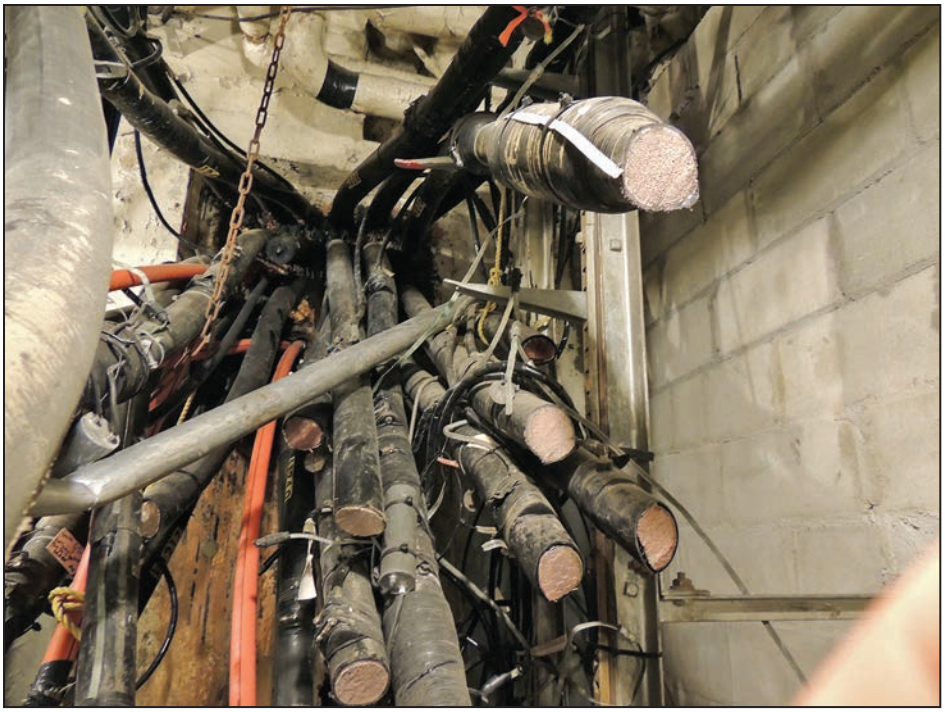

Figure 5-12: Copper communication cables that were damaged by water intrusion into the cable sheathing; positive gas pressure that kept the cables dry was lost when the equipment in the basement was flooded at this data center (Manhattan, NY)

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

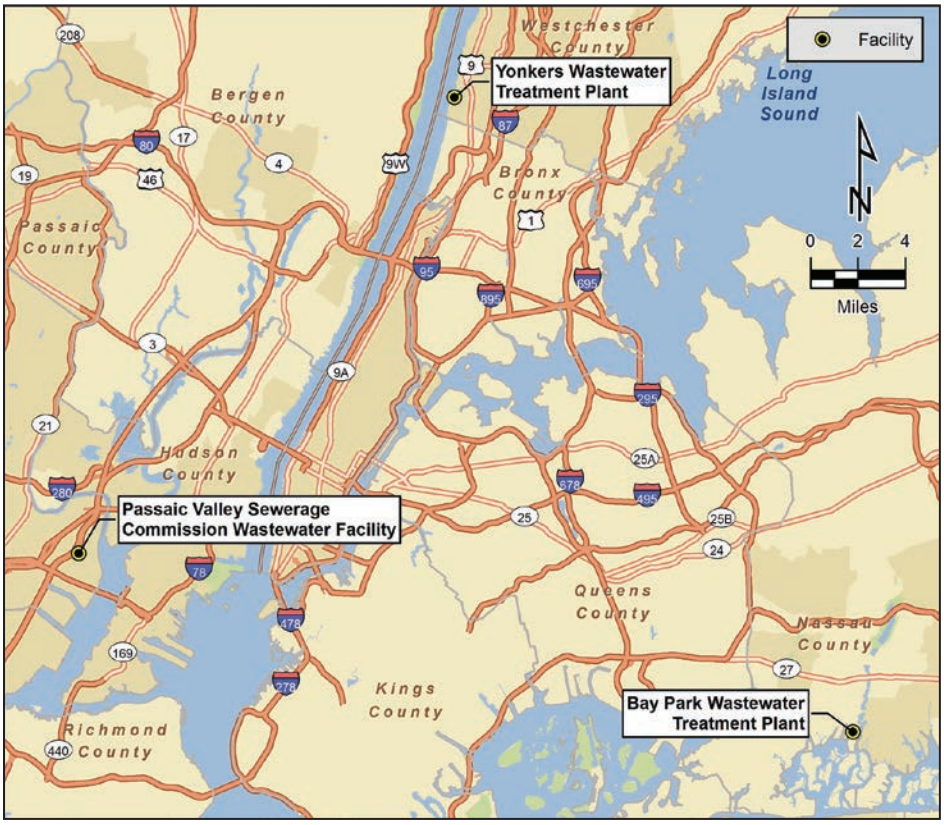

Table 5-6: BFEs, ABFEs, and Sandy Floodwater Elevations for WWTPs Visited by the MAT

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.

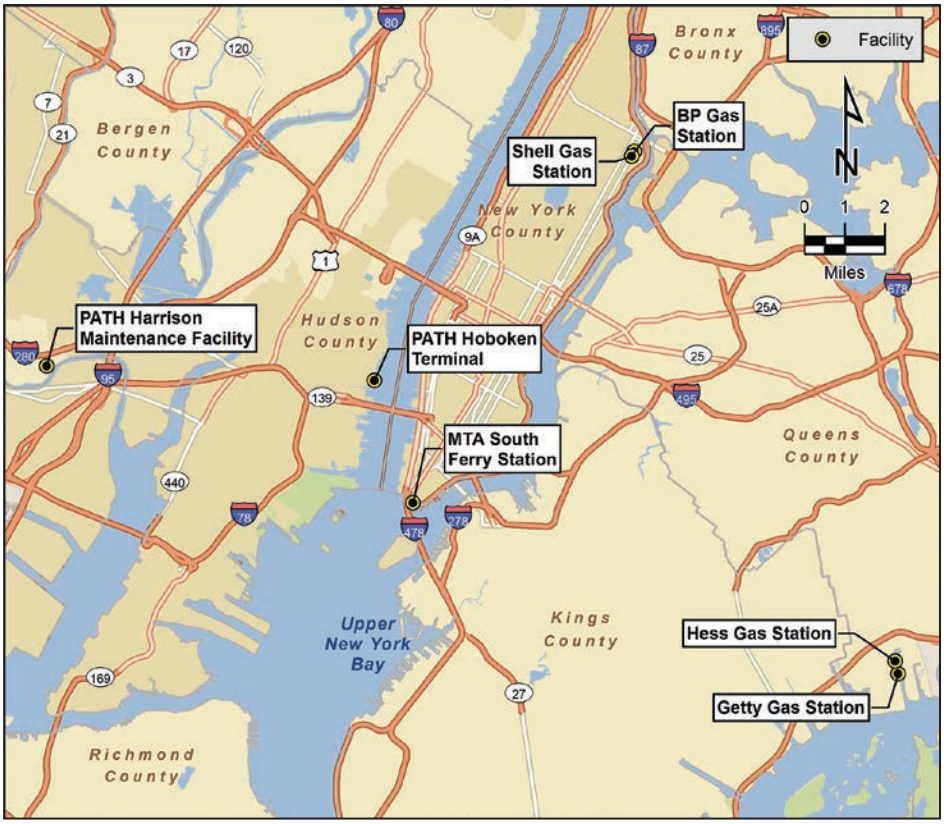

Figure 5-17: Locations of the transportation facilities visited by the MAT

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)

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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.