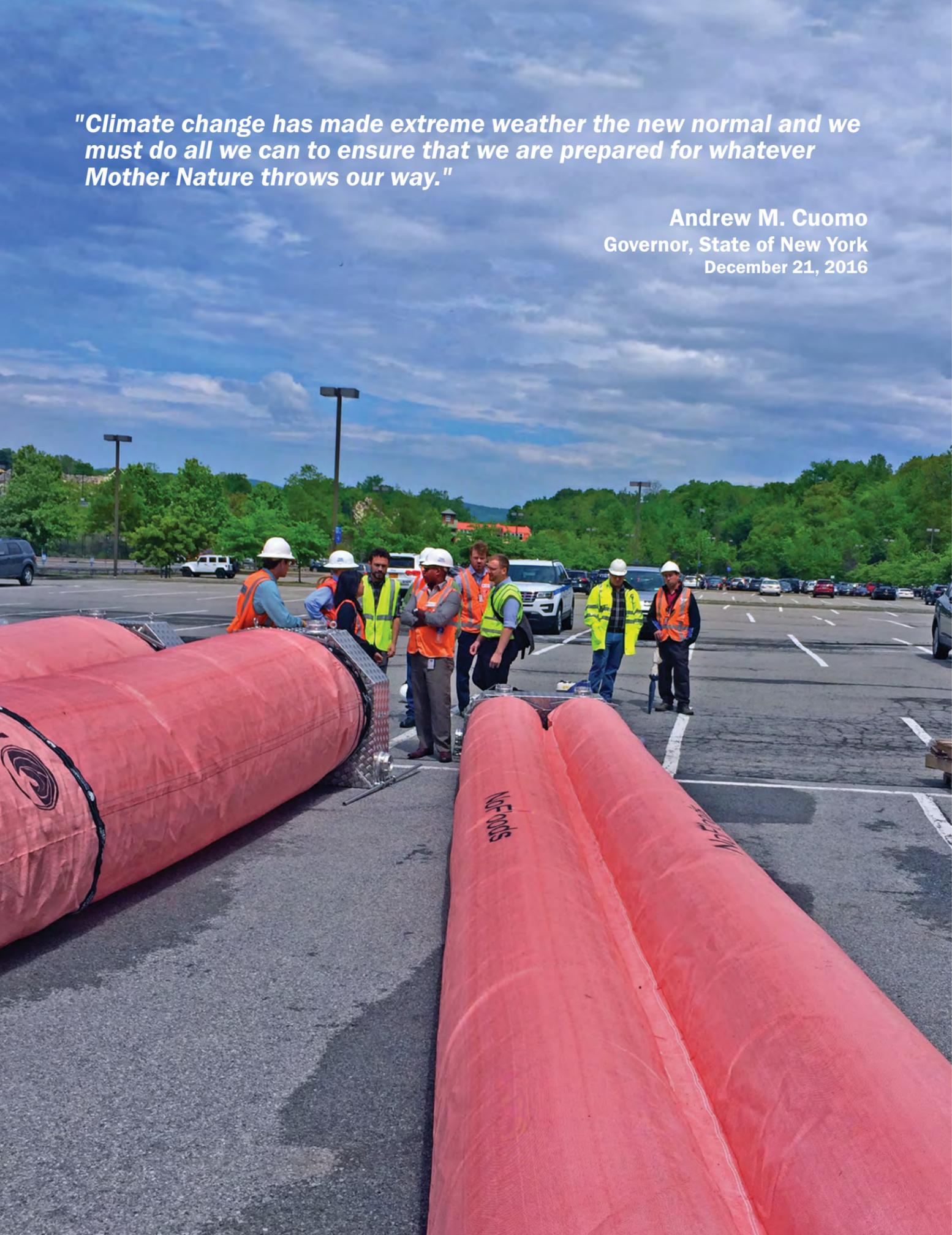


MTA Climate Adaptation Task Force Resiliency Report



"Climate change has made extreme weather the new normal and we must do all we can to ensure that we are prepared for whatever Mother Nature throws our way."

Andrew M. Cuomo
Governor, State of New York
December 21, 2016



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Opposite: Demonstration of deployable water-filled twin tube flood barrier.



“Preparedness for extreme weather events is one of the MTA’s foremost challenges, in providing mobility to our region. As we plan our operations, maintain a state of good repair and embark on expansion, and other capital projects, climate resilience is uppermost on our minds.”

Veronique Hakim, Interim Executive Director
Metropolitan Transportation Authority
March 2, 2017

Section 1. Introduction: How We Got Here

For the Metropolitan Transportation Authority (MTA), climate change is not only an urgent reality, it is a reality to which all six MTA agencies are already devoting extensive financial, planning, and engineering resources. There is no responsible alternative. The science of climate change is well established. The damages to New York’s transportation assets by Superstorm Sandy in 2012 gave the MTA no feasible option but to rebuild the system in anticipation of rising sea levels and increasingly volatile weather events. A disaster recovery budget of \$10.5 billion was approved in 2013.

This rebuilding effort is well underway. Some of the most badly damaged parts of the MTA network—such as MTA New York City Transit’s (NYCT’s) Montague Tube under the East River—were repaired, fortified, and returned to full revenue service with speed and efficiency. Further progress on these recovery/resiliency efforts is detailed in the MTA’s Capital Program, where superstorm projects are budgeted and tracked.¹ Significantly, over half of the currently approved post-Sandy budget is dedicated to resiliency projects aimed at fortifying the MTA system against severe storm surges and other future climate-driven weather events.

Those resiliency projects, viewed in the broader context of climate adaptation, are the focus of this report—the first annual report of the inter-agency MTA Climate Adaptation Task Force.

The Task Force was formed after Superstorm Sandy at the direction of then Chairman Thomas Prendergast; it has continued to meet regularly with MTA agency staff to coordinate information on climate adaptation efforts, while also exchanging information with experts from the NYC Panel on Climate Change, NYC Office of Recovery & Resiliency, the Port Authority of New York & New Jersey, and other outside organizations.

This initial report offers a broad view of the MTA’s climate actions to date, as well as a more detailed look at selected resiliency projects. These range from emergency protocols to the fortification of tunnels and the permanent elevation of flood-exposed electrical facilities and signal systems. Some use off-the-shelf flood preventions, such as stop logs; others entail customized or newly developed equipment, for which the Task Force has helped arrange vendor demonstrations. The majority of MTA climate adaptations are integrated into the post-Sandy repair capital projects.

Subsequent reports will track and expand upon this information. By annualizing this report, the MTA recognizes what Sandy proved four years ago. Repair is not enough. We must rebuild and adapt our critical transportation assets—upon which millions of individuals and businesses depend—to withstand rising sea levels, increased storm surges, and other trends identified by climate science.

Section 2. Climate Science and MTA Impacts: Where We Are Headed

A Climate Resilient MTA Helps Lower GHGs

Fortifying the MTA system against extreme weather plays a double role in regional climate adaptation. Scientists agree that the main driver of global climate change is the emission of greenhouse gases (GHGs) into the atmosphere. According to the U. S. Environmental Protection Agency (EPA), 29 percent of GHG emissions are due to transportation.² However, this number only takes into account “tailpipe” emissions, and does not include the energy refinement process. When refinement is included, the percentage of GHG emissions from transportation jumps to ~42 percent. By providing a fuel-efficient transportation alternative, the MTA prevents an estimated 17 million metric tons of GHG emissions per year.³

Moreover, by increasing mass transit options through capital expansions and aggressively reducing its vehicle and facility emissions, the MTA continuously mitigates the local accelerators of climate change. As a result, people living in the MTA’s service region are among the most carbon-frugal in the nation. Indeed, the MTA is one of the nation’s most powerful models for economic expansion with reciprocal GHG reduction. Resiliency projects fortifying and securing the MTA system contribute to this virtuous cycle.

Climate Adaptation Strategies for the MTA

Due to aging infrastructure and vulnerable assets, e.g. underground tunnels and under-river tubes, climate change disproportionately impacts the MTA. Resiliency measures will provide the MTA, and the region, the climate adaptation solutions to manage the risks resulting from higher temperatures, increased precipitation, and sea level rise. Some of these measures, such as raising critical infrastructure, retrofitting older infrastructure, improving and practicing emergency response, are highlighted in the upcoming sections of this report. In order for the MTA to properly prepare and design these resiliency measures, it must look to climate science to understand the different scenarios and climate projections that the region will face in coming decades.

While the MTA seeks to build climate science into its planning, climate research is beyond its public mission and skill set. For local climate models, the MTA draws on a number of expert sources—most notably the 2014 ClimAID⁴ Report by the New York State Energy Research and Development Authority (NYSERDA); the 2015 report of the New York City Panel on Climate Change⁵ (NPCC); and the North Atlantic Coast Comprehensive Study⁶ by the U.S. Army Corps of Engineers (USACE).

The MTA seeks to continually improve its network’s overall “climate resiliency,” which is defined by the International Panel on Climate Change (IPCC) as: “the ability of a system and its component parts to anticipate, absorb, accommodate, or recover from the effects of a potentially hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration, or improvement of its essential basic structures.”⁷



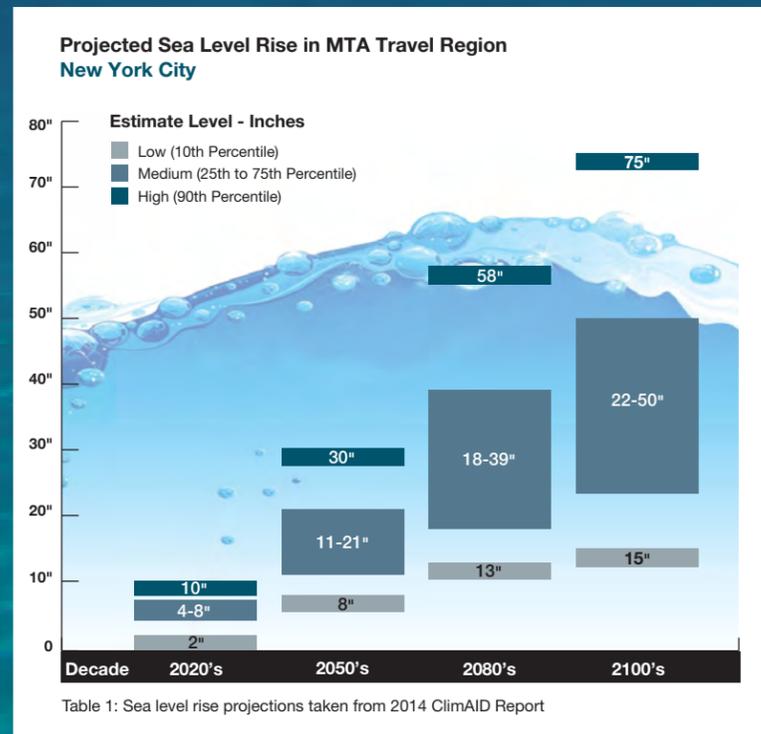
Climate Risk and Climate Change Projections for the MTA Travel Region

Climate change hazards for the MTA fall into three broad categories: sea level rise and coastal storm surge, rising temperatures, and increased precipitation. The sources listed on the previous page, ClimAID, NPCC, and the North Atlantic Coast Comprehensive Study, provide data on climate change projections relevant to the MTA's 5,000-square-mile service region. Summaries of those projections are outlined below. Table 4, which follows, outlines the linkages between these climate hazards and potential impacts to MTA assets.

Because of the coastal location of many MTA assets, the impacts from coastal storm surge are significant, i.e. long-term saltwater damage and erosion to electrical systems in addition to immediate damage from inundation, and thus it is the focus of much of the MTA's current resiliency program. Two other climate change related trends—extreme temperatures and increased precipitation—also play a role in the MTA's resiliency planning, as they have potentially measurable impacts on service delivery and asset security across the MTA network.

Sea Level Rise and Storm Surge

Of the factors cited above, rising sea levels and related storm surge represent the greatest threat to the MTA system—as evidenced by the enormous flood damage from Superstorm Sandy. Sea level rise affecting the MTA travel region has increased 1.2 inches every decade since 1900, and is projected to increase at accelerating rates over the coming decades. Sea level in the New York City and Lower Hudson



regions is projected to rise 8 to 30 inches by the 2050's.⁸ Rising sea levels will, in turn, exacerbate the magnitude and severity of future storm surges. If not addressed, these climate-related impacts could result in increased service disruptions and delays which in turn will affect the economic productivity of the region.

Projected Temperature Rise in MTA Travel Region New York City

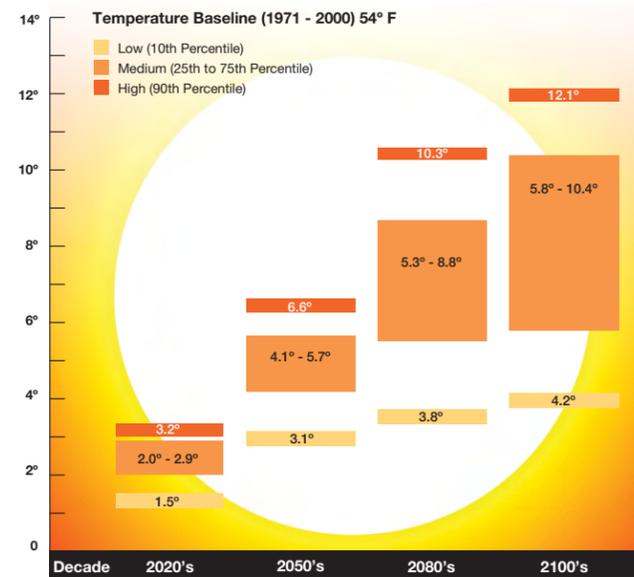


Table 2: Average temperature increase taken from 2015 NPCC Report

Temperature

Rising average temperatures and extreme temperature events will have a significant impact on MTA infrastructure and operations. According to the NPCC report, average temperatures in the MTA travel region are projected to rise between 3.1°F to 6.6°F by the 2050's.⁹ Higher average temperatures and more frequent heat waves would increase known stresses on MTA infrastructure. Given its reliance on electrical power, MTA operations will be broadly disrupted by heat-related blackouts or brownouts. Higher temperatures can also cause over-heated switch gears, along with expansion and buckling of steel rails. The increased stress on air conditioning systems in vehicles, stations, and operational facilities can result in service disruptions, while air conditioning and circulation outages can lead to medical risks to both passengers and workers.¹⁰

Projected Precipitation Increase in MTA Travel Region New York City

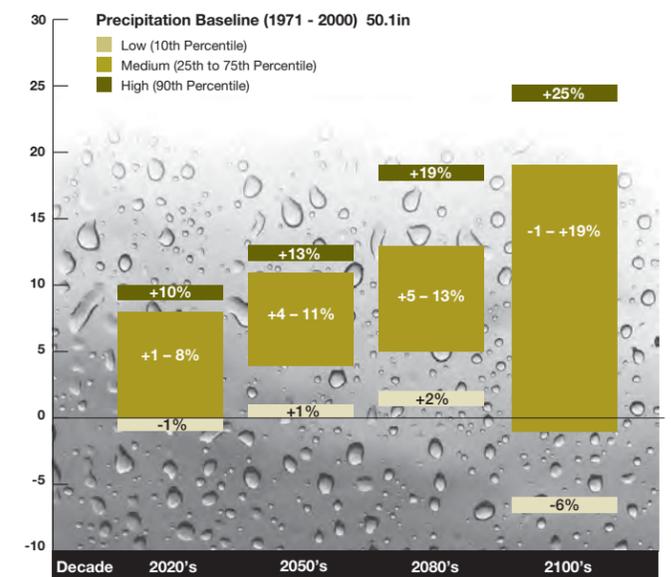


Table 3: Increase in precipitation taken from 2015 NPCC Report

Precipitation

While less dramatic, projected increases in average precipitation mean that inland flooding may produce system stresses similar to those presented by coastal flooding. Climate projections for New York City indicate an increase in average precipitation between 1 percent and 13 percent by the 2050's.¹¹ While the average increase may not seem significant, the likelihood of more severe rainstorms and rapidly melting winter snowfalls will mean a greater risk of inland flooding and erosion. The potential impact on MTA services and assets is indicated by the MTA's August 2007 Storm Report, which describes major delays due to insufficient drainage and pumping, affecting over 2.5 million customers. While those issues have been addressed with new protocols and system upgrades, including redesigned ventilation grates, future storms of increasing severity may once again test the MTA's resiliency to heavy inland rainfalls and flooding.¹²

Climate Impacts and MTA Infrastructure

The MTA's transportation network and infrastructure assets cover 5,000 square miles of service territory and 2,069 track miles, all of which are impacted by various, often compounded, climate change hazards. Since large portions of the MTA transportation network consist of aging infrastructure and are vulnerable to coastal inundation, a more precise correlation of climate impacts and MTA assets is necessary.

The following chart—based on lessons learned from previous storms, best practices from international transit agencies, and comparative climate adaptation studies—identifies the climate risks to specific MTA assets. Refining and quantifying these correlations will be one aim of future editions of this climate adaptation report.

Climate Impacts and MTA Infrastructure Assets		Climate Impacts and MTA Infrastructure Assets
Climate Change Hazards	Infrastructure Assets	Potential Impacts
Sea Level Rise	Bridges, Electrical & Communications Equipment, Maintenance Facilities & Shops, Railroad & Subway Track	<ul style="list-style-type: none"> Impacts to ship clearance below bridge spans Scour on bridge structures and infrastructure in tidal areas Corrosion of track and equipment from saltwater exposure Increased flooding of facilities and rights of way in low lying coastal areas Increased recurrence and inundation from coastal storm surge
Coastal Storm Surge	Bridges, Electrical & Communications Equipment, Fan Plants, Maintenance Facilities & Shops, Maintenance Vehicles & Support Fleet, Passenger Stations, Power Equipment, Pumping Facility, Railroad & Subway Track, Rolling Stock & Bus Fleet, Signal Equipment, Substations, Switches, Third Rail, Tunnels	<ul style="list-style-type: none"> Flooding leading to electrical equipment failure, severe or irreparable structural damage, and inundation of fleet vehicles and rolling stock Saltwater erosion—particularly to aging equipment, structures, machinery, wiring, and motor control equipment Potential impact on fan plants and air circulation in underground network, leading to fire hazards Potential impact to substations and power distribution systems; partial system failures and safety concerns as water levels reach elevation of third rail; dependence on electricity grid that may be experiencing blackout or brownout Ground erosion from flooding in and around facilities and yards; excessive debris from outside of property onto rights of way; potential damage to track and line structures Service interruptions, impediments to operations, and alternate routing in portions of the network (or individual stations) due to failures related to inundated equipment and machinery or due to evacuation or limited access to an area Water infiltration of facilities and below ground rail and subway network; overloading of drainage system with large volumes of water entering the system; subsequent problems with backflow from outlets; need for pre-storm deployment of flood barriers and additional pumping equipment
Extreme Winds	Bridges, Railroad & Subway Track, Tunnels & Underpasses, Yards, Stations	<ul style="list-style-type: none"> Safety concerns from intense winds along service network Damage to line structures and infrastructure damage to above ground rail network Excessive debris from outside of property onto right of way, causing damage to tracks, switches, and line structures, and potentially undermining track support Damage to structural integrity of maintenance facilities and yards
Average Temperature Increase and Heat Waves	Bridges, Electrical & Communications Equipment, Employee Facilities, Fan Plants, Maintenance Facilities & Shops, Maintenance Vehicles & Support Fleet, Passenger Stations, Power Equipment, Railroad & Subway Track, Rolling Stock & Bus Fleet, Signal Equipment, Substations	<ul style="list-style-type: none"> Need for additional air conditioning or air tempering to provide habitable work spaces; need for additional air conditioning to provide suitable customer environment; increased demand on air conditioning service and reliability Potential overheating of hydraulic fluids in equipment; need for added ventilation and fans to dissipate excessive heat Dependence on electricity grid that may be experiencing blackout/brownout; increased failures from over-heated switch gears and higher loads Heat induced expansion of steel rails in elevated structures and at grade sections of track; rail buckling and kinking in track and switch components Increased likelihood of failure of aging equipment and wiring, resulting in diminished useful life
Heavy Precipitation	Bridges, Electrical & Communications Equipment, Fan Plants, Maintenance Facilities & Shops, Maintenance Vehicles & Support Fleet, Passenger Stations, Power Equipment, Pumping Facilities, Railroad & Subway Track, Rolling Stock & Bus Fleet, Signal Equipment, Substations, Switches, Third Rail, Tunnel/Underpass, Yards	<ul style="list-style-type: none"> Flood water damage to wiring and aging equipment; increased run off entering basements and below ground portions of rail and subway networks Increased water infiltration and need for additional pumping of water throughout the below ground network Potential impact to substations, signaling and power distribution systems; partial system failures and safety concerns as water levels reach elevation of third rail Potential structural damage in facilities and passenger stations; potential undermining of track support and embankments; ground erosion from flooding in and around facilities and yards Overloading of drainage system with large volumes of water entering the system; subsequent problems with backflow from outlets

Table 4: Compiled by MTA Headquarters Sustainability Initiatives Department for the MTA Climate Adaptation Task Force

Summary Countdown for Coastal Storms

For storm planning, MTA defines “zero hour” as the onset of sustained 39 mph winds. Such winds may arrive well before landfall, in some cases extending hundreds of miles beyond the eye of the storm.

Approximately five days prior to a storm’s predicted arrival, the MTA Chairman and agency presidents begin holding storm preparedness calls, along with external calls to review storm forecasts and coordinate responses with partnering state and local agencies.

72 hours, state and local emergency organizations open their emergency operations centers (EOCs) and request MTA representatives, who will keep open lines of communication at all times with partnering agencies.

72 to 50 hours, agencies begin preparing equipment and staff to ensure around the clock response and recovery operations before, during, and after the storm. Generators, water pumps, water barriers, and other mobile equipment are deployed system wide. Permanent storm fighting equipment is serviced and refueled; catch basins and drains are checked and cleared; facilities are fortified.

48 hours, city and state officials announce a general evacuation of high-risk areas. In the worst-case scenario, 2.9 million New York City residents will be ordered to evacuate before landfall—of which 1.46 million will use public transportation to leave the evacuation zones. During evacuations, the MTA operates as close as possible to normal schedules, which are familiar to personnel and city residents, while utilizing bus fleets for emergency transport.

12 to 8 hours, rail and subway service begins an orderly shutdown. This allows MTA agencies time to secure equipment and evacuate staff.

8 to zero hours, buses begin shutdown 6 hours to zero hour. MTA Bridges & Tunnels monitors weather conditions and restricts travel accordingly. Vehicular tunnels may be closed up to 8 hours before zero hour to allow for deployment of mitigation measures across roadways. Pedestrian walkways on bridges are closed at zero hour, and bridges are closed to all traffic at sustained 60 mph winds.



Section 3. Climate Events and Emergency Operations: The Zero Hour

Emergency Management and Operations

The MTA’s first line of defense against increasingly volatile weather events—whether coastal storms, winter weather events, or heat waves—is prior planning and the preparedness of agency workforces. MTA continually develops and improves emergency plans, and enhances employee skills by regularly conducting emergency planning trainings and drills.

Each MTA operating agency maintains emergency response plans that are specific to each type of weather event. Protocols, response priorities, as well as communication strategies, are identified to insure that emergency response systems are in place and that vital information will be shared within the organization and with the public. These plans are updated annually; reviewed after drills and actual events; and continually revised to reflect new knowledge and lessons learned.

On the interagency planning level, the MTA Chairman, agency presidents, and executive staffs conduct joint briefings prior to each storm season. They assess the lessons of the most recent weather events, checklist emergency response plans, and review communications protocols that link agencies, customers, and government officials during emergencies. The MTA includes continuity and succession protocols in its emergency plans. These include “what-if” scenarios for the loss of critical services, communication lines, or infrastructure, as well as an “order of succession” in the event that key personnel are incapacitated.

Emergency Preparedness: Bus Operations

Since most MTA rail services are electrically powered on fixed lines and run underground and under riverbeds, they are susceptible to power outages and tunnel flooding. Therefore the MTA bus fleet plays a special role in emergency operations, including weather events. The bus fleet, the largest in North America, has over 5,700 vehicles on 300 plus routes, serving some 2.5 million customers daily. The ability of buses to deploy rapidly and flexibly on all major public roadways makes them a key component of the MTA’s resiliency planning. Emergency bus operations may include evacuations from flood zones, transport for emergency workers, shuttle operations during rail system outages, and even warming buses in the winter and emergency cooling stations during heat waves, especially when air conditioning fails at senior centers or public housing. The most extensive use of buses for resiliency

operations followed Superstorm Sandy in 2012, when the shutdown of all under-river tunnels halted subway service. While many flooded segments of the subway system remained closed, bus service was largely restored within 24 hours. Coordinating with the New York City Department of Transportation (NYCDOT), the MTA established an unprecedented system of “Bus Bridges” to substitute for subway service across the East River. Some 650 buses ran fare-free routes across the Manhattan and Williamsburg bridges, utilizing both established “rapid transit” and improvised bus priority lanes. For four days, as the MTA worked to restore subway tubes, the “Bus Bridges” carried about 3,700 riders per hour, replacing roughly 22 rush hour trains. Such emergency shuttle operations are now a part of the MTA’s resiliency planning.

Following Superstorm Sandy, subway tunnels under the East River remained out of service due to flooding. As a temporary means to allow people to travel across the East River, 330 shuttle buses connected MTA New York City Transit Subways’ customers and Long Island Rail Road’s customers at Barclays Center, MetroTech, and Hewes Street in Brooklyn with destinations in Manhattan.

Section 4. Resiliency Projects and MTA Capital Programs: How Much It Costs

MTA Capital Program Projects

Outside of operational planning, the major impacts of climate adaption on the MTA will be seen in ongoing capital projects—in particular, those “Sandy Recovery and Resiliency” projects identified in the MTA Capital Program and undertaken following Superstorm Sandy, largely with federal funding.

All capital projects are itemized and tracked under the MTA’s approved five-year Capital Program, which are updated and made public on the MTA’s Capital Program Dashboard. Nearly all of the MTA’s recovery and resiliency projects are identified as a distinct “Sandy Recovery and Resiliency” category under the ongoing 2010–2014 Capital Program.

While Capital Program budgets provide one of the best metrics for gauging the scale and type of ongoing resiliency work at the MTA, the following stipulations must be noted. Many line items may be components of larger projects or project phases. Project data is updated regularly, and costs are subject to future amendment and reconciliation.¹³

2016 Resiliency Projects at a Glance

Taken together, MTA’s rail and transit agencies—Long Island Rail Road (LIRR), Metro-North Railroad (Metro-North), NYC Transit (including Staten Island Railway (SIR)) and Bridges and Tunnels—have identified 46 major resiliency projects, most of which are underway. Out of approximately \$3.0 billion in resiliency funding, \$751 million has been committed system wide, with a large surge in resiliency commitments expected in 2017 and early 2018, including some \$0.8 billion in flood mitigation projects at NYC Transit yards.

MTA Resiliency Project Commitments: 2016 Summary		
	Projects Completed or Underway	Dollars Committed (Millions)
NYC Transit and SIR	29	\$580.4
LIRR	5	\$22.0
Metro-North	3	\$54.9
Bridges & Tunnels	9	\$93.5
Total	46	\$750.8

Table 5: Summary of Resiliency Project Commitments from MTA Capital Program

Resiliency Project Accomplishments: as of 2016

NYC Transit and SIR

- Completed Montague Tube Restoration Project in conjunction with tube repairs, including installation of corrosion-resistant duct banks and cabling.
- Completed installation of a temporary perimeter floodwall to protect Coney Island Yard.
- Increased NYC Transit’s pumping capacity by converting existing rolling stock into two new pump trains.
- Awarded hundreds of millions in resiliency contracts by year-end, including a resiliency rebuild of SIR’s Clifton Shop, and long-term protections at more than a dozen subway stations.
- Continued to seal street-level openings in Lower Manhattan and fan plants in Brooklyn and Queens.

LIRR

- Continued to advance protective measures at the LIRR Long Island City Yard.
- Initiated the design effort for the perimeter walls at the LIRR’s West Side Yard and flood barriers at the Queens Portal.
- LIRR’s Emergency Management Equipment Mitigation project continued to progress, as did the construction on the Atlantic Avenue Tunnel Mitigation project.

Metro-North

- Continued to advance flood protections and other protective measures for the Hudson Line, including flood proofing of 8 DC traction power substations power and 1 signal substation, using swing gate doors and perimeter wall reinforcement. Water level monitoring systems will be installed at 3 of the substations that are located below FEMA flood elevation standards.
- Continued to advance flood mitigation measures at railyard buildings for Croton-Harmon Yard and Highbridge Yard. Flood protection measures are to include water resistant flood doors and barriers, sealing of foundations, and concrete curbing.

Bridges and Tunnels

- Progressed tunnel restoration work at the Hugh L. Carey Tunnel and the Queens Midtown Tunnel, including resiliency measures such as submersible drainage pumps; this work is scheduled to be completed in 2018 at both tunnels.
- Continued to advance replacement of electrical substations and related equipment and relocation above the FEMA 500-year flood level at Rockaway bridges (Marine Parkway Bridge and Cross Bay Bridge).
- Awarded two-year design-build contract for long-term flood mitigation at the Hugh L. Carey Tunnel and Queens Midtown Tunnel. All mitigation measures are to be installed by the end of 2018.



Section 5. Selected MTA Climate Adaptation Projects: What We Are Doing

The MTA Capital Program seeks to address resiliency needs across its entire network to address all climate change-related risks in the coming decades. The range of projects is vast and ambitious. From shoreline stabilization along the Hudson River, to gates that seal both road and rail tunnels, to fortification of hundreds of hatch-doors and manhole covers; from raising electrical substations to installing marine doors for those which cannot be raised and using marine-grade cabling, the MTA has embraced a vast range of technologies and solutions to make its facilities resilient. The following section highlights specific notable projects, most of which sustained substantial damage during Superstorm Sandy. While service was successfully restored to all portions of the network, longer-term resiliency efforts are ongoing for some projects.

- 1 Substations and Breaker Houses***
MTA Metro-North Railroad
- 2 148th Street Portal**
MTA New York City Transit Subways
- 3 Michael J. Quill Bus Depot**
MTA New York City Transit Buses
- 4 Montague Street Tube**
MTA New York City Transit Subways
- 5 Hugh L. Carey Tunnel**
MTA Bridges & Tunnels
- 6 St. George Terminal**
MTA New York City Transit
Staten Island Railway
- 7 Coney Island Yard**
MTA New York City Transit Subways
- 8 Rockaway Bridges
(Marine Parkway Bridge)**
MTA Bridges & Tunnels
- 9 Rockaway Line***
MTA New York City Transit Subways
- 10 Rockaway Bridges
(Cross Bay Bridge)**
MTA Bridges & Tunnels
- 11 Far Rockaway Bus Depot**
MTA Bus Company
- 12 Long Beach Branch Signal and
Communications Systems***
MTA Long Island Rail Road
- 13 Long Beach Branch Substations***
MTA Long Island Rail Road

*multiple locations

Section 5 (a). MTA New York City Transit (NYCT) Subways and Staten Island Railway (SIR)

MTA New York City Transit (NYCT) Subways are particularly vulnerable to climate change impacts, rising sea levels, and storm surges from coastal weather events. The subway network is an electric-powered system operating largely below ground, with 14 under-river tunnels and extensive assets in coastal flood zones. Approximately \$3 billion will be spent on repairing flood damage from Superstorm Sandy in 2012, and more than \$5 billion of damage was sustained to Subway assets. The subsequent repairs, which will continue for a number of years, integrate many new resiliency features, including redundant cabling and water-resistant equipment. In addition, over \$2.5 billion will be spent on dedicated resiliency projects, which include sealing over 3,600 water inlets to the system, hardening substations and fan plants, elevating critical equipment, and much more. The following cases illustrate the impacts of an increased occurrence of flood events and necessary system adaptations.

Montague Tube

Type: Under-river subway tube for the R Line, serving 65,000 daily riders.

Impacts: Flood surge, debris, saltwater corrosion.

Scope: Approximately \$250 million, 14-month restoration-resiliency project.

Status: Completed, returned to revenue service Sept. 2014. Additional flood protections to come.

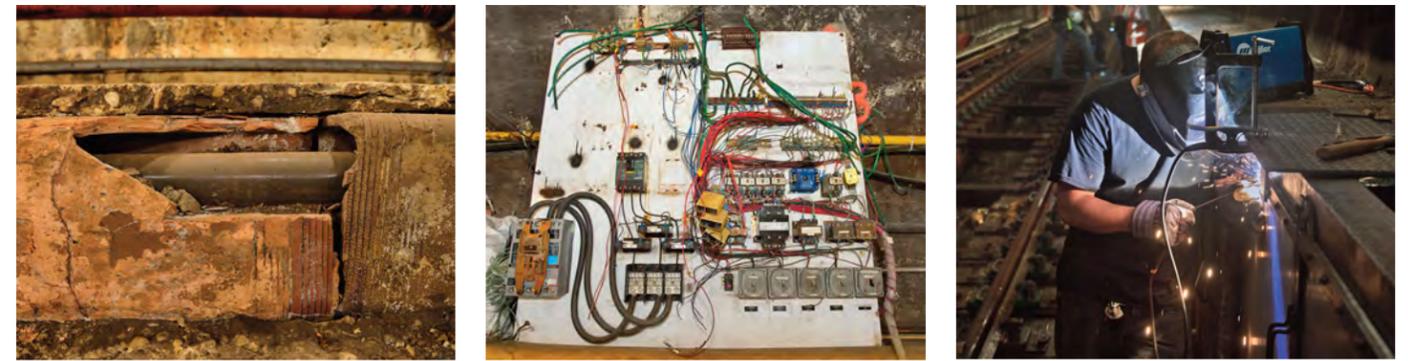
Adaptations:

- Constructed 30,000 linear feet of new duct banks, containing more than 78,000 feet of power cable.
- Installed 11,000 feet of new track and associated hardware, including resilient rail fasteners designed to provide a smoother ride.
- Replaced 105,000 linear feet of communication cable, 34,000 feet of antenna cable, and 35 emergency alarms and telephones.
- Installed three new pumps capable of removing more than 1,900 gallons of water per minute, as well as 8,000 feet of pump discharge line.
- Installed emergency pump control at higher elevation.
- Installed new signal room with 18 cabinets at higher elevation.
- Advancing additional resiliency measures to protect the tube against a Category 2 storm with an additional 3 foot safety factor, based on the NYCT design flood elevation guidelines.

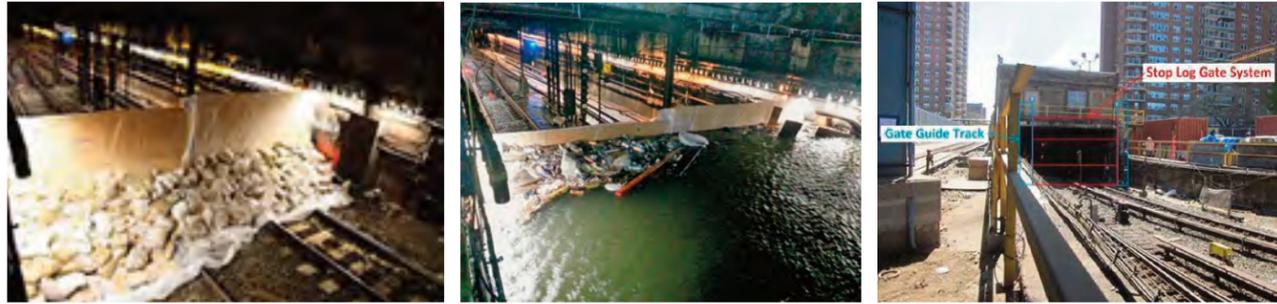
Project Description:

The Montague Tube is one of 14 under-river tunnels, nine of which were damaged by the 2012 superstorm. The Montague Tube, one of the most heavily damaged, was flooded to a length of about 4,000 feet and depth of approximately 20 feet with 27 million gallons of debris-filled saltwater. The flooding damaged signals, pumps, track, third rail, communications systems, electrical components, and concrete duct banks. Temporary service was restored within two months. The tube was closed for long-term repair in August 2013 and reopened weeks ahead of schedule in September 2014.

In addition to repairs, new resiliency measures included installation of marine cabling, hardening of pump systems, and protection of electrical facilities with watertight doors. Further resiliency projects will protect the fan plants and other flood vulnerabilities on either end of the tube. Vents will be protected, watertight doors will be installed, and structural walls will be fortified to withstand storm surges and debris.



Top, L to R: Post Sandy damage, Damaged circuit board, Repair of damaged infrastructure
Center, L to R: New cables running through duct banks, New pump room, Repair of damaged tube
Bottom: Tube, post repair



148th Street Portal

Type: Tunnel portal where No. 3 Subway Line emerges to above-ground terminal.

Impacts: Harlem River flooding minimized by temporary flood barriers.

Scope: Approximately \$7 million system of flood logs for a portal 15' high by 24' wide.

Schedule: Flood logs have been designed. Award of the project is expected in early 2017.

Adaptations:

- Seals portal against storm surge of Category 2 storm with an additional 3 foot safety factor, based on the NYCT DFE guidelines with an aluminum flood log system, replacing the labor-intensive and less-reliable temporary wooden barrier.
- Protects thousands of track feet and critical signal, power, communications systems.
- Coordinates with perimeter protection of Harlem-148th Street Yard and Station.

Project Description:

The 148th Street Portal, where tracks emerge from the subway to the above-ground terminal station and storage yard, represents a major flood risk from the Harlem River. If the walled perimeter of the station area were overtopped, flooding could inundate much of the Lenox Avenue Line. During Sandy in 2012 and prior events, flooding was minimized by the construction of plank walls. As flood levels rise, this labor-intensive, temporary solution is insufficient.

To ensure long-term protection, a system of flood logs has been designed for the portal. Aluminum logs with rubber gaskets can be fitted into pre-installed channels and support posts along the portal's perimeter. The system can be deployed within hours of an oncoming storm and will protect the portal from a Category 2 hurricane. This method of sealing the portal protects critical assets along the entire Lenox Avenue Line, while also allowing more rapid restoration of service.

Above, L to R: Pre Sandy storm prep, Flooding from Sandy, Current condition at 148 Street portal with design of flood protection measures
Opposite, L to R: Flooding at St George Terminal after Sandy, Rail ties from recycled materials at St George Terminal, Post Sandy restoration



St. George Terminal, SIR

Type: Terminus of Staten Island Railway, providing intermodal connections to buses and the Staten Island Ferry.

Impacts: Destructive flooding of 12 tracks and terminal infrastructure, slow area drainage.

Scope: Approximately \$115 million, excluding future protective wall for Category 2 storm protection.

Schedule: Two-phase recovery to be completed in 2017, full flood mitigation anticipated in 2020.

Adaptations:

- Replacing 12 terminal tracks and platform edges.
- Installing a new diamond crossover.
- Elevating signal equipment and facilities (relay room, battery room, signal hut, generators) above NYCT design flood elevation.
- Long-term protection of the St. George Terminal with new flood barriers, drainage systems, adaptive land use, and more.

Project Description:

Opened in 1950 and located on the northern end of Staten Island, St. George serves as the Staten Island Railway's main terminal, providing a key link to Staten Island Ferry service. During Superstorm Sandy, all twelve of the terminal's tracks flooded, resulting in significant damage to the traction power system, conduits, cables, signal equipment, rails, and other elements. Because the drainage system at the site could not handle Sandy's intense floodwaters, water levels receded at a very slow pace.

In the storm's aftermath, NYCT designed a rebuilt terminal to replace track and signal systems while also bringing assets in line with current standards. In addition to fixing damage caused by the storm, SIR sought to protect St. George's other critical infrastructure by building more reliable and resilient assets. For example, signal and battery rooms that flooded during the storm have been rebuilt on elevated platforms to prevent impacts from future floods. Similarly, the terminal's pumping system is being upgraded to improve drainage at the facility. Finally, NYCT plans to build a wall around the entirety of the St. George complex to protect it from future flood events.

St. George terminal tracks have replaced standard timber ties with recycled plastic ties. Due to the high water table at this location, timber ties rot faster than usual. This replacement makes the entire yard more resilient to water damage. Moreover, replacing a virgin material with a recycled one also helps from an environmental point of view.

To minimize impacts on riders, NYCT established a robust construction phasing plan that strategically sequenced the closure of tracks and platforms, allowing the facility to be rehabilitated while addressing its evolving climate risk.



Coney Island Yard Complex

- Type:** NYCT Subways' largest complex of train storage, maintenance, and repair facilities.
- Impacts:** Flooding in 2011 and 2012 damaged tracks and equipment causing service disruptions.
- Scope:** \$13 million for near-term mitigations; \$500+ million anticipated for long-term mitigations.
- Status:** Mitigation projects began in 2014. Near-term mitigations completed in 2014; long-term mitigations scheduled for completion in 2023.

Adaptations:

Near-Term Flood Mitigation

- Installed 3 miles of interim perimeter flood protection to FEMA 100 year storm base flood elevation with an additional 2 foot safety factor.
- Provides on-call contractor services for gate protection deployment.
- Improved drainage to minimize ponding during heavy rain.

Long-Term Flood Mitigation

- Construct 3 miles of permanent flood walls to NYCT 's design flood elevation, i.e. Category 2 storm with an additional 3 foot safety factor.
- Enhance drainage and provide additional water retention capacity.
- Protect traction power cables from water by elevating above the tracks.
- Protect bridges over Coney Island Creek from water and debris damage.

Project Description:

Encompassing three rail yards and multiple overhaul/repair shops, the Coney Island Yard Complex is the largest train storage and maintenance facility in the NYCT system. Loss of the complex would shut down subway service for large portions of the NYCT system. After flooding in 2011 and 2012 severely damaged tracks and equipment—causing major subway service disruptions—the need for extensive flood mitigations at this low-lying facility were apparent.

Near-term projects included a temporary perimeter barrier and improved drainage to prevent pooling. In addition, a contractor has been retained to deploy sandbags along openings to at the security gates and a bridge across Coney Island Creek when needed. This system provides temporary protection commensurate with the flood levels experienced during Superstorm Sandy: FEMA 100 year storm plus 2 feet.

The second, long-term mitigation, funded by an FTA resiliency grant, includes a permanent perimeter wall, about 3 miles long, surrounding the entire facility. This barrier is designed to protect the complex against the flood equivalent of a Category 2 storm with an additional 3 foot safety factor, based on the NYCT design flood elevation guidelines. The adaptations also include drainage improvements and added water retention capabilities. In addition, a cable bridge is being constructed to relocate traction power to an elevated, more protected position above the tracks.



Rockaway Line

- Type:** Above-ground NYCT subway line exposed to storm surge and flooding.
- Impacts:** Superstorm Sandy damage in 2012 washed out track, signals, and traction power, while also flooding substations and other facilities, suspending service for seven months.
- Scope:** Approximately \$300 million.
- Status:** Restoration of track and key systems, as well as resilient sheet-pile flood wall and washout protection completed in 2013; additional resiliency protection for Hammels Wye, exposed right-of-way, substations, three stations, and other assets in design.

Adaptations:

2013 Restoration/Resiliency:

- Removed 3,000 tons of debris, rebuilt 1,500 linear feet of track, and replaced 25,000 linear feet of signal cable.
- Poured 3,000 cubic yards of concrete and placed 12,000 tons of stone.
- Constructed 13,000 of sheet pile flood wall extending 30' below ground and rising 10' above ground.

Future Resiliency Projects:

- Protect 4 substations.
- Flood-proof signals, power, and communications rooms at stations and along the right-of-way.
- Improve washout and debris protection.
- Build a crossover at Beach-105th Street to provide operational resiliency for Rockaway Line service.

Project Description:

The Rockaway Line provides subway service via Howard Beach to JFK Airport, Far Rockaway, and Rockaway Park on the peninsula. Much of the track is located in a low-lying area near Broad Channel known as the Flats. It also includes two major viaducts and swing bridges. The Superstorm Sandy in 2012 washed out significant portions of the right-of-way, and disabled track, signals, and traction power. Substations and other facilities were flooded. Service to the mainland was suspended for over seven months; subway shuttle service was provided between points on the Rockaway Peninsula, mainly on elevated tracks, connecting to a bus shuttle at Far Rockaway.

Restoring service along the Flats required reconstructing collapsed embankments and replacing damaged wiring. These emergency repairs also incorporated resiliency measures—chiefly the construction of a 13,000-foot-long sheet-pile wall stabilizing the embankment. The wall fortifies the Rockaway Line against wave impacts and washouts, also helping to prevent boats and large debris from blocking the tracks, as happened during Sandy.

While this work allowed the resumption of service in May 2013, additional resiliency projects are needed to protect the surge-exposed Rockaway Line from future flood events. NYCT is exploring various alternatives to protect the right-of-way, as well as vulnerable stations, power substations, and communications and signals facilities.

Opposite, L to R: Substantial flooding outside Coney Island Yard Feb 2016, Current condition with flood measures
Above, L to R: Subway car getting ready to be transported for shuttle train use, Service restored May 2013

Section 5 (b). MTA Bus Company and New York City Transit (NYCT) Buses

While the bus operations of both NYCT Bus and MTA Bus Company are generally less susceptible to flooding and other climate impacts than the other MTA agencies, several bus depots in A level flood zones suffered significant damage from Superstorm Sandy in 2012, and resiliency planning is currently underway. For depots in flood zones, such measures include replacement of below-ground storage tanks, auxiliary pumping equipment, backflow preventers, sea walls, elevation of critical equipment, and increased power generating capacity. During severe weather events and service outages, MTA buses may also play a critical role in public evacuations, shuttle links for disrupted rail or subway lines, and other emergency functions. For this reason, it is critical that bus services plan for rapid recovery after storms. Mitigation resources for such services may include extra field equipment, electronic messaging signs, and tank trucks for mobile refueling in the field.



Far Rockaway Depot

Type: Bus depot located approximately 9 feet above mean sea level in Flood Zone A on the Rockaway Peninsula.

Impacts: Flood surge and wind damage from Sandy rendered the depot inoperable.

Scope: Extensive redesign of the depot with interior and exterior flood protections, due for completion in 2018. Construction cost is currently estimated at \$7,045,000.

Status: Operations were relocated to JFK Depot. Designs for a new, more resilient depot were completed, and construction has begun with completion expected in September 2018.

Adaptations:

- Distribution to all depots of new emergency procedures model, incorporating lessons learned from Sandy.
- Procurement of new emergency generators and high-capacity mobile pumping equipment.
- Relocation of main electrical distribution room.
- Redesign and construction of areas most effected by storm damages.

Project Description:

Far Rockaway Depot is approximately 9 feet above mean sea level in Flood Zone A, defined by the NYC Office of Emergency Management as having the highest risk of flooding from any category hurricane surge. The depot was rendered inoperable by flooding and wind damage during Superstorm Sandy. Operations were relocated to JFK Depot, adding \$175,000 to monthly operating costs. Mitigation measures following the storm included the acquisition of emergency generators and pumps, along with new preparedness and rapid recovery plans. A new, more resilient design for the depot's interior was completed and construction has begun. It includes passive flood mitigations and water-resistance materials. In addition, most of the east and south exterior walls will be replaced, and the depot's main electrical distribution room has been elevated to the second floor, above 500-year flood levels.



Michael J. Quill Depot

Type: Manhattan bus depot also located in Flood Zone A.

Impacts: Interior flooding and damage to sump pumps, but most mechanical equipment preserved by 24-hour emergency pumping and sand bagging.

Scope: With dry flood-proofing the most feasible approach, design options include a swing gate or side flex wall at strategic locations at the depot's west end. Budget to be determined.

Status: Flood mitigation concepts and studies are currently under development.

Adaptations:

- Development and distribution of a new NYCT Bus Operations Coastal Storm Plan.
- Review and recommendation of dry flood-proofing, using either a swing gate or side flex wall at four depot locations.
- Overhead protection of buses parked at roof parking lot.
- Procurement of emergency generators and high-capacity mobile pump equipment.

Project Description

Michael J. Quill Depot, which provides bus service for Manhattan is located in Flood Zone A, defined as having highest risk of flooding from any category hurricane's surge. During Superstorm Sandy in 2012, bus depot personnel worked around the clock to pump water out of the sub-basement in order to protect mechanical equipment. In the end, some flooding did occur but only sump pumps were damaged and required replacement.

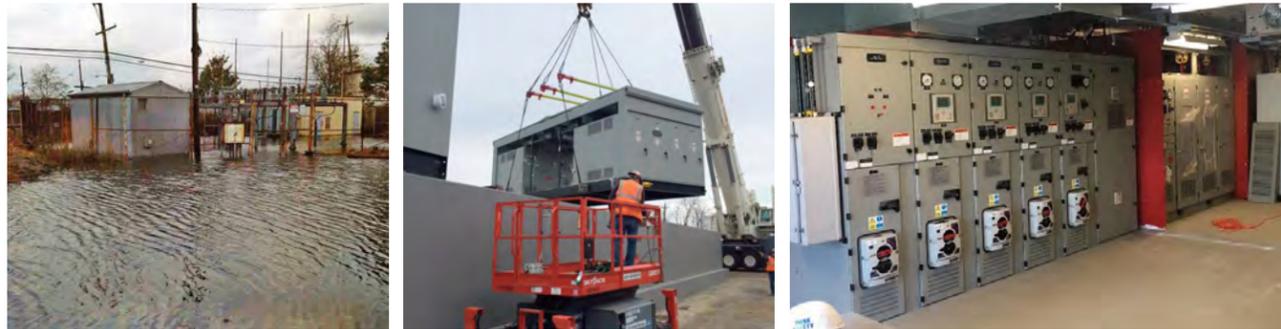
Following the storm, MTA New York City Transit ordered flood mitigation studies at this Manhattan depot and other Flood Zone A bus depots and began developing new emergency preparedness and recovery plans. After weighing numerous storm preparedness and flood mitigation measures, it was determined that the resiliency solutions for the depot would focus on the following: installation of a swing gate or side flex wall at four locations along the depot's west end, protection of buses on the roof top of the depot, and procurement of new emergency diesel generators and mobile pumps.

Opposite, L to R: Trailer moved by flood, Roller gate buckled under water pressure, Electrical Distribution Room is relocated from first floor to second, 500 KW mobile emergency generator

Above, L to R: Michael J. Quill Depot interior after Sandy, Temporary deployable flood barrier installed on west side of depot, Michael J. Quill Depot main entrance

Section 5 (c). MTA Long Island Rail Road (LIRR)

LIRR is highly exposed to flooding, storm surges, and wind damage, as well as the other climate variables of extreme heat, increased precipitation, ice storms, and heavy snowfalls. With its extensive coastal exposures, LIRR suffered costly damage from Superstorm Sandy in 2012. The damage included flooding of tracks, yards, the East River Tunnels, signal/communications equipment, and power substations, with long-term damage to electrical infrastructure from saltwater corrosion. Because of the extensive damage to power substations and loss of traction power on LIRR's highly exposed Long Beach Branch, that branch was the last to restore service following the storm, initially with limited service using diesel powered trains.



LIRR: Long Beach Branch Substations

Type: Three substations powering third-rail electrical traction on LIRR's five-station Long Beach Branch, all located in high-risk flood zones along Long Island's South Shore.

Impacts: Extensive damage from storm surge to three substations, with loss of traction power and long-term saltwater corrosion of electrical infrastructure.

Scope: Three substation replacements totaling \$51.6 million, with final completion scheduled for early 2018.

Status: Two replacement substations in service, and the third under construction.

Adaptations:

- Complete replacement of three flood-damaged substations.
- Redesigned substations for elevations above flood levels. New substations are being constructed on elevated foundations, featuring fully enclosed interior equipment spaces and waterproof cable vaults.

Project Description:

Sandy inflicted severe damage on three LIRR substations (Oceanside, Oil City, and Long Beach Yard) exposed to Atlantic coastal storm surge, with long-term damage to electrical components from saltwater corrosion. Full replacement of the three substations was necessary; rebuilding the substations to the latest standards will reduce equipment failures and improve reliability, on-time performance, and safety along the Long Beach Branch. By installing the substations at higher elevations, LIRR is mitigating flood damage from future storms.



LIRR: Long Beach Branch Signal and Communications Systems

Type: Replacement and upgrading of the Long Beach Branch's signal system including equipment, components and cabling for various signal, power, and communications systems along the branch.

Impacts: Inundation of critical communications and signal equipment from coastal storm surge, along with long-term saltwater corrosion.

Scope: Replacement of damaged communications and signal systems at a cost of \$64.9 million, with final completion scheduled for Fall 2019.

Status: Currently in construction. Many raised steel platforms, which will elevate critical signal and communications equipment, have been installed; the new signal system design is nearly complete.

Adaptations:

- Elevating critical components above flood plain to integrate resiliency.
- Installation of raised steel platforms to protect critical signal and communications equipment from future flooding/storm surge.
- Replacing cabling, switch machines, and other system infrastructure.
- New signal system incorporates enhanced capabilities, including microprocessor technology and bi-directional speed control on both tracks, thus improving system reliability and operational resiliency.

Project Description:

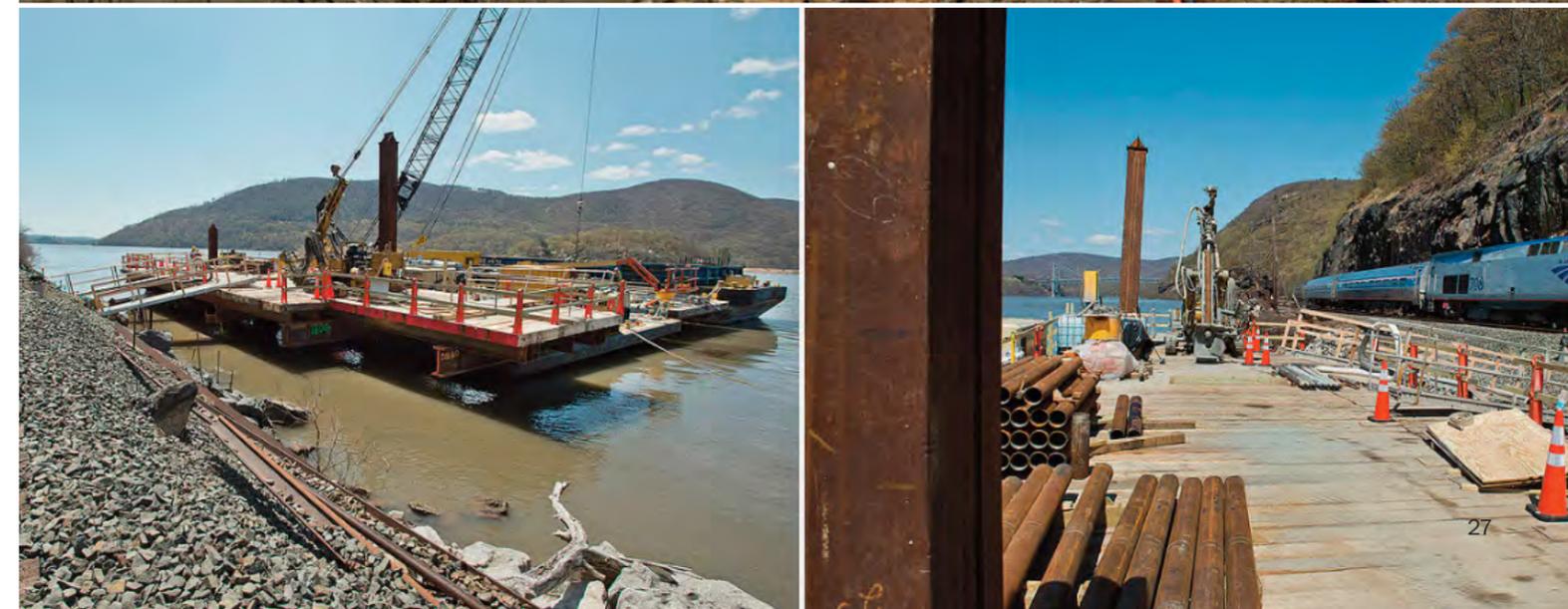
The Long Beach Systems Restoration project will replace and enhance the long-term operational reliability of service on the LIRR's Long Beach Branch, an area severely impacted by Superstorm Sandy. As part of this project, the LIRR is replacing the branch's signal system and associated utilities. The replacement system incorporates state-of-the-art signaling technology to improve reliability, on-time performance, safety, and resiliency. It incorporates microprocessor technology along with bi-directional speed control on both tracks between Valley and Lead interlockings, which will provide greater operational flexibility and faster recovery during service disruptions. The signal supervisory control system is also being replaced with the new upgraded signal field apparatus. Primary control will reside at Lead Tower, with back-up capability at Valley Tower. Communication huts, cases, and equipment that support the audio-visual paging and radio systems are also being replaced. Critical signaling and communications equipment are being installed at higher elevations on raised platforms to mitigate future storm surge damage.

Opposite, L to R: Exterior view of Oceanside Substation two days after Sandy, Installation of modular Oil City substation atop raised foundation April 2016, On-site fit-out of new Oil City substation July 2016

Above, L to R: Salt-water damaged signal relay, Boats and cargo containers on tracks in Island Park, Newly constructed elevated platform in East Rockaway for future communications hut, Newly constructed elevated platform in Long Beach Yard for future signal hut

Section 5 (d). MTA Metro-North Railroad (Metro-North)

Metro-North is exposed to flooding, storm surges, and wind damage, as well as extreme heat, increased precipitation, ice storms, and heavy snowfalls. With its Hudson River exposures, Metro-North suffered extensive infrastructure damage from Sandy in 2012. Overall damage included flooding of tracks, embankments, yards, bridge crossings, and substations, with long-term saltwater damage to signals, communications, and electrical systems. In addition, Metro-North sustained extensive damage from excessive rain and washouts during Hurricane Irene in 2011. Elevation and fortification of power substations, design of flood barriers for yards, and protection of signaling systems for Hudson line restorations are among the chief resiliency and restoration measures now underway. Metro-North maintains extensive training programs, emergency plans, and emergency equipment for rapid deployment in extreme weather events.



Metro-North: Substations and Breaker Houses

Type: Flood-damaged substations on the Hudson Line; AC facility houses and DC breaker houses on either side of the Harlem River Lift Bridge crossing the Harlem River.

Impacts: Major saltwater flooding of electrical power substations on the railroad's Harlem Line.

Scope: Restoration of substations, AC facility houses, and DC breaker houses at an approximate budget of \$49.5 million.

Status: Harlem River Lift Bridge initiatives completed ahead of schedule in August 2015; Hudson Line substation project scheduled for completion 4th quarter 2017.

Adaptations:

- Elevation of new breaker house floor levels to mitigate future flooding.
- Construction of new door systems and exterior waterproofing in refurbished substations to protect against future flood damage to power equipment.
- Increased floor elevations of redesigned Hudson Line substations to a conservative 4 feet above projected flood levels.

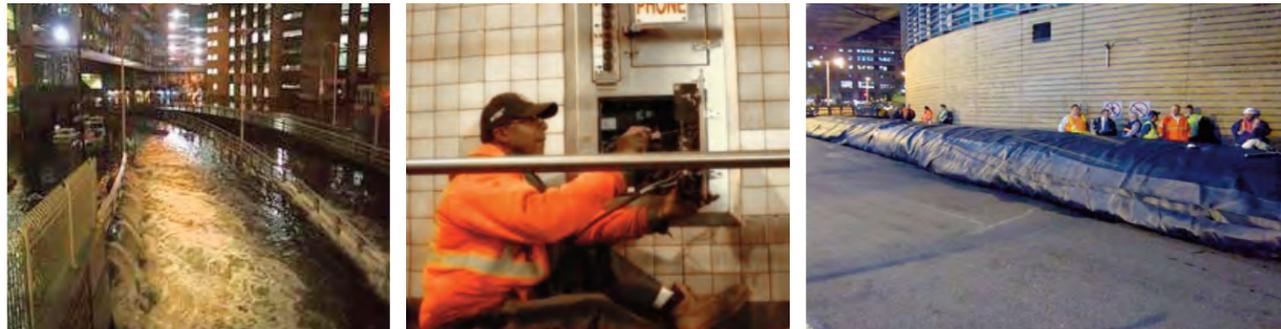
Project Description:

Flooding at the Manhattan and Bronx substations of the Harlem River Lift Bridge in 2012 caused extensive damage to critical traction and facility power. Existing substations are being refurbished with new equipment, rather than replaced. Climate-event protections will include a new door system and new waterproofing of the facility's existing brick structure. In addition, three DC traction power substations on the Hudson Line damaged in 2012 (Riverdale, Tarrytown, and Harmon Yard) will incorporate new floor elevations set well above current flood level requirements.

Above, L to R: Harlem River Lift Bridge AC substation, Tarrytown substation, Harlem River Lift Bridge elevated circuit breaker house

Section 5 (e). MTA Bridges & Tunnels

MTA Bridges & Tunnels sustained 16.4 percent of the MTA's total damages from Superstorm Sandy, as identified in the 2010–2014 Capital Program Amendment. The agency's two vehicular tunnels, the Hugh L. Carey Tunnel (formerly Brooklyn Battery Tunnel) and the Queens Midtown Tunnel, faced extensive flood damage to roadways and tunnel walls, including saltwater destruction of communications and signal infrastructure. Restoration required pumping approximately 60 million gallons of saltwater from the Hugh L. Carey Tunnel and 12 million gallons of saltwater from the Queens Midtown Tunnel. For the agency's bridges, the chief sources of damage were from "scour," i.e. erosion around support structures, and flood damage to electrical equipment and facilities. In addition, bridges may face long-term climate impacts to navigation clearance from rising sea levels.



Hugh L. Carey Tunnel (HLCT)

Type: A four-lane, twin-tube 9,117-foot-long tunnel connecting Manhattan and Brooklyn under the East River, with traffic of approximately 46,000 vehicles daily.

Impacts: Flooding overwhelmed pumping systems, knocked out critical functions, and rendered the tunnel impassable. Saltwater damaged ventilation buildings, electrical systems, communication systems, wall and ceiling finishes, fiber optic cables, traffic control devices, and security and monitoring systems.

Scope: Restoration of HLCT, including replacement of electrical, communications, lighting and structural systems as well as structural elements and interior finishes, exceeds \$300 million. Long-term flood mitigation measures approximately \$50 million.

Status: Long-term restoration work started in 2014, will be completed in March 2018. Resiliency contract was recently awarded, will be completed by end of 2018. Flood barriers to be installed at all tunnel portals by end of 2017.

Adaptations:

Short-Term Measures

- Removable flood panels and curb extensions at the Brooklyn Service Building, along with elevation of the building's emergency generator and electrical connections to the FEMA 500-year flood levels.
- Relocation of the data center, including E-ZPass equipment, from the basement to a newly constructed mezzanine level above the FEMA 500-year flood level.

Long-Term Measures

- Installation of a 1,500-kW emergency generator and elevation of sea walls at the Governors Island Ventilation Building.
- Replacement of split-case pumps in pump rooms with more resilient submersible pumps, along with elevation of pump controls.
- Large-scale flood mitigation, including deployable flood barriers at tunnel portals and fortified retaining walls around plazas with deployable barriers to close off protected plaza perimeters—al designed for FEMA 500-year flood elevations or higher.

Project Description:

After closing to traffic in anticipation of Superstorm Sandy, the Hugh L. Carey Tunnel was flooded by a severe storm surge, which entered the Manhattan Plaza through an open railing. Both tubes were flooded for more than 6,000 feet, about two-thirds of the tunnel's total length, overwhelming pumping systems, knocking out critical functions, and rendering the tunnel impassable. Saltwater damaged vital equipment in ventilation buildings, exhaust and fresh-air ducts, electrical distribution systems, communication systems, and pumping stations. The damage extended to electrical feeder and lighting systems, wall and ceiling finishes, fiber optic cables, traffic control devices, and security and monitoring systems.

Recovery entailed pumping out 60 million gallons of saltwater, followed by partial restoration of power and electrical systems, drainage systems, traffic signals, and CCTVs, along with the general repair and cleaning of roadways and tube interiors. The tunnel reopened all four lanes 19 days after the storm, the longest recovery period for any of the agency's crossings. Long-term recovery work continues, along with associated resiliency projects. The full \$300+ million tunnel restoration is scheduled for completion in 2018.

Resiliency measures at the tunnel involved both short-term and long-term projects. The short-term or "rapid mitigation" projects included water-inflated cofferdams at the Manhattan Plaza; a temporary wall system at Morris Street; sealing of spare ducts at the Manhattan Blower Building; and aluminum flood panels for doors and windows at the Governors Island Ventilation Building. All long-term projects are designed to protect assets against FEMA 500-year flood levels, about four feet higher than maximum flood water level. These include more resilient pumping systems; elevation of emergency generators and electrical equipment; and a major design-build project that will create deployable and permanent flood barriers at tunnel portals and plazas. This permanent, \$64 million mitigation project, funded largely by a FEMA grant, encompasses both the Hugh L. Carey and the Queens Midtown tunnels and is slated for completion by the end of 2018.

Note: Superstorm Sandy damages, repairs, and resiliency measures at the Queens Midtown Tunnel are similar to those outlined here for the Hugh L. Carey Tunnel. Traffic at the Queens Midtown Tunnel is higher, at about 78,000 daily users, and flooding inundated the tunnel to a length of about 2,500 feet with about 12 million gallons of saltwater.



Rockaway Bridges

Type: Two toll bridges on the Rockaway Peninsula, one vertical-lift bridge and one high-level fixed bridge, with combined daily traffic of approximately 43,000 vehicles.

Impacts: Flooding of abutments, electrical equipment, and facilities, with damage to seawall cribbing and “rip-rap,” the materials used to fortify shorelines and abutments.

Scope: Approximately \$3 million in repairs and mitigation to seawall and shoreline rip-rap, Approximately \$1 million for lighting repairs at Marine Parkway Bridge. Approximately \$20 million for replacement of electrical equipment/substations, relocation above flood elevation at both bridges.

Status: Seawall and shoreline repairs completed in 2013. Replacement/relocation of electrical equipment started in 2015, scheduled for completion in early 2018.

Adaptations:

- Repair of eroded seawall cribbing and shoreline rip-rap.
- Repair and elevation of lighting systems.
- Replacement and relocation of substations and emergency generators above the FEMA 500-year flood level.
- Installation of aluminum flood panels at service buildings and electrical rooms.

Project Description:

Two Rockaway Peninsula crossings, the Marine Parkway—Gil Hodges Memorial Bridge (MPB) and the Cross Bay Bridge (CBB), suffered significant damage from Superstorm Sandy. This included flooding of abutments, service facilities, and electrical equipment within facilities. Both bridges also suffered erosion, breaching, and displacement of seawall cribbing and shoreline rip-rap. Most erosion damage was repaired within one year. Lighting restoration was completed in 2014, with lighting elevated as a resiliency measure.

A separate design-build contract for replacement of electrical substations at both bridges was awarded in 2015, with completion scheduled for early 2018. Substations and emergency generators at both facilities are being relocated above FEMA 500-year flood elevations. The work under this contract, which totals more than \$20 million, is being funded primarily by FEMA. Further resiliency measures include installation of aluminum flood panels at exposed doors and windows of service buildings and electrical rooms.

Opposite: Mother Clara Hale Depot green roof installation.

L to R: Eroded CBB north abutment, Restored/Mitigated CBB north abutment, Restored MPB south seawall

Section 6. Conclusion: What Lies Ahead

The selected projects in this report represent only a fraction of the climate-related initiatives now underway at all MTA agencies. Most of those efforts combine new resiliency measures with the extensive recovery work resulting from Superstorm Sandy. The vast majority of such projects entail robust flood protections at low-lying areas of the MTA’s 5000-square mile travel region, which is rendered increasingly vulnerable by rising sea levels and more violent storm surges. They include the preparation of deployable and permanent flood barriers, the sealing of tunnels and system inlets, the elevation of power substations, and the protection of new electrical and communications equipment. While many of these recovery and resiliency projects have been completed or nearly completed, major work will continue into the 2020’s.

As this work progresses, the MTA Climate Adaptation Task Force and the recently appointed Chief Resiliency Officers at the MTA agencies will meet regularly to exchange and centralize related information. Annual updates of this report will identify, describe, and compare the resiliency and adaptation components of MTA capital projects within the larger context of climate change. The aim will be to refine climate-related metrics; to help incorporate climate adaptations into operations, planning, and asset management; and to regularize communication on climate issues between MTA agencies, outside authorities, and transit systems around the world. Adapting to this “new normal” is critical to the MTA network, which in turn is vital to the regional economy and to the global project of economic expansion with reciprocal GHG reduction.



Notes

1 Project budgets cited in this report from the 2010-2014 Capital Program are presented for purposes of comparison and as indicators of scale. Actual capital budgets are subject to regular revision and amendment.

2 U.S. Environmental Protection Agency. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2014. 2016.

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7 Rosenzweig et al. 2015 (as n.5 above).

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10 Rosenzweig, Cynthia, William D. Solecki, Stephen A. Hammer, and Shagun Mehrotra. Climate Change and Cities: First Assessment Report of the Urban Climate Change Research Network. Cambridge: Cambridge University Press, 2011.

11 Rosenzweig et al. 2015 (as n.5 above).

12 State of New York Metropolitan Transportation Authority. August 8, 2007 Storm Report. 2007.

13 Not all projects are fully funded. This 2016 report will focus on selected resiliency projects by agency. The dollar amounts shown are subject to change and should be used primarily to indicate the relative scale of projects. The complete list of recovery and resiliency projects can be found on the MTA website, as noted above.

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