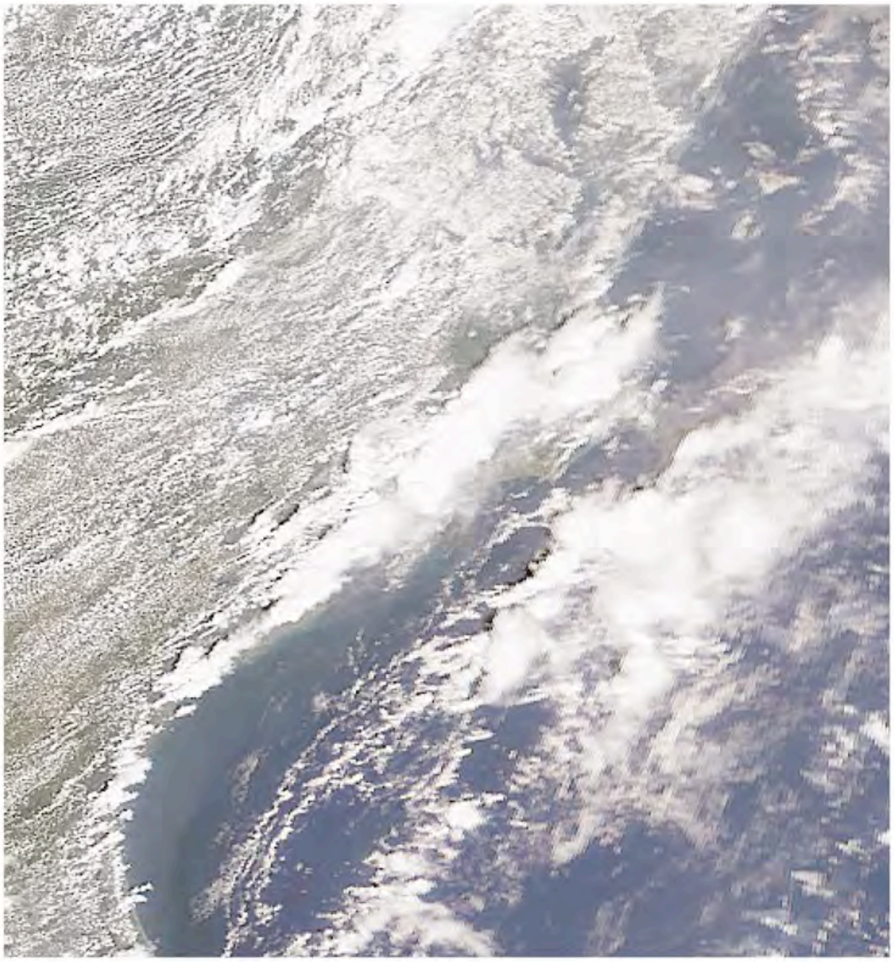
August 8, 2007
Storm Report



Metropolitan Transportation Authority

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September 20, 2007

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I. Executive Summary

In the aftermath of the August 8, 2007 weather-related disruption of MTA service, Governor Eliot Spitzer directed the MTA to complete a 30-day assessment of the agency's performance and vulnerability to future storms. To provide the thorough assessment requested by Governor Spitzer, the MTA formed a task force (Appendix 1) that included the presidents of its operating agencies, representatives from New York City's departments of transportation and environmental protection, the MTA Inspector General, and consultants from the University Transportation Research Center and Columbia University's Center for Climate Change Research.

This report presents the task force's findings, including a timeline of events that took place on August 8, the causes of the disruptions and communication failures, and a series of action items that the MTA believes will significantly limit the impact of future storms on service. Of equal importance, the report begins a broader discussion with our many governmental and non-governmental partners about the ability of the region's infrastructure to contend with the potential for more frequent and severe storms. The newly-formed MTA Sustainability Commission will also tackle this issue.

While the August 8 storm was by far the most severe in its impact, it was the fourth storm since 2004 – and the third this year – to trigger widespread regional flooding. In a report to this taskforce, Columbia University's climate change experts predict that the threat of flooding in the MTA system will only increase due to sea level rise, extreme weather events, and a disappearance of permeable land in the region.

While most of this report is internally focused, it necessarily looks beyond the MTA for more global solutions to the flooding issue. Over the long term, decisions will have to be made on a regional and national scale about the level of disruption that will be tolerable if storms become more frequent or severe. In the meantime, this report describes a number of very positive and promising steps that the MTA is taking immediately, in partnership with NYCDOT, DEP, and other municipalities to dramatically improve its performance in future storms.

August 8

The Storm

On the morning of August 8, 2007 – at the height of the morning rush hour and at high tide in parts of the region – the New York metro area suffered a severe and largely unpredicted storm that brought with it not only heavy rains and flooding, but the first tornados to hit parts of Brooklyn in over 100 years. Official rainfall tallies ranging from 1.4 to 3.5 inches (unofficial levels in excess of 4.2 inches were recorded at NYC's Owl's Head Wastewater Treatment plant in Western Brooklyn) fell within a two-hour period – or less – giving no time for normal drainage to take place. Pockets of intense, localized rain and flash flooding overtaxed regional drainage capabilities and severely disrupted transportation systems throughout New York, New Jersey, and Connecticut. As harsh as the weather was, its severity wasn't fully appreciated until late August and early September when the President declared Queens and Brooklyn as qualified for federal disaster assistance as a result of the damage done in two hours on August 8.

Impact on the MTA System and Customers

As flooding reports cascaded into MTA agency control centers starting soon after 6 a.m., MTA subways, buses, and commuter railroads as well as connecting roadways to Bridges and Tunnels facilities were overcome by flooding. Hundreds of thousands of commuters whose trips were already underway or about to begin felt the impact on the transit and road systems. By mid-morning, over two and a half million transit customers would be affected.

The first indications of the impact of the storm came shortly after 6:10 a.m. – the height of the storm and the beginning of the rush hour. Four locations in the subway in Brooklyn and Manhattan began to flood. Ultimately, disruptions on 19 major segments would force the shutdown of much of the subway system. This was an unprecedented impact on the NYCT system far more severe than the two previous storms in 2007 and the September 2004 storm.

At 6:46 a.m., as flood waters reached the platform edge at the Bayside station, MTA Long Island Rail Road (LIRR) suspended service on its Port Washington Branch. At 7:11 a.m., MTA Metro-North Railroad (MNR) received its first reports that Mott Haven Junction (where the Hudson, Harlem, and New Haven lines merge in the Bronx) was impassable as a result of flooding. By 7:20 a.m. MNR was forced to stop all service into and out of Grand Central Terminal (GCT).

Above ground, bus service, provided by MTA New York City Transit (NYCT), MTA Bus, and MTA Long Island Bus (LI Bus), was also undergoing significant disruptions across New York City and Nassau County as local roads and highways flooded and normal traffic congestion worsened. In addition, service was further stressed by tens of thousands of displaced subway customers attempting to use the bus network as an alternative. MTA Bridges and Tunnels (B&T) was also experiencing traffic backup onto its facilities as a result of localized flooding on approach roads and exits. Few parts of the MTA's physical operation were unaffected.

Recovery

As the rain subsided, so did the impact on the system. Most of the affected subway lines were, for the most part, up and running again by midday. Only four segments had not resumed normal service by noon. The LIRR Port Washington Branch was back by 12:55 p.m. Full MNR service to Grand Central resumed at 8:58 a.m. By noon, MTA buses resumed close to normal schedules on roads that slowly reemerged as sewers had time to catch up with the extraordinary volume of water. Traffic tie-ups began to recede along with the floodwaters on the roads leading to B&T facilities. The evening rush – with a few exceptions – was close to normal.

Findings and Recommendations

The MTA's performance on August 8 was assessed in terms of operations, engineering, and communication, and specific recommendations were made to respond directly to each identified shortcoming. Some have already been implemented. Others will take time, financial resources, and the cooperation of a number of regional partners. Taken together, these recommendations will enable the MTA to prevent most future flooding and better serve its customers.

Operations

The timing of the storm at a morning shift change increased the difficulty of responding with a coordinated operating plan, especially as many key employees struggled to get to work. Once personnel were in place, however, the men and women of the MTA recovered to complete a Herculean recovery effort in time to provide close to normal service on most operations by the evening rush hour.

Findings:

The storm was not predicted early enough by weather forecasters, hindering the MTA's response.

While in most instances MTA agencies worked together to maximize service options, communication across agencies was not as well-coordinated, efficient, and frequent as it could have been.

In many cases, MTA agencies failed to provide disrupted customers with travel alternatives.

Recommendations:

Create Early Warning and Response Capability – The MTA agencies will collaborate on a common and redundant weather forecasting system/capability and install Doppler radar monitoring in all agency operations centers. This will allow pre-deployment of operating personnel when potentially threatening weather is indicated. (30 days)

Create an MTA Emergency Response Center – The MTA ERC will provide a formal structure for coordinating activities across agencies during emergencies. MTA ERC will provide the status of MTA-wide operations during emergencies and give the Executive Director and CEO immediate access to agency operations centers. (In place)

Revise Agency Storm Operating Protocols – Amend all agency operations and emergency plans/protocols to ensure that the MTA's agencies work together to maximize travel options in an emergency. (End of 2007)

- **Standardize Storm Category Designations**
- **Formalize Inter-Agency Coordination/Notification Plans**
- **Develop Bus Service Alternative Plan**

- **Coordinate Interagency Service Alternatives**
- **Standardize Procedures for Communicating with Operating Personnel, Customers, and Other External Stakeholders**
- **Ensure key employees get to critical work locations during severe weather**

Six Month Progress Review – the MTA Chief Operating Officer will conduct a review every six months of progress made in each of the aforementioned areas.

Engineering and Regional Inter-Agency Issues

The August 8 storm was extraordinary in its severity. Using hourly rainfall as a guide, it would be classified as a ten-year storm; more relevant to the MTA's network is that the rain was concentrated in a two-hour period, outpacing the ability of the regional sewer systems and MTA's pumps to keep up. The MTA's network is especially vulnerable at many locations identified in this report. While not all of these locations flooded during this storm, these are the most likely to flood in the future and the focus of the MTA's action plan.

Findings:

Flooding occurred at points throughout the MTA's system for three primary reasons:

Extraordinary amounts of water entering subways or low-lying rights-of-way (ROW) areas. These areas have been subject to water entry or flooding in the past.

Overwhelmed pumps or backflow caused by water levels above design capacity. While only one pump in the system malfunctioned, the remainder could not remove the water inflow fast enough and in some instances had no place to pump it. In other areas, excessive water inflow came from backflow from external drainage systems where the MTA currently has no check valves.

Debris blocked interior and exterior drainage structures. Regular cleaning along rights-of-way (ROW) or roadways is necessary to ensure proper functioning of drainage systems. The initial downpour washed debris into drains that may not have been clogged. The MTA and our regional partners must do whatever they can to keep drains clean in advance and do whatever they can to clear them of debris during storms.

Recommendations:

Implement corrective action plan for top flood-prone locations – An action plan has already been developed for the top 10 locations including both short-term action and long-term solutions to flooding at the MTA's most vulnerable locations. Solutions for the remaining locations will be developed over the next 90 days in conjunction with NYCDEP and NYCDOT.

This effort will draw from a toolbox of potential fixes to both prevent water inflow and to remove it once it flows in, including installing check valves to prevent backflow, pursuing better sewer connections, increasing pumping capacity, pre-deploying portable pumps and personnel, installing closeable vents and constructing step-ups at station stairwell entrances that flood.

One of the most promising tools to fight sidewalk vent gratings/station entrance issues is street furniture designed to raise vent heights to prevent water inflow. MTA, NYCT, and DOT sponsored a design charette with top urban design experts to develop conceptual solutions for locations along the Queens Boulevard Line on Hillside Avenue.

In cooperation with the city, the MTA will also evaluate sites for the use of Best Management Practices (BMPs) as suggested in PlaNYC. Possible BMP projects could include:

- Blue roofs/green roofs to capture and/or detain runoff from buildings adjacent to the identified sites
- Tree pits designed to retain water for absorption by trees
- Greening and use of porous pavement in area parking lots
- Possible enhancement of nearby green spaces to retain more storm water

Create Permanent Inter/Intra-Agency Flooding Task Force – engineering and operations staff from all MTA agencies, NYCDEP, NYCDOT, other regional Departments of Public Works will meet twice a year (Feb/March and Aug/Sept) to:

- Ensure that all sewers, catch-basins, siphons, etc. in flood-prone locations are inspected and cleaned prior to rainy season(s). Explore the formation of joint inter-agency teams to expedite such efforts.
- Assess progress on implementing engineering solutions in flood-prone areas.
- Identify emerging factors, such as construction projects or zoning issues that could affect drainage in and around MTA facilities (as recommended in Columbia report).

Ensure that all recommendations in the MTA Inspector General Report and MTA Board Task Force Report on the September 2004 flooding incident have been implemented or otherwise appropriately addressed (within 60 days).

Six-month review of progress – The MTA Chief Operating Officer will conduct a review every six months of progress made in all the aforementioned areas.

Communication

The magnitude and unexpected nature of the storm highlighted gaps in communication both between agency operations centers and employees, and between the agencies and their customers. This situation was paralleled by inconsistent internal communication among most MTA operating agencies and with other regional stakeholders.

Findings:

Customers did not always have access to accurate information in stations.

Customers lacked access to real-time service information on the go.

Many customers had difficulty accessing the MTA's website, www.mta.info, or easily finding critical information on the site.

Information on the severity of the NYC Transit disruption was delayed reaching media outlets.

Recommendations:

Develop Capacity for Real-time Email and Text Messaging Service Alerts – to increase the number of emails/text messages that can be sent and reduce the time it takes to send them out. Currently, email service alerts take as long as 1.5 hrs to "push out" to recipients (i.e., to LIRR's 24,000 subscribers). The MTA is issuing an RFP to secure a provider capable of handling as many as 800,000 real-time email alerts simultaneously.

Increase Website Capacity, Clarity and Access to Service Alerts

- **Replace Firewalls and Load Balancers and Use Hosting Vendors –** to provide 7 to 10 times existing capacity (by September 30)
- **Redesign Homepage With Focus on Service Status –** to improve visibility and terminology of "Service Advisories" and "Service Alerts." (First Quarter of 2008)
- **Provide Universal PDA Access to www.mta.info –** to expand access to web-based service alerts. (Completed as of September 1)
- **Provide RSS Service Alert Feeds to Public and the Media, and NYC's 311 System –** will allow current service information to be delivered automatically to public and media subscribers, eliminating the need to search the MTA website for service information. As a direct link to NYC's DoITT 311 system, service information will be shared with both the 311 hotline and the NYC website, both of which can help communicate service messages to the public. (by November 1)

Improve communication between operations centers and field personnel – Include use of PDAs and Blackberrys to increase the speed and accuracy with which information is shared with station and operating personnel. (Immediate implementation.)

Implement consistent agency-wide media protocol – NYC Transit will adopt the successful media outreach protocol employed by LIRR and MNR and upgrade technology to ensure staff is reachable at all times. (Effective immediately.)

Improve customer information by developing clear emergency communications protocols and designating communications specialists at operations centers.

Advance public address and video screens technologies to better communicate with customers in-system – In addition to long-term technology projects, such as PA-CIS, MTA is exploring a range of interim solutions that could maximize technologies already being employed in the system (e.g., wireless connectivity to service info). (Meetings with vendors are under way)

Utilize and expand MTA's current inventory of wireless video displays – Currently the MTA has 80 wireless video displays over station entrances which are used for advertising but can be hooked into agency operations centers during emergencies to provide real-time service information. (Agency hook-ups and associated message protocols will be implemented within six months)

Provide cell phone service on subway platforms – Later this month the MTA Board will consider a contract for providing this service that would allow customers to communicate with the outside world in case of service disruption or emergency. (2008)

Implementing the Recommendations

The Task Force clearly concluded that many factors combined to disrupt MTA service on August 8. The storm was the most severe in recent memory, struck at a most inopportune time and without sufficient warning, and did its damage in a short period of time. The storm exposed vulnerabilities in the transportation system's operations, engineering, and communication. While some of the disruption was unavoidable, many areas were identified for improvement.

This report outlines a robust set of recommendations that address each shortcoming and will dramatically improve the MTA's performance both in future emergencies and on a daily basis. To begin implementing these solutions, the MTA has committed $30 million to fund a combination of capital and operating initiatives that can be put into place quickly, from providing text message service alerts to exploring how street furniture can be used to raise vents in flood-prone areas.

Just as importantly, the MTA will quantify the costs of the longer-term capital fixes needed to permanently prepare the system for operating in future storms and communicating with customers in all types of emergencies. These initiatives will be considered for inclusion in the MTA's expedited Capital Program, due to be presented to the State Legislature early next year.

Finally, this effort has helped form partnerships between the MTA and a number of city and state agencies which will work together to plan for and react to future storms. Over the long-term, the MTA is committed to working with these agencies to expand the conversation even further to address the potential impact of climate change and related pressures on the region's core infrastructure.

It is not possible to completely rid the MTA's transportation network of flooding, but the steps outlined here will help dramatically limit the impact of future events. ■

II. The Storm

The storm of August 8 caused widespread flooding and traffic disruption – no surprise given its unpredictability and intensity. Though not predicted until the front was virtually upon the region, it dropped 1.4 to 3.47 inches of rain in and around New York City within one to two hours. The volume of water it brought overwhelmed MTA and regional drainage systems designed to handle no more than 1.75 inches an hour and outstripped the MTA's ability to both prevent water incursion into the system and its ability to pump it out once it was in.

Two other storms in 2007 and a third in 2004 also disrupted service on the MTA network. A report prepared for the MTA by Columbia University's Center for Climate Systems Research indicates that intense storms such as the one on August 8 are likely to be more frequent in the future.

A. Weather Forecasting/Monitoring at the MTA

The weather forecasting methods used by MTA agencies clearly failed to predict the imminence and severity of the August 8, 2007 storm much before the start of the rush hour.

Accurate weather forecasting is a critically important element in the planning and delivery of daily transit service. Weather is monitored by all MTA operating agencies around the clock and each agency has developed specific protocols to follow when forecasts predict excessive precipitation. People, equipment, and operating strategies are put in place as necessary in the 12 to 24 hour period prior to a predicted threatening weather front and, if necessary, storm and hurricane plans are put into effect.

Each MTA agency has its own weather monitoring procedures and sources of information. Some contract with private weather forecasting services and assign staff to monitor those weather reports. For example, NYCT uses Precision Weather, B&T contracts with The Weatherdata Network, and LIRR and MNR use Metro Weather Service. LI Bus receives information from LIRR and MTA Bus relies on interaction with NYCT's Department of Buses (DOB) Command Center and on local television weather reports that are monitored at its command center.

At its Rail Control Center, NYCT receives information via fax from Precision Weather, which sends reports via fax and email two times in the a.m. and once in the p.m. The reports are reviewed by the general superintendent on duty or his/her designated staff member.

An LIRR engineering employee is assigned to monitor Metro Weather's reports, updates of which are issued every four hours, 24 hours a day. As storms form and move closer to LIRR operating territory, direct contact is made with Metro to obtain detailed predictions for the territory. Based on the information provided, storm preparation meetings are then scheduled and storm contingency plans are developed. The weather service did not indicate a storm with the potential for severe flooding and the LIRR was unaware of its severity until it began receiving reports of track flooding at around 6:30 a.m.

At MNR, weather monitoring is the responsibility of the Operations Control Center (Chief Dispatcher or designee) which is staffed 24 hours a day, 7 days a week. As was the case with the LIRR, the forecasts for MNR's service territory did not indicate a storm with the potential for severe flash flooding in parts of the region until after the weather actually started to impede their ability to run service.

NYCT's Bus Command Center (BCC) receives the Precision weather report from the Rail Control Center (RCC) each day via email. During severe weather the BCC receives this report hourly by phone and also monitors the weather via television and radio.

LI Bus receives its weather data by fax from LIRR.

Each B&T facility, as well as the Central Command Center, receives advance weather reports from its Weather Monitoring Service at least three times daily, but more frequently in the event that severe inclement weather is predicted. Each facility general manager, operations superintendent, and maintenance superintendent, as well as facility and maintenance supervisors, monitor these reports and are responsible for appropriate preparation. In addition, B&T's Command Center receives frequent notifications from NYCOEM of predicted or ongoing severe hazardous weather. These reports are immediately transmitted to each B&T facility and to Senior Staff. ▼

B. August 8 – Insufficient Warning

The August 8 storm began in the upper Midwest earlier in the week and was not expected to cause much trouble for New York City as it traveled east, according to National Weather Service forecasts.

On Tuesday, August 7, National Weather Service (NWS) staff at the Upton forecasting office (located on Long Island) were watching what was termed a "hazardous weather outlook" as it moved in from Michigan. Expectations were that the storm would miss the NY Metropolitan area by heading up and over it. Other forecasters predicted the same.

A 2 p.m. Metro Weather issued a forecast to LIRR and MNR that called for "early haze/fog, sun and clouds" for Wednesday morning. The 5:30 p.m. NWS forecast predicted rain for Wednesday afternoon.

At 6 p.m. the Metro Weather forecast for MNR included no precipitation for the morning of August 8 and a chance of showers and thunderstorms at night. The prediction for LIRR included a 63 percent chance of overnight thunderstorms diminishing to 50 to 22 percent after 6 a.m., with storms ending in the morning.

By 8 p.m. the Metro Weather forecast for the New York/Bronx zone for Wednesday, August 8, said: "Rain developing after 2200 hrs [Tuesday, 10 p.m.] with showers and thunderstorms. Rain could be locally heavy after midnight [into Wednesday] with a 50-60 percent chance of precipitation early and a 20 percent chance later in the day. Total rainfall amounts expected to be .20-.75+ inches for the period of 8 p.m. on 8/07/07 to 6 p.m. on 8/08/07."

At 10 p.m. Metro Weather's forecast for the MNR area posted a revised forecast indicating a 51-72 percent probability of showers/thunderstorms with .25 to .50 inches of precipitation between 6 p.m. on August 8 through 6 a.m. on August 9, noting rainfall may be "locally higher in any thunderstorms." This was actually a slight reduction in the predicted rainfall from the 8 p.m. report. Such rainfall levels are not unusual and do not normally present extraordinary operations concerns.

It was not until after midnight, in the early morning hours of August 8 that predictions regarding the storm began to change. By then it was over central Pennsylvania, stretching roughly from Canada to Maryland. At the back of the storm, near western Pennsylvania, hot, humid air helped create rain and thunderstorms. These heavier storms began heading east toward New York City at about 30 miles per hour as the rest of the storm moved off into upper New York State.

The first true signs of the severity of the storm heading for the region were issued by the NWS Upton office at 4:15 a.m. on Wednesday, when it issued separate flood advisories for northeastern New Jersey and New York City. These flood advisories called for "...minor flooding of urban areas...highways...streets and underpasses as well as other poor drainage areas and low lying spots...."

Twenty-four minutes later, at 4:39 a.m., the NWS issued a Hazardous Weather Outlook for the area calling for "showers, thunderstorms, gusty winds, and locally heavy rains resulting in minor urban and small stream flooding."

As of 6 a.m. the Metro Weather forecast for LIRR remained largely unchanged from that sent at 6 p.m. the previous evening but included for the first time a discussion at the end of the forecast that predicted local heavy thunderstorms and warned of local flooding.

At 6:08 a.m., as the New York rush hour was already underway, the NWS issued a flash flood warning for New York City, increasing the previously predicted amount of rainfall to 2 to 3.5 inches. This was followed by two tornado warnings, one at 6:28 a.m. for northern Staten Island and Brooklyn and another at 6:50 a.m. for eastern Brooklyn and southern Queens.

The 6 a.m. reports from the two other private weather forecasting services contracted by various MTA entities did not mention the flood advisories. Those reports called for "...Disturbance moving thru the Northeast this a.m. with showers & a t'storm till 10 a.m....." and "morning showers and thunderstorms" and "rain and thunderstorms...locally heavy...will move though this morning."
In addition to the heavy rain, a tornado swept through parts of Brooklyn and threatened parts of the South Shore of Long Island, resulting in disruption to subway service on two major lines due to downed trees across four tracks. Such severe weather activity had not been seen in the New York City area in over 100 years.

Because of the suddenness and intensity of the storm, critical parts of the MTA system were quickly overwhelmed by flash flooding. Others were affected by downed trees and other debris. Had there been sufficient warning the day of or even the evening before, rather than on the cusp of the storm, normal precautionary measures, such as inspecting key locations and cleaning drains and their surrounding areas, which normally require the attention of a full eight-hour shift, would have been taken.

In addition employees were themselves delayed by the weather which, in turn, slowed the deployment and stationing of equipment and personnel. ▼

C. Flooding

Reports of heavy rains, water on subway and railroad tracks, and street flooding began pouring into the various MTA operations centers starting just before 6 a.m.

By 6:30 a.m., flooding in various parts of the system began to have an impact on subway and rail operations. Rainfall in New York City peaked around 7 a.m. and tapered off by 8:30 a.m. In the westernmost part of the LIRR system, rain tapered off after 7:30 AM. At 7:33, the Railroad received reports that water was receding at Win Curve in Queens; at 7:40 water was reported receding in Mineola and Hunterspoint Avenue. New reports of flooding were received at 8 a.m. in Far Rockaway, indicating that the storm was moving in a southeasterly direction. It tapered off later in the morning in the more southern and eastern parts the LIRR service territory.

This storm was significant in two ways: 1) the extreme intensity of precipitation in a very short period of time and 2) the extent to which these high peaks were distributed throughout the city.

Seven of eight weather monitoring stations in the city experienced between 1.0 and 2.2 inches of rain during the peak hour, and four of these locations were subject to 1.0 to 1.6 inches in a single half hour. Far more troubling, however, was the fact that this level of intensity continued for nearly two consecutive hours, overwhelming regional drainage systems – designed to handle a maximum of 1.75 inches of rain per hour – with no time to recover before additional water was introduced.

The result was, in many instances, the unavoidable flooding of roadways, rail rights of way (ROW) and subway tunnels and stations via other paths, such as directly through subway entrances and vent gratings. ▼

D. Previous Storms

To put the storm of August 8 in perspective, it is instructive to look at two storms that occurred earlier in 2007 – one on April 15, the other on July 18 – and one which took place in September of 2004, all of which disrupted transit service on parts of the MTA network. While the 2004 storm disrupted a substantial part of the subway system, and prompted an investigation by the MTA IG, its intensity was less than that of August 8. The timing, intensity and the impact of both of the storms prior to August 8 in 2007 were also less severe and their effects were more limited; neither caused a complete disruption of the system.

April 15, 2007

On April 15, there was severe rainfall in New York City and throughout the entire metropolitan region. Over the course of the day, more than 7 inches of rain fell, the most recorded since September 23, 1882.

At the storm's peak, 1.11 inches fell between 2:51 and 3:51 p.m. and an additional 0.80 inches between 3:51 and 4:51 p.m. Rainfall measurements taken across the city showed that the heaviest concentrations were in northern Manhattan.

The storm caused significant, but more localized, delays on the subway system than those experienced on August 8. The 5 line was closed north of 180th Street because of mud slides and fallen trees and the 1 line was suspended between 137th Street and Dyckman Street because of flooded tracks.

On Monday, the 1, 2, and 3 lines were affected by a water condition, resulting in delays between 7:18 a.m. and 2:02 p.m. There were 12 lines that had reduced or no service; seven lines were disrupted for 3-8 hours and the 1 line was disrupted for more than 8 hours.

Although the record rainfall fell on Sunday, LIRR's problems came Monday morning when the Railroad was unable to use its Line 2 into the East River Tunnels and its connections and had limited access to Hunters Point Avenue tracks 1 & 2 due to high water conditions. As a result, 130 morning peak, 119 afternoon peak, and 78 off-peak trains were delayed (a total of 327 trains). The Railroad's on-time performance, generally over 90 percent on a daily basis, fell to approximately 65 percent on April 16. Residual delays continued into Tuesday, with 7 morning peak and 5 off-peak trains delayed.

Due to flooding in Mott Haven in the Bronx, MNR could not operate its Harlem and New Haven line trains into Grand Central Terminal from 4:46 p.m. until 7:31 p.m. on Sunday. A total of 32 trains were cancelled and nearly 100 were late. Service recovered in time for the morning rush on Monday.

July 18, 2007

On the morning of July 18, a severe storm ripped across Long Island, traveling west. A tornado hit Islip Terrace. The storm system lasted from 8 a.m. to 1 p.m., peaking between 10 and 11 a.m., when nearly 3 inches of rain fell in some spots.

The disparity in rainfall levels throughout the region was evidenced by measurements at Kennedy Airport with only 0.75 inches of rain for the entire day, Garden City with 5.18 inches, and other parts of Long Island averaging 3-4 inches of rain.

The rain on Long Island was described by the National Weather Service as the equivalent of 10 percent of the area's yearly rainfall in two hours. At the height of the storm, Manhattan was hit with 1.5 inches of rain over a two-hour period. Again, these levels of rain were dwarfed by the 2.5 to 3.5 inches of rain that fell in parts of the region over the two-hour period from 6 a.m. to 8 a.m. on August 8.

Roads began flooding shortly after 8 a.m., causing closures on portions of the Northern State Parkway at 8:10 a.m., the Long Island Expressway at 8:40 a.m., and the Southern State Parkway, Route 110 and Meadowbrook Parkway at 9:45 a.m. More than 100 auto accidents were recorded in the first two hours of the storm, and by 11 a.m., more than 51,000 customers on the Island were without power.

The storm flooded the Queens Boulevard corridor causing a suspension of NYCT's E, F, R, V subway service. Track at 65th Street and Broadway in Queens was reported to have a 600-foot length covered by nearly two feet of water. NYCT provided shuttle bus service to ameliorate this situation. Delays were also reported on the B, D lines. A total of 9 lines had reduced or no service and two of the lines experienced delays of 3 to 8 hours.

The LIRR shut down at Mineola just before 9 a.m., suspending service on the Oyster Bay, Ronkonkoma, and Port Jefferson branches. By 11:30 a.m. service was restored on the Oyster Bay and Hempstead Branches. However, service remained suspended on the Ronkonkoma and Port Washington Branches until 1:15 p.m. and 3:20 p.m. respectively. From 2:26 to 4:06 p.m. service was suspended on the Port Jefferson Branch due to a fatality that occurred when a man walked around lowered crossing gates and into the path of a train in Syosset. Residual issues from the storm and the fatality resulted in an afternoon peak with two canceled trains and 13 late trains for an OTP of 90.15 percent.

Flooding in the Bronx delayed more than 50 MNR New Haven Line trains and temporarily shut down service out of Grand Central. Seven trains were cancelled. Water rising over the running rails on the two outside tracks also meant no trains could stop at Bronx stations on the Harlem and New Haven lines.

September 8, 2004

On September 8, 2004, a substantial portion of the subway system was severely disrupted as a result of flooding due to intense rains. The rainfall averaged 1.76 inches in the hour between 7 and 8 a.m., and averaged 2.52 inches over the two hour period through 9 a.m. in Central Park. The extent of the rainfall overwhelmed MTA and regional drainage systems. Subway lines and stations flooded despite fully functioning pump rooms.

While still less intense overall, the storm's unpredicted nature as well as its timing were the most similar to what was experienced on August 8 – particularly as it affected the MTA subway system. Flooding resulted in 1,156 NYCT train cancellations, beginning in the rush hour period, impacting the commutes of hundreds of thousands of subway riders.

MTA performance on that day prompted an MTA Inspector General investigation that looked at a host of operations, engineering, and communication failures and made a series of recommendations. An MTA Board Task Force subsequently did its own investigation of the flooding in the subway and offered additional recommendations. Both reports are discussed in some detail in the following section of this report. ▼

E. MTA Inspector General and MTA Board Reports

In order to further inform the discussion of the storm of August 8, this report considered the extensive work done by the MTA Inspector General and a subsequent MTA Board Task Force on a similar flooding incident that took place on September 8, 2004. What follows is a summary of those reports, the recommendations they provided, and the action taken by NYCT to date to address them.

Overview

On September 8, 2004, a substantial portion of the subway system was severely disrupted as a result of flooding due to intense rains. The rainfall averaged 1.76 inches in the hour between 7 a.m. and 8 p.m., and totaled 2.52 inches in the two hour period through 9 AM in Central Park. The extent of the rainfall overwhelmed NYCT pump capabilities as well as the drainage system and sewers. Subway lines and stations flooded, resulting in 1,156 train cancellations, beginning in the rush hour period and impacting the commutes of hundreds of thousands of subway riders.

The MTA Office of the Inspector General (OIG) report #2005-64 investigated this incident and made recommendations to improve response to future storms. In a companion report, #2006-21L, the OIG separately explored communication problems experienced by MTA personnel and customers. Locations affected by the flooding can be seen in the Incident Map, Figure 1 (pg. 21), taken from the OIG Report. The MTA Board created its own Task Force in 2006 when the IG report was released, to further investigate the results. The Task Force independently reviewed the event, reviewed the status of NYCT's compliance with the OIG's recommendations and made additional recommendations.

Operations and Engineering Issues and Solutions

A typical subway drainage and pumping system for the sewer located above the subway is shown in Figure 2 (pg. 22). As the street is flooded, the water level rises above the sidewalk and enters the subway system through entrance staircases and ventilation gratings. Once in the subway, the water is directed to the troughs between the tracks and then to the drains leading to sewers or a pump room. As the water continues to rise above the running rail, service must be stopped as eventually the switches, signal boxes and third rail are submerged (Figure 3, pg. 23), shows water receding from this condition) and service must be suspended.

Both the IG report and the MTA Board Task Force agreed that a variety of factors led to significant flooding on September 8, 2004. At some locations the existing drainage and pumping capacity could not operate as designed because of the accumulation of sediment blocking the drains to pump rooms and gravity flow sewers. Blocked drains restricted removal of water and increased the duration required to restore service. Contributing to the accumulation of debris was the decline in track cleaning resources due to budget cuts and the proliferation of new sources of litter in the system, such as free newspapers.

In addition, some locations, such as Hillside Avenue shown in Figure 4 (pg. 23) were more vulnerable to flooding due to road grading issues or already overtaxed sewer capacity, both of which had an impact on the ability to pump water out of the system faster than it came in. This type of impact in such a weather situation was not an unanticipated one, since the storm levels exceeded the design criteria – 1.75 inches per hour – of the drainage plan in the area.

The OIG and the MTA Board Task Force agreed that the problems that existed in 2004 required a combination of operating and engineering solutions to improve the flow of water and MTA drainage design and/or pumping capacity in certain areas.

Both agreed that some of the flooded areas could have been prevented or minimized by more frequent clearing of debris. The OIG also reviewed and drew the conclusion that the response time to restore service could be improved with better procedures and deployment of resources.

From an engineering perspective, the flat track beds at East 23rd Street and Lexington Avenue and the large distances between pump rooms at Parsons Boulevard and 65th Street hinder drainage. Making matters worse is that the area is easily overwhelmed with additional roadway flooding entering the ventilation gratings. NYCT had tested temporarily covering the street ventilation gratings under a sudden downpour scenario. However, this is practical only when there is sufficient notice of bad weather. Elevated gratings, which interfered with pedestrian flow, were deemed unsightly. Neither were considered efficient or acceptable long-term solutions.

Ultimately, the OIG report recommended:

- More regular maintenance of gravity sewers, check valves, and drain components is needed
- Additional track cleaning
- The need for clear, informed command over resources responding in the field so there can be prioritization of incidents and the most efficient use of resources (i.e., people, trucks, and pumps)
- Better procedures, direction, and training to be given to field responders to improve effectiveness and shorten overall response time
- Improving response time by strategically locating equipment in advance and providing alternate ways for first responders to reach the site
- Providing more suitable portable pumps for emergency use
- Better data collection on incident conditions and response are needed so there can be improved lessons learned and problem solving
- Working with DEP, DOT, and NYPD to resolve issues related to drainage and response time

The MTA Board Task Force of 2006 agreed with many of the recommendations in the IG's report and additionally recommended the following:

- NYCT needed to prepare a schedule for implementation of the OIG recommendations
- The entire system needed to be reviewed for vulnerability and cost effective (and short term) solutions
- Hire a drainage consultant to work cooperatively with NYCDEP and NYCDOT to validate longer term solutions
- Install additional Kem gratings (drain cages) at key drain locations
- Extend the pump room recording and notification system to additional locations
- Provide additional information to support the claimed improvement in track cleaning that was given as a response to the OIG's recommendation

The Task Force did, however, acknowledge that flooding will continue to occur where debris blocks drains – a continual challenge. Also, flooding due to direct sewer connections and pumping limitations will continue unless more global improvements are made. Critical to successfully addressing these issues will be the continued cooperative relationship with NYCDEP and NYCDOT.

Communication

As noted earlier, on June 6, 2006, the OIG issued a report MTA/OIG #2006-21L on customer communication during the September 8, 2004 subway flooding. The report concluded that the information provided to transit customers that day did not fully convey the actual conditions that existed throughout the system and noted the lack of adequate plans and procedures for communicating with transit riders, as well as with the commuter railroads and other transit providers.

The report also noted that 28 percent of the 469 subway stations lacked a public address system and that communication with riders were often hampered by internal communication systems overwhelmed due to a lack of adequate capacity. The OIG accordingly recommended that:

- Passenger communication be upfront about the extent of the service problems, including advice to avoid the system, or parts of the system, when necessary
- Service impacts be more effectively communicated to the commuter railroads and other transit providers
- Public address systems be installed in all stations and that NYCT should consider the use of email and improved telephone systems to communicate with certain announcers
- The capacity of the communication system to customer service booths be increased.

Response to the Reports/Status of Recommendations

NYCT has fully implemented a third of the recommendations made by the OIG since the release of the reports in February and June 2006. Engineering problems specific to two sites discussed in the February report were fixed and trash problems were pursued, in part through increased station cleaning. An additional 50 percent of the recommendations are in progress. The remaining recommendations are being carefully reevaluated in light of August 8. In addition NYCT is addressing a number of recommendations made in the June report regarding how to communicate with customers during unanticipated emergencies.

NYCT has also complied with or is in the process of pursing solutions to all recommendations included in the Board Task Force Report. ▼

Figure 1: Major Subway Flooding Incidents on September 8, 2004

MTA OIG Report #2005-64

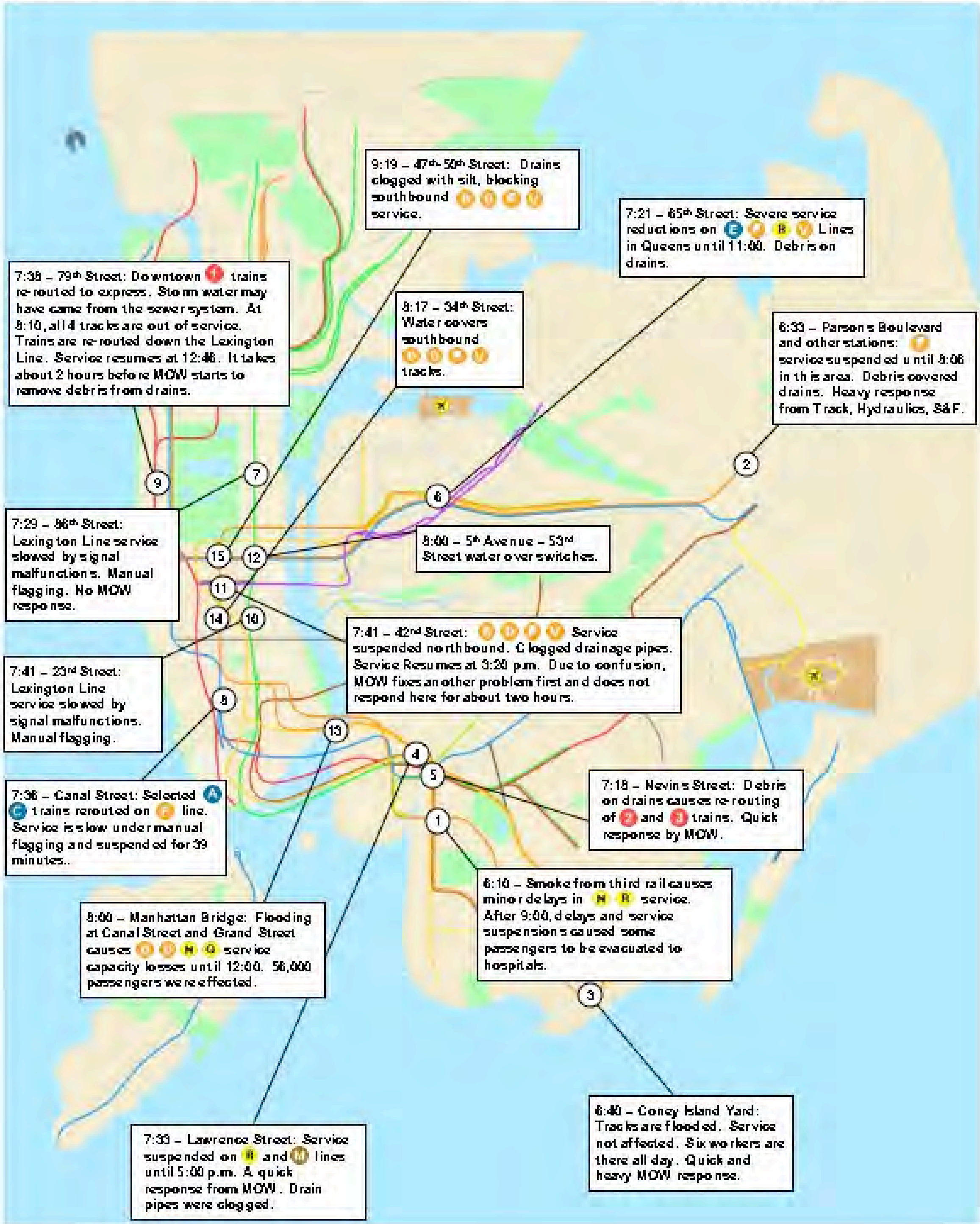
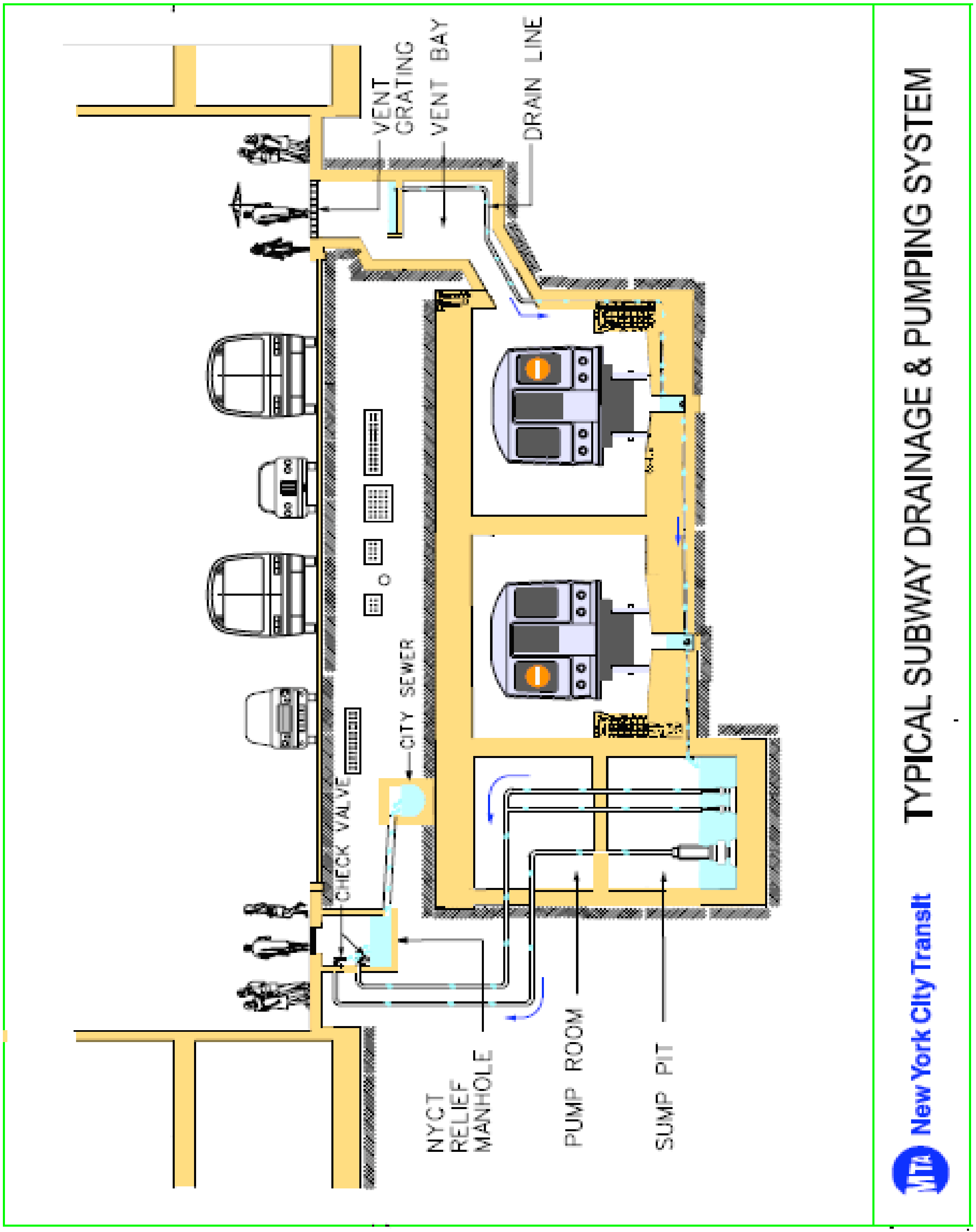


Figure 2


VENT GRATING
VENT BAY
DRAIN LINE
CITY SEWER
CHECK VALVE
NYCT RELIEF MANHOLE
PUMP ROOM
SUMP PIT
TYPICAL SUBWAY DRAINAGE & PUMPING SYSTEM
New York City Transit

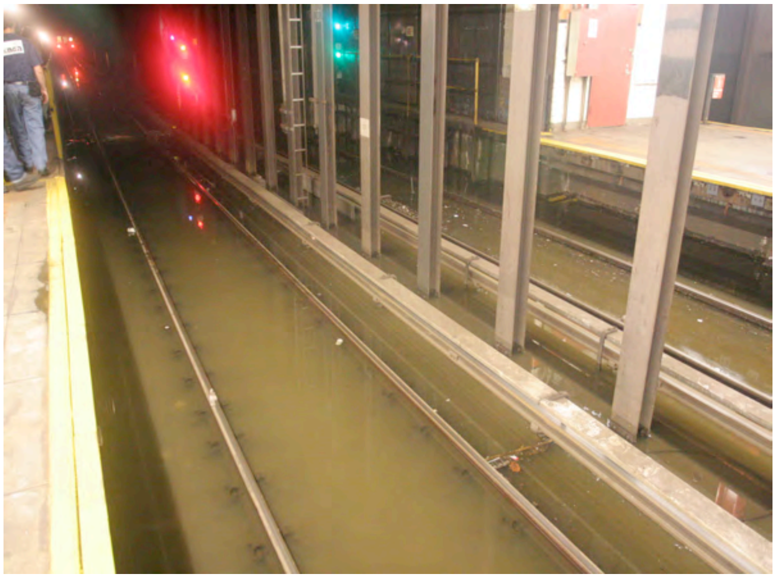


Figure 3
F Line Hillside Ave Related Flooding

Figure 4
F Line Hillside Ave Flooding

F. Climate Change

There are some indications that intense climate events that lead to flooding have been increasing in the region since 1990. Storms such as the one the New York region experienced on August 8 are likely to increase in frequency and intensity due to climate change. As a result, the design standards to which systems like the MTA and other governmental entities concerned about drainage should adhere need to be reviewed and potentially revised.

The MTA and NYCDEP have worked with Columbia University's Center for Climate Systems Research (CCSR) to gauge the likelihood of experiencing similar storms and flooding in the near future. CCSR analyzed precipitation data to determine the frequency of climate events that lead to flooding in the New York Metropolitan Region, and how they may be changing in the current climate. (Appendix 2)

The 2.5 inches of rainfall on August 8, 2007 at Central Park correspond to an amount of precipitation expected on average approximately once per year. More exceptional, and probably more disruptive for the MTA, were the very high hourly rainfall rates exceeding 1.65 inches per hour at Central Park and 1.87 inches at La Guardia. These rates, experienced during the morning rush hour, placed the event very close to a 1-in-5 year event for Central Park and 1-in-10 year event for La Guardia, as defined by the historical record.

Two of the eleven 1-in-10 year daily rainfall totals have occurred in the last decade, and four of the eleven have occurred since 1990. This is approximately double what would be expected by chance alone. Results are similar for 1-in-5 year rainfall events.

The hourly analyses show that 1-in-5 year and 1-in-10 year events over the past decade have slightly exceeded their expected values. These recent increases in extreme hourly precipitation events cannot be attributed to climate change, due to the shortness of the data record and high variability of precipitation. These findings, combined with the tendency for the top 15 hourly precipitation events to cluster in latter portions of the data records, are consistent with what might be expected in the future given an intensified hydrological cycle associated with global warming.

The study concluded that:

- There are some indications that intense climate events that lead to flooding have been increasing in the region since 1990. These indications are in line with what is projected to occur with global climate change due to increasing anthropogenic greenhouse gas emissions. These emerging trends need to be monitored for longer periods before natural variability can be ruled out.
- In the coming decades, sea level rise and an intensified hydrological cycle due to climate change are expected to lead to more frequent and severe flooding events. The combined effect of damaging high-water levels and more extreme precipitation events is very likely to enhance the flooding threat faced by the MTA.

The Columbia University team also examined how various MTA operating agencies have tried to solve flooding problems, and found that the agencies often asked for minimal input and help from other agencies. This means that the MTA units often have to find engineering solutions for flood causes that in many instances originate within their own operations and administrative "territory"; but in many instances the solutions to the flood problems may lie in solving the flood causes at the sources, not the "sinks." The report recommends cooperation with outside agencies, owners, and entire communities.

Mitigation has focused on increasing drainage capacity and reliability (the demand side). It is important that future efforts will look at the changing supply side (of water in whatever form). The supply of excess water to MTA sites, which could impact reliable operations, has actually been shaped by man-made changes. That includes land use and related changes in surface permeability where the ground has less ability to absorb precipitation, which lowers peak run-off and spreads total run-off to already overtaxed storm sewers/drainage systems.

The Columbia report recommends that in order for the MTA to avoid future flooding problems while maintaining reliable and safe operations, a broad systematic approach will be required. Flooding cannot be solved by narrow engineering solutions based solely on past experience. While these issues will be discussed as part of the larger set of recommendations presented in other parts of this report, Columbia suggests that the MTA take a more systematic approach to its flooding plans that factor the following elements:

- A staggered approach should be considered: quick solutions may cost less, but may not be effective measures to deal with long-term conditions caused by climate change.
- A systematic assessment of the hazards is needed, both for current and future climate conditions and time horizons.
- Assets at risk and their vulnerability (fragility) to these hazards need to be inventoried and quantified.
- Risk assessments of the assets, given their vulnerability and given the hazards need to be performed, again for different time horizons.
- Green roofs, planting trees on streets etc. will have positive effect.
- Multiple options for reducing the risks (whether by modifying the hazards or the assets/fragility side of the risk) need to be explored and their cost estimated.
- Reduction of future losses from these mitigation efforts needs to be quantified.
- Costs and benefits, not only in monetary terms, but also in terms of environmental and community sustainability, need to be considered in the decision process.
- Many of these procedures will require a change in the institutional culture to include a range of professions and stakeholders involved in the planning and decision process. ▼

G. Peer Systems Review

Dr. Robert E. Paaswell, Distinguished Professor of Civil Engineering and Director, University Transportation Center of the City College of New York, was asked as part of this study, to conduct a review of the operating practices of a number of national and international transit systems in order to develop peer comparisons as it relates to dealing with system flooding.

Interestingly, the report cites a July 2007 London Underground flooding experience that caused a similar impact to what the MTA system experienced on August 8, with the exception that it occurred during the evening rush hour. Floods closed many tube stations and riders turned – unsuccessfully in many instances – to oversubscribed buses.

While the report is included in its entirety as Appendix 3 of this report, basic findings are that while systemwide flooding is rare, all systems have experienced some level of floods that have been significant enough to shut service. The number of such events varies per year from once a year, as is the case in Toronto, to three times a year as indicated in discussions with Atlanta.

Pumps, drainage, and other techniques were utilized for most of the rail systems to mitigate the impact of flooding. And while all systems have pumping standards, there are no national Public Transit Protocols or Standards to address floods. Standards are adopted locally based on local experience and most likely conditions. For example, WMATA's pumps are scaled to handle a 50-year storm (although the regional combined sewer system is only designed to accommodate at 15-year storm.) San Francisco's new Central Subway is being designed to handle a 100-year rainfall.

As is the case with the MTA system, most properties reinforce pumping capacity with portable pumps at those stations or points most susceptible to flooding. While pumps are the main line of defense against flooding, some stations in Tokyo and London can be closed by gates against water (effectively shutting down that part of the system.)

And as the MTA has done in this report, London and Tokyo have begun to seriously look at the impact of global warming and its consequences on their transit operations.

The conclusion drawn by Dr. Paaswell is that the response of the MTA to the storm of August 8 is consistent with that of its peer properties. The MTA's technical response to the flood itself followed accepted protocols, including maintaining pumps, testing circuits and other functions associated with shutting down and starting service.

The MTA, however, did fall short in two key areas: 1) in communicating the severity of the flood conditions to its customers and 2) in planning for how buses can be better employed to assist in the case of a subway or rail shutdown.

While the MTA is clearly addressing flooding issues in a similar or superior fashion to other major national and international systems, the MTA will continue to interact with peer systems to search for more efficient and effective solutions to prevent system flooding and achieve our goal to avoid or limit future incidents that affect service. ■

III. Operating Impact, Response, and Recommendations

Over the course of the storm service on the MTA network was seriously disrupted. The severity and duration differed at various locations throughout the region.

At NYCT, flooding of subway stations and tunnels caused significant subway service delays and disruptions across the city, and service was completely shut down for more than eight hours on four subway lines.

Commuter rail line service experienced significant delays on nearly all lines. In addition, LIRR suffered a brief disruption on its Hunterspoint line, but its Port Washington service was interrupted for about six hours, and flooding on local roads prevented staff from getting to their work sites.

MNR was unable to operate any of its trains into or out of Grand Central Terminal for approximately 20 minutes, at which time Hudson Line service was restored. It would be another hour before Harlem and New Haven line trains resumed service through the flooded area and into GCT. MNR terminated five Harlem and New Haven Line trains at Wakefield and Woodlawn stations in the Bronx.

Bus service, provided by NYCT, MTA Bus, and LI Bus, was also disrupted across the city and Nassau County due to flooded roads. Service was slowed by the thousands of subway customers who attempted to use the bus network as an alternative.

B&T facilities were affected by localized flooding that occurred on approach roads and exits. This contributed to the overall transportation problems in the aftermath of the storm by slowing traffic on approach roads, some of which were flooded or more crowded than usual.

A. Impact by Mode

Subway

Twenty-six incidents of serious flooding occurred on the MTA New York City Transit (NYCT) subway system on August 8. Those incidents caused 19 disruptions, six of which lasted from three to eight hours and four lasted over eight hours.

Four locations in the system – Parsons Boulevard, 65th Street, and 36th Street-Steinway Street in Queens and 79th Street in Manhattan – are the most frequently flooded. Predictably, all four flooded on August 8. Of ten other flood-prone subway locations, three flooded. Among the reasons that seven of these other stations did not flood, five were because their drains had been jett-cleaned;

one was because of a properly maintained direct sewer connection; and one had temporary pumps installed.

NYCT does not believe that any drains were clogged before the storm. NYCT has a program for annually jetting out drain lines and pump room inlets, and does this more frequently at flood-prone sites. Additionally, two-thirds of the system drains have had Kem boxes installed. These provide four to five times the surface area of a normal flat drain for water to be cleared.

All permanent and temporary pumps functioned except for the Meserole Pump Room on the G line, which failed because of an electrical fault. Temporary pumps at the 57th Street and Broadway Pump Room on the E and F lines did not operate due to a tripped circuit breaker. Temporary pumps at the 153rd Street and Hillside Avenue Pump Room tripped, but were immediately reset by Capital Program Management personnel who were at the site. Portable pump trucks were dispatched to flood-prone areas, including 23rd Street and Lexington Avenue, Hillside Avenue and 153rd Street, 149th Street and Grand Concourse, Sand Street, and Broadway/Lafayette.

The pump train dispatched from the 38th Street Yard to the Queens Boulevard corridor took three hours and 40 minutes to arrive due to impassable tracks.

For subway customers, the length of time that service on a line segment is cancelled or reduced before returning to normal is most important. The August 8 storm brought a total of 19 disruptions, six of which lasted from three to eight hours and four lasted over eight hours. This was the most extensive service impact of the four recent storms (September 8, 2004 April 15, July 18, and August 8, 2007), affecting as many as 2.3 million subway riders.

	Number of Line Segments with Reduced or No Service			
	Sept. 8, 2004	April 15, 2007	July 18, 2007	Aug. 8, 2007
All Disruptions	7	12	9	19
Disruptions of 3 to 8 hours	2	7	2	6
Disruptions of over 8 hours	3	1	0	4

In this widespread disruption, train service was maintained on some line segments, but was queued and congested due to the density of diverted rail traffic, the limited capacity of temporary terminals, improvised crewing, and overloading. The ability of trains to move was further restricted by the need to berth queued trains at platforms to the greatest extent possible. Under these circumstances, a line that NYCT views as "running" is, from a customer perspective, "not running" because the trains are stationary or because the line does not reach the customer's destination.

On lines which were running with normal crewing and terminals, such as the Flushing line, service was reduced when overloading slowed boarding, increasing running times and reducing throughput capacity.

Of the 21 storm-related incidents that occurred that morning, most could have by themselves stood as a major disruption. The first 15 incidents were reported within 45 minutes – a rate of one every three minutes.

Unfortunately, NYCT's procedures manage incidents on an incident-by-incident basis. NYCT also has procedures for system shutdown, such as blackouts, strikes and security-related shutdowns, but these are different in nature from incident response.

The key to successfully responding to incidents and communicating to customers relies on recognizing when to make the transition from managing incidents to managing a (near) system shutdown. Clearly the incident of August 8 was not managed as if it were a shutdown early enough on in the process.

Commuter Railroads

Given the forecasts of the weather services used by LIRR and MNR, the severity of the storm on the morning of August 8, 2007 was totally unexpected. At 6 a.m. LIRR trains were running on or close to schedule. At about 6:40 a.m. a very heavy downpour started, and morning radio reports indicated the possibility of tornadoes in the region.

Both LIRR and MNR have emergency plans applicable to all types of service disruptions, including storms. They are designed to be realistic and to minimize inconvenience to customers while service is being restored as quickly and efficiently as possible. The emergency plans were followed and effective on August 8.

For the LIRR, the storm caused the interruption of service starting around 6:46 a.m. for approximately six hours on the Port Washington Branch, due to flooding above the third rail at Bayside. Service to Hunterspoint Avenue was delayed due to flooding, but was quickly restored.

Severe flooding and very congested traffic on local roads impeded LIRR staff from quickly arriving at key station locations.

MNR's service began to be affected at 6:31 a.m. when high water conditions began to be reported at Melrose/Claremont Parkway, Fordham, and Mott Haven in the Bronx and on track three on the Hudson line between Yonkers and Riverdale.

Short circuits occurred ("track circuits down") in the signal system, an indication, in this situation, that water was starting to infiltrate the infrastructure. When short circuits occur, MNR operates on that section at restricted speed or on adjacent tracks if possible until the extent of the problem is known, diagnosed, and corrected. [Operating problems of this sort are routine and normally have little or no impact on the customer's experience.]

Three other incidents of short circuits (some involving multiple circuits at one location) coupled with reports of high water at each location mentioned above were reported through 6:53 a.m. Because of these reports during this early period, a "Code Yellow" (a problem likely to last for more than a short period of time, an actual or an imminent disruption of service on one line, or a partial shutdown of GCT) was put into effect at 7:00 a.m. MNR's Emergency Management Task Force began reporting to the railroad's Situation Room.

At 7:16 a.m. MNR put its "Code Red" into effect, indicating that it was experiencing a severe, potentially long-lasting disruption, and service on all lines and/or Grand Central Terminal was being affected. MNR's Situation Room was now staffed. At 7:20 a.m. all service into and out of GCT was suspended. Trains approaching Woodlawn were instructed to give customers the choice of leaving the train for NYCT service. Most customers elected to wait until MNR service was restored. (Communication had occurred between the Operations Control Center/Situation Room and NYCT in order to coordinate – and then terminate when it was determined that NYCT subways were not running – alternate service in the Bronx. This communication was handled in accordance with the existing alternate service agreement between MNR and NYCT.)

All three Metro-North Lines (Hudson, Harlem, and New Haven) were affected due to the flooding at the Mott-Haven area at 149th Street, where MNR's three lines converge. Other flooded areas were Claremont Parkway/Melrose and Fordham, neither of which experienced service disruptions. Of the 77,238 customers who normally ride Metro-North into Grand Central during the morning peak period, an estimated 57,869 were affected.

Of the 190 revenue trains that are operated during the morning peak period, 13 trains were 6 to10 minutes late, 8 trains were 11 to 15 minutes late, 7 trains were 16 to 30 minutes late, 35 trains were over 30 minutes late, 75 trains were cancelled, and 52 trains were on time.

Buses

All three of the MTA's bus operations – NYCT buses, LI Bus, and MTA Bus – had significant delays on the morning of August 8.

Under current NYCT Department of Buses (DOB) procedure, the RCC provides information via telephone/Nextel to alert the Bus Command Center (BCC) regarding subway service disruptions. The regular bus route network and the dedicated, substitute routes were unequal to the task of handling peak-hour subway loads. Subway peak loads range from approximately 15,000 passengers per hour on the lighter corridors to over 50,000 on the heavier corridors. Bus service is generally inoperable on city streets at loads above 5,000 passengers per hour, due to the combined effect of loading dwell times, traffic signals and street space.

In addition, dedicated substitute service of any size draws buses off regular routes. In this event, 185 buses were removed from normal service. For every busload of delayed subway customers who were accommodated, a busload of regular bus customers, or subway customers attempting to use regular bus routes, were delayed somewhere in the system.

DOB's ability to respond was also constrained by reduced availability of bus operators caused by subway and street disruptions affecting their timely reporting for duty; in this event, 71 fewer buses were on the street during the morning peak due to this effect. Bus service on city streets was subject to delay from traffic congestion and street flooding.

NYCT has a draft plan for an overall bus system reconfiguration in response to a subway shutdown, developed in the aftermath of the regional blackout of August 2003. NYCT will use lessons learned from August 2007 as a framework to reassess the bus plan.

LI Bus does not have a formal storm plan; rain is not considered an unusual or emergency occurrence and is handled as part of regular operations. In the event of serious emergencies, the agency communicates with the Nassau County Office of Emergency Management, although this was not necessary on August 8. As part of its normal operations, LI Bus contacts the county Department of Public Works to report blocked storm drains.

As heavy rains moved into the LI Bus service area during the predawn hours of August 8, the LI Bus command center began receiving field reports of flooded streets throughout the region just as the LI Bus morning service reached peak.

The first reports were received at 6:55 a.m. concerning flooding in Massapequa Park and Merrick Boulevard in Jamaica. Shortly thereafter, numerous reports of flooding were received from a number of other locations throughout the LI Bus system.

Throughout the morning peak rush hour period, LI Bus service on north-south routes generally ran between 15 and 30 minutes late, while east-west routes experienced delays ranging from 30 to 75 minutes or longer. This occurred because most Long Island drivers are traveling eastbound toward Queens and Manhattan and use local roads to avoid crowded highways.

Although all routes incurred significant delays, the following roads/locations used by LI Bus for regular line services were reported flooded and impassible during the August 8, 2007 storm. (Route numbers appear in parentheses.)

- Sunrise Highway in Massapequa Park near Sunrise Mall (N19 and N80/81)
- Merrick Boulevard/Liberty Avenue in Jamaica (N4)
- Northern Boulevard (N20/21)
- Hillside Avenue/186th Street (N24)
- Route 106/Jericho Turnpike (N20/21 and N48/49)
- Route 110/Conklin Avenue (N70)

Delays were largely due to impassible roads from street flooding conditions, route diversions around flooded areas, and severe traffic congestion. Ultimately, however, no LI Bus service was cancelled.

The MTA Bus Command Center at its College Point Depot works closely with the NYCT Department of Buses to monitor weather and traffic conditions throughout the region. At about 7:25 a.m. MTA Bus personnel were on full alert and providing service from every scheduled/available bus. Running at peak morning rush hour capacity, MTA Bus provided 570 out of a scheduled 574 local trips and 529 out of a scheduled 533 express trips despite increasingly degraded weather that began to affect both street conditions and traffic congestion. Virtually the entire fleet was involved in providing this service and no spare bus operators or buses were available at that time.

MTA Bus express bus trips in the peak period, particularly from Queens, have few extra seats and operate at wider intervals than local buses. Trying to accommodate subway closure passenger volumes that can easily number more than 1,000 people at a time is impractical.

Bridges and Tunnels

For the most part, MTA Bridges and Tunnels (B&T) does not have areas on MTA property that flood. In fact, all the areas that flooded and affected B&T operations on August 8, as well as during the previous storms of April 15 and July 18 were off-property. However, adjacent roadways and low-lying areas adjacent to B&T facilities do have an impact on the amount of traffic and congestion on those facilities.

The major recurring problem areas that affect B&T are described below. In each instance, the NYPD Traffic Management is contacted to facilitate the coordination of other city agencies. Closures can last between 2 to 4 hours. In no case were B&T facilities closed.

The Grand Central Parkway at the foot of the Triborough Bridge (off-property) is a major problem during rain storms as it often forces the closure of the Parkway, forcing all eastbound traffic to exit onto the local streets via the 31st Street exit. The westbound Parkway is also prone to flooding, causing motorists to detour onto local streets in order to access the Manhattan/Bronx-bound bridge.
The Cross Island Parkway (CIP) eastbound at the foot of the CIP Exit Ramp of the Throgs Neck Bridge floods at the catch basins where the ramp meets the parkway. This condition forces B&T to close the exit ramp, leaving the Clearview Expressway as the only egress from the bridge. The westbound CIP occasionally floods at the foot of the bridge causing the closure of the "onbound" ramp in extreme instances.
The Henry Hudson Parkway southbound, north of the 181st Street exit causes the closure of the parkway southbound and traffic often backs up all the way to and onto the Henry Hudson Bridge.

Other Regional Transportation

The MTA was one of many transportation systems affected by the severe weather of August 8. Flash floods occurred throughout the New York region, creating conditions that slowed traffic and caused major congestion and delays on expressways, highways, and other regional transit systems.

All major thoroughfares into the city experienced severe delays by the start of the morning rush hour, and by 7 a.m. flooding that required partial or complete closing of traffic lanes was reported on sections in at least one direction of the FDR and Harlem River Drives in Manhattan, the Grand

Central Parkway in Queens, the Bronx River Parkway, Hutchinson River Parkway, and Cross Westchester Expressway.

By 8:30 a.m. most of these highways were experiencing closings in both directions, and some were still flooded as of noon. Delays on all major highways continued throughout the rest of the day.

Major highways throughout New Jersey were also flooded during the morning rush and into the afternoon, causing significant delays and closures.

NJ Transit rail service reported delays of up to 30 minutes for trains out of Northern New Jersey, Hoboken, and Newark, as well as stations further south. This lasted from 6:40 a.m. when the storm started until late morning at around 11:30 a.m.

The Newark City subway suspended service between Newark Penn Station and Orange Street for about an hour between approximately 7 and 8 a.m. During this same period, NJ PATH train delays suspended service into and out of the Manhattan 33rd Street Station for approximately 50 minutes and had minor delays until almost 10:30 a.m. ▼

B. Recovery

NYCT subways were hit hardest by the effects of the storm-caused flooding – their disruptions were longer and more widespread. Commuter rail lines were less affected, though the LIRR had to deal with more severe problems and longer outages than MNR.

Buses had to deal with the street congestion, reroutings, and delays that come with flooding, as well as the additional customers who tried to use buses when subways and commuter rail service were disrupted. Delays varied by local route conditions, but most disappeared when drainage systems had time to recover.

It was in the recovery stage, however, where the Herculean efforts of the MTA workforce paid dividends for the region as they worked tirelessly to restore service. Their efforts to pump millions of gallons of water, clear tons of muck and debris, replace water-logged equipment, and perform inspections and safety checks allowed most service to be restored before the evening rush.

Subways

The resumption of subway service after a near systemwide shutdown required a massive "all hands" effort across the agency. Once the water was pumped and drained from the right-of-way, the work to restore service entailed deploying hundreds of skilled and labor personnel to locations throughout the system to perform time-consuming and intricate cleaning, inspection, validation, repair, and replacement activities essential to the safe and orderly return to service. The time required to clear debris and clean, inspect, and repair track and signal equipment often far exceeds the time it takes to pump out the water.

According to NYCT Maintenance of Way (MOW) records, 16,000 pounds of debris, silt, and mud were removed by work forces in the aftermath of the storm. Infiltrating flood waters had brought with them huge volumes of silt and debris which settled onto the track bed around subway drains and grates.

In addition, the tornado which hit sections of southwest Brooklyn affected operations along the Brighton and Sea Beach lines, uprooted trees and branches and distributed them along the along the right-of way in the Bay Ridge and Bensonhurst sections of Brooklyn. Work crews with chainsaws were dispatched to cut and haul away this debris before service on the B, N, and Q lines could be resumed.

Since much of the signal and track equipment on the right-of-way was submerged for varying amounts of time, a rigid protocol of inspection, testing, and validation of the operation and reliability of this critical infrastructure was performed. The result of this testing and inspection by teams of signal and electrical engineers revealed significant replacement needs, including the replacement of 18 induction stop motors, 29 track relays, 53 resistors, 7 track transformers, and 4 electric switch motors. Inspections also identified the following cleaning and overhaul needs of 46 stops, 32 switches and 6 insulated joints.

In addition to repairing damaged signal equipment, track personnel were enlisted to clean and restore third rail power. This work entailed scraping the rails of silt and debris, clearing obstructions, and ultimately clearing for re-powering. Safety procedures require that all sections of third rail that were de-energized be physically inspected before power can be restored. This procedure is required whether the rails have been submerged or not.

When service stopped due to the flooding, various trains were rendered idle and out of service until safe service could be guaranteed. The service schedule associated with the deployment of these cars was adjusted and repositioning was therefore necessary. Additional forces were required to oversee these movements.

All in all, these efforts on the part of the MTA workforce, largely unseen by subway customers and the public, resulted in most NYCT service being resumed by midday, with only a few line segments remaining out of service until the evening rush and most remarkably, with the Queens Boulevard service being restored prior to 4 p.m.

Commuter Railroads

The most significant impact on service was on the LIRR's Port Washington Branch where service was suspended due to flooding. LIRR contacted private bus providers and LI Bus to obtain bus service for the customers on the Port Washington Branch. Bus availability was constrained by time of day (since it was also peak time for bus travel and usage) and difficult road conditions (which prevented buses from being positioned where needed.) Limited train service was restored at 10:04 a.m. and full service by 12:55 p.m. The impact on LIRR customers, however, was not entirely limited to their trip on the railroad itself. While lines other than the Port Washington Branch continued to bring customers to Penn Station and Atlantic Terminal, many of those customers found that connecting subway service for the last leg of their commute was not available.

Subway riders who would normally have taken the Queens Boulevard lines went to Jamaica Station in order to use LIRR to travel to Penn Station or Flatbush Avenue. The Railroad permitted them to board using MetroCard.

In an important family-wide effort to assist NYCT prepare for the potential that no subway service would be available for the afternoon rush on the Queens Boulevard line, the LIRR developed an emergency service plan to provide subway customers with alternative shuttle service out of Penn Station that paralleled the Queens Boulevard subway and provided access to Woodside, Forest Hills, and Kew Gardens stations. To create capacity for this service, LIRR combined or cancelled 15 regular service trains. Fortunately, by 3:46 p.m. NYCT successfully instituted a shuttle train of its own between the 7 line at Jackson Heights-Roosevelt Avenue and Jamaica Center/Parsons-Archer beginning at 4 p.m., with shuttle buses from Sutphin Boulevard to the F line station at 179th St. This restoration dramatically reduced the need for the LIRR to provide that backup service and allowed them to refocus on dealing with anticipated extra ridership for a Mets game that evening at Shea Stadium.

By 7:29 a.m. conditions were improving on MNR. Water was receding naturally and the Harlem line tracks at Mott Haven became passable. Harlem and New Haven line tracks, however, were still problematic. MNR instituted its alternate service plan with NYCT; southbound Harlem Line trains were unloaded at Wakefield and southbound New Haven Trains were unloaded at Woodlawn for customers to transfer to NYCT.

Hudson Line service was restored at 7:44 a.m., and field reports indicated that water was beginning to recede on the Harlem and New Haven line tracks at Mott-Haven as well. At 7:54 a.m., with NYCT's 4, 5, 6 subway lines shut down, the transfer of passengers at Wakefield was cancelled and trains stopped unloading there. (Three Harlem Line trains unloaded at that location, with most customers electing to await the resumption of MNR service.) The first southbound track was restored to service at 8:34 a.m. and northbound service began operating out of Grand Central at 8:45 a.m.
By 8:58 a.m. all service was restored with speed restrictions through the area. By 9:52 a.m. all tracks were operating at normal speed. Residual delays lasted until approximately 10:46 a.m. when MNR resumed a normal schedule. Service remained unaffected for the remainder of the day.

Buses

Twenty NYCT bus routes (out of a total of 243) were rerouted due to flooding and downed trees or power lines. Service was also affected by excessive traffic congestion. Route diversions occurred in Manhattan, Brooklyn, Queens, and the Bronx, primarily in the morning hours, while express routes returning to Staten Island were diverted to the service road of the Staten Island Expressway. In addition, the Department of Buses provided 185 buses throughout the day to provide supplementary service along subway lines that were affected in Brooklyn, Queens, and Manhattan. Most normal service resumed by midday, with two exceptions in Queens and Staten Island, which resumed at 4 p.m. and midnight respectively.

MTA Bus responded to known key locations (Kew Gardens Station, 60th Street and 2nd Avenue, Queens Plaza, Woodside LIRR Station, Jamaica LIRR Station, Main Street, and Roosevelt Avenue) to assist NYCT Department of Subways and NYCT Department of Buses. As large crowds formed at these locations, all express buses returning from Manhattan were pressed into local service at Queens Plaza. MTA Bus supplemented service on westbound Q60 which runs along Queens Boulevard with these buses. All JFK Airport Shuttle service was curtailed on the Q11 and Q37 at Kew Gardens and those buses were also used to supplement westbound Q60 service. All express buses arriving at Kew Gardens were loaded beyond normal capacity to accommodate as many customers as possible.

Eight scheduled runoff trips (where operators are finishing the day's work and are scheduled to pull into the depot) on various lines were used at the LIRR's Jamaica Station to also supplement westbound Q60 service. In addition, supplemental BXM4B and BXM11 express service was provided from the Bronx to Manhattan.

The MTA Bus Command Center made bus radio announcements every 15 minutes authorizing express bus operators to carry standees. The greatest hindrance to providing service was the extraordinary amount of vehicular traffic. By 11:30 a.m. the number of customers requiring transportation had greatly diminished and buses were released to their depots.

By 2 p.m. MTA Bus and NYCT DOB jointly devised a plan for the afternoon rush hour, under which DOB would provide shuttle service along the Queens Boulevard corridor and MTA Bus would enhance service at key locations. Supervisory personnel at 23rd Street and Madison Avenue and 26th Street and Madison Avenue were put on alert for additional customer loads. Cooperation between NYCT DOB and MTA Bus was exceptional.

LI Bus service on north-south routes experienced delays of 15 to 30 minutes while east-west routes had delays of 30 to 75 minutes during the morning rush. By mid-day LI Bus service was operating normally.

Bridges and Tunnels

The flooding impact on Bridges and Tunnels facilities was actually not on B&T property but on access/egress points to those facilities from City/State roadways. Flooded areas included the on-bound ramp from the Cross Island Parkway (CIP) to the Throgs Neck Bridge; the eastbound Grand Central Parkway near 31st Street at the Triborough Bridge; the Clinton Street entrance ramp to the Brooklyn-Battery Tunnel; and the southbound Henry Hudson Parkway at 181st Street. All of these affected traffic at B&T crossings.

As the rains subsided conditions improved and reached normal levels. Traffic was back to normal at the Brooklyn-Battery Tunnel at 8:06 a.m.; at the Throgs Neck Bridge at 9:30 a.m.; at the Triborough Bridge at 9:30 a.m.; and at the Henry Hudson Bridge at 9:50 a.m. ▼

C. Interagency Coordination

The flexibility of the MTA system is due to its many intersecting and parallel lines. This allows for workarounds when elements of the system experience difficulties. In a normal situation where one part of the system is affected, customers are frequently accommodated on other MTA services that can help get them to their destinations. In a normal emergency situation, the MTA family does a terrific job of coordinating between services. Coordination during the August 8 storm was handled on an operations basis; there is clearly a need for higher levels of and more formalized procedures for interagency coordination and cooperation to optimize system performance and customer satisfaction. This is an area that is heavily dependent on the ability of various parts of the operations to absorb the overflow from other parts of the system, but it also depends heavily on the quality of communication between the affected agencies and with the riding public.

When their subway is delayed or shut down, customers attempt to find alternate subway routes or parallel bus lines, but when the severe storm of August 8 forced the closure of several major subway lines the numbers of commuters seeking to board buses was overwhelming. When commuter rail trains shut down inside city limits commuters sought subway alternatives to get into work, but on August 8, communication to train crews about the lack of alternative service on subways, buses, or railroads exacerbated an already bad situation for the customer.

These facts underscore the importance of timely, accurate sharing of service information among agencies so that they have an accurate picture of actual (and changing) conditions and can determine the best way to respond to them and, in turn, inform their customers and suggest alternatives where possible.

In the accounts of the impact of the August 8 storm on the MTA Network and the response and recovery of the MTA agencies, there are examples of good interagency communication and coordination and examples where the interaction should have been more timely. What they reveal is that consistent, effective interagency coordination can significantly improve the performance of the MTA network as a whole – and customer satisfaction – in storm situations.

LIRR and LI Bus

Because service was suspended on the Port Washington Branch at 6:54 a.m. due to flooding, LIRR contacted LI Bus and a number of private bus providers and seeking some supplementary bus service for the customers on the Port Washington Branch. LI Bus did not have resources to respond immediately and advised LIRR it would dispatch buses as they became available. (Availability was drastically limited by flooding, route diversions and severe traffic conditions.)

Limited LIRR train service was restored at 10:04 a.m. and full service by 12:55 p.m.

Throughout the morning, LIRR & LI Bus remained in contact about the status of bus deployment. At 10:10 a.m., three buses were made available and were dispatched to Port Washington branch.

LI Bus and NYCT

LI Bus also received a telephone call at 9:34 a.m. from NYCT's Department of Subways division requesting LI Bus to extend its routes in Jamaica to Parsons/Archer Ave LI Bus complied with this request and stationed a dispatcher at the Archer Ave bus stop location'

During the morning rush, LIRR permitted subway riders at Jamaica to travel to Penn Station or Flatbush Avenue using MetroCard.

LIRR and NYCT

Because there was no subway service along the Queens Boulevard Line, during the morning rush LIRR allowed customers to use MetroCard from Jamaica Station to Manhattan or Brooklyn.

When NYCT reported 2 p.m. that no subway service was expected for the afternoon on the Queens Boulevard line, the LIRR developed an afternoon service plan by noon to provide subway customers with shuttle train service out of Penn Station. To create capacity for this service, LIRR combined and cancelled 15 regular service trains. A conference call was held at 12:30 p.m. with the NYCT vice president-subways to confirm NYCT's service status and all contingency plans. LIRR developed a script for announcing the service changes to its customers and by 1:30 p.m. NYCT had developed its script.

At approximately 3:46 p.m. via email, NYCT notified the LIRR that NYCT had successfully instituted a shuttle train between the No. 7 at Roosevelt and Parson/Archer to begin at 4 p.m., with shuttle buses from Sutphin Boulevard to the F line station at 179th Street. This service restoration dramatically reduced the need for the LIRR to provide Queens Boulevard subway customers with contingent shuttle train service from Penn Station. Given the impact on Shea Stadium service for the game that evening, the LIRR restored previously cancelled trains on the Port Washington line and further reduced Queens shuttle service as demand lessened. Approximately three shuttle trains operated.

MTA Bus and NYCT Buses and Subways

Transit's DOB and MTA Bus communicated throughout the day and by 2 p.m. had jointly devised a plan for the afternoon rush under which DOB would provide shuttle service along the Queens Boulevard corridor and MTA Bus would enhance service at its key locations. In addition, supervisory personnel at 23rd Street and Madison Avenue and 26th Street and Madison Avenue were put on alert during both morning and evening rush hours for additional customer loads.

Throughout the day MTA Bus Road Operations and Depot personnel also responded to known key locations during morning and evening rush hours to assist NYCT. Key locations were Kew Gardens station, 60th Street and 2nd Avenue, Queens Plaza, Woodside LIRR Station, Jamaica LIRR Station, Main Street, and Roosevelt Avenue.

Through communication with Road Operations of both DOB and its own employees, MTA Bus was notified of large crowds formed at key locations, and all express buses returning from the city were pressed into local service at Queens Plaza. MTA Bus supplemented service on westbound (city-bound) Q60 which runs along Queens Blvd with these buses. All JFK Airport Shuttle service was curtailed on the Q11 and Q37 at Kew Gardens and those buses were also used to supplement westbound Q60 service, where NYCT subway E, F, R lines were out of service by 6:20 a.m. All express buses arriving at Kew Gardens were loaded beyond normal capacity to accommodate as many customers as possible.

Eight scheduled runoff trips (where operators are finishing the day's work and are scheduled to pull into the depot) were used at LIRR's Jamaica Station to also supplement westbound Q60 service. In addition, supplemental BXM4B and BXM11 express service was provided from the Bronx to Manhattan. The MTA Bus Command Center made bus radio announcements every 15 minutes authorizing express bus operators to carry standees. The greatest hindrance to providing service was the extraordinary amount of vehicular traffic.

By 11:30 a.m. the number of customers requiring transportation had greatly diminished. At this time, most of the buses were released to return to the depots to be serviced.

By 2 p.m. MTA Bus and NYCT DOB jointly devised a plan for the afternoon rush. DOB would provide shuttle service along the Queens Blvd corridor and MTA Bus would enhance service at key locations. Supervisory personnel at 23rd St and Madison Ave and 26th St and Madison Ave were put on alert for additional customer loads.

Conclusion

While there were instances of excellent cooperation among the MTA agencies, it would clearly have been more helpful to have formal communication protocols in place. ▼

D. Operations Findings and Recommendations

Findings:

The storm wasn't predicted by weather forecasters, hindering the MTA's response.

While the MTA agencies worked together to maximize service options, communication across agencies was not as efficient and frequent as possible.

In many cases, MTA agencies failed to provide disrupted customers with travel alternatives.

Recommendations:

1. **Create Early Warning and Response Capability**
   a. **Establish Common Weather Forecasting –** within 30 days, MTA agencies will develop common and redundant weather forecasting capability.
   b. **Install Doppler Radar Screens in All Agency Operations Centers –** this will immediately improve Ops Centers ability to visualize hot spots in real time as they move over the region. This will both inform the decision- making process and target reaction/response to the most severely affected areas of the system.
   c. **Pre-deploy Operating Personnel in Flood-Prone Areas –** when indicated by potentially threatening weather.

2. **Create MTA Emergency Management Response Center –** the MTAPD, in conjunction with the MTA Corporate Affairs Department, has already established a preliminary protocol to stand up an MTA HQ Emergency Management Response Center which will alert senior management of developing weather and emergency issues; ensure that during emergencies that MTA-wide operations and communication are being coordinated and providing the Executive Director and CEO with real time SITREPS and immediate communication access to agency operations centers.

3. **Revise Agency Storm Operating Protocols** – Amend all agency operations and emergency plans/protocols, to:
   a. **Standardize Storm Category Designations** – currently each agency uses different categories for weather incidents (i.e. Yellow, Red). A common definition will avoid confusion and allow for unified levels of response in region-wide storms.
   b. **Formalize Inter-Agency Coordination/Notification Plans** – to improve the ability of other MTA agencies to share information with the public and notify other emergency organizations such as NYCOEM and NYS SEMO.
   c. **Develop Bus Service Alternative Plan** – for optimal use of MTA bus operations in providing supplementary service during subway and rail service disruptions.

d. **Coordinate Interagency Service Alternatives** – pre-plan interagency service alternative methods.

e. **Standardize Procedures for Communicating with Operating Personnel, Customers, and Other External Stakeholders**

f. **Ensure key employees get to critical work locations during severe weather**

4. **Establish Common Structure for Employee Emergency Response Teams** – Building on NYCT and LIRR Customer Assistance Program (CAP) teams and MNR Management Emergency Response Teams (MERTs), create a common structure to contact geographically dispersed employees (by email, telephone, text messaging, or fax) in emergencies and assign them to specific locations in their systems to provide customer information across the MTA family, particularly at intermodal locations.

5. **Conduct Six-Month Progress Review –** the MTA Chief Operating Officer will conduct a review every six months of progress made in each of the aforementioned areas.

IV. Engineering and Regional Inter-Agency Issues/Recommendations

As previously discussed, the volume of water brought by the storm overwhelmed MTA and municipal drainage systems outstripped the MTA's ability to both prevent water incursion into the system and its ability to pump it out once it was in. Municipal drainage systems are currently designed for a five-year storm. The following solutions and recommendations cannot eliminate impacts of severe storms but are intended to reduce the impact.

While the MTA can address a number of internal flooding issues, there are a number that must be addressed on an inter-agency basis, along with various regional partners such as the NYC Department of Transportation, NYC Department of Environmental Protection, and county Departments of Public Works. The August 8 flood has focused attention on the necessity of close cooperation among these entities. This cooperation is currently bearing fruit in work on remedying chronic flooding problems and will be crucial to insure continued success.

A. Causes and Locations of Flooding

This storm's intensity varied dramatically from neighborhood to neighborhood within the city and its surrounding suburban counties, causing flooding at various locations throughout the region. These impacts occurred in a small set of "chronic" repeat locations as well as other more dispersed areas. Flooding at these locations resulted from three primary causes:

1. Extraordinary amounts of water entering subways or low-lying rights of way areas
2. Overwhelmed pumps or back flow caused by water levels above design capacity
3. Debris blocked interior and exterior drainage structures

Addressing these causes promises to reduce the likelihood of flooding at these locations in the future. Since these solutions are often a shared responsibility with other regional agencies, the NYCDOT, NYCDEP, and Nassau County DPW have assisted reviewing, resolving or participating in the solution of many of the issues. Exhibits 1 through 4 at the end of this section provide a map of the flooding locations for each MTA agency and a list of the cause of the flooding for each location. While the causes of flooding may be inter-related, each will be discussed in turn to better evaluate solutions to each.

1. Extraordinary Amounts of Water Entering Subways or Low-lying ROWs

NYCT has identified flood-prone locations in the system, including problem NYCT station areas that flooded during the August 8, 2007 storm, and other locations where flooding or water entry into the system occurred in the past (Exhibit 1, pgs 49-50). One of the most significantly affected lines is the Queens Boulevard line, with its miles of street vent gratings and many station entrance locations that coincide with repeat street flooding.

NYCDOT has surveyed the curb reveal along Hillside Avenue (Exhibit 1, location 11), as well as the crown cross slope on the roadway and curb heights, to see if they meet specifications. DOT has also surveyed the curb height in other affected areas in Manhattan, Queens, and Brooklyn. Six locations in Manhattan have been deemed to have less then desirable curb reveals (<5 inches; locations 1, 6, 8, 18, 19, 21). NYCDOT has reported that these six locations are scheduled prior to 2010 for rehabilitation. At Brooklyn location 17, less than desirable curb reveal will undergo resurfacing prior to 2010 to improve curb height.

NYCT has requested NYCDEP assistance at its flooding locations as well as at its Revenue Facility and Grand Avenue Bus Depot, which experience extensive flooding. As an initial step in response to this request, NYCDEP and NYCT have begun joint surveys of these locations. The joint effort will examine catch basins and NYCT connections to sewers. NYCT and NYCDEP will also work collaboratively to define agency responsibilities, procedures and protocols for storm preparation.

Numerous past efforts to reduce the NYCT system vulnerability have been at least somewhat successful in improving the ability of the system to accommodate heavy, steady rain over a period of three or more hours. Seven of the fourteen most frequently flooded subway stations (locations 25-31) did not flood on August 8 despite receiving significant rainfall. Efforts will be undertaken to ensure similar success at all locations prone to floods.

In order to mitigate flooding where curb heights and crown slopes cannot be changed, solutions must be engineered to keep water out of the system in the first instance. A temporary solution is to close off gratings with plywood. (See location near bicycle in Figure 1 below.) A permanent solution will involve closing strategically chosen sidewalk vents that would not have an impact on station venting ability. Unfortunately, there are a limited number of such opportunities available.

Depending on location, there are a variety of solutions that will be employed to eliminate or dramatically reduce the impact of flooding. Some are short-term actions and others will take longer to implement and must be done collaboratively with other regional partners. This effort will draw from a toolbox of potential fixes to both prevent water inflow and to remove it once it flows in, including installing check valves to prevent backflow, pursuing better sewer connections, increasing pumping capacity, pre-deploying portable pumps and personnel, installing closeable vents and constructing step-ups at station stairwell entrances that flood.

A promising permanent alternative is to create vent structures that will physically raise the grates and thereby prevent the water from entering the subway. Past efforts, such as the trial elevated vent structure installation along Hillside Avenue on Queens Boulevard (as seen in Figure 1) have raised neighborhood aesthetic issues.

Figure 1
F Line Hillside Ave Flooding

Perhaps a more promising and intriguing solution to the sidewalk grating and station entrance water inflow problem is already being pursued in conjunction with NYCDOT. In fact, in the last week the MTA, NYCT, and NYCDOT have co-sponsored a design charette with top urban designers to develop solutions to the problem. The three conceptual designs they came up with will hopefully lead to a more refined alternative that will address both pedestrian impact and neighborhood aesthetics (Figures 2, 3, 4). The MTA has already begun to work with the city and the Art Commission, which reviews all such street fixtures, and we expect that in the next 30 days we will follow the more formal review process to come up with a final product that works for all. ▼

Figures 2, 3, 4

Renderings of grating protection designs by Antenna Design (upper left), Grimshaw Architects (above), and Rogers Marvel Architects (left).

In addition, addressing flooding over the long-term points to more comprehensive solutions that involve discussions beyond the MTA. For example, as part of PlaNYC, a Task Force will be recommending areas where Best Management Practices (BMP) can be applied to solving a host of city-wide concerns. In that context, the City and MTA have agreed that sites prone to flooding will be evaluated jointly for the use of appropriate BMPs to reduce storm water impacts. Possible BMP projects could include:

- Blue roofs/green roofs to capture and/or detain run off from buildings adjacent to the identified sites;
- Tree pits designed to retain water for absorption by trees;
- Greening and use of porous pavement in area parking lots;
- Possible enhancement of near-by green spaces to retain more storm water.

2. Overwhelmed pumps or backflow caused by water levels above design capacity

While only one pump in the system malfunctioned, the remainder could not remove the water inflow fast enough and in some instances had no place to pump it. In other areas excessive water inflow came from back flow from external drainage systems where the MTA currently has no check valves.

Where NYCT and LIRR have operations in a cut or below ground, MTA pump drainage systems or gravity flow sewers provide for the removal of water. When the receiving sewer is flowing at or above design capacity, however, flow from pumping stations is reduced or the direct gravity sewers can experience inflow of water from the receiving sewer by backflow, a condition to be corrected by NYCT, causing or contributing to flooding.

Sewer back flow occurred at three NYCT locations (5, 14, 33) on August 8. NYCT intends to install check valves at these locations which will prevent such back flow.

In addition, NYCT experienced failure of a pump room (location 22) due to an electrical failure.

LIRR has recently begun to experience flooding at the Bayside Station (Exhibit 2, location 2). Bayside is at a low point of the ROW and there is no place for the water to go, causing flooding to the platform level. NYCDEP has agreed to clean and line a 22-inch sanitary line running underneath LIRR tracks at the Bayside Station to rule this out as a potential source of the problem. LIRR believes this will solve the problem but is prepared for continued evaluation of other potential solutions.

Implementing all of the necessary solutions will involve all of the regional agencies with a responsibility for flood-related infrastructure. NYCDOT, NYCDEP, and Nassau County DPW are supporting the MTA effort to evaluate locations and implement solutions. Where intervention by other agencies has not resolved the issues, the Recommendations section identifies proposed solutions.

3. Debris blocked interior and exterior drainage structures

Regular cleaning along ROW or roadways is necessary to ensure proper functioning of drainage systems. Primary responsibility for cleaning within the system rests with MTA agencies that have their own drainage tie-in to regional sewers or their own pumping facilities are responsible for the MTA ROW.

Additional coordination is required with regional partners such as the NYC Department of Sanitation, which is responsible for NYC streets; the NYC Department of Transportation (NYCDOT) which is responsible for highways; the NYC Department of Environmental Protection (NYCDEP) other county Departments of Public Works (DPWs) which are responsible for catch basins and street drainage systems.

Each agency periodically reviews issues associated with debris accumulation and rebalances the frequency of cleaning known chronic flood-prone locations with available resources.

Each agency has identified problem areas associated with this storm and taken remedial action where possible. Further investigation is necessary in some cases and is being undertaken.

For example, the LIRR has identified areas, shown on Exhibit 2, where it believes that the drainage system in a storm is inadequate.

- The Village of Great Neck (location 3) drainage system overflowed onto the ROW. Nassau County Department of Public Works (NC DPW) and the Village of Great Neck are working with the LIRR to investigate the possibility of a drainage connection at that location to the NC DPW system to alleviate flooding.
- LIRR has experienced repeated service disruptions due to flooding caused by inadequately drained roadways at Willis Avenue and Main Street in Mineola (location 4). NC DPW has agreed to clean the catch basins and has been requested to add catch basins or otherwise improve drainage at these locations. Connecting the catch basins to the county storm drain system is being investigated.
- Flooding occurred in the area of the LIRR Hillside support facility (location 6). NYCDEP cleaned storm drains blocked by construction debris in the area in September 2007 and NYCDOT has issued a summons to a contractor performing street work in the area and is monitoring their compliance with their permit.
- LIRR experienced washout of the embankment near the ROW in Elmhurst (location 7) on August 8, 2007. NYCDOT has determined that curb heights in the area are adequate, and NYCDEP has determined that their structures and systems are operating properly. The functionality of an existing 15-inch drain line under the Railroad’s ROW is now under review.

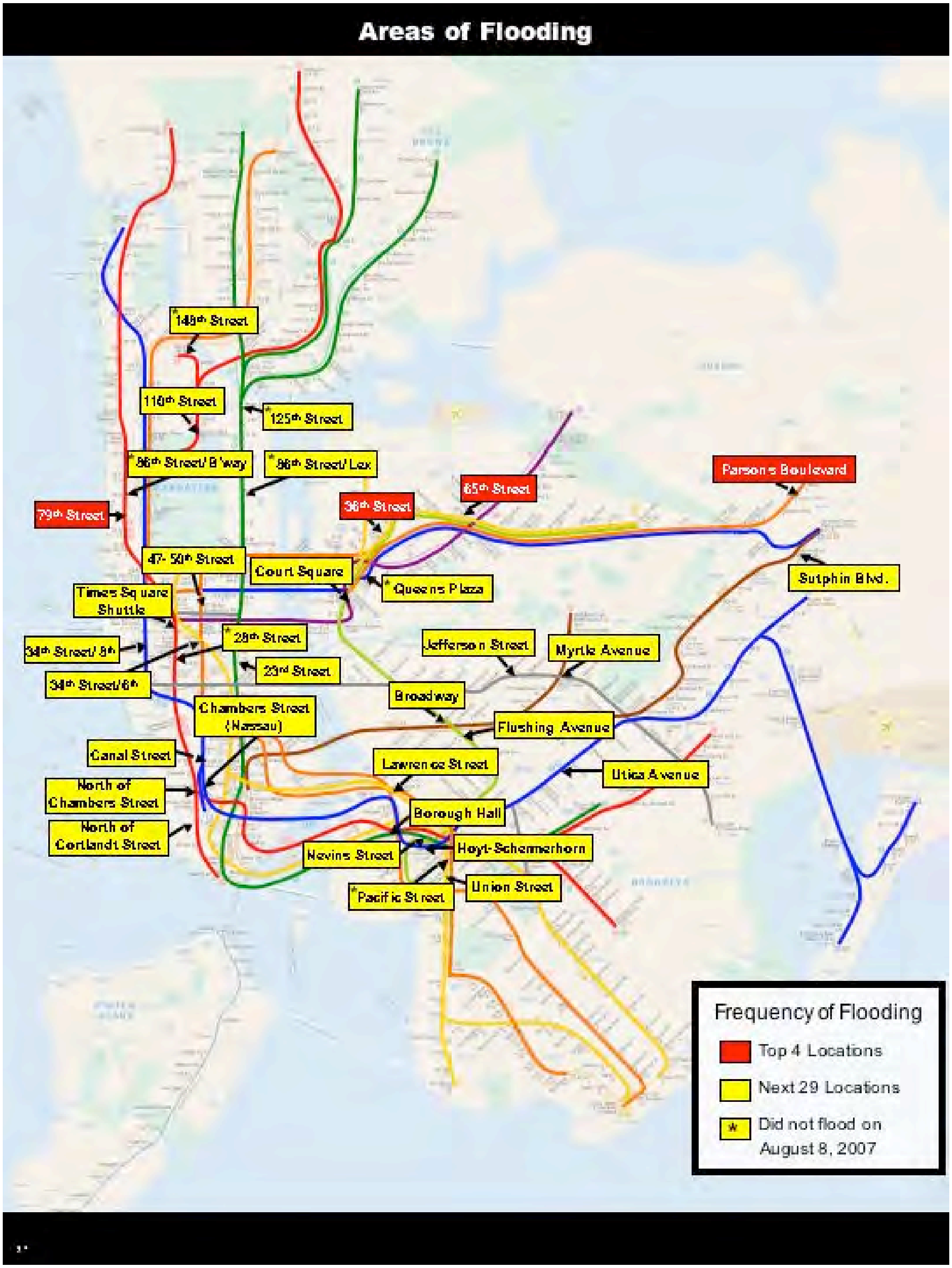
MNR has identified three locations related to the August 8, 2007 storm as shown on Exhibit 3.

- Mott Haven (location 1) experienced flooding during several storms. NYCDEP has investigated the condition of the existing storm sewer serving the facility and found no deficiencies. NYCDEP is currently inspecting a drainage structure in the ROW and the two siphons to determine if blockage exists. In any event, an annual maintenance program will be implemented in the future. NYCDEP has determined that the permanent storm water management plan for the new SCA facility adjacent to Mott Haven is adequate. NYCDEP is reviewing the storm water management plan being utilized during construction. Depending on the outcome of the inspections and ongoing investigations, a long-term solution may need to be determined. NYCDOT has agreed to repair the expansion joints of the East 149th Street Bridge adjacent to MNR property at Mott Haven.
- Flooding in the areas of Fordham Station and Claremont Parkway (locations 2 and 3) has been investigated by NYCDOT. No deficiencies related to sidewalks and roadways were found. NYCDEP has determined that their existing facilities serving the Fordham Station are operating properly. NYCDEP is investigating the possibility of additional catch basins. At Claremont Parkway, NYCDEP has determined that their facilities are operating properly. MNR will investigate drainage issues with an adjacent property owner.
- For other locations involving past flooding events within the past 10 years, the solution consists of coordinating improvement (to existing storm sewer systems and adjacent properties) with private property owners adjacent to the ROW and/or local municipalities. Municipalities include the city Yonkers (for locations 7, 8, 9), New York City (for locations 4, 5, 6), and the village of Ossining (for location 10). Contact has been initiated or will be within 30 days to begin coordination.

B&T has identified two on-property and 10 off-property locations in Exhibit 4.

- Four B&T locations (locations 1, 2, 3, 10) had been swept within two weeks prior to August 8, 2007 as verified by NYCDOT.
- Henry Hudson Parkway catch basins (locations 3, 4) were cleaned by NYCDEP in September 2007. Catch basins completed are working properly. Due to difficulties in maintaining existing drainage structure in the area of 179th and 181st Streets, NYCDEP and NYCDOT will investigate possible modifications.
- Flooding near the Grand Central Parkway on the Queens side of the Triborough Bridge has been investigated by NYCDEP. It was determined that the pumping station serving the area is operating properly. Issues along the Grand Central Parkway appear to stem from debris collecting during storms. Periodic maintenance procedures will be implemented to prevent future flooding (locations 1, 7).
- In the area of the Verrazano-Narrows Bridge in Staten Island at the Lily Pond Road exit, NYCDEP is implementing an emergency request for the installation of catch basins (location 10). NYCDEP has serviced catch basins along the Belt Parkway and is addressing drainage structures with other agencies.
- NYCDEP is investigating locations 5, 6, and 8.
- NYCDOT is implementing periodic maintenance procedures at location 9. ▼

Exhibit 1



Areas of Flooding
148th Street
110th Street
125th Street
86th Street/ B'way
86th Street/ Lex
79th Street
65th Street
36th Street
Parsons Boulevard
47- 50th Street
Court Square
Queens Plaza
Sutphin Blvd.
Times Square Shuttle
28th Street
34th Street/ 8th
23rd Street
34th Street/6th
Jefferson Street
Myrtle Avenue
Broadway
Chambers Street (Nassau)
Flushing Avenue
Canal Street
Lawrence Street
Utica Avenue
North of Chambers Street
Borough Hall
North of Cortlandt Street
Nevins Street
Hoyt-Schermerhorn
Union Street
Pacific Street
Frequency of Flooding
Top 4 Locations
Next 29 Locations
Did not flood on August 8, 2007

Exhibit 1

Table 1 – MTA New York City Transit – Flooding Incidents by Location

Location		Aug. 8, 2007 Flooding	Aug. 8, 2007 Flooding Cause	Aug. 8, 2007 Non-Flooding Reason
1	34th St.-8th Ave.	X	Water from streets and sidewalks	
2	Cortlandt St.	X	Water from streets and sidewalks	
3	Court Square	X	Water from streets and sidewalks	
4	Borough Hall	X	Water from streets and sidewalks	
5	23rd St.-Park Ave.	X	Sewer back flow	
6	Chambers St. (7th Ave.)	X	Water from streets and sidewalks	
7	Canal St.	X	Water from streets and sidewalks	
8	34th St.-Herald Sq.	X	Water from streets and sidewalks	
9	Flushing Ave. station	X	Water from streets and sidewalks	
10	Hoyt-Schermerhorn station	X	Water from streets and sidewalks	
11	Parsons – Hillside	X	Water from streets and sidewalks	
12	65th St. Station – Northern Blvd	X	Water from streets and sidewalks	
13	36th St. & Steinway St. stations	X	Water from streets and sidewalks	
14	Times Sq.	X	Sewer back flow	
15	Jefferson St.	X	Water from streets and sidewalks	
16	Myrtle Ave.	X	Water from streets and sidewalks	
17	Lawrence St.	X	Water from streets and sidewalks	
18	79th St./Bwy	X	Water from streets and sidewalks	
19	Chambers St. (Nassau)	X	Water from streets and sidewalks	
20	Sutphin Blvd.	X	Water from streets and sidewalks	
21	47th-50th Sts./Rockefeller Center	X	Water from streets and sidewalks	
22	Broadway	X	Mechanical failure	
23	Utica Ave.	X	Water from streets and sidewalks	
24	Union St.	X	Water from streets and sidewalks	
25	148th St.	None		Sewer not surcharged
26	86th St. & Broadway	None		Maint. of sewer connection/ check valve okay
27	28th St. & 7th Ave.	None		Maint. performed
28	125th St.	None		Maint. performed
29	86th St.	None		Maint. performed
30	Queens Plaza	None		Maint. performed
31	North of Pacific St.	None		Maint. performed
32	Nevins St.	X	Water from streets and sidewalks	
33	110th St. (Lenox Ave.)	X	Sewer back flow	

* 86th St. and 79th St. both drain into the same direct sewer connection. Water accumulates at 79th St. first. Incidents are generally only attributed to 79th St.

Exhibit 2

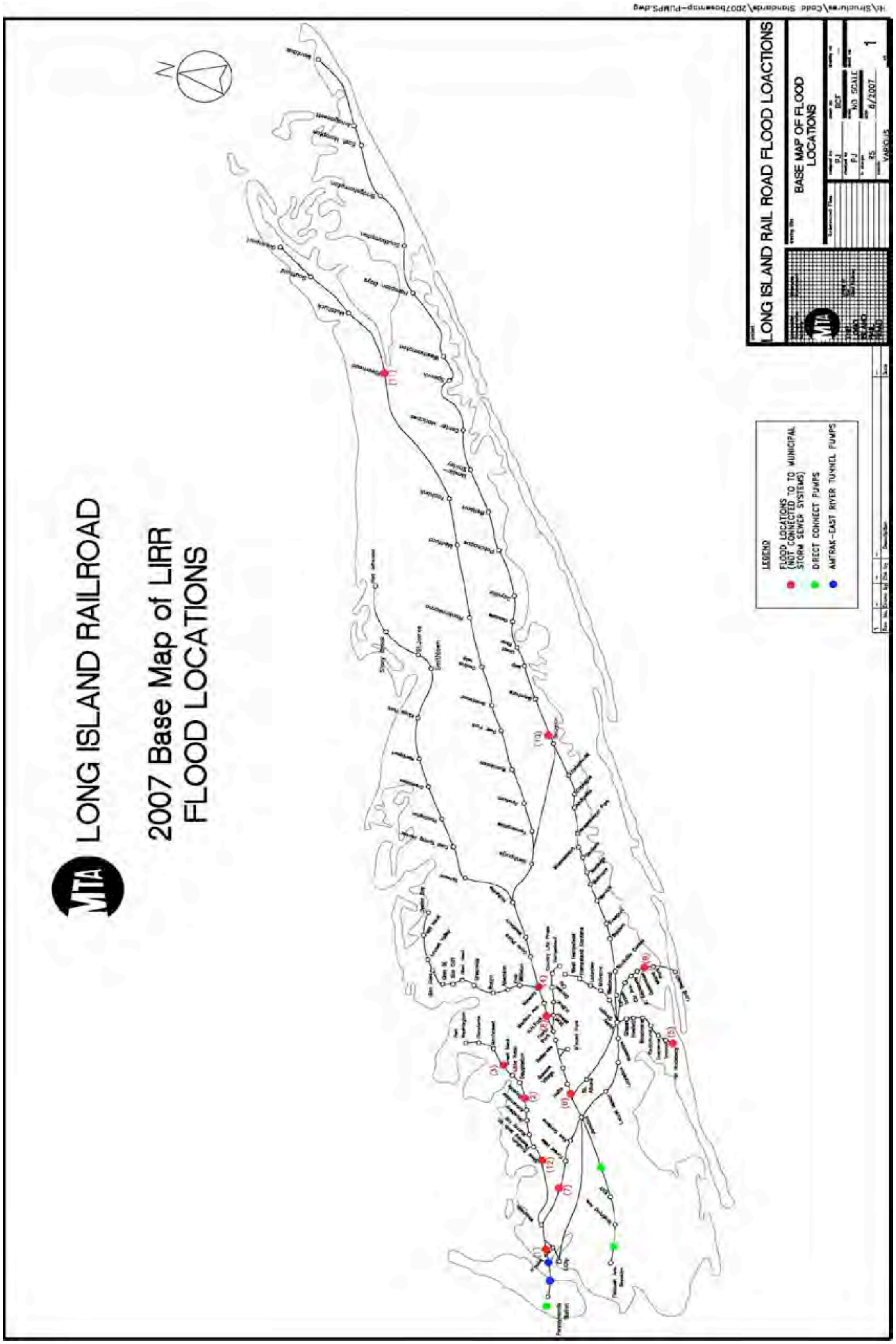

LONG ISLAND RAILROAD
2007 Base Map of LIRR
FLOOD LOCATIONS
LEGEND
FLOOD LOCATIONS (NOT CONNECTED TO TO MUNICIPAL STORM SEWER SYSTEMS)
DIRECT CONNECT PUMPS
AMTRAK-EAST RIVER TUNNEL PUMPS
LONG ISLAND RAIL ROAD FLOOD LOACTIONS
BASE MAP OF FLOOD LOCATIONS

Exhibit 2

Table 2 – MTA Long Island Rail Road – Flooding Incidents by Location

LIRR August 8, 2007 Flooding Locations		
Location		Cause
1	HPA & Line 2	Tidal effects & low area & efficiency capacity of drainage system.
2	Bayside Station	Possible broken 22-inch diameter storm/sewer line.
3	Great Neck Station	Overflow from NC DPW, VOGN storm sewer system.
4	Mineola	Storm water runoff from Nassau County & VOM streets.
5	Far Rockaway	High groundwater & tidal effects.
6	HSF – 183rd & Liberty	Overflow from NYCDEP storm sewers caused by construction debris from KeySpan contractors.
7	Elmhurst/Calmus	Storm runoff from roadway.
8	New Hyde Park	Storm water runoff from south parking lot
LIRR Historical Flooding Locations		
Location		**Cause**
9	Oceanside/Island Park	Tidal effects & overflow from storm sewers.
10	Babylon Yard	High groundwater & tidal effects.
11	Riverhead Station	No drainage facilities.
12	Shea Stadium	Tidal effects from the Flushing River.

Exhibit 3


Metro-North Railroad
HUDSON LINE
HARLEM LINE
NEW HAVEN LINE
Poughkeepsie
New Hamburg
Beacon
Breakneck Ridge
Cold Spring
Garrison
Manitou
Peekskill
Cortlandt
Croton-Harmon
10 Ossining
Scarborough
Philipse Manor
Tarrytown
Irvington
Ardsley-on-Hudson
Dobbs Ferry
Hastings-on-Hudson
Greystone
9 Glenwood
8 Yonkers
7 Ludlow
6 Riverdale
4 & 5 Spuyten Duyvil
Marble Hill
University Hts
Morris Hts
1
Harlem-125 Street
Grand Central Terminal
Wassaic
Tenmile River
Dover Plains
Harlem Valley-Wingdale
Appalachian Trail
Pawling
Patterson
Southeast
Brewster
Croton Falls
Purdy's
Golden's Bridge
Katonah
Bedford Hills
Mount Kisco
Chappaqua
Pleasantville
Hawthorne
Mt.Pleasant
Valhalla
North White Plains
White Plains
Hartsdale
Scarsdale
Crestwood
Tuckahoe
Bronxville
Fleetwood
Mt Vernon West
Wakefield
Woodlawn
Williams Bridge
Botanical Garden
Fordham 3
Tremont
2
Melrose
Danbury
Bethel
Redding
Branchville
Cannondale
Wilton
Merritt 7
New Canaan
Talmadge Hill
Springdale
Glenbrook
Waterbury
Naugatuck
Beacon Falls
Seymour
Ansonia
Derby-Shelton
New Haven-Union Station
New Haven State Street
Milford
Stratford
Bridgeport
Fairfield
Southport
Green's Farms
Westport
East Norwalk
South Norwalk
Rowayton
Darien
Noroton Heights
Stamford
Old Greenwich
Riverside
Cos Cob
Greenwich, CT
Port Chester, NY
Rye
Harrison
Mamaroneck
Larchmont
New Rochelle
Pelham
Mt. Vernon East
Metro-North System-Wide (Past 10 Years)
PRIORITY FLOOD LOCATIONS

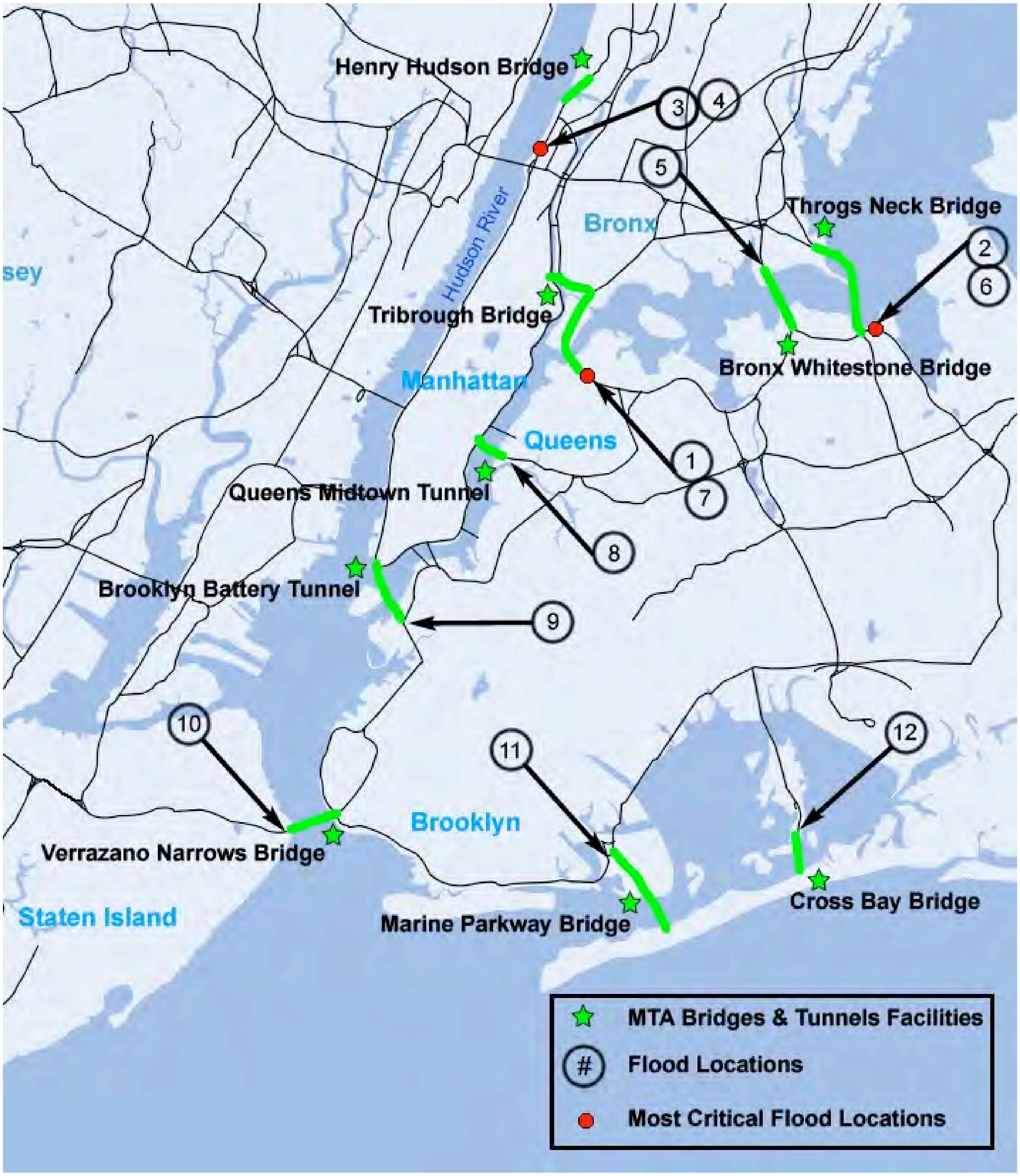
Exhibit 3

Table 3 – MTA Metro-North Railroad – Flooding Incidents by Location

Location		Cause
MNR August 8, 2007 Flooding Locations		
1	Mott Haven Yard/149th St.	Possible DEP sewer surcharge
2	Tk 4 – Claremont Parkway MP 7.23	Runoff from roadways
3	Tk 3 & 4 – Fordham Station	Runoff from Webster Avenue/Fordham University/surcharged DEP pipe

MNR Historical Flooding Locations		
4	Tk 3 CP 12 – Spuyten Duyvil	Runoff from roadways/property above mudslide
5	Tk 3 – Spuyten Duyvil MP 11.62	Runoff from roadways
6	Tk 3 – Riverdale at 254th St	Runoff from roadways overflows catch basins and curbing
7	Tk 3 – Ludlow	Runoff from city storage property
8	Tk 3 – Yonkers	Mud: private property. City water off roadway through property.
9	Tk 3 Glenwood at the Park	Runoff from Trevor Park
10	Tk 3 Ossining, br. 31.00	Sing Sing Creek; runoff from roadways

Exhibit 4



Henry Hudson Bridge
3
4
5
Throgs Neck Bridge
2
6
Bronx
sey
Hudson River
Tribrough Bridge
Bronx Whitestone Bridge
Manhattan
Queens
1
7
Queens Midtown Tunnel
8
Brooklyn Battery Tunnel
9
10
11
12
Brooklyn
Verrazano Narrows Bridge
Staten Island
Marine Parkway Bridge
Cross Bay Bridge
MTA Bridges & Tunnels Facilities
#
Flood Locations
Most Critical Flood Locations

Exhibit 4

Table 4 MTA Bridges and Tunnels Historical Flooding Locations

Location		Cause
1	Grand Central Parkway at the foot of the Triborough Bridge	This area is a major problem during rain storms as it often forces the closure of the Parkway, forcing all eastbound traffic to exit onto the local streets via our 31st Street exit. The westbound Parkway is also prone to flooding, causing motorists to detour onto local streets in order to access the Manhattan/Bronx-bound bridge.
2	Cross Island Parkway eastbound at the foot of the CIP exit ramp of the Throgs Neck Bridge	This area floods at the catch basins where the ramp meets the Parkway. The condition forces B&T to close the exit ramp, leaving the Clearview Expressway as the only egress from the bridge. The westbound CIP occasionally floods at the foot of the bridge, causing the closure of the "onbound" ramp in extreme instances.
3	Henry Hudson Parkway southbound	Flooding north of the 181st Street exit causes the closure of the Parkway southbound and traffic often backs up all the way to and onto the Henry Hudson Bridge.
4	Henry Hudson Parkway, northbound	Flooding occurs before the tolls: between the George Washington Bridge and Dyckman Street. Two areas in this stretch are prone to flooding, 170th Street and 181st Street. The Henry Hudson Parkway service road, northbound and southbound, between 232nd and 231st Streets also flood during heavy rain events.
5	Bronx-Whitestone Bridge	Ferry Point Park Road under bridge structure. Whitestone Expressway (678N) approach to bridge just south of 3rd Avenue exit. Whitestone Expressway (678N) between 20th Avenue and the 14th Avenue underpass.
6	Throgs Neck Bridge	Cross Island Parkway at base of ramp causing backup northbound and southbound.
7	Triborough Bridge	Grand Central Parkway off-bound and on-bound under 31st Street overpass, under Steinway Street overpass, at BQE entrance, and at BQE entrance to Marine Air Terminal. Also, FDR Drive 116th Street and 96th Street northbound and southbound.
8	Queens Midtown Tunnel	11th Place and 50th Avenue at the beginning of the entrance ramp from 50th Avenue.
9	Brooklyn-Battery Tunnel	Hamilton Avenue exit slip ramp and the Clinton Street entrance ramp.
10	Verrazano-Narrows Bridge	The Belt Parkway eastbound causes backups onto the bridge. Lily Pond exit ramps from the Staten Island Expressway.
11	Marine Parkway-Gil Hodges Memorial Bridge	End of the Breezy Point exit ramp on the border of the B&T and NYC property.
12	Cross Bay Veterans Memorial Bridge	The beginning of the entrance ramp from Beach Channel Drive westbound.

B. Engineering Findings and Recommendations

Findings:

Flooding occurred at points throughout the MTA network for three primary reasons: debris blocked interior and exterior drainage structures; excessive water entered subways or low-lying rights-of-way (ROW) areas; and pumping capacity limitations of backflow caused by storm sewers receiving water above design capacity in a storm.

Recommendations

1. **Implement Corrective Action Plan for Flood-Prone Locations –** This effort will specifically address short and long term issues to both prevent water from entering the system and remove it effectively when it has already entered: An action plan (Table 5) is already being implemented for priority locations (by agency). Preliminary solutions for remaining locations, described in Exhibits 1 through 4, have been developed and will be finalized over next 90 days in conjunction with NYCDEP, NYCDOT, and NC DPW.
   a. **Address Sidewalk Vent Gratings/Station Entrance Issues to Prevent Water Intrusion –** This effort has already resulted in conceptual designs of a unique system to block water intrusion at various subway locations along the Queens Boulevard Line on Hillside Avenue, while meeting city street furniture design standards.
   b. **Install Check Valves at All Subway Sewer Connections** – to prevent backflow from charged sewers.
2. **Create Permanent Inter/Intra-Agency Flooding Task Force –** engineering and operations staff from all MTA agencies, NYCDEP, NYCDOT, other regional Departments of Public Works will meet twice a year (Feb/March and Aug/Sept) to:
   a. Ensure that all sewers, catch-basins, siphons, etc. in flood-prone locations are inspected and cleaned prior to rainy season(s). Explore the formation of joint inter-agency teams in order to expedite such efforts.
   b. Assess progress on implementing engineering solutions in flood-prone areas.
   c. Identify emerging factors, such as construction projects or zoning issues that could affect drainage in and around MTA facilities (as recommended in Columbia report.)
3. **Ensure that all recommendations in the MTA Inspector General Report and MTA Board Task Force Report on the September 2004 flooding incident have been implemented or otherwise appropriately addressed –** This effort will be completed within 60 days.
4. **Six Month Progress Review –** the MTA Chief Operating Officer will conduct a review every six months of progress made in each of the aforementioned areas. ▼

Table 5 – Top Priority Flood Locations by Agency

		LOCATION	ISSUE	SHORT-TERM ACTION	LONG-TERM SOLUTION
NYCT	1	65th Street & Northern Blvd Stations	Street flooding through sidewalk gratings and station entrances	Temporarily block ingress points upon storm warning	Protect gratings and entrances (aesthetic concepts for gratings have been developed)
	2	36th Street & Steinway Street Stations (IND)	Street Flooding through sidewalk gratings and station entrances	Temporarily block ingress points upon storm warning	Protect gratings and entrances (aesthetic concepts for gratings have been developed)
	3	Parsons Blvd (IND)	Street Flooding through sidewalk gratings and station entrances	Temporarily block ingress points upon storm warning	Protect gratings and entrances (aesthetic concepts for gratings have been developed)
	4	79th Street (IRT)	Street Flooding through sidewalk gratings and station entrances	Temporarily block ingress points upon storm warning	Protect gratings and entrances
	5	86th Street (IRT)	Street Flooding through sidewalk gratings and station entrances	Temporarily block ingress points upon storm warning	Protect gratings and entrances
	6	Chambers Street (IRT)	Street Flooding through sidewalk gratings and station entrances	Temporarily block ingress points upon storm warning	Protect gratings, entrances and elevator
LIRR	7	Mineola	Water from Main Street, Willis Avenue and Roslyn Road accumulates on the LIRR roadbed. Local storm water system has limited capacity.	Dispatch crews to stage portable pumps at a secured location near this area when storm predictions indicate possible flooding.	Nassau County to connect existing catch basins to the storm drain system, provide a conduit to channel water into the new recharge basin presently under construction and/or install additional catch basins to increase storm drainage capacity
	8	Bayside	Bayside Station experienced flooding by water coming up from under the ROW.	The 22" drain line that runs in the location of the water leak will be sleeved by NYCDEP within the month of September 2007. Upon completion, the drain line will be tested for adequate functionality. The short-term plan is to deploy field forces, prior to a storm, with portable pumps to facilitate water removal.	Should the correction fail to fully mitigate the problem, the long-term plan is to create a new pumped or gravity drainage system

MNR	9	Mott Haven Yard/149th Street	Right-of-way flooding	Semi-annual cleaning of siphons and drainage system. Procurement of vacuum truck (will be used systemwide at other problem locations) for drainage structure cleaning	Consultant to determine adequacy of short-term solution and existing system. Continue to coordinate and work with regional Partners on permanent solution if necessary
	10	Track 3 and 4 Fordham Station	Run off from Webster Ave./Fordham Univ./surcharge	Installation of additional catch basins in the roadway area by NYCDEP, and MNR increasing the existing retaining wall height 1-2 feet to prevent roadway run off from entering the MNR ROW.	Long-term solutions may also require an increase to the existing storm water system capacity in the area

V. Communication Issues and Recommendations

MTA communication with customers on August 8 was inadequate. In many instances, customers could not get reliable information from the regular sources of communication they rely on for transit information: station and operating personnel; public address announcements; the media; the MTA website; and email alerts. Station agents, train crews and bus operators – the front line customer service reps – had insufficient, conflicting, or no information to share with confused and frustrated customers. Late communication to the media about the severity of the impact on the system led hundreds of thousands of commuters to begin their journeys only to be turned away once they reached an MTA facility. Late posting of service alert information on the web and the inability of tens of thousands of customers to even access the MTA website led to greater frustration and dissatisfaction.

A. In-System Communication

Subways

NYCT subways responded to the August 8 storm in a spontaneous and decentralized way, rather than a systematic and coordinated manner because the event was both unpredicted and severe. That left the agency unable to put into place its hurricane/storm plan. There were substantial delays (in some cases, hours) between the reporting of an incident and detailed communication of the service impact to employees and customers.

Customer information for incident-based response, especially in the field, assumes that the remainder of the system is functional. As a result, widespread disruption or a near-system shutdown may be under-communicated and portrayed as a local incident.

The quality of the customer information provided depended on the passing of information accurately through several levels, the communication skill of the front-line employee presenting the information to customers and the interpretation of the information by the customer. The quality of the announcements was also affected by the availability and performance of public address systems in stations and on board trains.

The current system providing information to over 900 station booths is the “Mass Call” system, which is limited in the number of booths with which it can communicate simultaneously (approximately 40). This can be problematic when information is changing rapidly. Beyond this the Emergency Booth Communication System (EBCS) may also be used. A system for rapid instant messaging to all token booths simultaneously does not currently exist.

Under the Mass Call system incidents are reported from the Station Command Center (SCC) at the RCC to station agents in the field who in turn inform the public of the incidents. SCC gets its first-hand information from the RCC Communication Desk and the RTO general superintendents at the RCC. Because of the immediacy of the flood situation and rapidly deteriorating service conditions, Mass Call was not the most suitable means of communication between the Rail Control Center and station agents. However, the Emergency Booth Communication System (EBCS), which permits active communication between field personnel and the Rail Control Center, was heavily relied on and allowed information-sharing between the SCC and station agents at affected locations.

On August 8:

- The service pattern in each affected corridor was subject to change as incidents occurred in other corridors served by the same train routes. There were at least seven "iterative" changes made in previously established, emergency service patterns.
- Internal and customer communication lagged well behind real time. Notifications lagged behind on the order of an hour or more in the following instances:
- 12 incidents reported by Stations via Mass Call to their agents
- 9 incidents reported by RCC via text message to NYCT management
- 9 incidents reported via web site to the public.
- All three means of communication lagged by over an hour for five incidents which closed the Lexington Ave., Queens Blvd., Fulton Street (Brooklyn), Canarsie and Crosstown lines.
- In some incidents communication was not apparent:
  - Three incidents not communicated by Stations to their agents
  - Two incidents not communicated on the web site
  - Eight incidents not communicated by text message
- The Crosstown line closure was not communicated for over eight hours

With the exception of the Crosstown line closure, the late communication noted above should be viewed in the context of the intense rate at which incidents were reported, and the priority given to assuring safety in the first moments of an incident. As noted previously, major incidents were being reported at a rate of one every three minutes during the first 45 minutes.

The most sophisticated tools for communicating with passengers are public address (PA) systems and customer information screens (CIS), which provide digital text messages. Several generations of PA and CIS systems – now referred to simply as PA-CIS – are used in the NYCT system. The most advanced PA-CIS systems can deliver announcements directly from the RCC. Older systems, still present in many stations, can be operated only by field personnel, including key dispatchers in signal towers, local dispatchers, and station agents. About 75 percent of all subway stations have some form of PA system.

- 24 stations on the Canarsie Line have both local and remote messaging from the RCC as well as real-time train arrival information.

- 132 stations have local and remote messaging functionality from the RCC, although no train arrival information is provided.
- 192 stations have legacy systems with only local announcement capability.

This leaves 120 stations without any public address system completed. Of this total, 33 will receive PA-CIS under contracts currently under construction, leaving 87 stations without any PA system.

NYCT has proposed advancing the installation of speakers and screens for the PA-CIS contract in the B division (lettered lines), with priority installation at stations with no public address system. NYCT is piloting work at two stations to test simplified connections to the RCC.

At the time of the storm, NYCT did not have a formal policy of communicating with NYCOEM (such a policy is now in place), but the log at the Rail Control Center (RCC) indicates that there was at least one conversation with NYCOEM on the morning of August 8. NYCT did communicate with the New York Police Department (NYPD) on that morning. NYPD is hooked into the subway's six-wire communication and monitors all information about train incidents. In addition, a police sergeant is assigned to the RCC.

Internal and customer communication were unable to keep pace with the incidents which developed on the morning of August 8. Of the 21 storm-related incidents reported, most could have stood as a major disruption of the year. The first 15 incidents were reported within 45 minutes. Major incidents were reported at a rate of one every three minutes during that time.

NYCT's procedures for responding to incidents, while emphasizing communication and customer information, prioritize safety for customers and employees above all else. When major incidents are so closely spaced, other communication will lag as safety is assured for each incident.

NYCT's procedures manage incidents on an incident-by-incident basis. NYCT also has procedures for system shutdown, such as blackouts, strikes and security-related shutdowns, but these are different in nature from incident response. The key to successfully responding to incidents and communicating to customers relies on recognizing when to make the transition from managing incidents to managing a (near) system shutdown. Clearly the incident of August 8 was not managed as if it were a shutdown early enough on in the process. ▼

Commuter Railroads

On the morning of August 8, LIRR sent Customer Assistance Personnel (CAP) and Transportation Managers to Jamaica Station platforms and the customer waiting room. By 8 a.m. announcements were being made at Jamaica to alert subway customers from the E, J and Z lines that their MetroCard would be accepted on LIRR trains. All Main Line trains made local stops between Jamaica and Penn Station to alleviate reported crowding on platforms at Kew Gardens, Forest Hills, and Woodside as subway customers flocked to those LIRR stations. In addition, express trains that normally bypassed Jamaica were stopped to pick up passengers queuing at Jamaica. Four equipment trains were pressed into service to make local stops at all stations between Jamaica and Penn.

LIRR announcements by train crews onboard trains are specified in LIRR's Operations Manual. The following announcements were made to train crews on the morning of August 8:

8:01 a.m.:	"Heavy customer crowding; no service on NYCT 2, 3 lines"
8:16 a.m.:	"No service on F, D, G, L, R lines"
8:18 a.m.:	"All westbound trains departing Jamaica will make local stops due to crowding at all stations"
9:54 a.m.:	Announcements provided to train crews: "No NYCT service between Jamaica and New York/Brooklyn

Communication to MNR customers were initiated by every means available on August 8. Messages were crafted for timeliness, content, consistency and accuracy. MNR's announcements by train crews onboard trains are specified in MNR's Operations Manual. Information was tailored to the specific incident by operating department managers in the Operations Control Center and read to train crews over the radio. The message given was "Due to flooding conditions, we are unable to provide train service through the Bronx." This message was transmitted to all trains every 10-15 minutes throughout the 90-minute shutdown at Mott Haven.

When NYCT 2, 4, and 5 subway lines were operating in the Bronx, specific announcements were radioed to the five trains that were stopped at Wakefield and Woodlawn advising them of NYCT services as an alternative.

Station announcements were handled by the either the Public Address System controlled by the Operations Control Center or by local station agents in staffed stations. Messages communicated at stations were crafted either by Customer Service Department personnel or by the situation room. Station announcements about connecting NYCT service are made at the line stations but only after the information is confirmed though the Operations Control Center and/or Situation Room.

Interactions with external agencies (e.g., PDs, regional DOTs or DPWs) are handled by the MTAPD representative in the Situation Room.

Buses

Customer Service Alerts on the MTA website were frequently updated during the storm and are very effective at reaching bus customers prior to their leaving home. Nonetheless, it is quite difficult to reach customers at bus stops and between segments of their commute. Accordingly, NYCT Buses made two system-wide announcements to their customers who were already onboard buses, addressing subway disruptions. This effort appears to have been ad hoc, since no clear protocol of which subway disruptions should be reported to bus customers currently exists.

The subway stations on Hillside Avenue are termini for several LI Bus routes and service as transfer points to the subway system. On August 8, LI Bus operators (and dispatchers stationed in Jamaica) notified bus passengers bound for the F line on Hillside Avenue that the trains were not operating and, as a special service modification at that time due to the subway outage, the bus route would be extended to Parsons Boulevard and Archer Avenue where access to other subway lines were available.

The MTA Bus website was updated as quickly as possible through MTAHQ staff as information and updates were received through the Command Center. MTA Bus does not have a press office and relied on information passed on by NYCT and the MTA website.

Bridges and Tunnels

Traffic problems were relayed to the public via a number of avenues, including TRANSCOM, which relayed information to media outlets, and variable message signs. The Operations Central Command Center (OCCC) of B&T communicates with TRANSCOM via telephone and electronically through the "Regional Architecture Computer." Messages are developed and coordinated with B&T Public Affairs. ▼

B. External Communication

Media

News media in the MTA's coverage area play a key role in communicating travel information from the MTA's operating agencies to our customers. While new technologies have and will increase the MTA's ability to communicate travel information directly to customers, the news media has a unique ability to reach millions of commuters quickly.

New York City Transit (NYCT), the Long Island Rail Road (LIRR), Metro-North Railroad (MNR), and Long Island Bus (LIB), each maintains its own public affairs office responsible for communicating service and policy information to local, regional and national media outlets. The MTA Media Relations office oversees and coordinates the agency operations, handles press for MTA Bus and the MTA Police, and communicates to press regarding multi-agency issues and MTA policy.

This analysis focuses on NYCT, LIRR and MNR, since these three operating agencies were most affected by the storm and were responsible for communicating with the press that day.

Each operating agency's public affairs office is typically staffed from before the start of the morning rush hour until after the completion of the evening rush to communicate any service disruptions to the news media. In all cases, press officers are available 24 hours a day via pager, Blackberry or cell phone, in case of emergency.

The media relations function is especially critical leading up to the morning rush hour, as commuters preparing to head to work make decisions about their morning trip, often with the help of a television, radio or internet traffic and transit report. Each agency has a protocol for disseminating routine service information to the press each day. This exercise focuses on providing accurate and timely information to a handful of traffic and transit reporting outlets that distribute or report updates for the majority of regional news organizations. This list includes Shadow Traffic, Metro Traffic, TRANSCOM, Traffic Pulse, the Associated Press, WCBS radio, and generally a few local outlets specific to each operating agency. In most cases, these updates appear on the traffic and transit updates that run periodically throughout the morning.

The demand on the MTA agencies' public affairs offices increases dramatically, however, when a service disruption is considered serious enough to be reported not just in the traffic report but also as a major news story. In those cases, the public affairs offices are often inundated with requests for both information and live interviews from many news outlets.

The MTA website has become an increasingly critical component of this effort, as both customers and media outlets have come to rely on the site for up to date service alerts.

With so many incoming calls to field, it is even more important that information first be disseminated to the traffic reporting organizations and, if possible, simultaneously posted on the MTA website, so that all media outlets can have immediate access to the most vital information.

On the morning of August 8, the storm caused service disruptions that very rapidly grew from routine to the top news story of the day, albeit to different degrees across the agencies. The situation was complicated by the timing of the storm, which had its impact right at the start of the peak rush hour period, after many commuters had begun their trips – but before the press offices were fully staffed.

Each agency faced a different media relations challenge, but there are a number of lessons that can be learned by analyzing the morning across the three agencies and MTA Media Relations, as chronicled in the truncated timelines below (includes highlights but not all press activities):

NYCT

NYCT was faced with systemwide subway delays that developed rapidly right before 7 a.m. There were major service disruptions throughout the morning, with extensive delays on the Queens Boulevard line extending into the evening rush. When the morning emergency struck, the public affairs office was not staffed (until 7:30 a.m.), there was a public information officer on duty via pager, and the Public Affairs Vice President was out of contact due to flooding in his home (from 6:45 to 7:30 a.m.).

LIRR

The LIRR was tasked with communicating systemwide delays along with suspension of service on two lines. Most of the service disruption was cleared by 10:25 a.m., and the afternoon rush was mostly on schedule. The LIRR also communicated afternoon service changes needed to provide service for diverted NYCT customers. There was a public information officer in the office throughout the incident and another public information officer was reachable by phone and communicated directly with the press remotely. LIRR Public Affairs performed media outreach per department protocol, quickly notifying media outlets of delays and frequently updating the message as the morning progressed.

MNR

MNR was faced with communicating disruptions into and out of Grand Central that lasted approximately 90 minutes. By the time the first major disruption was reported, three public information officers were in the office and prepared to contact media. The afternoon rush proceeded without major incident. MNR Media Relations performed media outreach per department protocol, quickly notifying media outlets of delays and frequently updating the message as the morning progressed.

Conclusion

The protocol followed by LIRR and MNR effectively communicated the service disruptions of August 8 to the news media. News of the disruptions was quickly conveyed from operating personnel to the public affairs offices, which was in turn posted online and transmitted to the media by phone.

While NYCT generally follows a similar practice, the lack of an explicit protocol left the agency unable to provide timely information to the news media when faced with an unprecedented weather event and a number of unfortunate circumstances that kept key staff out of reach. (The inability of the web site to handle the traffic demand on August 8 is discussed elsewhere in the report, but it is worth noting that it put additional strain on the media relations effort.)

To ensure that NYCT more effectively communicates with the news media in future extreme situations, the following changes were recommended and most have already been implemented:

- The NYCT Public Affairs office will be staffed by a media representative beginning at 6 a.m. each day, instead of 7 a.m.
- Each NYCT public information officer (PIO) will be issued a Blackberry for immediate access to email and text messages at all hours.
- The PIO on duty will be authorized to initiate emergency notifications to media upon notification from the Rail Control Center.
- When the system suffers major service disruptions, NYCT will follow a protocol similar to the railroads, with immediate phone calls to a set list of traffic and transit desks followed by live phone interviews and blast emails as appropriate.

Website

The August 8 storm brought extraordinary access demand for updated travel information on MTA's website www.mta.info. Before August 8, the highest MTA web traffic occurred during the last NYC Transit strike – 35 million hits in a single day, with an hourly peak of 2 million. On August 8 there were 44 million successful hits for the day, with an hourly peak that exceeded 3.8 million.

The website uses approximately 100 processors which house and distribute the information provided on the website. The different processors are invisible to the customer. Collectively these processors were operating at 20-25 percent of their capacity on August 8. However, many customers experienced slow access or no access to the site, leaving them with the perception that the system had crashed. While this was not the actually the case, it effectively was for those customers who were unable to access it in a timely fashion.

The reason for this limited access was not the capacity of the website itself, but that of the firewall servers which filter all traffic to and from the website to prevent hackers and viruses. They hit 100 percent CPU utilization in the morning rush period. The MTA Enterprise Information Technology Group, realizing this situation and in the interest of trying to alleviate this saturation of the firewalls, took the following actions during the actual event to improve capacity:

- Discontinued non-critical logging activity on the firewall to reduce overhead
- Temporarily disabled webcasting capabilities and access to archived webcasts
- Discontinued internet access for MTA employees
- Requested that the MTA webmaster in the MTA Marketing and Corporate Communication division change the content on the homepage to a compressed, text-based format for the duration of the incident.

Though these actions had a positive impact on the number of transactions the firewalls could process, they could not compensate for the unprecedented demand the system was experiencing.

Despite the heavy load, and long wait times to make a connection to the site, Service Alerts for all agencies were, in fact, updated frequently and were available throughout the day.

Email Alerts

Among the MTA agencies, only LIRR and MNR have the capability of sending current email "Service Alerts" alerts to their customers. NYCT has the ability to send weekly "Service Advisories" or longer-term/planned service diversions. (There are 56,000 subscribers to NYCT's weekly Service Advisory emails.) MTA Bus, LIBus and B&T do not yet have this capability.

Over the course of the day on August 8, the LIRR sent a total of 17 email alerts to the 24,000 customers who are registered for their service. The alerts were targeted to those who had requested information by branch. Some alerts were sent to customers of a single branch, others went to the customers of many of the railroad's branches.

MNR sent a total of five emails to the 16,000 registered customers advising them of the suspension and later restoration of service and a service update to report that all delays had been cleared.

When a Service Alert is sent by email, there is generally adequate time between the time the alert is physically sent and the time it reaches the email account of the subscriber to influence their travel decision. Due to the rapidly evolving impacts on MTA service on August 8, by the time the email alerts were created and "pushed out" of the system and made their way through the Internet, through various firewalls and onto the screens or customer Blackberry type devices, the information was frequently out of date. Current email alert server capacity at both LIRR and MNR can take as much as an hour to an hour and a half to push out such large volumes.

Nonetheless, customer expectation on August 8 was that they should have been receiving real-time service information throughout the morning in order to better plan their trip. Certainly the matter of capacity and the consistency in terms of the type of email product the MTA family provides is an issue that needs to be addressed immediately to better serve a more technologically sophisticated customer base. ▼

C. Communication Findings and Recommendations

Findings:

Customers did not always have access to accurate information in stations and lacked real-time information on the go.

Many customers had difficulty accessing the MTA's website, www.mta.info, or easily finding critical information on the site.

Information on the severity of the NYC Transit disruption was delayed reaching media outlets.

Recommendations:

A. **Dramatically Improve Customer Information**

   a. **Establish Clear Emergency Communication Protocols –** to ensure redundancy and consistency in communicating with the media, customers and other stakeholders.

   b. **Designate Dedicated Customer Communication Specialists in Each Ops Center** – to assess operations developments that need to be communicated to both internal and external players immediately.

   c. **Ensure Emergency Interagency Communication Coordination –** ensure communication coordination when service issues cross agency lines to ensure customers are aware of potential service alternatives.

B. **Develop Capacity for Near to Real-time Email and Text Messaging Service Alerts** – to support the volume of emails/text messages that can be sent and reduce the time it takes to send them out. Currently, email service alerts take as long as 1.5 hrs to "push out" to recipients (i.e., to LIRR's 24,000 subscribers.) The MTA is issuing an RFP to secure a provider capable of handling as many as 800,000 email alerts simultaneously.

C. **Provide Cell Phone Service on Subway Platforms –** Later this month the MTA Board will consider a contract for providing this service that would allow customers to communicate with the outside world in case of service disruption or emergency.

D. **Increase Website Capacity, Clarity, and Access to Service Alerts**

   a. **Replace Firewalls and Load Balancers and Use Hosting Vendors** – to provide 7 to 10 times existing capacity (by September 30)

   b. **Redesign Homepage With Focus on Service Status** – to improve visibility and terminology of "Service Advisories" and "Service Alerts." (First Quarter of 2008)

   c. **Provide Universal PDA Access to www.mta.info –** to expand access to web-based service alerts. (Completed as of September 1.)

   d. **Provide RSS Service Alert Feeds to Public and the Media, and NYC's 311 System –** will allow current service information to be delivered automatically to public and media subscribers, eliminating the need to search the MTA website for service information. As a direct link to NYC's DoITT 311 system, service information will be shared with both the 311 hotline and the NYC website, both of which can help communicate service messages to the public (by November 1).

E. **Improve Communication Between Ops Centers and Field Personnel –** maximize use of available technologies to communicate between Ops Centers and operating personnel. NYCT's "Mass Call" and EBS systems were not adequate to handle the volume and timeliness of communication to station and operating personnel on August 8. Mobile tablets, PDAs and Blackberrys will be provided to increase speed and accuracy of information sent to field personnel (including bus operators, dispatchers, and road control management).

F. **Advance Public Address and Video Screens Technologies to Better Communicate with Customers In-System –** While PACIS at NYCT subways, AVL on NYCT and MTA buses, and similar efforts on LIRR and MNR will ultimately provide integrated real-time service information to customers at station booths and platforms, the MTA will issue an RFI to advance interim off-the-shelf technology solutions (i.e. wireless connectivity to service info.)

G. **Expand MTA's Current Inventory of Wireless Video Displays –** Currently the MTA has 80 wireless video displays over station entrances which are used for advertising. They have the capability to be linked to agency operations centers during emergencies to provide real-time service information, especially helpful to customers as they enter a station where service may not be running.

H. **Conduct Six-Month Progress Review –** The MTA Chief Operating Officer will conduct a review every six months of progress made in each of the aforementioned areas. ■

APPENDIX 1
Task Force Members

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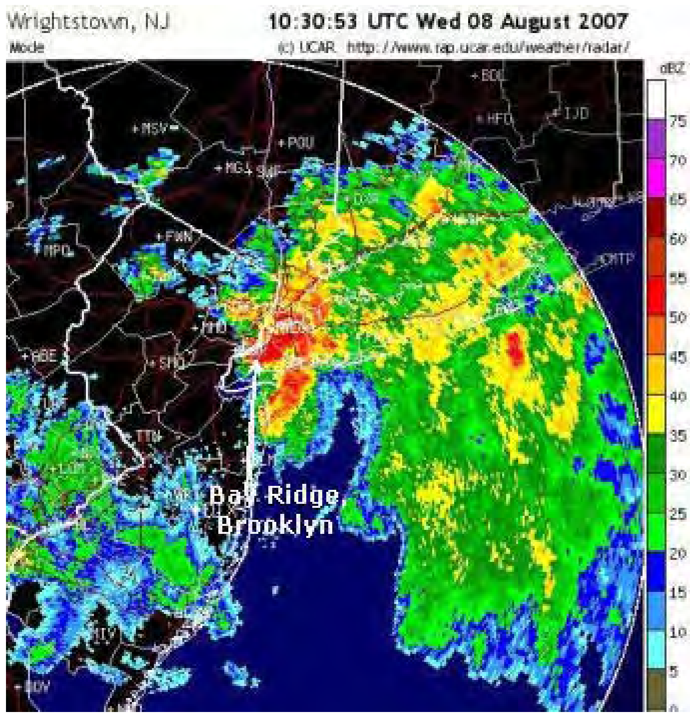
APPENDIX 2

"Climate Component, 8.8.07 MTA Task Force Report" prepared by the Columbia Center for Climate Systems Research

Climate Component

MTA 8.8.07 Task Force Report



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September 18, 2007

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Introduction

The New York metropolitan transportation system is particularly vulnerable to disruption by major storms now and in the future at both inland and coastal locations. The sudden downpour on August 8, 2007 dumped 1.7 inches (43.2 mm) in one hour, with a daily total of 2.8 inches (71.1 mm) in Central Park (Barron, 2007), and caused system-wide delays. Portions of the three major airports (JFK, LaGuardia, and Newark), most area rail lines, tunnel points of entry, and many subway entrances as well as sections of some highways lie at elevations of 10 feet (3 m) or less; this elevation represents a critical threshold for coastal flooding. In the future, water heights of only 1 to 2 feet (0.3 to 0.6 m) above that which occurred during the December 1992 Nor-easter or Hurricane Donna in 1960 could result in serious inundation and even loss of life (USACE/FEMA/NWS/NY/NJ/CT State Emergency Management, 1995).

The worst-case scenario of a Category 3 hurricane on the Saffir-Simpson scale following a track slightly west of New York City would produce a storm surge far surpassing the 10-foot level in many places, even at present-day sea level. The region has experienced several Category 3 hurricanes in the past two centuries. Moreover, the intensity of Atlantic hurricanes appears to have increased within the past 30 years as the climate has warmed (IPCC, Emanuel, 2005; Webster et al., 2005), although this could possibly reflect normal variability, rather than climate change (e.g., Nyberg et al., 2007).

With rising sea levels, not only would the New York Metropolitan Region be threatened by higher floods associated with hurricanes and other coastal storms, but the interval between floods of a given elevation could drop sharply. Significant sections of the Financial District, lower Manhattan, Coney Island, the Rockaways, and low-lying Staten Island neighborhoods could experience more frequent coastal flooding, and risks of city-wide shutdowns of the metropolitan transportation system could increase.

This report describes climate risks and vulnerabilities for the Metropolitan Transportation Authority 8.8.07 Task Force Study. The report provides a concise review of the relevant climate science; describes how precipitation, storms, and sea level are currently changing in the New York metropolitan area; presents potential future changes due to global warming; and assesses expected impacts on the transportation system. Detailed assessment is based on three key MTA facilities: Hillside Avenue, Corona/Shea Yards, and Mott Yard (Figure 1). The report has 6 parts: 1) Global Climate Change; 2) Current Trends in the Region; 3) Future Projections; 4) Historical Record of Regional Flood Events; 5) Case Studies; and 6) Conclusions and Recommendations.

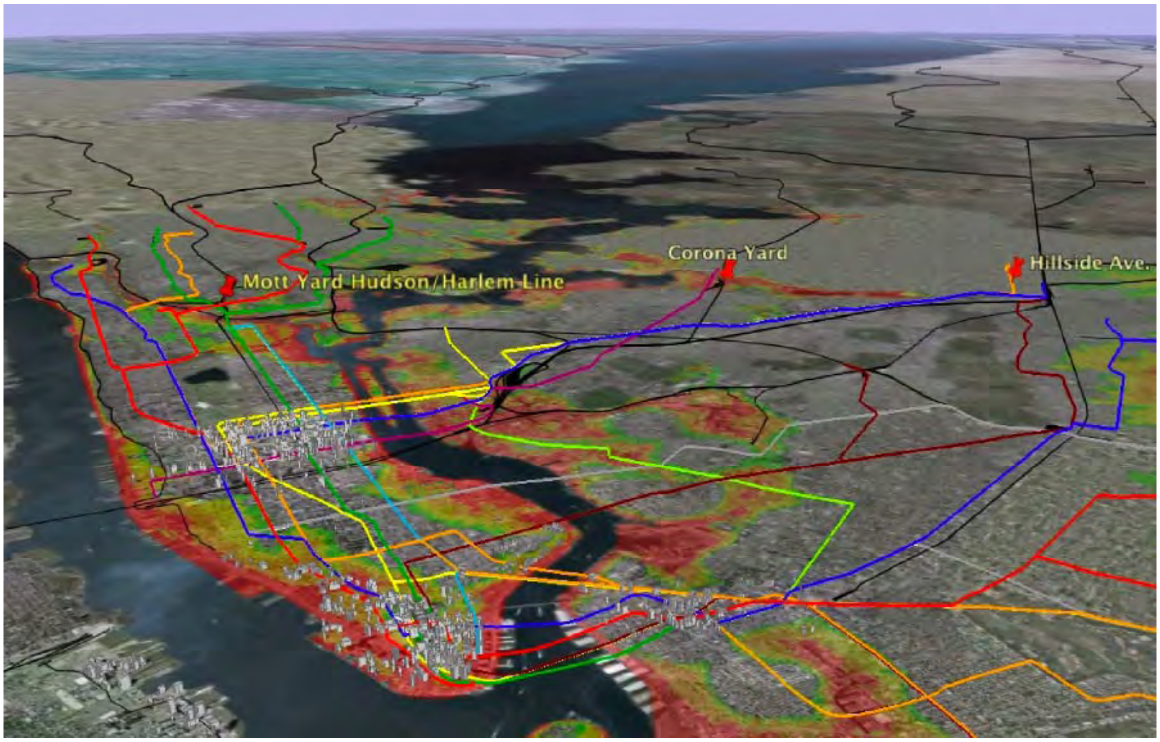


Figure 1: *Location of the 3 case study sites: NYCT Hillside Ave. Pump Station on the F-line Metro-North; NYCT / LIRR Corona/Shea Yards – Flushing Meadows, Queens; and Mott Yard (Bronx). Colored areas are worst-track storm surge flood zones for Saffir -Simpson Category-1 in red, SS2 in yellow, SS3 in brown, and SS4 in green. Colored lines are subways, black lines are rail sytems. See text for details.*

Source: Lamont-Doherty Earth Observatory, Google Earth, and NYSEMO (for colored flood zones and NYCT subway lines)

Global Climate Change

The evidence is now compelling that human activities, especially fossil fuel combustion and tropical deforestation, have altered the energy balance of the planet, with ensuing changes to the global climate system. Before turning to the implications for the New York region, we briefly describe some of the global evidence for anthropogenic climate change.

Observational Evidence

Climate records on multiple time scales are based on recent instrumental records and proxy evidence such as ice core and sediments extending back millions of years. All types of evidence suggest that the Earth is currently experiencing some of the highest temperatures in 400,000 years and point to increasing atmospheric greenhouse gases associated with human activities – including fossil fuel combustion and deforestation – as the likely explanation for the global warming (IPCC, 2007).

Global temperature records show an increase of 1.33 ^{o}F (.74 ^{o}C) over the past 100 years, and the trend has accelerated in the past three decades (IPCC, 2007). The warmest year in the global record (which dates back to 1861) was 2005 (GISS, 2006), and eleven of the past 12 years rank among the 12 warmest years on record (IPCC, 2007). The world's oceans have warmed simultaneously, and there has been widespread melting of snow and ice. These climate changes are well correlated with atmospheric concentration of CO_2 and other greenhouse gases that have increased as a result of human activities ranging from fossil fuel combustion to deforestation.

The relationship between greenhouse gases and surface temperature extends back much further in time. Measurements of air trapped in ice cores show that the high correlation between atmospheric carbon dioxide, methane (another greenhouse gas), and temperature extends back over 650,000 years, spanning the rise and fall of ice ages and interspersed interglacial periods (Jouzel et al., 2007; Siegenthaler et al., 2005; Spahni et al., 2005).

Scientific Consensus

The observed trends and their link to human activities have been documented and endorsed by the world-wide scientific community. A key element of the scientific response to climate change has been the work of the Intergovernmental Panel on Climate Change (IPCC), which has recently completed its Fourth Assessment Report (IPCC, 2007). With each successive report since the early 1990s, the IPCC has expressed increasing confidence that warming is indeed taking place as a result of human activities. The latest report states that there is a greater than 90 percent chance that observed warming is a consequence of human activities.

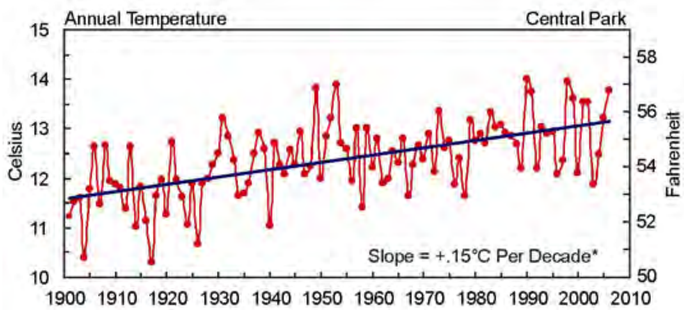
Current Climate Trends in New York Metropolitan Region

A trend towards higher temperatures and precipitation over the last century especially in recent decades extends throughout much, but not all of the Northeast. Long-term and recent trends in New York City for mean temperature and extreme heat, mean precipitation and extreme rainfall, and sea level rise are analyzed below. The key types of storms that affect the region are also described.

Observed Temperature and Heat Waves

The annual mean temperature in the New York Metropolitan Region has risen at a rate of 0.25°F (0.14°C) per decade for a total cumulative temperature change of roughly 2.5°F (1.4°C) over the course of the last century (Figure 2). This trend is statistically significant.

Figure 2: Annual temperature in Central Park (1900-2006).
**statistically significant at the 95% confidence level*
Source: Columbia Center for Climate Systems Research



Hot days and heat waves may be defined in several ways using daily data, which are available for Central Park since 1900 (Figure 3):
1) Individual days with maximum temperatures above 90^{o}F (32.2^{o}C),
2) Individual days with maximum temperatures above 95^{o}F (35^{o}C),
3) Two consecutive days with maximum temperatures above 90^{o}F (32.2^{o}C) and
4) Three consecutive days with maximum temperatures above 90^{o}F (32.2^{o}C).

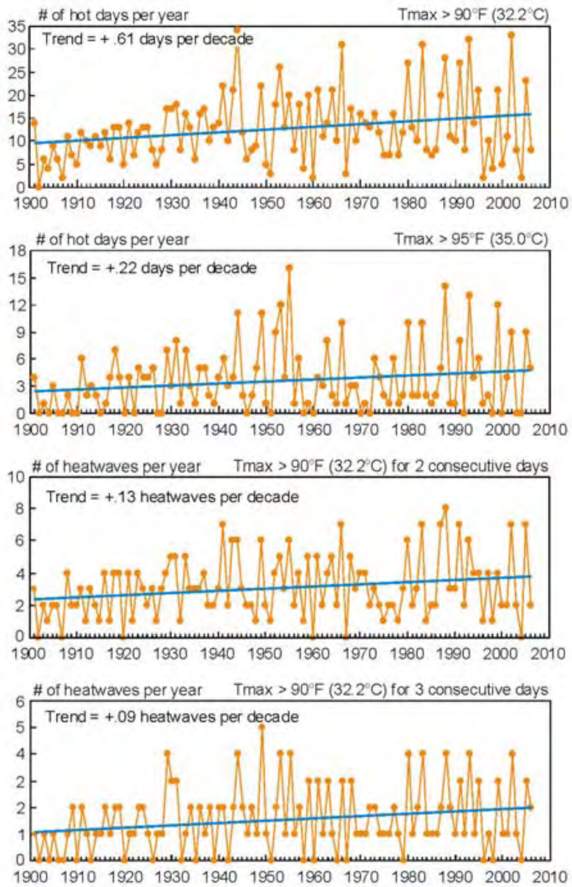


Figure 3: Hot days and heat waves in Central Park, based on maximum temperatures exceeding: 90°F, 95°F, 90°F for two consecutive days, and 90°F for three consecutive days.
Source: Columbia Center for Climate Systems Research

The number of days per year with extreme heat over the last 25 years has far exceeded the historical 100-year average for the region. The trend for the last 100 years is 6.1 additional 90^{o}F days, 2.2 additional 95^{o}F days, 1.3 additional two-day heat waves, and 0.9 additional three-day heat waves per year. Relative to the historical average frequencies of occurrence, these positive trends are 48%, 61%, 42%, and 59% respectively.

Observed Precipitation and Extreme Rainfall Events

The interannual variability of precipitation has also increased in recent decades (Figure 4). The standard deviation of the annual precipitation data for the period 1901-1959 is 6 inches (148.9 mm) per year, as compared to 10.5 inches (262.2 mm) per year for the period 1960-2004. This pattern of increasing interannual variability is consistent with observed trends in extreme precipitation events.

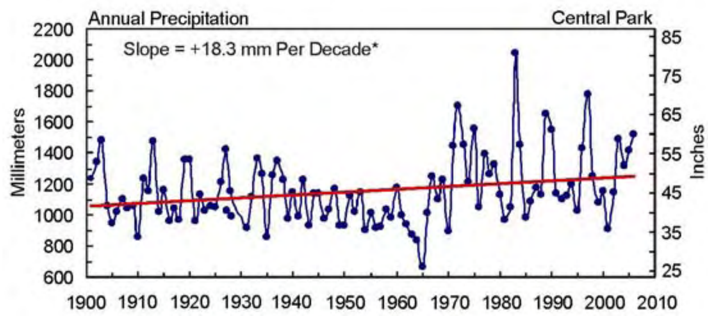


Figure 4: Annual precipitation in Central Park (1900-2006).
Source: Columbia Center for Climate Systems Research

Since extreme precipitation events tend to occur infrequently over small regions, long time series are used to identify trends. Figure 5 shows the number of occurrences per year of precipitation above 2, 3, and 4 inches for the New York metropolitan region since 1900. Trends in extreme precipitation events are all positive, with increases of 1.15, 0.46, and 0.14 days respectively over the period of record. These represent a 48%, 66%, and 78% increases in the average number of occurrences for the three thresholds. Despite the large trends relative to the small frequencies of occurrence, these results are not statistically significant at the 95 percent level. The infrequency of extreme events and the non-normal statistical properties of precipitation set a very high threshold for statistical significance.

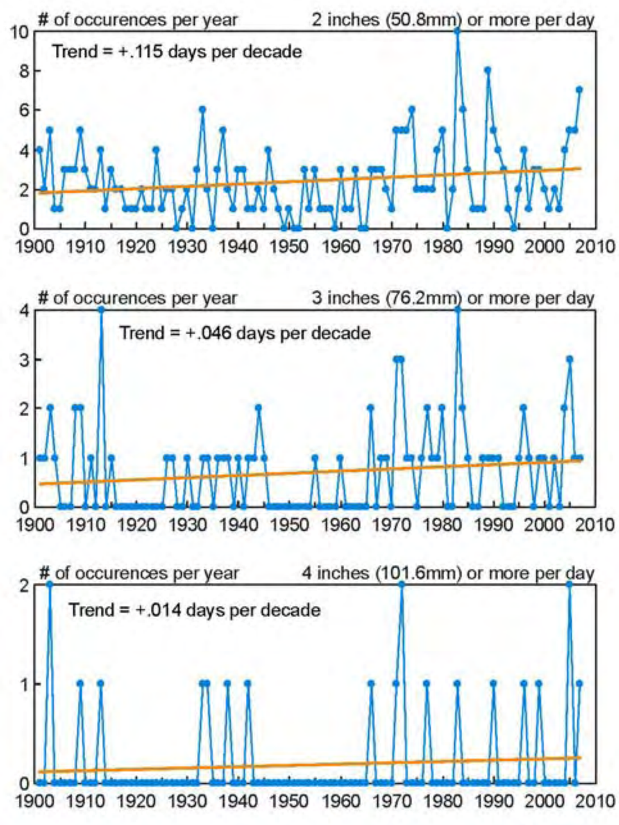


Figure 5: Heavy precipitation events in Central Park (1900-2006), based on daily precipitation exceeding 2, 3, and 4 inches.
Source: Columbia Center for Climate Systems Research

A subset of Central Park hourly data from days with heavy precipitation and/or interruptions of MTA service were analyzed to assess the impacts of sub-daily precipitation intensity and the time of day of peak rainfall intensity on MTA operations. Results for selected recent flood events are shown in Box 1 and Figure 6. Note that this analysis is limited by the availability of hourly data. The Central Park record is not necessarily indicative for the entire NYC region, especially for short-term (less than three-hour) events.

Rainfall events concentrated in short (less than 3 hours) periods and events during rush hour seem particularly disruptive to MTA operations. From the small subset of hourly data analyzed, it appears that rainfall rates below 0.4 inches (10 mm) per hour pose minimal threats to MTA operations at current sea levels, provided that the rainfall is not accompanied by a storm surge.

Box 1 Summary of recent rainfall flooding events

8/8/2007 *Service suspended for eight hours*. Although the total precipitation of 2.5 inches (63.5 mm) does not rank in the top 100 daily rainfall events since 1900 for Central Park, 43 mm fell in one hour, the highest hourly rainfall total in the available hourly data record. The rain also occurred during the morning rush hour, likely contributing to the disruption of service.

7/18/2007 *Five lines suspended*. A relatively small daily rainfall event of just over 1.5 inches (~40 mm), which did not rank in the top 250 daily precipitation amounts, produced extensive disruptions. Almost an inch of the rainfall fell over a one-hour period during rush hour.

4/15/2007 *At least five lines suspended*. Central Park's highest precipitation total on record--7.6 inches (192 mm), produced widespread disruptions. Although the precipitation event is spread across the majority of the day, as is common for non-summer storms, the precipitation rate twice exceeded one inch (25.4 mm) per hour.

11/8/2006 *No reported disruptions*. The 34th wettest day in Central Park, produced no known disruptions. The rainfall was distributed fairly evenly throughout the 24 hour period, not exceeding .6 inches (14 mm) per hour. The most intense rainfall occurred in the mid-day hours.

8/10/2006 *No reported disruptions*. A brief but intense downpour of 1.6 inches (40 mm) per hour, the third highest hourly rate observed, produced no known disruptions. The rainfall occurred after 8 PM.

Observations from New York City are consistent with continental-scale results that suggest climate change is producing more heavy rainfall events. Continental-scale statistical analyses of precipitation do not suffer to the same extent from the problem of a small event sample. Numerous studies (including Frich et al. 2001; Meehl et al. 2000; Katz, 1999; and Karl and Knight 1998) find statistically significant evidence of an increase in extreme events for the U.S. as a whole during the 20th century. This provides support for process-level understanding that a warming world will produce an enhanced hydrological cycle, where more rain falls more intensely during extreme events, leading to more severe flooding.

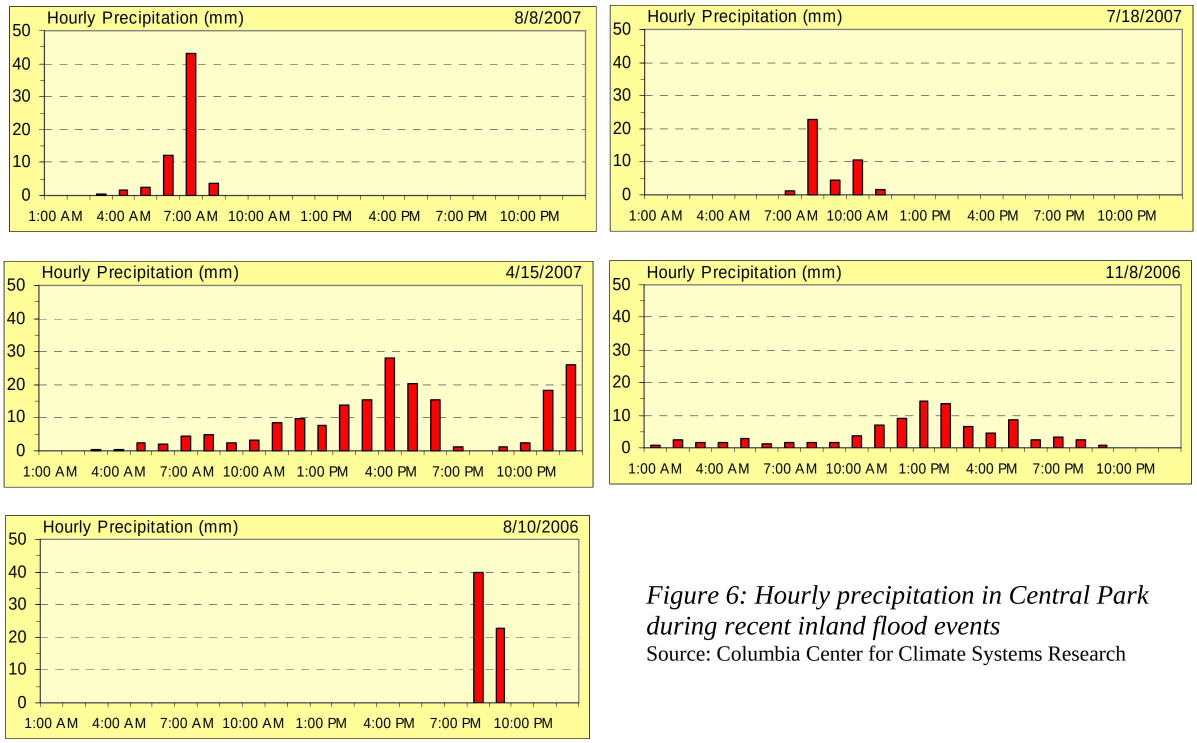


Figure 6: Hourly precipitation in Central Park during recent inland flood events
Source: Columbia Center for Climate Systems Research

Observed Sea Level Rise

Sea level has been rising along the U.S. East Coast since the end of the last ice age, starting around 20,000 years ago. The region is gently subsiding (at rates of 0.31 to 0.39 inches per decade (0.08 to 0.1 mm/decade)) as the Earth's crust still slowly re-adjusts to the melting of the ice sheets. Within the past 100-150 years however, as global temperatures have increased, regional sea level has also been rising more rapidly than over the last few thousand years (Gehrels, et al., 2005; Donnelly et al., 2004; Holgate and Woodworth, 2004). Currently, rates of sea level rise in the New York Metropolitan Region range between 0.86 and 1.5 inches per decade (0.22 and 0.39 mm/decade) (Figure 7). These rates of *relative* sea level rise, as measured by tide gauges, include both the effects of global warming and residual crustal adjustments to the removal of the ice sheets.

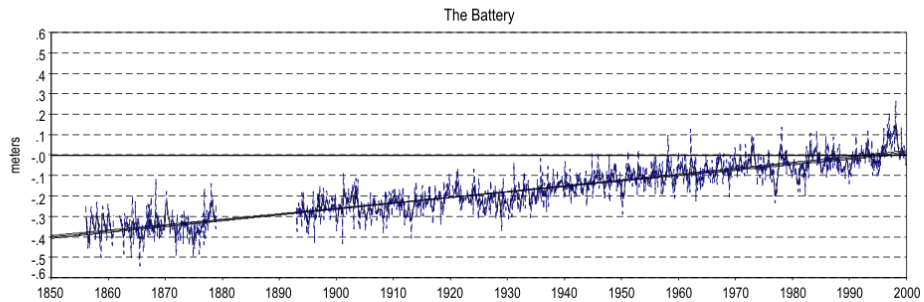


Figure 7. Historic sea level rise at the Battery tide gauge station, New York City
Source: http://tidesandcurrents.noaa.gov

Storms

Hurricanes and nor'easters are the two types of storms that have historically inflicted the most damage in the New York Metropolitan Region (Box 2). Because much of the region is located adjacent to an estuary, the nearby waters are subject to both tides and storm surges. The storm surges occur largely during *hurricanes* (in mid-summer to late fall); and during *nor'easter* storms (most prevalent during early winter to early spring). Hurricane storm surges can be higher, but are typically shorter in duration (on the order of hours) than nor'easter surges, which can last several days. Therefore the former may not always coincide with cresting high tides, while the latter have a higher probability of spanning one or more of the twice-daily high-tide stages, thus often leading to similarly hazardous storm-surge flooding conditions. In the New York City estuary, nor'easter storm surges tend to be more frequent than those from hurricanes. Sea level rise has the potential to increase the flood risks associated with both types of storms.

Harmful Historical Hurricanes

The only known hurricane whose central eye hit what is now New York City directly occurred on September 3, 1821, making landfall at Jamaica Bay (Table 1). Moving northward rapidly, the storm (estimated as a Category 3 or 4 on the Saffir-Simpson scale) produced a storm surge of 13 feet (3.9 m) in only one hour, causing widespread flooding of lower Manhattan as far north as Canal Street. However, the storm caused few deaths because the population density was rather low at the time. In late August 1893, a powerful hurricane (estimated as a strong Category 1) wiped out Hog Island, a small resort island off Rockaway Beach.

The 'Long Island Express' or 'Great Hurricane of 1938' (Category 3) slammed across central Long Island and ripped into southern New England on September 21, 1938, killing nearly 700 people and injuring thousands more. The storm raised a wall of water 25 to 35 feet (7.6 to 10.6 m) high, sweeping away protective barrier dunes and buildings. Because of the tremendous population growth and development that have occurred in the Metropolitan Region since then, damages from such a storm today would be enormous.

Box 2 Types of storms that influence the New York Metropolitan Region

There are two major types of severe, low-pressure storms that occur in the New York Metropolitan Region – hurricanes and nor'easters.

Hurricanes A Category 3 or larger hurricane making first landfall in the New York City region could be devastating to life and property. New York City has experienced near misses with the Hurricane of 1938– which killed 700 people in the Northeast, Hurricane Donna in 1960, and Hurricane Gloria in 1985. Even the weaker remnants of prior hurricanes, including Tropical Storm Floyd in 1999, have produced extreme rainfall over the region.

While the New York region is not as prone to major hurricanes as some other metropolitan regions such as New Orleans, the higher concentration of people and property in New York, along with peculiarities of coastline shape (New Jersey and Long Island meet in a "corner" where a storm surge could be amplified) implies a high level of risk if and when such a storm does strike. Since portions of the City's subway system could be flooded, along with many of the city's transportation routes adjacent to waterways, developing effective evacuation plans is a challenge.

Nor'easters While geography generally shelters the region from the full brunt of most hurricanes, physical geography favors the development of mid-latitude storms known as nor'easters along the mid-Atlantic coast and New England (hence the name 'nor'easter'). Since the 1960s, there has been a notable increase in the frequency and intensity of nor'easters (NOAA, 2005). Insurance losses have increased both as a result of climatological and societal factors such as amount of property insured (Kunkel, et. al., 1999).

On September 12, 1960, Hurricane Donna (Category 3) pounded New York City with winds gusting up to 90 miles per hour, dumped 5 inches (127 mm) of rain, and flooded lower Manhattan almost to waist level on West and Cortlandt Streets (at the southwest corner of what later became the site of the World Trade Center). The water level at the Battery tide gauge (in lower Manhattan) registered 8.4 feet (2.56 m) above mean sea level. Normal travel was disrupted as airports sharply curtailed service, subways shut down, and highways closed due to flooding.

Hurricane Floyd (Category 3 at its earlier peak) was the most recent hurricane to hit New York City (Figure 8). With sustained winds by then of 60 miles per hour, Floyd dumped 10 to 15 inches (250 to 380 mm) on upstate New Jersey and New York over a 24-hour period in September 1999, causing extensive inland flooding. However, because the hurricane struck at low tide and was already beginning to dissipate as it made landfall on the Long Island shoreline, it did not produce a significant storm surge.

Table 1. Major New York Metropolitan Region hurricanes

Date	*Name*	*Category*	*Details* *mb = millibars*
Sept 3-5, 1815	Great September Gale of 1815		Eastern Long Island and New England
Sept 3, 1821		1-2	CP 979-985 mb, max. winds 55-78 mph (89-126 km/hr); only direct strike on NYC; surge 13 ft (3.96 m) in 1 hr; flooded lower Manhattan as far north as Canal Street
Sept 1858	New England Storm	1	CP 976 mb, max.winds 80 knots
Sept 1869	Eastern New England Storm	1	CP 963 mb, max. winds 100 knots
Aug 23, 1893	Midnight Storm	1-2	CP 986 mb, max. 75 knots. Flooded south Brooklyn and Queens. Hog Island (near Rockaway Beach) disappeared
Sept 21, 1938	Long Island Express New England Storm	3	CP 946 mb. Long Island and southern New England, ~ 700 people killed. Gusts to 100 mph in NYC, surge up to 17 ft in southern New England
Sept 15, 1944		1 (3?)	CP 947 mb. Hit central Long Island
Aug 1954	Carol	3	CP 960 mb; sustained winds >100 mph, gusts 115-125 mph
Sept 12, 1960	Donna	3	CP 930 mb; sustained winds 100 mph; gusts to 125 mph; 11 ft surge. 2.55m (8.36 ft) highest water level at the Battery. Lower Manhattan to West & Cortland Streets flooded nearly waist deep
June 1972	Agnes	1	CP 980 mb. Significant flooding
Aug 10, 1976	Belle	1	CP 980 mb, peak gusts 95 mph
Sept 27, 1985	Gloria	3	CP 942 mb, max. winds 90 knots. 6.14 ft (1.87 m) highest water level at the Battery tide gauge (low tide)
Aug 1991	Bob	2	Eastern Long Island to Cape Cod. CP 962 mb, max.winds 90 knots
Sept 1999	Floyd	2	Sustained winds 60 mph, 10-15 in rain upstate New Jersey and New York State in 24 hrs. Major inland flooding

Sources
Blake, E.S., Rappaport, E.N., and Landsea, C.W., 2007. The Deadliest, Costliest, and most intense United States Tropical Cyclones from 1851 to 2006 (and other frequently requested hurricane facts. NOAA Technical Memorandum NWS TPC-5. http://www.nhc.noaa.gov/Deadliest_Costliest.shtml
Coch, N.K., 1994. Hurricane hazards along the northeastern Atlantic Coast of the United States. J. Coast. Res. Spec. Issue No. 12, 115-147.
Onisihi, N., 1997. The little island that couldn't. New York Times, March 18, 1997. (about the disappearance of Hog Island).
Revkin, A.C., 2001. Experts unearth a stormy past, New York Times, July 24, 2001, Science Times.
http://www.newyorkmetro.com/nymetro/news/people/columns/intelligencer/12908
http://www.nyc.gov/html/oem/html/readynewyork/hazard_hurricane_html
http://www.hurricanecity.com/city/longislandny.html

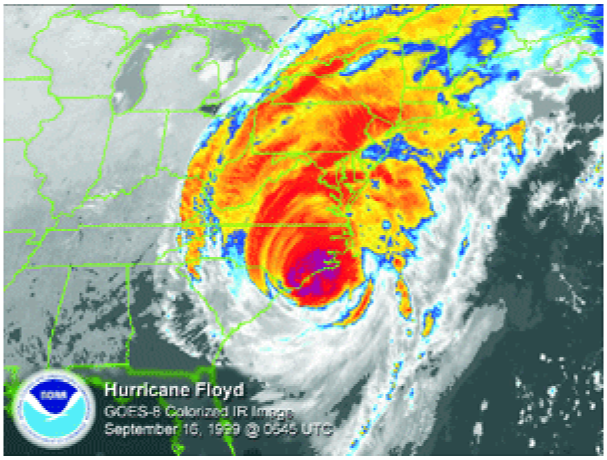


Figure 8. Hurricane Floyd sweeping across the mid-Atlantic states, Sept. 16, 1999, causing widespread flooding and damage
Source: NOAA National Climate Data Center and http://www.ncdc.noaa.gov/oa/climate/extremes/1999/september/extremes0999.html

<u>Harmful Nor'easters</u>

On December 11, 1992, a winter storm pummeled New York City with hurricane-force wind gusts of up to 90 miles per hour, causing tidewaters to rise 7.7 feet (2.34 m) above normal (Table 2). The nor'easter crippled transportation, business, and schools, produced numerous power failures, and flooded wide areas. This near-hurricane strength gale was likely the worst nor'easter in New York City during the 46-year period of detailed tidal records.

Table 2. Major New York Metropolitan Region nor'easters

Date	*Name/Type*	*Details*	*Effects*
Mar 6-8, 1962	Ash Wednesday Storm	2.21 m (7.25 ft) high water at the Battery tide gauge, duration >5 tidal cycles	Widespread coastal erosion and flooding
Feb 6, 1978	Major blizzard	>16 inches snow, gusts >90 mph. 2.04m (6.69 ft) at the Battery	
Mar 29-30, 1984	Major blizzard	2.01 m (6.59 ft) at the Battery. Winds 80 mph and 20 ft waves around region	
Oct 29-Nov 2, 1991	Halloween Storm Perfect Storm	2.05 m (6.72 ft) at the Battery.	Widespread coastal erosion in New Jersey, Long Island, and especially New England.
Dec 11-12, 1992		2.36 m (7.74 ft) at the Battery. "Howling like Valkyries on a rampage", wind gusts 80-90 mph.	Disrupted transportation, flooded lower Manhattan, Seagate, Broad Channel, and many coastal towns on Long Island and New Jersey
Mar 13-14, 1993	Storm of the Century	"A monster with the heart of a blizzard and the soul of a hurricane" Wind gusts to 71 mph in NYC. 1.94 m (6.34 ft) at the Battery	Affected entire East Coast.
Feb 17, 2003	Major blizzard (~20 inches of snow)	wind gusts to 55 mph. 1.59 m (5.22 ft) at the Battery	
Feb 12, 2006	Major blizzard (record snowfall)	Central Park (26.9 inches). 1.35 m (4.43 ft) at the Battery	

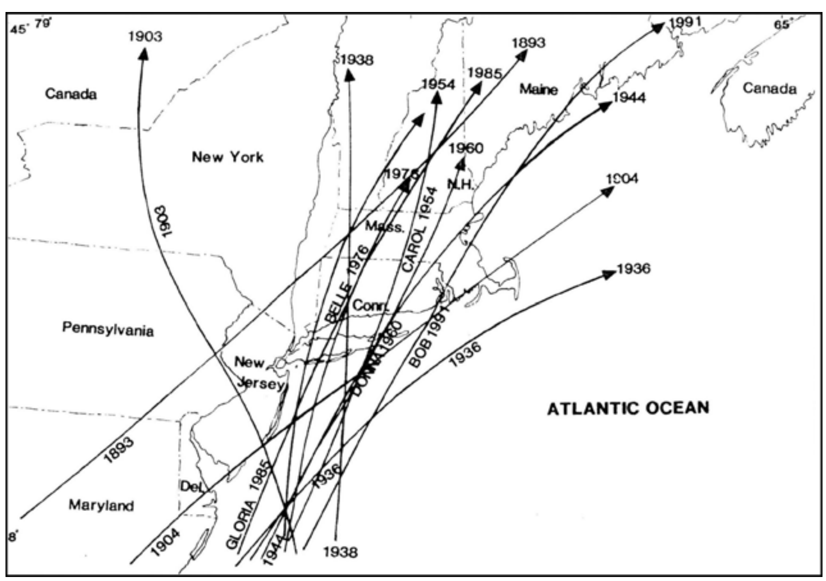
The “Ash Wednesday” storm of March 6-8, 1962, produced extensive coastal erosion along barrier beaches in the mid-Atlantic states, as well as New Jersey and Long Island. In New York City, flooding occurred in lower Manhattan, Far Rockaway, Coney Island, and Howard Beach. Families were evacuated from Breezy Point, ferry service was suspended, and rail and highway traffic was disrupted (New York Times, March 7 and 8, 1962).

Other notable nor’easters that generated high surge levels include major late winter blizzards. For example, the “Storm of the Century” on March 13-14, 1993, which has been described as “a monster with the heart of a blizzard and the soul of a hurricane”, affected the entire East Coast from Florida to Maine. Wind gusts of up to 71 miles per hour and snowfall up to 11 inches (280 mm) were recorded in New York City. Airports were closed, trains, bus, and car traffic halted, and many public events cancelled (New York Times, March 14, 1993). The “Halloween Storm” or “Perfect Storm” of October 29-Nov. 2, 1991, caused extensive coastal erosion and also produced high surge levels in New York City. Within the city limits, Sea Gate, Brooklyn was hardest hit. Service was shut down for an hour on the Port Authority Trans-Hudson rail lines between the World Trade Center and Hoboken, New Jersey (New York Times, Oct. 31-Nov. 1, 1991).

Storm Tracks and Storm Surges

Because of the unique configuration of the shoreline, New York City is especially vulnerable to major hurricanes that travel northward along a track slightly to the west of the city (Figure 9). Since the highest, hence most destructive, winds lie to the right of the eye of a hurricane, a storm moving on such a path would pass directly over the city. Furthermore, the counterclockwise, westerly flowing winds of the approaching hurricane would funnel surge waters toward the near right-angle bend between the New Jersey and Long Island coasts into the apex, i.e., the New York City harbor.

Figure 9. Hurricane tracks crossing New York City Metropolitan Region during the past century



Surge levels for hurricanes have been calculated by the U.S. Army Corps of Engineers for the 1995 *Metro New York Hurricane Transportation Study* using NOAA's SLOSH model. A Category 3 hurricane on a worst-case track could create a surge of up to 25 feet (7.6 m) at JFK Airport, 21 feet (6.4 m) at the Lincoln Tunnel entrance, 24 feet (7.3 m) at the Battery, and 16 feet (4.9 m) at La Guardia Airport. These figures do not include the effects of tides nor the additional heights of waves on top of the surge. Areas potentially under water include the Rockaways, Coney Island, much of southern Brooklyn and Queens, portions of Long Island City, Astoria, Flushing Meadows-Corona Park, Queens, lower Manhattan, and eastern Staten Island from Great Kills Harbor north to the Verrazano Bridge.

Although potentially devastating, a Category 3 hurricane *on a worst-case track* striking New York City is fortunately a rare occurrence, perhaps a once-in-200-year to once-in-500-year event.

Future Climate of the New York Metropolitan Region

Given the climate changes that are already occurring, there is a great need for projections of future climate at the region scale. Climate scientists have developed an array of observational and simulation tools to assist in this endeavor. These tools provide projections of future climate risks, with associated uncertainties.

Climate Change Scenario Framework

A principal source of uncertainty about climate change is future atmospheric concentrations of greenhouse gases. One approach to incorporating this uncertainty in future climate projections is to create greenhouse gas emissions scenarios based on a range of population growth rates, economic growth rates, and technological change. The Intergovernmental Panel on Climate Change created a set of such emissions scenarios (known as SRES) in a Special Report (IPCC, 2000). The different IPCC SRES emissions scenarios result in a range of atmospheric concentrations of carbon dioxide and other greenhouse gases, which are then used to project climate change for the 21st century.

A principal reason to explore the historical climate record is to try to get a better understanding of the character of potential future changes. However, given the complexity of the climate system and the pace of changes in climate variables and greenhouse gas emissions, it is not possible to rely completely on historical or analogue techniques. The IPCC and scientists world-wide therefore utilize global climate models (GCMs) with the SRES and other emission scenarios for future predictions; one set of climate models is housed at the Goddard Institute for Space Studies, a NASA research facility located at Columbia University.

General circulation or global climate models are mathematical representations of the behavior of the Earth's climate system through time (Box 3). Such models divide the ocean and atmosphere into multiple layers and the Earth's surface into thousands of grid boxes defined by latitude and longitude boundaries in order to calculate the response of climate variables to greenhouse gases and other forcings.

To predict future climate, scientists drive these climate models with projected levels of greenhouse gases. Out of the suite of IPCC SRES greenhouse gas scenarios, three were selected for analysis of potential impacts and adaptations options. The selected scenarios, B1, A1B, and A2, span a broad range of possible future greenhouse gas emissions (low to moderately high).

Box 3 Global Climate Models

Global Climate Models divide the earth into gridboxes for calculations. The range in size of these gridboxes is about 100 to 350 miles, and for each grid the atmosphere is vertically divided into many gridboxes. In discrete timesteps, climate models solve multiple equations for multiple variables (for example horizontal and vertical winds, moisture, temperature, and pressure). These equations are physically based, and statistical parameterizations are used for processes that occur at sub-grid spatial scales such as convection.

A climate model may be made up of hundreds of pages of computer code, with various subcomponents such as radiation, dynamics, clouds, land surface, vegetation, carbon cycle, and atmospheric chemistry.

Fourteen global climate models utilized in the latest IPCC report and the three emissions scenarios were used to produce regional climate scenarios. The combination of models and greenhouse gas scenarios produces a matrix of results that forecast future regional climate probabilistically. This scenario approach produces results that span a range of possible futures and risk scenarios and thus provides a comprehensive framework for the analysis of impacts on and adaptations for infrastructure.

Regional Climate Projections

Projected regional changes in annual temperature and precipitation for the Metropolitan Region are presented for the fourteen models and three emissions scenarios. This shows a range of possible outcomes, and allows some assessment of the probabilities associated with changes of varying magnitudes.

Model-based changes in extreme events were assessed by using threshold values: 90^{o}F (32.2^{o}C) for maximum daily temperature for two GCMs and 2 inches (51 mm) per day for precipitation for three GCMs.

Future Temperature and Heat Waves

As shown in Figure 10, the majority (almost 60%) of the simulations project temperature increases of between 2 and 3^{o}F (1.1 and 1.7^{o}C) by the 2020s, relative to the 1970-1999 base period. For the 2050s, the majority of the simulations project temperature increases of more than 4°F (2.2°C). As the century progresses, projected temperatures continue to rise for the region, but with a greater range due to uncertainty in the greenhouse gas emissions and the response of the climate system to greenhouse gas forcing. By the 2080s, the projected temperature range is 2 to 10°F (1.1 to 5.5°C), although the majority of projections are clustered between 4 and 7°F (2.2 and 3.8°C).

Analysis of a smaller daily data set, available from two GCMs for two future time periods, yields an ensemble-average increase in 90°F days of 2.7 per year for the 2050s and 8.2 per year for the 2080s (relative to the 1980-1999 period). These projections highlight the fact that even relatively modest increases in mean temperature can produce large changes in extreme weather.

Future Precipitation and Extreme Rainfall Events

There is a wide range in regional projections of annual precipitation relative to 1970-1999 (Figure 11). By the 2050s a clearer pattern emerges, with 70% of the models producing projected precipitation increases of between 5 and 15%. These increases in annual precipitation would increase the probability of intense rainfall events that affect MTA operations.

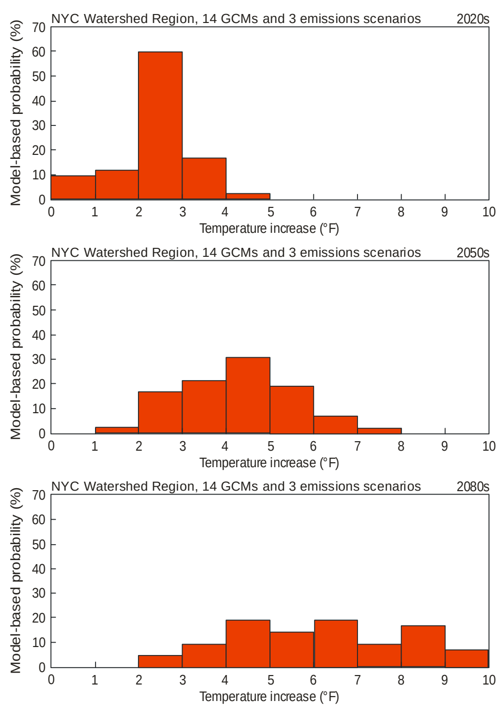


Figure 10: Estimated temperature changes (°F) in NYC watershed, relative to the 1970-1999 base period, for 14 models and three emissions scenarios. Frequency distribution shown.
Source: Columbia Center for Climate Systems Research

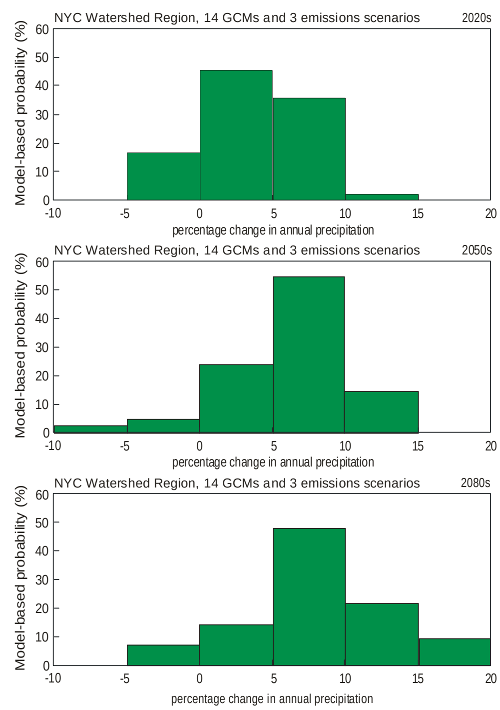


Figure 11: Estimated precipitation changes (%) in NYC watershed, relative to the 1970-1999 base period, for 14 models and three emissions scenarios. Frequency distribution shown.
Source: Columbia Center for Climate Systems Research

Extreme precipitation events have been evaluated using three GCMs. In the climate models, rain events of two inches or more per day occur approximately an additional 0.3

days per year in the 2050s and 0.43 days per year at the end of the century. In percentage terms, the latter corresponds to an almost 100% increase.

Future Sea Level Rise

Sea level rise projections are composed of several components, including local changes in land elevation, extrapolation of recent trends, and climate model projections. An additional component reflects the potential for major sea level rise due to melting of the ice sheets.

Sea level rise projections for New York Metropolitan Region have been made using the Goddard Institute for Space Studies GISS ModelE (New York, USA), Max Planck Institute MPI ECHAM5 (Hamburg, Germany), and UKMO HadCM3 (U.K. Meteorological Office, Devon, UK) climate models. The projections are for the IPCC SRES B1, A1B, and A2 greenhouse gas emissions scenarios for three time slices: the 2020s (average of 2010-2039), 2050s (2040-2069) and 2080s (2070-2099) relative to the current period, 2000-2009 (Rosenzweig et al., 2007). Projected sea levels for the Battery range from relatively small increases of 2 to 4 inches (51 to 102 mm) for all three scenarios and models in the 2020s up to 20 inches (0.5 m) in the A2 and A1B scenarios by the 2080s (Table 3). By comparison, sea level at the Battery has risen nearly 11 inches (280 mm) in the past 100 years. Thus, sea level trends are projected to nearly double over the 21st century.

Table 3. Sea level rise (in/cm), Battery Park, New York City relative to 2000-2009, by greenhouse gas emission scenario and GCMs.

Sea Level Rise	**Low (B1)**	**Medium (A1B)**	**High (A2)**
2020s	in(cm)	in(cm)	in(cm)
GISS	3 (7.6)	3.6 (9.2)	3.3 (8.5)
MPI	4.2 (10.8)	2.1 (5.5)	(3.6 (9.3)
HADLEY	4.3 (10.9)	2.3 (5.9)	3.9 (10.1)
2050s	in(cm)	in(cm)	in(cm)
GISS	8.5 (21.7)	9.9 (25.5)	10.3 (26.3)
MPI	9.2 (23.6)	10.5 (27)	9.5 (24.3)
HADLEY	6.8 (17.5)	7.3 (18.7)	9.3 (23.8)
2080s	in(cm)	in(cm)	in(cm)
GISS	14.1 (36.2)	16.8 (43.1)	19 (48.7)
MPI	16.1 (42.1)	20.4 (52.4)	20.5 (52.6)
HADLEY	11.2 (28.6)	12.8 (32.7)	17.4 (44.6)

Future Coastal Flooding and Storms

Historical flood events are used to project the impacts in the Metropolitan Region of sea level rise associated with global climate change. Once regional storms are identified, 21st century sea level rise projections are added to the historical tidal data set to assess possible future effects due to increases in mean sea level. For this study, average local sea level rise from several global climate models associated with the B1, A1B, and A2 SRES emissions scenario was calculated. Results shown do not include possible changes in storms themselves, or mean sea level increases exceeding those predicted by GCMs that could be brought about by accelerated glacial mass loss in Greenland and/or West Antarctica.

The frequency and duration of actual coastal flood events was assessed over a 46-year period (from 1960 through 2006) by examining hourly tidal data for the New York City (Battery) tide gauge (Rosenzweig et al., 2007). The linear trend of sea level rise was removed and an "anomaly" data set (showing deviations from the long-term average) was generated. The astronomical tide cycle was also removed in order to allow calculation of the storm surge levels. Current and projected sea levels were added to the surge heights of the five largest storm events during the 46-year period. Recurrence intervals were defined as follows: the once-in-five-year storm was defined as one with a flood level that was exceeded only 9 times in the 46-year period; the one-in-ten-year storm corresponds to one with a flood level exceeded only five times within this period. Table 4 shows that even without stronger storms or rapid ice sheet melting, mean sea level rise will significantly increase the frequency of coastal flooding events because the surge is superimposed on a higher mean ocean height. By the 2080s, results indicate that flooding that currently occurs once every ten years will occur on average at least once a year.

Table 4. Estimated future recurrence intervals for the current 1 in 5 year and 1 in 10 year coastal flood events with sea level rise, Battery Park, New York City.

Sea Level Rise	**Low (B1)**	**Medium (A1B)**	**High (A2)**
Recurrence Interval 1 in 5 years			
2020s	2x / 3 years	1x / 3 years	2x / 3 years
2050s	1x / year	1x / year	1.5x / year
2080s	~1x / 3 months	>1x / 3 months	1x / month
Recurrence Interval 1 in 10 years			
2020s	1x / 3 years	1x / 3 years	1x / 3 years
2050s	2x / 3 years	2x / 3 years	2x / 3 years
2080s	1x / year	1x / 6 months	~1x / 3 months

Role of Ice Sheets

The role of ice sheets near the two poles in global sea level rise is an active area of scientific research. During most of the 20th century, global sea level has been steadily creeping upward at a rate of ~0.07 inches per year (1.7 to 1.8 mm/yr), increasing to nearly 0.12 inches per year (3 mm/yr) within the last decade. Most of this rise in sea level comes from warming of the world's oceans and melting of mountain glaciers, which have receded dramatically in many places, especially within the last few decades of the 20th century. According to the latest Intergovernmental Panel on Climate Change report (IPCC, 2007), global sea level could rise 7 to 23 inches (0.18 m to 0.59 m) by 2100.

However, recent trends from Greenland and the West Antarctic ice sheet are potentially more worrisome. Either ice sheet, *if melted completely*, contains enough ice to raise global sea level by around 23 feet (7 m). Although both ice sheets may have been adding only some 0.014 inches per year (0.35 mm/yr) to sea level rise within the last few years (Shepherd and Wingham, 2007), satellites detect a thinning of parts of the Greenland Ice Sheet at lower elevations, and glaciers are disgorging ice into the ocean more rapidly.

The extent of polar warming projected by 2100 in the SRES A1B scenario may make much of the Greenland Ice Sheet unstable. Such polar warming is comparable to that of the last interglacial, ~125,000 years ago, when global sea level stood 13 to 20 feet (4 to 6 m) higher. Greenland may have contributed 6.5 to 13 feet (2 to 4 m) to those higher seas, with Antarctica contributing the balance. The timeframe over which such extensive melting occurred is on the order of millennia, rather than decades.

The West Antarctic Ice Sheet (WAIS) is also showing some recent signs of thinning (Shepherd and Wingham, 2007; Velicogna and Wahr, 2006). In regard to future projections, however, global climate models project increased snow and ice accumulation on Antarctica and hence a negative sea level contribution of 0.15 to 0.78 inches per decade (0.4 to 2.0 mm/yr) for SRES A1B at 2100 greenhouse gas levels. This could be offset by increased ice discharge, especially if buttressing by the major West Antarctic ice shelves were to be reduced. Ice shelves could weaken or collapse through thinning by surface or basal melting. Warming of 1°C under major ice shelves could wipe them out within centuries (IPCC, 2007). Oppenheimer and Alley (2005) suggest that a 2°C global warming could be enough to destabilize the West Antarctic Ice Sheet.

Current climate models do not include all relevant dynamic ice processes, so the rate and magnitude of their ice sheet projections are marked by high uncertainty. Therefore, analogies are often drawn from paleoclimate evidence. Hansen et al. (2007) point out that evidence exists for episodes of rapid ice break-up. Approximately 14,000 years ago, maximal rates of sea level rise have been separately estimated to have at least briefly reached 1.53 inches per year (38.9 mm/yr) (Fairbanks, 1989), and 2.1 inches per year (53.3 mm/yr) (Hanebuth et al., 2000; Kienast et al., 2003). Such high dynamical discharge rates are considered unlikely by the IPCC in part because there is currently much less land ice on the planet than there was 14,000 years ago.

In regard to the effects that melting ice sheets may have on local sea level rise in the New York City region, current rates of melting and associated global sea level rise need to be closely monitored for their potential effects on the region. Future sea level rise projections with and without the potential for accelerated ice sheet melt should be included in long-term (e.g., century scale) planning.

Analysis of Historical Record of Flood Events in New York Metropolitan Region

The team also conducted an analysis of historical extreme events, ranking storms by severity and looking at trends through time.

To analyze the frequency of climate events that could potentially lead to flooding in the New York Metropolitan Region and how they may be changing in the current climate, we look at three indicators: (1) daily-average tide gauge data from 1960-2006, (2) daily precipitation data from 1901 to 2006, and (3) intense hourly precipitation. The tide gauge data provide a measure of storm surge and coastal flooding, and the precipitation data provide a measure of flooding due to intense precipitation events.

Storm Surge and Coastal Flooding (1960-2006)
First we analyze the 1-in-5 year coastal storms from 1960-2006, defined as the nine highest surges of coastal waters during the period, and find that two of the nine storms have occurred in the last decade (1997-2006), and 4 of the 9 have occurred since 1990 (Table 5). This may be compared to two 1-in-5 year coastal storms in the 1970s, two in the 1980s and one in the 1960s.

Table 5. One-in-five year coastal storm surge as indicated by Battery Park tide-gauge data, 1960-2006.

Year	*Month*	*Day*	*Tide (in)*	*Tide (cm)*	*Rank*
2005	10	25	32.7	83.1	4
1998	2	5	28.6	72.7	9
1996	10	19	31.1	78.9	5
1992	12	11	45.7	116.1	1
1985	11	5	30.1	76.4	7
1984	3	29	40.9	104.0	3
1977	11	8	30.5	77.4	6
1972	2	19	28.9	73.4	8
1962	3	7	41.4	105.2	2

In regard to the five strongest (1-in-10 years) storms over this period, one such coastal storm occurred in the last decade (1997-2006), and three of the five have occurred since 1990 (Table 6). Only one such event occurred in the 1980s and one in the 1960s.

For both categories of coastal storms, the rates of occurrence over the past decade are in line with expectations based on chance alone, although the rates since 1990 exceed expectations based on chance alone by approximately 33 percent (for the 1-in-5 year storms) and by 80 percent (for the 1-in-10 year storms).

Table 6. One-in-ten year coastal storm surge as indicated by Battery Park tide-gauge data, 1960-2006.

Year	*Month*	*Day*	*Tide (in)*	*Tide (cm)*	*Rank*
2005	10	25	32.7	83.1	4
1996	10	19	31.1	78.9	5
1992	12	11	45.7	116.1	1
1984	3	29	40.9	104.0	3
1962	3	7	41.4	105.2	2

If we consider the next six strongest coastal storms in the region in terms of tide levels, five of those next six strongest storms have occurred since 1990 (Table 7). Thus these data also indicate a possible increase in coastal storms since 1990.

Table 7. Coastal storm surge ranked 10-15 as indicated by Battery Park tide-gauge data, 1960-2006.

Year	*Month*	*Day*	*Tide (in)*	*Tide (cm)*	*Rank*
1968	11	12	28.6	72.7	10
2005	10	13	28.1	71.4	11
1994	3	3	27.4	69.7	12
2006	9	2	27.4	69.6	13
1991	10	30	27.2	69.1	14
1996	1	8	27.0	68.7	15

Flooding Related to Intense Daily Precipitation (1901-2007)

Daily precipitation data from 1901-2007 (to August 20) in Central Park show that four of twenty-one 1-in-5 year events have occurred in the last decade (1997-2006), and six of the twenty-one have occurred since 1990 (Table 8).

The daily total of the August 8, 2007 event was a rainfall event that exceeded 2 inches per day, and was characterized by exceptionally high hourly rainfall rates exceeding 1.65 inches (42mm) per hour at Central Park. Its daily total of 2.5 inches (63.5 mm) place it as a 1-in-1 year storm. Intense downpours such as occurred on August 8th are generally expected to increase in frequency and intensity with climate change.

Table 8. One-in-five year daily rainfall totals in Central Park, 1901-2007.

Year	*Month*	*Day*	*Pcp (in)*	*Pcp(mm)*	*Rank*
2007	4	15	7.57	192.3	1
2005	10	12	4.26	108.2	15
2005	10	8	4.26	108.2	14
1999	9	16	5.02	127.5	6
1996	10	19	4.35	110.5	11
1990	8	10	4.64	117.9	10
1983	4	10	4.31	109.5	12
1977	11	8	7.40	188.0	2
1972	11	8	5.60	142.2	4
1972	10	7	4.09	103.9	19
1971	8	27	4.16	105.7	17
1968	5	29	3.99	101.3	21
1966	9	21	5.54	140.7	5
1942	8	9	4.10	104.1	18
1938	9	21	4.05	102.9	20
1934	9	8	4.86	123.4	8
1933	9	15	4.16	105.7	16
1913	10	1	4.98	126.5	7
1909	8	16	4.80	121.9	9
1903	10	9	7.33	186.2	3
1903	10	8	4.30	109.2	13

Two of the eleven 1-in-10 year daily rainfall totals have occurred in the last decade, and four of the eleven have occurred since 1990 (Table 9).

Table 9. One-in-ten year daily rainfall totals in Central Park, 1901-2007.

Year	*Month*	*Day*	*Pcp (in)*	*Pcp(mm)*	*Rank*
2007	4	15	7.57	192.3	1
1999	9	16	5.02	127.5	6
1996	10	19	4.35	110.5	11
1990	8	10	4.64	117.9	10
1977	11	8	7.40	188.0	2
1972	11	8	5.60	142.2	4
1966	9	21	5.54	140.7	5
1934	9	8	4.86	123.4	8
1913	10	1	4.98	126.5	7
1909	8	16	4.80	121.9	9
1903	10	9	7.33	186.2	3

The number of 1-in-5 year and 1-in-10 year daily rainfall events over the last decade are each approximately 100 percent higher than would be expected by chance alone. However, the trends in the extreme events are not statistically significant. Nevertheless, the recent patterns of enhanced daily rainfall totals are consistent with what is expected to occur with climate change. Also consistent is the finding that the period since January 1, 2004, despite comprising only about 3.5 percent of the daily data record from Central Park, contains 8.2 percent of the total number of days with at least 2 inches of rain.

Intense Hourly Precipitation in the New York Metropolitan Region

Using three datasets of varying length, we here evaluate intense precipitation at the hourly timescale in the New York Metropolitan Region.

La Guardia Airport (1973-2007)

First we analyze the 1-in-5 year hourly precipitation totals from 1973-2007, defined as the seven highest hourly rainfall rates during the period, all of which were 1.59 inches or higher (Table 10). This is comparable to the estimate from the New York City Intensity-Duration-Frequency (IDF) curve provided by the MTA, of 1.75 inches per hour. There have been two such events at La Guardia in the past decade, which is the most likely number of occurrences per decade based on chance alone.

The 1-in-10 year hourly total can be defined as the three highest precipitation totals at La Guardia, or events of 1.97 inches per hour or higher. The IDF curve value for the 1-in-10 year event is comparable at approximately 2.2 inches per hour. There has been one such event in the past decade, which is the most likely number of occurrences per decade based on chance alone.

While the number of occurrences of 1-in-5 year and 1-in-10 year storms are in line with expectations, it is noteworthy than 11 of the top 15 hourly rainfall sums at La Guardia have occurred since 1990. The maximum hourly total of the August 8, 2007 event was 1.87 inches, placing the event very close to a 1-in-10 year event.

Table 10. Top 15 hourly rainfall totals at LaGuardia Airport, 1973-2007.

Year	*Month*	*Day*	*Hour*	*Prcp (in)*	*Prcp (mm)*	*Rank*
2007	8	8	7	1.87 (1-in-5)	47.5	4
2006	8	10	23	1.41	35.8	9
2006	6	2	20	1.34	34.0	12
2004	9	8	11	1.39	35.3	10
2004	8	11	19	1.43	36.3	8
2003	7	22	18	1.31	33.3	15
1998	8	17	18	2.09 (1-in-10)	53.1	2
1997	7	16	0	2.44 (1-in-10)	62.0	1
1995	7	18	4	1.97 (1-in-10)	50.0	3
1993	8	12	15	1.37	34.8	11
1990	8	10	8	1.33	33.8	13
1989	8	12	8	1.31	33.3	14
1987	6	21	7	1.59 (1-in-5)	40.4	7
1980	7	29	15	1.78 (1-in-5)	45.2	6
1975	7	6	22	1.83 (1-in-5)	46.5	5

Central Park (1996-2007)

Hourly precipitation data from 1996-2007 (to August 20) at Central Park show that one 1-in-5 year event has occurred over the length of the record, and no 1-in-10 year events, as defined by the New York City IDF curve (Table 11). Due to the shortness of the hourly data record, a statement about trends is not possible, but it is noteworthy than 13 of the top 15 hourly rainfall sums have occurred since September 2004, a period that covers only 30 percent of the record.

The maximum hourly total of the August 8, 2007 event in Central Park was 1.7 inches, tied for second in the 11-year record, and placing the event very near to a 1-in-5 year event.

Table 11. Top 15 hourly rainfall totals in Central Park, 1996-2007.

Year	*Month*	*Day*	*Hour*	*Prcp (in)*	*Prcp (mm)*	*Rank*
2007	8	8	10	1.70	43.18	3
2007	8	4	3	1.11	28.19	9
2007	7	18	11	0.90	22.86	15
2007	4	16	3	1.03	26.16	11
2007	4	15	19	1.11	28.19	8
2006	8	11	0	0.90	22.86	14
2006	8	10	23	1.57	39.88	4
2006	6	2	19	1.12	28.45	7
2005	8	14	23	1.70	43.18	2
2005	7	6	6	1.26	32.00	5
2004	9	18	13	0.95	24.13	13
2004	9	18	12	1.15	29.21	6
2004	9	8	11	1.76 (1-in-5)	44.70	1
1998	10	1	7	0.97	24.64	12
1996	10	19	21	1.07	27.18	10

Nassau County (1941-2007)

This dataset is limited to days with 3 or more inches of rainfall. Of the five events in this record that exceed the 1-in-5 year event as defined by the NYC IDF curve, four have occurred since 1990. Of the three events that exceed the 1-in-10 year event, two have occurred since 1990. It should also be noted that five of the top 15 precipitation events in Minneola's 66-year record of days with 3 in or more of rainfall have occurred since 1996.

Examination of this record reveals lower hourly precipitation amounts than were described above for the New York City weather station records and NYC IDF curve. The primary explanation is probably that some intense downpours were not included since the Long Island dataset only includes events that produced at least 3 inches of rain over a 24-hour period, It is also possible that slight differences in the rainfall distribution to the east of New York City are partially responsible for the numerical discrepancy.

Historical Analysis Conclusions

Based on analyses of tide gauge data from 1960-2006, daily precipitation data from 1901-2007, and hourly data for a range of record lengths, there are some indications that intense climate events that lead to flooding events have been increasing in the region since 1990. These indications are in line with what is projected to occur with global climate change due to increasing anthropogenic greenhouse gas emissions. However, these emerging trends need to be monitored for longer periods before natural variability can be ruled out. Sea level rise and an intensified hydrological cycle due to climate change are expected to lead to more frequent and intense flooding events in the coming decades. The combined effect of more frequent damaging high-water levels and more intense precipitation events is very likely to enhance the flooding threat faced by the MTA.

Finally, combining the results of the three separate hourly analyses above, we find that 1-in-5 year and 1-in-10 year events over the past decade have slightly exceeded their expected values. These recent increases in extreme hourly precipitation events cannot be attributed to climate change. However, these findings, combined with the tendency for the top 15 hourly precipitation events to cluster in latter portions of the data records, are consistent with what might be expected in the future given an intensified hydrological cycle associated with global warming. Intense downpours such as occurred on August 8th, 2007 are generally expected to increase in frequency and intensity with climate change.

Hourly Analysis Addendum

For the Nassau Country weather station data, we also calculated the 1-in-5 year and 1-in-10 year events based on how often extreme events occurred in this data record of high-rainfall days. The data from three of the stations (Wantagh, Planting Fields and Plandome) were too short to allow estimation of the 1-in-5 year and 1-in-10 year storms, so analysis was limited to the lengthy record from the remaining station, Mineola (1941-2007).

Using this technique, the 1-in-5 year hourly total for the 24-hour events exceeding 3 inches can be defined as the 13 highest precipitation totals, or events of .98 inches per hour or higher. There have been four such events in the past decade, whereas two would be the most likely number of occurrences per decade based on chance alone.

The 1-in-10 year hourly total for the 24-hour events exceeding 3 inches can be defined as the seven highest precipitation totals, or events of 1.36 inches per hour or higher. There have been two such events in the past decade, whereas one would be the most likely number of occurrences per decade based on chance alone.

Case Studies of Infrastructure at Risk due to Climate Change

The possible impacts of climate change on the MTA's infrastructure could be very substantial. Three representative case studies were selected to assess threats posed by inland and coastal flooding on different types of facilities. Deleterious impacts of future coastal flooding will be caused by the additive effects of storm surge, sea level rise, and heavy precipitation.

Selected Sites

- **Hillside Avenue**, Queens
  Between approximately 143rd and 160th Streets along the F subway line, including the Sutphin and Parsons Boulevard subway stations and NYCT Pumpstation at 153rd Street.

- **Corona/Shea Yard,** Queens
  Two adjacent yards, also known as "Corona Shops", near Shea Stadium. The Corona Yard is operated by NYCT with track access from the 7 subway line. Shea Yard is operated by LIRR with access from the LIRR Port Washington Line.

- **Mott Yard (Junction),** South Bronx
  Sometimes referred to as Mott Haven Yard where the Metro North Hudson and Harlem/New Haven Lines branch in a Y-shaped configuration.

Stations and Flooding Environments
The three sites typify three different environments with respect to flooding.

<u>Hillside Avenue</u> in Queens (Figure 12) is representative of a locality that experiences frequent inland *rainfall flooding*. The locality and its surroundings are landlocked with relatively steep surface topography; local maximum slopes are up to 30%, and average slopes a few percent, yielding elevation ranging from between 54 and 145 feet above mean sea level.

Figure 12: Hillside Avenue, Queens, with F-subway (orange-brown line) and elevations (ft) for selected points. The NYCT Pump Station is below the red pin, where Hillside Ave. and the F line tracks (which are 30 ft below grade) are the lowest. Run-off from the terminal moraine hills to the north contributes to the flooding. See text for details.
Source: Lamont-Doherty Earth Observatory, Google Earth, and NYSEMO (for NYCT subway lines)

The densely settled slopes have mixed (residential/commercial) land use. The area has a large proportion of impermeable parking lots and street pavements with high runoff, but also a limited drainage capacity via the marginally-dimensioned storm sewer lines operated by the NYC DEP. Resulting *urban street flooding* leads to water inundating the subway system through ventilation grates along Hillside Avenue. During intense precipitation events, this subway flooding can overburden a NYCT Pump Station servicing the F-line tracks at the locally lowest point at Hillside Avenue and 153rd Street. There the tracks are about 30 feet below street grade. The location of the minimum elevation of this segment of Hillside Avenue coincides with the local low elevation in the F-line tracks where, necessarily, the NYCT pump station is placed. It is reported that flooding has increased since the late 1980s, when the Department of Transportation repaved and changed the crown elevations of Hillside Avenue. The track sloping to the sump room, projected to the surface on Hillside Avenue, is from 139th to 178th Streets. The critical section is reported to be from 144th to 160th Streets.

The projected increase in the number of days per year with heavy precipitation (i.e. more days with more than 2 inches of rain per day) suggests that flooding conditions at Hillside Avenue are likely to worsen with time unless mitigated. Generic options for risk reduction are discussed in a later section.

<u>Corona/Shea Yards</u>**,** near Shea Stadium, is located in low-lying Flushing Meadows, Queens (Figure 13). The purpose of the Shea Yard is to hold trains during off hours, so that they are stationed appropriately for the high-usage rush hours of the LIRR. The Corona Yard has track access to the 7 subway line. Shea Yard has access from the LIRR Port Washington line. Corona Yard has served for decades as a shop and storage area primarily of subway rolling stock.

Figure 13: Location of the Corona/Shea Yards, Queens, in close proximity to Flushing Creek, and Flushing Bay. The tidal East River is to the north. Colored areas are worst-track storm surge flood zones for Saffir -Simpson (SS) Category-1 in red, SS2 in brown, SS3 in yellow, and SS4 in green. Colored lines are subways, black lines are rail systems. See text for details
Source: Lamont-Doherty Earth Observatory, Google Earth, and NYSEMO (for colored flood zones and NYCT subway lines)

The Shea Yard is located on the Port Washington branch of the LIRR. The Port Washington Branch is made up of 11 commuter stations in addition to Shea Station. The 2006 AM Peak West-bound ridership for the Port Washington branch was over 15,000 customers per day, each way. The 2006 AM Peak reverse commuter ridership was 6,000 per day, each way. Shea Yard can store up to 46 train cars on the existing three yard tracks (Tracks 3, 4 and 5). Pit services exist on the three yard tracks and provide resources for on-site train maintenance and repairs.

The low-lying yard is susceptible to flooding in heavy rain or more severe storms, and can disrupt or cut off service to the entire Port Washington Branch.

There is a large tract of land north of the current yard, bounded by the watercourse and reaching toward Shea Stadium that has been under consideration for development by

LIRR and other transportation agencies in the future. Thus, the area subject to flooding could be greatly expanded in the future if this development is accomplished.

Corona/Shea Yard is representative of locations where estuarine *storm surge flooding* is a recognized hazard. Some limited urban rainfall flooding from poor drainage during heavy precipitation events may also affect the site. The site is located in close proximity to the *Flushing Creek/River* that enters Flushing Bay; in turn the Bay is connected to the East River. The latter is part of the tidally-controlled NYC estuary and connects the Long Island Sound with the NY Inner Harbor and Hudson River. Flushing Meadow is a former tidal marshland largely filled by New York City a century ago as a depository for ash and cinder waste generated by coal burning.

Urban street-flooding is enhanced because of extensive impermeable paving of parking lots and streets. The lots serve Shea Stadium and the USTA National Tennis Center, which bracket the Corona/Shea Yards on their North and South sides, respectively.

Mott Yard (or Mott Junction) is located in the South Bronx (Figure 14). It is at the center of a busy Y-shaped branching of the *Metro North's* Hudson and Harlem/New Haven lines, the latter with various sub-branches into Connecticut. All lines originate from Grand Central Station in Manhattan, and cross the Harlem River to the SW of the Mott Yard Junction. (Note that the Mott Yard is sometimes also referred to as 'Mott Haven Yard', despite the fact that another rail yard with the same name formerly existed on the Bronx Kill facing, and across from, the Triborough Bridge. The Mott Yard should not be confused with the latter).

The Hudson line takes the northwesterly branch of the Y and returns, after a short distance, to the east bank of the Harlem River, near Yankee Stadium. The tracks of the Harlem/New Haven lines take the northeasterly branch of the Mott Yard Junction. These tracks run NNE through a shallow valley with potential lateral run-off from slopes towards Park Avenue east of the tracks and from the Grand Concourse and parallel streets (157^{th} W) to the west of the tracks. The valley occupied by the tracks is also subject to natural drainage and potential ponding along the longitudinal axes of the valley. The valley's southern extension used by the combined lines below and south of the Mott Yard branching point opens to the south where under extremely severe hurricane conditions (Saffir-Simpson Category 2 to 3, and higher) the valley floor could be marginally subjected to estuary *storm-surge floods*.

Such surges could enter from the tidal Harlem River. However, the tracks become increasingly elevated, relative to the southwest sloping ground, as the tracks cross the Major Deegan Expressway (I-87) and the Harlem River. Track elevations at the Mott Yard measure between about 14 and 19 feet (4.3 and 5.8 m) above current mean sea level. The center of the Y and its valley floor have benefited from an improved drainage along the Harlem line, but drainage of the Mott Yard is seemingly still insufficient. The problem may in part stem from a system of east-to-west running and sloping streets that bring runoff towards Park Avenue. The catch basins along Park Avenue and the storm sewers and siphons should be checked for their capacity to drain the excess runoff from these easterly striking cross streets (E 149th to E 154th Street, and perhaps beyond).

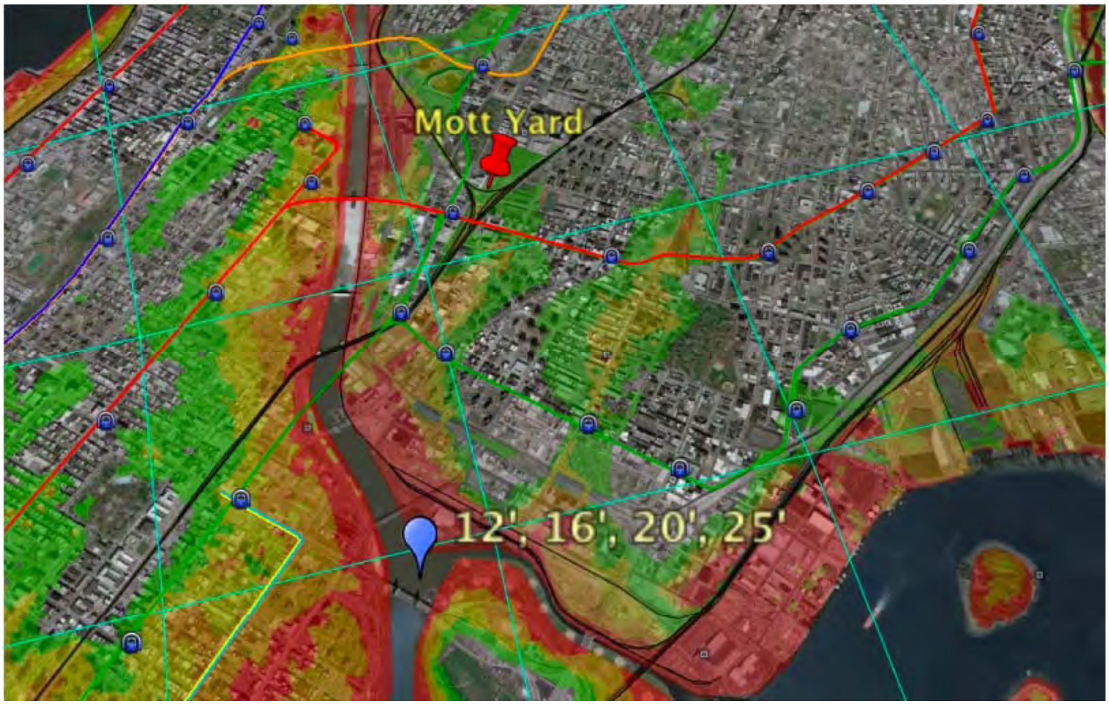


Figure 14: Location of the Mott Yard, Bronx, at the Y-shaped branching of the Metro North Lines. The Hudson Line takes the NW branch, and the Harlem/New Haven Lines take the NE branch of the 'Y' pattern of tracks (in gray). Note their combined SW crossing of the Harlem River into Manhattan to continue into Grand Central Station. Also shown is the relation to storm surge flood zones for worst-case tracks of hurricanes with different Saffir-Simpson (SS) categories. SS1 flood zone in red, SS2 in brown, SS3 in yellow, and SS4 in green. The blue grid defines the cells for the SLOSH computations for which the storm surge heights were calculated by the US Army Corps of Engineers / National Weather Service. At the location of the blue symbol, the approximate SLOSH worst-track storm surge heights are indicated; for SS1 about 12 feet; SS2 about 16 ft; for SS3 about 20 ft; for SS4 about 25 ft. Note that the likelihood of an intense worst-track hurricane is very low. See text for details.

Source: Lamont-Doherty Earth Observatory, Google Earth, and NYSEMO (for colored flood zones and NYCT subway lines)

Increased Hazards from Climate Change

Hillside Avenue. Engineering studies have been performed to assess and mitigate the flooding of the subway below Hillside Ave. These studies do not take into account that rainfall events may become more frequent and more intense. Hence these fixes may be only marginally effective.

Corona/Shea Yards. Climate change will affect these two yards in multiple ways. Precipitation events will become more extreme and more frequent. Engineering efforts that only take the past flooding events after heavy rainfalls as guidance will not be sufficient to mitigate future flooding hazards. The precipitation projections discussed in other sections of this report, or similar data should be consulted for setting design targets for effective drainage systems.

Similarly, the earlier sections of this report refer to the increased storm surge flooding to which the Corona/Shea Yards will be subjected. This increase can be a combination of sea level rise and increased storm frequency/intensity.

Mott Yard. The future climate vulnerabilities that exist for the Corona/Shea Yards apply equally to the Mott Yard, particularly with respect to flooding from heavy precipitation events. Sea level rise will affect the storm surge hazards for this site later in this century.

Risk Reduction Options

There are common features to the options for risk reduction and strategies that apply to all three sites, notwithstanding that each site requires its own engineering response. The site-specific issues are addressed first.

Hillside Avenue. The options for risk reduction planned or undertaken for reducing the flood hazards that can overwhelm the capacity of the NYCT Pump Station below Hillside Avenue should be considered as temporary, local measures. They will serve to remediate the flood situation by locally re-engineering the surface configurations of Hillside Avenue in the vicinity of the subway ventilation grates. Other options can be considered for more fundamental, longer-lasting solutions. They may include:

- Finding solutions that may make it unnecessary to have ventilation grates in the flood prone, low-lying sections of Hillside Ave.

- Redesigning (in cooperation with NYC DEP) the drainage system of the streets and properties to the north and for shorter distances to the east and west of the Pump Station on Hillside Avenue. This option may include (with cooperation from NYC DOT and private owners of parking lots) placing permeable pavements on streets and parking lots to encourage infiltration of precipitation into the ground, thereby reducing the amount and intensity of runoff, and distributing it over a longer period of time. This would reduce the demand on the NYCT pump station.

Corona/Shea Yards. The flooding of these two yards from excessive rainfall could be reduced by increasing infiltration of rain water through the parking lot and yard surfaces by switching to permeable pavements. Increasing the capacity of engineered drainage systems will be an obvious option. This requires in part inter-agency cooperation with owners of adjacent private and public lands.

More difficult will be reduction of storm surge flood risks. Multiple options from the most local to more regional may be contemplated and assessed for their costs and benefits. The more regional, the more costly, the longer the time-span for planning and construction, and the more administratively demanding in terms of cooperation with non-MTA institutions. Environmental issues will also increase with the scope and magnitude of adaptations. Options for the decades to come include:

- Raising tracks and facilities to target elevations to be determined.

- Surrounding the Shea Yard and the Corona Yard individually with a dam/levee and pumping system with a protective elevation to be determined, again preferably based on cost/benefit analysis.

- Having a dam/levee/system that jointly protects the Corona and Shea Yards.

- Contemplating more regional/longterm options to protect the entire storm-surge-prone Flushing Creek valley and portions of the Flushing Bay waterfront. This will require a multi-agency and community consensus with broad public and some private financing likely. The time horizon for such a solution would be more on a century than a decadal scale. It would greatly benefit from the more reliable estimates of sea level rise and storm surge frequencies that will become available over time.

Mott Yard. To date, most risk reduction efforts at this site, which has great importance for the reliability of Metro North services, seem to have focused on dealing with the engineering aspects of existing and some modified drainage and sewer systems, most of it on MTA property, but some under the control of NYC DEP and perhaps other owners/agencies. Pertinent unearthed engineering drawings go back to the 1880s!

It seems prudent to add a more regional perspective by asking how the flow from streets and properties to the east and west of the various Metro North right-of-ways can be directed away from the tracks and the drainage systems serving them. Again, permeability of streets, catch basin and sewer capacity, perhaps even reshaping the incline of street surfaces of N-S avenues near the intersections with E-W streets, to distances of several hundred yards from the Metro North tracks should be considered. All this requires input from multiple agencies such as NYC DEP and NYC DOT.

Conclusions and Recommendations

Current and future climate

- Both *rainfall* concentrated in short periods (less than 3 hours) and during rush hour seem particularly disruptive to MTA operations. The August 8th rain event met both criteria. From the small subset of hourly data analyzed, rainfall rates below 0.4 inches (10 mm) per hour pose minimal threats to MTA operations at current sea levels and provided the rainfall is not accompanied by storm surge.

- There is an increased risk that the region will experience severe *inland rainfall flooding* in the coming decades.

- Even without stronger storms or rapid ice sheet melting, mean sea level rise will significantly increase the frequency of *coastal flooding* events because the surge is superimposed on a higher mean ocean height. By the 2080s, flooding that currently occurs once every ten years will occur on average at least once a year according to a range of climate change scenarios.

MTA Facilities and Infrastructure

The three case studies do not deal with engineering details and, based on the available information and short time frame for preparing them, can only provide some basic conclusions and recommendations. The essence is, however, that so far the various MTA units have tried to solve the flooding problems in a largely agency-self-reliant way, asking for minimal input and help from other agencies. This means that the MTA units often have to find engineering solutions for flood causes that, in many instances originate within their own operational and administrative "territory"; but in many instance the solutions to the flood problems may lie in solving the flood causes at the 'sources,' not the 'sinks.' This will require cooperation with outside agencies and owners, or entire communities.

Another overarching pattern emerges: risk reduction has focused on increasing drainage capacity and reliability (the demand side). It is important that future efforts will look at the changing supply side (of water in whatever form). In addition to climate change, the supply of excess water to MTA sites sensitive for the agency's reliable system operations can be shaped by man-made changes in topography, land use and related changes in surface permeability and ability for the ground to absorb precipitation, thus lowering the peak run-off and spreading the total run-off to be handled by storm sewers and drainage systems over longer periods of time.

Green (vegetated) roofs on buildings, planting of trees on streets, etc. can have a positive effect. There is no single-bullet solution to the flooding problem. It will require an overall strategy with multiple facets. A staggered approach should be considered: simple and quick solutions may cost less, but may not be effective for the increasing future long-term conditions determined by how climate changes.

A more systemic approach is recommended:

1. A systematic assessment of the flood hazards is needed, both for current and future climate conditions and time horizons.

2. The facilities and assets at risk and their vulnerability (fragility) to these hazards need to be inventoried and quantified.

3. Risk assessments of the facilities and assets, given their vulnerability and given the hazards need to be performed, again for different time horizons.

4. Multiple options for reducing the risks (whether by modifying the hazards or the assets/fragility side of the risk) need to be explored and their cost at least estimated if not quantified.

5. The reduction of future losses from these efforts needs to be quantified.

6. The cost and benefits, not only in monetary terms, but also from an environmental and community sustainability aspect need to be used for input in the decision process.

7. Many of these procedures will require a change in the institutional culture to include a range of professions involved in the planning and decision process.
   The three cases used in this brief survey give a good indication that the flooding problems that the various branches of the MTA face in their efforts to maintain reliable and safe operations need a broad systemic approach. They cannot be solved by narrow engineering solutions based solely on past experience.

Finally, in addition to the above recommendations, MTA should also take steps to lessen its contribution to the rate and magnitude of future climate change through mitigation of greenhouse gases. A comprehensive greenhouse gas inventory should be undertaken, and the MTA should devise ways to meet greenhouse gas emissions reduction goals in cooperation with other regional initiatives.

References

Barron, J., 2007. A sudden storm brings a metropolis to its knees. *New York Times, The Metro Section*, Aug. 9, 2007.

Coch, N.K., 1994. Hurricane hazards along the northeastern Atlantic Coast of the United States, in: *Coastal Hazards: Perception, Susceptibility, and Mitigation*, C.W. Finkl, ed., J. Coastal Research Special Issue No. 12, p. 115-147.

Donnelly, J.P., Cleary, P., Newby, P., and Ettinger, R., 2004. Coupling instrumental and geological records of sea-level change: Evidence from southern New England of an increase in the rate of sea-level rise in the late 19th century. *Geophys. Res. Lett.*, 31, L05203, doi:10.1029/2003GL018933.

Emanuel, K., 2005. Increasing destructiveness of tropical cyclones over the past 30 years. *Nature*, 436, 686-688.

Fairbanks, R.G., 1989. 17,000-year glacio-eustatic sea level record: influence of glacial melting rates on the Younger Dryas event and deep-ocean circulation. *Nature*, 342, 637-642.

Frich, P., Alexander, L.V., Della-Marta, P., Gleason, B., Haylock, M., Klein-Tank, A., & Peterson, T., 2001. Observed coherent changes in climatic extremes during the second half of the 20th century. *Climate Resources*.

Gehrels, R.W., Kirby, J.R., Prokoph, A., Newnham, R.M., Achertberg, E.P., Evans, H., Black, S., and Scott, D.B., 2005. Onset of recent rapid sea-level rise in the western Atlantic Ocean. *Quat. Sci. Rev*., 24, 2083-2100.

Goddard Institute for Space Studies, 2006. Global Temperature Trends: 2005 Summation.

Gornitz, V., 2001. Sea-level rise and coasts. In: Rosenzweig, C. and W.D. Solecki, eds., *Climate Change and a Global City: the Potential Consequences of Climate Variability and Change–Metro East Coast*. Report for the U.S. Global Change Research Program, National Assessment of Potential Consequences of Climate Variability and Change for the United States, Columbia Earth Institute, New York, Chap. 3, p. 19-46.

Gornitz, V., Couch, S., and Hartig, E.K., 2002. Impacts of sea level rise in the New York City metropolitan area. *Glob. & Planet. Changes*, 32, 61-88.

Gornitz, V., Horton, R., Siebert, A., and Rosenzweig, C., 2006. Vulnerability of New York City to storms and sea level rise. *Geol. Soc. Am. Abstracts with Programs*, vol. 38, No. 7, p. 335.

Gregory, J.M., Hubrechts, P., and Raper, S.C.B., 2004. Threatened loss of the Greenland ice-sheet. *Nature*, 428, 616.

IPCC, 2000. *Emissions Scenarios 2000: Special Report of the Intergovernmental Panel on Climate Change.* Cambridge, UK: Cambridge University Press

IPCC, 2007. *Climate Change 2007: The Physical Science Basis*. *Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Chaps. 5, 6, 10*. http://www.ipcc.ch.

Hanebuth, T., Stattegger, K., and Grootes, P. M., 2000. Rapid flooding of the Sunda Shelf: A late-glacial sea-level record. *Science*, 288, 1033-1035.

Hansen, J. and others, 2007. Dangerous human-made interference with climate: a GISS modelE study. *Atmos. Chem. Phys*., 7, 2287-2312.

Holgate, S.J. and Woodworth, P.L., 2004. Evidence for enhanced coastal sea level rise during the 1990s. *Geophysical Research Letters*, 31, L07305, doi: 10.1029/2004GL019626.

Huybrechts, P., Letréguilly, and Reeh, N., 1991. The Greenland ice sheet and greenhouse warming. *Paleogeogr., Paleoclim., Paleoecol*., 89, 399-412.

Jacob, K. H., 2001. Infrastructure. In: Rosenzweig, C. and W.D., eds., *Climate Change and a Global City: the Potential Consequences of Climate Variability and Change–Metro East Coast*. Report for the U.S. Global Change Research Program, National Assessment of Potential Consequences of Climate Variability and Change for the United States, Columbia Earth Institute, New York, Chap. 4, p. 47-65.

Jouzel, J., 2007. Orbital and millennial Antarctic climate variability over the past 800,000 years. *Science*, 317, 793-796.

Karl, T. R., and Knight, R. W., 1998. Secular Trends of Precipitation Amount, Frequency and Intensity in the USA. *Bulletin of the American Meteorological Society*, 79, 231-241.

Katz, R.W., 1999. Extreme value theory for precipitation: Sensitivity analysis for climate change. *Advances in Water Resources*, 23, 133-139

Kienast, M., Hanebuth, T.J.J., Pelejero, C., and Steinke, S., 2003. Synchroneity of meltwater pulse 1a and the Bølling warming: evidence from the South China Sea. *Geology*, 31,67-70.

Oppenheimer, M. and Alley, R.B., 2005. Ice sheets, global warming, and Article 2 of the UNFCCC. *Clim. Change*, 68, 257-267.

Meehl, G.A., Karl, T., Easterling, D.R., Changon, S., Pielke, Jr., R., Changon, D., Evans, J., Ya Groisman, P., Knutson, T.R., Knukel, K.E., Mearns, L.O., Parmesan, C., Pulwarty, R., Root, T., Sylves, R.T., Whetton, P., & Zweirs, F., 2000. An introduction to trends in extreme weather and climate events: Observations, socioeconomic impacts, terrestrial ecological impacts, and model projections. *Bulletin of the American Meterological Society*, 81, 413-416

Nyberg, J., Malmgren, B.A., Winter, A., Jury, M.R., Kilbourne, K.H., and Quinn, T.M., 2007. Low Atlantic hurricane activity in the 1970s and 1980s compared to the past 270 years. *Nature*, 447, 698-702.

Rignot, E. and Kanagaratnam, P., 2006. Changes in the velocity structure of the Greenland ice sheet. *Science*, 311, 986-990.

Rosenzweig, C. and W.D. Solecki, eds., 2001. *Climate Change and a Global City: the Potential Consequences of Climate Variability and Change–Metro East Coast*. Report for the U.S. Global Change Research Program, National Assessment of Potential Consequences of Climate Variability and Change for the United States, Columbia Earth Institute, New York. 224 pp.

Rosenzweig, C. Horton, R., Gornitz, V., and Major, D.C., 2007. *Climate Scenarios for the New York City Watershed Region*, NYC DEP Technical Report, Columbia University Earth Institute, Center for Climate Systems Research.

Siegenthaler, U. et al., 2005. Stable carbon cycle-climate relationship during the late Pleistocene. *Science*, 310, 1313-1317.

Shepherd, A. and Wingham, D., 2007. Recent sea-level contributions of the Antarctic and Greenland ice sheets. *Science*, 315, 1529-1532.

Spahni, R. et al., 2005. Atmospheric methane and nitrous oxide of the late Pleistocene from Antarctic ice cores. *Science,* 310, 1317-1321.

U.S. Army Corps of Engineers/FEMA/National Weather Service, NY/NJ/CT State Emergency Management, 1995. *Metro New York Hurricane Transportation Study*. Interim Technical Data Report.

Velicogna, I. and Wahr, J., 2006. Measurements of time-variable gravity show mas loss in Antarctica. *Science*, 311, 1754-1756.

Weart, S.W., 2003. *The Discovery of Global Warming.* Cambridge, MA.: Harvard University Press.

Webster, P.J., Holland, G.J., Curry, J.A., and Chang, H.-R., 2005. Changes in tropical cyclone number, duration, and intensity in a warming environment. *Science*, 309, 1844-1846.

APPENDIX 3

“Discussion of Storm Impacts, Summary of Findings” prepared by Region II, University Transportation Research Center

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REGION II
UNIVERSITY TRANSPORTATION RESEARCH CENTER

Discussion of Storm Impacts
Summary of findings.

September 19, 2007

<u>Objective:</u> To consider MTA operations during the unanticipated storm of August 8, 2007 and whether they were within the bounds of Good Practice.

<u>Study:</u> A survey was conducted among a number of US peer properties. Additional information was obtained from London Underground (TfL) and from Tokyo RR. The survey asked whether systems are designed to prevent or minimize flood impact, whether they followed design standards, how often floods occurred and whether they had Standard Operating Procedures to address flood conditions.

<u>Findings:</u> The findings are presented in detail in the appended reports. Report 1 is "Summary of findings". Report 2 is Transit Property Survey.

The basic findings are:

- All surveyed properties have experienced some level of floods that have been significant enough to shut service.
- For example, London Underground experienced flooding due to the torrential – and unpredicted – heavy summer storms during July 2007. **From BBC**, *July 20, 2007) Parts of south London were hard-hit on 20 July. Most of the London Underground suffered severe delays, many roads were forced to close and the overground rail network struggled to cope with the evening rush hour.* **From a Blog** *Yesterday I observed an interesting public transport failure mode*. Floods *had closed many tube stations, so people took to the buses. The buses filled up. People making journeys that would otherwise have been unaffected by the tube station closures were left stranded as the full buses drove past their stops.* This London experience is quite similar to NYs.

- Pumps, drainage and other techniques were utilized for most of the rail systems to mitigate flooding. Toronto is currently making investments to separate its storm and sanitary sewers to provide more capacity to prevent flooding. In Tokyo, underground tunnels susceptible to flooding have triple pumps, so two can still be used even if one breaks down.

- Most of the rail systems flood very rarely. Toronto reported that service disruptions due to flooding occur perhaps once/year, and Atlanta says this has happened three times in the past decade. In most cases, these are not the direct result of heavy rainfall, but due to other causes, such as water main breaks or normal leakage following a pump failure.

- Responses indicated that varying design standards for addressing water in the rail system are in use. To combat flooding, all systems have pumping standards – but there are no general national Public Transit Protocols or Standards to address floods. Standards are adopted locally based on local experience and most likely conditions.

- o In some systems, the pumps are designed to provide the pressures needed for fire fighting purposes. Both Toronto and San Francisco's BART system provide two pumps each with 500 gallons per minute capacity, which appears to be based on a fire hose related standard.
- o WMATA's pumps are scaled to handle a 50-year storms, although the combined sewer system is only designed to accommodate at 15-year storm.
- o SF's new Central Subway is being designed to handle a 100-year rainfall (1.5 inches/hr), plus normal water infiltration, plus water needed for firefighting.

- ß Majority of the rail systems did not identify additional measures to address water or flood conditions. WMATA stores portable pumps and generators in problem areas.

- ß Several of the rail systems have written operating protocols for flooding events. San Francisco has sent its documents to us.

- ß In all systems, large scale service interruption is rare (but does occur).

- ß Standards among properties range from meeting a 50 or 100 year flood to providing the ability to move a certain number of gallons/minute. Most properties reinforce pumping capacity at those stations or points most susceptible to flooding. In the properties surveyed, pumps are the main line of defense against flooding, although some stations in Tokyo and London can be closed by gates against water (effectively shutting down that link in the system.)

- ß London and Tokyo have begun studying and making preparations for global warming and its consequences including rising sea levels. These preparations are coordinated nationwide, transit being only one area of concern.

MTA response

Based upon this brief survey of major transit properties, I can conclude that

- ß MTA operating units (NYCT, LIRR, MNR) response to the storm was consistent with that of their peer properties. It should be noted that NYCT, like Boston and Philadelphia and London is an old property. NYCT also operates within the 5 Boroughs, and must address street flooding, runoff and sewer capacity in concert with the City's ability to remove flood waters.
- ß MTA's technical response to the flood itself followed accepted protocols. This includes maintaining pumps, testing circuits and other functions associated with shutting down and starting service.
- ß MTA however did not have adequate response to communicating the severity of the flood conditions to its customers.
- ß It does not seem that NYCT has a bus substitution plan – similar to Philadelphia – that would move customers through the system. One should be developed, using the recent storm as a model.

- Nonetheless, MTA should be sure that its flood removal protocols are fully met:

  - All primary pumps and redundant and back up pumps must be in full working order, and routinely tested to insure full capacity can be met.
  - All drainage paths must be kept clear
  - Redundancy must be assured in the most critical stations and points along the ROW. Based upon the recent storm and predictions of strong storms with greater frequency, MTA must develop a new list of critical points and develop a pumping strategy for those.
  - In fact, MTA might take this opportunity to develop a modern –system wide – storm plan for a new level of storm severity and frequency. To carry out such a plan effectively, there MUST BE regional agreement (NYCDOT, NYSDOT, NJT, PATH, and others) on what the new design criteria will be, areas of greatest susceptibility, and ways to maximize availability of system wide resources during these emergencies.
  - MTA must integrate current State of Practice design for new station construction (SAS), minimizing the probability of intrusion of water from street level.
  - MTA should play a leadership role in assessing – together with all appropriate regional agencies – the impacts of global warming similar to that done for Great Britain.