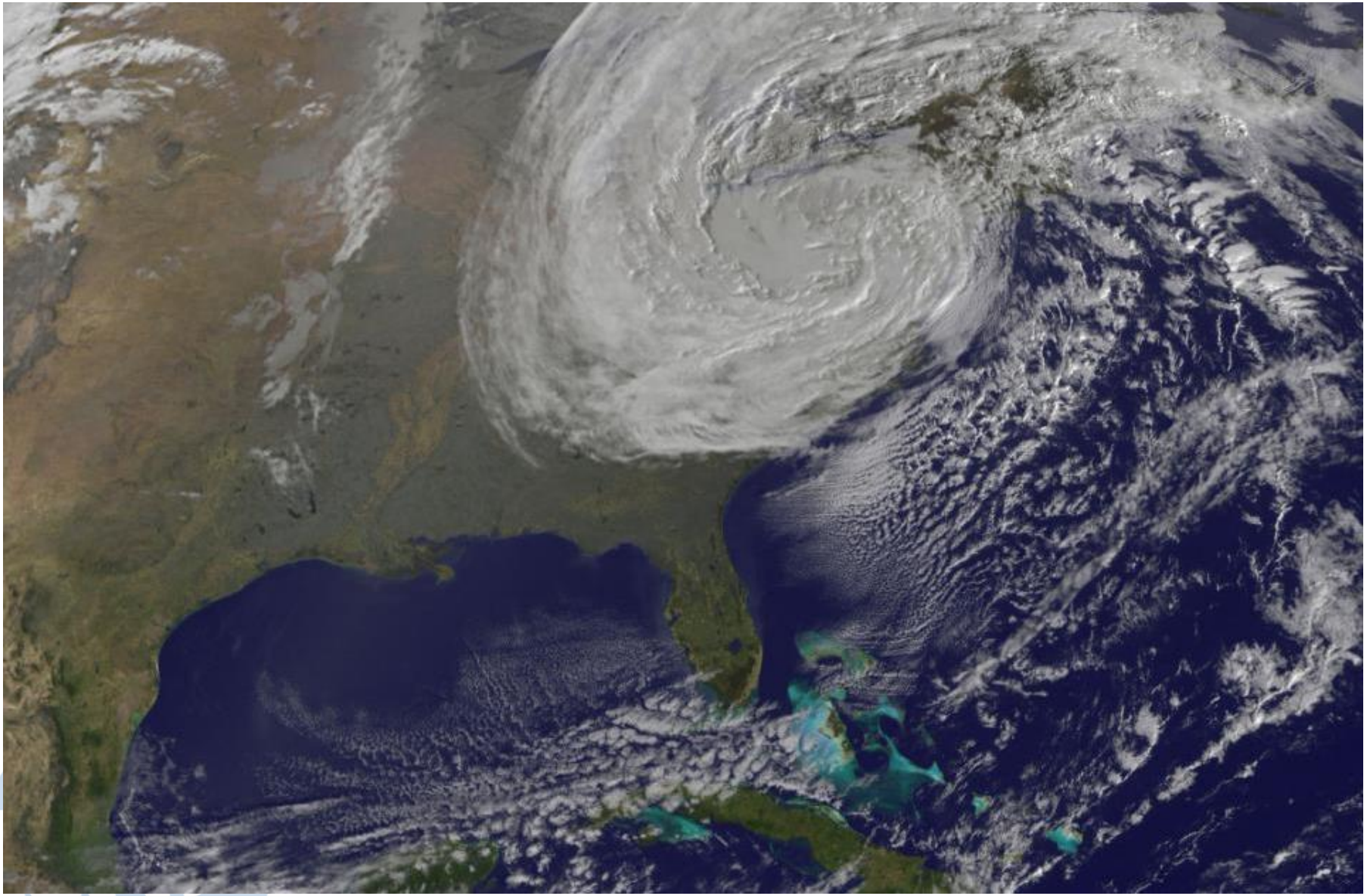
Superstorm Sandy

Preparations, impact, recovery, and fortification

Society of American Military Engineers

September 17, 2013



NYCT Storm preparations

-- guided by extensive table top exercises and established plans

Pre Sandy event (business as usual)

- Extensive table top exercises internally and with state and city

- Review and updating of comprehensive hurricane plans (along with cold weather plans etc)

Sandy event

Mon Oct 22	Tue Oct 23	Wed Oct 24	Thur Oct 25	Fri Oct 26	Sat Oct 27	Sun Oct 28	Mon Oct 29

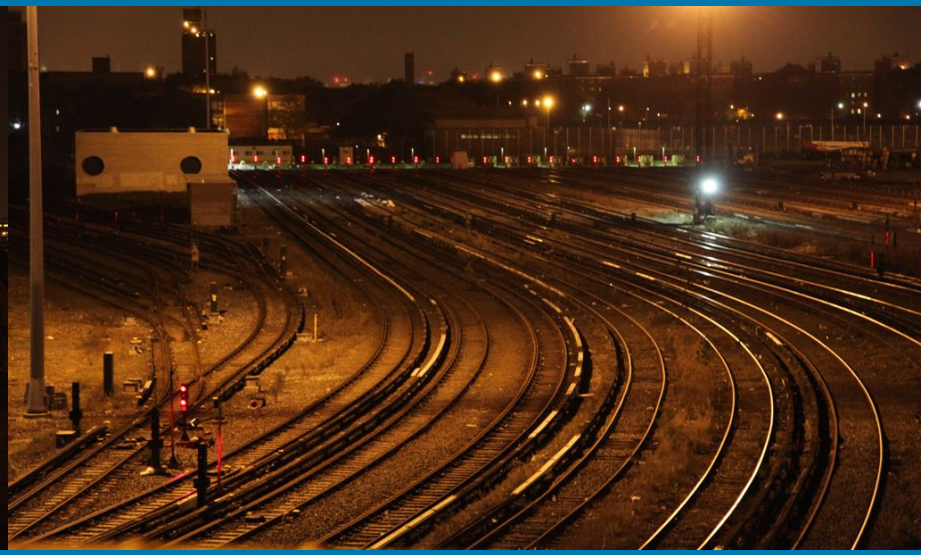
- Mon Oct 22: Internal storm preparation procedures begin
- Wed Oct 24: Physical protection of system begins with sandbags etc
- Thur Oct 25: Regular coordination calls begin with external partners
- Sat Oct 27: Physical protection of system complete
- Sun Oct 28:
  - Incident command centers and situation rooms activated
  - Assistance with evacuation, ~200 extra buses, 60 paratransit vehicles
  - Planned service shut down
  - Storage of vehicles in safe locations
- Mon Oct 29: Storm peaks

MTA coordination with Governor Cuomo and his staff

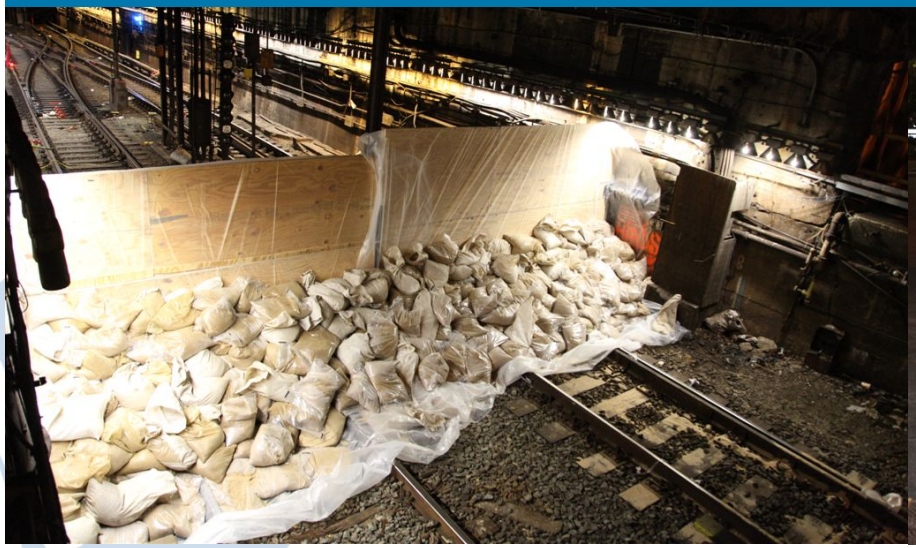
Subways

Coney Island Yard

Stillwell Yard



Lenox Terminal



Bowling Green

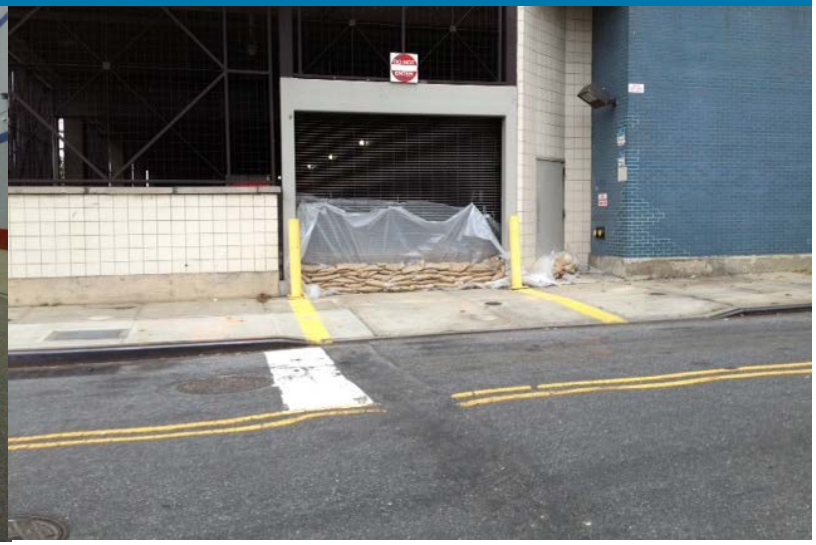
Buses

Buses staged for evacuation (City Island)

Castleton depot

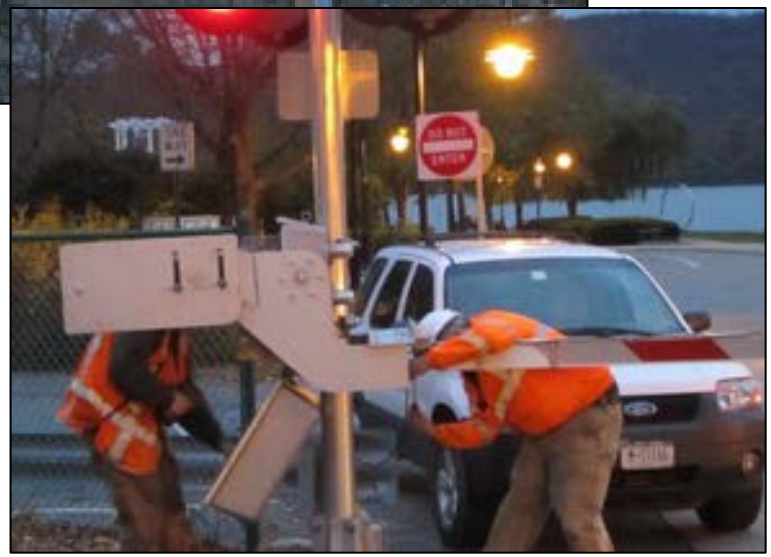
Buses relocated to higher ground (Gun Hill depot)

Quill depot



LIRR Preparations

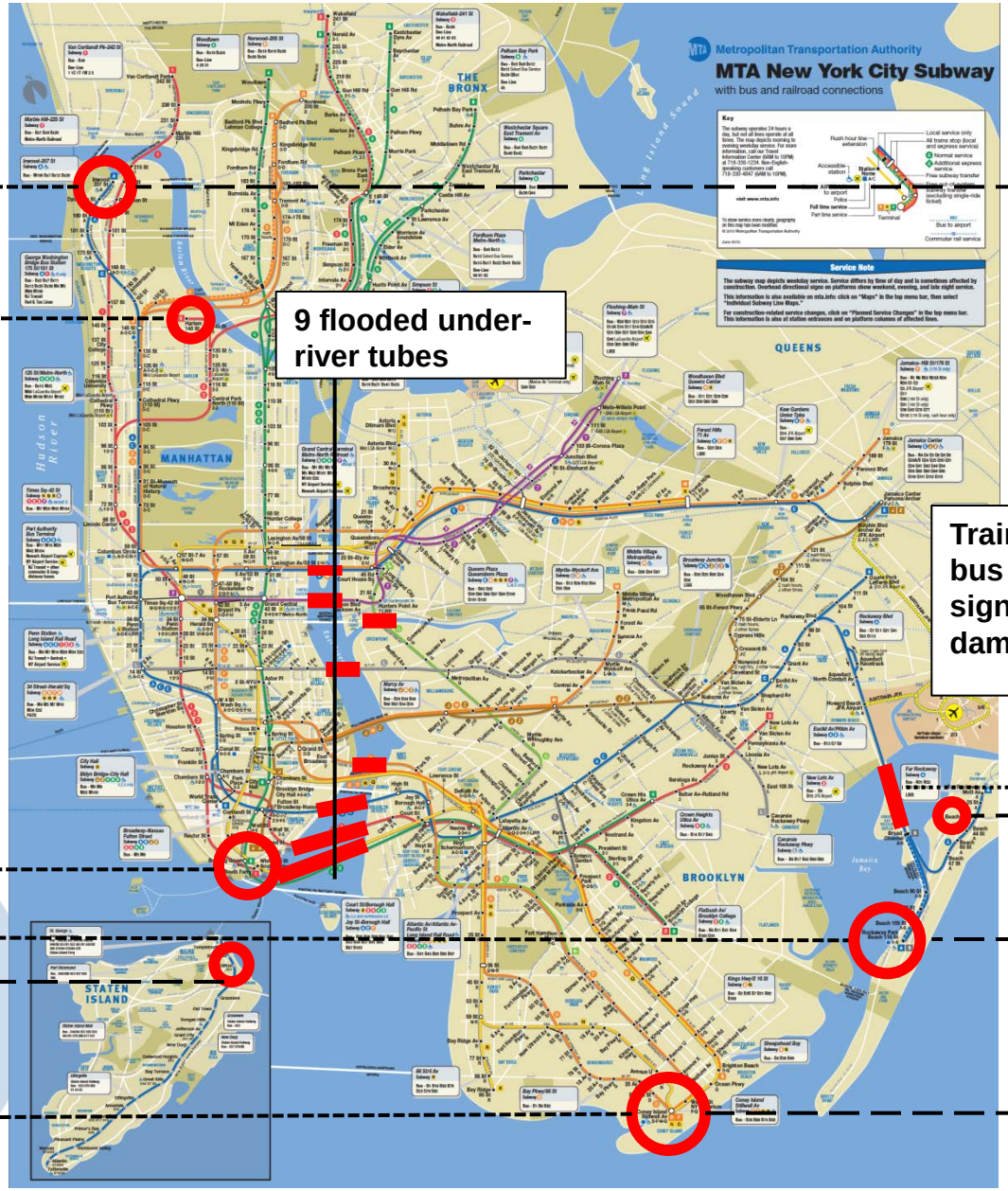
- More than 1,500 engineering staff used in preparation for the storm
- Over 340 pieces of rolling stock moved to higher ground
- De-energized the entire system plus removed circuit boards at signal huts.
- 6 foot diameter Aqua Dam—filled with 32,000 gallons of water—was installed to protect Penn Station
- All tracks taken out of service and placed in engineering control
- Declared emergency
- Response teams positioned



MNR Preparations

- Grade crossings secured by removing crossing gates and tying down gates
- Stockpiled material in preparation for washouts or bank erosion
- Culverts cleared of fallen limbs and other debris
- Ditches and swales cleaned out
- Pumps tuned up and put in place at known low-spots
- Generators at all rail yards fueled and tested
- Cranes, excavators, and back hoes positioned along the tracks
- Equipment and employees moved to safer ground

Sandy caused major flood damage across the system



9 flooded under-river tubes

8 stations with major flood damage – South Ferry, Whitehall, 148th St, 207th St, Dyckman, Beach 116th Station, 86th St Sea Beach, Stillwell

Staten Island Railway maintenance shop major flood damage

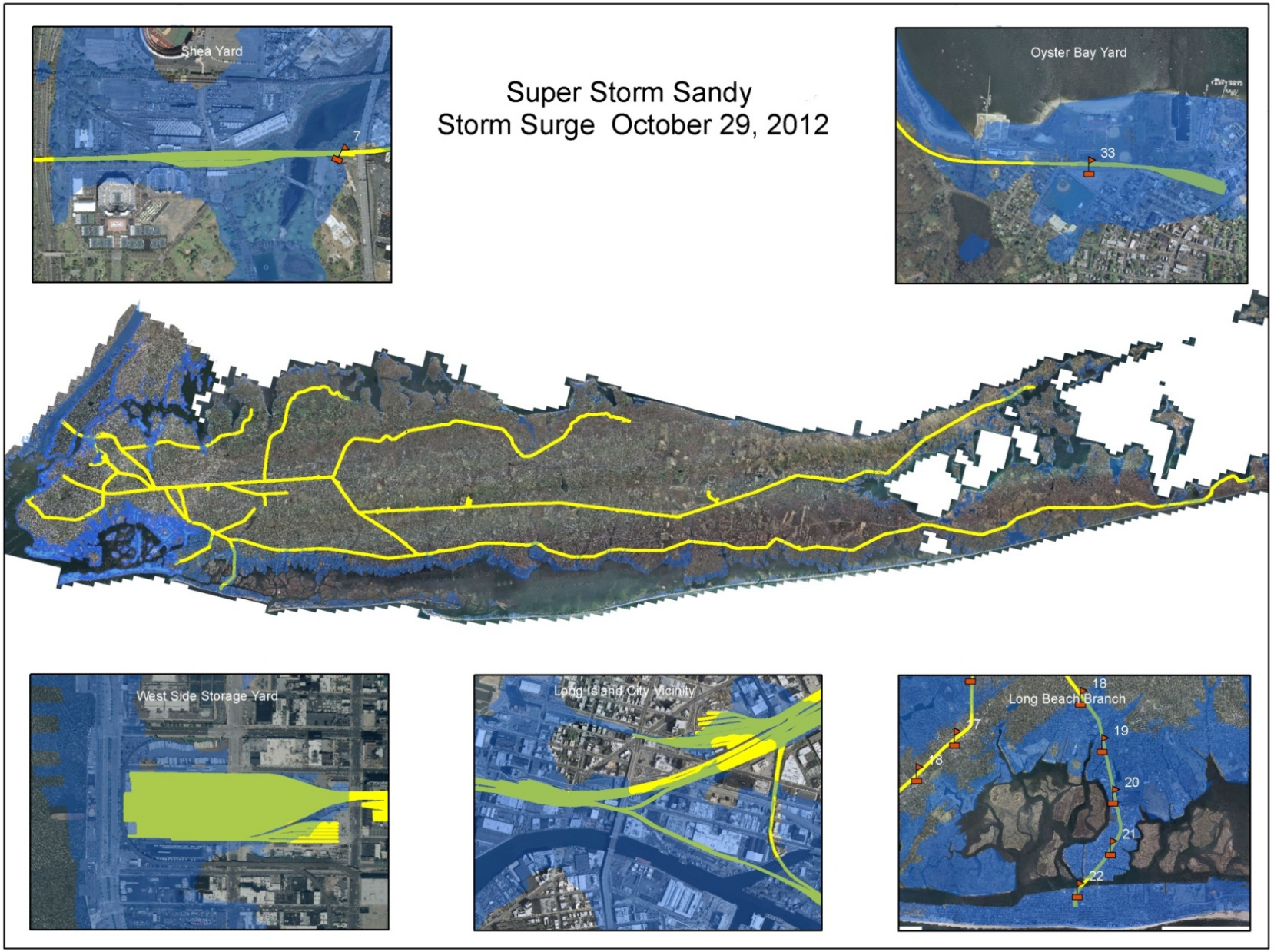
Train yards and bus depot with significant flood damage

Rockaways track washout

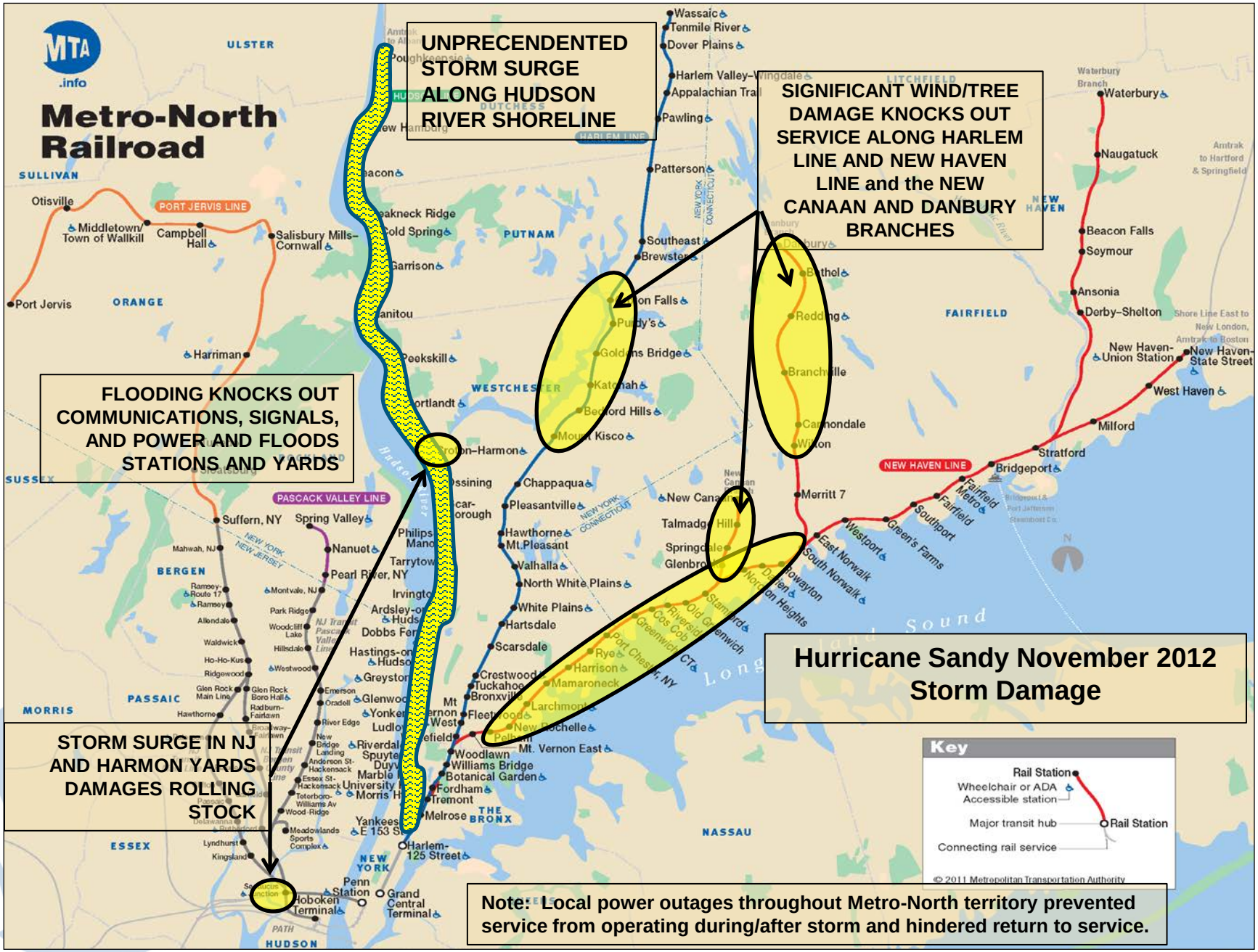
Numerous other locations with moderate flooding and wind damage including

- Downed trees
- Roof / canopy / sidings damages
- Communication systems damages
- Signal system damages

Storm surges in LIRR territory

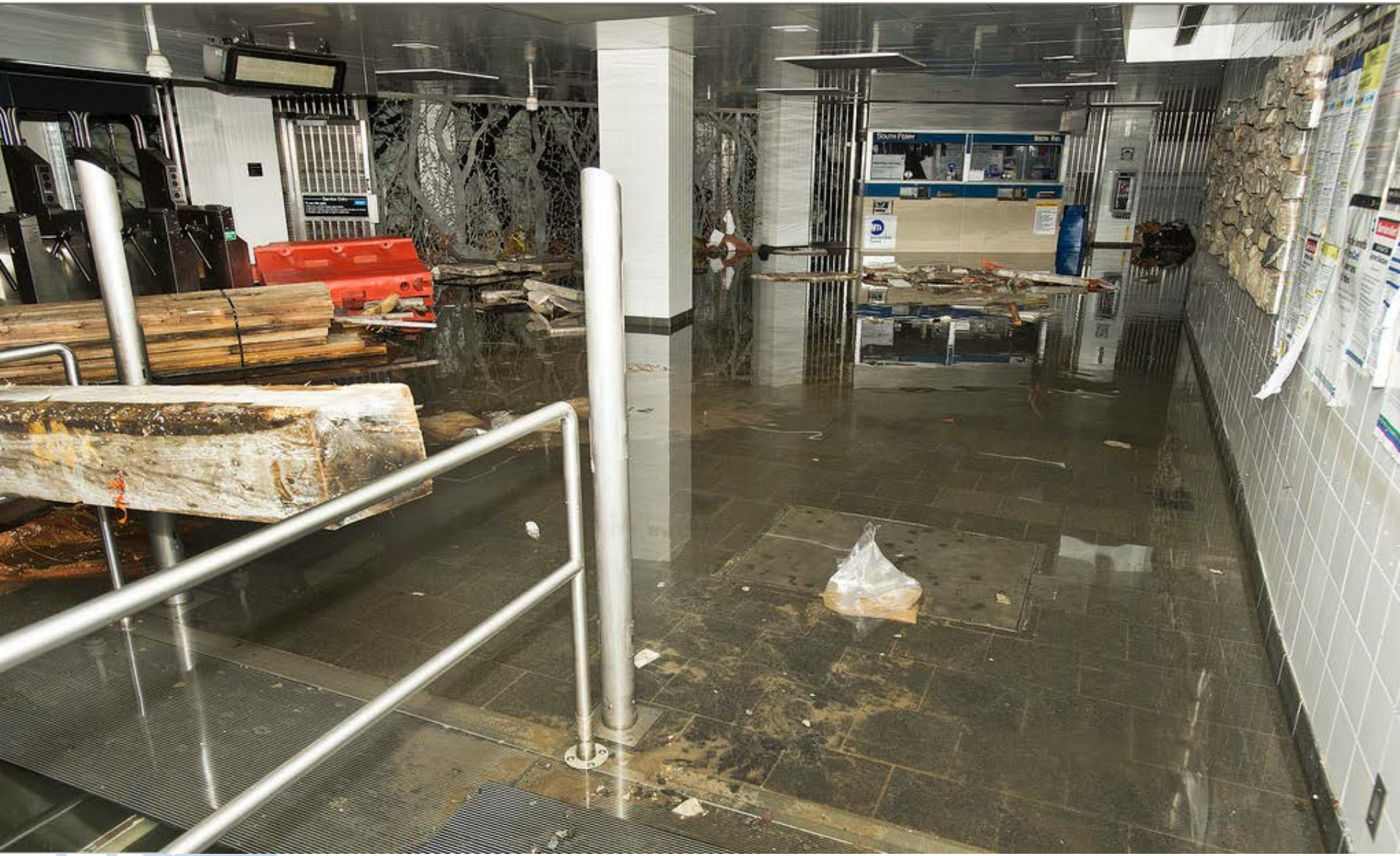


Metro-North Railroad Sandy damage map



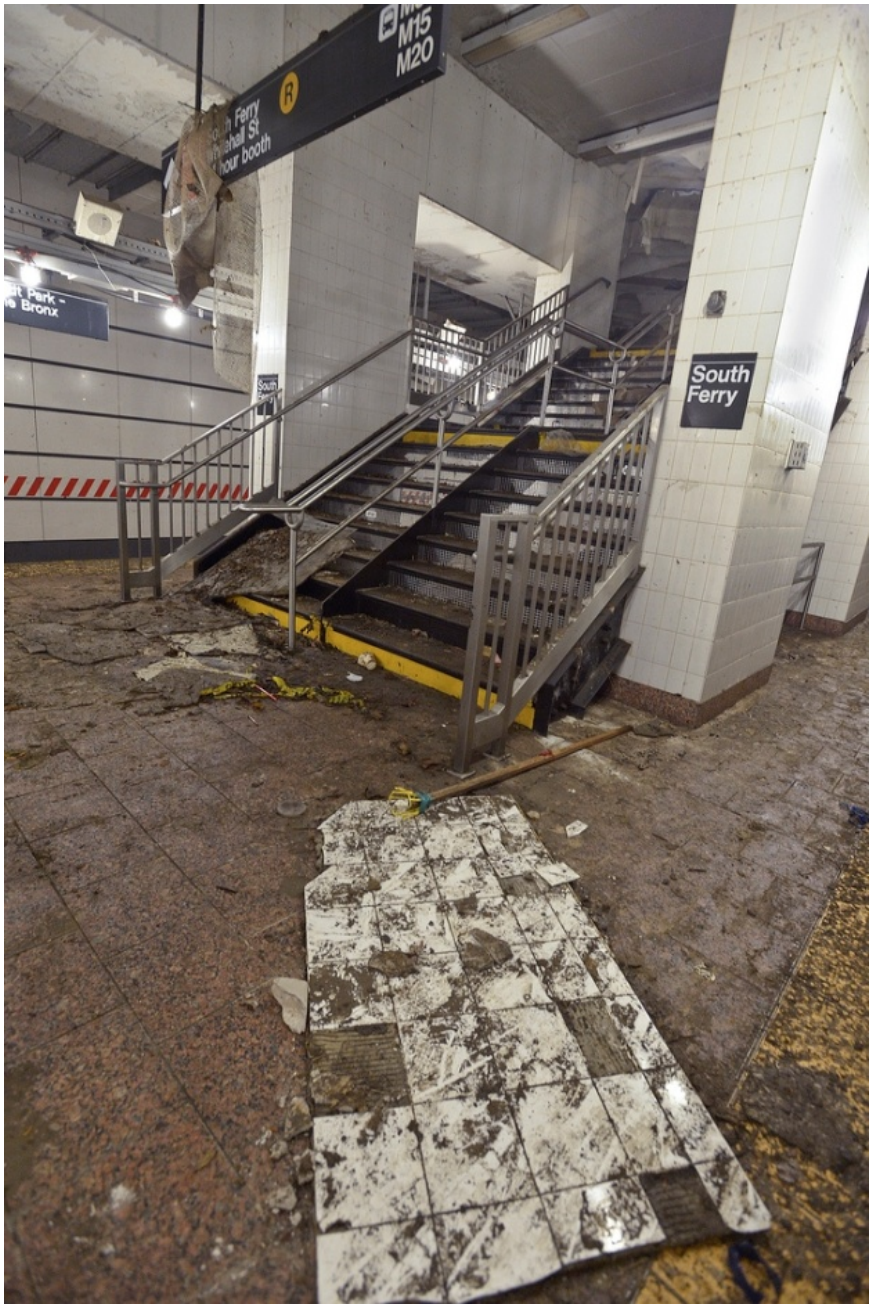
South Ferry

South Ferry



South Ferry

South Ferry



86th St Sea Beach line

Flooded under-river tubes - Cranberry

Rockaways washout

Rockaways washout

Rockaways washout

LIRR West Side Storage Yard

Trees and utility poles/wires down along the Long Island Rail Road

Stranded Boat along Metro-North's tracks at Ossining

Hugh L. Carey (Brooklyn Battery) Tunnel west side underpass and tube

Flooded Queens-Midtown Tunnel tube and toll plaza

Post-storm recovery

Bus service restoration –

Began 7 hours after storm and supported restored subway service with an unprecedented ‘bus bridge’

Buses operating on modified routes initially due to routes blocked by trees, cars, boats etc

‘**Bus bridge’ shuttle between Manhattan and Brooklyn** – Buses also added extra service to Lower Manhattan where there was initially no power and subway service

Buses performed **evacuations and patient repatriations**; also contributed to broader city recovery efforts through **election day shuttle bus specials** and ongoing **OEM ‘Warming Bus’** deployment

Most subway service was recovered within a week of the storm

2 days after storm: 57%

3 days after storm: 60%

4 days after storm: 65%

5 days after storm: 81%

6 days after storm: 87%

7 days after storm: 89%

8 days after storm: 91%

9 days after storm: 94%

Capital repair costs from Hurricane Sandy

Agency	Est. Cost*	Types of Damage
New York City Transit	$3,449	Rolling Stock, Stations, Track, Power, Signals, Structures and Shops/Yards
Long Island Rail Road	$ 267	East River Tunnels, Communications, Signals, West Side/LIC Yards and Power
Metro North Railroad	$ 188	Rolling Stock, Right of Way, Communications, Signals and Power
MTA Bus	$ 25	Rockaway Bus Depot
MTA Capital Construction	$ 48	Damage to equipment. Contract delays
Bridges & Tunnels	$ 778	Hugh Carey and Queens Mid-town Tunnels
Total	$4,755	

NOTE: We amended our Capital Program to reflect this need, and this amendment was approved by New York State earlier this year.

Maintenance requirements have increased significantly since Sandy

Canarsie L tube pump discharge line ruptured under normal loads April 24 with excessive stress from Sandy event likely root cause
Emergency repairs and customer delays resulted

Montague and Greenpoint tunnels must close due to Sandy-related damages

R Montague tube

- Opened 1920
- Flooded to ceiling
- Longest tube in system (5000')
- Re-entered service Dec 21
- Extensive damage to all systems

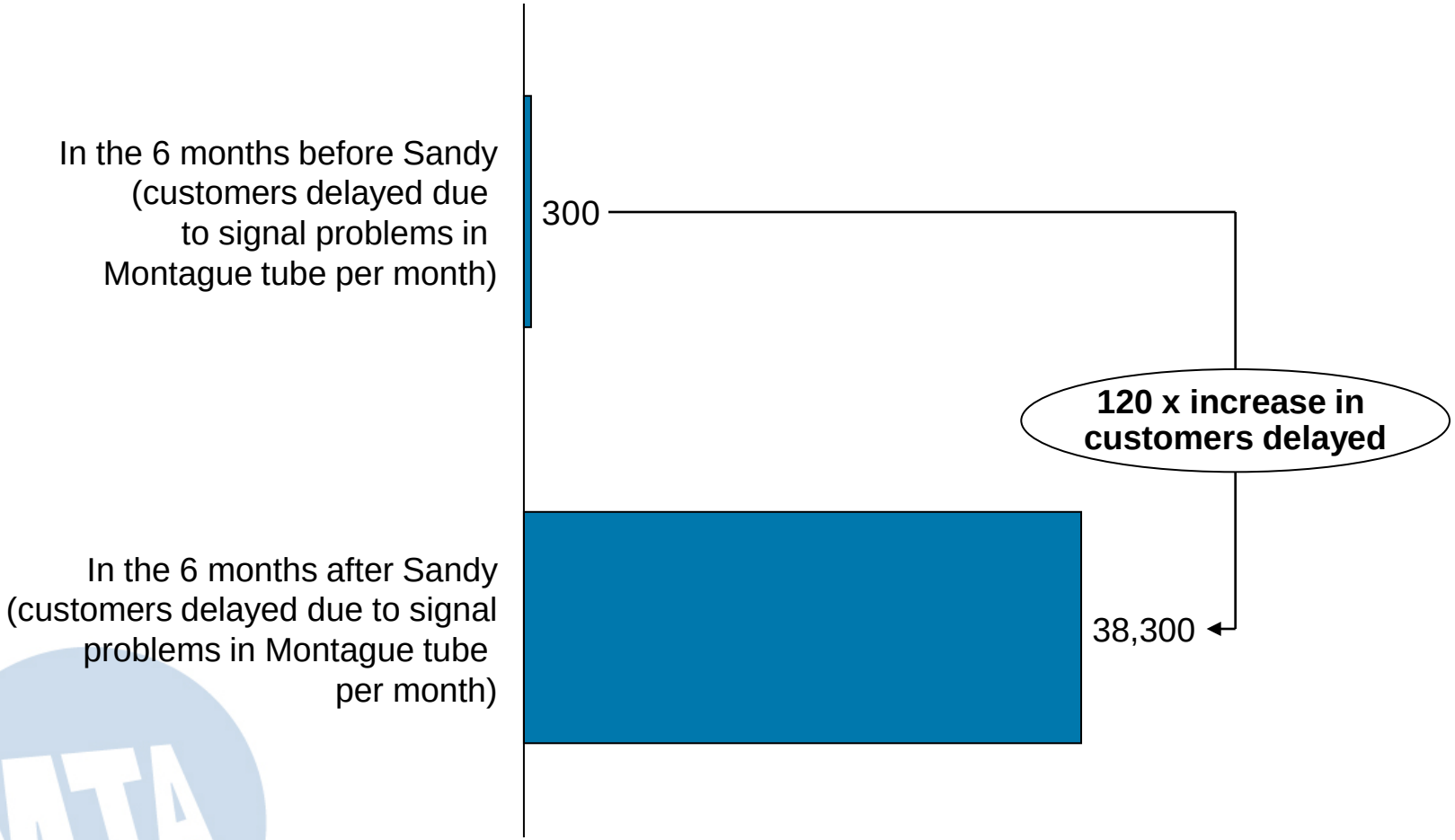
G Greenpoint tube

- Opened 1933
- Flooded to ceiling
- Re-entered service November 10
- Extensive damage to all systems

Damage makes pulling cable without rebuilding of the 28,000 linear feet of the duct bank infeasible

Failures affecting customers have dramatically increased in some areas post-Sandy

Number of customers delayed per month due to signal failures in Montague Tube



Recovering from Superstorm Sandy has three stages

1

Initial service restoration
- Focused on rapid, safe restoration of service

2

Permanent Repair
- Detailed inspection and engineering
- Repair work necessary for long term safety and reliability

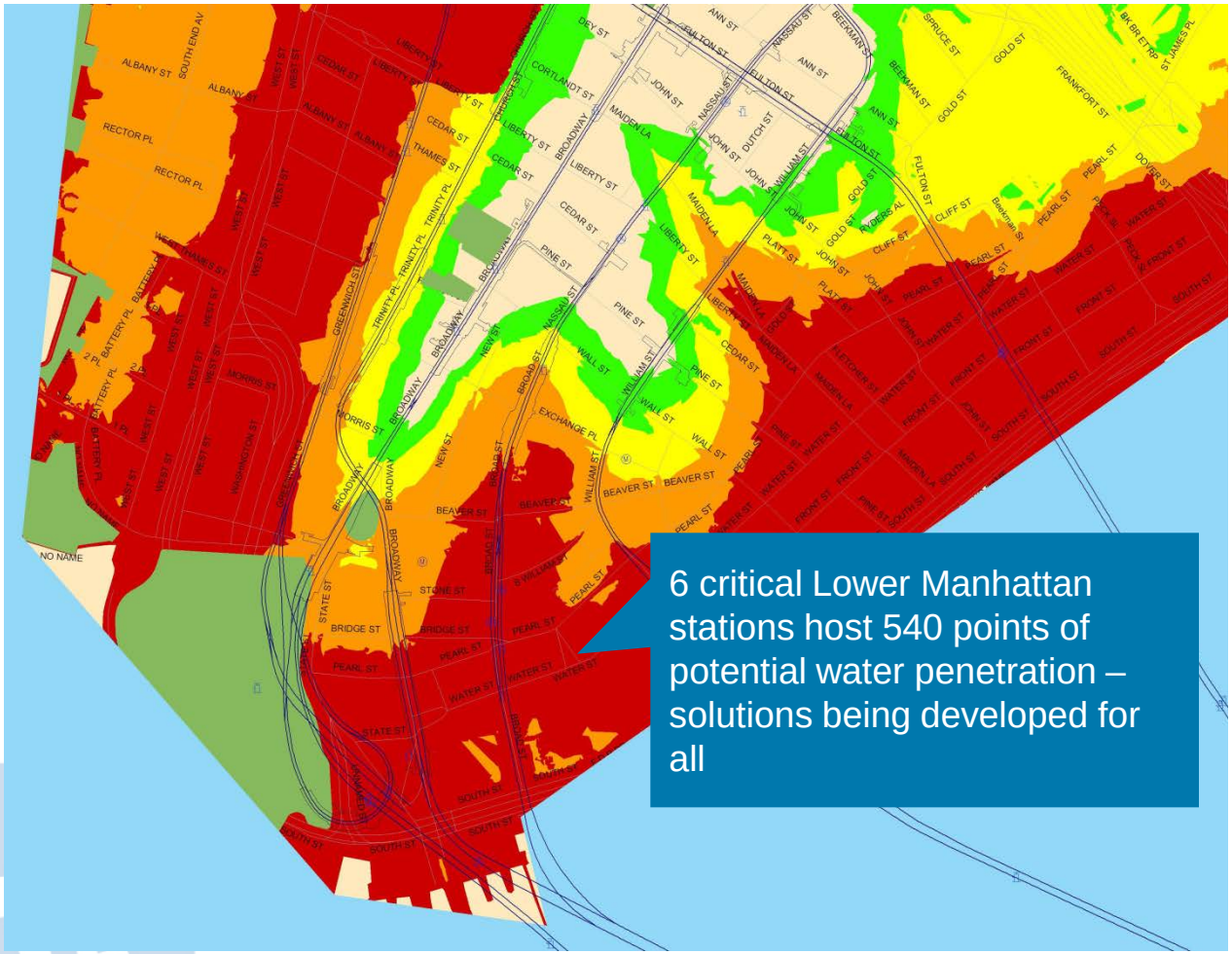
3

System Resiliency
- Near term actions to mitigate flooding
- Updating design criteria
- Novel equipment and solutions
- Federal funds sought for infrastructure

Resiliency projects may include …

- Bladders and floodgates
- Additional pump trains
- Adding alternate BRT routes for redundant service
- Mechanical alternatives to seal vent gratings
- Additional deep wells

Long-term resiliency must overcome system vulnerability to catastrophic flooding



Hurricane flooding

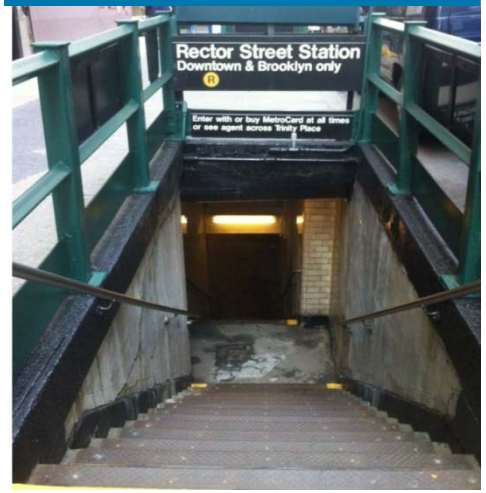
- Category 1
- Category 2
- Category 3
- Category 4

Multiple types of water ingress vulnerabilities exist

Elevators

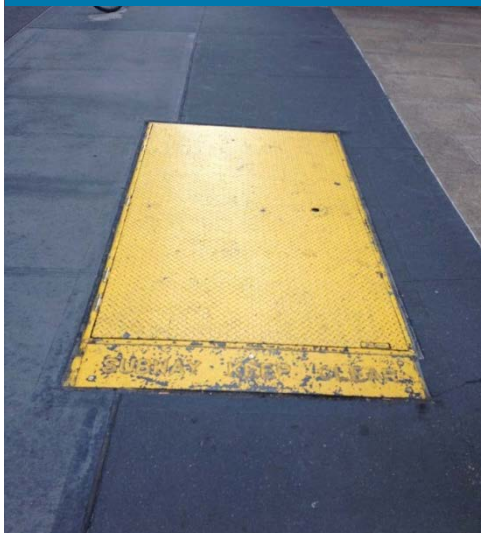
Vents

Stairways

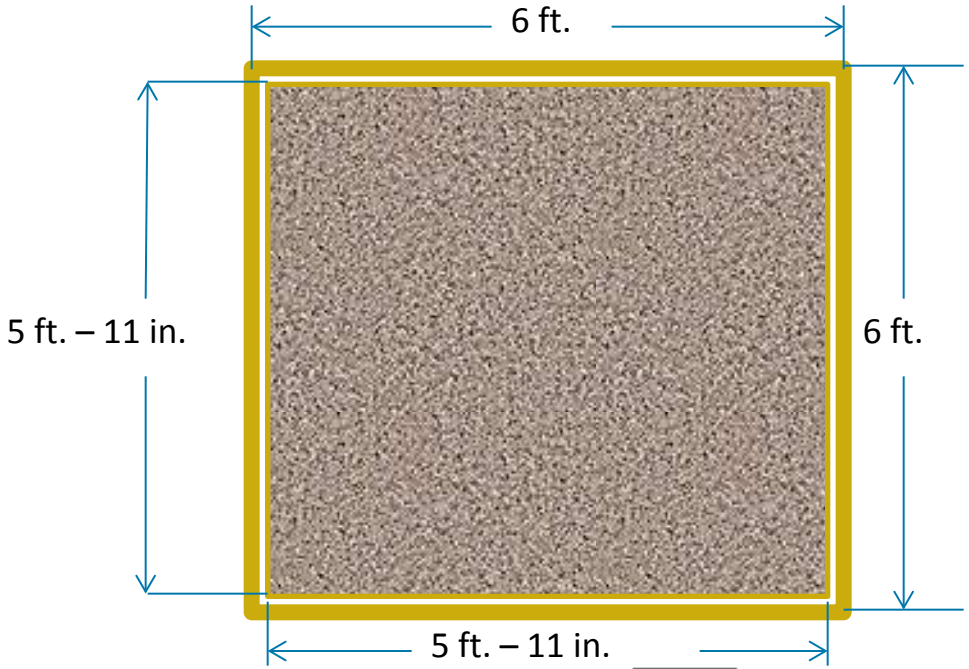


Manholes

Hatches



The engineering challenge is formidable – small openings can deliver huge amounts of water under pressure



$$Q_0 = C_0 A \sqrt{2 g h}$$

Coefficient C = 0.67
g = 32.2 ft./sec/sec
h = 3.0 ft. water head

Q = 9.25 cu. ft./sec = 4,152 gal/min = **249,120 gal/hr.**

In 4 hrs.: approximately **1 M gallons** would have entered

Category 1 surge could flood an under-river tube in 30 minutes

- **Assumptions**
  - Two entrances and adjacent vents affected. Area of openings: 270 sq. ft.
  - Duration: 40 min.
  - Max. Flood Height: 5.1 ft.
  - Flow: Q = 1451.7 * SQRT(H) cfs;
  - Volume (cu. ft.) = Q*seconds
  - 0-10 min.: H avg = 0.75 ft.; Q = 1257 cfs; Volume = 1257*600 = 754200 cu. ft. = 6 M gal.
  - 10-20 min.: H avg = 3.3 ft.; Q = 2637 cfs; Volume = 2637*600 = 1582200 cu. ft. = 12 M gal.
  - 20-30 min.: H avg = 3.3 ft.; Q = 2637 cfs; Volume = 2637*600 = 1582200 cu. ft. = 12 M gal.
  - 30-40 min.: H avg = 0.75 ft.; Q = 1257 cfs; Volume = 1257*600 = 754200 cu. ft. = 6 M gal.

- **The Montague St. Tunnel (having a total volume of 26.5 M gal.) will completely flood in 30 minutes**

The Road Ahead

- Major latent defects work (recovery)
- Resiliency
- Delivery of daily service