Session 4: Hurricane Sandy - Lessons Learned

June 20, 2013
Webinar Series

Session 1: Getting Started – Determining Assets to Study and Using Climate Information

Session 2: System-Level Vulnerability Assessments

Session 3: Applying the Results

Session 4: Hurricane Sandy - Lessons Learned
Agenda

Introduction  Tina Hodges, FHWA

Lessons Learned - Hurricane Sandy

New Jersey DOT  Richard M. Shaw

New York City Transit  Antonio Cabrera

Q&As
FHWA’s Climate Change Adaptation Efforts

- FHWA’s Climate Change and Extreme Weather Vulnerability Assessment Framework – draws from past work, will be updated with ongoing work
- U.S. DOT Gulf Coast Study
- 2nd round of climate pilots
- Update FHWA’s Hydraulics Engineering Circular 25: Highways in the Coastal Environment, with approaches for incorporating climate change
- Hurricane Sandy Follow-up, Vulnerability Assessment and Adaptation Analysis

Reports, Resources, Info on Ongoing Work Available at: www.fhwa.dot.gov/environment/climate_change/adaptation
Climate Change & Extreme Weather Vulnerability Assessment Framework

1. Define Project Scope
   • Objectives
   • Relevant Assets
   • Climate Variables

2. Assess Vulnerability
   • Climate Inputs
   • Asset data, criticality, sensitivity
   • Vulnerabilities, risk

3. Integrate Vulnerability Into Decision Making
OUR BOUT WITH SUPERSTORM SANDY

Presented By Richard M. Shaw
Assistant Commissioner For Operations, NJ DOT

Best Practices and Lessons Learned

June 12, 2013
Sandy was the largest Atlantic hurricane on record as measured by diameter with winds spanning 1100 miles.

- Initial damage estimates at $71 Billion
- More than 110 Fatalities
IN SOME AREAS, DEVASTATION WAS COMPLETE

- Childhood memories gone
- Businesses gone
- Lives shattered
- Where do you start in order to recover
LESSON #1 PRIOR PLANNING PREVENTS POOR PERFORMANCE

- Within 5 hours of wind subsidence, NJ DOT had contractors and state forces on the ground
- Be Ready to move at all times 24/7, 365

October 30, 2012

December 11, 2012
LESSON #2: PREPARATION BEGINS AT HOME

- Prepare yourself and your family first if you have enough prior notice
  1. Bottled Water
  2. Flashlights
  3. Batteries and battery operated radio
  4. First aid supplies
  5. Food that does not require refrigeration
  6. Pre-storm checklist
LESSON #3: PREPARATION IS YEAR ROUND

- Develop pre-storm checklist
  - Notional timeline
  - Emergency contracts in place 24/7
  - Practice your plans
  - Debris removal contracts are a must have
  - Top off Fuel Supplies
  - Inventory resources beforehand

Route 35, debris laden, (note house in middle of highway)
LESSON #4: INCIDENT COMMAND SYSTEM

- Provides for Unified Command
- Helps to better organize your response
- Provides for common database of resources and requests
- Provides for clarity of purpose and command decision making
POST STORM SITUATION
“Restore Stability. Maintain Safety”

- Closed the breaches in Mantoloking by SAT, 3 NOV
- Cleared nearly 581 road incidents within 3 days
- Opened RT 35 (plus side streets) and RT 36 in one week
- Provided 59,031.80 gallons of fuel to first responders and medical professionals
- Repaired/restored nearly 1100 traffic signals by 7 Nov
- BTW....Nor’easter snow storm on 7 NOV!
Establish the NJ DOT “Presence” (Forward Command Post)
- NJ DOT Mobile Command Center moved to Seaside Heights
- Create relationships with law enforcement; utility companies; political leaders; Federal agencies
- Create operational chain of command and reporting structure to NJ DOT HQ

Establish battle rhythm; scope and accountability
- Organized teams and assigned individuals to take charge of affected locations
- Organized and tasked emergency contractors based on locations and who was assigned to specific locations (Over 400 personnel and 200 pieces of equipment pressed into service).
- Set up a daily schedule of meetings and report requirements. Empowered field personnel to “get the roads open”
- Implemented a communication plan and communication rules
- Provided daily situational report to HQ and NJSP personnel
Swift response was successful due to many things, but among them was communication.

Daily meetings on site with field staff to communicate assignments and hand out maps, obtain feedback, establish priorities.

Daily sit reports sent out to Sr. Leadership and other key personnel.

Information clearinghouse established at State OEM.
LESSON #6: ACT AS IF YOU ARE ALL ALONE
LESSON #7: HAVE AN ORGANIZED RESPONSE
Organized response means:

- Establish geographic sectors or grids
- Assign areas of work to staff by geographic area
- Incident Command Center on site or as close as possible
- Use GIS to establish maps, update daily to capture work complete.
- Log all activity in some type of document for use later
THE RESULTS

- Reconstruction of three breaches along RT 35 complete and road fully open on 21 DEC (53 days after storm)
- 80 sink holes repaired
- 4425 truckloads of debris removed from roadways
- 4330 truckloads of “clean sand”
- RT 71 draw bridge repaired by 19 DEC (51 days after storm)
- Over 1250 signs erected
KEYS TO SUCCESS

- Excellent Leadership
- “Can-Do” attitude
- Effective Operational organization
- Emergency contracts
- Good prior planning
  - “Storm kit” for field personnel
- Good coordination with Federal agencies; other state agencies and local officials
OTHER LESSONS LEARNED

- Document, Document, Document!! You will need this for FEMA
- Prepare and Practice – Prepare for the worst, hope for the best!
- Know the process, work the process – it will help you get results quicker. The CFR is online, review if often. Get a FEMA applicants guidebook and review it often.
FUTURE PLANNING INITIATIVES FOR NJDOT

- Traffic Signal upgrades to be able to hook up to generators
- Fuel – have contracts with multiple vendors from multiple refinery sites
- Obtain a videography contract to embed with DOT forces.
- Changes in our cost accounting system to help us better separate FHWA eligible work from FEMA eligible work.
Storm Surge Flooding in NYCT

Prepared by: Antonio Cabrera, P.E.
Track Engineering Officer, MTA-NYCT
Storm Surge Flooding in NYCT – Some Questions

• How is the NYCT System affected by Storm Surge Flooding?
  – What are the critical areas to be protected?
  – How much flooding of the system could be expected?
  – Can we estimate the height and extent of the storm surge for each Category?

• How was the system impacted by Super Storm Sandy?
  – Was the data used to prepare for it adequate?
  – Were the preparations adequate?
  – What were the lessons learned?

• How can we protect against future storms?
Storm Surge Flooding in NYCT – Overview

- Previous NY Metro Area Hurricane Studies
- Elevation Datum and Critical Facilities’ Surveys
- NYCT Subway Flooding under Category 2 Hurricane
- Super Storm Sandy – Impacts on NYCT’s Facilities
- Possible Mitigation Strategies and Lessons Learned
- NY State 2100 Commission Report
U.S. Army Corps of Engineers • FEMA
National Weather Service
NY/NJ/CT State Emergency Management

INTERIM
TECHNICAL
DATA REPORT
November 1995

METRO NEW YORK
HURRICANE TRANSPORTATION STUDY
SLOSH surge heights in NYC: 11 ft. (Cat. 1) to 30 ft. (Cat. 4)

Rail tunnels have points of entry less than 10 ft. above NGVD29

Significance of the 1992 Nor’easter
Metro New York Hurricane Transportation Study

Storm of December 11-12, 1992

L train backed out of flooded 14th St. Tube; G train abandoned in the Greenpoint tube; A train stranded at Broad Channel
Figure 17- Potential Category 2 Hurricane Surge at South Ferry (Battery) Subway Station
### Metro New York Hurricane Transportation Study

**Table 13 – Facility Vulnerability**

<table>
<thead>
<tr>
<th>FACILITY</th>
<th>CRITICAL ELEVATION</th>
<th>POTENTIAL HURRICANE SURGE (FT)(^{\circ}) ABOVE NORMAL TIDE</th>
<th>TIME HAZARDS COULD OCCUR(^{\circ}) SURGE/WIND</th>
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<td>(NGVD)</td>
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<td>Lexington Avenue</td>
<td>9.9</td>
<td>8.4</td>
<td>12.7(^{\circ})</td>
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Metro New York Hurricane Transportation Study

Figure 5 – **Worst Case Track** for Hurricanes Impacting the Metro NYC Area
Metro New York Evacuation Project

Summary of Changes from 1995 to 2010

- Includes 327 transportation facilities in three states
- Data collected in new datum, NAVD88
- Integrates new SLOSH data from the 2010 model run
- Updates and refines mobilization/decision, clearance, shutdown/closure, and pre-landfall hazard times for each facility.
Sea, Lake, and Overland Surge from Hurricanes (SLOSH)

The SLOSH model computes the maximum envelope of water (MEOW) or expected storm surge for multiple storm tracks. The maximum inundation for each MEOW, or the maximum or maximums (MOMs), compiles all the MEOWs to represent the worst elevation for each category of hurricane to form a line of demarcation that can be mapped.
When a hurricane approaches, communities should rely on the Storm Surge Inundation Maps [SLOSH maps] and storm surge forecast products from NOAA [SLOSH] when making evacuation and other emergency management decisions”

(a collaborative paper between U.S.A.C.E., NOAA & FEMA, Dec. 2011)
SLOSH Display – Cat.2 Hurricane – Max. Surge
SLOSH Zones

Category Hurricane

1  2  3  4

*Sea/Lake Overland Surge from Hurricanes inundation by Hurricane category worst case scenario
Google Earth View of Whitehall St. Station Entrances

Vents

Whitehall St Station Entrances
El. 6.5 ft. (NAVD88)
Google Street View of Whitehall St. Station Entrances
Sketch of Whitehall St. Station Entrances
### Survey Data (NAVD88) of Whitehall St. Station Entrances

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<td>Top of concrete coping</td>
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<td>Critical Facility Name</td>
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<td>Critical Facility Elevation in Feet from NYC OEM Lidar Data or NYCT's CPM Survey (NAVD88)</td>
<td>Critical Facility Elevation in Feet from the 1995 HEVAC Study (NAVD88)</td>
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Page 1 of 6
NYCTA Datum vs. NAVD88

Elevation 100.00 of NYCTA = 2.653 feet above MSL at Sandy Hook

At Sandy Hook Station #8531680, as per NOAA data:

\[ \text{NAVD88} = 0.24 \text{ feet above MSL} \]

Therefore,

\[ \text{Elevation 100.00 NYCTA} = 2.413 \text{ feet above NAVD88} \]
MTA NYCT Revised Critical Facilities List
Storm Surge Elevations in NYCT Datum Added

<table>
<thead>
<tr>
<th>Critical Facility Name</th>
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<th>Worst Case 2010 SLOSH Surge Elevations at High Tide in Feet (NAVD88)</th>
<th>Depth of Flooding by Category of Storm in Feet (NAVD88)</th>
<th>Worst Case 2010 SLOSH Surge Elevations at High Tide in Feet (T.O.R. in NYCT Datum)</th>
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Whitehall St. Station Entrances below Water St.
Potential Cat. 1 Hurricane Flooding in the NYCT System

CRITICAL FLOODING LOCATIONS

1 - 207th ST. YARD AND PORTAL
2 - 148th ST. YARD AND PORTAL
6 - 53RD ST. TUBE - 44th DR. FAN PLANT
8 - GREENPOINT TUBE - VERNON BLVD. FAN PLANT AND SHAFT
9 - 14th ST. TUBE - AVENUE D FAN PLANT AND SHAFT
10 - IRT 7th AVENUE LINE CANAL ST. ENTRANCES AND VENTS
11 - IND 8th AVENUE LINE CANAL ST. ENTRANCES AND VENTS
12 - RUTGERS ST. TUBE - RUTGERS ST. FAN PLANT
13 - CRANBERRY ST. TUBE - FULTON ST. FAN PLANT AND SHAFT
14 - CLARK ST. TUBE - OLD SLIP FAN PLANT AND SHAFT
15 - MONTAGUE ST. TUBE - BROAD ST. FAN PLANT AND SHAFT
16 - IRT SOUTH FERRY STATION ENTRANCE AND VENTS
17 - BMT WHITEHALL ST. STATION ENTRANCE AND VENTS
18 - JORALEMON ST. TUBE - BATTERY PARK FAN PLANT AND SHAFT
19 - CONEY ISLAND CREEK
20 - ROCKAWAY PARK YARD - JAMAICA BAY
Potential Cat. 2 Hurricane Flooding in the NYCT System

CRITICAL FLOODING LOCATIONS

1 - 207th ST. YARD AND PORTAL
2 - 157th ST. FAN PLANT
3 - 148th ST. YARD AND PORTAL
4 - 143rd ST. FAN PLANT
5 - 135th ST. & PARK AVE. FAN PLANT
6 - 131st ST. & LEXINGTON AVE. FAN PLANT
7 - VERNON BLVD. & 41st AVE. FAN PLANT
8 - SUTTON PL. S. & 53rd ST. FAN PLANT
9 - ROOSEVELT ISLAND & 53rd ST. TUNNEL FAN PLANT
10 - 44th DRIVE (53rd ST. TUNNEL) FAN PLANT
11 - 50th AVE. & 2nd ST. FAN PLANT
12 - 54th AVE. & VERNON BLVD. FAN PLANT
13 - AVENUE D & 14th ST. FAN PLANT
14 - N. 7th ST. FAN PLANT
15 - HOUSTON ST. STATION ENTRANCES & VENTS
16 - CANAL ST. STATION (IRT 7th AVE.) ENTRANCES & VENTS
17 - CANAL ST. STATION (IND 8th AVE.) ENTRANCES & VENTS
18 - CANAL ST. STATION (BMT BROADWAY) ENTRANCES & VENTS
19 - FRANKLIN ST. STATION (IRT 7th AVE.) ENTRANCES & VENTS
20 - CANAL ST. STATION (IRT LEX. AVE.) ENTRANCES & VENTS
21 - RUTGERS SLIP & SOUTH ST. FAN PLANT
22 - CANAL ST. STATION (JAMAICA) ENTRANCES & VENTS
23 - FRONT ST. & FULTON ST. FAN PLANT
24 - OLD SLIP & FRONT ST. FAN PLANT
Potential Cat. 2 Hurricane Flooding in the NYCT System

207th St. Yard and Portal
Potential Cat. 2 Hurricane Flooding in the NYCT System

Potential Cross-Flooding at Lexington Ave. & 59th St.
Flooding Through Small Spaces: Height of Water and Open Area Are Significant

\[ Q_0 = C_0 A \sqrt{2gh} \]

Open area, \( A = 0.993 \text{ sq. ft.} \)
Coefficient \( C = 0.67 \)
\( g = 32.2 \text{ ft./sec/sec} \)
\( h = 3.0 \text{ ft. water head} \)

\( Q = 9.25 \text{ cu. ft./sec} = 4,152 \text{ gal/min} = 249,120 \text{ gal/hr.} \)

In 4 hours approximately 1 M gallons would have entered.
Case Study: Potential Flooding at Whitehall St. Station Under Cat.1 and Cat. 2 Storm Surges

Assume that the two entrances (below) and adjacent vents (at the corner of Water St.) are breached, or that their protective measures fail.
Case Study: Category 1 and 2 Hurricane Surges

- Two entrances and adjacent vents affected. Area of openings: 270 sq. ft.
- Duration: 40 min. (Cat. 1) or 100 min. (Cat. 2)
- Max. Flood Height: 5.1 ft. (Cat. 1) or 11.4 ft. (Cat. 2)

- Cat. 1: in 40 minutes, a total of 36 M gal. of water would enter
- Cat. 2: in 100 minutes, a total of 117 M gal. of water would enter

- The Montague St. Tunnel (having a total volume of 26.5 M gal.) will completely flood in 30 minutes under the Cat. 1 surge; and it will completely flood in less than 25 minutes under the Cat. 2 surge

- The excess water will migrate North and South of the tube to flood adjacent areas
Precautions Were Taken Using the SLOSH Data and Flood Maps
How Did We Do?
Sandy Caused Major Flood Damage Across the System

Numerous other locations with moderate flooding and wind damage including:

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

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

8 flooded under-river tubes

Train yards and bus depot with significant flood damage

Rockaways track washout

Staten Island Railway maintenance shop major flood damage
Flooding at the New South Ferry Terminal
Sandy damage to under river tubes was historic

- Flooded track and equipment
- Destroyed pump control
- Shorted electrical equipment
- Damaged fan control
- Failed signals
- Broken communication gear
Rail and Fastener Damage in Flooded Tubes
# Subway Flooding After Hurricane Sandy

<table>
<thead>
<tr>
<th>UNDER RIVER TUBE</th>
<th>RADIUS</th>
<th>NO. OF TUBES</th>
<th>LENGTH OF THE FLOOD</th>
<th>DEPTH OF THE FLOOD</th>
<th>Gallons in Millions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rutgers St.</td>
<td>7'-10 1/2&quot;</td>
<td>2</td>
<td>1000</td>
<td>8 ft</td>
<td>1.5</td>
</tr>
<tr>
<td>Joralemon St.</td>
<td>7'-9&quot;</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Montague St.</td>
<td>10'-3&quot;</td>
<td>2</td>
<td>4025</td>
<td>20 ft</td>
<td>27</td>
</tr>
<tr>
<td>Cranberry St.</td>
<td>7'-10 1/2&quot;</td>
<td>2</td>
<td>1000</td>
<td>8 ft</td>
<td>1.5</td>
</tr>
<tr>
<td>Clark St.</td>
<td>7'-6&quot;</td>
<td>2</td>
<td>600</td>
<td>4 ft</td>
<td>0.5</td>
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<tr>
<td>161st St.</td>
<td>7'-10 1/2&quot;</td>
<td>3</td>
<td>0</td>
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<tr>
<td>60th St.</td>
<td>7'-6&quot;</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>53rd St.</td>
<td>7'-6&quot;</td>
<td>2</td>
<td>800</td>
<td>4 ft</td>
<td>0.5</td>
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<tr>
<td>14th St.-Canarsie</td>
<td>7'-9&quot;</td>
<td>2</td>
<td>2700</td>
<td>15 ft</td>
<td>7</td>
</tr>
<tr>
<td>63rd St.</td>
<td>9'-2&quot;</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>149th St.-Harlem R.</td>
<td>25'-0&quot;</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Lex. Ave.-Pelham</td>
<td>2x 8'-9&quot;+2x6'-6&quot;</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Greenpoint</td>
<td>7'-10 1/2&quot;</td>
<td>2</td>
<td>1000</td>
<td>15 ft</td>
<td>3</td>
</tr>
<tr>
<td>Steinway</td>
<td>7'-9&quot;</td>
<td>2</td>
<td>1000</td>
<td>6 ft</td>
<td>1</td>
</tr>
<tr>
<td>South Ferry Terminal Station</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14.5</td>
</tr>
<tr>
<td>207th St Yard Leads</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>9</td>
</tr>
</tbody>
</table>
High-Water Mark

HWM-NY-NEW-101

Status: approved
Latitude: 40.70 Longitude: -74.02

Elevation (NAVD88): 11.4 (ft)
Approx Height above Ground: (ft)
Peak date: 10/30/2012 GMT
Survey method: GPS

Brief Description of HWM:
Good mud line on patio of building

Link to full data and photos

Zoom to
86\textsuperscript{th} St. Station – Sea Beach Line – HWM = 10.2 ft.
Rockaway Line Damage
Rockaway Flats
Remediation and Mitigation Work (Ongoing)

Before (November 2012)

After (January 2013)
How to Protect Entrances Such As This Against a Potential 11.4 ft. Flood Surge?
Example: Flood Defense Measures Worldwide
Example: Conventional Flood Defense Measures of Tokyo Metro

Flood Wall at the Kitasenju Outlet of the Chiyoda Line Tunnel

Flood Sealing Door at an Entrance of the Toyoko Station

Frame Barrier at an Entrance of the Honkomagome Station

Flood Gate in a Tube

Flood Sealing Door

Frames are removed at normal times
Example: Conventional Flood Defense Measures of Tokyo Metro

Automatic Shutter to Prevent Flood Flow

Sensor

Outlet of a Ventilation Duct

Manual Operation in Case of Malfunction of Automatic Shutter

Cross Section

OPEN

View of an Automatic Shutter

CLOSED
Example: Enhanced Flood Defense Measures of Tokyo Metro

Structural Measures

**Protection of Ventilation Outlets (27 sites)**
Raise of heights and/or reinforcement of the walls are scheduled.

**Station Entrance (229 sites)**
Improve water sealing function by proper measures considering possible water depth.

- Raise the height of existing frame barrier
- Install reinforced glass wall on existing side walls
- Install water sealing gate on existing structure to make a total protection. Apertures on side walls are covered by reinforced glass.
- If existing structure cannot support water pressure, renew structure completely
FLOOD DOORS/GATES

IBS Single Leaf Flood Door

Flood Panel™ Doors

Flood Control Lift-Hinged Gates

Hinged Flood Door

Puddle Panel™
Hong Kong MTR - Floodgate at Eastern Harbor Crossing Tunnel
FLIP-UP/AUTO-CLOSE BARRIERS

Automatic Flood Barrier

Aquobex Flip-up Barrier
Slot-in Systems:
- Train Yard
- Building entrances
- Garage entrances
- Station entrances
- Mechanical/electrical room entrance
SLATS/FRAME BARRIERS

RSA Removable Floodwall Panels:
• Station Entrance

Flood Log:
• Building entrances
• Garage entrances
• Station entrances
• Mechanical/electrical room entrance
INFLATABLE BARRIERS

NoFloods Mobile Barrier (air or water; max. height: 2.6 ft)

Dam-it Portable Cofferdams (water-filled; 1 to 12 ft)
Coney Island, Stillwell and Avenue X Yards
Flood Wall Concept

Perimeter Flood Wall
Significant Consequences of NYCTS’ Flooding

- Tunnel flooding above platform level will impact numerous critical equipment enclosures.
- Category 2, and even Category 1 Hurricane flooding of tunnels will result in damages costing hundreds of millions of dollars.
- Most important, the time required to restore functionality of the system will be measured in years.
- Existing scheduled services will be severely disrupted for a long time.
Climate Change Risks

After the damage inflicted by recent extreme storms, it is clear that New York State must prepare for the new normal. Planning for the future will never again mean the same thing. The recent storms are not anomalies. They represent further evidence in a developing pattern: an increased frequency and intensity of severe weather attributable to climate change.
NYS 2100 Commission

NYS 2100 COMMISSION
Recommendations to Improve the Strength and Resilience of the Empire State’s Infrastructure

Identify vulnerable assets
Review design guidelines
Protect against flooding
Elevation data and post-Sandy assessment should be used to identify critical locations
Flood walls should be used where appropriate
Upgrade pumps in flood-prone areas
Summary of Mitigation Priorities

• **The first line of defense is to prevent water from entering the system by all possible means.**

• **Closure and protection of openings:**
  – Stairs, vents, elevator shafts, emergency exits, fan shafts, ConEd cable entrances

• **Under river pumps:**
  – Harden/upgrade pumps and make them operable under water; raise switchgear and starters; waterproof enclosures for controls
  – Install emergency power generators in protected areas
Summary of Mitigation Priorities

• Revise design guidelines. Establish an integrated repair and resiliency strategy.

• Start hardening critical assets to reflect the need to protect flood-susceptible areas.

• Relay rooms, communication rooms and substations must be designed for survival.


• Protect the Rockaway Flats against a Cat. 2 surge.

• Add more pump trains.
Sea Level Could Rise 5 Feet in New York City by 2100

The U.S.'s largest metropolis and the entire east coast could face frequent destruction unless the region takes previously unthinkable actions.
How High Will the Next Storm Surge Be?