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

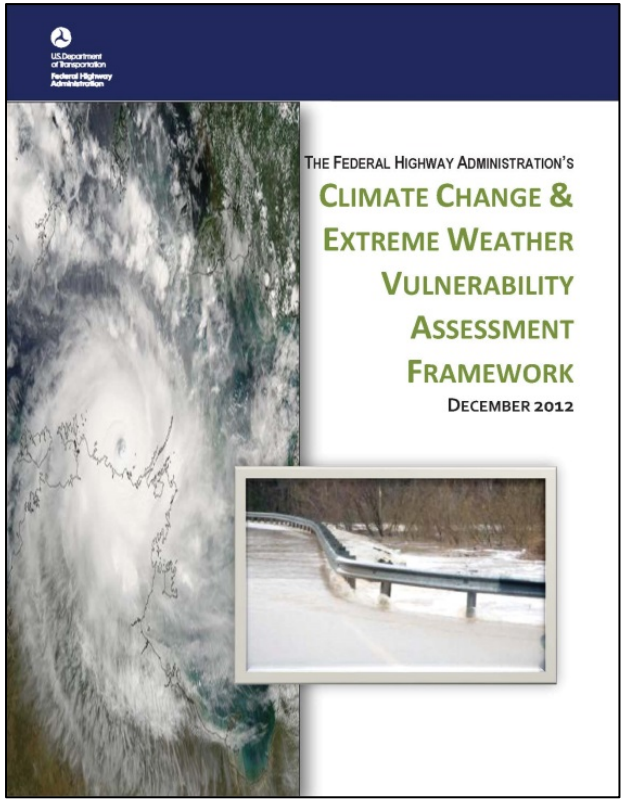
Session 3: Applying the Results

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

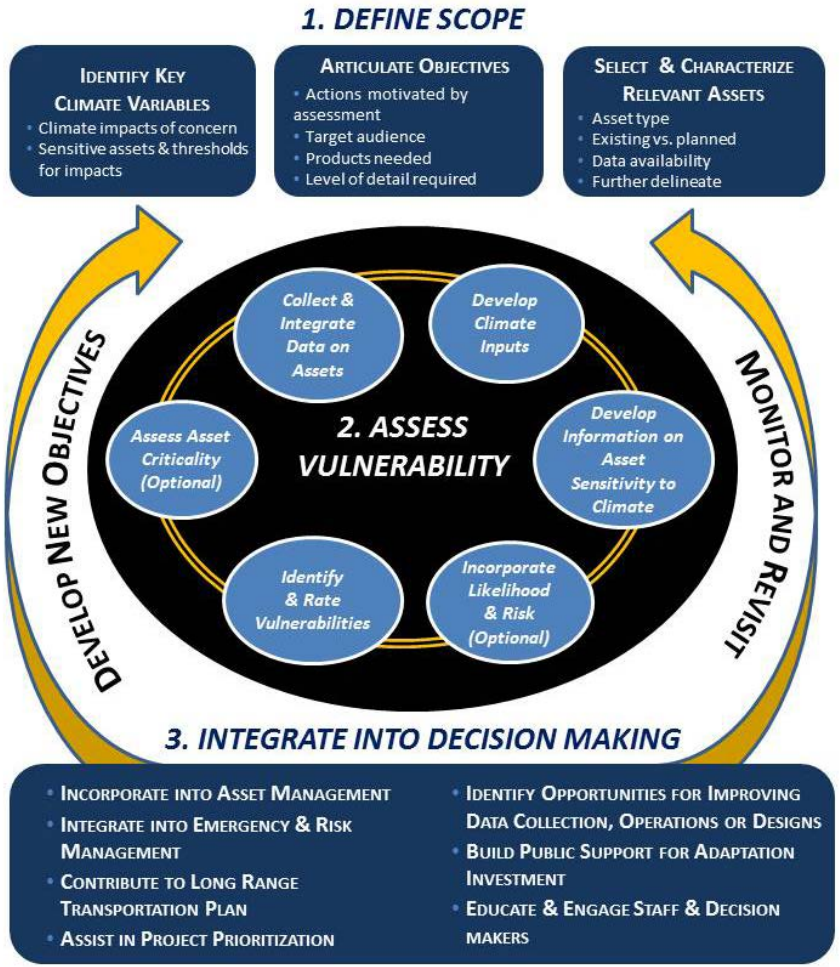


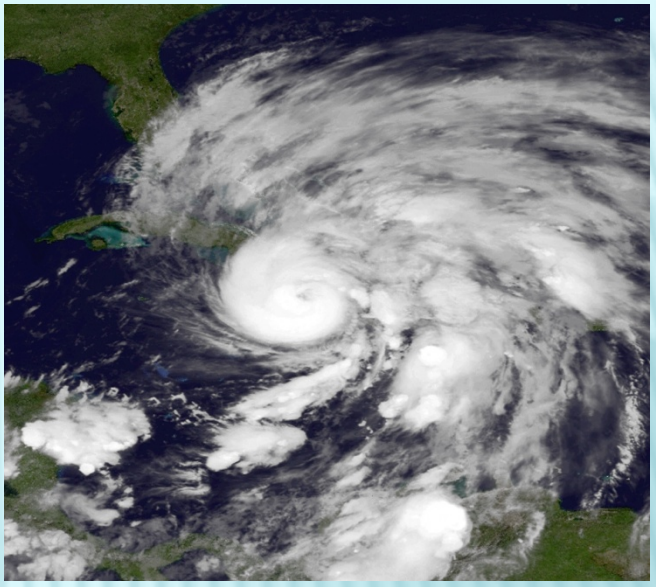
- FHWA's Climate Change and Extreme Weather Vulnerability Assessment Framework – draws from past work, will be updated with ongoing work
- U.S. DOT Gulf Coast Study
- 2nd round of climate pilots
- Update FHWA's Hydraulics Engineering Circular 25: Highways in the Coastal Environment, with approaches for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

Best Practices and Lessons Learned

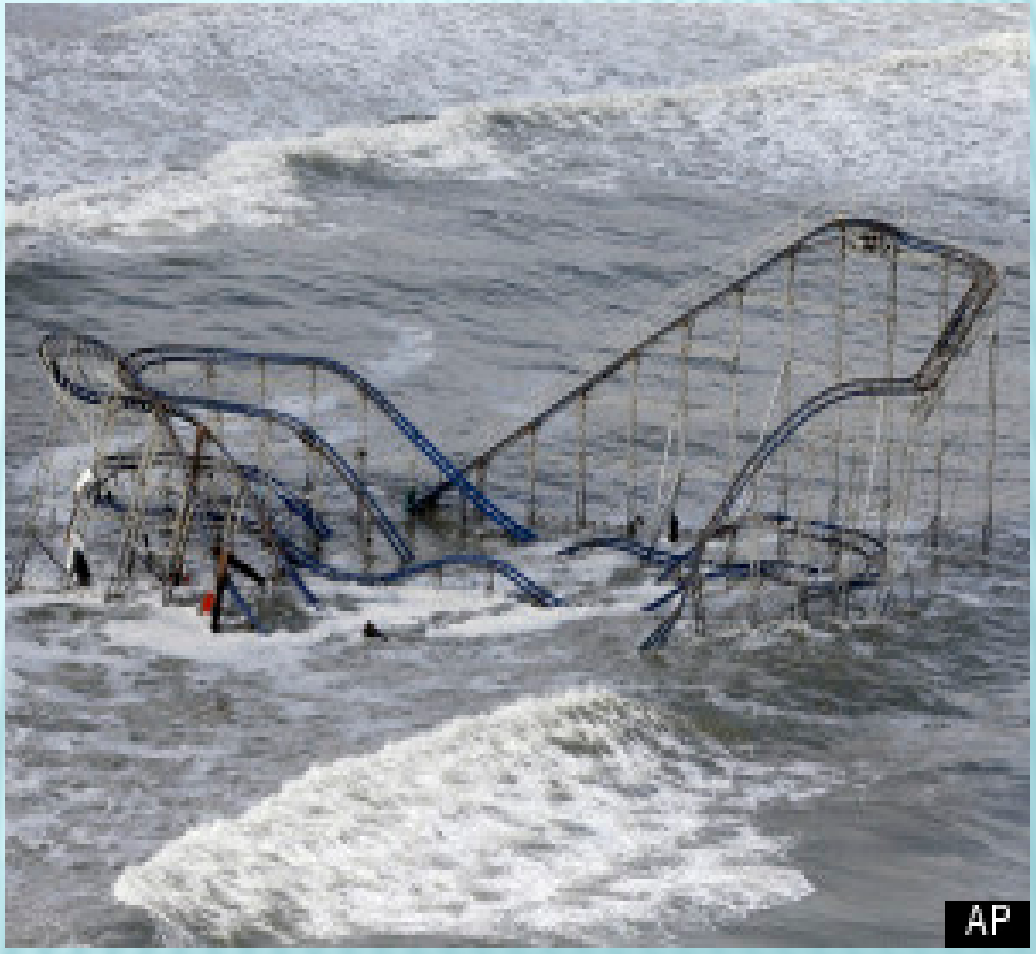
June 12, 2013

THE SUPERSTORM

- 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, NJDOT had contractors and state forces on the ground
- Be Ready to move at al 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

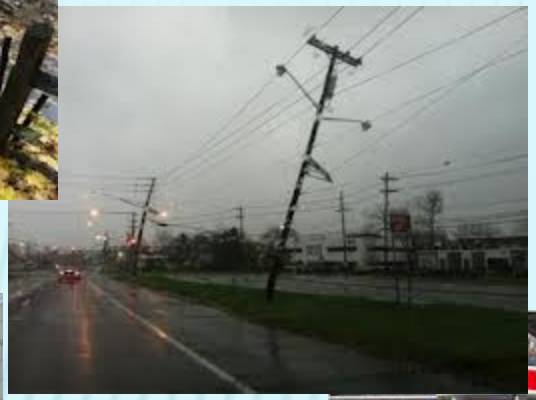
- Develop pre-storm checklist
  - Notional timeline
  - Emergency contracts in place 24/7
  - Practice your plans
  - Debris removal contracts are a must have
  - Top off Fuel Supplies
  - Inventory resources beforehand

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



NJDOT IMMEDIATE STORM RESPONSE

“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!

NJDOT POST STORM RECOVERY

- Establish the NJDOT “Presence” (Forward Command Post)
  - NJDOT 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 NJDOT 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

LESSON #5: COMMUNICATION IS KEY

- 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

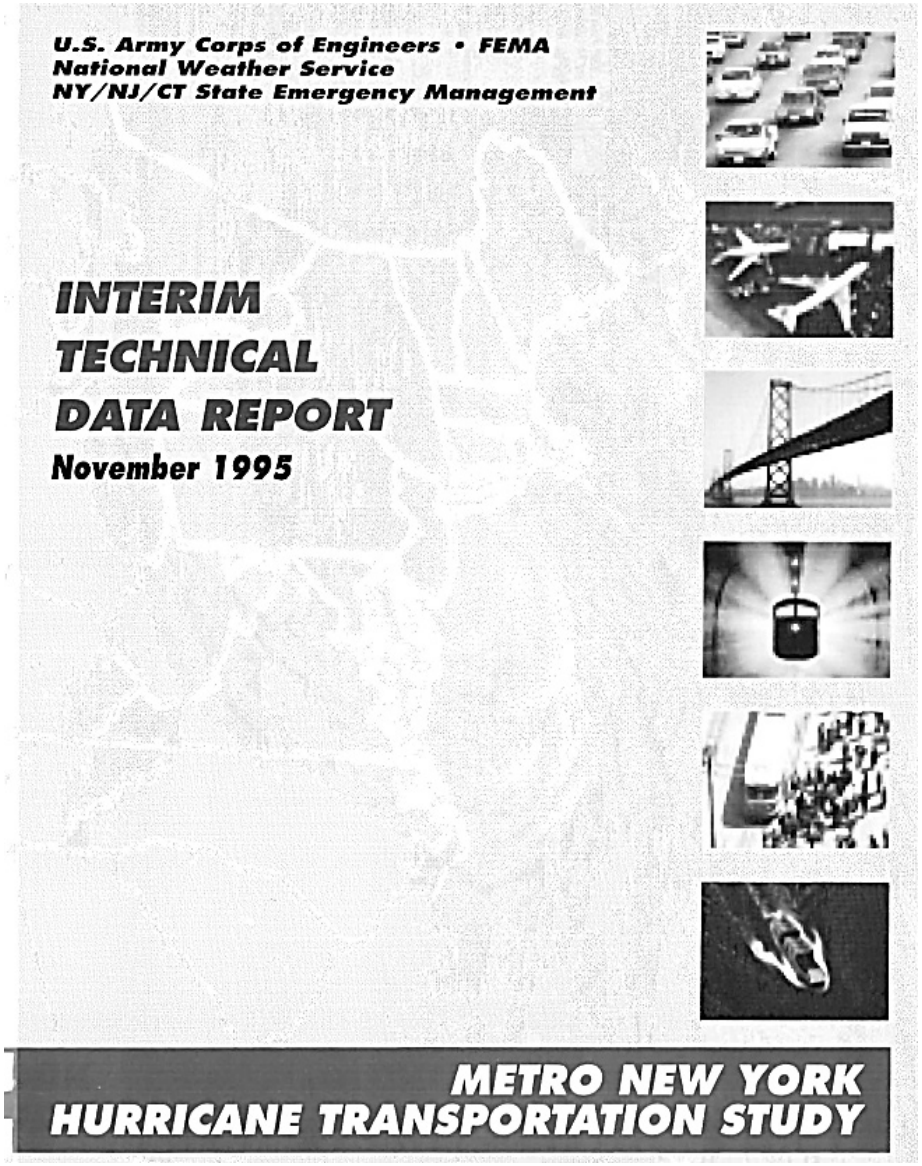
- Previous NY Metro Area Hurricane Studies
- SLOSH Model and its Application to Identify NYCT's Critical Facilities: T-Map, Flood Maps, NYCT Critical Facilities List
- Elevation Datum and Critical Facilities' Surveys
- NYCT Subway Flooding under Category 2 Hurricane
- Super Storm Sandy – Impacts on NYCT's 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

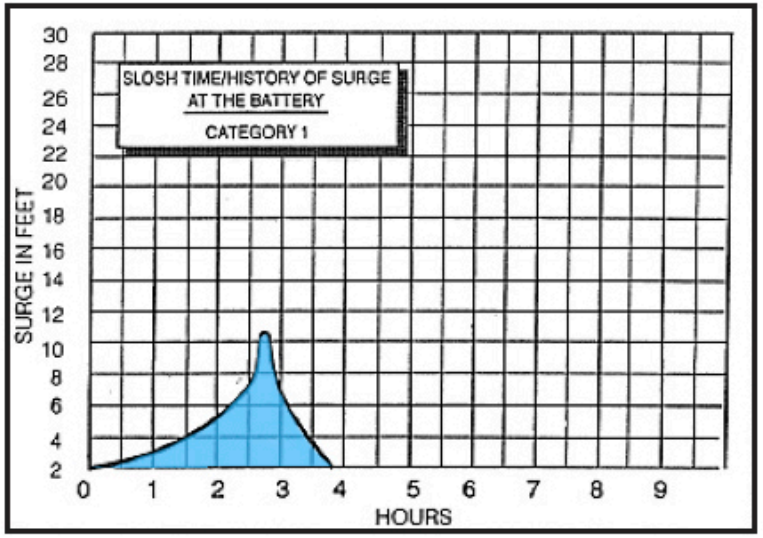
Metro New York Hurricane Transportation Study

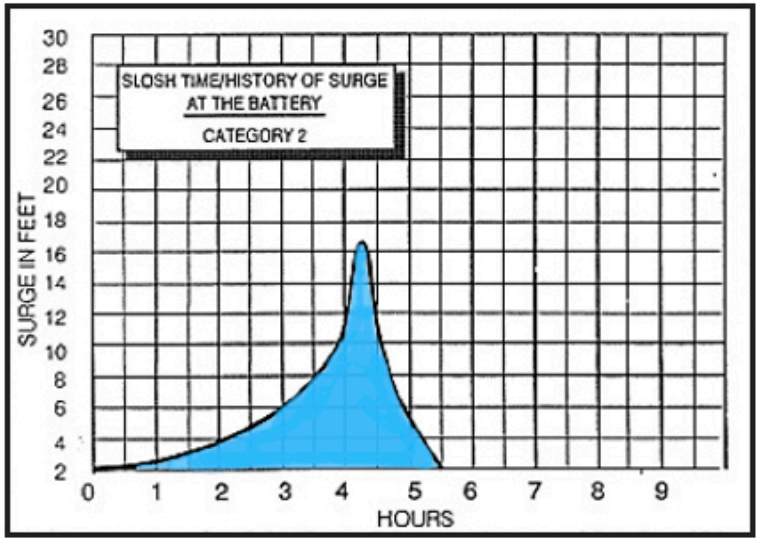
Figure 17- Potential Category 2 Hurricane Surge at South Ferry (Battery) Subway Station

Metro New York Hurricane Transportation Study

Table 13 – Facility Vulnerability

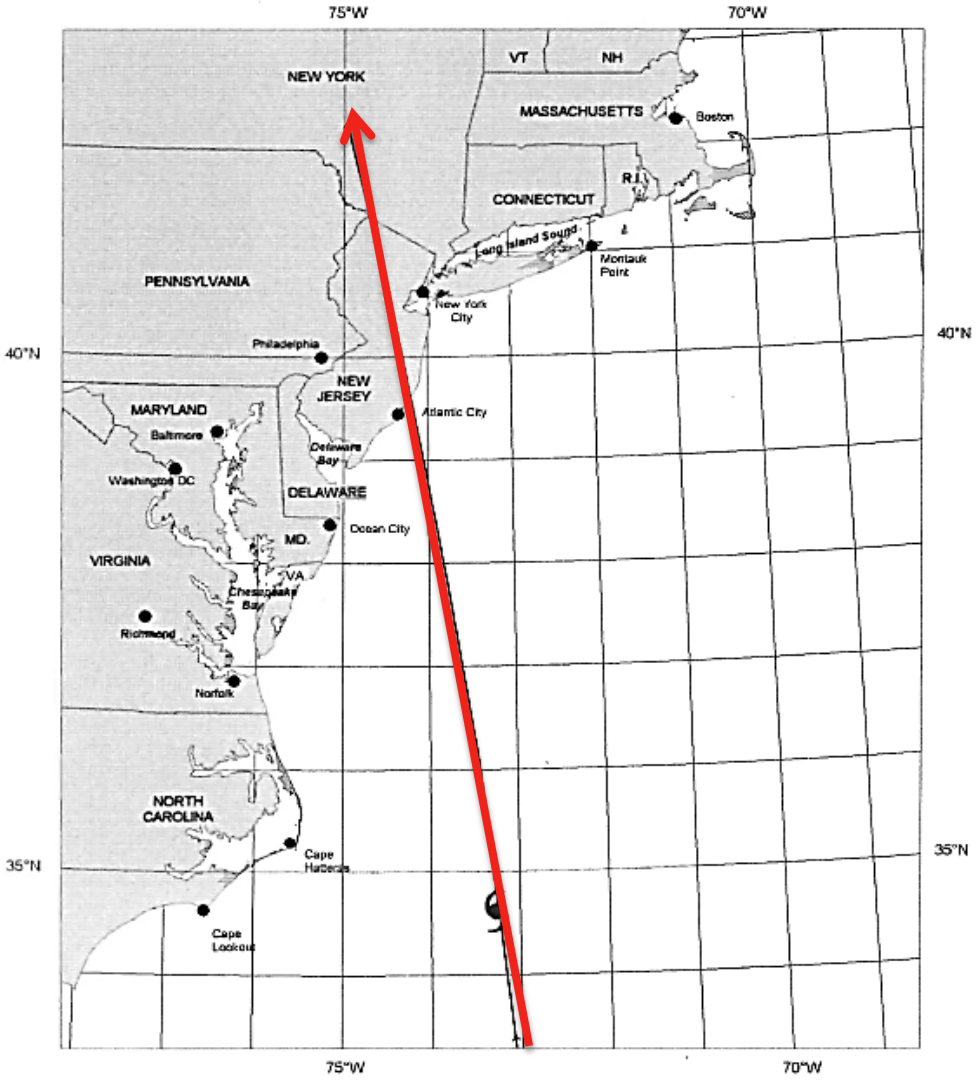
FACILITY	CRITICAL [1] ELEVATION (NGVD)	POTENTIAL HURRICANE SURGE (FT)[4] ABOVE NORMAL TIDE				TIME HAZARDS COULD OCCUR [3] SURGE/WIND			
		CAT 1	CAT 2	CAT 3	CAT 4	CAT 1	CAT 2	CAT 3	CAT 4
NYC TRANSIT AUTHORITY									
STATIONS									
World Trade Center	8.1	10.6 [4]	16.4 [4]	24.3 [4]	28.6 [4]	0.3/-	0.9/-	1.4/-	1.8/-
South Ferry	9.1	10.5 [4]	16.6	24.0	28.7	0.2/-	0.8/-	1.3/-	1.5/-
TUNNEL VENTS									
Cranberry Street	7.0	10.2 [4]	16.0 [4]	25.1 [4]	31.3 [4]	0.3/-	1.1/-	1.7/-	2.0/-
14th Street	7.2	9.7 [4]	14.7 [4]	22.0 [4]	24.9 [4]	0.2/-	1.0/-	1.6/-	1.8/-
Montague Street	7.5	10.5 [4]	16.6 [4]	24.0 [4]	28.7 [4]	0.3/-	1.0/-	1.6/-	1.8/-
Greenpoint (Newtown)	8.1	9.7 [4]	14.7 [4]	22.0 [4]	24.9 [4]	0.2/-	0.8/-	1.2/-	1.5/-
Clark Street	9.1	10.5 [4]	16.6 [4]	24.0 [4]	28.7 [4]	0.2/-	0.8/-	1.3/-	1.5/-
Joralemon Street	9.8	10.5 [4]	16.6 [4]	24.0 [4]	28.7 [4]	0.0/-	0.5/-	1.1/-	1.3/-
Lexington Avenue	9.9	8.4	12.7 [4]	16.4 [4]	20.4 [4]	0.0/-	0.3/-	0.6/-	1.0/-





Metro New York Hurricane Transportation Study

Figure 5 – Worst Case Track for Hurricanes Impacting the Metro NYC Area



Metro New York Evacuation Project

Metro New York Transportation Agencies

Hurricane Evacuation Study

Facilities Update and Evacuation Decision Tools

TECHNICAL DATA REPORT

Final Report

Completed September 2011

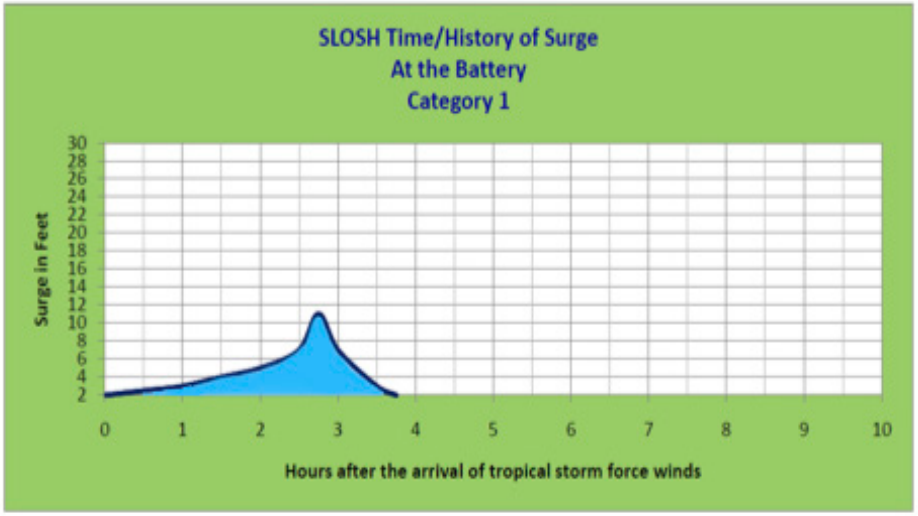
US Army Corps of Engineers

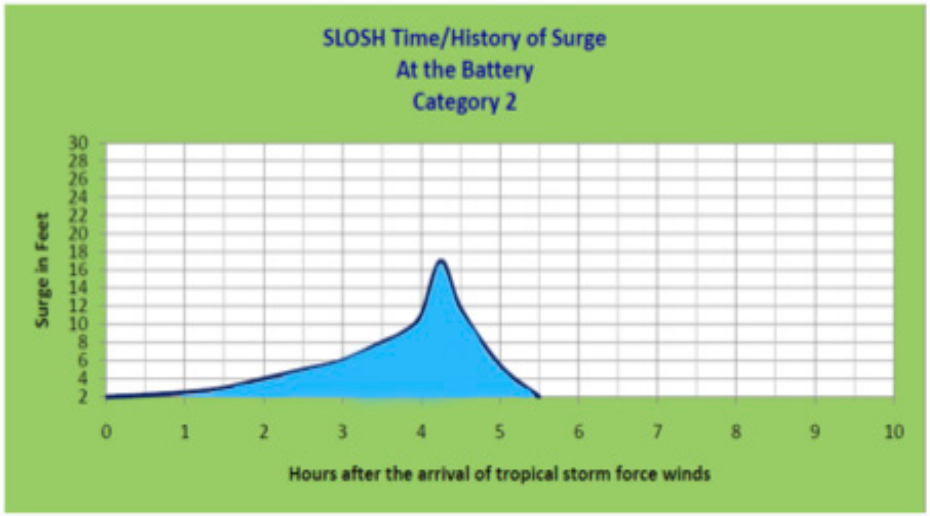
NOAA

OEM
New York City Office of Emergency Management

Metro New York Evacuation Project

Summary of Changes from 1995 to 2010

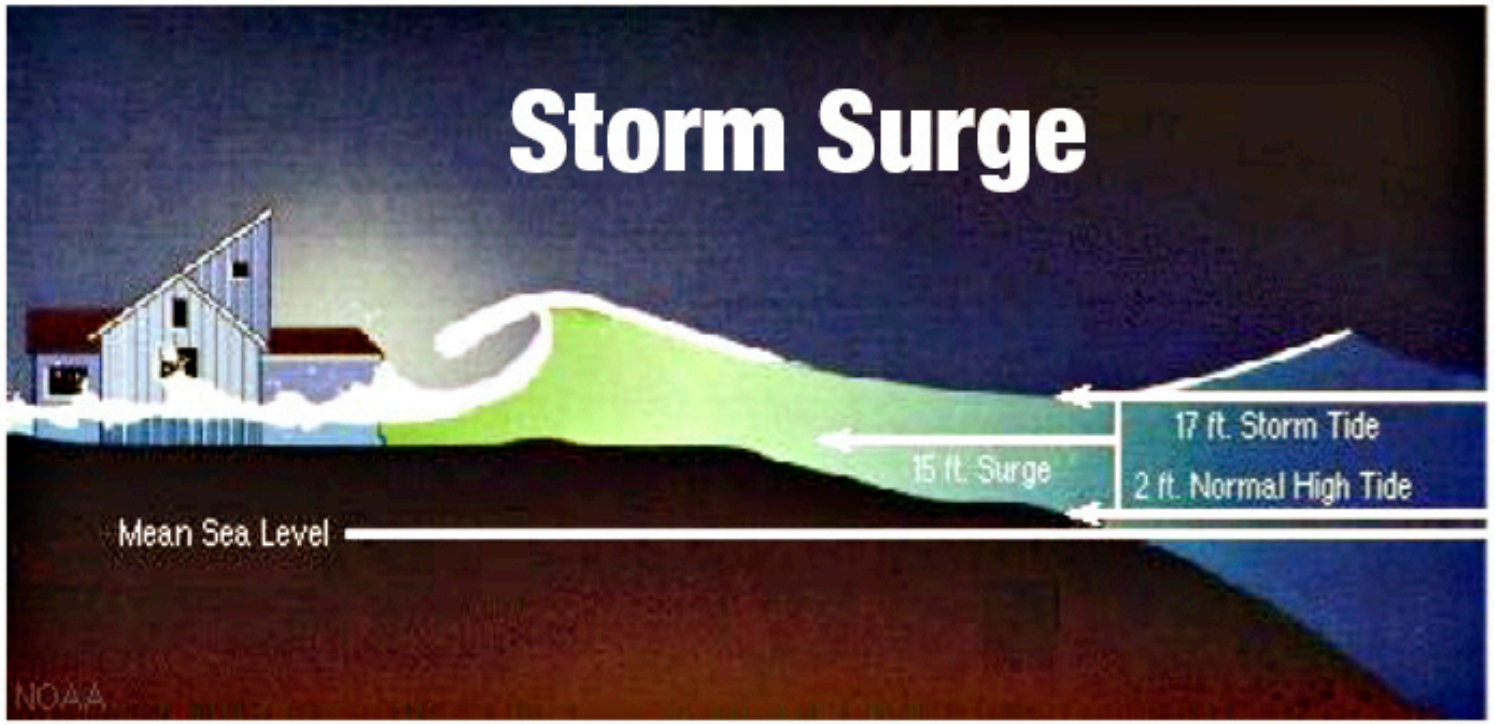




- Includes 327 transportation facilities in three states
- Data collected in new datum, NAVD88
- Integrates new SLOSH data from the 2010 model run
- Updates and refines mobilization/ decision, clearance, shutdown/closure, and pre-landfall hazard times for each facility.

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.



FEMA's F.I.R.M.s vs. SLOSH Maps

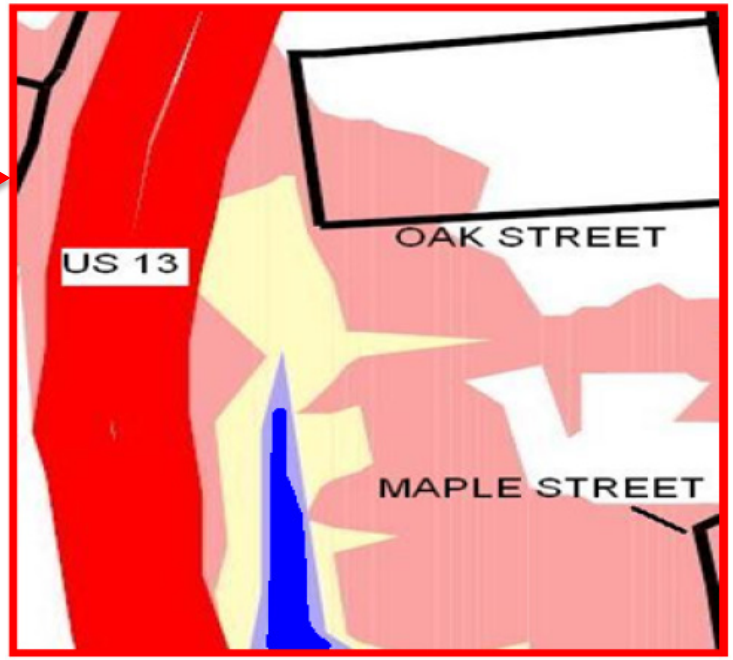
Below is an example of a F.I.R.M. (left) and an SSIM (right) for the same area.

"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"

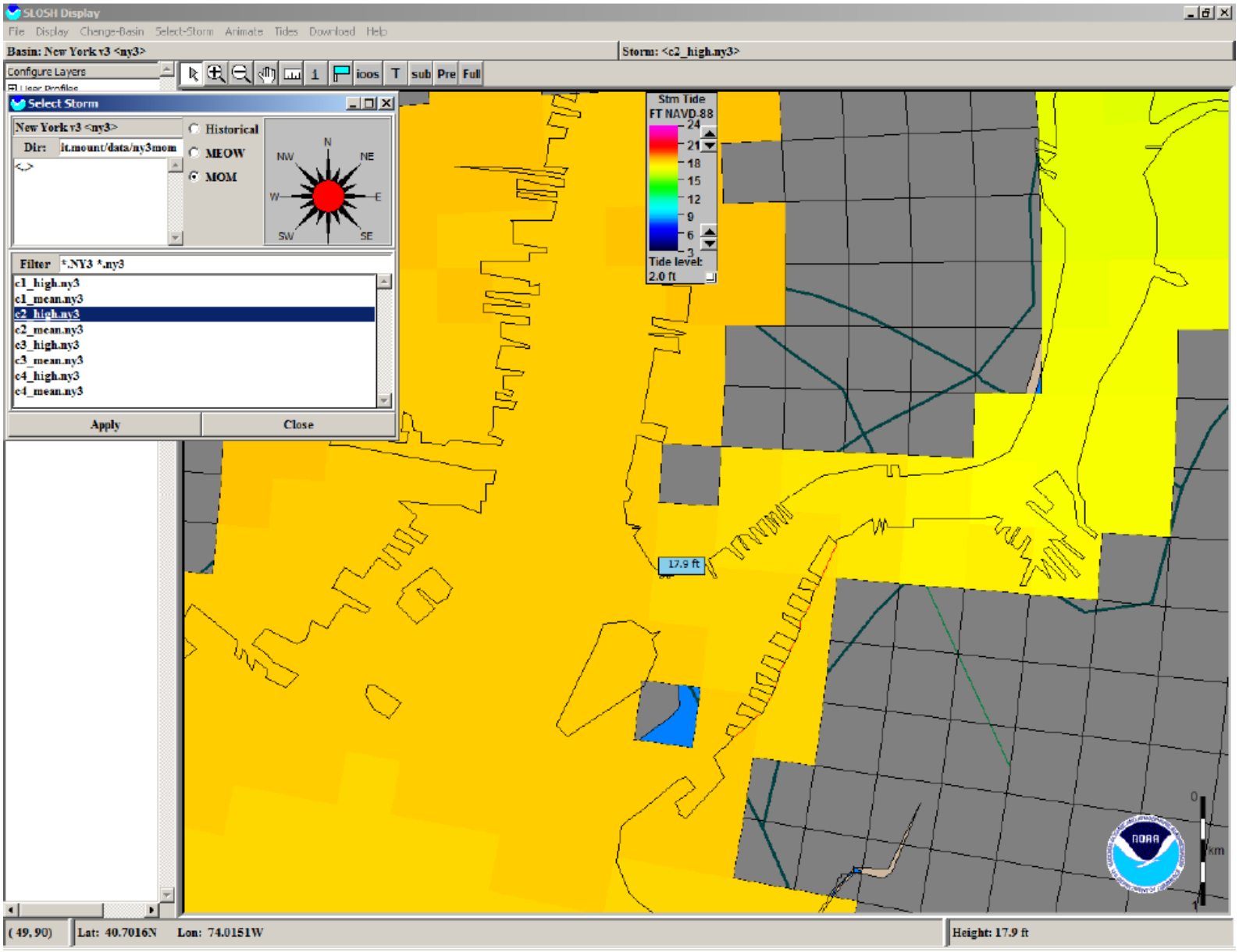
(a collaborative paper between U.S.A.C.E., NOAA & FEMA, Dec. 2011)

F.I.R.M (Flood Insurance Rate Map)

SSIM (Storm Surge Inundation Map)



SLOSH Display – Cat.2 Hurricane – Max. Surge



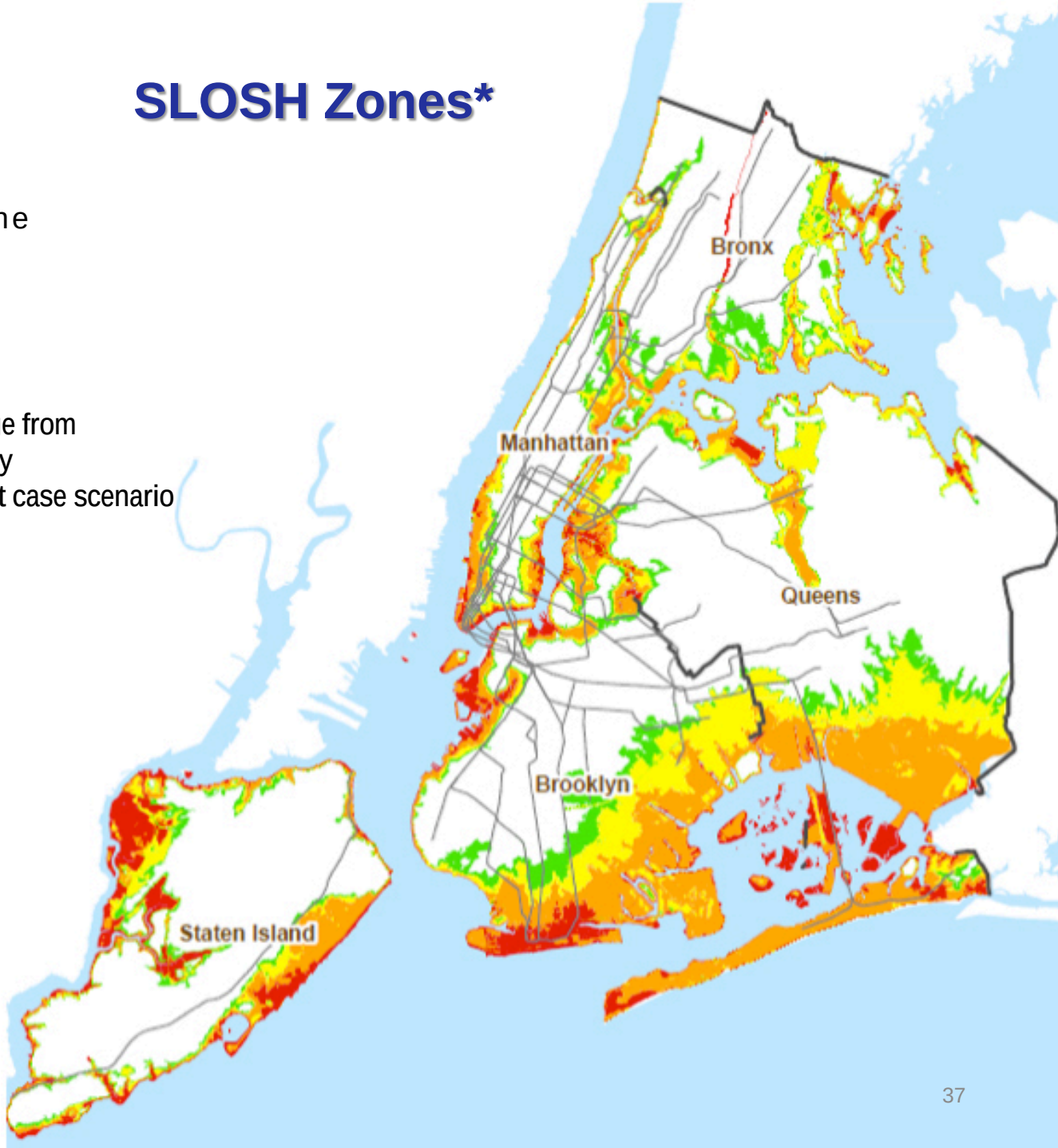
SLOSH Zones*

Category Hurricane

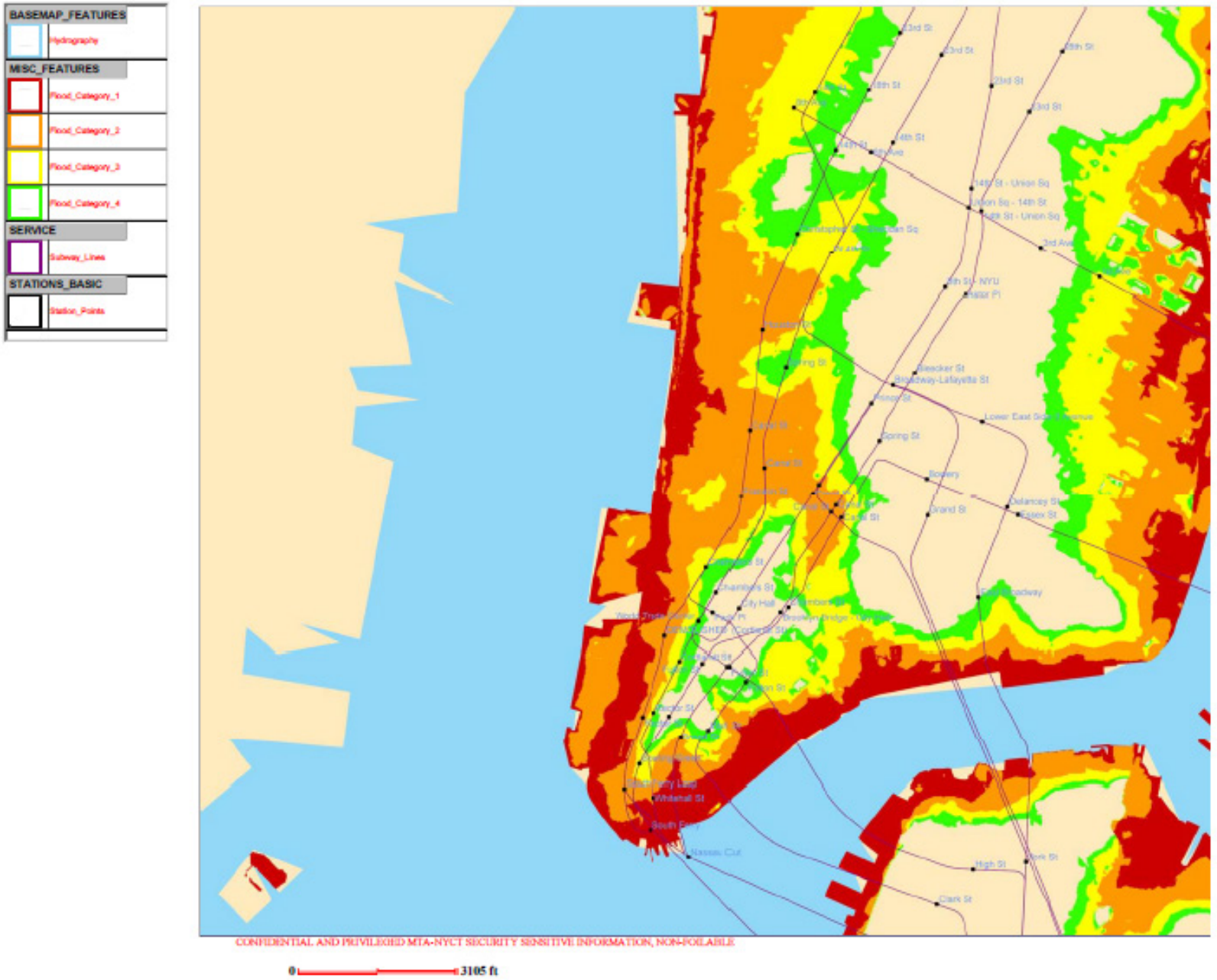
1 3

2 4

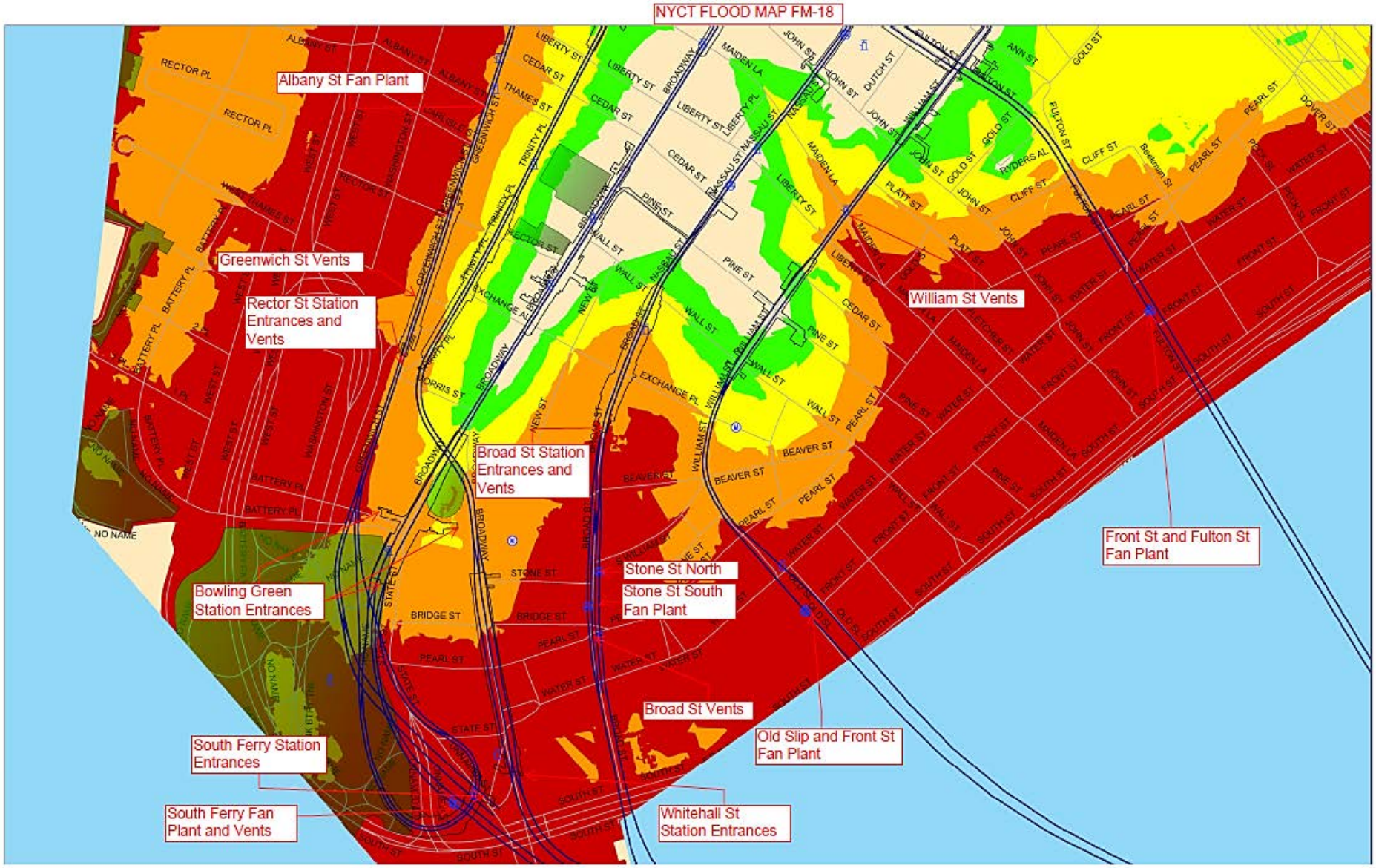
*Sea/Lake Overland Surge from Hurricanes inundation by Hurricane category worst case scenario



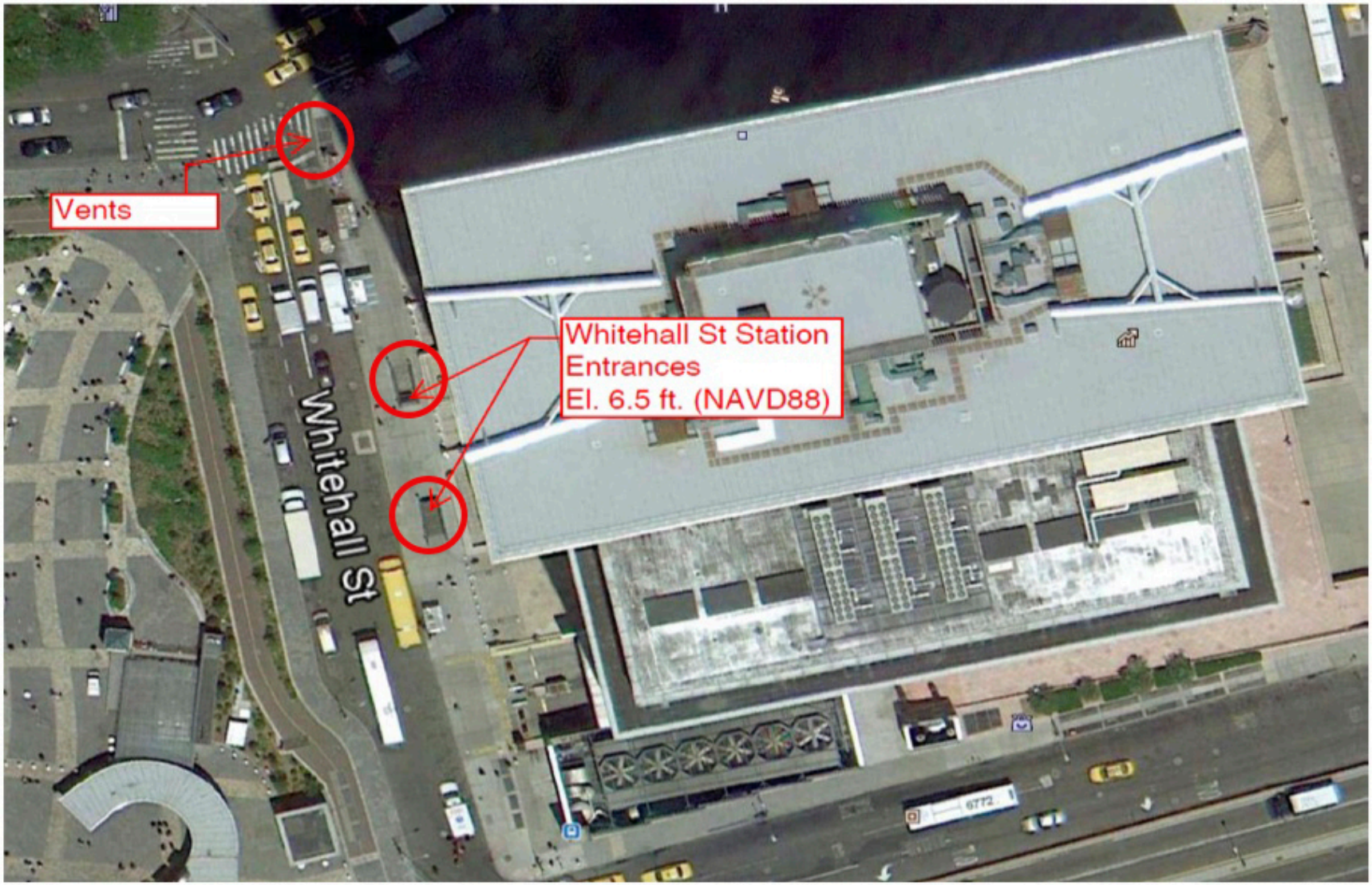
New York City Transit – T-Map



New York City Transit – Flood Map FM-18



Google Earth View of Whitehall St. Station Entrances



Google Street View of Whitehall St. Station Entrances

Sketch of Whitehall St. Station Entrances

Capital Program Management
Design & Engineering Services
Survey Subdivision

New York City Transit

CREW NAMES

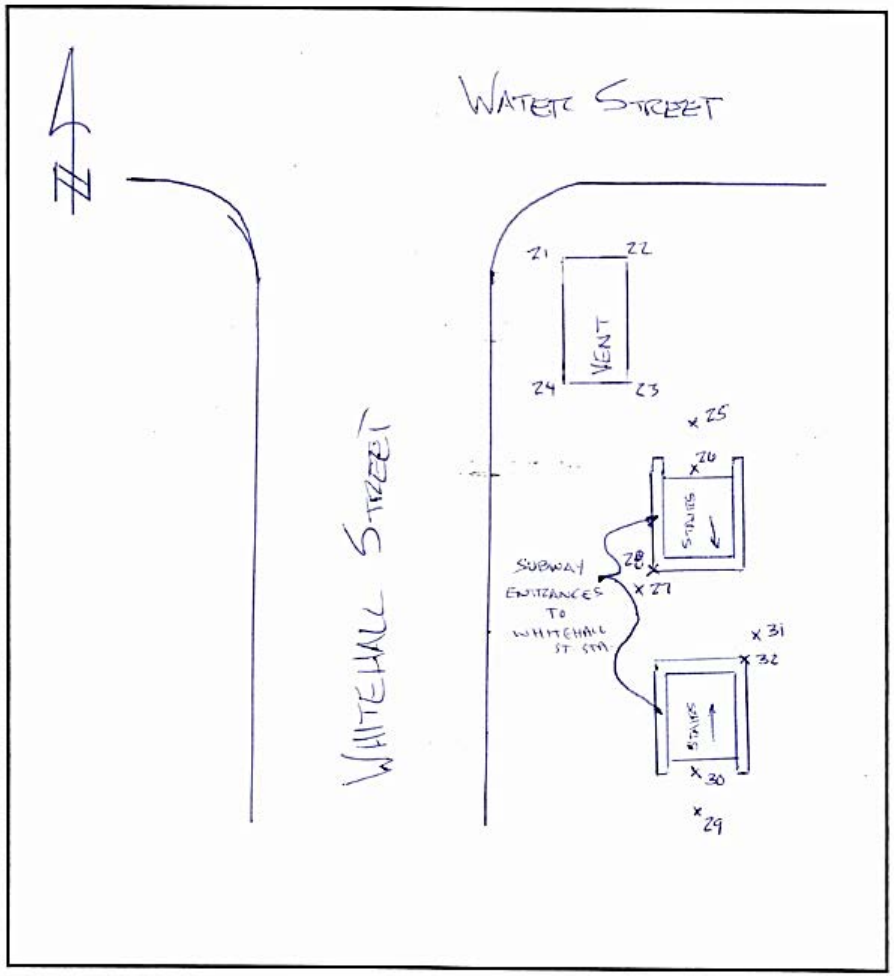
CONTRACT: R-30591 DATE: JUNE 20 '12 P. NAIK

PREPARED BY: D. NEEL CHECKED BY: P. NAIK V. PATWA

DESCRIPTION: Critical Facility - Elevations D. NEEL

LOCATION: White hall & Water st. MANH.

FILE NAME: _____ SHEET NO.: _____ OF _____



Survey Data (NAVD88) of Whitehall St. Station Entrances

Capital Program Management
Design & Engineering Services
Survey Subdivision

New York City Transit

CREW NAMES

CONTRACT: R-50591 DATE: 6/20/2012 P. NAIK

PREPARED BY: M.G. CHECKED BY: D.G. V. PATHAK

UNIT: US FEET DATUM: NAVD88 D. NOEL

LOCATION: Whitehall Street station, MH

DESCRIPTION: Critical Facilities - Whitehall Street Station Entrances, MH

FILE # r-50591_46-6_Whitehall Street station_navd88.xls SHEET NO.: 1 OF 1

PT #	B.S.	H.I.	F.S.	ELEV.	
580				15.890	B.M. KV0580 Tidal Bench, NAVD88 Ortho Ht. 15.89
99				10.775	Top of steel plate, S.W. Cor., at Elevator Shaft to
					South Ferry Station
21				6.58	Vent
22				6.63	"
23				6.67	"
24				6.57	"
25				6.76	N. Ent. To Whitehall Street Station
26				7.20	"
27				6.75	"
28				7.64	Top of concrete coping
29				6.46	S. Ent. To Whitehall Street Station
30				6.60	"
31				6.89	"
32				7.58	Top of concrete coping

MTA NYCT Critical Facilities List

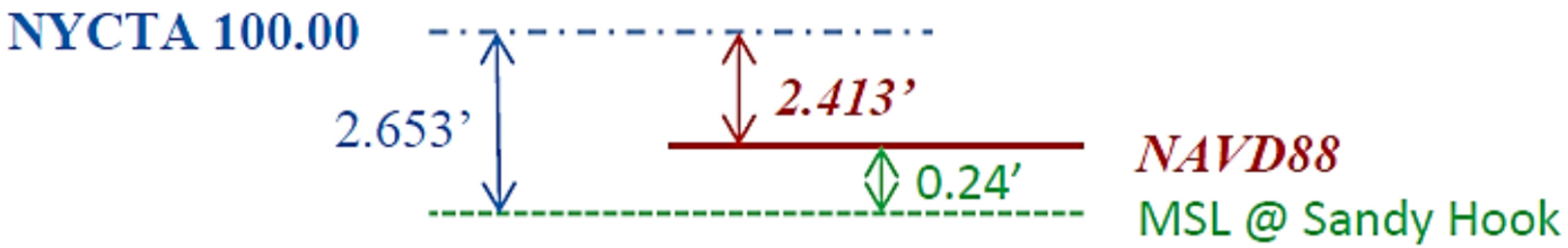
Critical Facility Name	Borough	NYCT Flood Map No.	Critical Facility Elevation in Feet from NYC OEM Lidar Data or NYCT's CPM Survey (NAVD88)	Critical Facility Elevation in Feet from the 1995 HEVAC Study (NAVD88)	Worst Case 2010 SLOSH Surge Elevations at High Tide in Feet (NAVD88)				Depth of Flooding by Category of Storm in Feet (NAVD88)			
					Cat 1	Cat 2	Cat 3	Cat 4	Cat 1	Cat 2	Cat 3	Cat 4
148th Street Portal	Manhattan	FM-2	*2.7*	*4.18*	9.1	16.1	22.5	28.1	6.4	13.4	19.8	25.4
Cranberry Street Tunnel-Front Street at Fulton Street Fan Plant	Manhattan	FM-18	5.6	*5.9*	11.5	17.7	23.8	29.1	5.9	12.1	18.2	23.5
207th Street Portal	Manhattan	FM-1	*3.9*	*5.71*	9.2	15.8	23.8	31.4	5.3	11.9	19.9	27.5
Broad St. Vents	Manhattan	FM-18	6.01	*N.A.*	11.6	17.9	24.0	29.2	5.6	11.9	18.0	23.2
Stone St South Fan Plant	Manhattan	FM-18	6.01	*N.A.*	11.6	17.9	24.0	29.2	5.6	11.9	18.0	23.2
IND 8th Ave. Canal St. Station Vents	Manhattan	FM-22	6.5	*7.6*	11.5	18.2	24.6	29.8	5.0	11.7	18.1	23.3
Whitehall St. Station Entrances below Water St.	Manhattan	FM-18	6.46	*8.0*	11.6	17.9	24.0	29.2	5.1	11.4	17.5	22.7
Rockaway Park Rail Yard	Queens	FM-30	*5.5*	*6.18*	8.4	16.0	21.7	27.6	2.9	10.5	16.2	22.1
Stone St North Fan Plant	Manhattan	FM-18	7.06	*N.A.*	11.6	17.9	24.0	29.2	4.5	10.8	16.9	22.1
IND 8th Ave. Canal St. Station Entrances	Manhattan	FM-22	7.6	*7.6*	11.5	18.2	24.6	29.8	3.9	10.6	17.0	22.2
14th Street Tunnel-Canarsie Line-14th Street at Avenue D Fan Plant	Manhattan	FM-14	*6*	*6.1*	10.6	16.4	22.0	27.6	4.6	10.4	16.0	21.6
Clark Street Tunnel-Old Slip at Front Street Fan Plant	Manhattan	FM-18	7.49	*8.0*	11.5	17.8	23.9	29.1	4.0	10.3	16.4	21.6
Westchester Rail Yard	Bronx	FM-26	*6.1*	*6.61*	Dry	16.0	23.5	28.5	Dry	9.9	17.4	22.4
Howard Beach Station - Rockaway line	Queens	FM-35	*8.4*	*N.A.*	Dry	18.3	24.9	31.5	Dry	9.9	16.5	23.1
148th Street Lenox Yard	Manhattan	FM-2	*6.5*	*6.75*	9.1	16.1	22.5	28.1	2.6	9.6	16.0	21.6

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:

NAVD88 = 0.24 feet above MSL



Therefore,

Elevation 100.00 NYCTA = 2.413 feet above NAVD88

MTA NYCT Revised Critical Facilities List

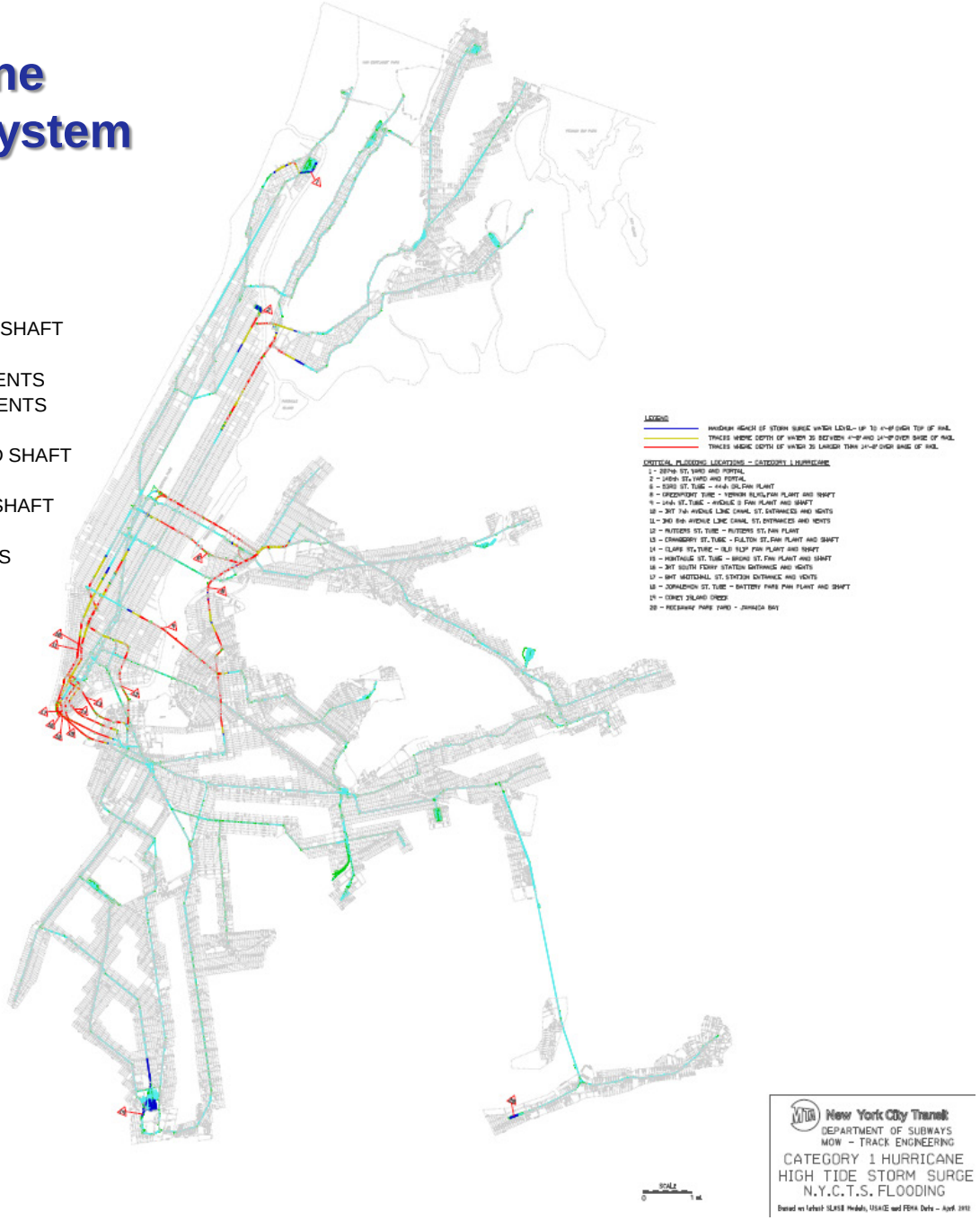
Storm Surge Elevations in NYCT Datum Added

Critical Facility Name	Borough	NYCT Flood Map No.	Critical Facility Elevation in Feet from NYC OEM Lidar Data or NYCT's CPM Survey (NAVD88)	Worst Case 2010 SLOSH Surge Elevations at High Tide in Feet (NAVD88)				Depth of Flooding by Category of Storm in Feet (NAVD88)				Worst Case 2010 SLOSH Surge Elevations at High Tide in Feet (T.O.R.* in NYCT Datum)			
				Cat 1	Cat 2	Cat 3	Cat 4	Cat 1	Cat 2	Cat 3	Cat 4	Cat 1	Cat 2	Cat 3	Cat 4
148th Street Portal	Manhattan	FM-2	2.7	9.1	16.1	22.5	28.1	6.4	13.4	19.8	25.4	107.16	114.16	120.56	126.2
Cranberry Street Tunnel-Front Street at Fulton Street Fan Plant	Manhattan	FM-18	5.6	11.5	17.7	23.8	29.1	5.9	12.1	18.2	23.5	109.56	115.76	121.86	127.2
207th Street Portal	Manhattan	FM-1	3.9	9.2	15.8	23.8	31.4	5.3	11.9	19.9	27.5	107.26	113.86	121.86	129.5
Broad St. Vents	Manhattan	FM-18	6.01	11.6	17.9	24.0	29.2	5.6	11.9	18.0	23.2	109.66	115.96	122.06	127.3
Stone St South Fan Plant	Manhattan	FM-18	6.01	11.6	17.9	24.0	29.2	5.6	11.9	18.0	23.2	109.66	115.96	122.06	127.3
IND 8th Ave. Canal St. Station Vents	Manhattan	FM-22	6.5	11.5	18.2	24.6	29.8	5.0	11.7	18.1	23.3	109.56	116.26	122.66	127.9
Whitehall St. Station Entrances below Water St.	Manhattan	FM-18	6.46	11.6	17.9	24.0	29.2	5.1	11.4	17.5	22.7	109.66	115.96	122.06	127.3
Rockaway Park Rail Yard	Queens	FM-30	5.5	8.4	16.0	21.7	27.6	2.9	10.5	16.2	22.1	106.46	114.06	119.76	125.7
Stone St North Fan Plant	Manhattan	FM-18	7.06	11.6	17.9	24.0	29.2	4.5	10.8	16.9	22.1	109.66	115.96	122.06	127.3
IND 8th Ave. Canal St. Station Entrances	Manhattan	FM-22	7.6	11.5	18.2	24.6	29.8	3.9	10.6	17.0	22.2	109.56	116.26	122.66	127.9
14th Street Tunnel-Canarsie Line-14th Street at Avenue D Fan Plant	Manhattan	FM-14	6	10.6	16.4	22.0	27.6	4.6	10.4	16.0	21.6	108.66	114.46	120.06	125.7
Clark Street Tunnel-Old Slip at Front Street Fan Plant	Manhattan	FM-18	7.49	11.5	17.8	23.9	29.1	4.0	10.3	16.4	21.6	109.56	115.86	121.96	127.2
Westchester Rail Yard	Bronx	FM-26	6.1	Dry	16.0	23.5	28.5	Dry	9.9	17.4	22.4	Dry	Dry	Dry	126.6
Howard Beach Station - Rockaway line	Queens	FM-35	8.4	Dry	18.3	24.9	31.5	Dry	9.9	16.5	23.1	Dry	116.36	122.96	129.6
148th Street Lenox Yard	Manhattan	FM-2	6.5	9.1	16.1	22.5	28.1	2.6	9.6	16.0	21.6	107.16	114.16	120.56	126.2

Potential Cat. 1 Hurricane Flooding in the NYCT System

CRITICAL FLOODING LOCATIONS

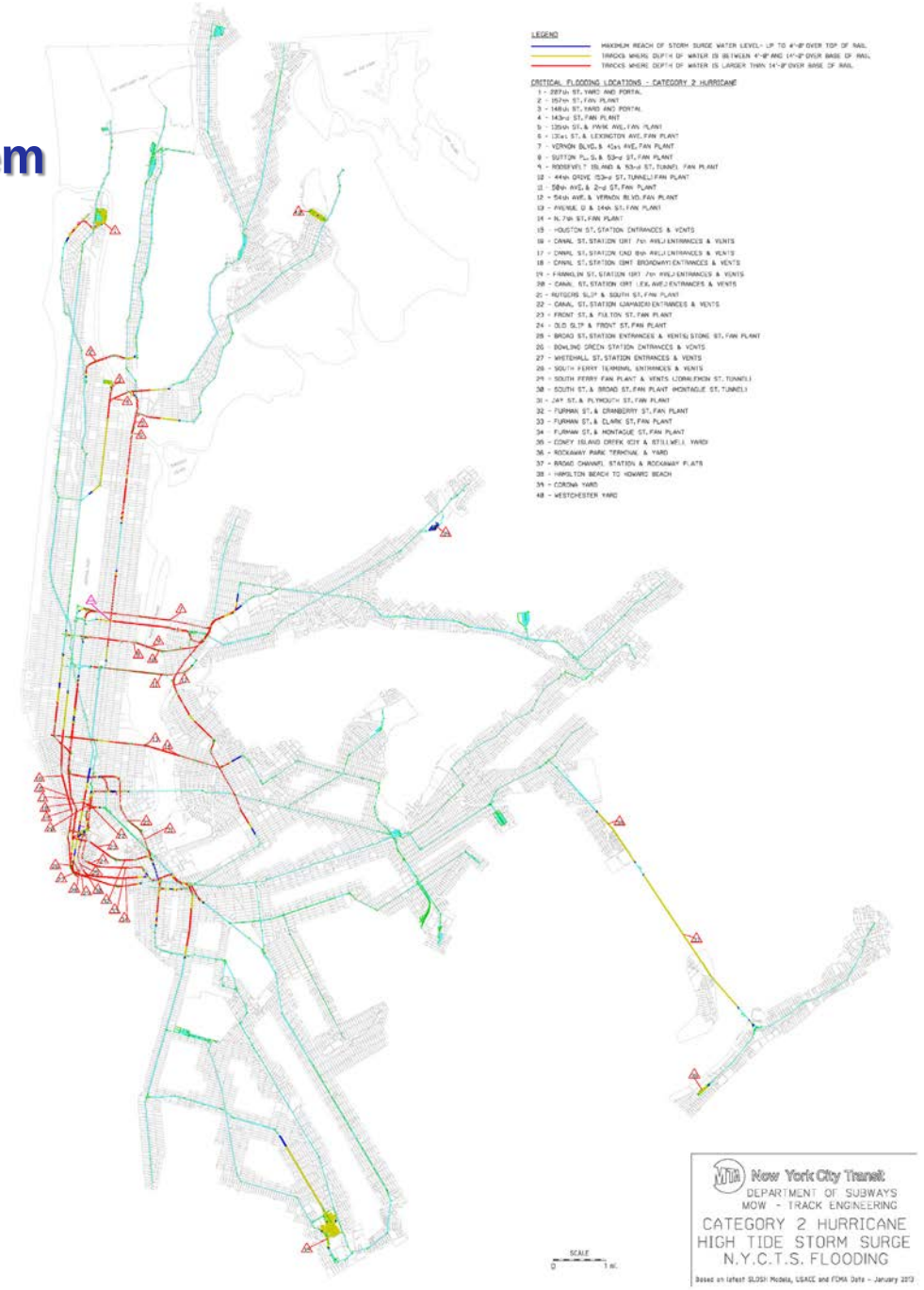
1 - 207th ST. YARD AND PORTAL
2 - 148th ST. YARD AND PORTAL
6 - 53RD ST. TUBE - 44th DR. FAN PLANT
8 - GREENPOINT TUBE - VERNON BLVD. FAN PLANT AND SHAFT
9 - 14th ST. TUBE - AVENUE D FAN PLANT AND SHAFT
10 - IRT 7th AVENUE LINE CANAL ST. ENTRANCES AND VENTS
11 - IND 8th AVENUE LINE CANAL ST. ENTRANCES 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

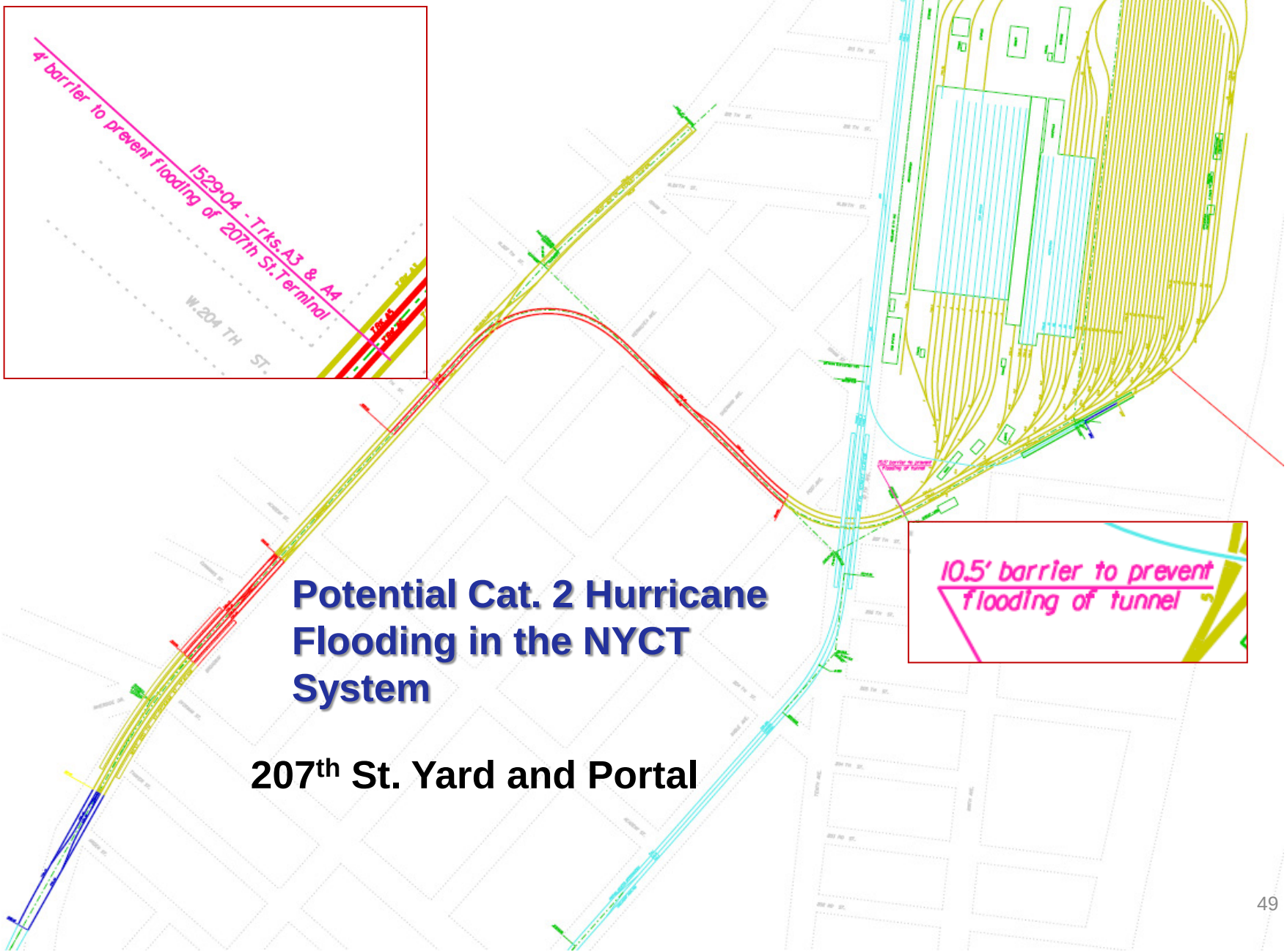


Potential Cat. 2 Hurricane Flooding in the NYCT System

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



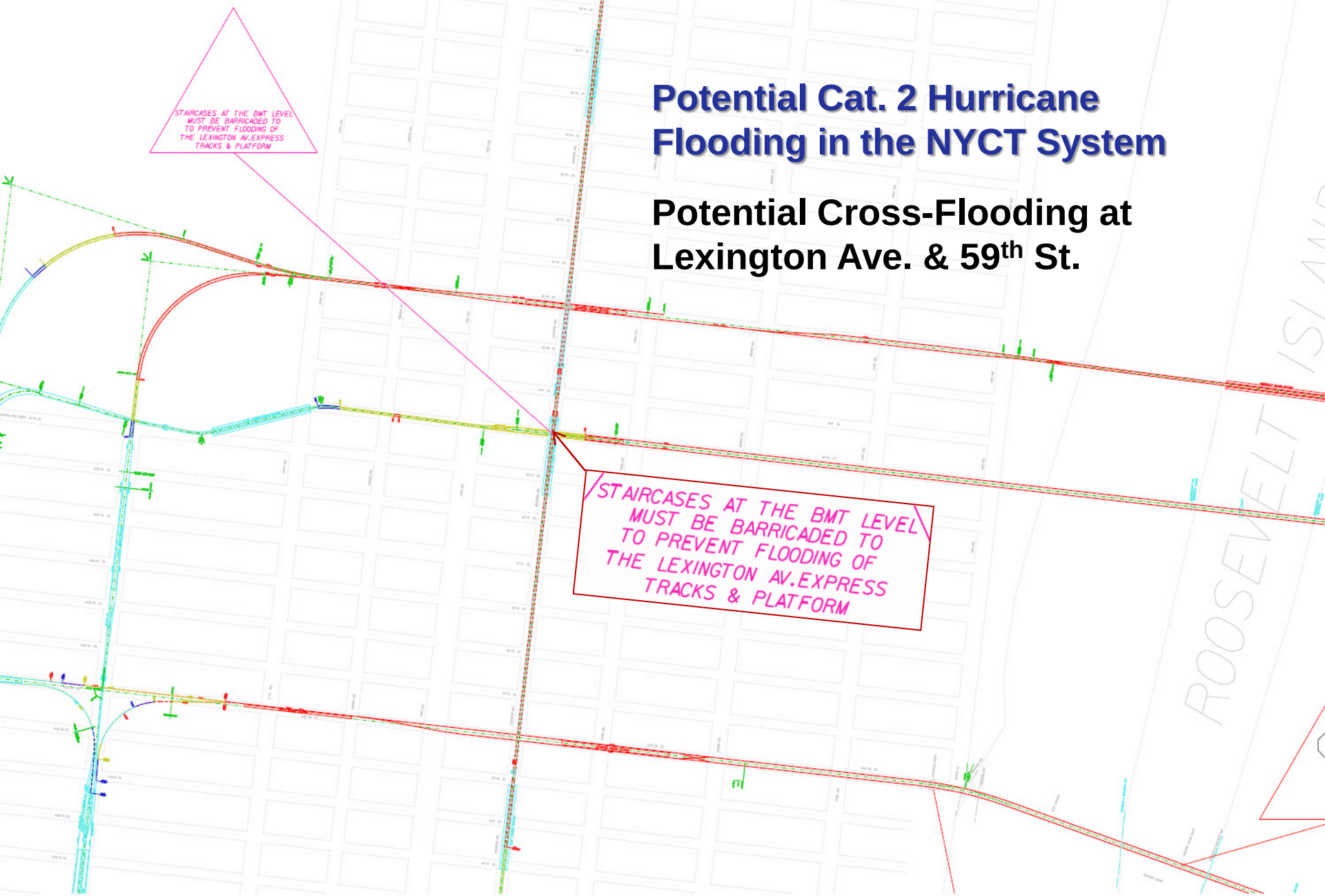


Potential Cat. 2 Hurricane Flooding in the NYCT System

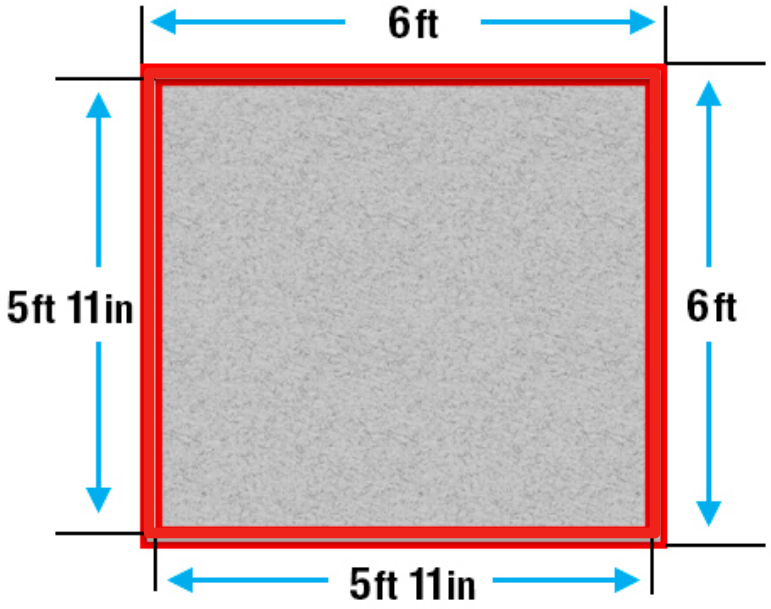
207th St. Yard and Portal

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

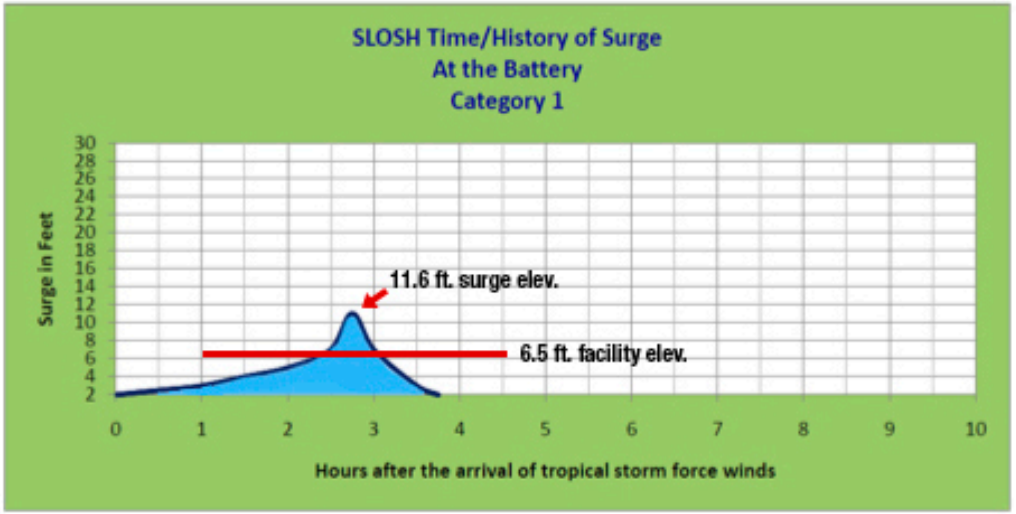
Q = 9.25 cu. ft./sec = 4,152 gal/min = **249,120 gal/hr.**

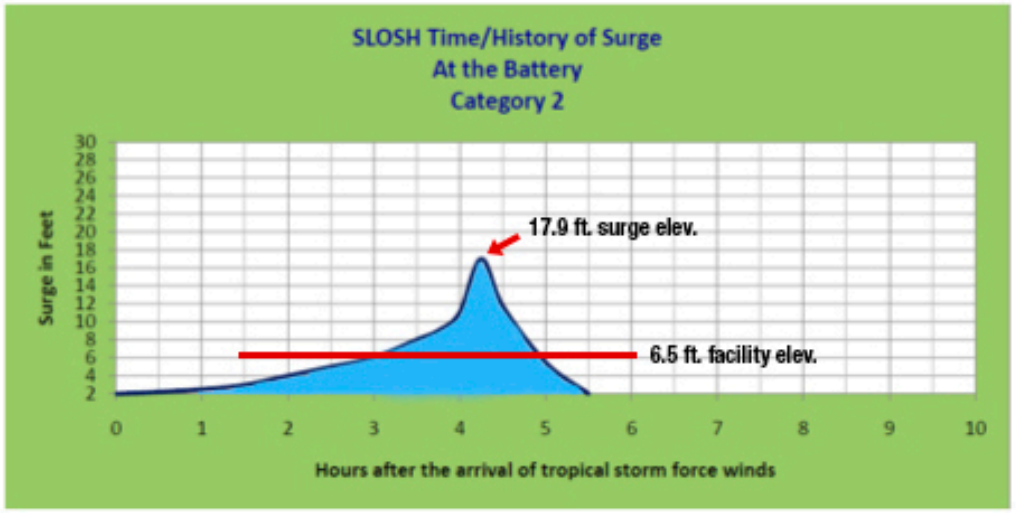
In 4 hours approximately 1 M gallons **would have entered**

PATH Hoboken Station: Flooding Through Closed Door

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



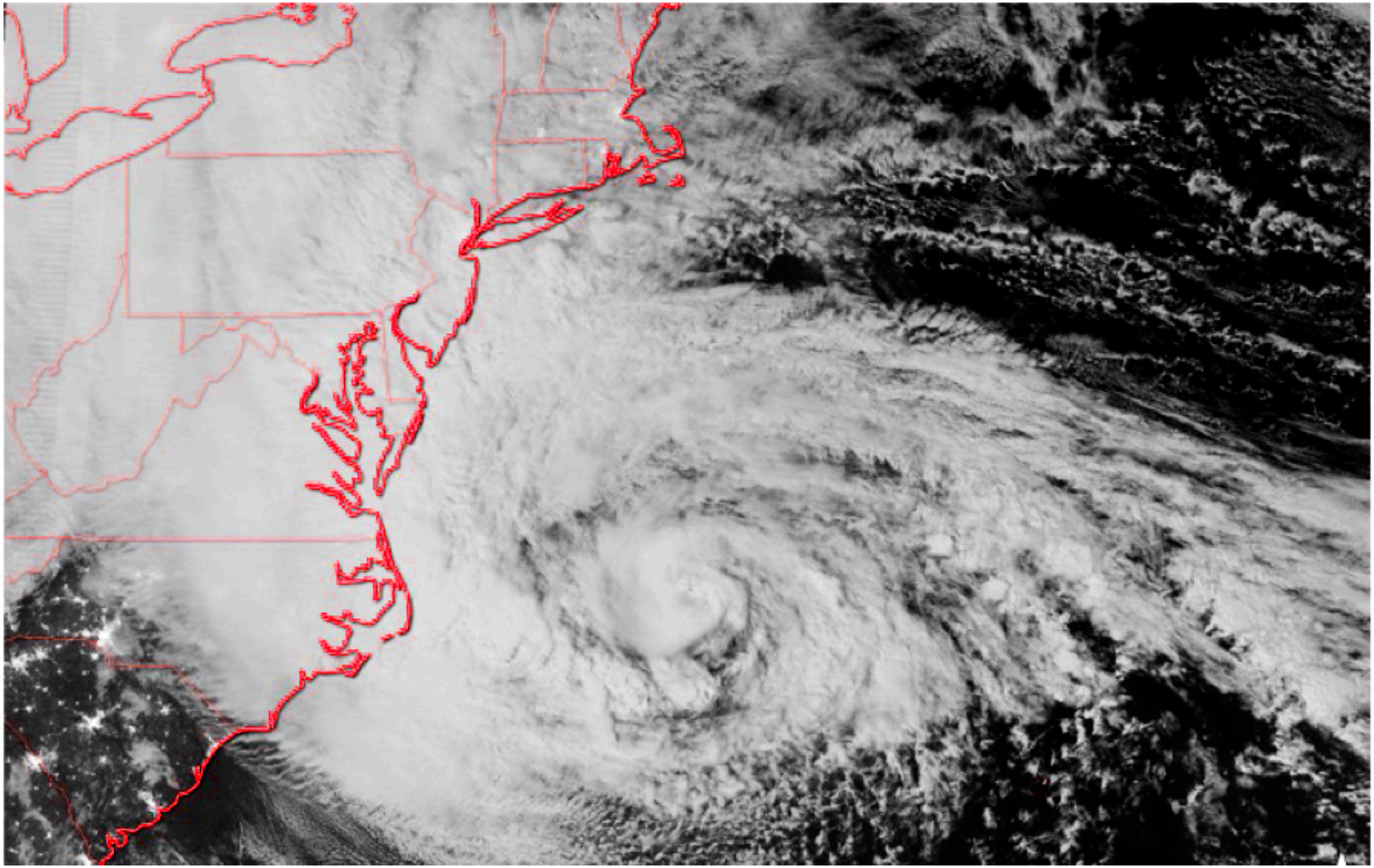


Case Study: Category 1 and 2 Hurricane Surges

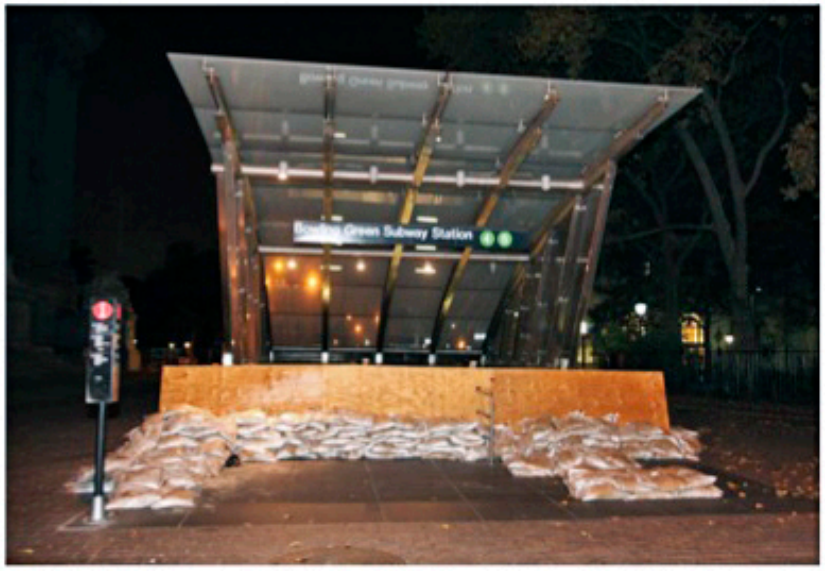
- Two entrances and adjacent vents affected. Area of openings: 270 sq. ft.
- Duration: 40 min. (Cat. 1) or 100 min. (Cat. 2)
- Max. Flood Height: 5.1 ft. (Cat. 1) or 11.4 ft. (Cat. 2)

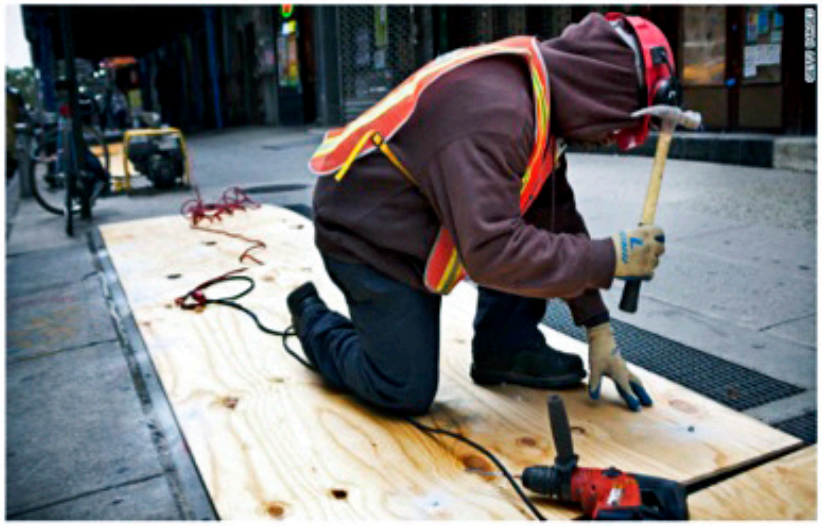
- Cat. 1: in 40 minutes, a total of **36 M gal.** of water would enter
- Cat. 2: In 100 minutes, a total of **117 M gal.** of water would enter
- The Montague St. Tunnel (having a total volume of 26.5 M gal.) will completely flood in 30 minutes under the Cat. 1 surge; and it will completely flood in less than 25 minutes under the Cat. 2 surge
- The excess water will migrate North and South of the tube to flood adjacent areas

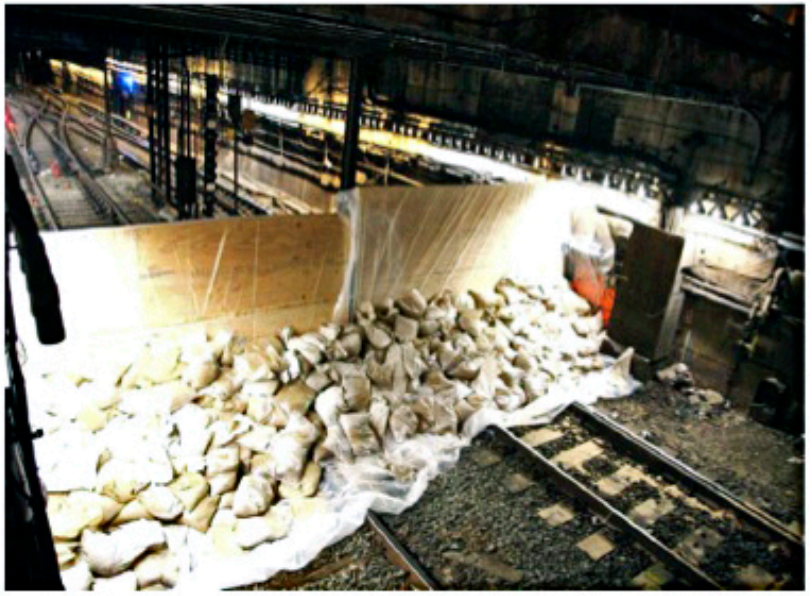
Hurricane Sandy Approaching the NJ Coast – October 29, 2012

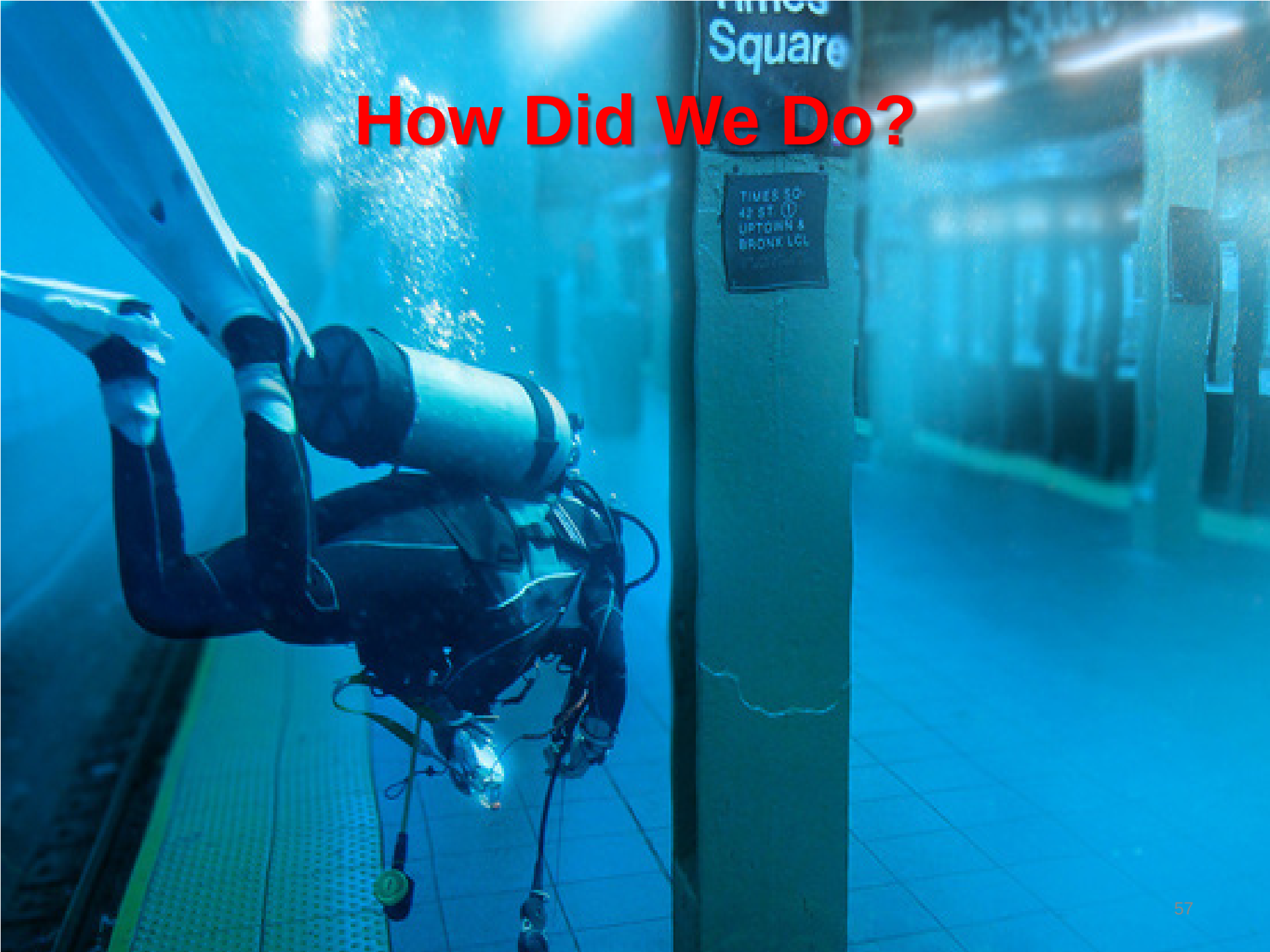


Precautions Were Taken Using the SLOSH Data and Flood Maps

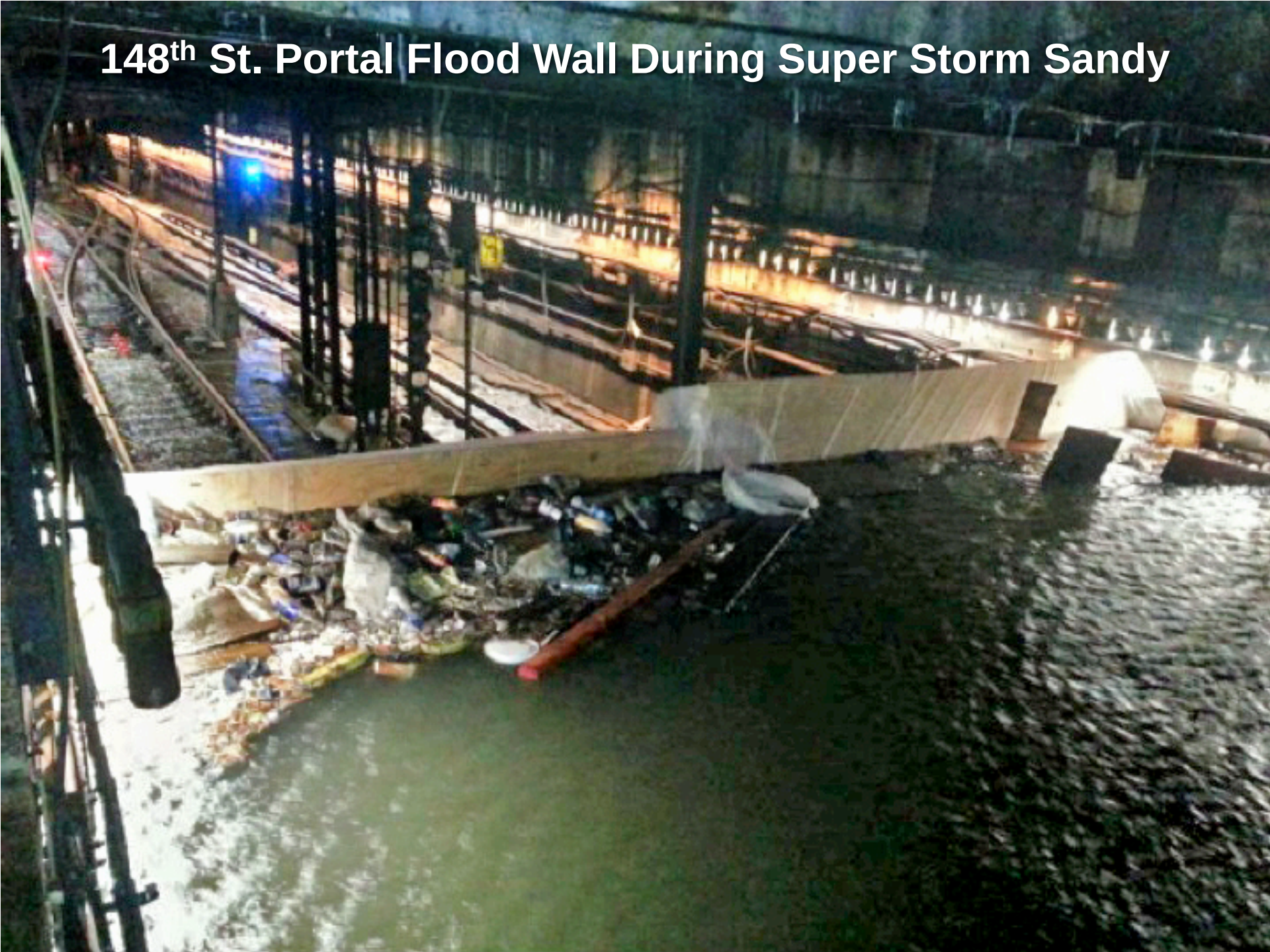







How Did We Do?
Square

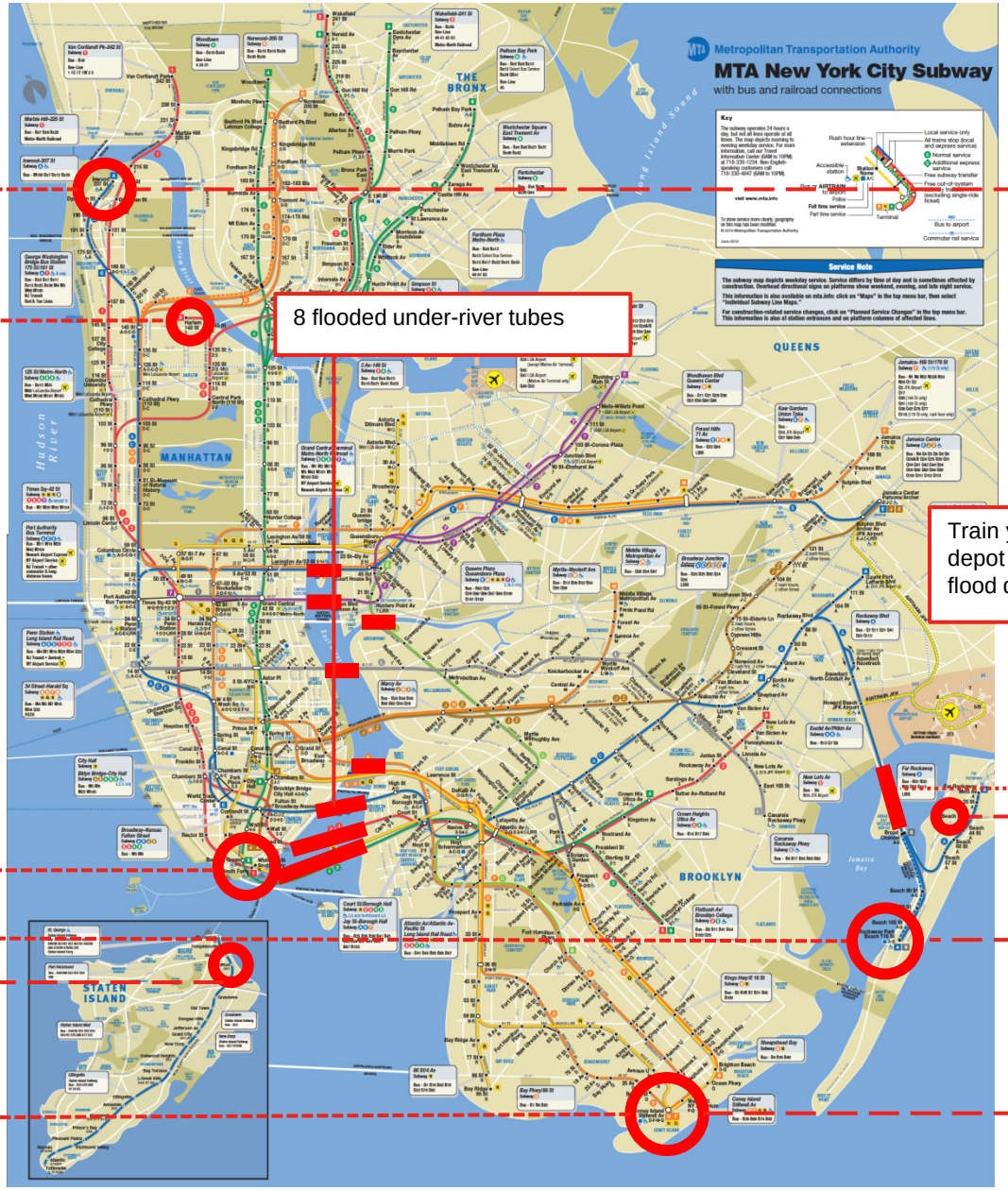
148th St. Portal Flood Wall During Super Storm Sandy



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 flooded under-river tubes

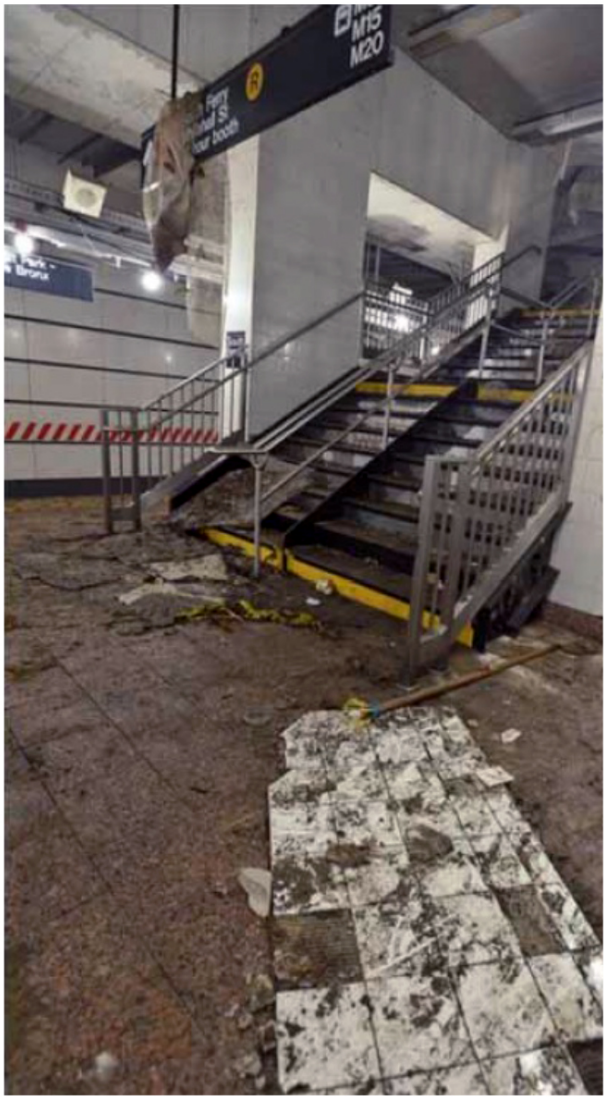
8 stations with major flood damage – South Ferry, Whitehall, 148th St, 207th St, Dyckman, Beach 116th Station, 86th St Sea Beach, Stillwell

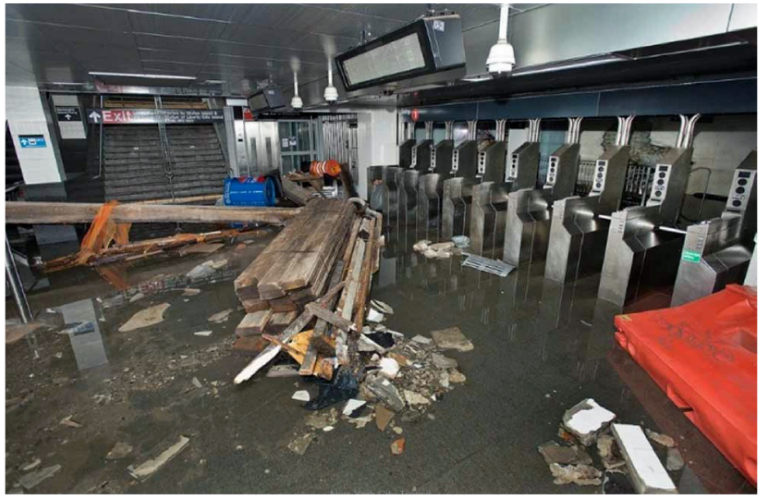
Train yards and bus depot with significant flood damage

Rockaways track washout

Staten Island Railway maintenance shop major flood damage

Flooding at the New South Ferry Terminal



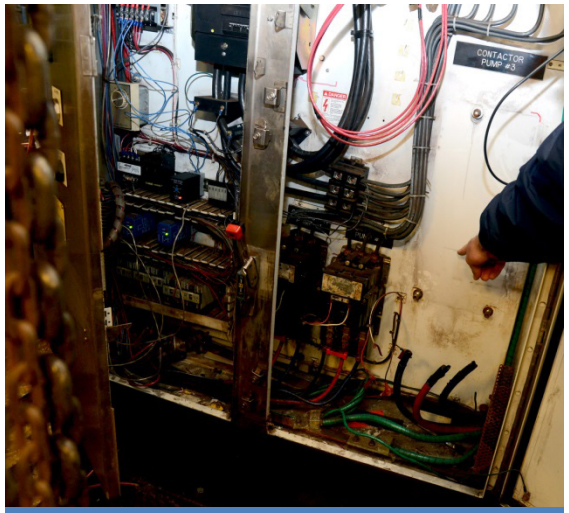


Sandy damage to under river tubes was historic

Flooded track and equipment

Destroyed pump control

Shorted electrical equipment



Damaged fan control

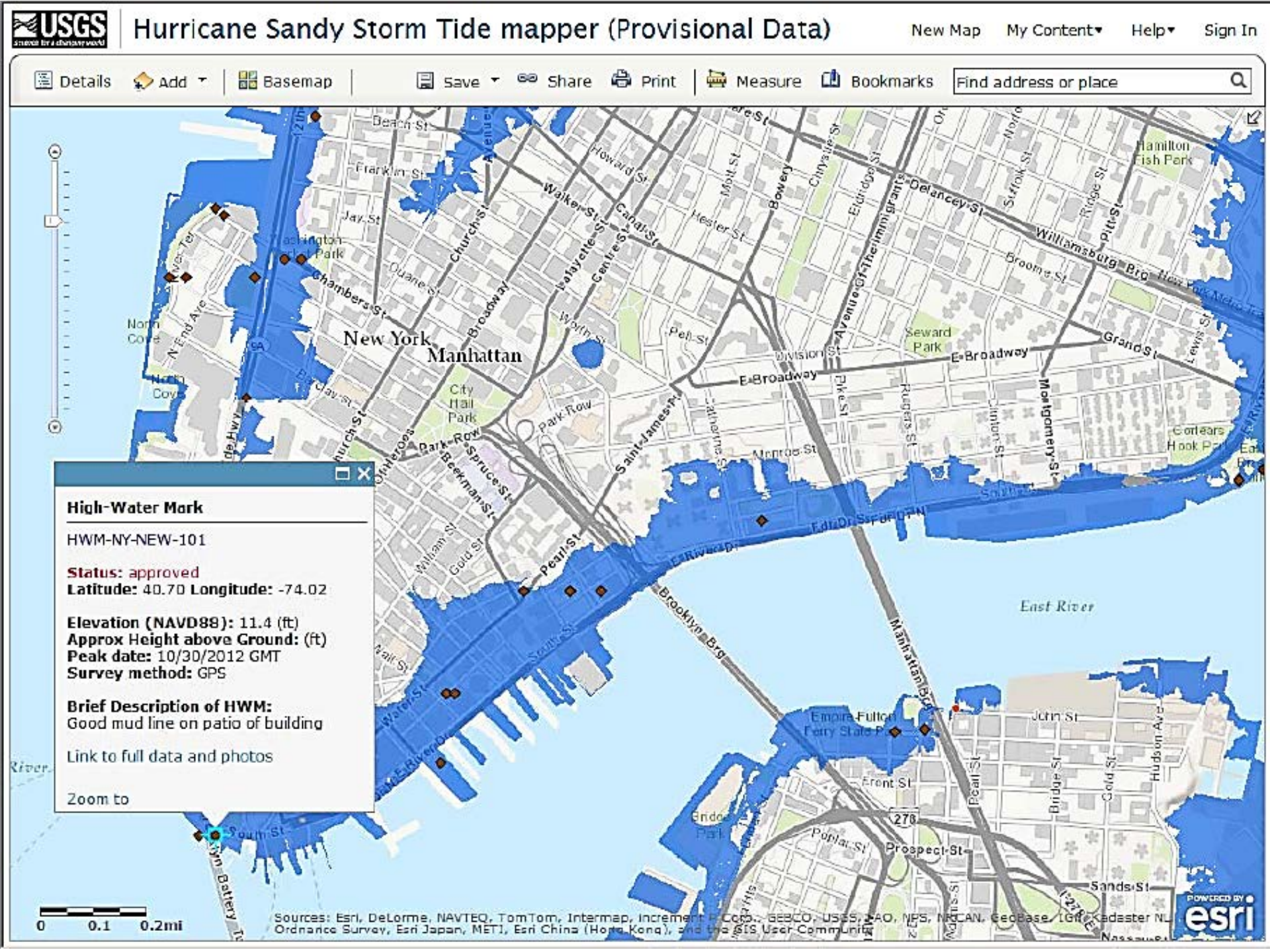
Failed signals

Broken communication gear

Rail and Fastener Damage in Flooded Tubes

Subway Flooding After Hurricane Sandy

UNDER RIVER TUBE	RADIUS	NO. OF TUBES	LENGTH OF THE FLOOD	DEPTH OF THE FLOOD	GALLONS IN MILLONS
RUTGERS ST.	7'-10 1/2"	2	1000	8 ft	1.5
JORALEMON ST.	7'- 9"	2	0	0	0
MONTAGUE ST.	10' -3"	2	4025	20 ft	27
CRANBERRY ST.	7'-10 1/2"	2	1000	8 ft	1.5
CLARK ST.	7' -6"	2	600	4 ft	0.5
161st ST.	7'-10 1/2"	3	0	0	0
60th ST.	7' -6"	2	0	0	0
53rd ST.	7' -6"	2	800	4 ft	0.5
14th ST.-CANARSIE	7'- 9"	2	2700	15 ft	7
63rd ST.	9'-2"	2	0	0	0
149th ST.-HARLEM R.	25'-0"	2	0	0	0
LEX. AVE.-PELHAM	2x 8'-9"+2x6'-6"	4	0	0	0
GREENPOINT	7'-10 1/2"	2	1000	15 ft	3
STEINWAY	7'- 9"	2	1000	6 ft	1
SOUTH FERRY TERMINAL STATION					14.5
207th St YARD LEADS					9


USGS
Hurricane Sandy Storm Tide mapper (Provisional Data)
New Map
My Content
Help
Sign In
Details
Add
Basemap
Save
Share
Print
Measure
Bookmarks
Find address or place
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
New York
Manhattan
East River
0
0.1
0.2mi
Sources: Esri, DeLorme, NAVTEQ, TomTom, Intermap, increment P Corp., GEBCO, USGS, FAO, NPS, NRCAN, GeoBase, IGN, Kadaster NL, Ordnance Survey, Esri Japan, METI, Esri China (Hong Kong), and the GIS User Community
esri

86th St. Station – Sea Beach Line – HWM = 10.2 ft.

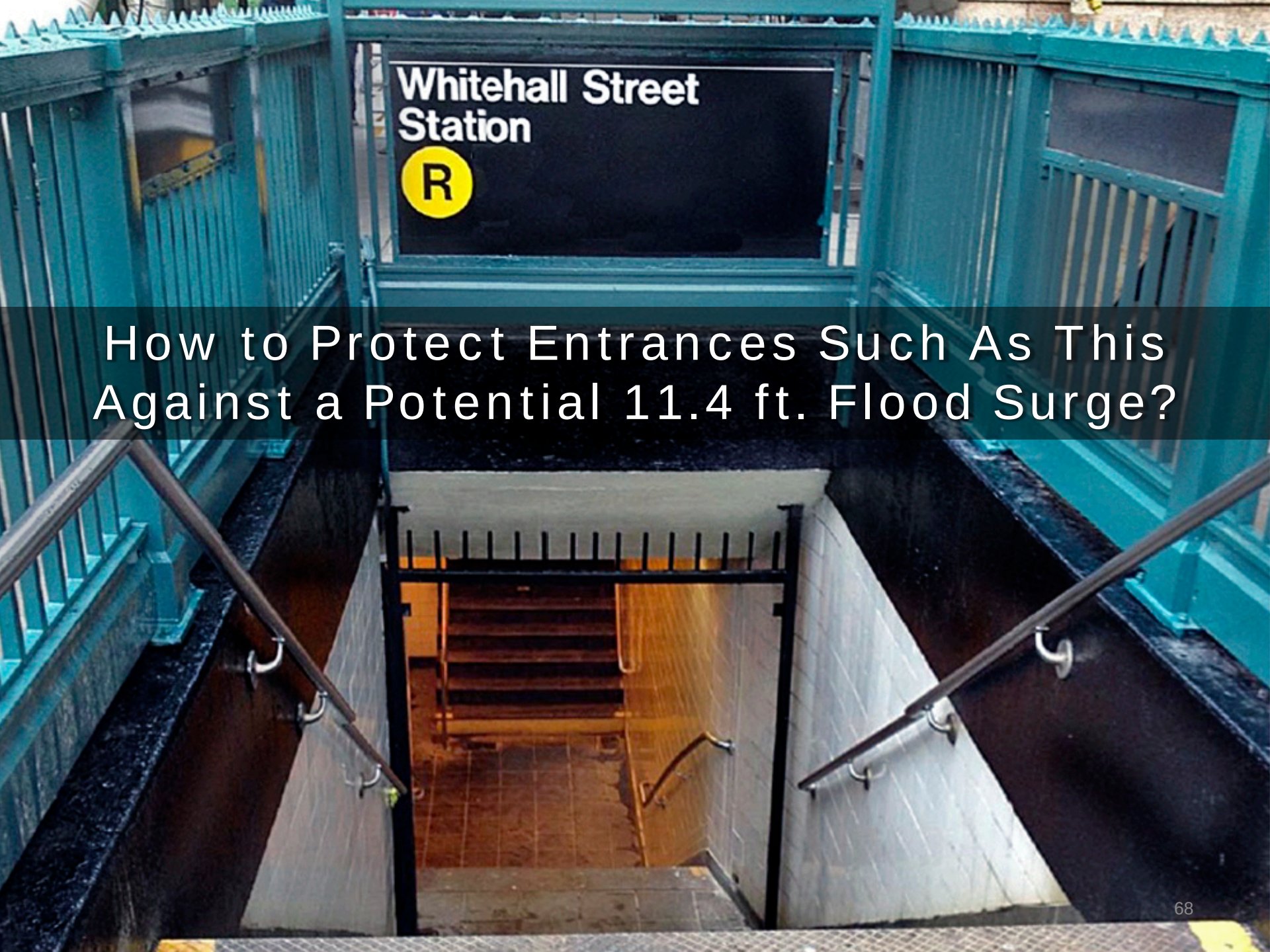
Rockaway Line Damage

Rockaway Flats

Remediation and Mitigation Work (Ongoing)

Before (November 2012)

After (January 2013)



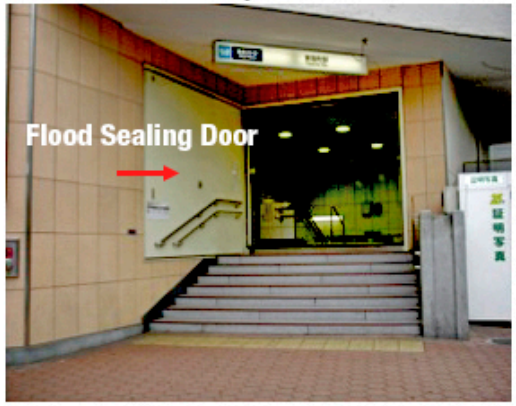
How to Protect Entrances Such As This Against a Potential 11.4 ft. Flood Surge?

Example: Flood Defense Measures Worldwide

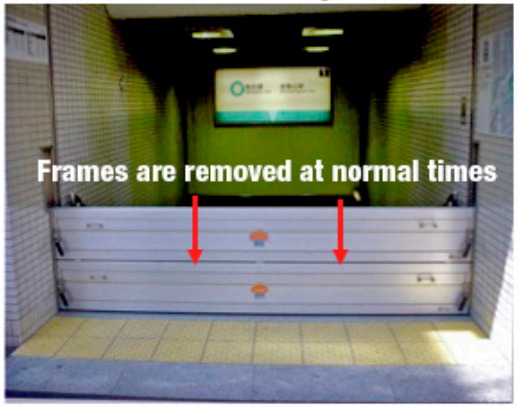
Example: Conventional Flood Defense Measures of Tokyo Metro

Flood Wall at the Kitasenju Outlet of the Chiyoda Line Tunnel

Flood Sealing Door
at an Entrance of the Toyocho Station



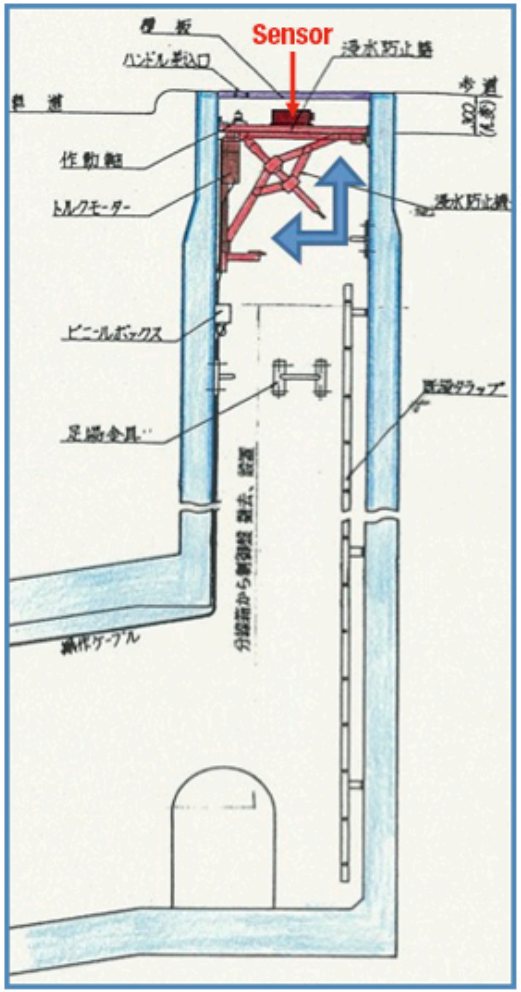
Frame Barrier
at an Entrance of the Honkomagome Station



Flood Gate in a Tube

Example: Conventional Flood Defense Measures of Tokyo Metro

Automatic Shutter to Prevent Flood Flow



Cross Section

Outlet of a Ventilation Duct

Manual Operation in Case of Malfunction of Automatic Shutter

OPEN

View of an Automatic Shutter

CLOSED

Example: Enhanced Flood Defense Measures of Tokyo Metro

Structural Measures

Ventilation Outlet located between Kitasenju and Machiya on Chiyoda Line

Ventilation Outlet located between Ojikamiya and Shimo on Nanboku Line

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

SLATS/FRAME BARRIERS

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

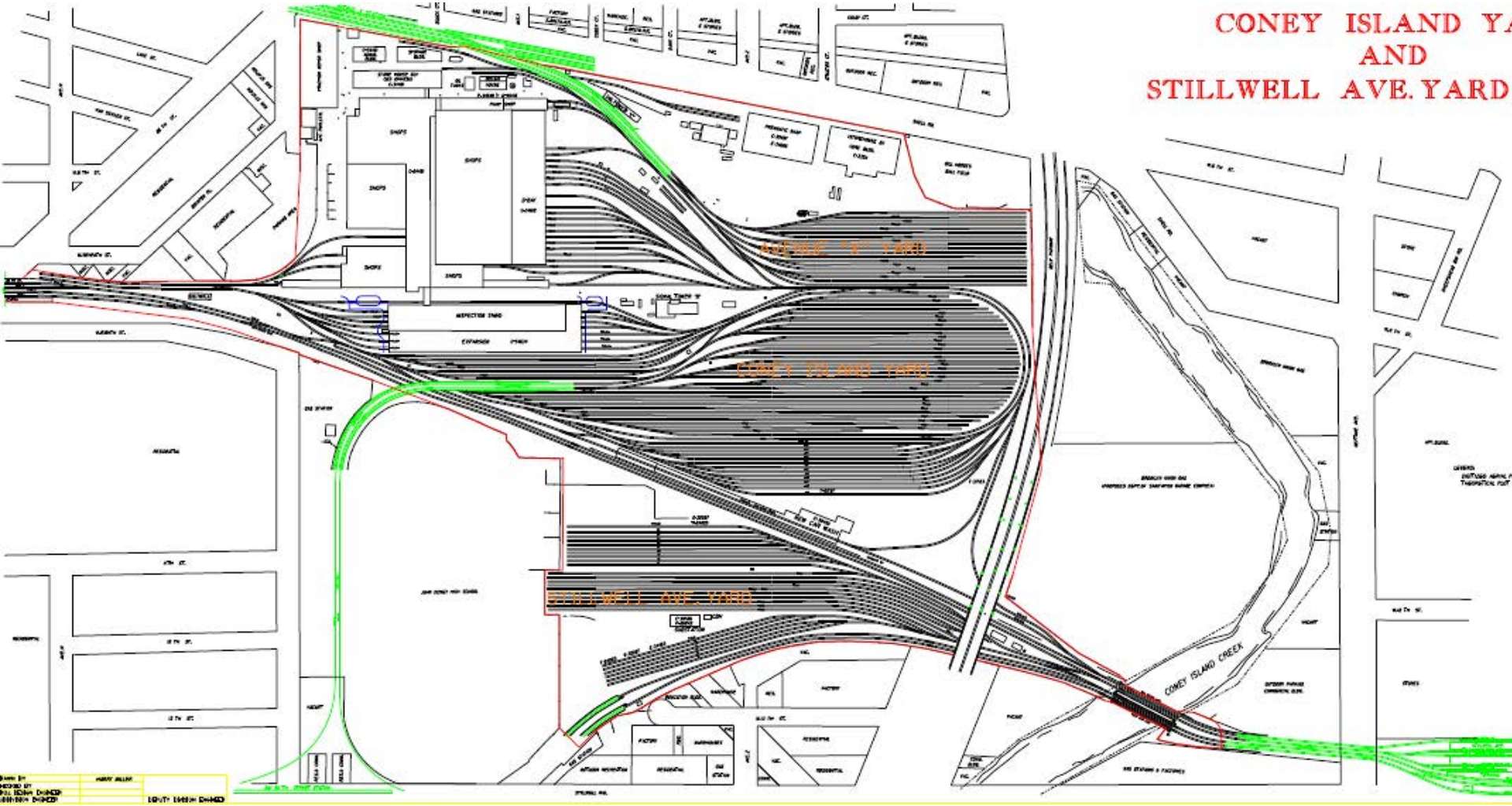
NoFloods Mobile Barrier (air or water; max. height: 2.6 ft)

Dam-it Portable Cofferdams (water-filled; 1 to 12 ft)

INFLATABLE TUNNEL PLUG

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

NYS 2100 COMMISSION

Recommendations to Improve
the Strength and Resilience of
the Empire State's Infrastructure

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

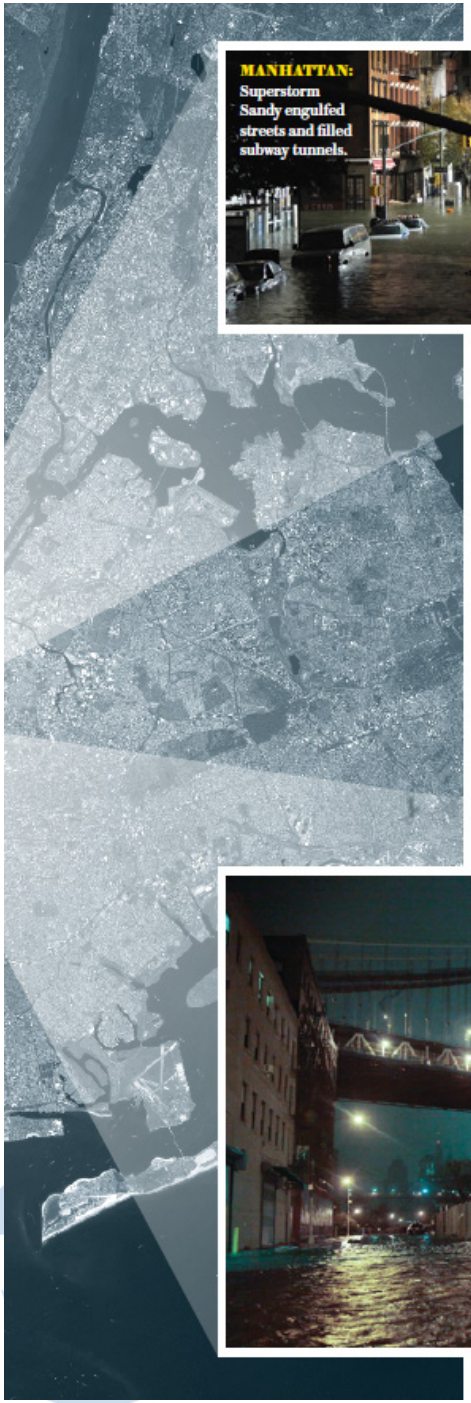
- Identify vulnerable assets
- Review design guidelines
- Protect against flooding
- Elevation data and post-Sandy assessment should be used to identify critical locations
- Flood walls should be used where appropriate
- Upgrade pumps in flood-prone areas

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.**
- **Perimeter flood walls and flood gates to be built for protection of Coney Island Yard, 148th St. Yard & Portal, 207th St. Yard & Portal and Rockaway Park Yard & Terminal.**
- **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

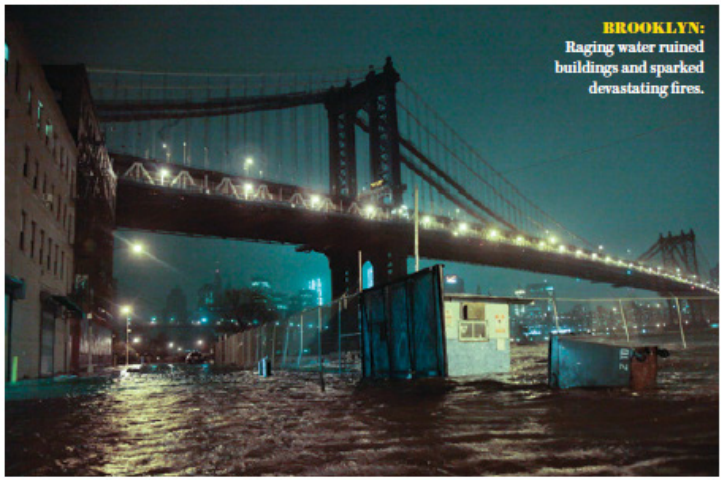
CLIMATE SCIENCE

STORM OF THE CENTURY*

*EVERY TWO YEARS

New York City and the entire U.S. East Coast could face frequent destruction unless the region takes drastic action

By Mark Fischetti *Maps by XNR Productions*



SCIENTIFIC AMERICAN

June 2013

How High Will the Next Storm Surge Be?