Storm Surge Flooding in NYCT: A Presentation Concerning the Water-Rail Interface

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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

- NY State 2100 Commission Report
- Previous NY Metro Area Hurricane Studies:
  - 1995 Metro New York Hurricane Transportation Study
  - 2009/2011 NY State Hurricane Evacuation Restudy
- 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

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 a 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.

Sector-specific Recommendations

These recommendations are grouped into broad headings, and details on specific actions are presented fully in each sector-specific chapter. Additionally, numerous case examples of effective implementation of similar measures can be found in the corresponding chapters of this report.

Transportation

Develop a risk assessment of the State's transportation

Identify vulnerable assets

Strengthen existing transportation networks
Improve the State's existing infrastructure with an emphasis on key bridges, roads, tunnels, transit, rail, airports, marine facilities, and transportation communication infrastructure. Focus on improved repair, as well as protecting against multiple hazards including flooding, seismic impact and extreme weather.

Protect against flooding

- Strengthen vulnerable highway and rail bridges
- Protect waterway movements
- Safeguard airport operations

Strategically expand transportation networks in order to create redundancies
Make the system more flexible and adaptive. Encourage alternate modes of transportation.

- Modernize signal and communications systems
- Build a bus rapid transit network
- Expand rail access to/from Manhattan
- Create new trans-Hudson tunnel connection
- Expand rail Access to/from Manhattan with Metro-North Penn Station access
- Expand capacity on the LIRR's Main Line
- Develop alternative modes of transportation

Build for a resilient future with enhanced guidelines, standards, policies, and procedures

Change the way we plan, design, build, manage, maintain and pay for our transportation network in light of increased occurrences of severe events.

Review design guidelines

NYS 2100 COMMISSION

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

Protect transit systems and tunnels against severe flooding

Protect underground transit systems and tunnels

- Installing waterproof, vertical roll-down doors at the foot of subway stair entrances.
- Installing mechanical below-grade vent closures to prevent water from entering through ventilation shafts.
- Using inflatable plugs/bladders to keep flood waters out of tunnel entrances.
- Sealing electrical equipment against water infiltration.

Elevation data and post-Sandy assessment should be used to identify critical locations

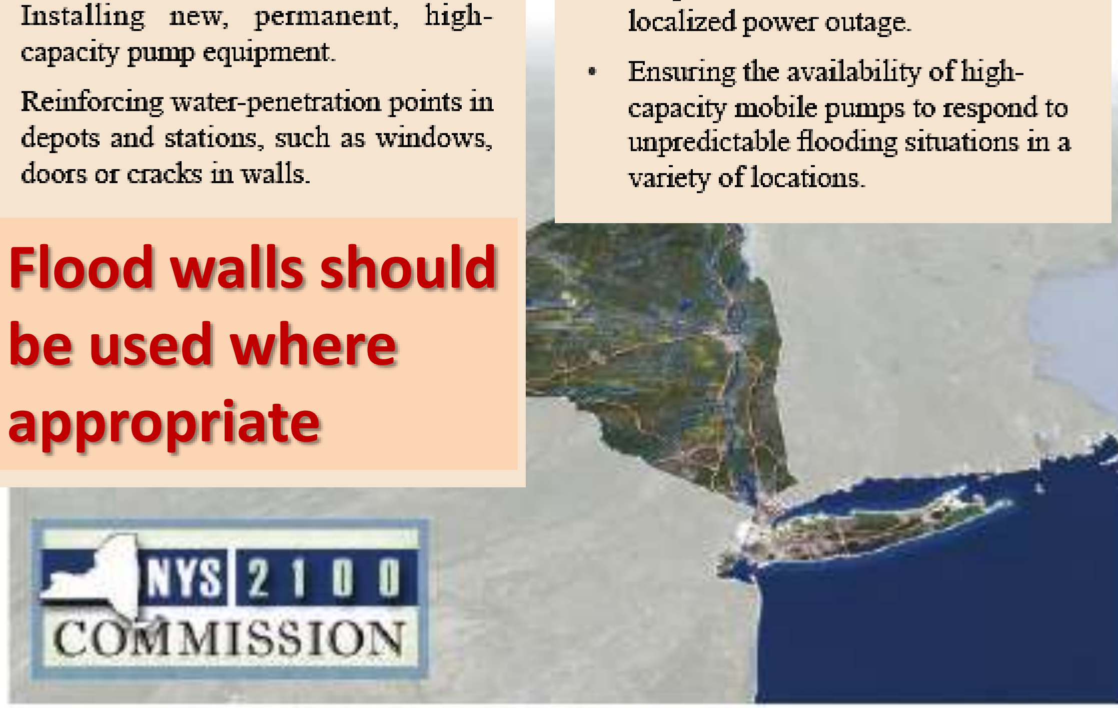
Protect aboveground transit systems

- Installing aluminum dam doors at depots that house buses and trains in low-lying areas prone to flooding (e.g., Zones A, B and C).
- Relocating sensitive equipment from the basement and first floor to higher floors or to the roof.
- Installing new, permanent, high-capacity pump equipment.
- Reinforcing water-penetration points in depots and stations, such as windows, doors or cracks in walls.

Flood walls should be used where appropriate

Upgrade pumps in flood prone areas

- Installing new, higher-capacity discharge lines at points of water accumulation.
- Upsizing existing fixed pumps.
- Installing adequate back-up power sources to ensure that pumps continue to operate even in the event of a localized power outage.
- Ensuring the availability of high-capacity mobile pumps to respond to unpredictable flooding situations in a variety of locations.



Previous NY Metro Area Studies

Date	Title
1987	NY1 - New York Basin SLOSH Model Run (first iteration)
1992	New Jersey Hurricane Evacuation Study
1993	New York State Hurricane Evacuation Study Technical Data Report
1995	Metro New York Hurricane Transportation Study – Project Findings
1995	Metro New York Hurricane Transportation Study – Technical Data Report
2000	NY2 - New York Basin SLOSH Model Run (second iteration)
2007	New Jersey Hurricane Evacuation Study Transportation Analysis
2009	New York State Hurricane Evacuation Restudy Technical Data Report (for New York City, Nassau, Suffolk, and Westchester Counties)
2010	New Jersey Technical Data Report
2010	NY3 - New York Basin SLOSH Model Run (third iteration)

U.S. Army Corps of Engineers • FEMA
National Weather Service
NY/NJ/CT State Emergency Management

INTERIM TECHNICAL DATA REPORT

November 1995

EXECUTIVE SUMMARY

Early in 1990, work associated with Hurricane Evacuation Studies for New York, New Jersey, and Connecticut revealed a potential for much higher hurricane surge in the metropolitan New York City (Metro) area than previously believed possible. After researching parameters of hypothetical hurricanes that could affect the Metro area, the National Weather Service used the Sea, Lake, and Overland Surge from Hurricanes (SLOSH) numerical model to compute expected surge heights. **Those computations showed that worst-case surge heights in New York City ranged from about 11 feet for a Category 1 hurricane to over 30 feet for a Category 4 storm.**

SLOSH surge heights in NYC: 11 ft. (Cat. 1) to 30 ft. (Cat. 4)

transit systems. **Nearly every rail tunnel system has significant points of entry less than 10 feet above National Geodetic Vertical Datum (NGVD).** When the implications of hurricane strength

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

accidents that closed several high-rise bridges. Flooding had major impacts in many areas but, with only a few exceptions, stopped just short of being life-threatening. If the storm surge had peaked

Significance of the 1992 Nor'easter

computed by the SLOSH model for Manhattan at the Battery. If the surge associated with that storm had instead resulted from a moderate to severe hurricane, it could have peaked from 16 to 30 feet above normal water levels with a maximum rate-of-rise of 17 feet per hour.

METRO NEW YORK HURRICANE TRANSPORTATION STUDY

Storm of December 11-12, 1992

The threshold of vulnerability for most Metro transportation systems was exceeded by the surge and winds accompanying the December 1992 extratropical storm. During that event, the still-water level at the Battery NOS tide gage peaked at about 8.5 feet above NGVD and high winds caused traffic accidents that closed several high-rise bridges. Although critical flood levels (elevation at which flood water will begin entering or covering system facilities) for most systems were surpassed for fairly brief periods, and by only 1 to 2 feet, near paralysis of the Metro area resulted. The flooding had major impacts on important transportation systems but, with only a few exceptions, stopped just short of being life-threatening. If this storm surge had peaked 2 feet higher, lives could have been lost on the roadways and rail systems.

Two of the most vulnerable systems, the underground rail networks belonging to Port Authority Trans-Hudson (PATH) and New York City Transit Authority (subway) were completely shut down. Storm surge entered the PATH system in at least one location, the Erie-Lackawana staircase at the Hoboken Terminal where the critical elevation is 7.4 feet NGVD (see Figure 11). Low points in the rail tunnels were flooded and major damage occurred to the control signals. The Port Authority's *Pathways* newspaper reported that a train with 19 passengers stalled 75 yards from the Hoboken Terminal. Rescuers worked for 1-1/2 hours to move those passengers from the train into the terminal. Portions of the system were out of operation for 10 days. Surge only 1 to 2 feet higher than the December 1992 storm would involve other points of entry and probably cause massive flooding of the PATH tunnels.

Almost simultaneously, the New York City Transit Authority lost electrical power for subway signalization, crippling the entire system. The *New York Times* reported that an N-Train was stopped for nearly 2 hours between 8th Street and Union Square. An L-Train was backed out of the 14th Street tunnel when it began filling with water. Three hundred passengers had to leave a G-Train and walk 1000 feet out of the flooded Greenpoint tunnel. No required time was reported for that incident. Above ground, 100 passengers were stranded on an A-Train in flood waters at Broad Channel.

“L” train backed out of flooded 14th St. Tube; “G” train abandoned in the flooded Greenpoint Tube; “A” train stranded at Broad Channel

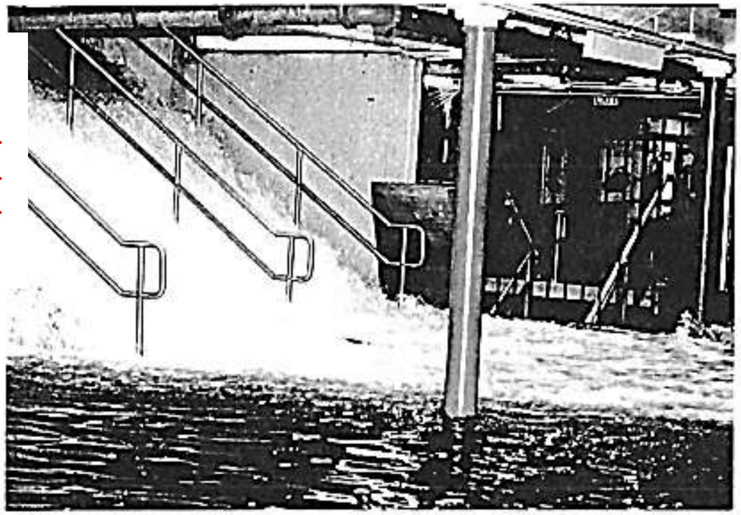
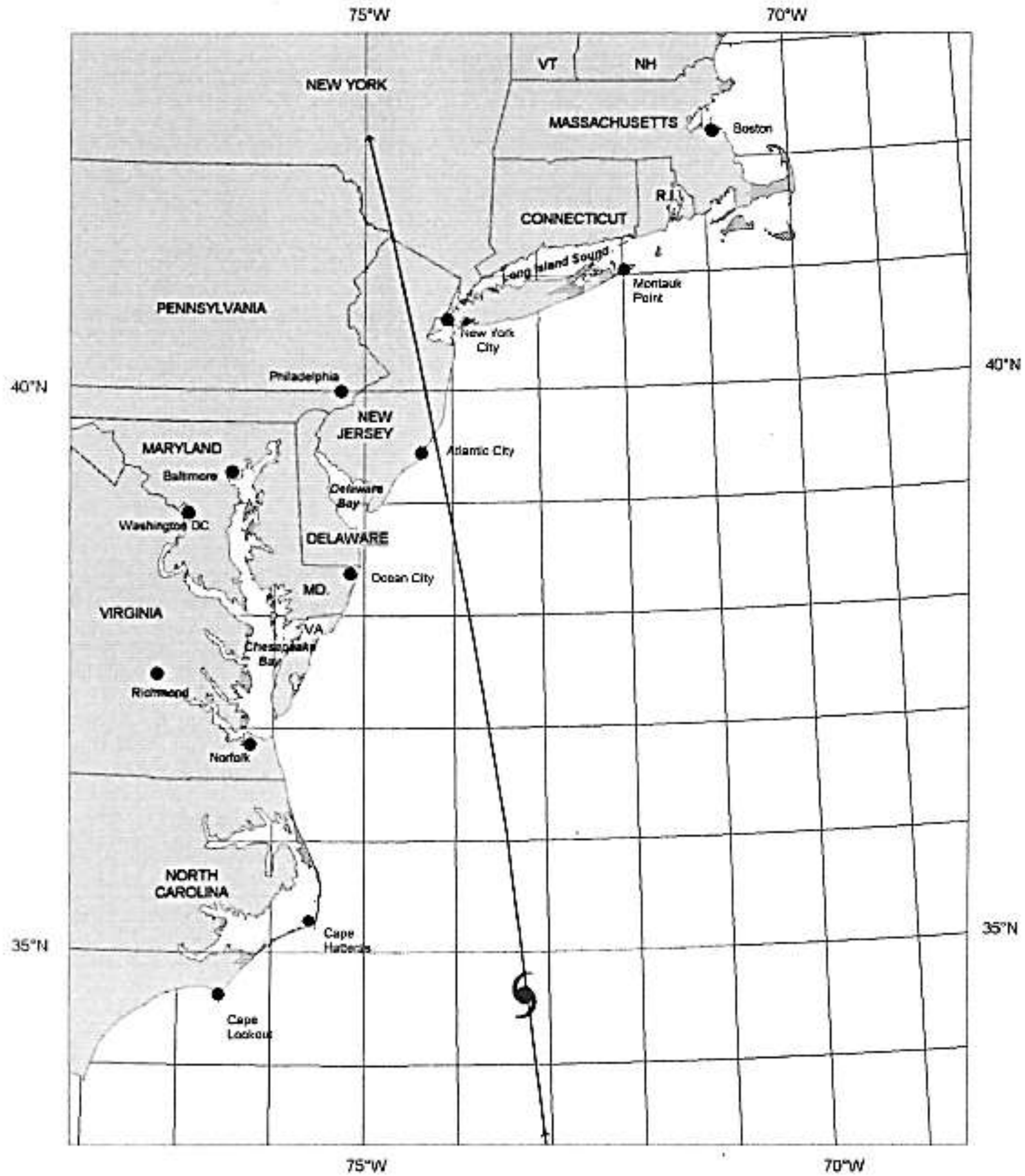


FIGURE 11

Floodwater cascades into the Hoboken PATH Station
December 11, 1992

FIGURE 17 - Potential Category 2 hurricane surge at South Ferry (Battery) Subway Station



WORST CASE TRACK FOR HURRICANES IMPACTING
THE METRO NEW YORK CITY AREA

FIGURE 5

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

OEM

New York City Office of Emergency Management

The current project, the Metro NY Evacuation Project, updates the *Metro New York Hurricane Transportation Study TDR* (1995). Just as the 1995 work efforts augmented and expanded upon the original 1993 work, this effort expands upon the transportation analysis performed for the *New York State Hurricane Evacuation Restudy TDR* (2009) and has been formatted to serve as an appendix to that report.

3.7 Summary of Changes from 1995 to 2010

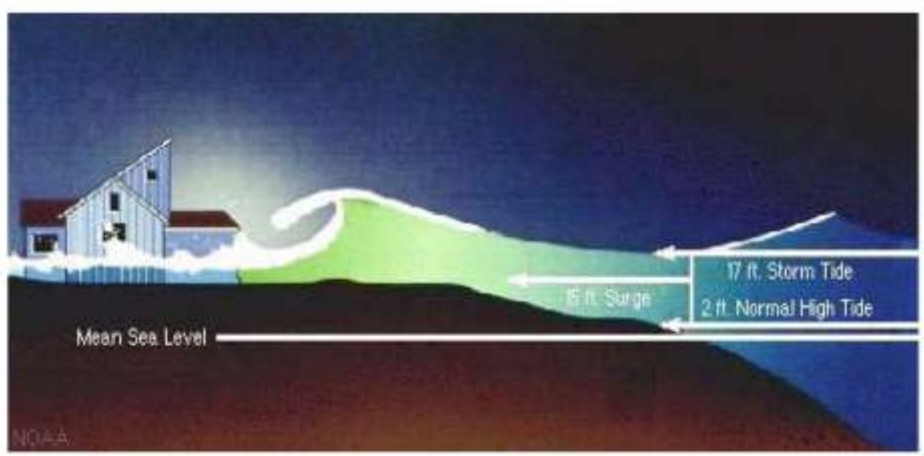
- Includes 327 transportation facilities in three states,
- Data collected in new datum, NAVD88,
- Integrates new SLOSH data from the 2010 model run,
- Updates and refines mobilization/decision, clearance, shutdown/closure, and pre-landfall hazard times for each facility.

Sea, Lake & Overland Surge from Hurricanes (SLOSH)

The SLOSH model was developed by the NOAA-NWS in the 1970s. The model computes the water height over a geographical area or basin resulting from storm surge. The expected surge values from several hundred hypothetical storm tracks are compiled into a composite map that represents potential areas of surge for the five modeled categories of hurricane. The primary use of the SLOSH model is to define flood-prone areas for evacuation planning. SLOSH output, including storm surge mapping, is used by the NHP when conducting HESs as a hazard analysis tool to help develop state and local evacuation plans and evacuation zones. It remains the only official surge model used by NHC.

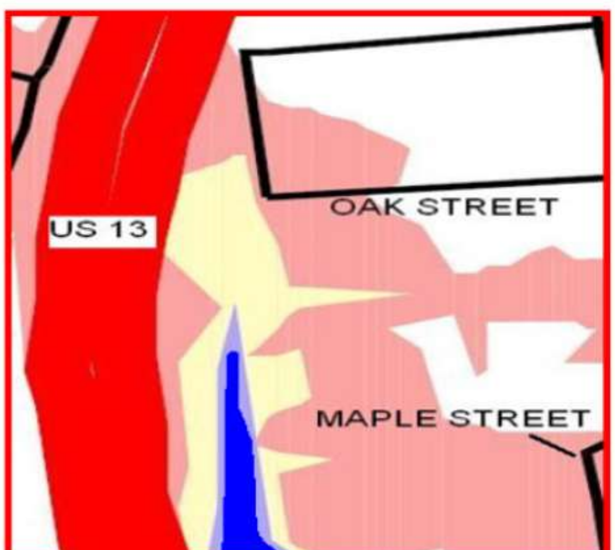
The SLOSH model computes the maximum envelope of water (MEOW) or expected storm surge for multiple storm tracks. The maximum inundation for each MEOW, or the maximum of maximums (MOMs), compiles all the MEOWs to represent the worst elevation for each category of hurricane to form a line of demarcation that can be mapped.

Storm Surge



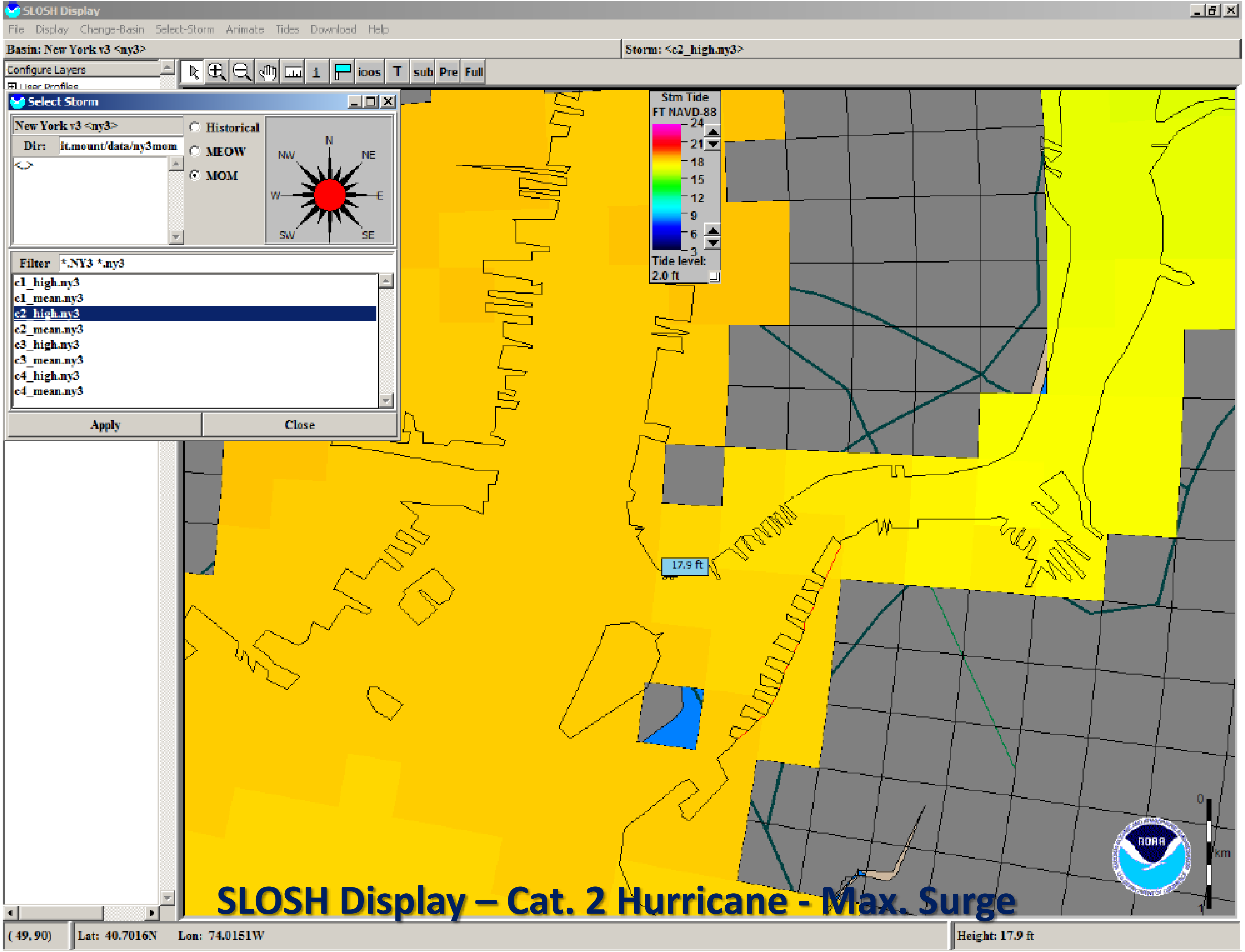
Below is an example of a FIRM (top image) and an SSIM (bottom image) for the same area. On the FIRM, the 1% annual chance floodplain is shown in light blue, and a flood zone and base flood elevation are included. The red box on the FIRM represents the area shown on the SSIM. On the SSIM, the blue designates the areas of possible flooding from Category 1-4 hurricanes, the purple from Category 2-4 hurricanes, the yellow from Category 3-4 hurricanes, and the pink from Category 4 hurricanes. Note that this area is not included in the 1% annual chance floodplain shown on the FIRM. This means that some types of Category 1-4 hurricanes, with certain size, forward speed, and track trajectory characteristics , impacting at high tide, are expected to produce a water level higher than the 1% annual chance water level, and inundate a larger area than the 1% annual chance water level would inundate.

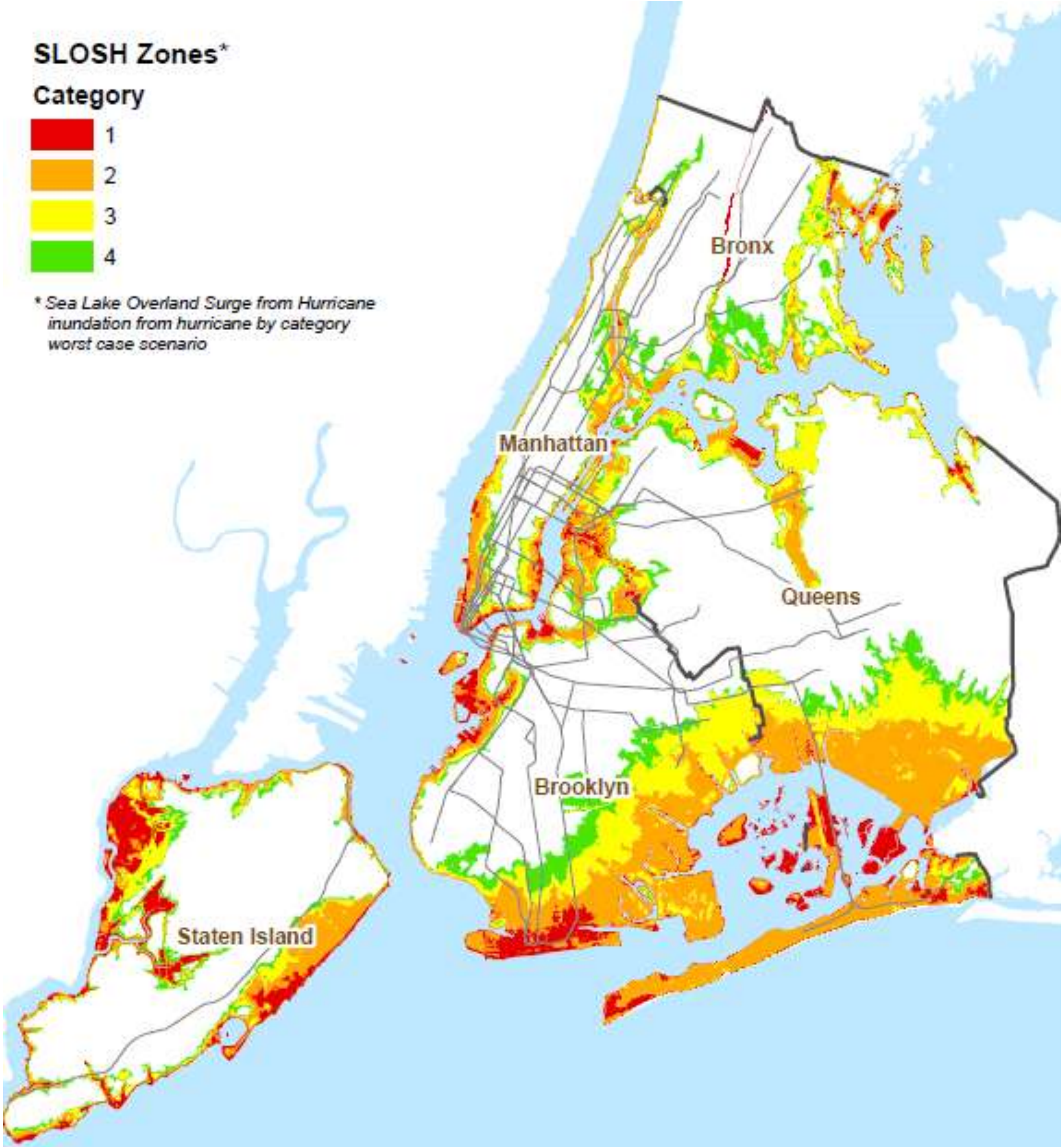
FEMA's F.I.R.M.s vs. SLOSH Maps



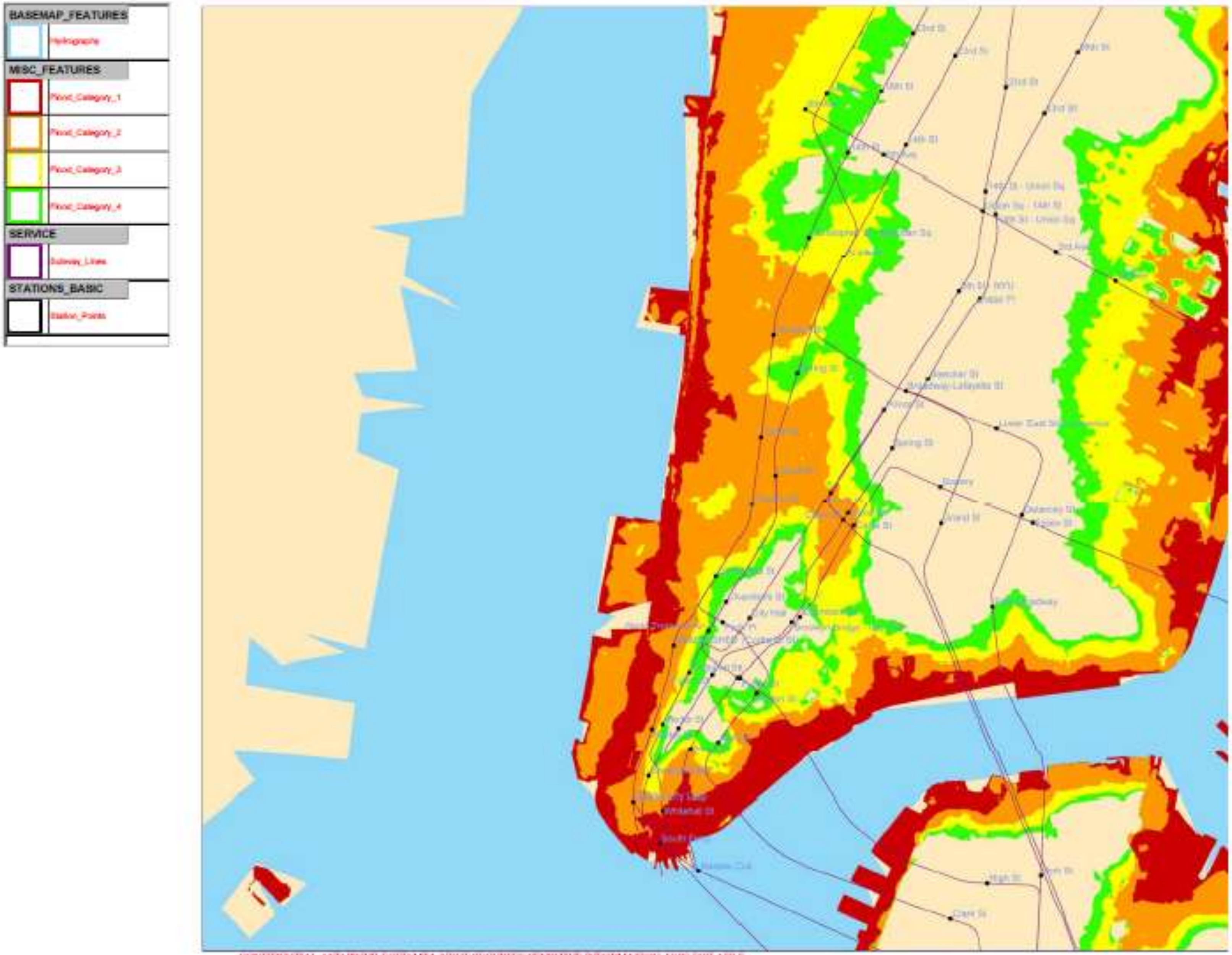
"When a hurricane approaches, communities should rely on the Storm Surge Inundation Maps [SLOSH maps] and storm surge forecast products from NOAA [SLOSH] when making evacuation and other emergency management decisions"

SLOSH Display – Cat. 2 Hurricane - Max. Surge




SLOSH Zones*
Category
1
2
3
4
* Sea Lake Overland Surge from Hurricane inundation from hurricane by category worst case scenario
Bronx
Manhattan
Queens
Brooklyn
Staten Island

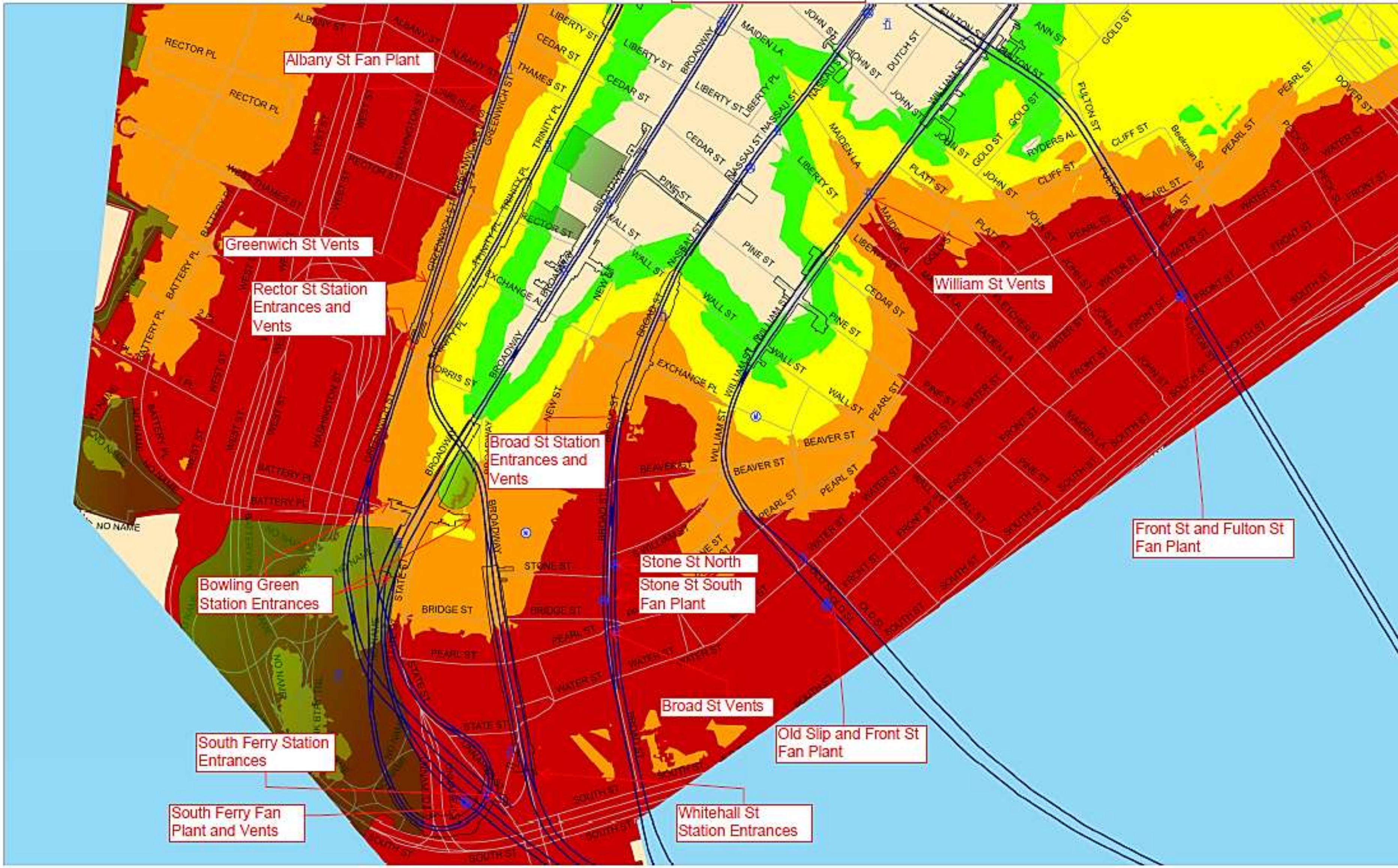
NEW YORK CITY TRANSIT -T-MAP

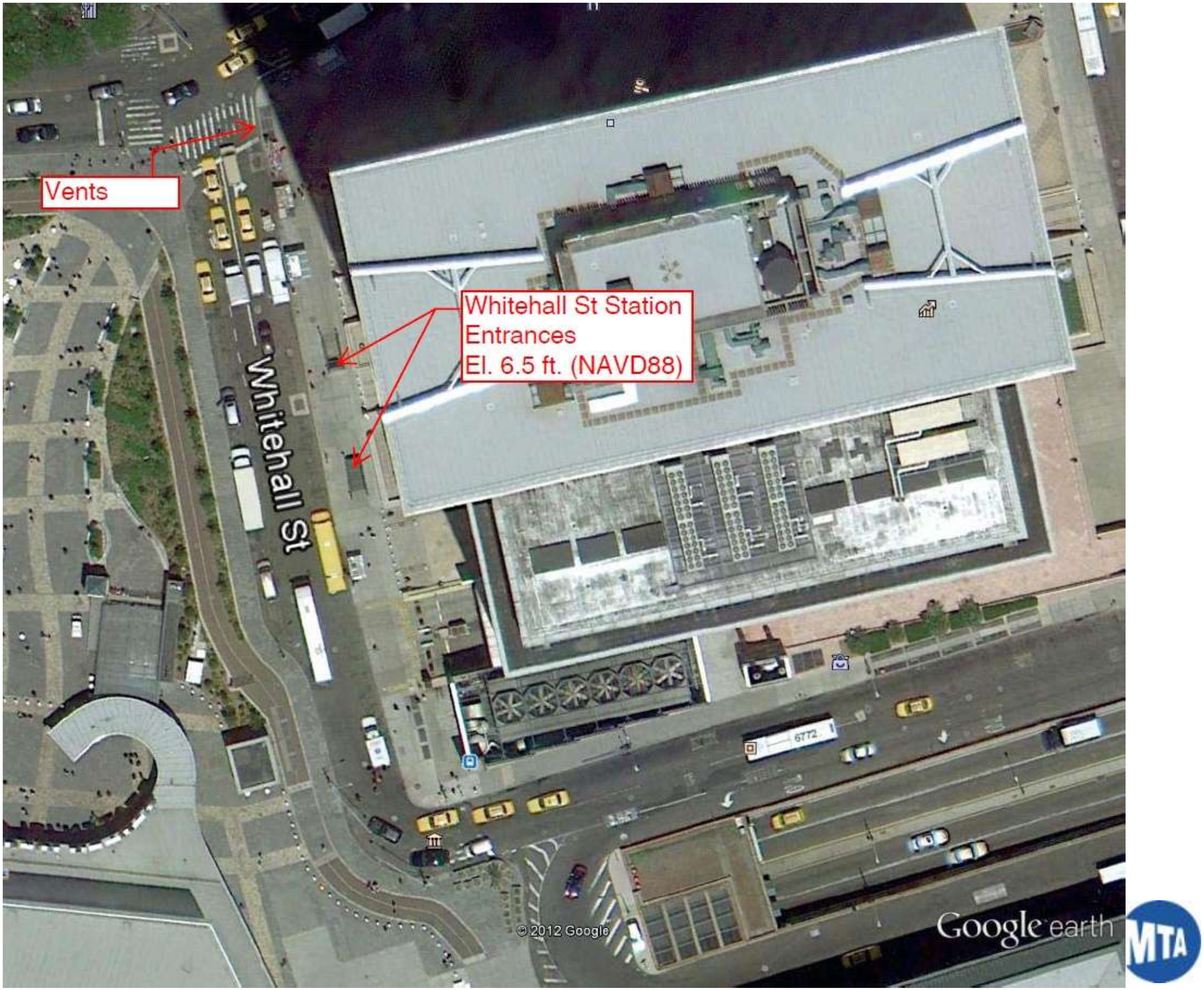


CONFIDENTIAL AND PRIVILEGED MTA-NYCT SECURITY SENSITIVE INFORMATION, NON-SOLABLE

0 —— 3105 ft

NYCT FLOOD MAP FM-18




Vents
Whitehall St Station
Entrances
El. 6.5 ft. (NAVD88)
Whitehall St
© 2012 Google
Google earth
MTA


Subway
© 2013 Google
© 2013 Google
Google earth
5 ft

Capital Program Management

Design & Engineering Services
Survey Subdivision

New York City Transit

CREW NAMES

CONTRACT: R. 50591 DATE: JUNE 20 '12

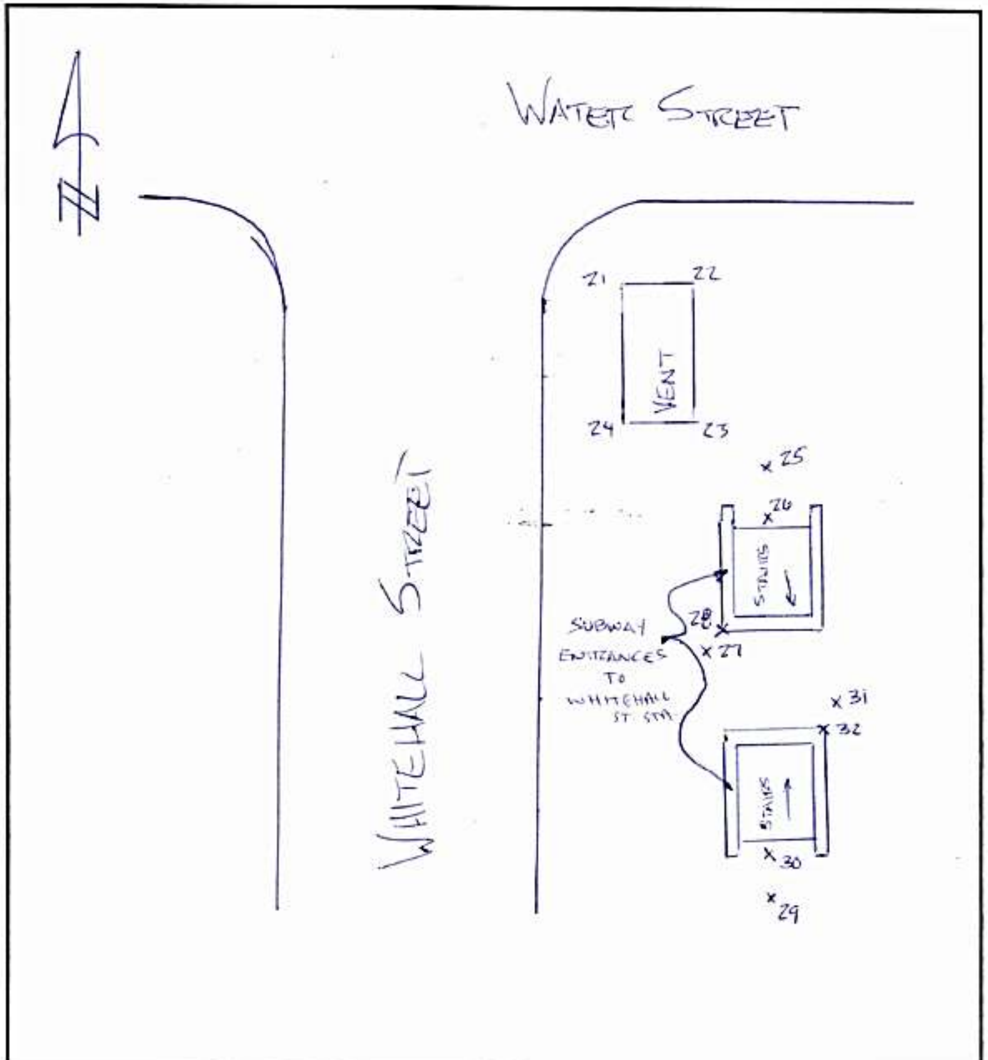
PREPARED BY: D NOEL CHECKED BY: P. NAIK

DESCRIPTION: Critical Facility - Elevations

LOCATION: White hall & Water st. MANH

FILE NAME: SHEET NO.: OF

P. NAIK
V. PATHAK
D. NOEL



Capital Program Management
Design & Engineering Services
Survey Subdivision

New York City Transit

CREW NAMES

CONTRACT: R-50591 DATE: 6/20/2012

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

UNIT: US FEET DATUM: NAVD88

P. NAIK
V. PATHAK
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

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 Street Station Entrances below Water Street	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

4.3 Datum Conversion

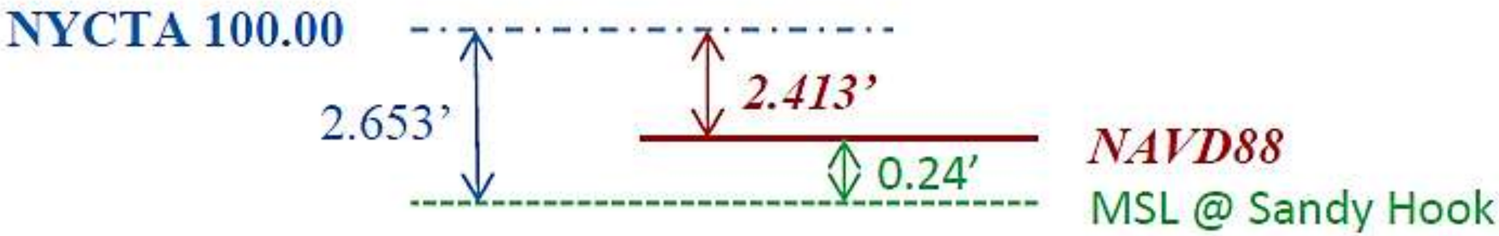
One consideration that had to be addressed in comparing the 1987 data to the 2010 is that the benchmark for estimating the storm surge elevation, the vertical datum, changed from NGVD29 to NAVD88. If a flood depth is estimated to be ten feet, the datum answers the question, "Ten feet above what level?" The datum provides the base elevation in relation to which other elevations are measured. In most cases, this basis corresponds with MSL, so that measurements can be referred as "x" number of feet above MSL. NGVD29 was the system that had been used throughout most of the 20th Century. It was the basis for relating ground and flood elevations, but it has been replaced by the more accurate NAVD88. Because elevation has such an impact on floodplain management, it is important that the most accurate benchmark be used.

NYCTA Datum vs. NAVD88

Elevation 100.00 of NYCTA = 2.653 ft. above MSL @ Sandy Hook

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

- NAVD88 = 0.24 ft. above MSL



Therefore,

Elevation 100.00 NYCTA = <u>2.413 ft. above NAVD88</u>

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 Street Station Entrances below Water Street	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
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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
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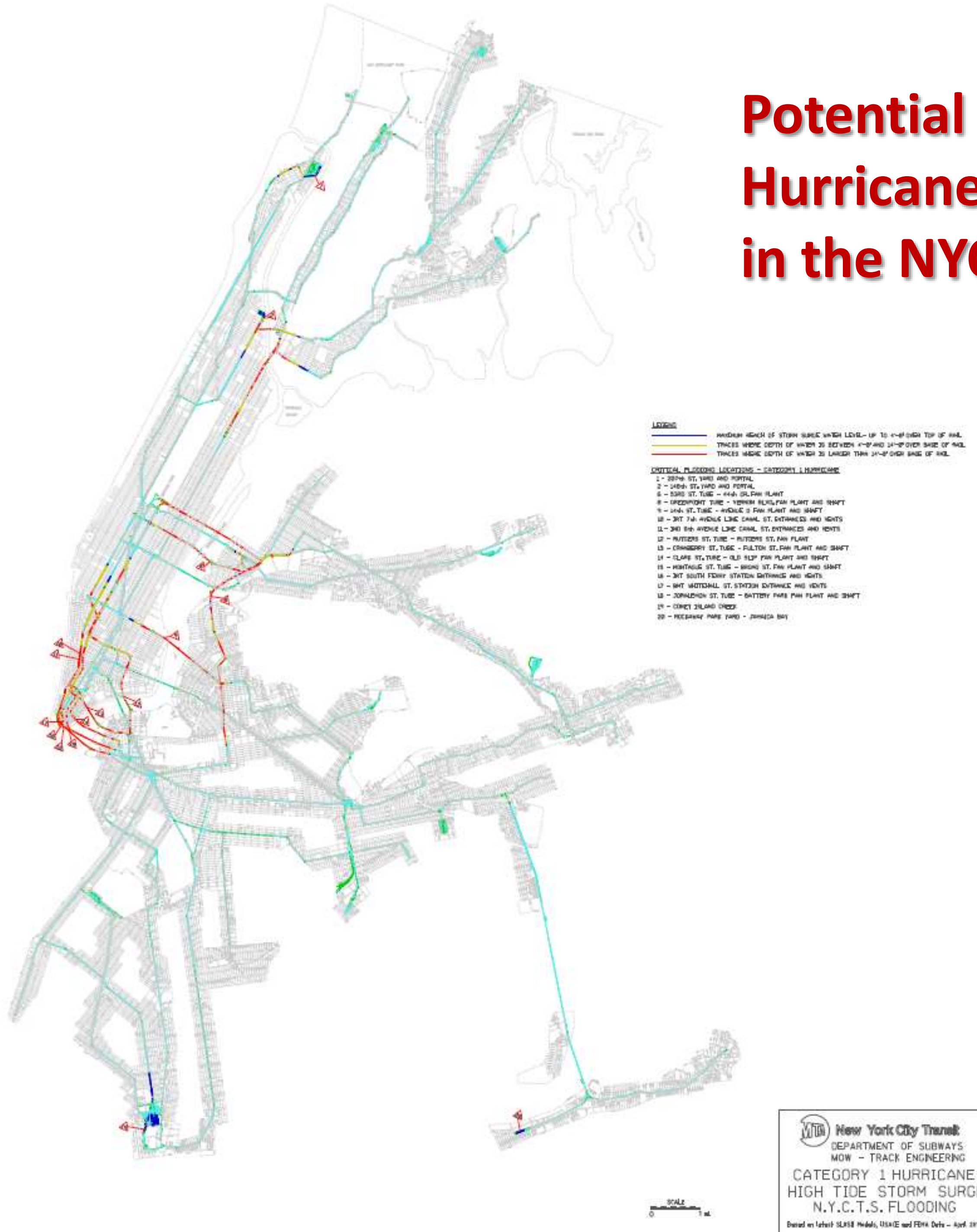
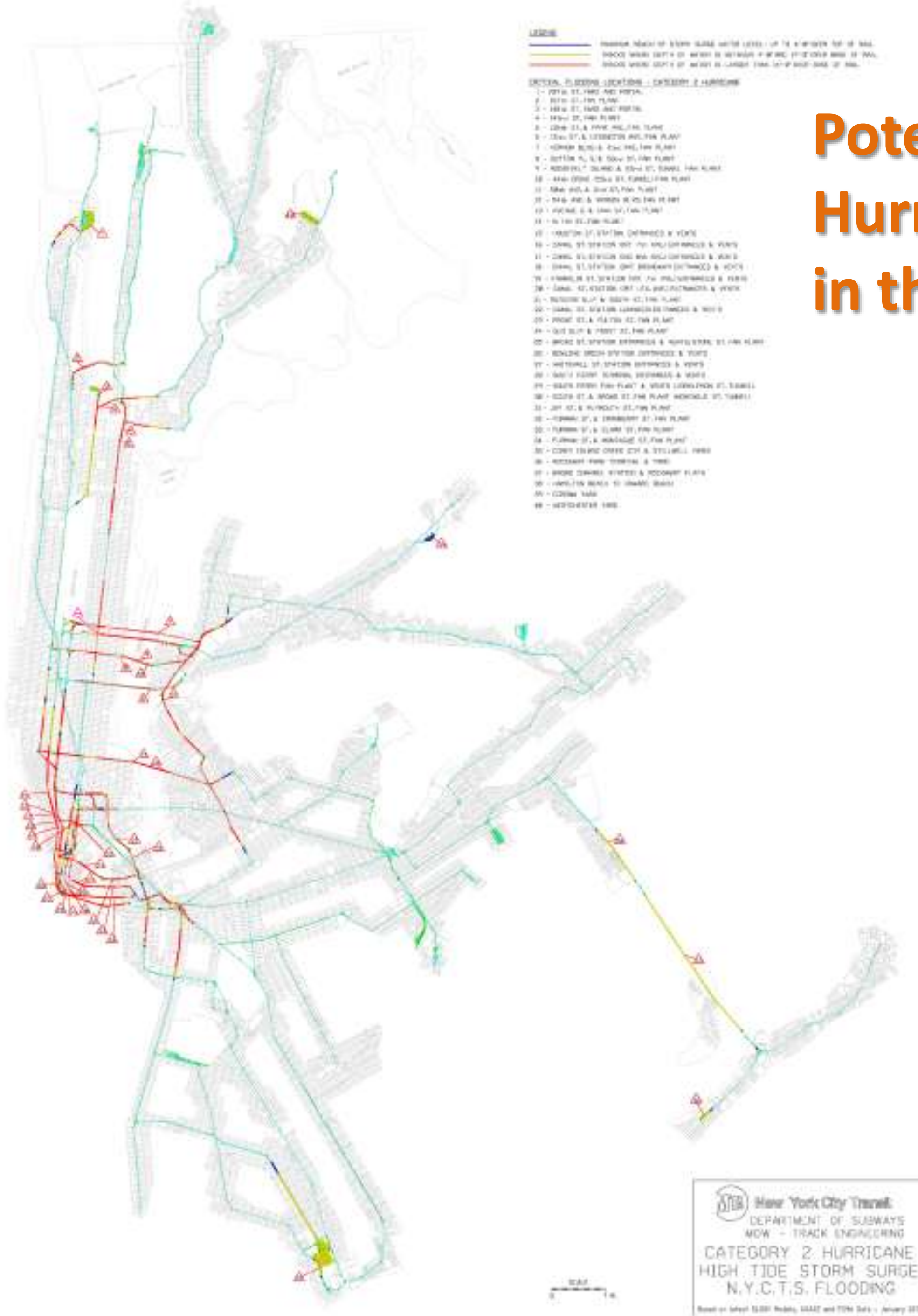
Westchester Rail Yard	Bronx	FM-26	*6.1*	Dry	16.0	23.5	28.5	Dry	9.9	17.4	22.4	Dry	Dry	Dry	126.6
Howard Beach Station - Rockaway line	Queens	FM-35	*8.4*	Dry	18.3	24.9	31.5	Dry	9.9	16.5	23.1	Dry	116.36	122.96	129.6
148th Street Lenox Yard	Manhattan	FM-2	*6.5*	9.1	16.1	22.5	28.1	2.6	9.6	16.0	21.6	107.16	114.16	120.56	126.2

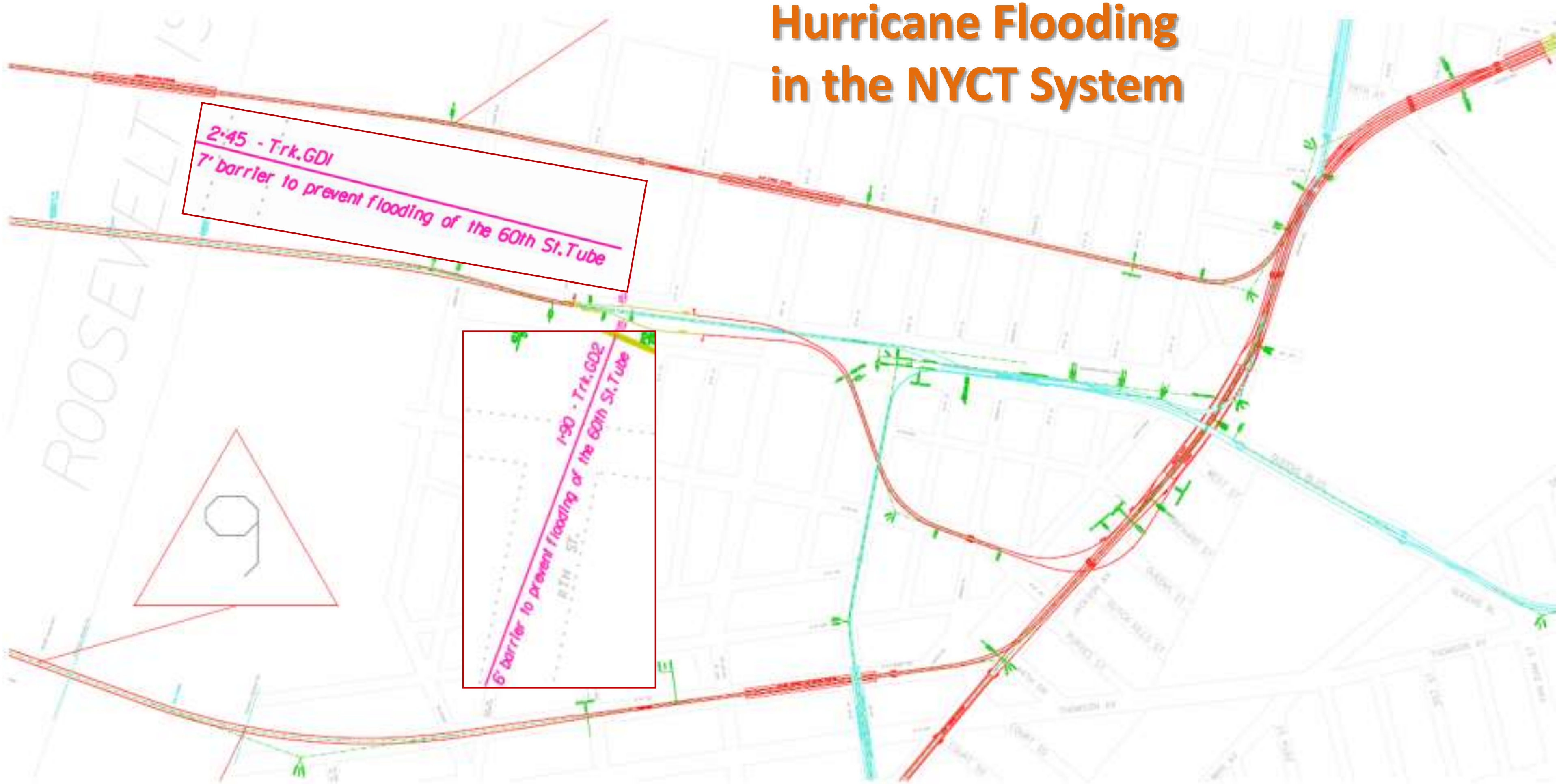
Potential Cat. 1 Hurricane Flooding in the NYCT System



Potential Cat. 2 Hurricane Flooding in the NYCT System

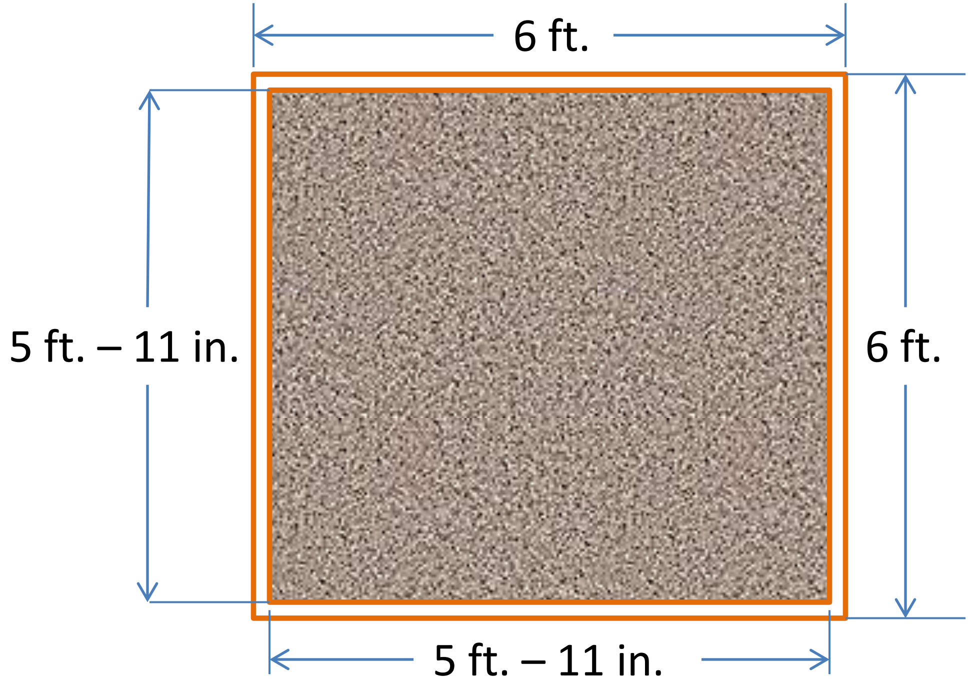


Potential Cat. 2 Hurricane Flooding in the NYCT System



53rd St. and Greenpoint Tunnels

Flooding Through Small Spaces: Height of Water and Open Areas



$$Q_0 = C_0 A \sqrt{2gh}$$

Open area, A = 0.993 sq. ft.
Coefficient C = 0.67
g = 32.2 ft./sec/sec
h = 3.0 ft. water head

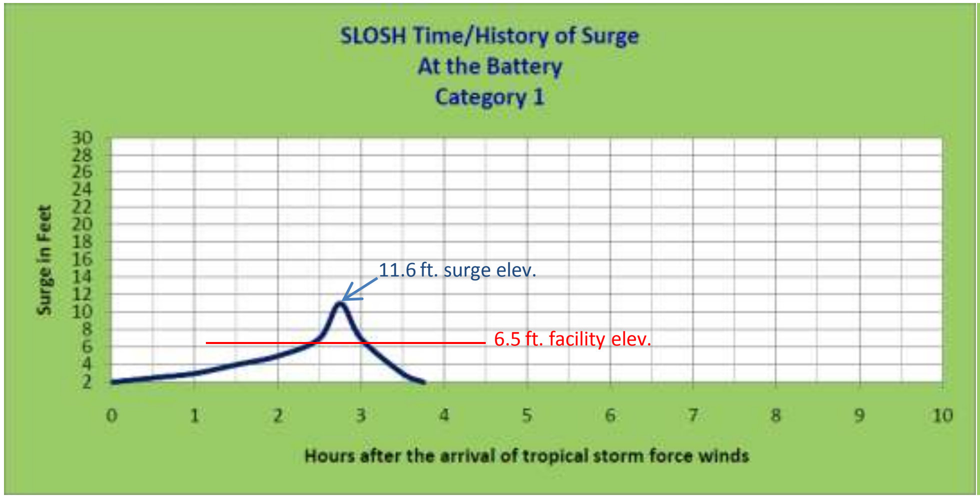
Q = 9.25 cu. ft./sec = 4,152 gal/min = **249,120 gal/hr.**

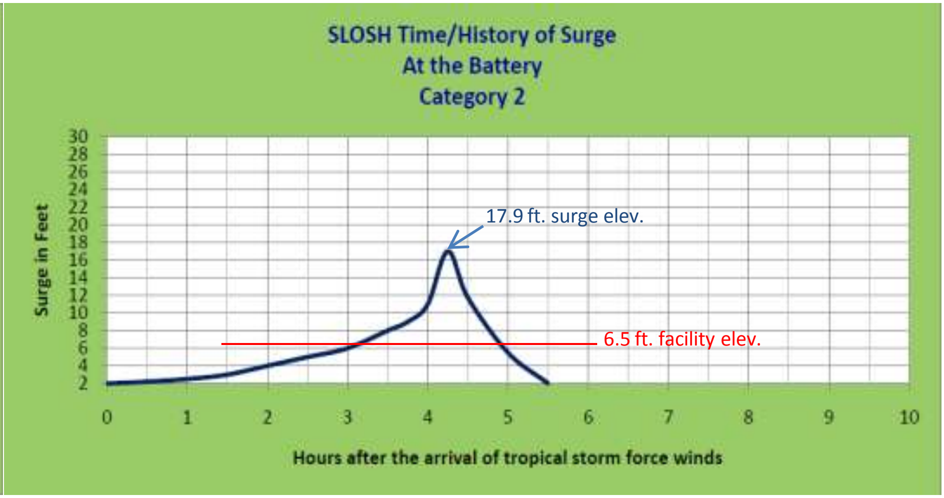
In 4 hrs.: approximately **1 M gallons** would have entered

PATH Hoboken Station: Flooding Through Closed Door

Case Study: Potential Flooding at Whitehall St. Station Under Cat. 1 and Cat. 2 Hurricane Storm Surges

Assume that the two above entrances and adjacent vents (at the corner of Water St.) are breached, or that their protective measures fail





Category 1 Hurricane Surge

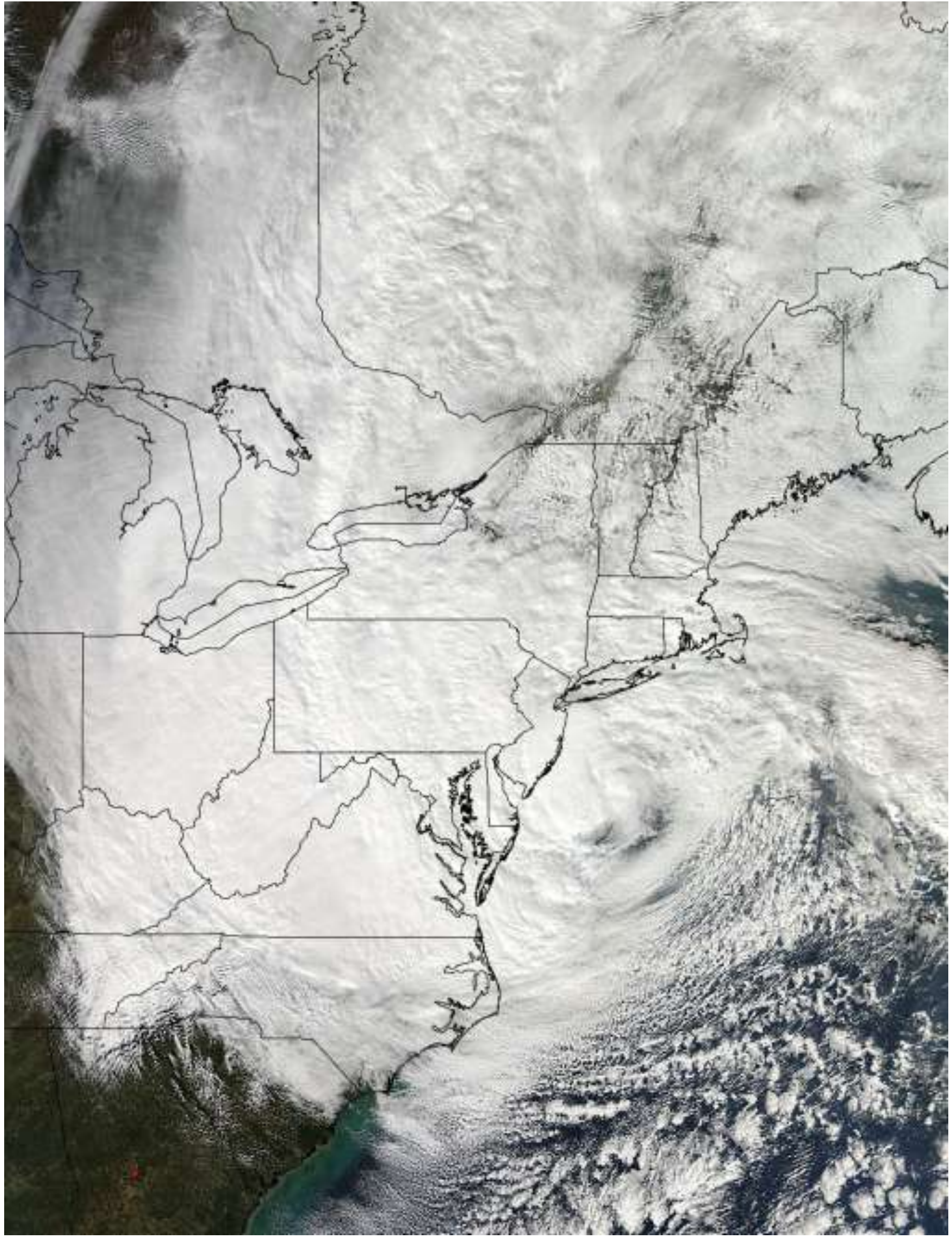
- Assumptions:
  - Two entrances and adjacent vents affected. Area of openings: 270 sq. ft.
  - Duration: 40 min.
  - Max. Flood Height: 5.1 ft.
  - Flow: Q = 1451.7 * SQRT(H) cfs;
  - Volume (cu. ft.) = Q*seconds
  - 0-10 min.: H avg = 0.75 ft.; Q = 1257 cfs; Volume = 1257*600 = 754200 cu. ft. = 6 M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

- In 40 minutes, a total of 36 M gal. of water would enter, at an average rate of 0.9 M gal./ minute

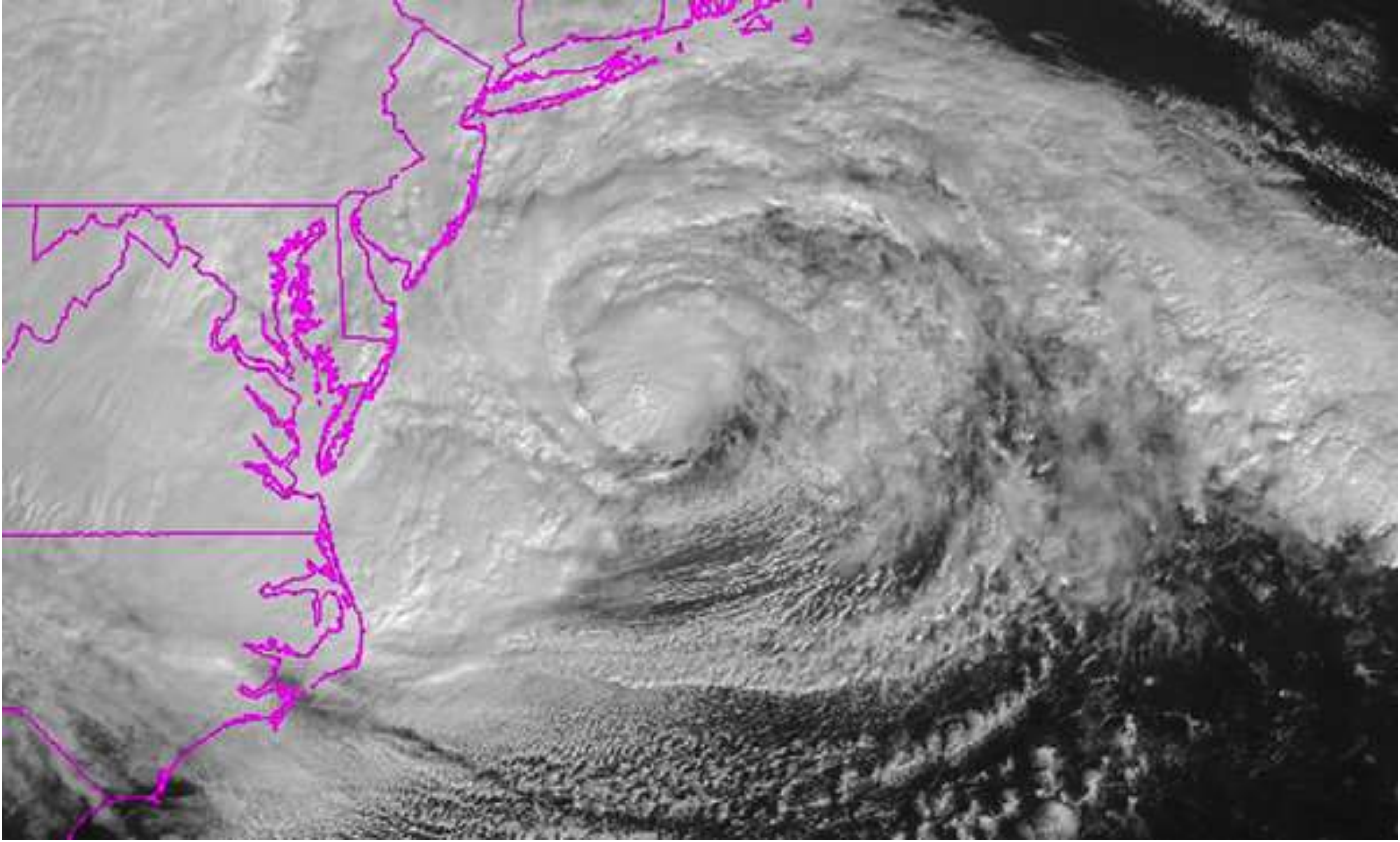
- The Montague St. Tunnel (having a total volume of 26.5 M gal.) will completely flood in 30 minutes

Category 2 Hurricane Surge

- Assumptions:
  - Two entrances and adjacent vents affected. Area of openings: 270 sq. ft.
  - Duration: 100 min.
  - Max. Flood Height: 11.4 ft.
  - Flow: Q = 1451.7 * SQRT(H) cfs;
  - Volume (cu. ft.) = Q*seconds
  - 0-30 min.: H_{avg} = 0.8 ft.; Q = 1257 cfs; Volume = 1257*1800 = 2262600 cu. ft. = 17 M gal.
  - 30-60 min.: H_{avg} = 3.0 ft.; Q = 2514 cfs; Volume = 2514*1800 = 4525200 cu. ft. = 34 M gal.
  - 60-75 min.: H_{avg} = 7.9 ft.; Q = 4080 cfs; Volume = 4080*900 = 3672000 cu. ft. = 28 M gal.
  - 75-90 min.: H_{avg} = 8.2 ft.; Q = 4157 cfs; Volume = 4157*900 = 3741300 cu. ft. = 28 M gal.
  - 90-100 min.: H_{avg} = 2.5 ft.; Q = 2295 cfs; Volume = 2295*600 = 1377000 cu. ft. = 10 M gal.
- In 100 minutes, a total of 117 M gal. of water would enter, at an average rate of 1.17 M gal./ minute
- The Montague St. Tunnel (having a total volume of 26.5 M gal.) will completely flood in less than 25 minutes
- The excess water will migrate North and South of the tube to flood adjacent areas



Hurricane Sandy Approaching the NJ Coast – Oct. 29, 2012



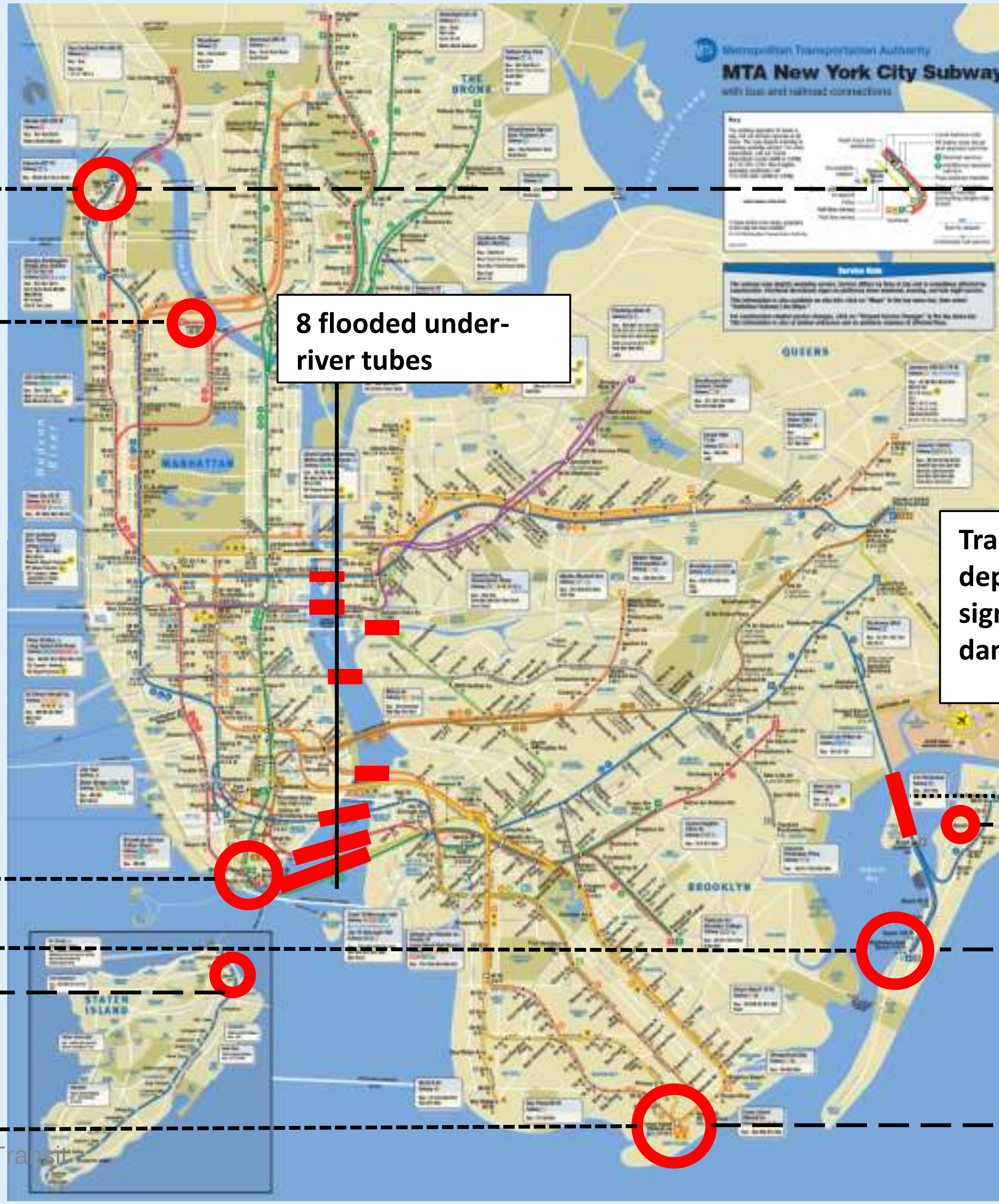
Hurricane Sandy Approaching the NJ Coast – Oct. 29, 2012

Precautions were taken, using the SLOSH Data and Flood Maps


How did we do?

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

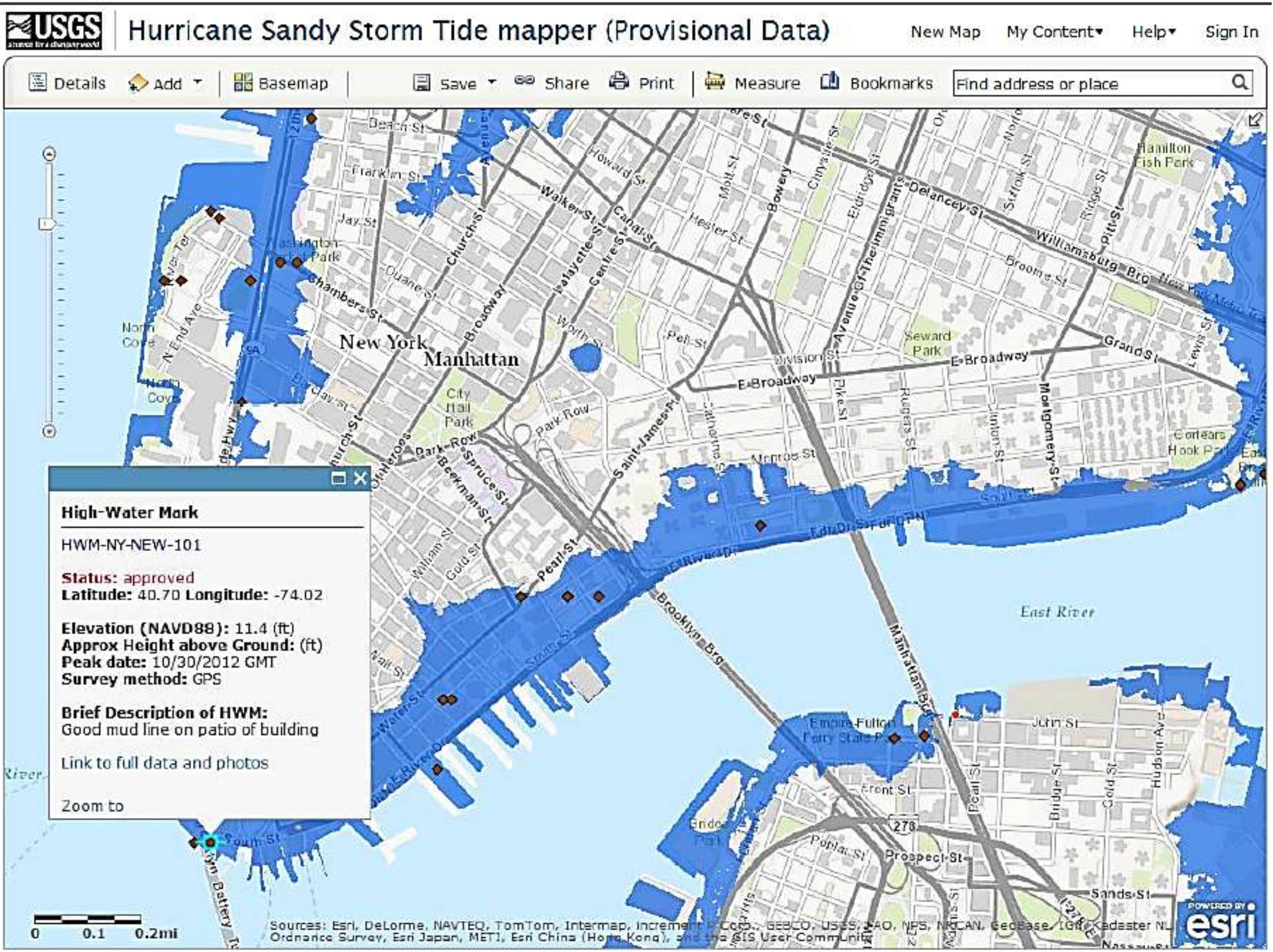
8 flooded under-river tubes

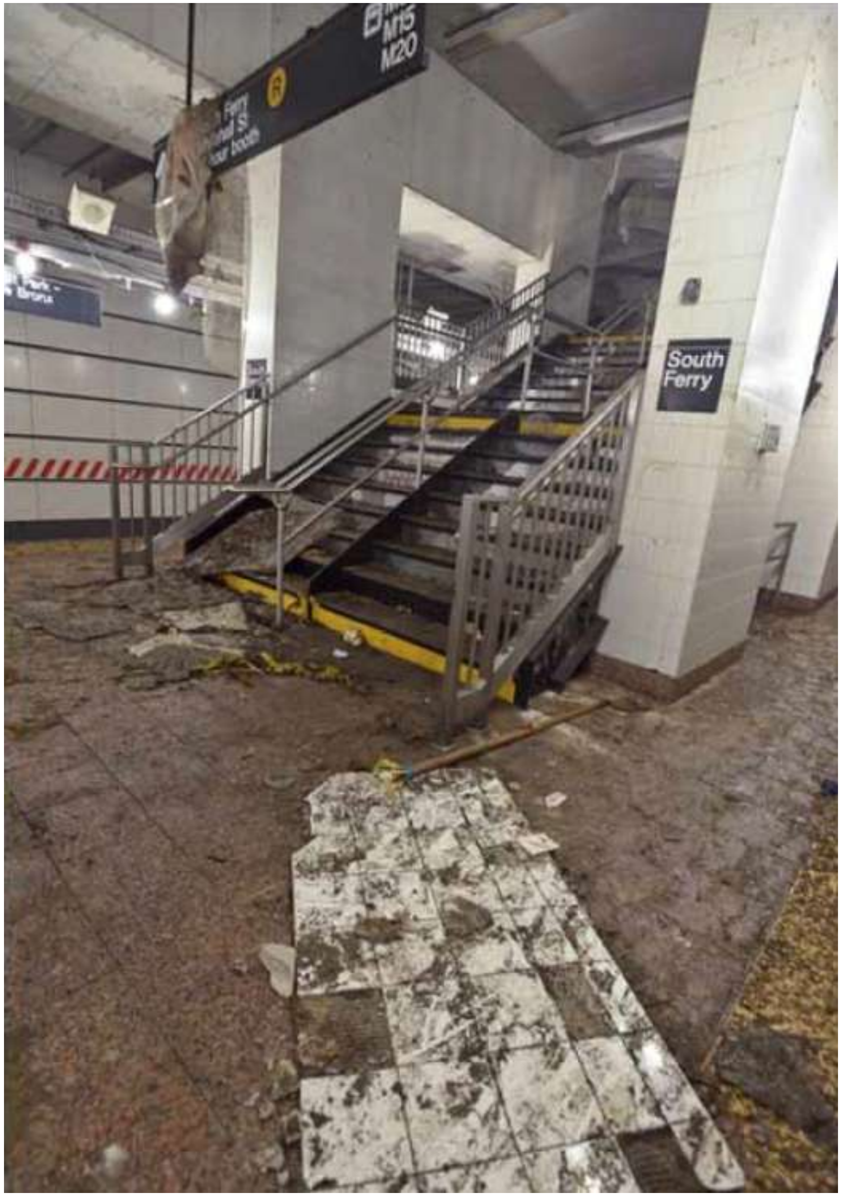
8 stations with major flood damage – South Ferry, Whitehall, 148th St, 207th St, Dyckman, Beach 116th Station, 86th St Sea Beach, Stillwell

Train yards and bus depot with significant flood damage

Rockaways track washout

Staten Island Railway maintenance shop major flood damage


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
City Hall Park
Seward Park
Hamilton Fish Park
Corlears Hook Park
Empire Fulton Ferry State Park
Brooklyn Brg
Manhattan Brg
Beach St
Franklin St
Jay St
Chambers St
Duane St
Church St
Broadway
Walker St
Canal St
Howard St
Hester St
Centre St
Lafayette St
Worth St
Pell St
Mott St
Bowery
Chrystie St
Eldridge St
Delancey St
Williamsburg Brg
Broome St
Grand St
E Broadway
Division St
Pike St
Rutgers St
Montgomery St
Saint James Pl
Park Row
Spruce St
Beekman St
Pearl St
Gold St
Water St
South St
John St
Front St
Prospect St
Sands St
Bridge St
Hudson Ave
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



Flooding at the New South Ferry Terminal

Rail & Fastener Damage in Flooded Tubes

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**

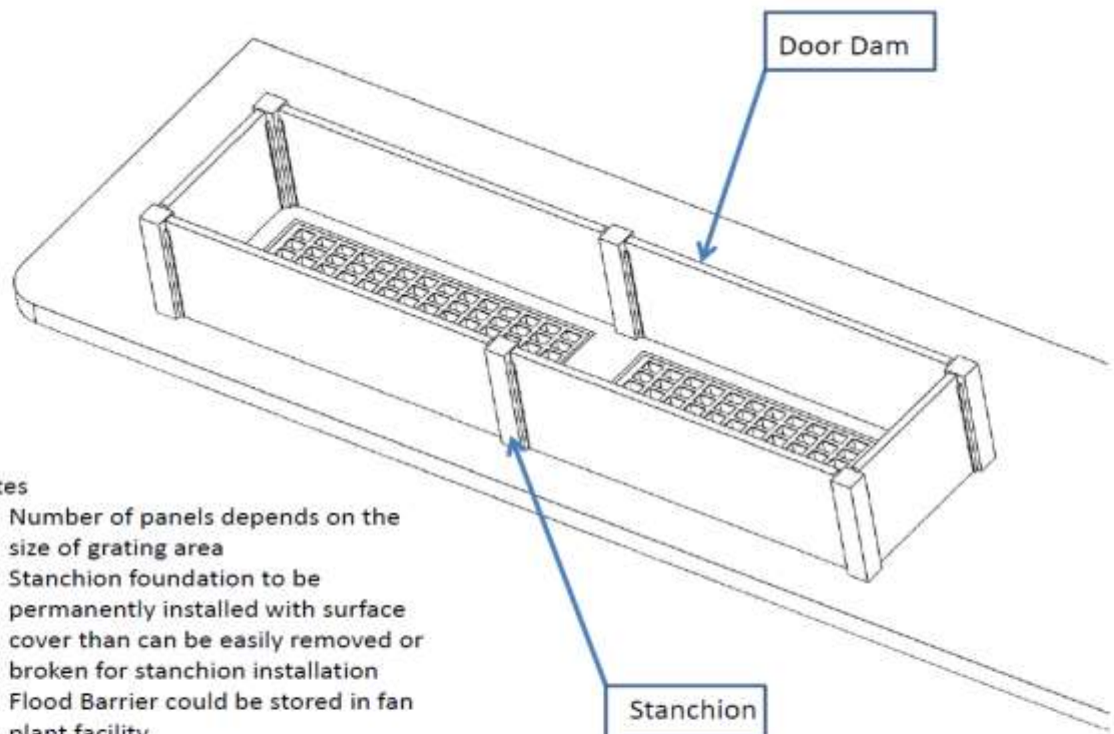
Subway Flooding After Hurricane Sandy

86th St. Station – Sea Beach Line – HWM = 10.2 ft. (NAVD88)




Rockaway Line Damage

How to protect entrances such as this against a potential 11.4 ft. flood surge?



Notes

1. Number of panels depends on the size of grating area
2. Stanchion foundation to be permanently installed with surface cover than can be easily removed or broken for stanchion installation
3. Flood Barrier could be stored in fan plant facility

Example: Conventional Flood Defense Measures of Tokyo Metro

<u>Flood Wall</u> at the Kitasenju Outlet of the Chiyoda Line Tunnel

<u>Flood Gate</u> in a Tube

<u>Flood Sealing Door</u> at an Entrance of the Toyocho Station

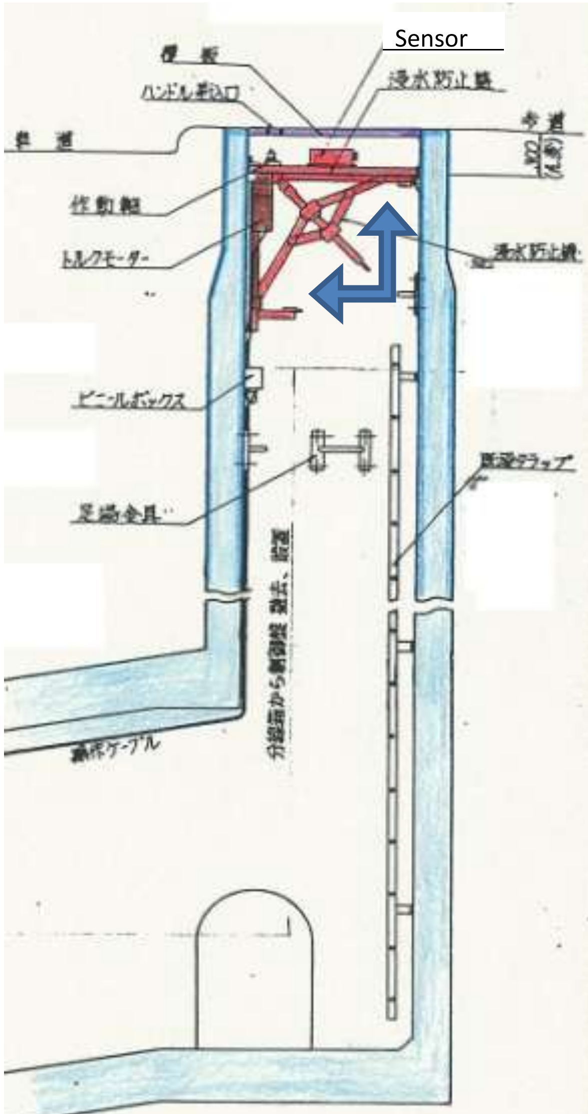
Flood Sealing Door

<u>Frame Barrier</u> at an Entrance of the Honkomagome Station

The frames are removed at normal times

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

View of an automatic shutter when it is **open**

View of an automatic shutter when it is **closed**

Example: Enhanced Flood Defense of Tokyo Metro

- Structural Measures
  - **Protection of Ventilation Outlets (at 27 sites)**

    Raise of heights and/or reinforcement of the walls are scheduled.

Ventilation Outlet located between Kitasenju and Machiya on Chiyoda Line

Ventilation Outlet located between Ojikamiya and Shimo on Nanboku Line

  - **Station Entrance (at 229 sites)**

    Improve water sealing function by proper measures considering possible water depth

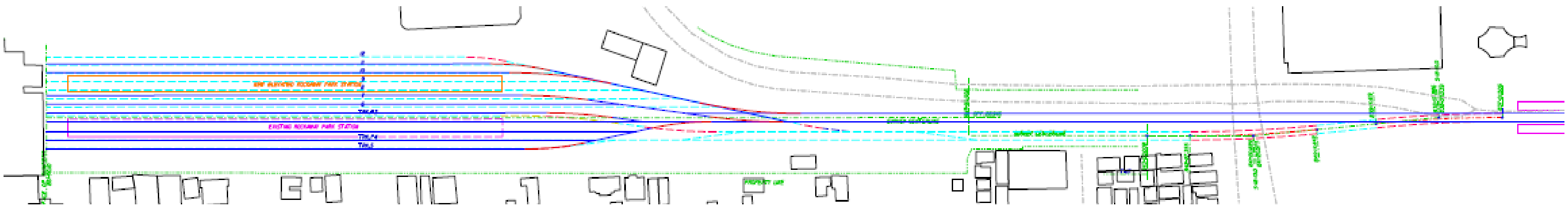
Raise the height of existing frame barrier

Install reinforced glass wall on existing side walls

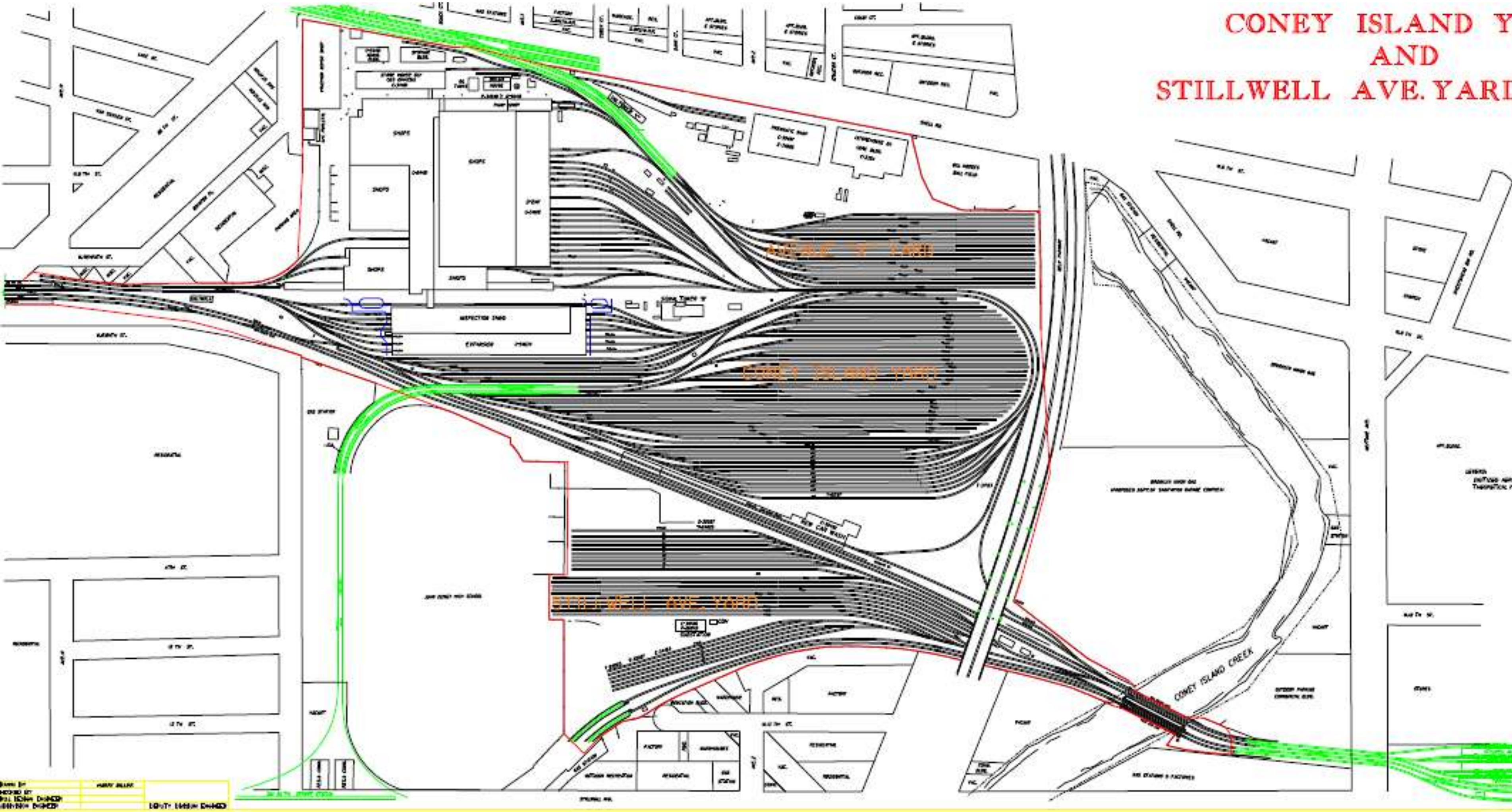
Install water sealing gate on existing structure to make a total protection. Apertures on side walls are covered by reinforced glass.

If existing structure cannot support water pressure, renew structure completely

Rockaway Flats Remediation & Mitigation Work (Ongoing)



Rockaway Park Terminal and Yard – Elevated Structure Concept



Perimeter Flood Wall

Coney Island, Stillwell and Avenue X Yards – Flood Wall Concept

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

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.

How High Will the Next Storm Surge Be ?