Volpe
The National Transportation Systems Center
U.S. Department of Transportation | Research and Innovative Technology Administration

Pre-Sandy Modeling of Storm Surge Impact on the NYC Metro Region's Transportation Infrastructure, Validation by Sandy, and Post Sandy Resilience Issues.

Tuesday Nov 19, 2013
12:00-12:45PM

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Key Points Upfront (1)

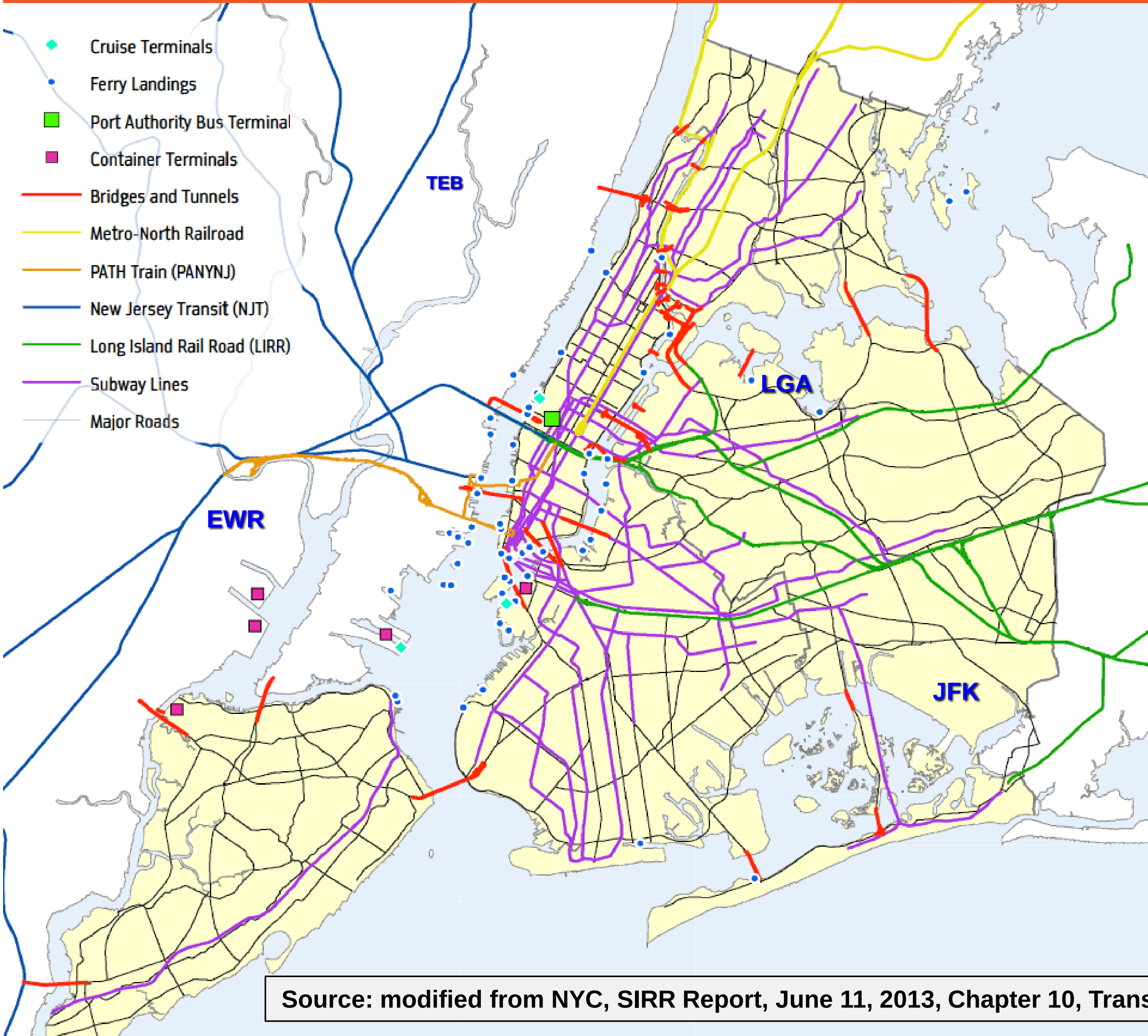
- **Pre-Sandy Storm Surge Modeling of NYC Metro Region's Transportation System was Performed for NYS via the ClimAID Project to Assess the Risks from *Climate Change (CC) & Sea Level Rise (SLR)*, the projections for which were produced by NPCC (NYC Panel on Climate Change).**

- **<u>Findings</u>: Risks will increase significantly due to:**
  - **Accelerating SLR of ≈ + 6 ft by 2100 (90-percentile) above 2000 sea level, plus more & faster SLR later !**
  - **SLR Combined with (a) Nor'easter winter (extra-tropical) storms, and (b) Hurricanes (tropical cyclones) will ever more often & more severely flood the coastal Region's Infrastructure, thereby increasing by 2100 annualized risks by factors up to ~30, unless mitigated.**
  - **Increases in severe rain events (cause street and subway floods)**
  - **Increases in severe heat waves (affect power, health risks & operational costs)**

Key Points Upfront (2): Recommendations:

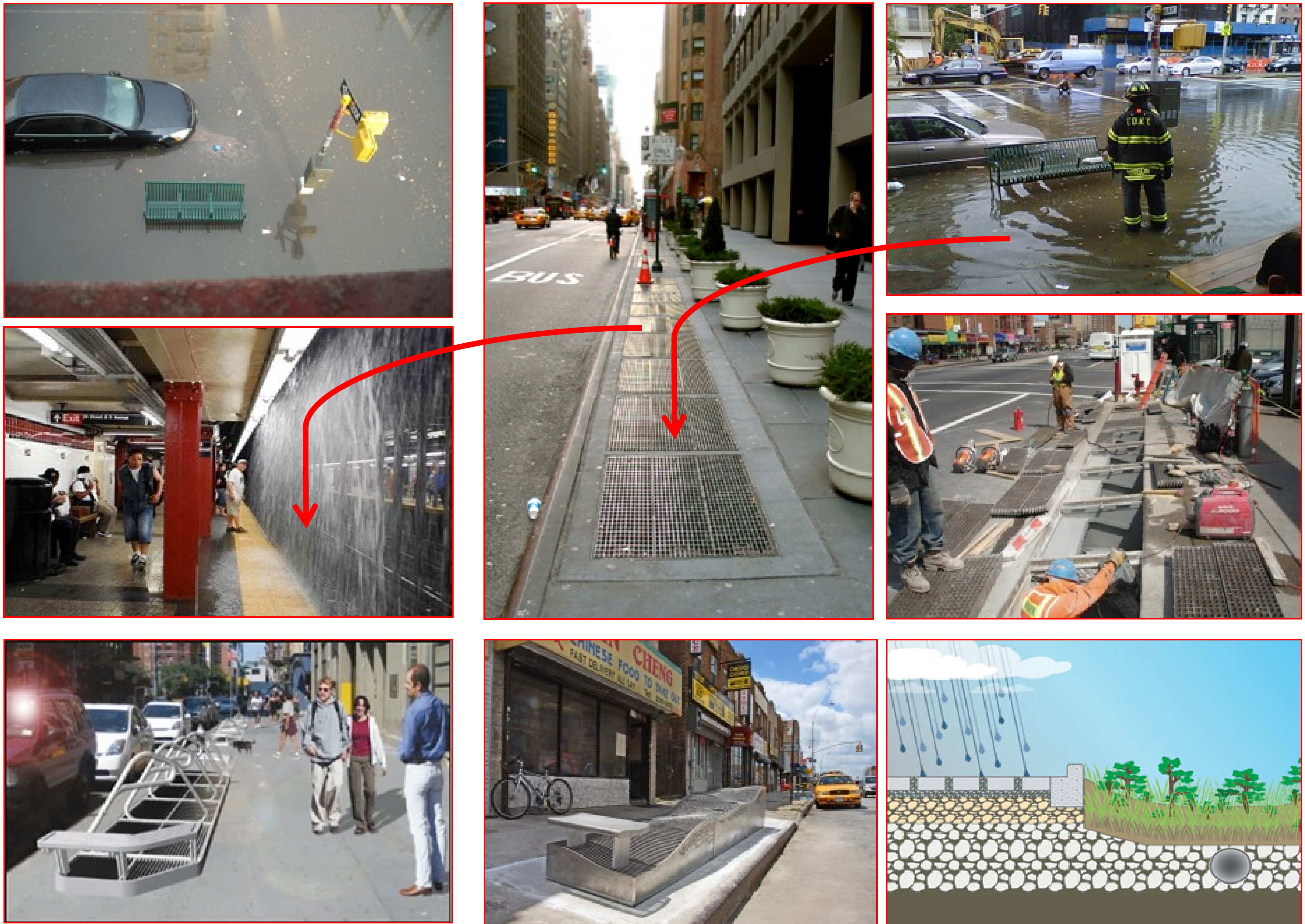
- City, State, Federal & Private Transportation Operators of all modes need to take into account robust CC and SLR projections for all capital spending projects.
- FEMA flood maps need to be updated showing flood elevations for 100 and 500-year recurrences. To these current base elevations, the projected SLR needs to be added.
- Transportation systems need to be designed/retrofitted to make them adaptively resilient by adding to current base flood elevations amounts of SLR commensurate with the *expected lifecycle* of systems / components.
- Until the systems are engineered to be CC resilient, robust operational emergency plans and temporary protection measures must be planned, designed, financed, implemented, tested, and readied for use on short notice.

Regional Transportation Network

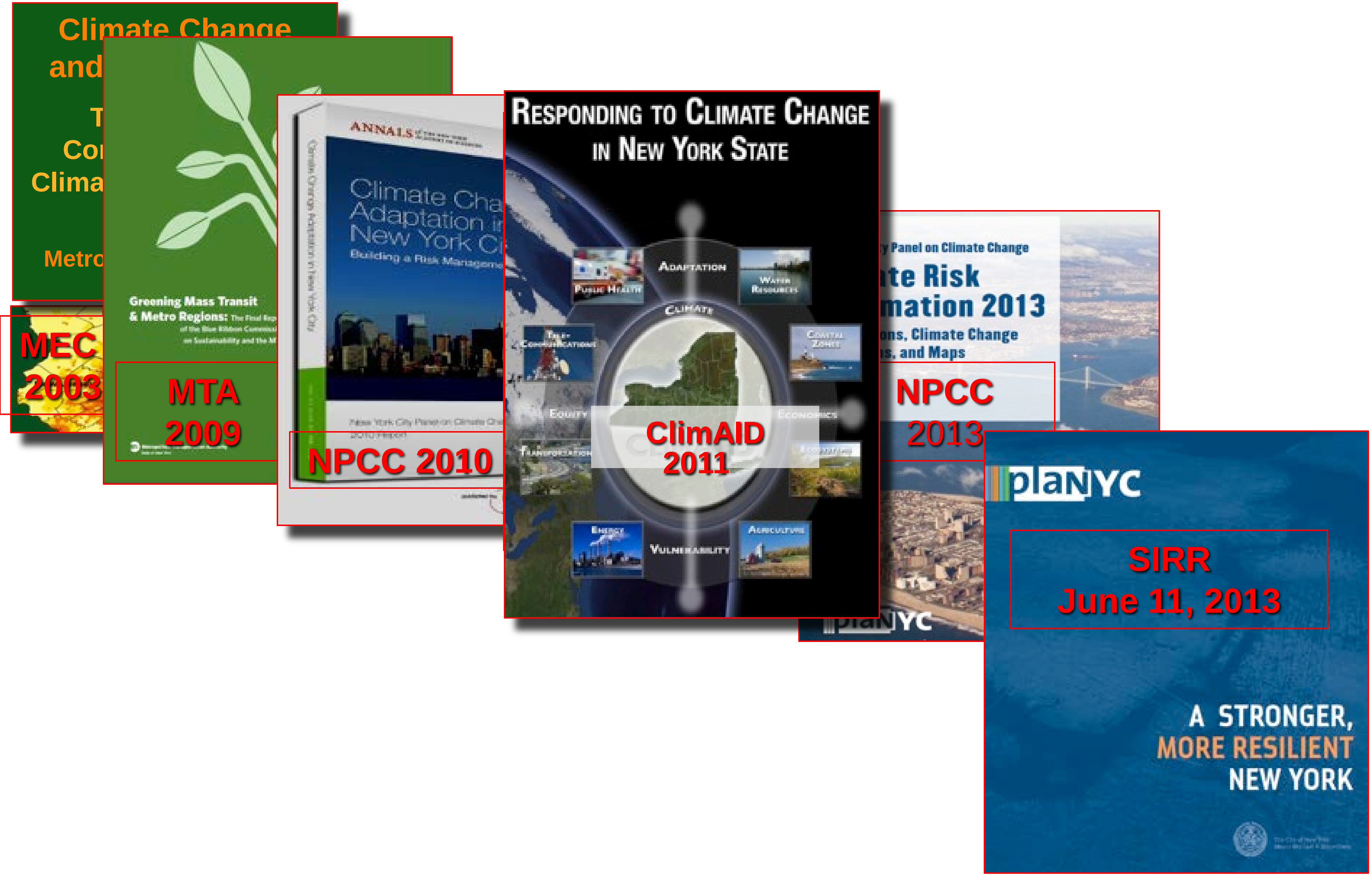


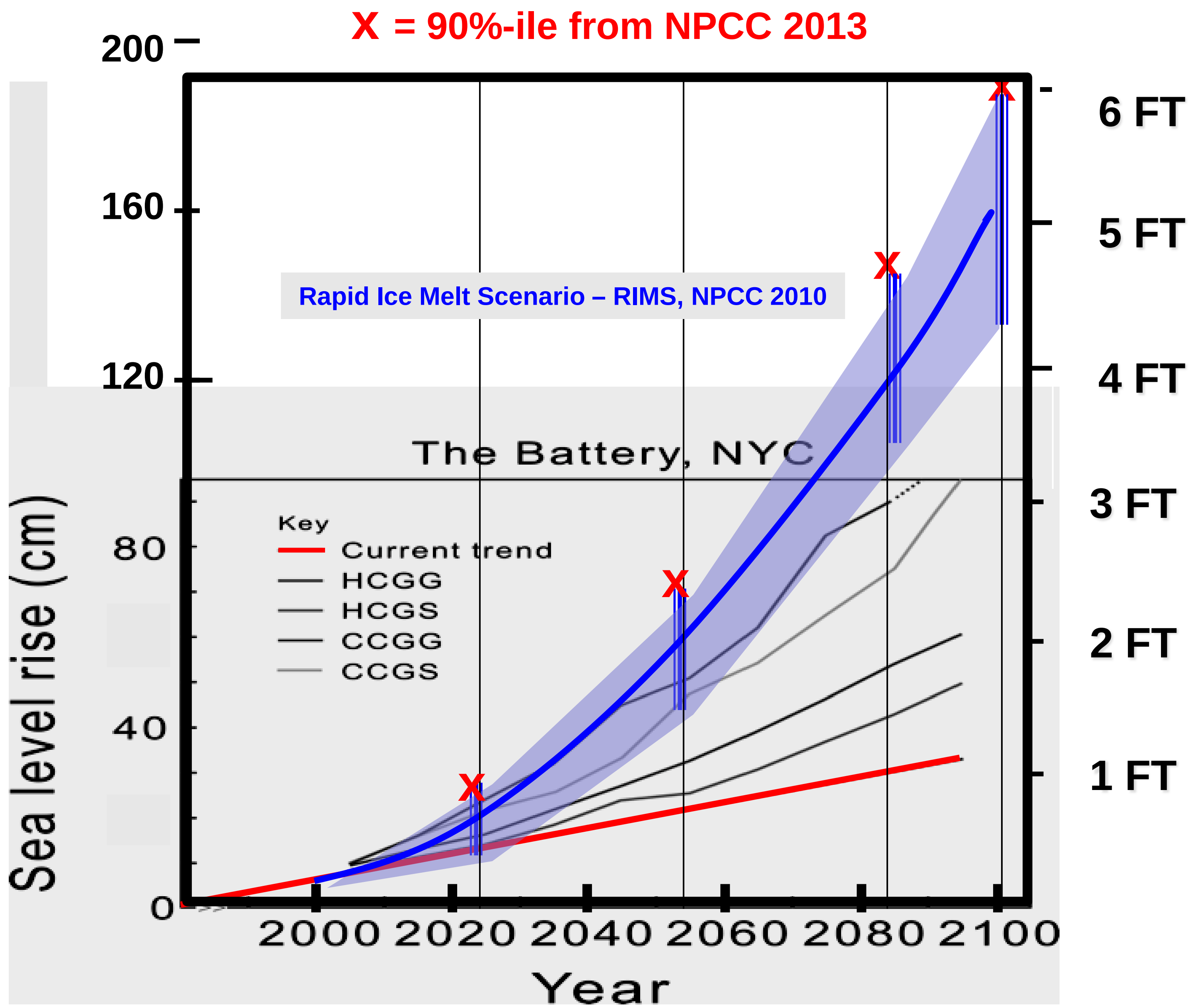
Source: modified from NYC, SIRR Report, June 11, 2013, Chapter 10, Transportation

Long-Standing Common Problems and Past Trial Solutions:
Flash Flooding - Subway as Overflow Sewer - Raised Ventilation Grates – Self Closing Gates - Permeable Pavements



Many Excellent Studies & Reports, but Limited Action & Adaptation $$'s invested prior to SANDY, although post-SANDY some are now in the pipeline.





Warmer Oceans expand, Land based Ice Caps melt; both cause Sea Level Rise

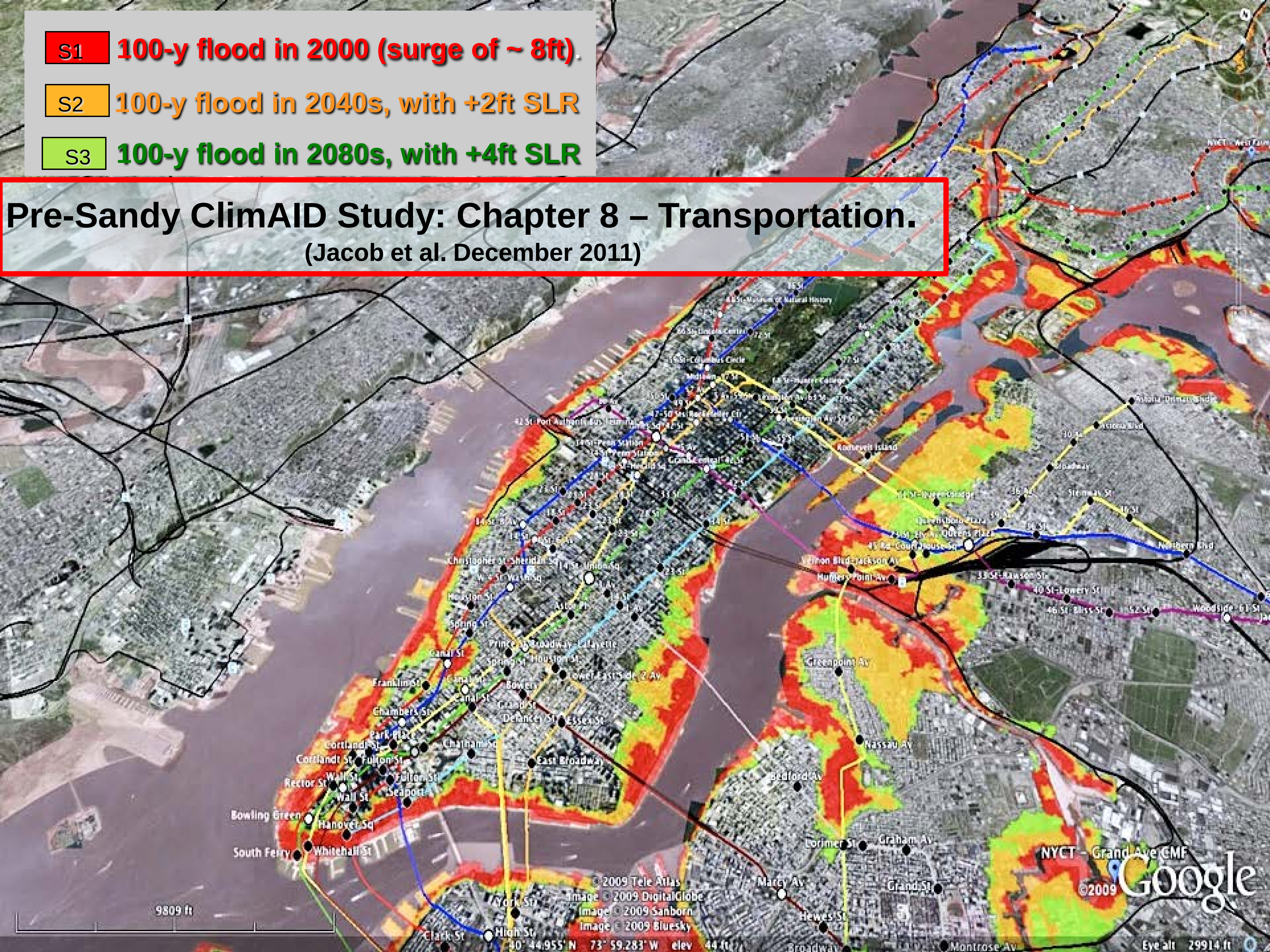
Pre-Sandy ClimAID Study: Chapter 8 – Transportation.

(Jacob et al. December 2011)

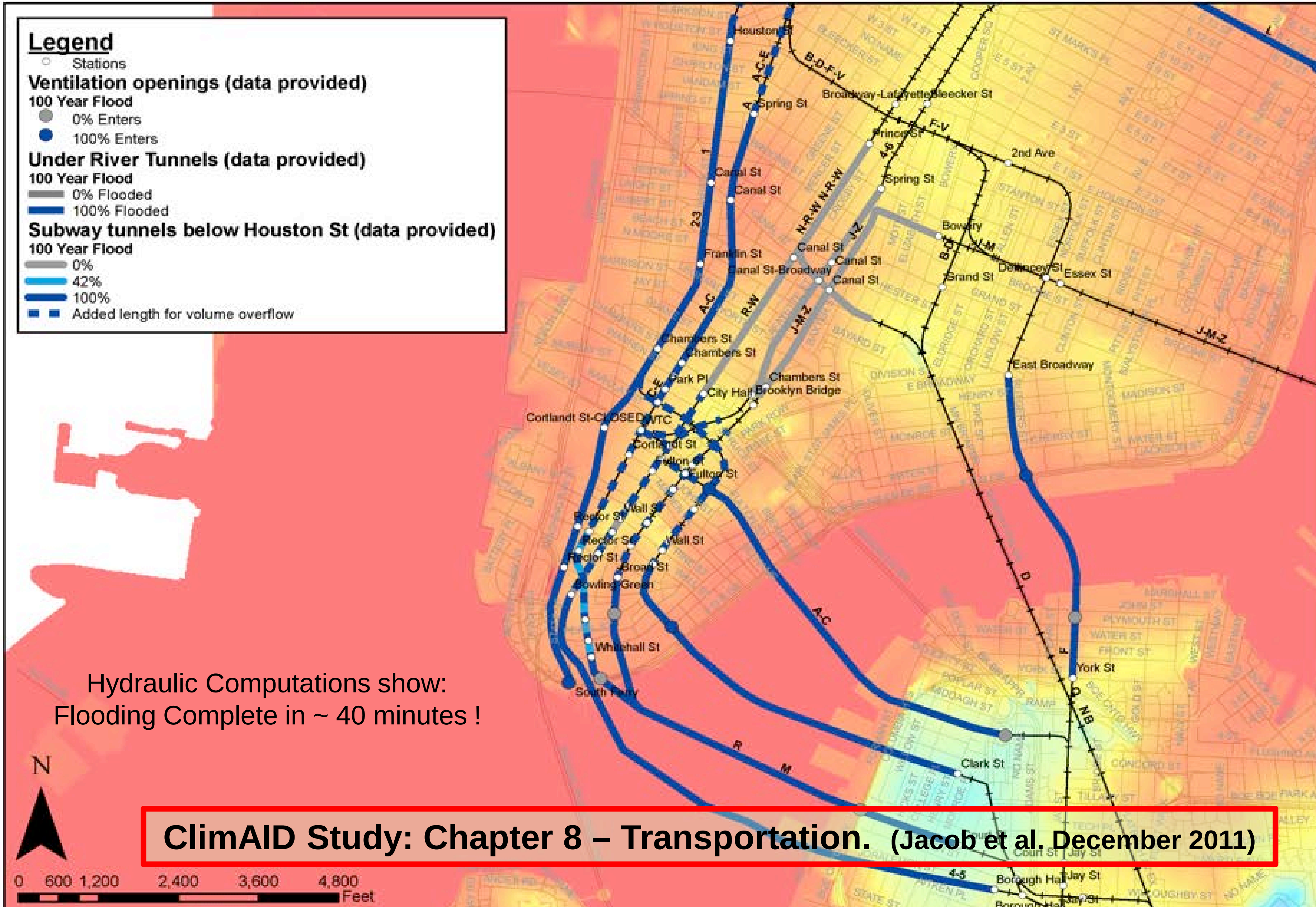
S1 100-y flood in 2000 (surge of ~ 8ft).

S2 100-y flood in 2040s, with +2ft SLR

S3 100-y flood in 2080s, with +4ft SLR



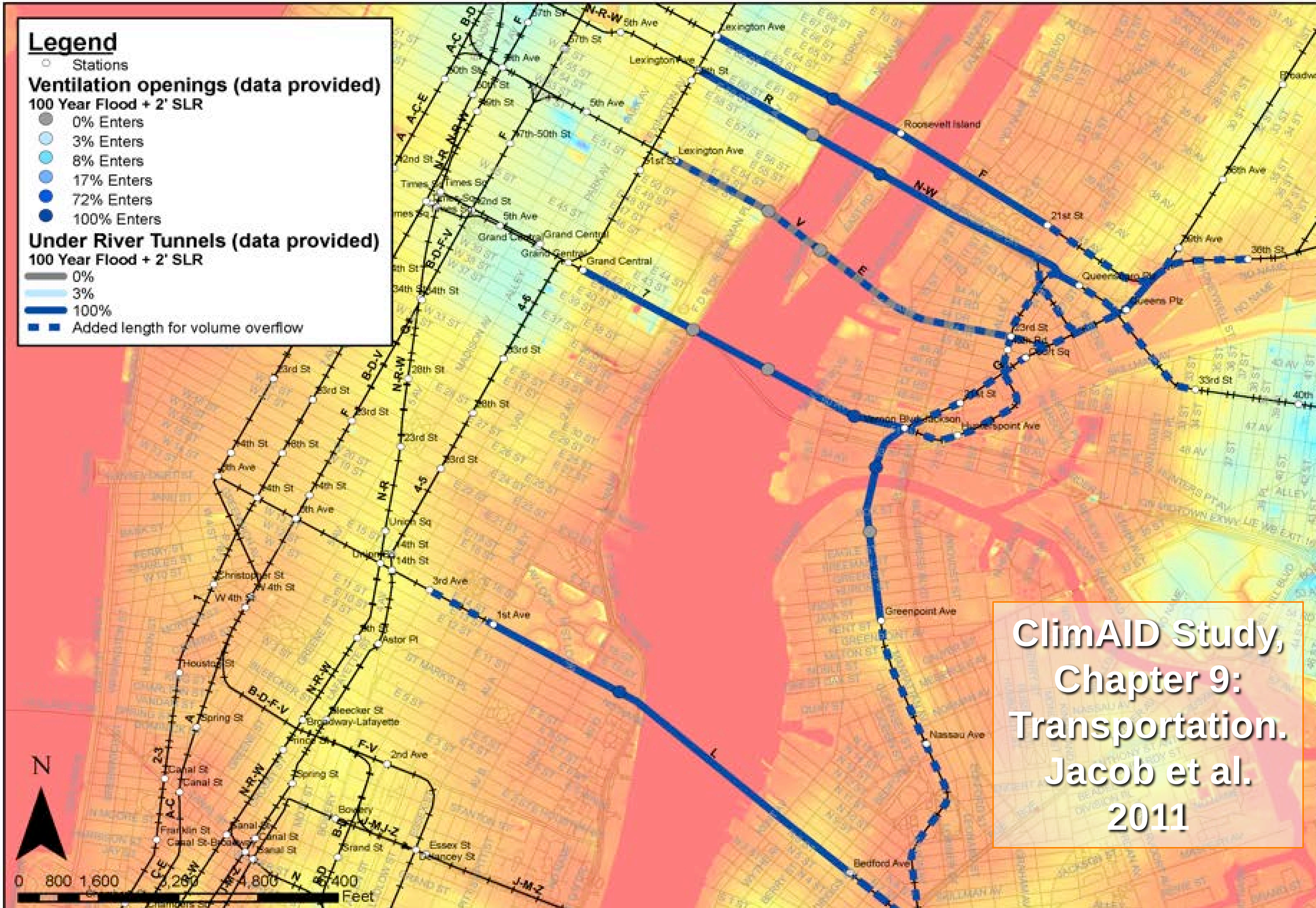
Flooded Subway and Under-River Tunnels, Lower Manhattan, 1% Flood (length overflow)



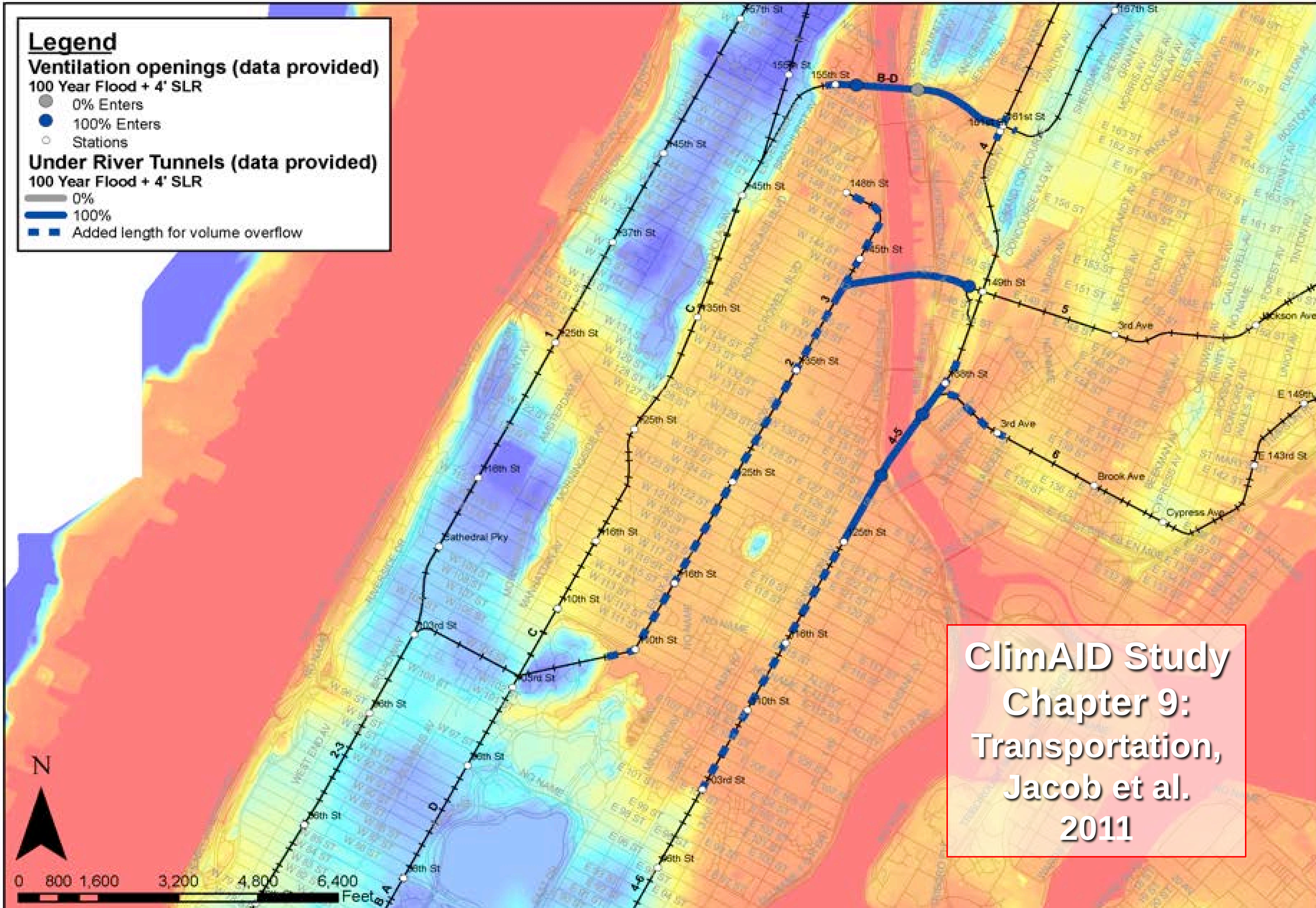
Hydraulic Computations show:
Flooding Complete in ~ 40 minutes !

ClimAID Study: Chapter 8 – Transportation. **(Jacob et al. December 2011)**

Flooded Under River Tunnels, Midtown, 1% Flood + 2' SLR (length overflow)



Flooded Under River Tunnels, Harlem River Crossings, 1% Flood + 4' SLR (length overflow)



T90 (days) = **Max** {D, E, L|P>0} + **Max** {P, A, R} ≥ 1

	1	2**	3	4	5
	TYPE OF DELAY		1%/y BFE	BFE +2ft	BFE +4ft
1	Surge Duration, D++		≤ 1	≤ 1	≤ 1
2	Restore Power, E		≤ 1	≤ 1.5	≤ 2
3	Logistics Set-Up, L |P>0		≤ 1	≤ 2	≤ 3
4	**Max{D, E, L}**		**≤ 1**	**≤ 2**	**≤ 3**
			T90	T90	T90
5	**FACILITY**	**LCE / Zi (ft)**	Max{P,A,R}	Max{P,A,R}	Max{P,A,R}
6	Lincoln Tunnel*	22.6*/Z5=9	{0,0,0} T= 1	{0,0,1} T=1	{0,0,1} T= 2
7	Holland Tunnel*	12.1*/Z5=9	{0,0,0} T= 1	{0,0,1} T=1	{3/2/6} T= 9
8	Queens-Midtown T.	9.5/Z2=11	{1/1/1} T= 2	{4,2,4} T= 6	{6,2,7} T=10
9	Brooklyn-Battery T.	7.5/Z1=9	{2/1/2} T= 3	{5,3,6} T= 6	{6,3,7} T=10
10	PATH System	9.9/Z5=9	{0,1,1} T= 2	{6,3,7} T= 9	{7,3,8} T=11
11	LIRR/Amtr ERvr 42ndStr T	7.9/Z2=11	{6,3,10} T=11	{6,3,11} T=13	{6,3,12} T=15
12	NJTHudsonTubesPennSt	8.9/Z5=9	{5,3,7} T= 8	{7,3,11} T=13	{7,3,12} T=15
13	NJT ARC Tunnel***	11.5/Z5= 9	{0,0,0} T= 1	{0,0,0} T= 1	{5,2,7} T=10
14	LIRR 63rdStrE-River>GCT	11.6 /Z2=11	{0,0,0} T= 1	{7,3,11} T=13	{8,3,10} T=13
15	to GCT via Steinway T.	9.9/Z2=11	{6,3,10} T=11	{7,4,11} T=13	{8,5,12} T=15
16	NYC Subway System	≥5.9/Z5=9	{7,5,20} T=21	{8,6,23} T=25	{9,7,26} T=29
17	MNR Hudson Line along Harlem River (SpuytenDvl.Stn.)	6.6/Z4=8	{0,2,3} T= 4	{0,3,6} T= 8	{0,4,9} T=12
	Bridge Access Ramps+ to				
18	MarineParkw-Rockaway	6.9/Z8=9	{0,0,0} T= 1	{0,1,1} T= 2	{0,1,2} T= 4
19	CrossBayBrdChnlRockaw.	6.9/Z8=9	{0,0,0} T= 1	{0,1,1} T= 2	{0,1,2} T= 4
20	ThrogsNeck	8.9/Z1=14	{0,0,0} T= 1	{0,1,1} T= 2	{0,1,2} T= 4
21	BronxWhitestone	10.9/Z1-2=12.5	{0,0,0} T= 1	{0,1,1} T= 2	{0,1,2} T= 4
22	RFK (Triboro)	13.9/Z3-2=10	{0,0,0} T= 1	{0,0,0} T= 1	{0,1,1} T= 2
23	Verrazano-Narrows	7.6/Z5=9	{0,0,0} T= 1	{0,1,0} T= 2	{0,1,0} T= 2
24	Airports: JFK	10.6/Z7=8	{0,0,0} T= 1	{0,1,1} T= 2	{1,3,4} T= 6
25	LaGuardia*	10.0*/Z2=11	{2,2,3} T= 3	{3,2,4} T= 4	{3,2,6} T= 8
26	Newark	9.2/Z5a=8	{0,0,0} T= 1	{0,1,2} T= 3	{0,2,3} T= 5
27	Teterboro	3.9/Z5s≤8	{0,1,1} T= 2	{0,2,2} T= 3	{0,2,3} T= 5
28	Marine Ports:		Information currently not available		
29			Scenario 1	Scenario 2	Scenario 3
30	**T90min to T90max (days):**		**1 to 21**	**1 to 25**	**2 to 29**

Estimates of the Number of Days Contributing to T90, the Time Needed to Restore various NYC Metro Region Transportation Systems to ~ 90% Functionality after a 100-year coastal flood storm at current sea level and with +2 and +4ft SLR, respectively. (Note: without Adaptation Measures!)

ClimAID Study Chapter 9: Transportation, Jacob et al. 2011

ClimAID Study: Chapter 8 – Transportation. **(Jacob et al. December 2011)**

- **What is the expected direct damage from the 100yr flood to the transportation infrastructure ?**

~ $ 10 Billion

- **How long will it take for the various components of infrastructure to have their services restored ?**

~ 3 weeks (at ~ $ 4 B/day =>)

- **What will be potential economic losses from the transportation / utility outages and extended restoration times ?**

~ $ 50 B (+ Losses to Building Stock)

NPCC >ClimAID 2011:

Identify Options for Solutions:

Example: Subway System:

1. In flood zones, seal ventilation street grates, replace passive 'open' ventilation with forced 'closed' ventilation. Requires additional ventilation fan plants, and $$!

2. Flood gates at vulnerable entrances; or berms / levees: *"Taipei-Solution"*- Go up before you step down !

3. Costs? Engineering designs getting gradually underway, Our Estimate: at least 25% of the expected avoided losses: in excess of $12B for integrated below-ground subway & RR

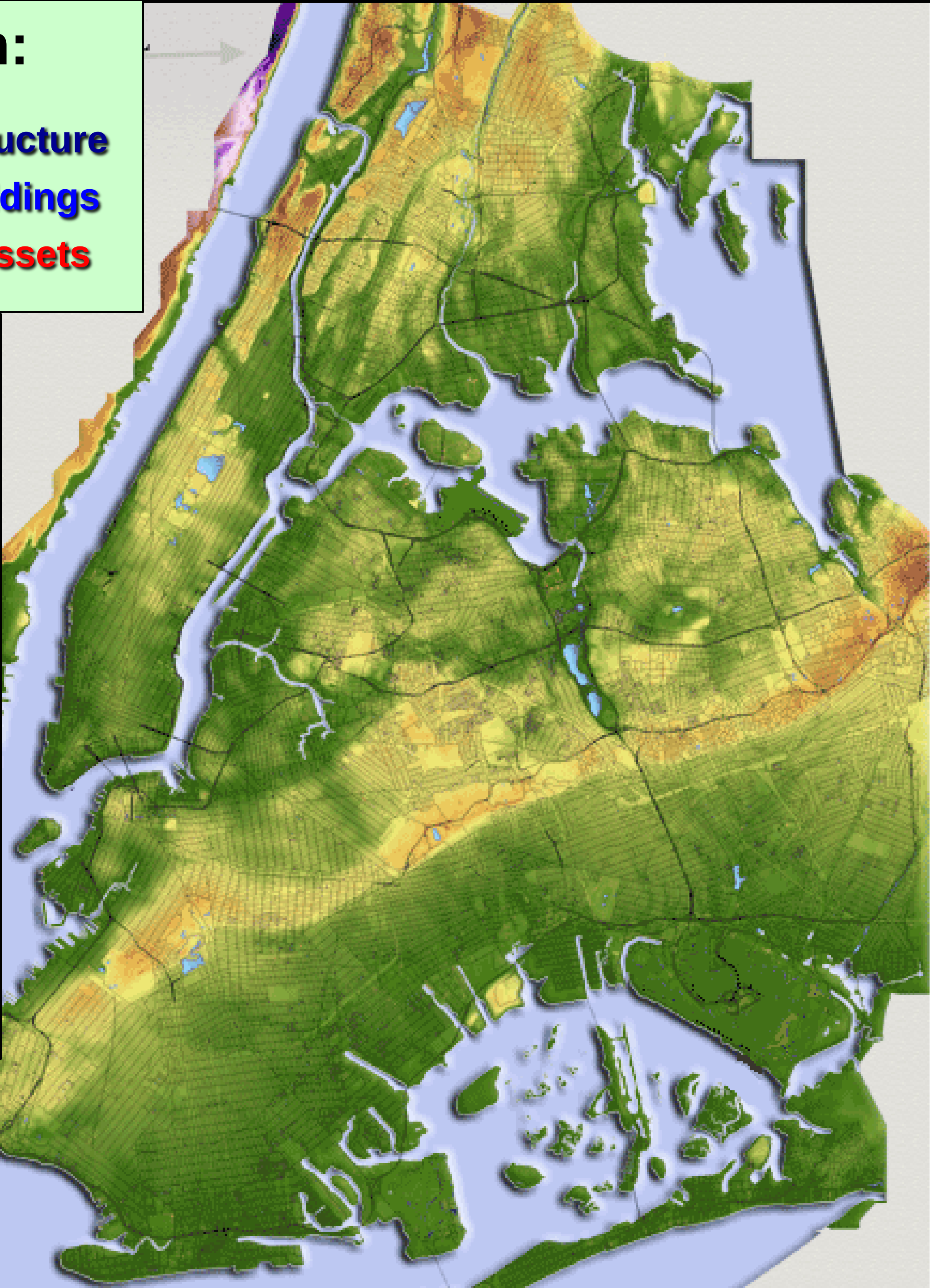
Or: Build **barriers** to protect the entire NY Harbor and Estuary.

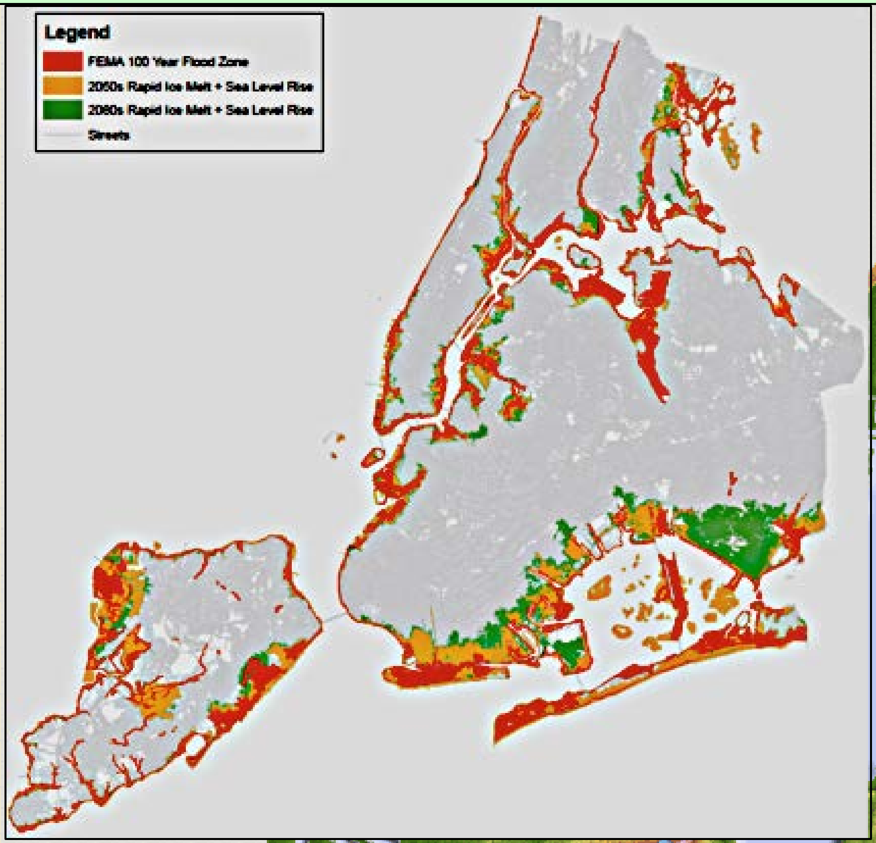
But is this an effective and sustainable solution ?

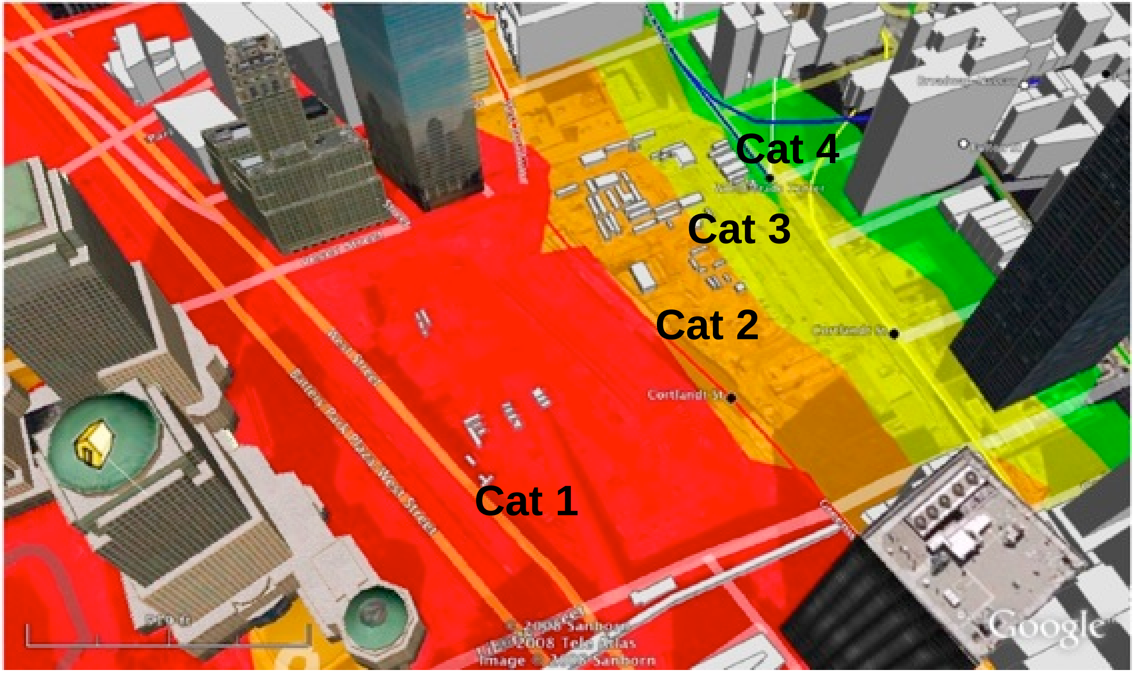
3 Barriers; or 1 big & 1 regular. Is this cost-beneficial & sustainable ?

3 Basic Modes of Adaptation:

- **Protection** — mostly for Infrastructure
- **Accommodation** — " for high-rise buildings
- **Strategic Retreat** — " for residential assets







Past Missed Opportunities: Example – WTC – Reconstruction Site:

Questions
(Presented to PANYNJ in 2007):

Can the West-Tub Flood?
Can the East Tub Flood?
For which Storm Surge Elevations?

How will Flooding affect PATH System?
- **Hudson Tunnels**
- **Stations / Tracks / Control Systems**
- **New Transportation Hub?**
- **For how Long ?**

Will Flooding of NYCT Subway System(s) Affect / Connect with PATH & WTC facilities?

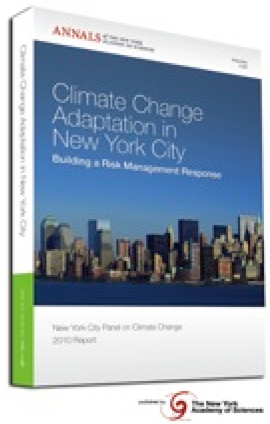
If Answers to Above are YES:

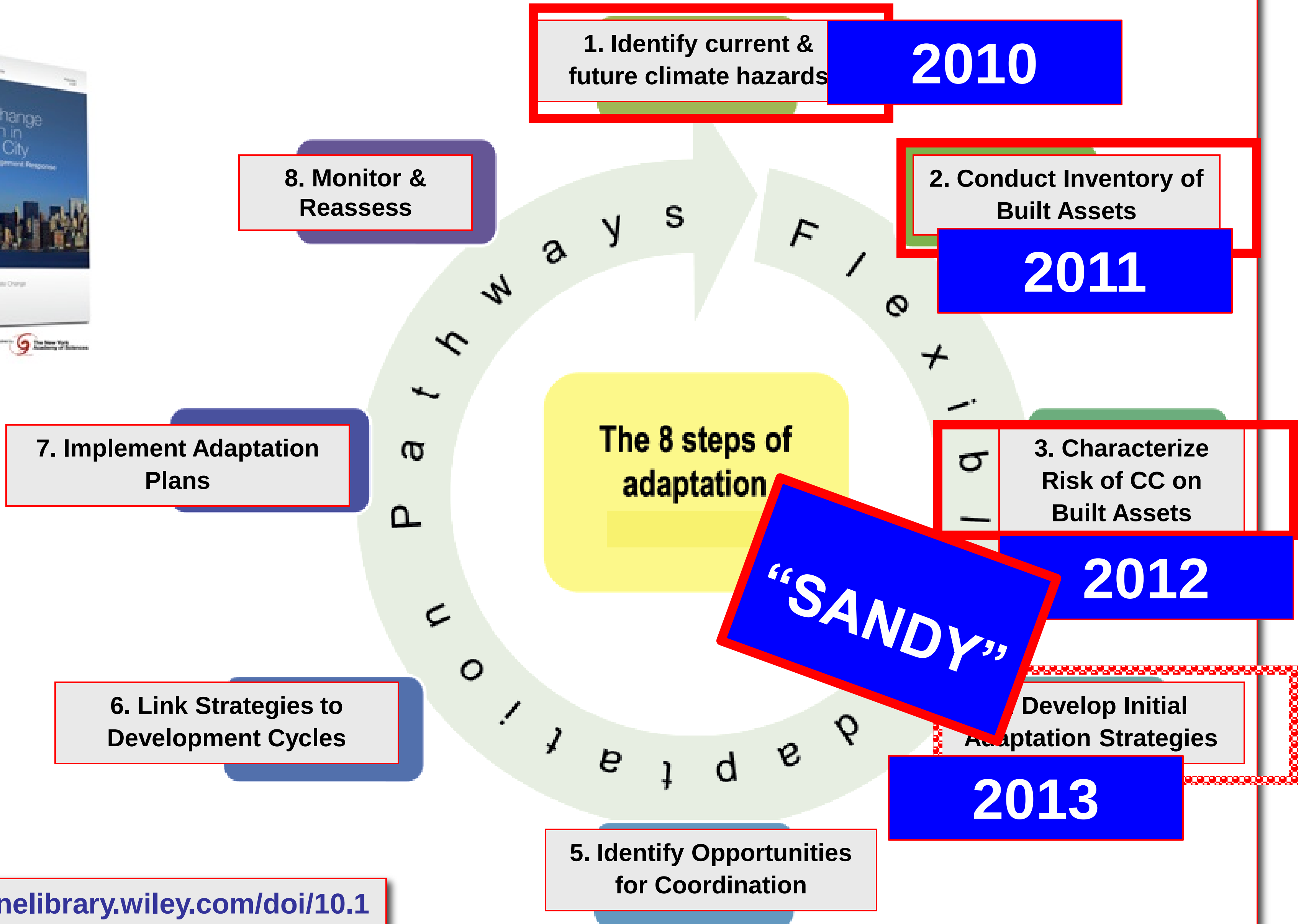
What Sealing-Off Options Exist ?

What Pumping Facilities are Planned ? Where ? Capacity? Reliability ?

Is a Levee System || to West Street Feasible? Up to what Height? How long would it be effective, given SLR.

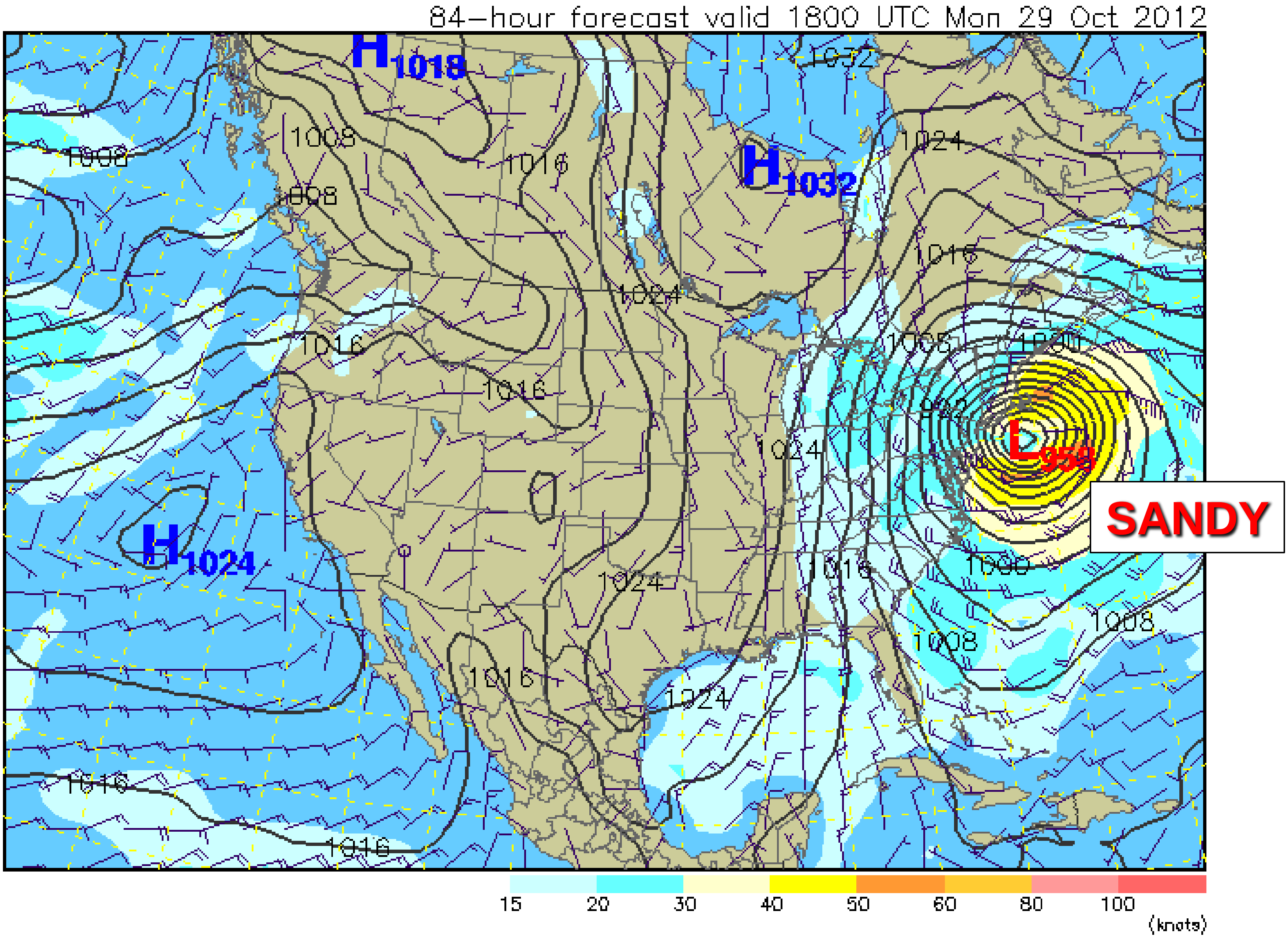
NPCC-Recommended Adaptation Steps





http://onlinelibrary.wiley.com/doi/10.1111/j.1749-6632.2010.05324.x/pdf

Sea-level pressure (mb) / surface wind speed (kts)



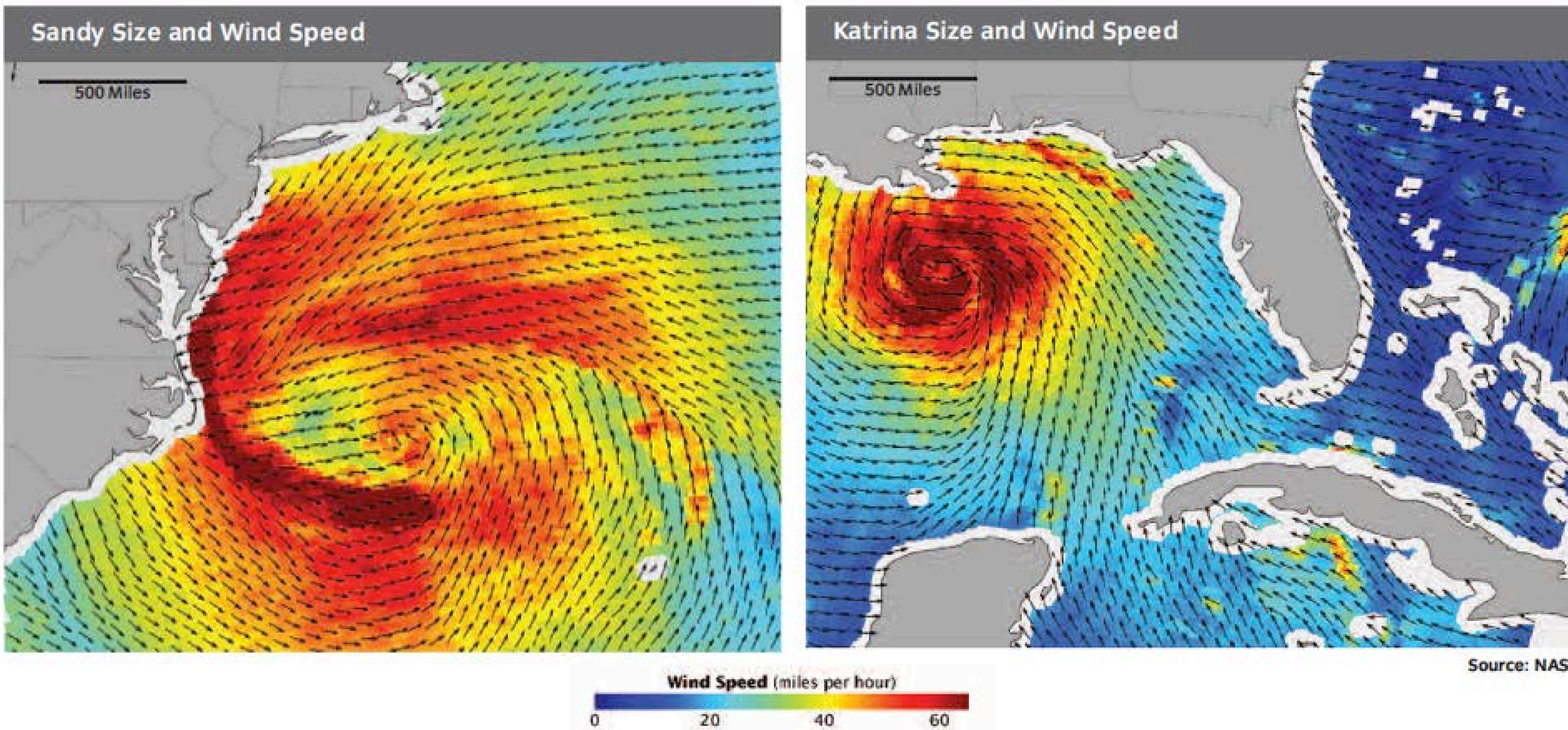
MTA Storm Preparations, Downtown Subway Grates / 148th St Subw. Tunnel / Penn Station LIRR yard

SIRR
June 11, 2013

A STRONGER, MORE RESILIENT NEW YORK

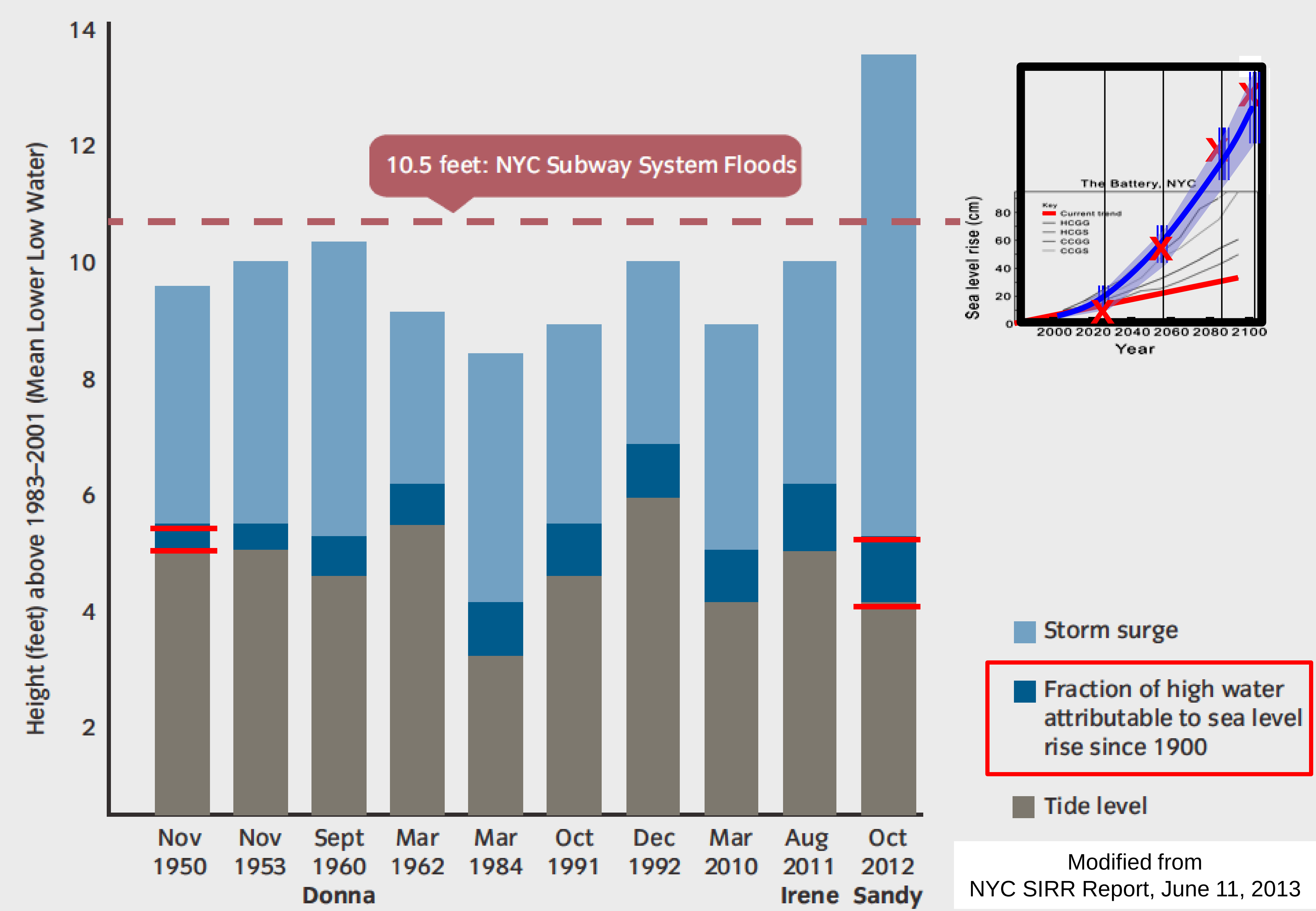
The City of New York
Mayor Michael R. Bloomberg

43 deaths… 6,500 patients evacuated from hospitals and nursing homes… Nearly 90,000 buildings in the inundation zone… 1.1 million New York City children unable to attend school for a week… close to 2 million people without power… 11 million travelers affected daily… $19 billion in damage…

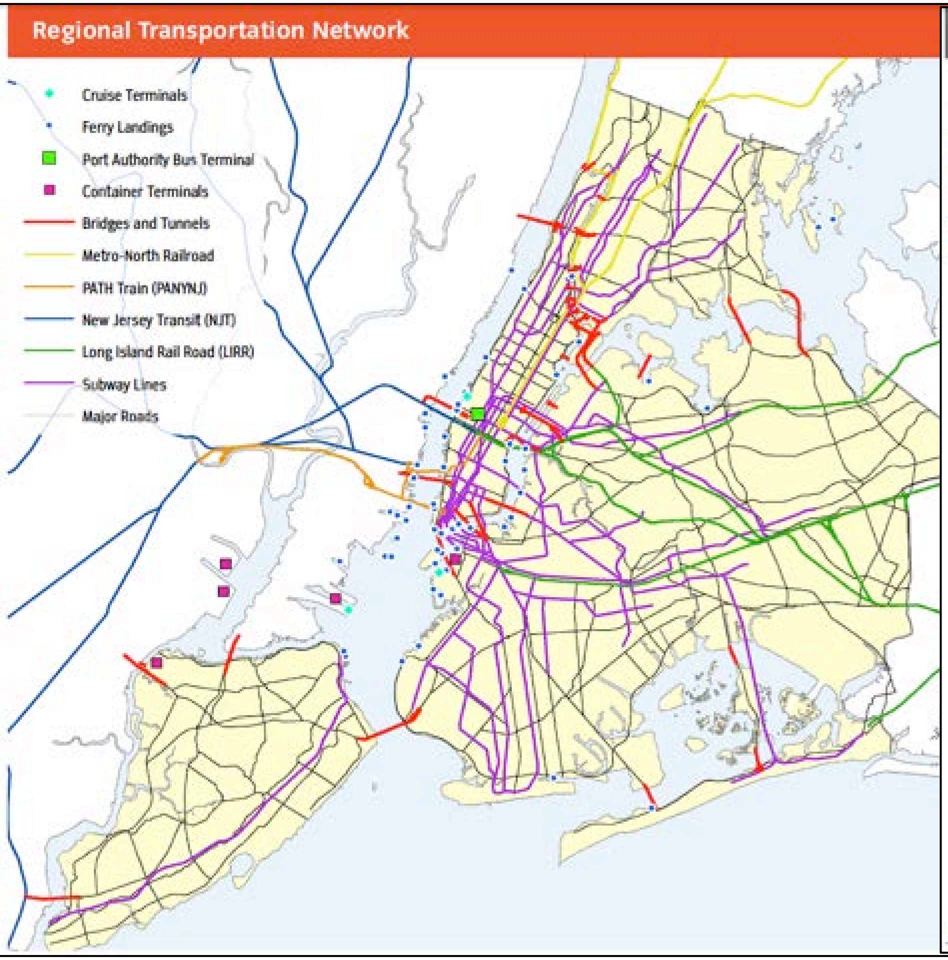


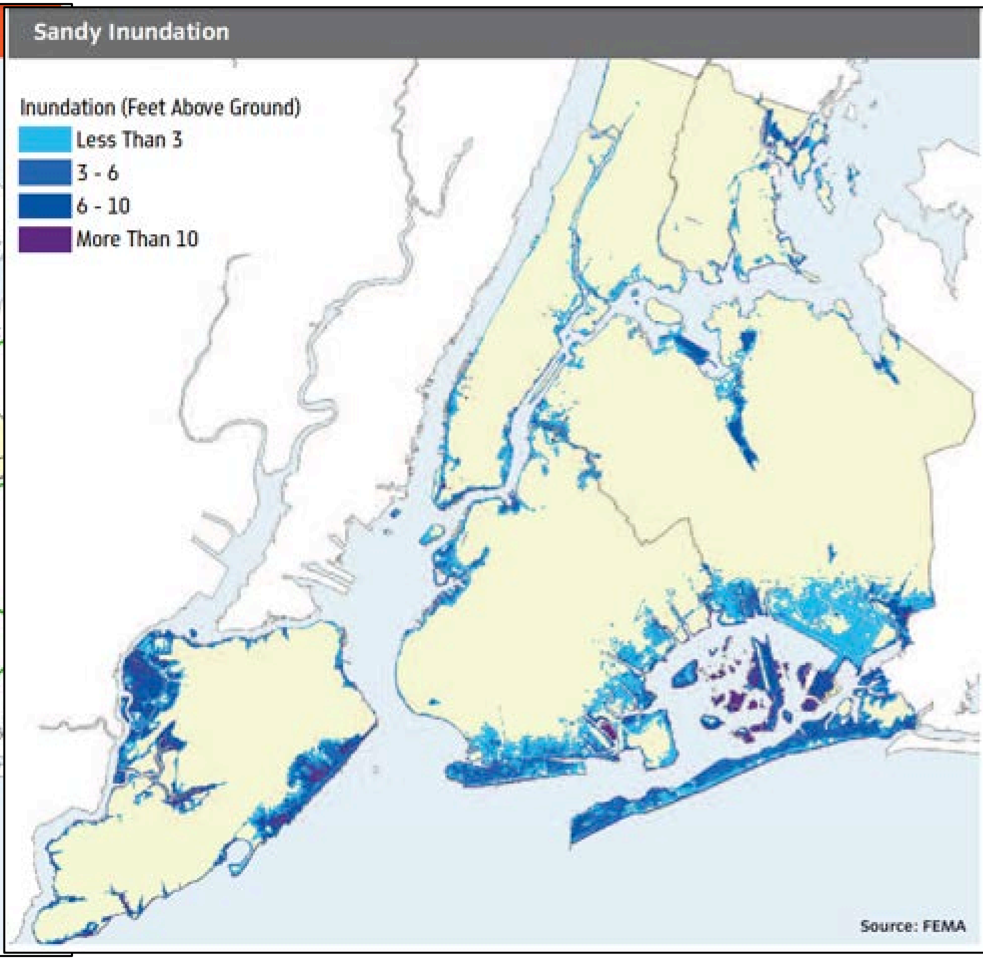
NYC SIRR Report, June 11, 2013

High-Water Events in Lower Manhattan



Modified from NYC SIRR Report, June 11, 2013

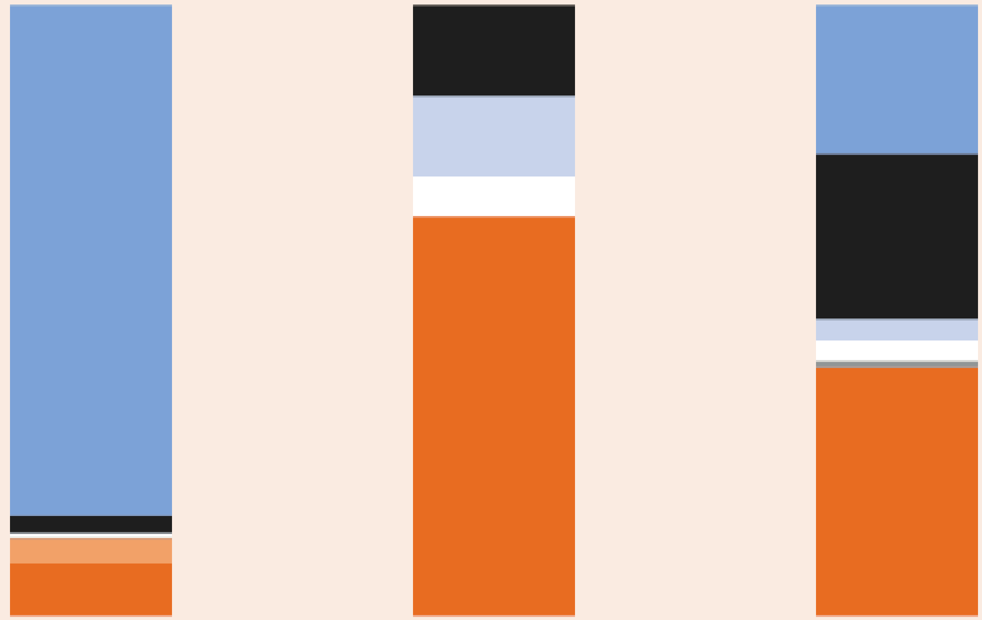




NYC SIRR Report, June 11, 2013

East River Crossings Before and After Sandy

	Typical Weekday	Oct. 31 (2 days after Sandy)	Nov. 2* (4 days after Sandy)
Total	621.9K	82.5K	226.3K



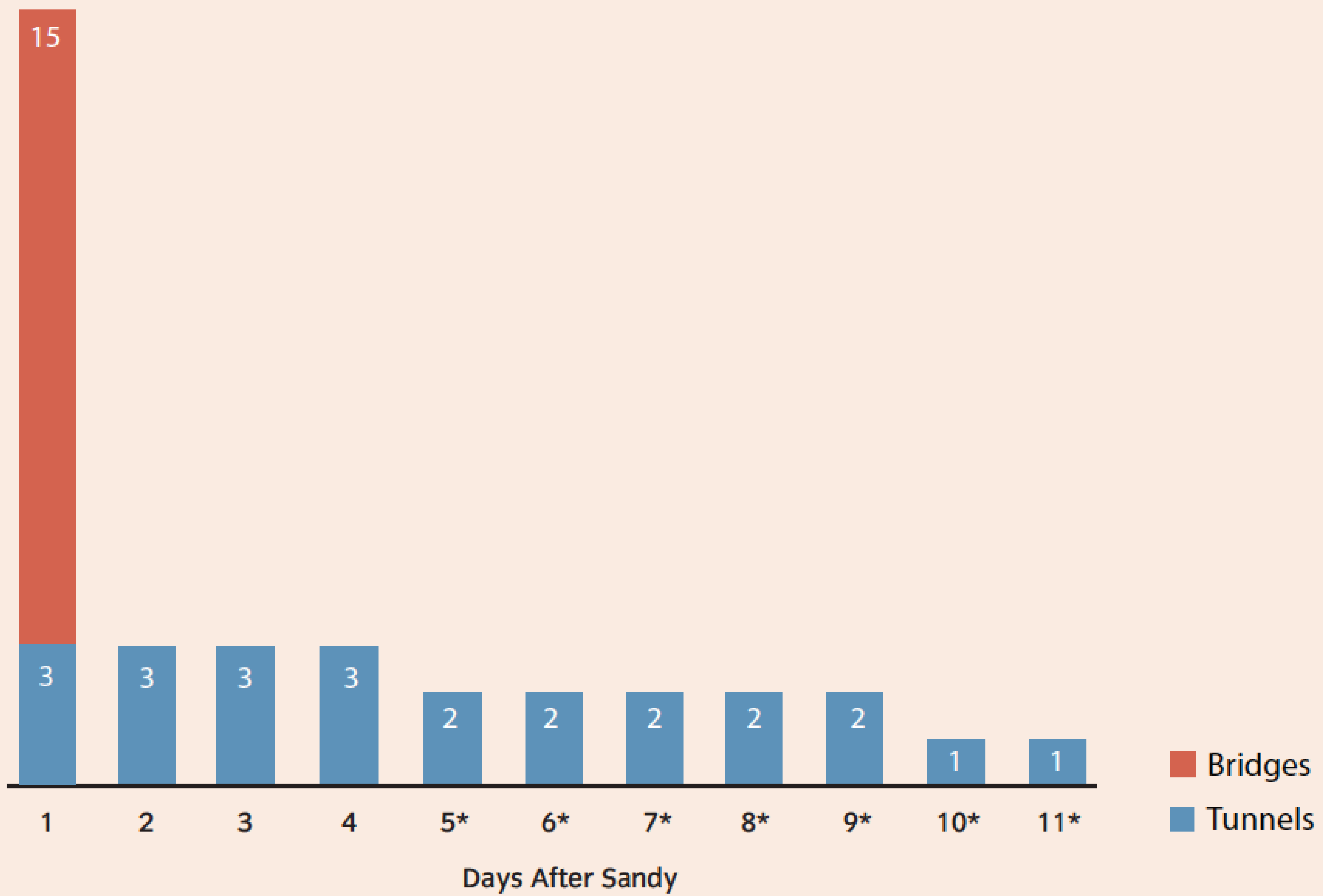
	Typical Weekday	Oct. 31 (2 days after Sandy)	Nov. 2* (4 days after Sandy)
Subways	520,000	0	55,000
Buses	17,400	12,200	61,300
Pedestrian	1,100	10,900	7,800
Bicycle	3,500	5,400	7,800
Ferries	900	0	2,400
Tunnels-Private Vehicles	25,000	0	0
Bridges-Private Vehicles	54,000	54,000	92,000

NYC SIRR Report, June 11, 2013

*Note: Bus bridges and HOV requirements were in effect on Nov. 2

Source: NYCDOT

Major Vehicular Bridge and Tunnel Closures After Sandy



*partial tunnel closures continued due to ventilation system damage

NYC SIRR Report, June 11, 2013

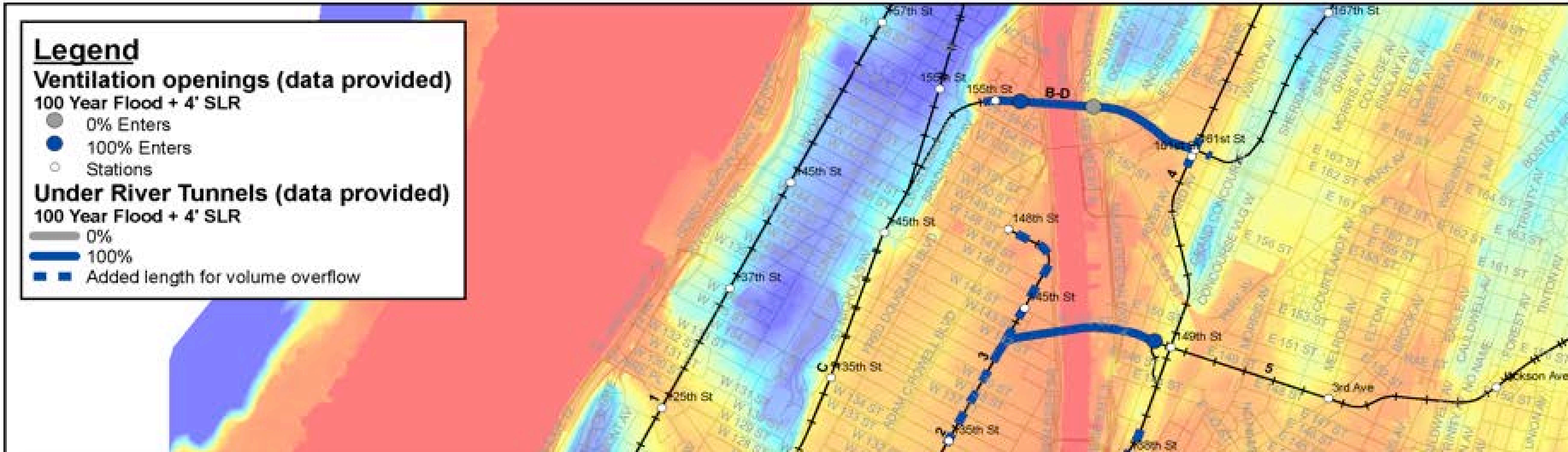
Source: NYCDOT, MTA, and Port Authority of NY & NJ

Temporary "Bus Bridges" (Non-Stop Bus Service) After Sandy

NYC SIRR Report, June 11, 2013

Source: NYCDOT

Flooded Under River Tunnels, Harlem River Crossings, 1% Flood + 4' SLR (length overflow)



Sandy eerily verified ClimAID Impact & Cost Projections: but with 2 Remarkable Exceptions:

(1): Temp. Barrier at 148th Str. Harlem River Tunnel prevented flooding of subway lines between Manhattan & Bronx

(2): MTA removed sensitive signal & control systems from most tunnels that were forecast to flood, reinstalled post Sandy the signals unharmed by salt water, saved 1 to 2 weeks of recovery time and hence saved NYC's economic losses probably in the order of $10B or more.


The City and the Storm
Starting on p.17

Risk Assessment: Impact of Climate Change on Transportation

Major Risk Moderate Risk Minor Risk

	Scale of Impact			
Hazard	**Today**	**2020s**	**2050s**	**Comments**
Gradual				
Sea level rise				Some protection required, but most infrastructure is above future sea level
Increased precipitation				Minimal impact
Higher average temperature				Minimal impact
Extreme Events				
Storm surge				Increased flooding of key at-grade and underground infrastructure as storms worsen
Heavy downpour				Flooding of underground infrastructure possible during heaviest downpours
Heat wave				Movable infrastructure (bridges, switches) could be impacted, as well as safety/comfort on subway platforms INDIRECT: reduced electrical supply reliability impacts many aspects of infrastructure
High winds				General damage to infrastructure possible, as well as impact on aviation

Source: NYC SIRR Report, June 11, 2013

Risk Assessment: Impact of Climate Change by Category of Transportation Asset

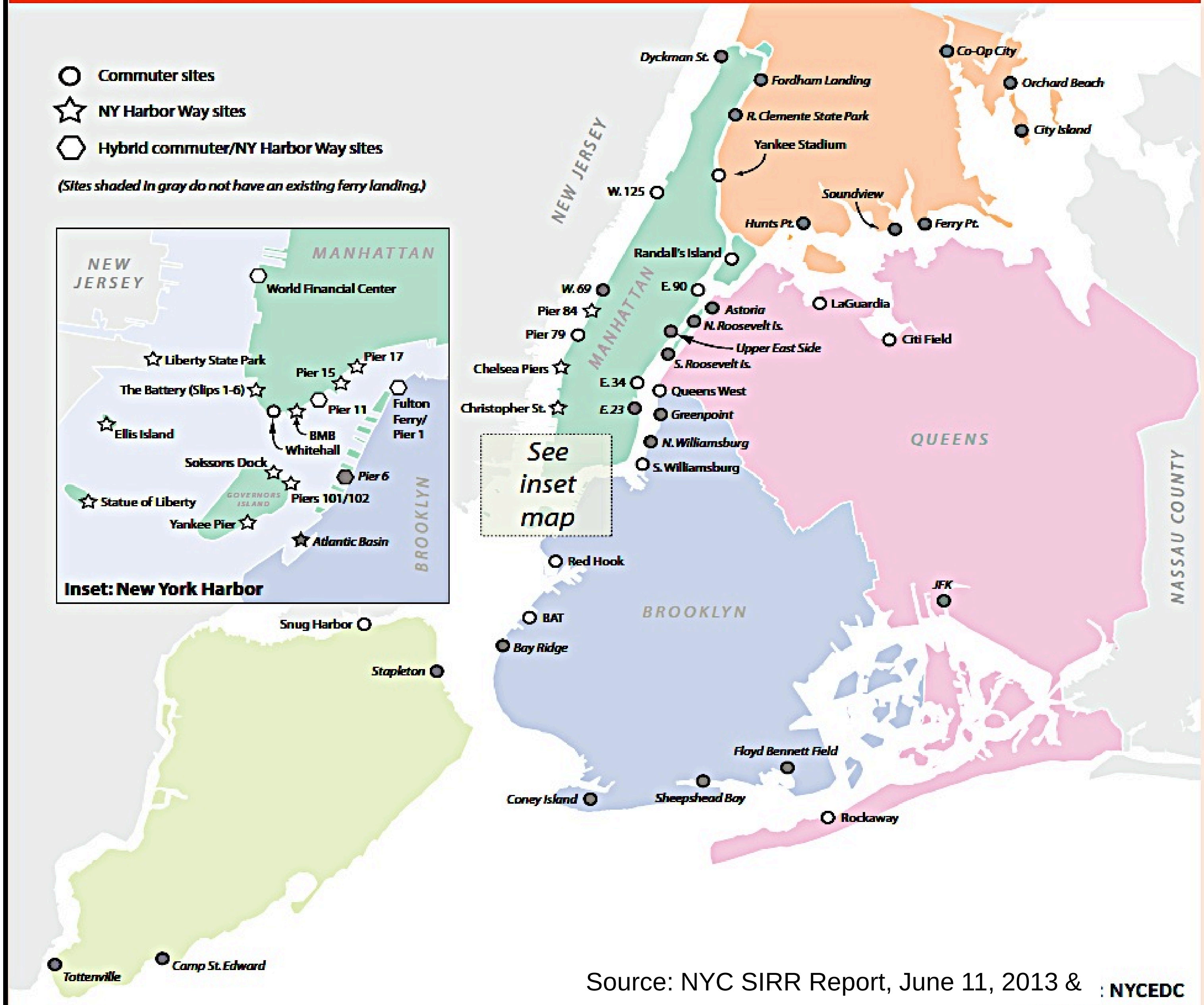
Major Risk | Moderate Risk | Minor Risk

	Asset Impacts				
Hazard	**Roads, Bridges, and Vehicular Transportation**	**Ferries and Marine Transport**	**Tunnels and Subways**	**Rail** (includes above-ground subways)	**Airports**
Gradual					
Sea level rise	Moderate Risk	Major Risk	Moderate Risk	Moderate Risk	Moderate Risk
Extreme Events					
Storm surge	Moderate Risk	Major Risk	Major Risk	Moderate Risk	Moderate Risk
Heavy downpour	Moderate Risk	Minor Risk	Major Risk	Minor Risk	Minor Risk
Heat wave	Moderate Risk	Minor Risk	Moderate Risk	Moderate Risk	Minor Risk
High winds	Moderate Risk	Moderate Risk	Minor Risk	Moderate Risk	Moderate Risk

Note: This chart excludes increased precipitation and higher average temperature because these are expected to have minimal impact on the transportation system

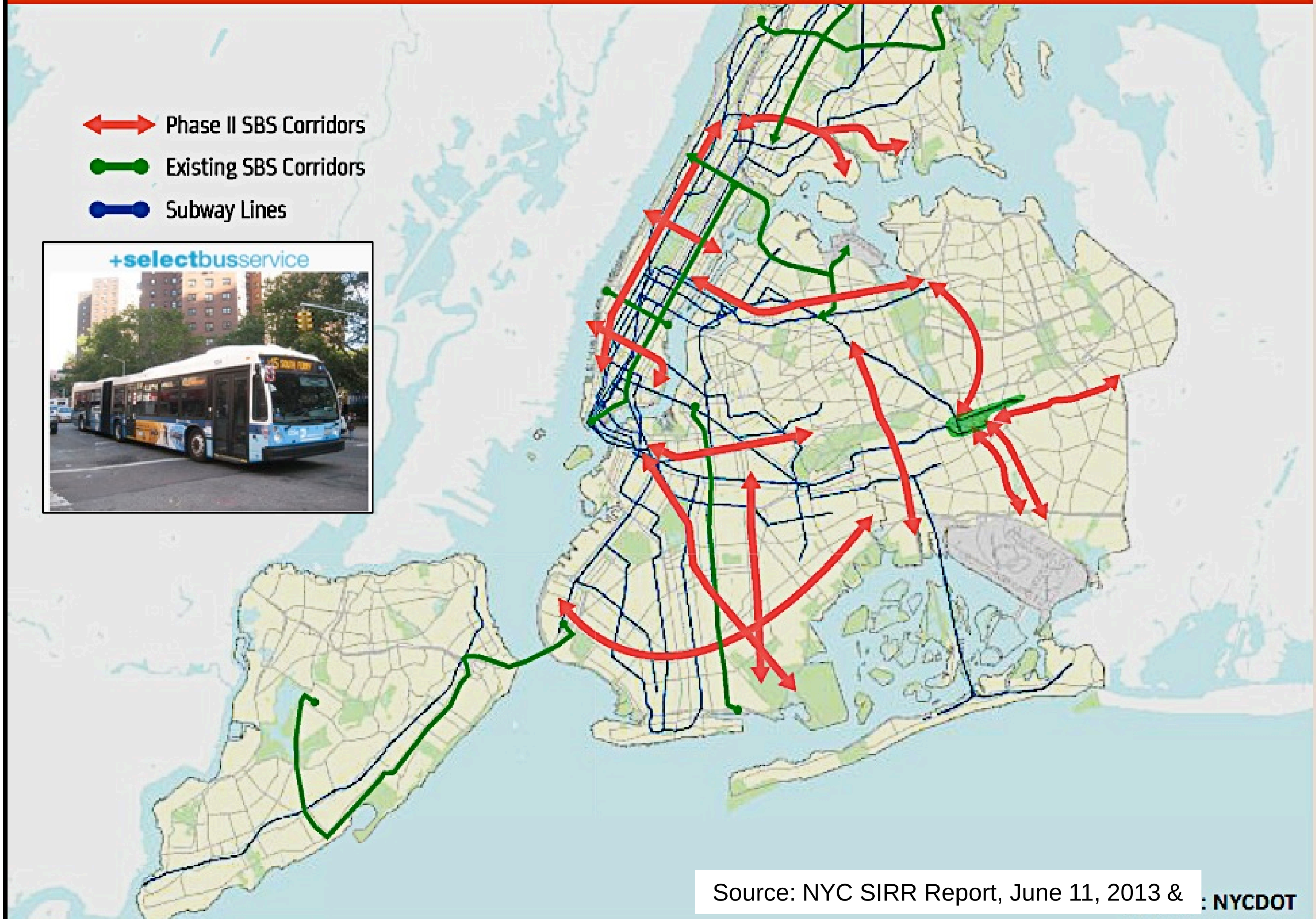
Source: NYC SIRR Report, June 11, 2013

Citywide Ferry Study

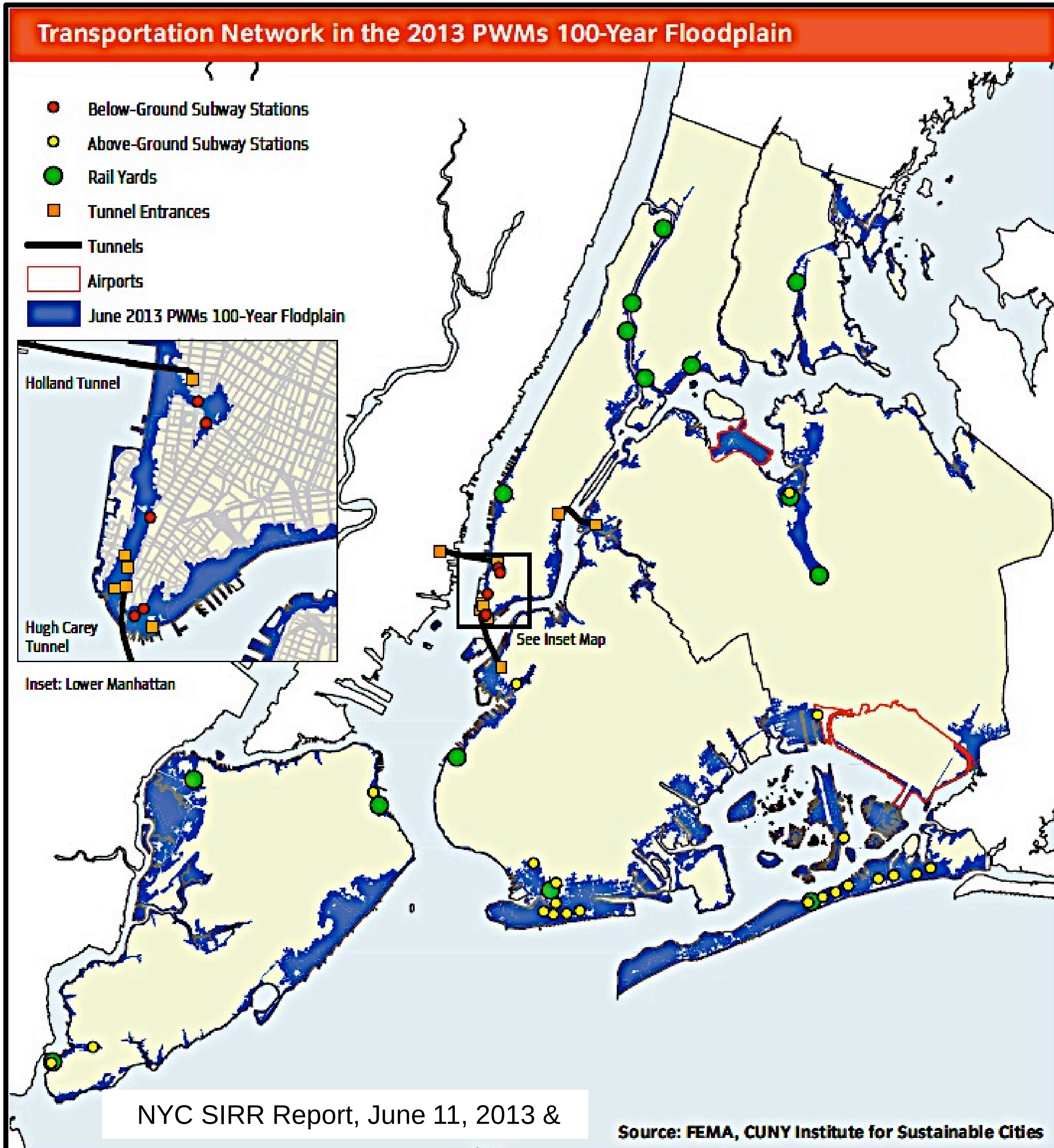


Source: NYC SIRR Report, June 11, 2013 & : NYCEDC

Existing and Proposed Select Bus Service Corridors



Source: NYC SIRR Report, June 11, 2013 & : NYCDOT



NYC SIRR Report, June 11, 2013 &

Conclusions / Suggestions for the Region (1 of 2):

1. Make **time-dependent risk-based Benefit/Cost Assessments** using updated Probabilistic Flood Maps and Flood Vulnerabilities as a Function of SLR (i.e. for various time horizons according to expected asset life times) until optimal, adaptive resiliency pathway is found, while also accounting for changing Physical and Social Asset Configurations and Vulnerabilities.

1. Develop jointly with Public & Private Sector Regional SLR Adaptation **Policy/Strategy** & **Regional SLR Land Use Plans** that balance the merits from Temporary Protection, with Medium-Term Protection and Accommodation to rising waters, with Long-Term Sustainable Managed Retreat (Horizontal and Vertical) to relative safety – by combining Risk-Based Landuse and Transit Oriented Urban Design, Accessibility, Insurance Pricing, Rezoning, Codes & Eng. Standards Improvements, Financial and Tax Incentives, Buy-Out Trust Funds, with Market-Driven Risk Averseness while taxing SLR-risk-prone Developments.

Conclusions / Suggestions for the Region (2 of 2):

3. **Incorporate the CC information & Probabilistic Risk Estimates for Various Time Horizons into all strategic planning and capital-spending decisions.**

3. **Use each CC + SLR Challenge as Opportunity for regular Infrastructure and Urban Renewal. The costs just for the NYC metro region alone will be upward of $100 Billion for the next few decades, and upward of $30 Billion for the Transportation sector alone. But not investing in these resilience measures will be more expensive by factors of 4 to 10 in incurred direct and economic losses combined.**

3. **Ensure robust interim Operational Emergency and Business Continuity Plans until assets can be engineered to be CC, SLR and storm surge resilient with an acceptable hazards target of better than 10^{-4}/yr to *minimize* impact and losses, and/or allow for expedient recovery.**

Timing makes a Difference.