Department of Geological Sciences, Faculty of Sciences
Masaryk University/Brno & Czech Geological Society

September 12-14, 2011

Short Course on Geological Hazards

Day 3 (Wed AM), Lecture 5:

(Topic 5 of Original Announcement)

Hazards and Risks Associated with Climate Change: the NYC Case Study.

Klaus H. Jacob

Lamont-Doherty Earth Observatory
of Columbia University, NY
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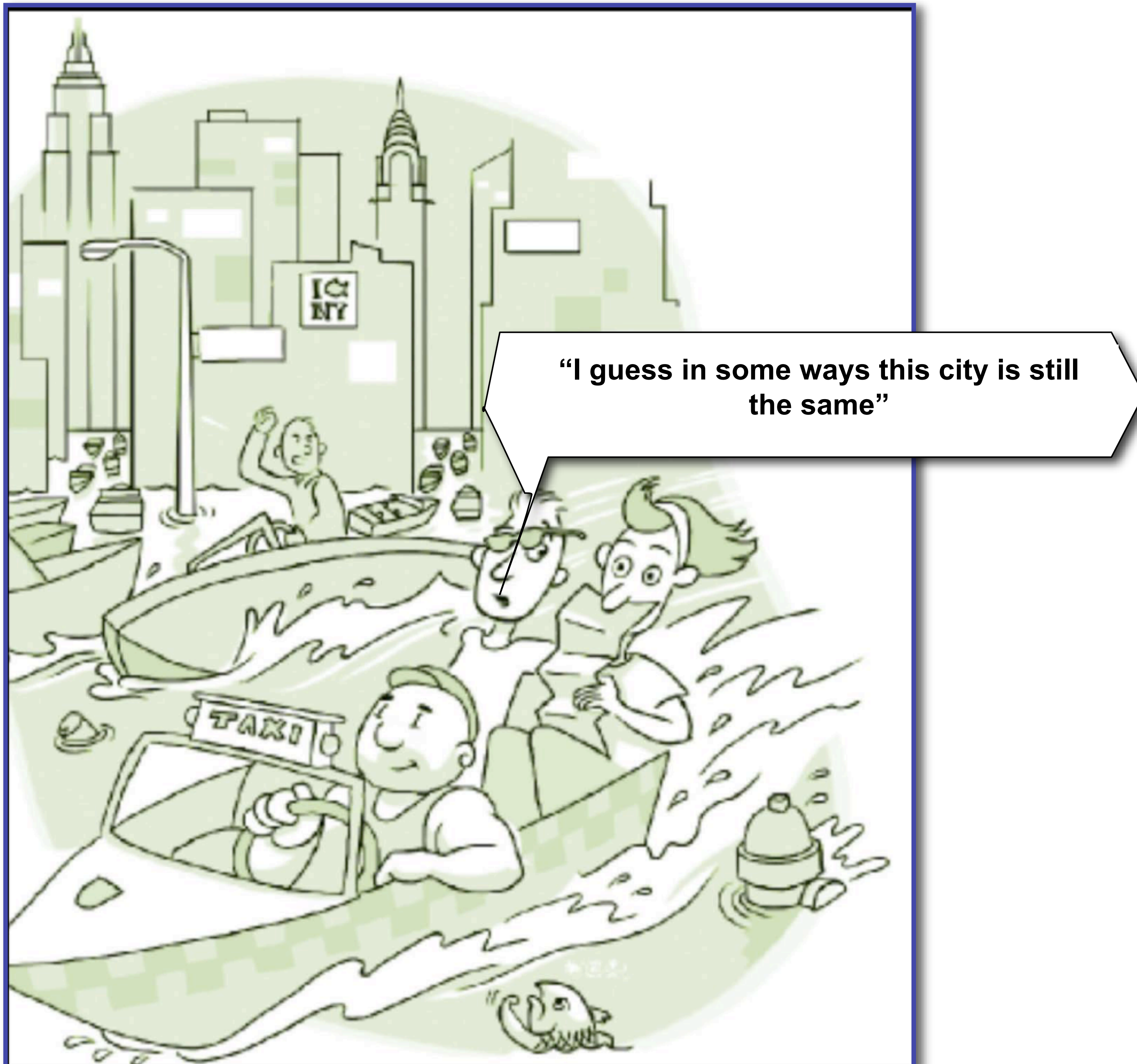
In Essence:

- **NYC has developed and maintained its economic viability largely without -- at least until 3 years ago -- conscientious consideration of climate change (CC) and, especially, *sea level rise* (SLR).**

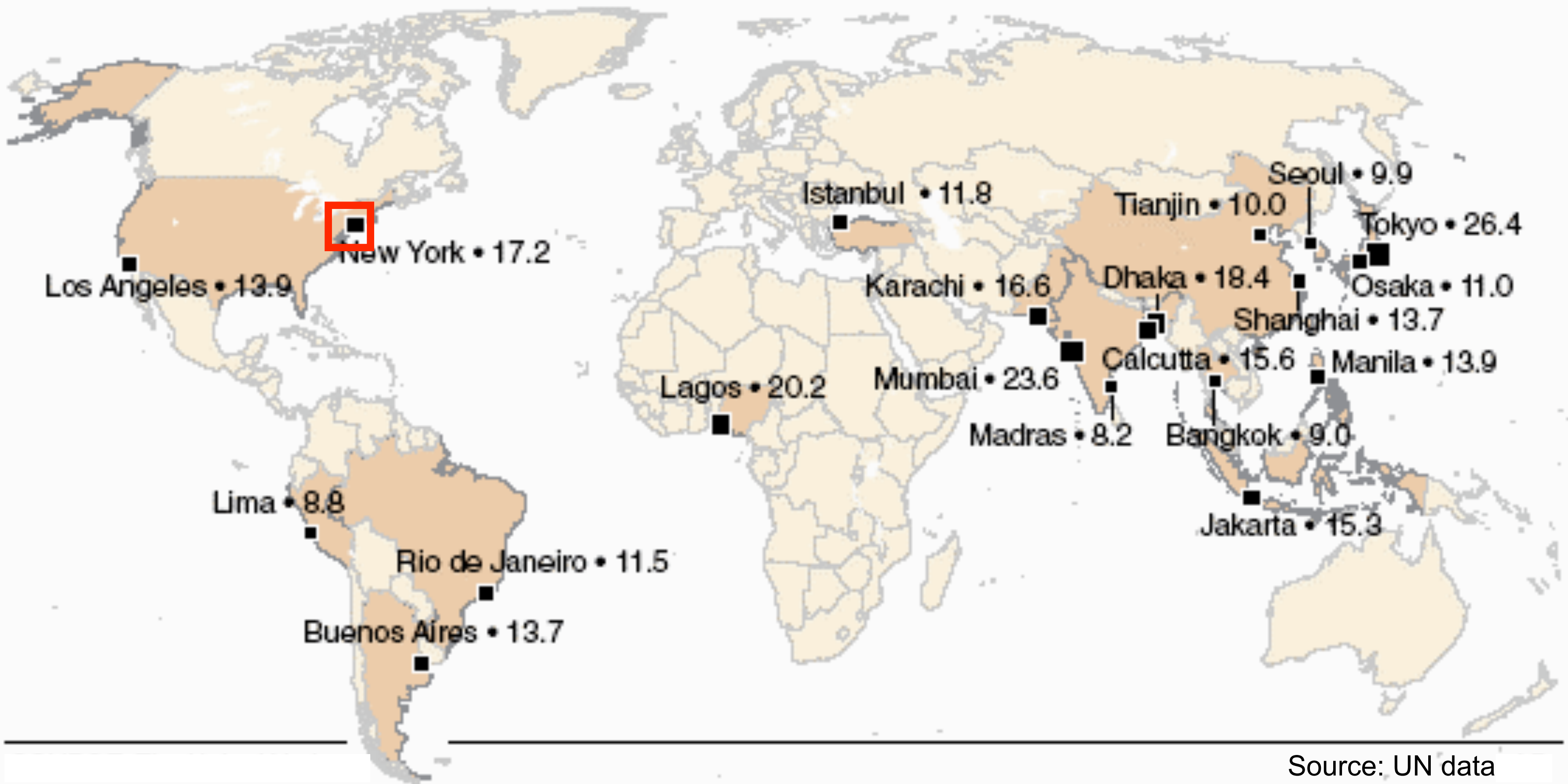
- **CC Adaptation policies and practice need (and seem now) to gradually change. If they were not, NYC's built infrastructure and other vital economic assets, will be at growing risks from SLR and storm surge inundations. Without well planned and financed adaptation measures, the growing perils will gradually undermine the City's economic viability, and eventually - or catastrophically - make parts of the City unsustainable. In any case, CC adaptation will become a persistent RACE AGAINST TIME !!**

- **This presentation**
  - **Outlines expected risks from CC and SLR as function of time;**
  - **Estimates potential losses if the risks remain unaddressed;**
  - **Discusses cost-beneficial, *sustainable* adaptation options;**
  - **Provides estimates of the magnitude of needed investments to manage the expected risks, preferably as an integral part of an ongoing, much needed infrastructure upgrade & renewal process.**


"I guess in some ways this city is still the same"
TAXI

The Global Context:

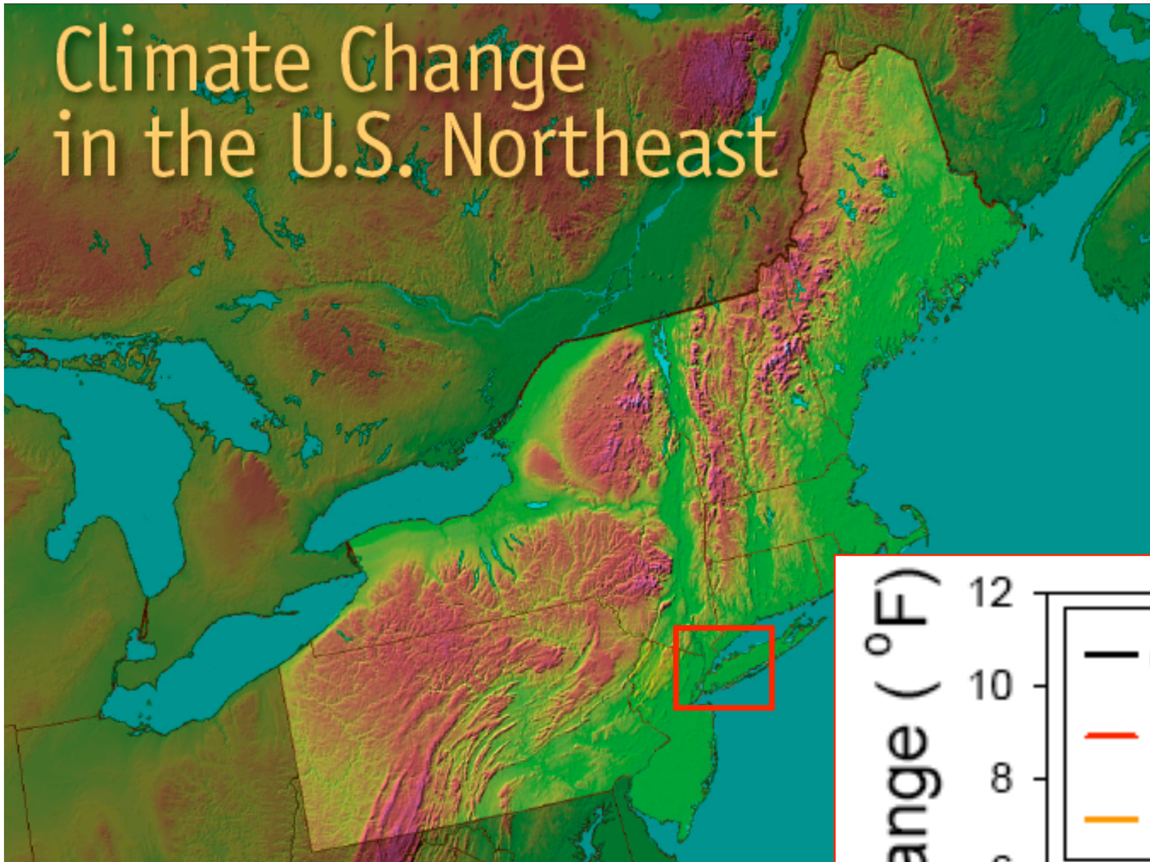
Coastal urban agglomerations with populations more than 8 million in 2010



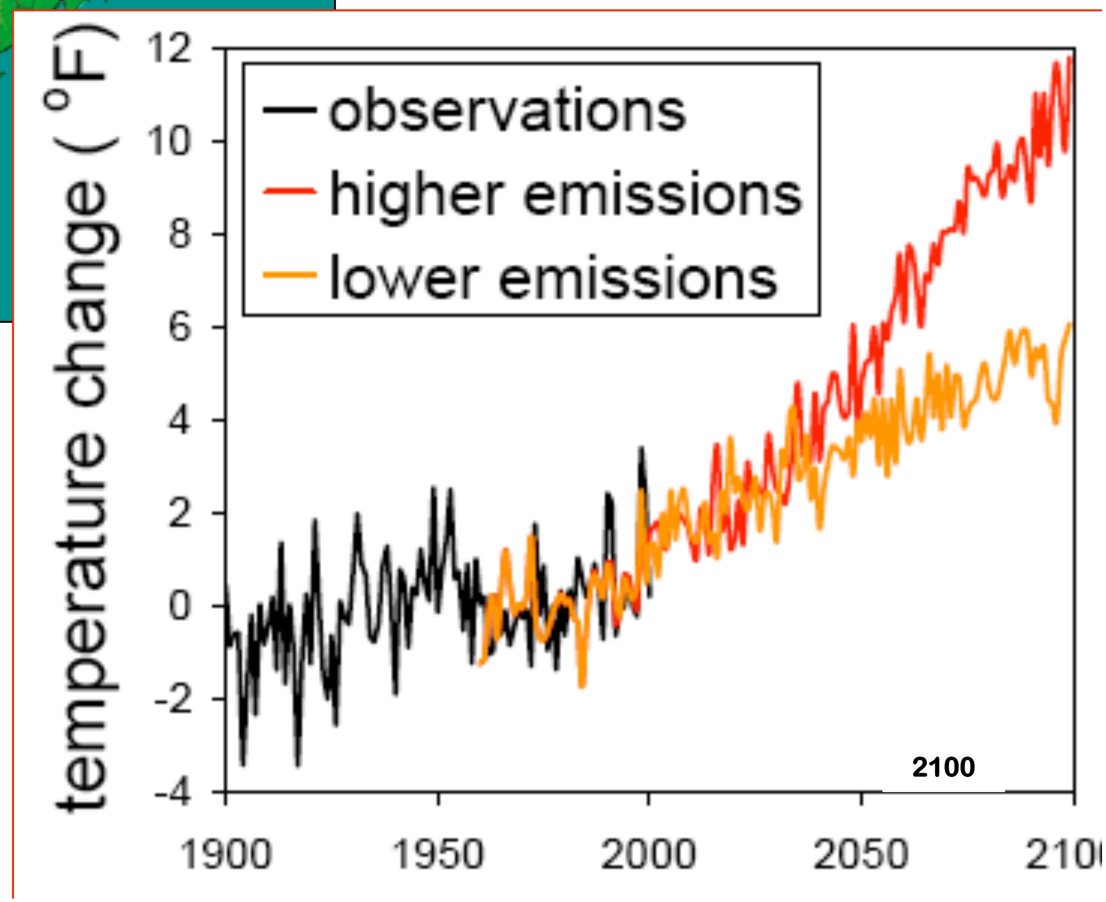
Source: UN data

REGIONAL Studies & Resources:

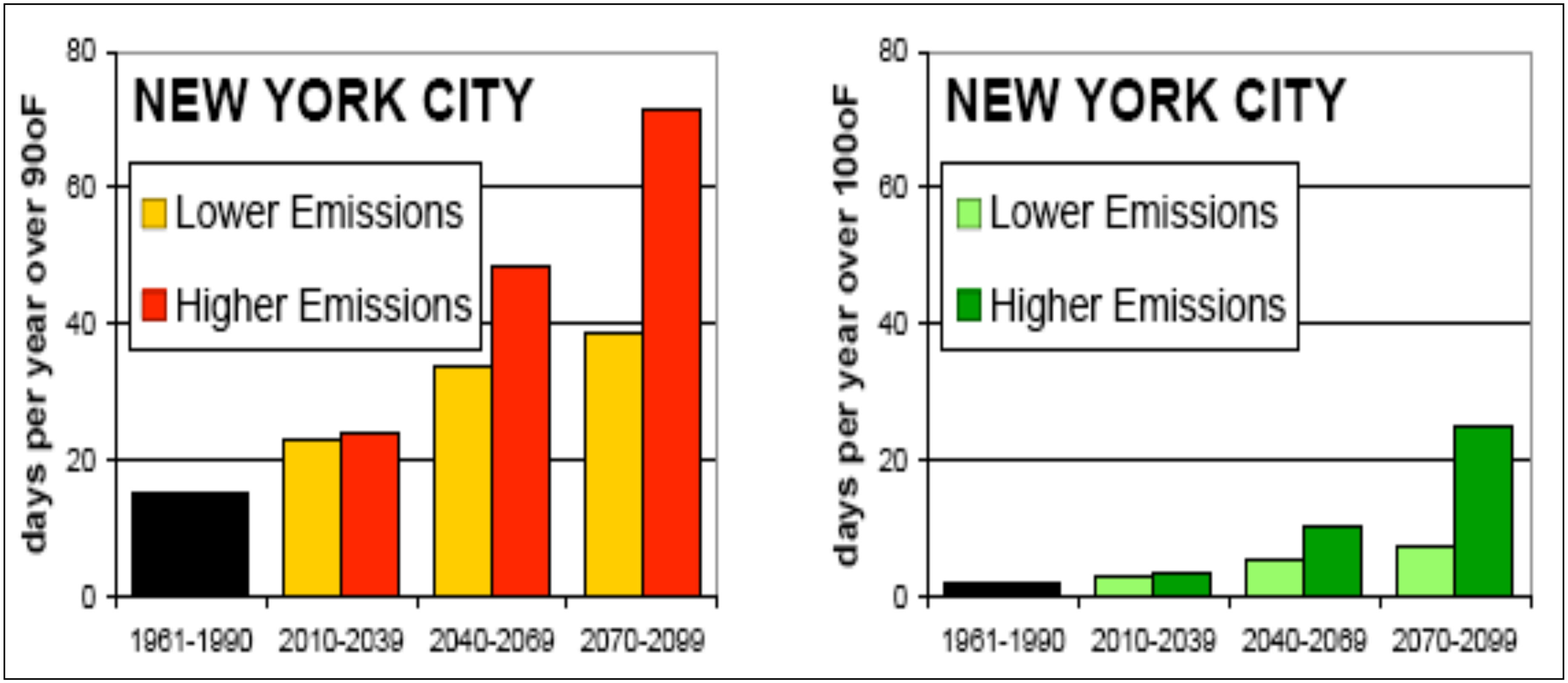
- **1995: Metro NY Hurricane Transportation Study**
  Interim Technical Data Report. USACoE, FEMA, NYSEMO, NYCOEM et al.: Evacuation Planning
- **2001: Metro-East Cost (MEC) Climate Change Impact Study**
  http://metroeast_climate.ciesin.columbia.edu/reports/infrastructure.pdf Early Science Baseline
- → **2006/07: Climate Change Assessment for the NE US** More Recent Sc. B.L.
  Union of Concerned Scientists - Working Group http://www.northeastclimateimpacts.org
- **2007: MTA 8/8/2007-Storm Report to Governor & Mayor**
  See Appendix 2 of : http://www.mta.info/mta/pdf/storm_report_2007.pdf MTA-Specific Case Study
- **2007: Mayor's PlaNYC 2030** Sparse on Specific ADAPTATION Goals
  http://www.nyc.gov/html/planyc2030/html/home/home.shtml
- **2008: National Academies / TRB Report # 290:** Has National Scope
  Impacts of Climate Change on US Transport. http://onlinepubs.trb.org/onlinepubs/sr/sr290.pdf
- **2009: MTA Blue Ribbon Commission on Sustainability**
  http://mta.info/environment/pdf/SustRptFinal.pdf MTA Conceptual Guide for Climate Change Adaptation:
  http://www.mta.info/sustainability/pdf/Jacob_et%20al_MTA_Adaptation_Final_0309.pdf
- → **2010: NPCC - NYC Panel on Climate Change** NYC Rigorous Science Baseline
  http://www3.interscience.wiley.com/cgi-bin/fulltext/123443059/PDFSTART :
  in: http://www3.interscience.wiley.com/journal/123443047/issue
- → **2011: NYS ClimAID:** Report due Oct 1, NYS-Wide Rigorous Science Baseline
- **2010/2011: NYS SLRTF** Sea Level Rise Task Force; Report due Oct 1, 2011.
- **2010/2011: NYS CAC - Climate Action Council** (Energy, Mitigation, Adaptation)



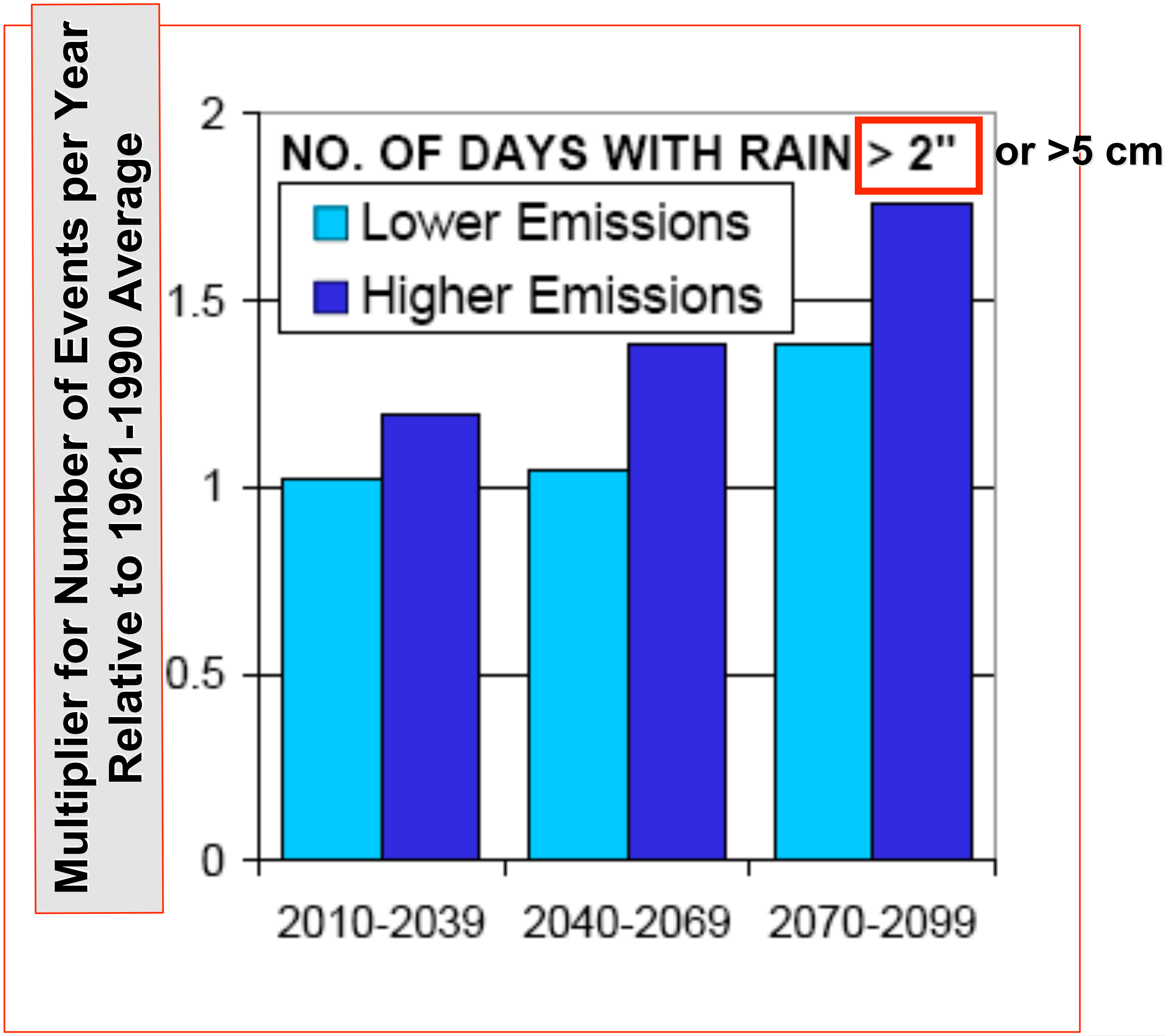
http://www.climatechoices.org/assets/documents/climatechoices/NECIA_climate_report_final.pdf



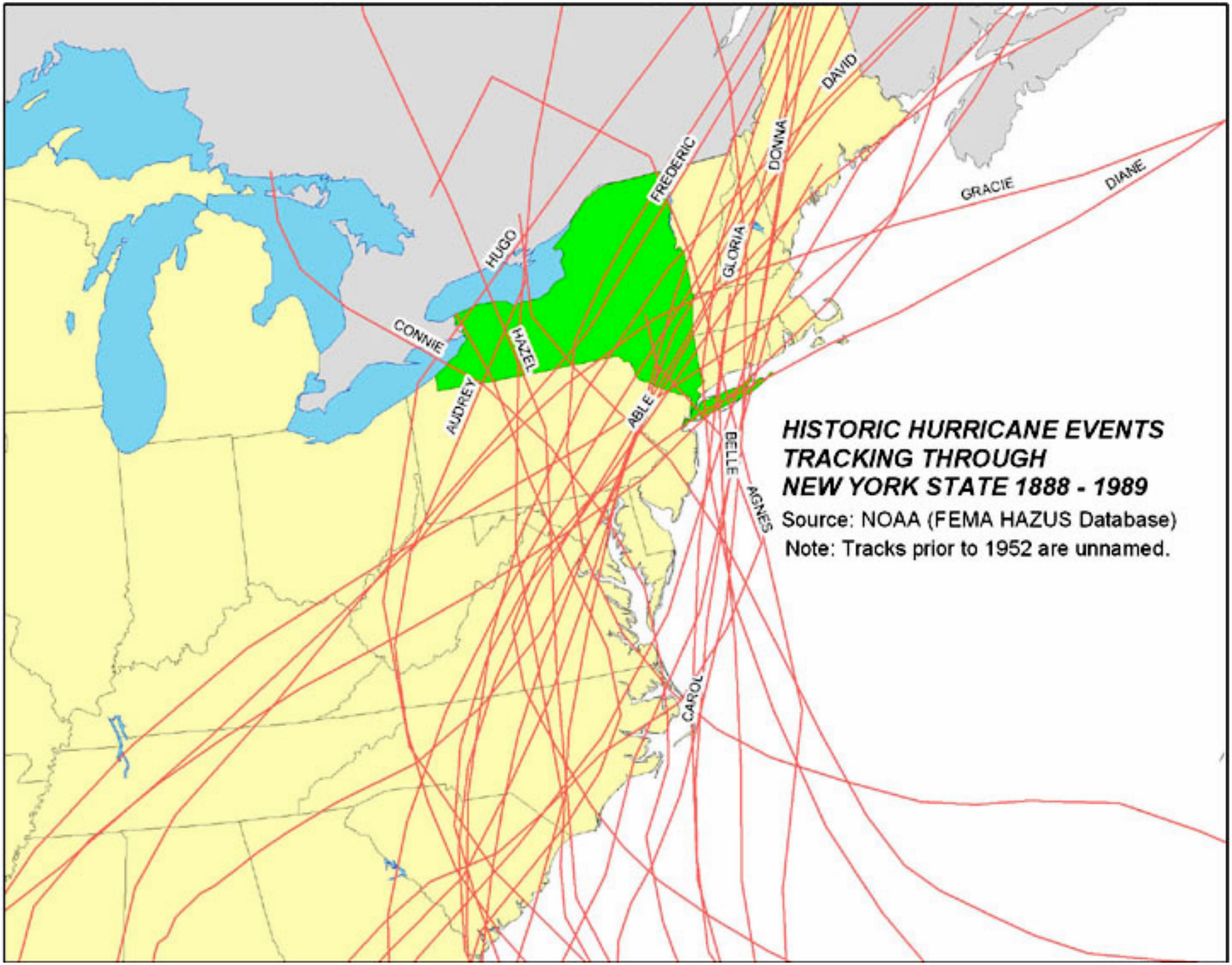
No. of days >90ºF (32ºC) **No. of days >100ºF (38ºC)**

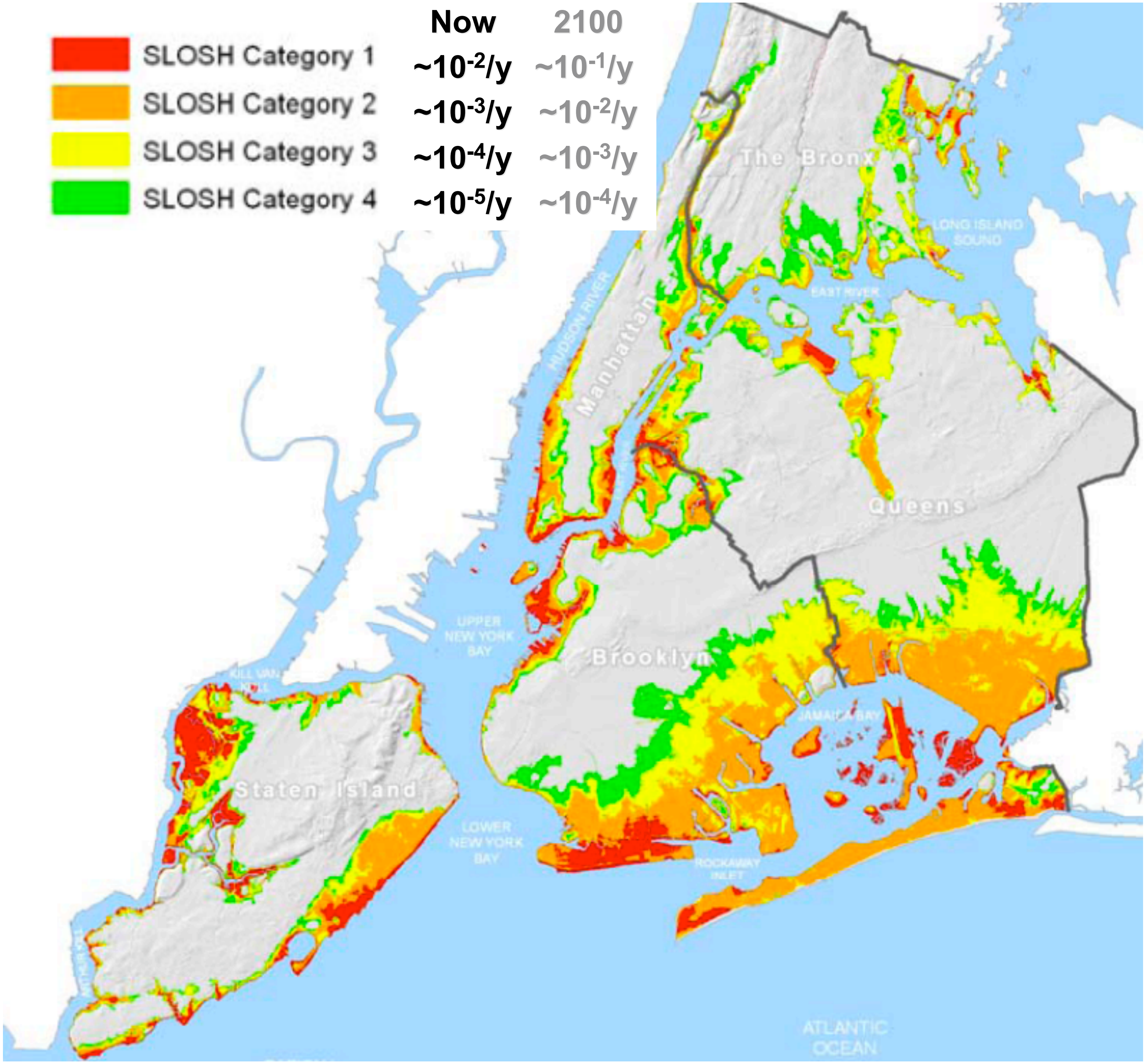


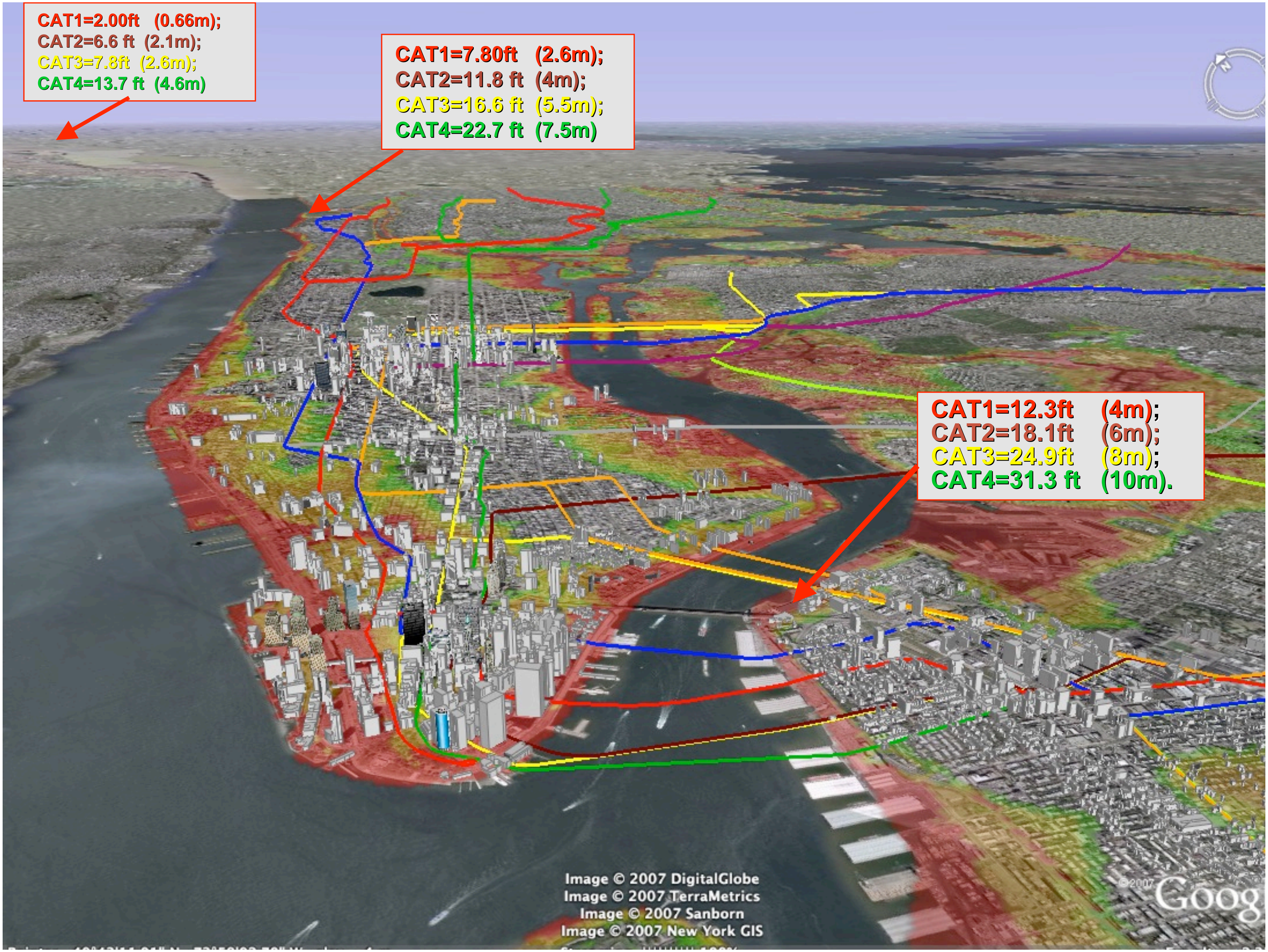
=> more air conditioning, heat strokes, energy, CO2, more warming !

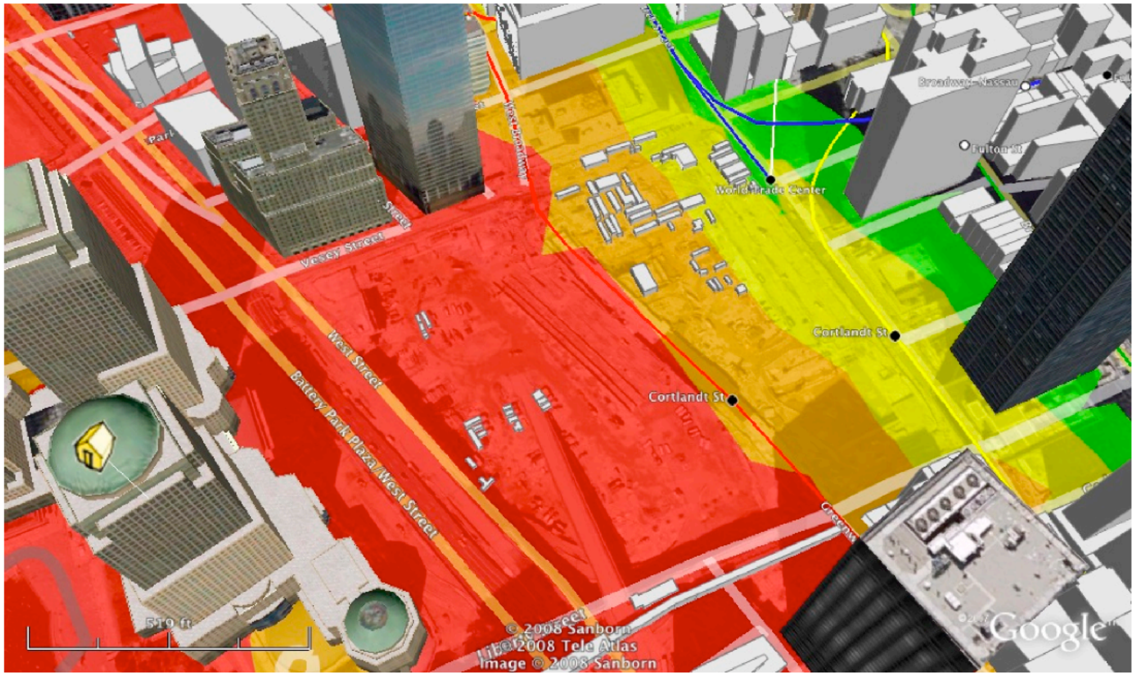


Many of these heavy rains occur during Nor'easters or Hurricanes


HISTORIC HURRICANE EVENTS
TRACKING THROUGH
NEW YORK STATE 1888 - 1989
Source: NOAA (FEMA HAZUS Database)
Note: Tracks prior to 1952 are unnamed.
DAVID
DONNA
FREDERIC
GRACIE
DIANE
GLORIA
HUGO
CONNIE
HAZEL
AUDREY
ABLE
BELLE
AGNES
CAROL


Now
2100
SLOSH Category 1 $\sim10^{-2}$/y $\sim10^{-1}$/y
SLOSH Category 2 $\sim10^{-3}$/y $\sim10^{-2}$/y
SLOSH Category 3 $\sim10^{-4}$/y $\sim10^{-3}$/y
SLOSH Category 4 $\sim10^{-5}$/y $\sim10^{-4}$/y
The Bronx
LONG ISLAND SOUND
EAST RIVER
HUDSON RIVER
Manhattan
Queens
UPPER NEW YORK BAY
Brooklyn
KILL VAN KULL
JAMAICA BAY
Staten Island
LOWER NEW YORK BAY
ROCKAWAY INLET
ATLANTIC OCEAN


CAT1=2.00ft (0.66m);
CAT2=6.6 ft (2.1m);
CAT3=7.8ft (2.6m);
CAT4=13.7 ft (4.6m)
CAT1=7.80ft (2.6m);
CAT2=11.8 ft (4m);
CAT3=16.6 ft (5.5m);
CAT4=22.7 ft (7.5m)
CAT1=12.3ft (4m);
CAT2=18.1ft (6m);
CAT3=24.9ft (8m);
CAT4=31.3 ft (10m).
Image © 2007 DigitalGlobe
Image © 2007 TerraMetrics
Image © 2007 Sanborn
Image © 2007 New York GIS



WTC - Site:

Questions:

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 ?**

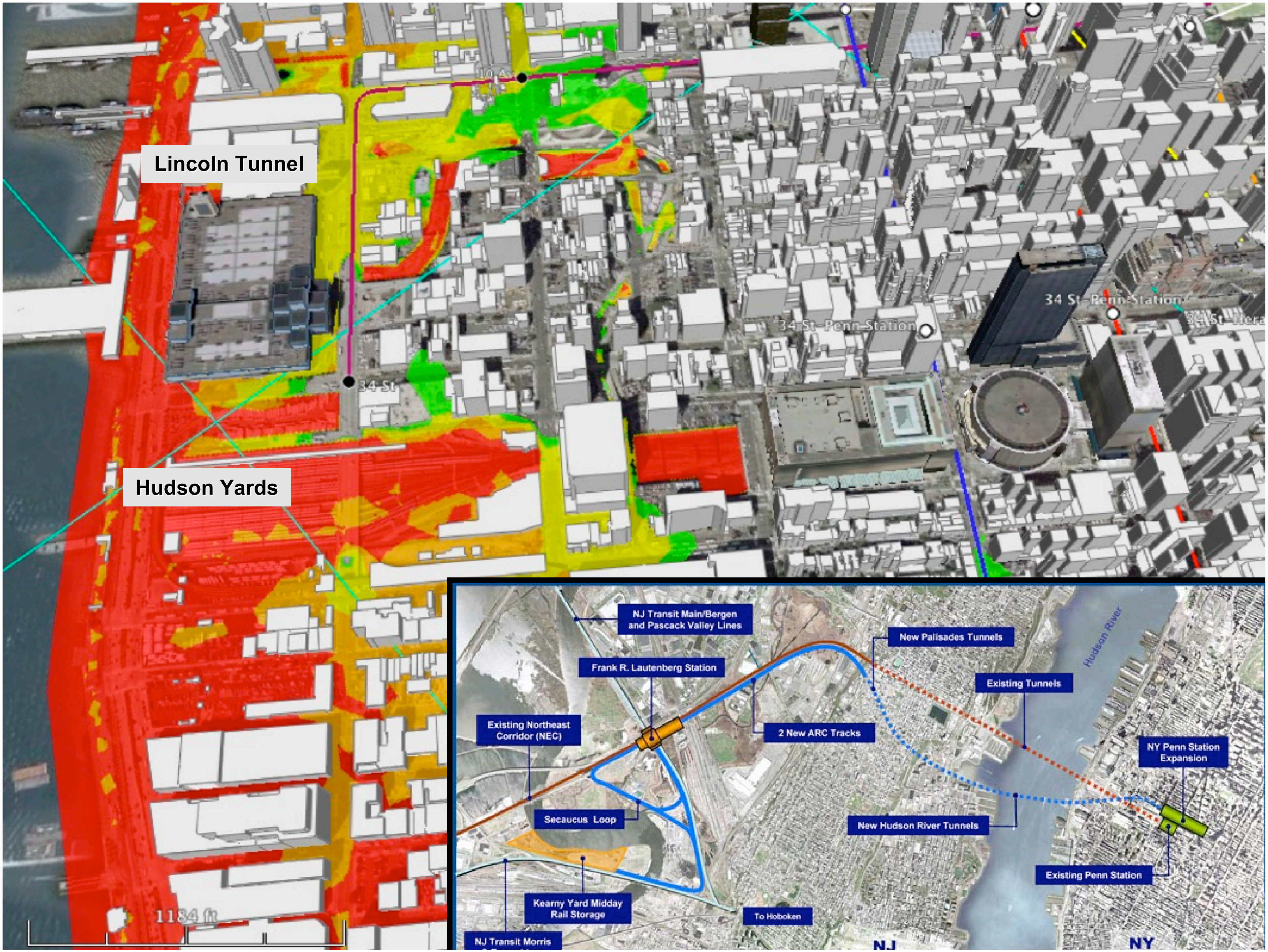
Will Flooding of NYCT Subway System(s) Affect / Connect with PATH & WTC facilities?

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.

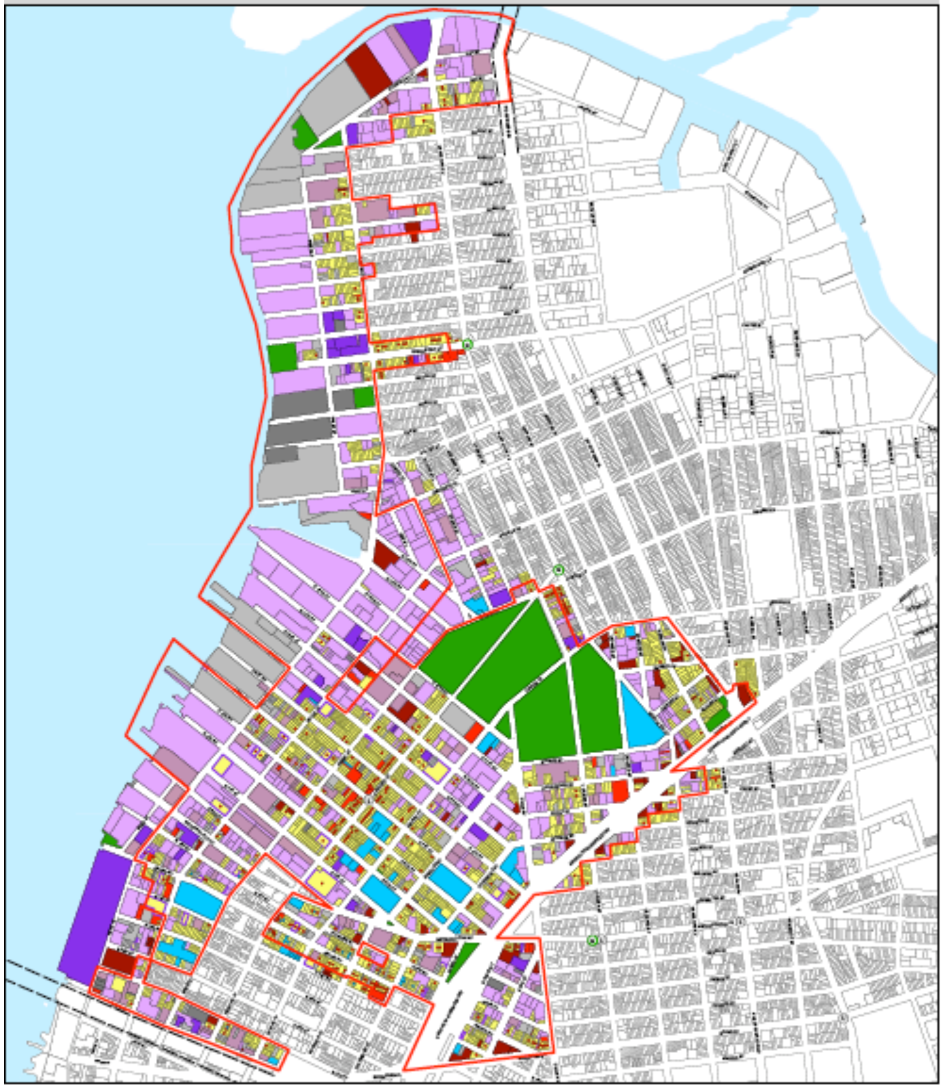


Lincoln Tunnel
Hudson Yards
34 St
34 St–Penn Station
34 St–Penn Station
1184 ft
NJ Transit Main/Bergen and Pascack Valley Lines
New Palisades Tunnels
Hudson River
Frank R. Lautenberg Station
Existing Tunnels
Existing Northeast Corridor (NEC)
2 New ARC Tracks
NY Penn Station Expansion
Secaucus Loop
New Hudson River Tunnels
Existing Penn Station
Kearny Yard Midday Rail Storage
To Hoboken
NJ Transit Morris
NJ
NY

Greenpoint-Williamsburg Rezoning

Land Use

The City of New York
Department of City Planning
July 2004



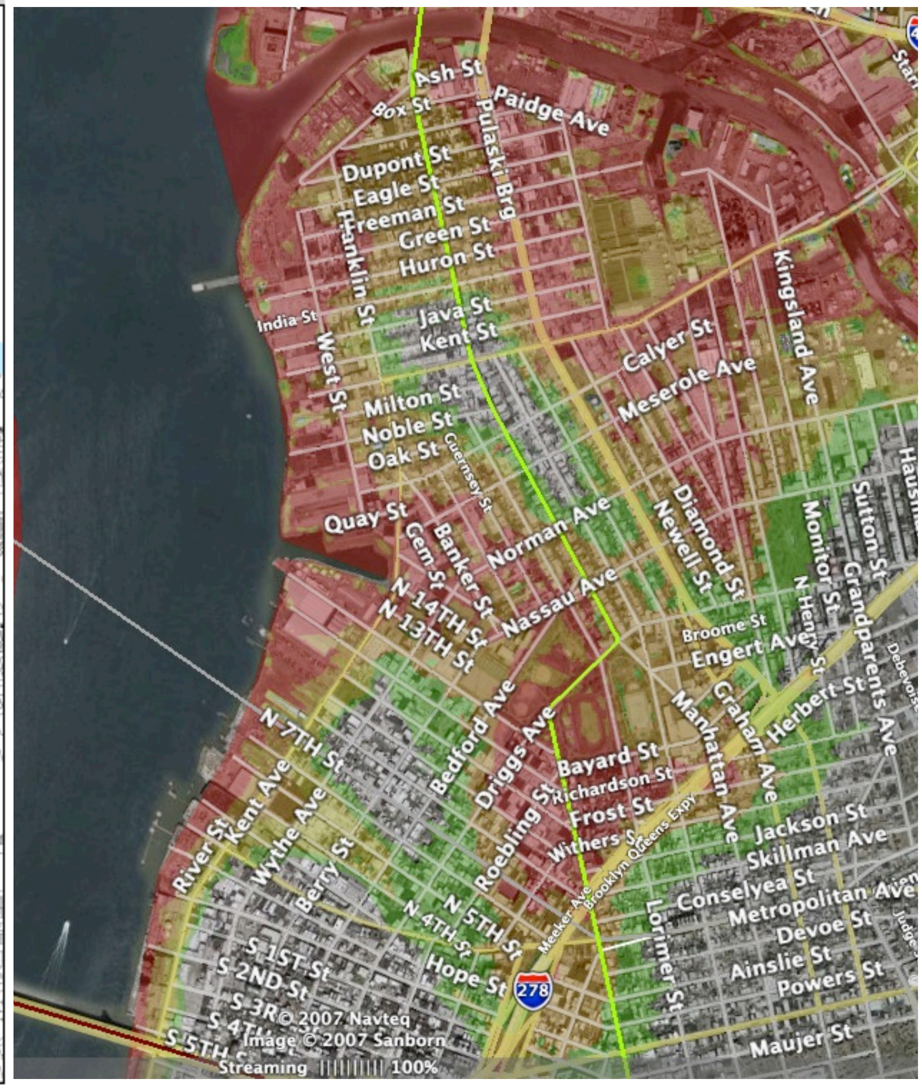
- Residential
- Commercial
- Automotive
- Community facility
- Park
- Vacant land
- Vacant building

Industrial, 3+ floors

- Manufacturing/wholesale
- Mixed M/R
- Converted to residential

Industrial, 1 or 2 floors

- Manufacturing
- Mixed M/R
- Ground floor commercial
- Ground floor community facility



GIS-based Risk Assessment Tool 'HAZUS - MH'

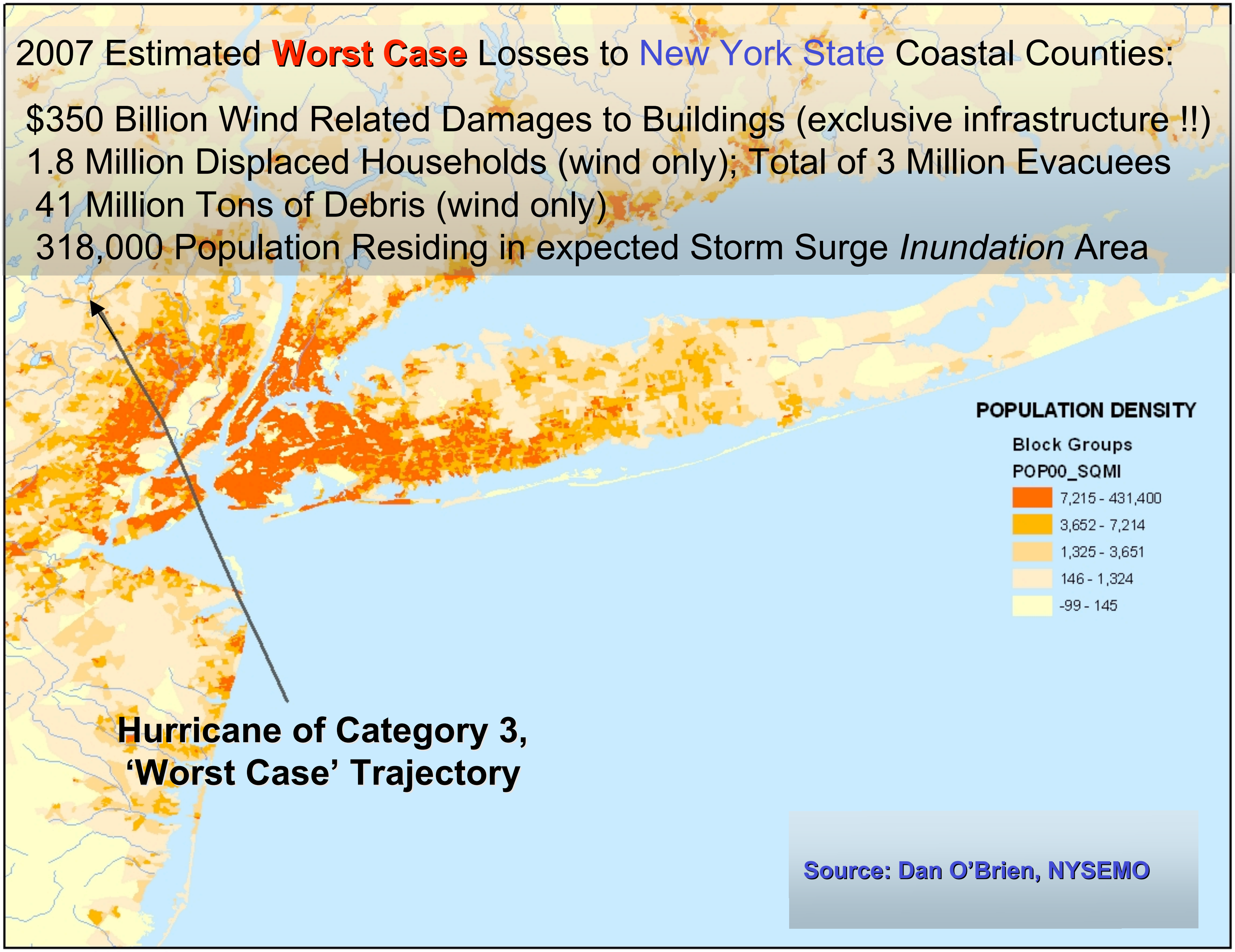
(FEMA's "*Hazards in the United States - Multi Hazards Version*": Earthquakes, Wind, Flood).

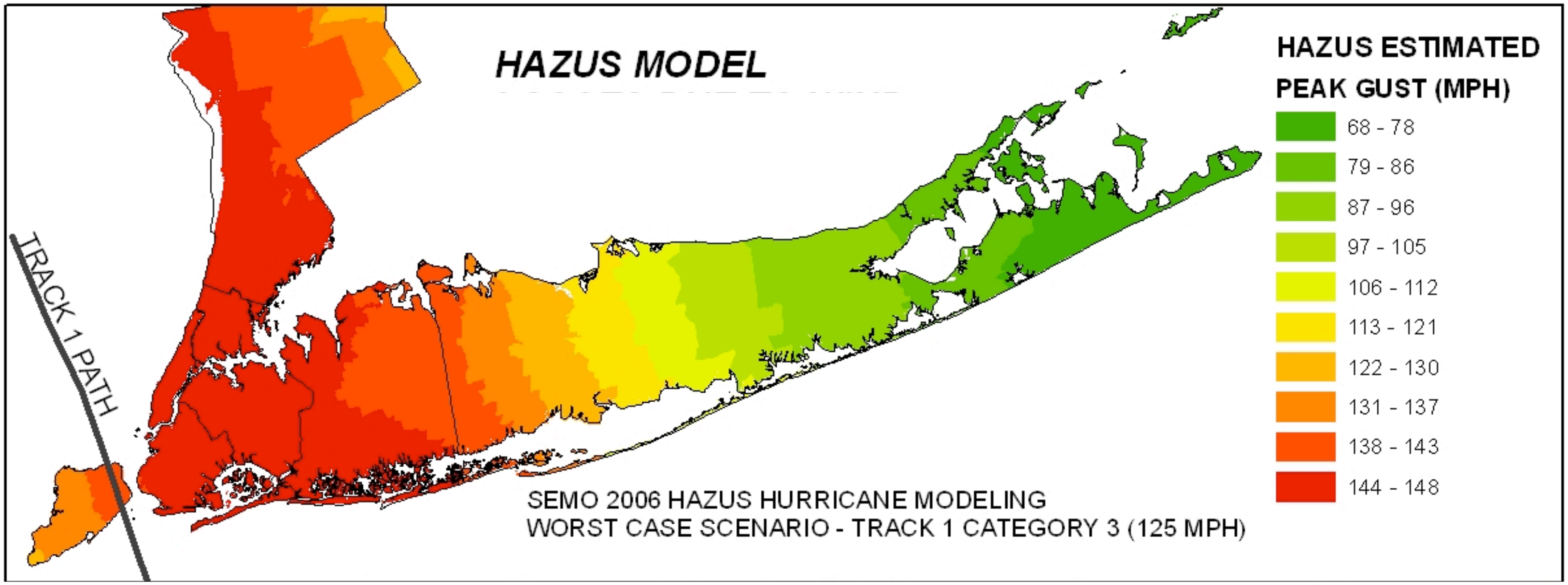
Risk = Sum (Hazard x Assets x Vulnerability)

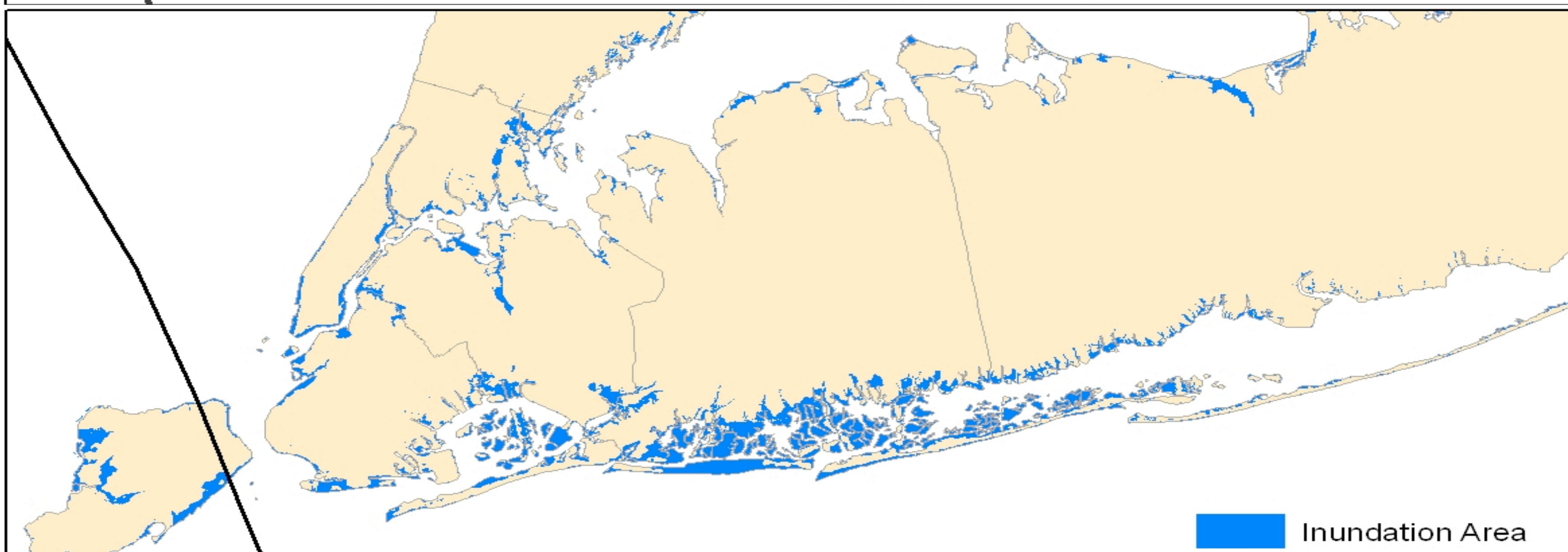
$ / year or /event — over Region — probability per time — $ value — 0 < V < 1

Risk	Expected Losses for either a scenario event ($) or in terms of probabilistic annual losses ($/year)
• **Hazards**	Probability per unit time of exceeding a certain hazard, e.g. wind speed or flood height (P=1 for scenario event)
• **Assets**	Replacement Value in Dollars for Buildings or Infrastructure, (or $ / live !)
• **Vulnerability**	Dimensionless Value between 0 and 1. It is the Damaged Fraction of Replacement Value of a Given Asset, for the Specified Hazard Level the Asset is exposed to.

HAZUS-MH also has a Built-in Economic Model for Damage-Related, indirect Economic Losses; e.g. for Losses related to building damage and closure; but its default version is weak in assessing vulnerabilities of infrastructure systems. Requires user input for infrastructure assets and their vulnerabilities.

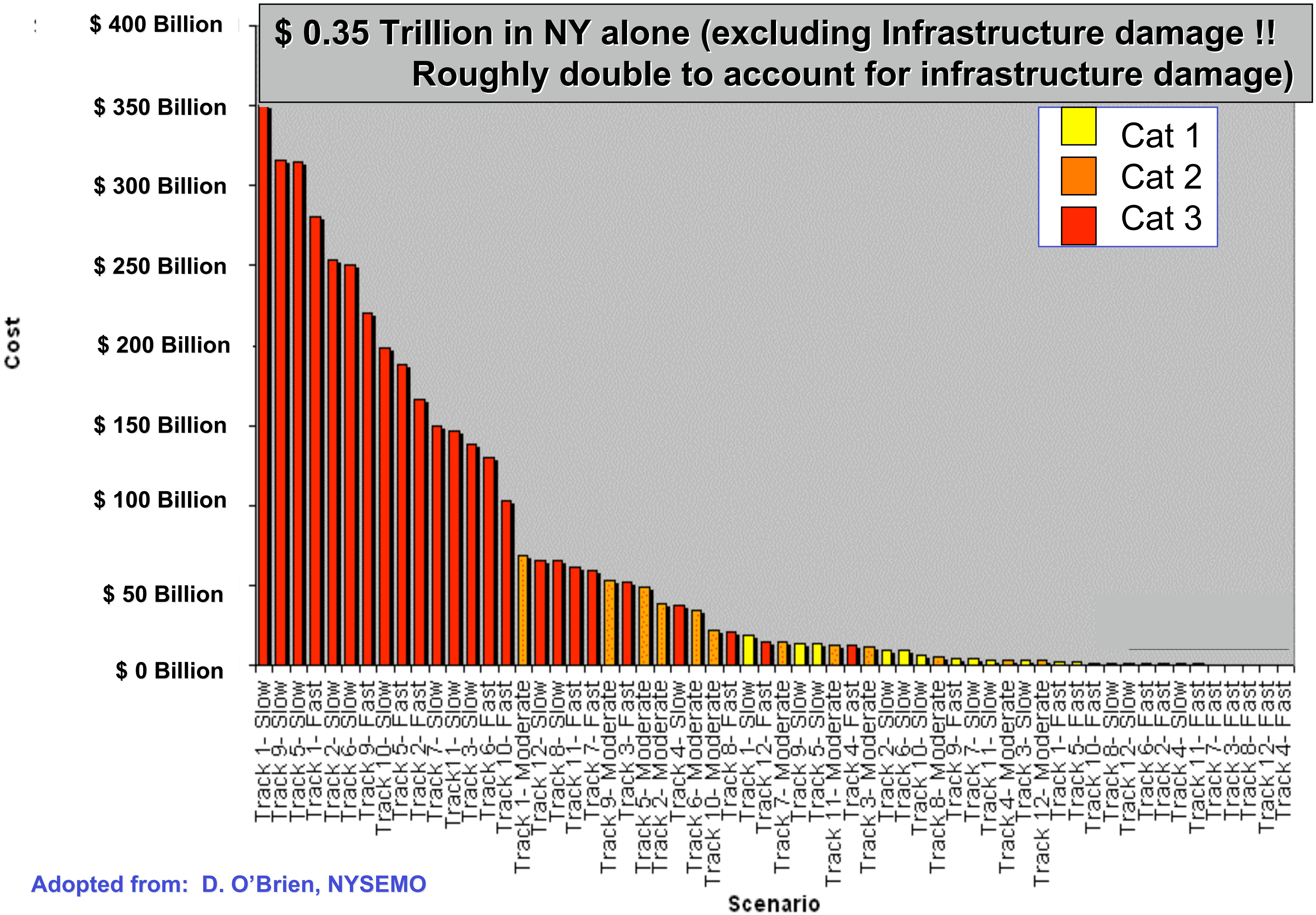

2007 Estimated Worst Case Losses to New York State Coastal Counties:
$350 Billion Wind Related Damages to Buildings (exclusive infrastructure !!)
1.8 Million Displaced Households (wind only); Total of 3 Million Evacuees
41 Million Tons of Debris (wind only)
318,000 Population Residing in expected Storm Surge Inundation Area
POPULATION DENSITY
Block Groups
POP00_SQMI
7,215 - 431,400
3,652 - 7,214
1,325 - 3,651
146 - 1,324
-99 - 145
Hurricane of Category 3,
'Worst Case' Trajectory
Source: Dan O'Brien, NYSEMO





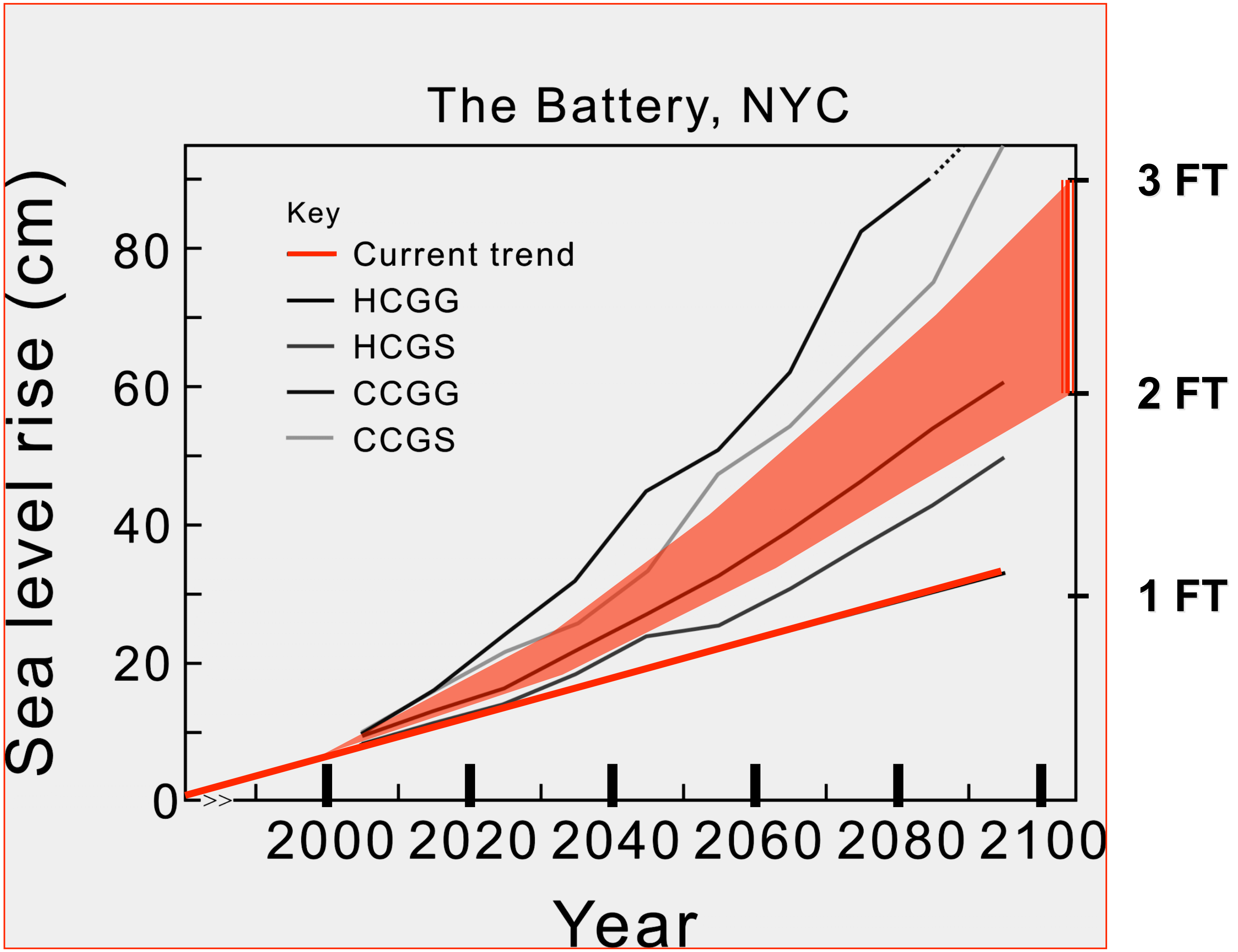
NOAA SLOSH MODEL: Surge Heights Translated into Inundated Areas by Dan O'Brien, NYSEMO

HAZUS-MH-Modeled Building-Related Total Economic Losses for 72 Hurricane Scenarios



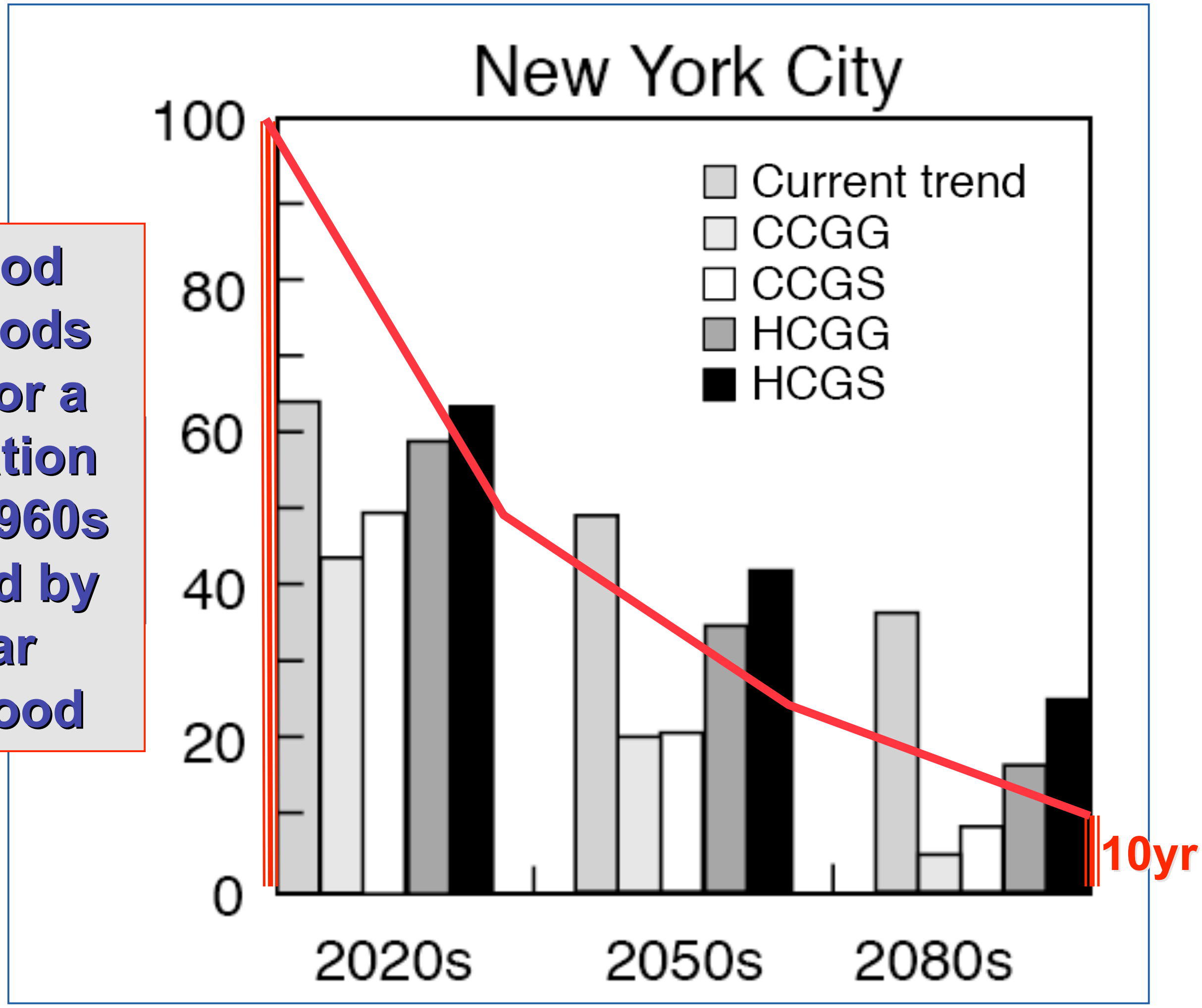
Adopted from: D. O'Brien, NYSEMO

Sea Level Rise Makes a Bad Situation Worse !



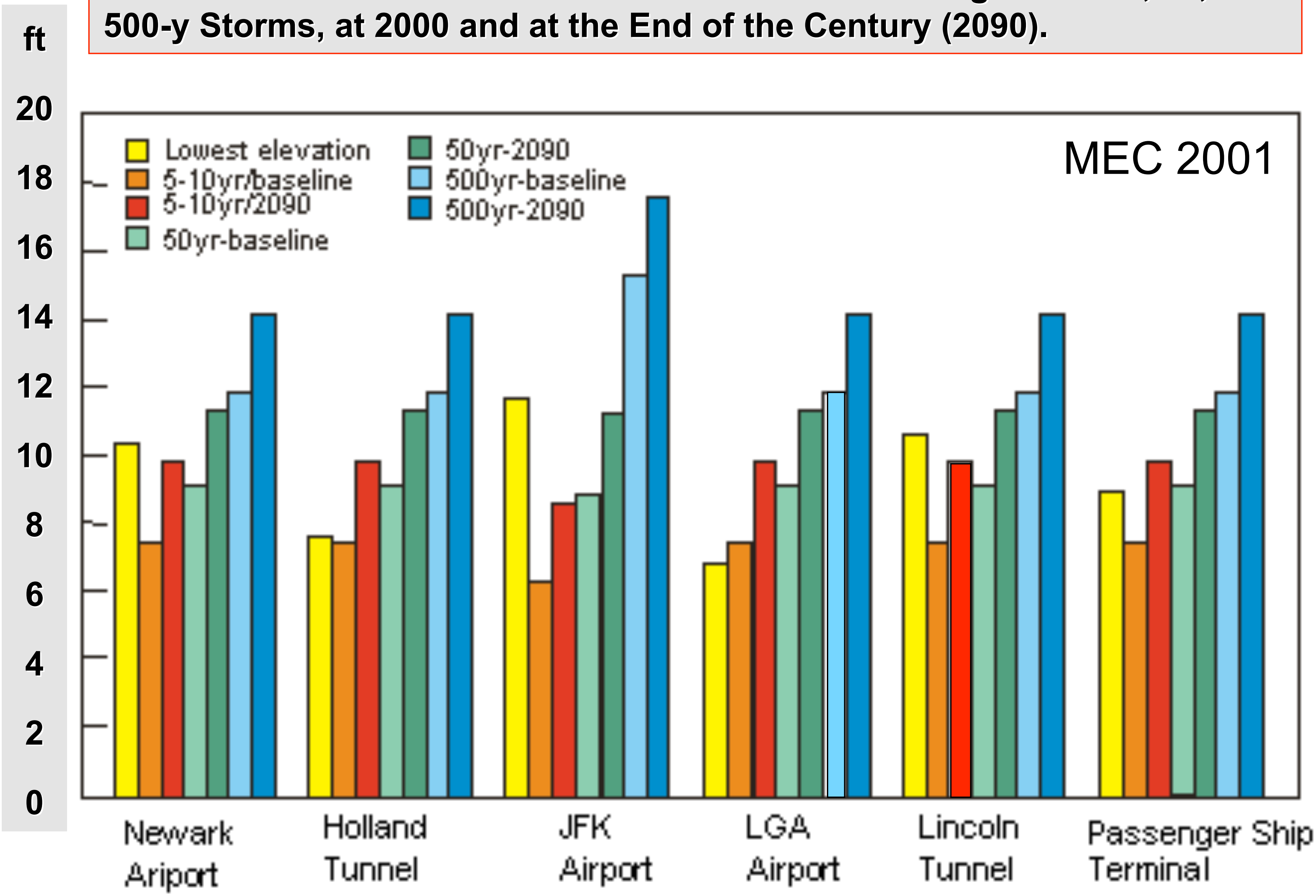
Reduction in Return Period of the 100-Year Flood due to Sea Level Rise Only (Constant Storm Frequency).

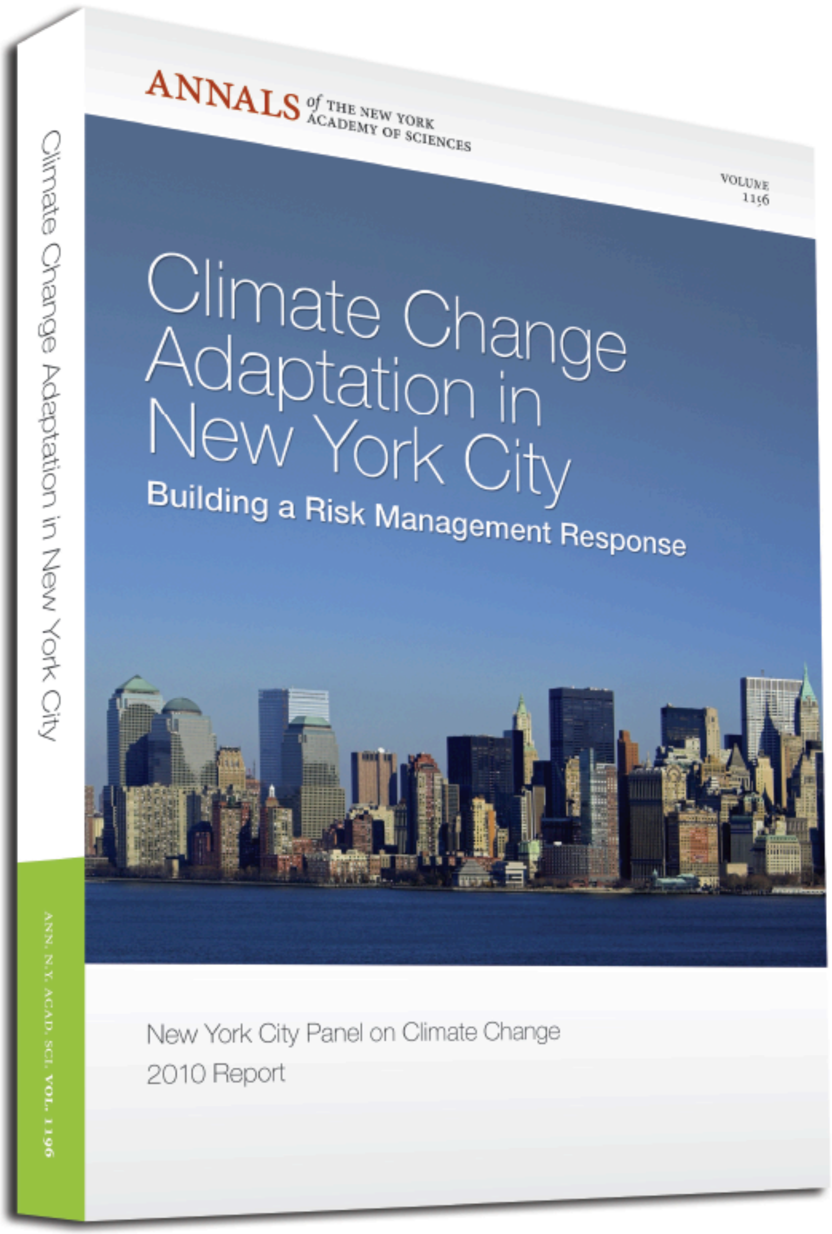
Future Flood Return Periods (in Years) for a Land Elevation that in the 1960s was reached by a 100-Year Coastal Flood



21st Century Decades

Lowest Critical Elevations and Probabilistic Flood Heights for 10, 50, and 500-y Storms, at 2000 and at the End of the Century (2090).





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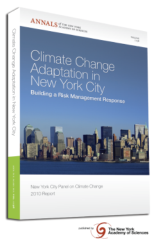
Annals of the New York Academy of Sciences

Volume 1196,

Climate Change Adaptation in New York City: Building a Risk Management Response.

New York City Panel on Climate Change 2010 Report
May 2010

http://onlinelibrary.wiley.com/doi/10.1111/nyas.2010.1196.issue-1/issuetoc



Appendix A

CLIMATE RISK INFORMATION

Climate Change Scenarios & Implications for NYC Infrastructure

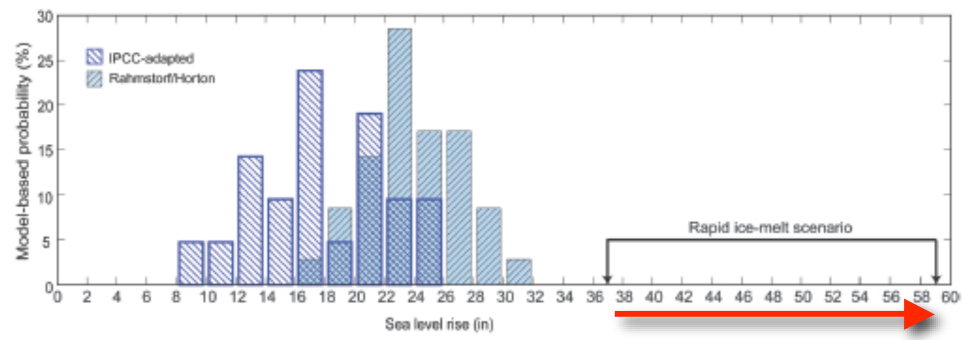
New York City Panel on Climate Change

Lead Authors
Radley Horton (Columbia University), Cynthia Rosenzweig (NASA, Columbia University)

Contributing Authors
Vivien Gornitz (Columbia University), Daniel Bader (Columbia University), Megan O'Grady (Columbia University)

http://onlinelibrary.wiley.com/doi/10.1111/j.1749-6632.2010.05323.x/pdf

FIGURE C.1. Comprehensive Set of Sea Level Rise Projections New York City and the Surrounding Region



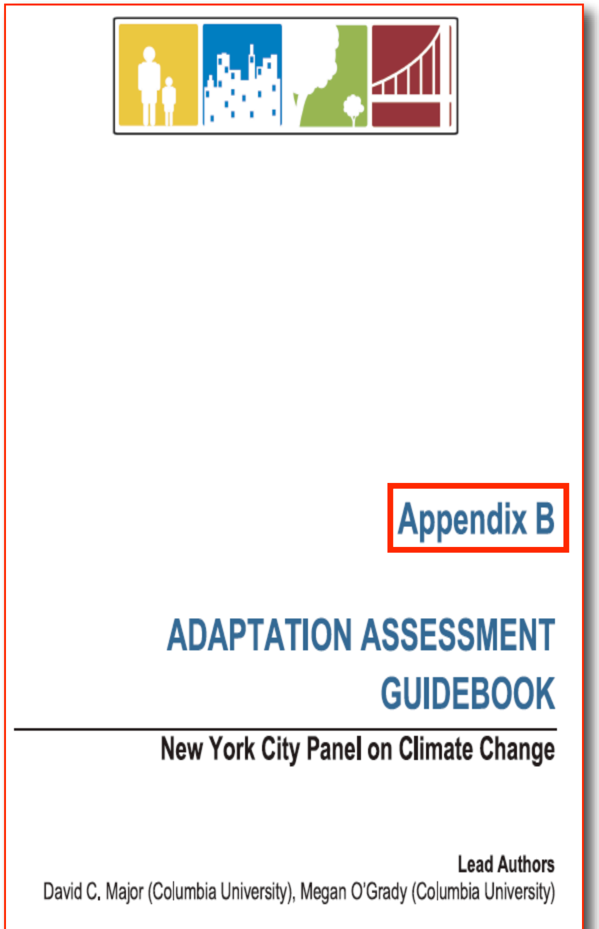
This schematic shows sea level rise projections for the 2080s, relative to the 2000 – 2004 period, based on three distinct methodologies. The dark blue hatched bars show projections based on the IPCC-adapted method. The light blue hatched bars show projections based on the Rahmstorf//Horton method, adjusted for local conditions. Each of the two is shown as histogram, with the y-axis containing the model-based probability for that model alone, associated with the sea level rise interval shown on the x-axis. The Rapid Ice-Melt sea level rise is indicated by the bracket on the x-axis; no probability is associated with this range. Source: Columbia University Center for Climate Systems Research

TABLE C.1. Total Sea Level Rise Projections in Inches for New York City and the Surrounding Region for Four Different Methods

Average *(minimum to maximum)*	**2020s**	**2050s**	**2080s**	**2090s[1]**
IPCC Global Estimate + Local Subsidence	NA[2]	NA[2]	NA[2]	(10.4 to 23.4)[5]
IPCC-adapted Methods for the NYC Region	3.7 (1.4 to 5.5)[3]	9.7 (5.0 to 13.6)[3]	17.8 (9.3 to 25.6)[3]	22.2 (14.9 to 30.0)[6]
Rahmstorf/Horton Method + Local Subsidence	4.9 (3.7 to 6.2)[4]	13.1 (10.0 to 16.6)[4]	24.6 (18.2 to 31.6)[4]	28.1 (22.6 to 33.7)[7]
CRI Rapid Ice-Melt Sea Level Rise	~ 4 to 10[8]	~ 17 to 30[8]	~ 37 to 59 in[8]	~ 48 to 70 in[9]

Sources: CCSR, 2008; IPCC, 2007; Horton et al., 2008.

~4 ft **~5 ft**



Appendix B

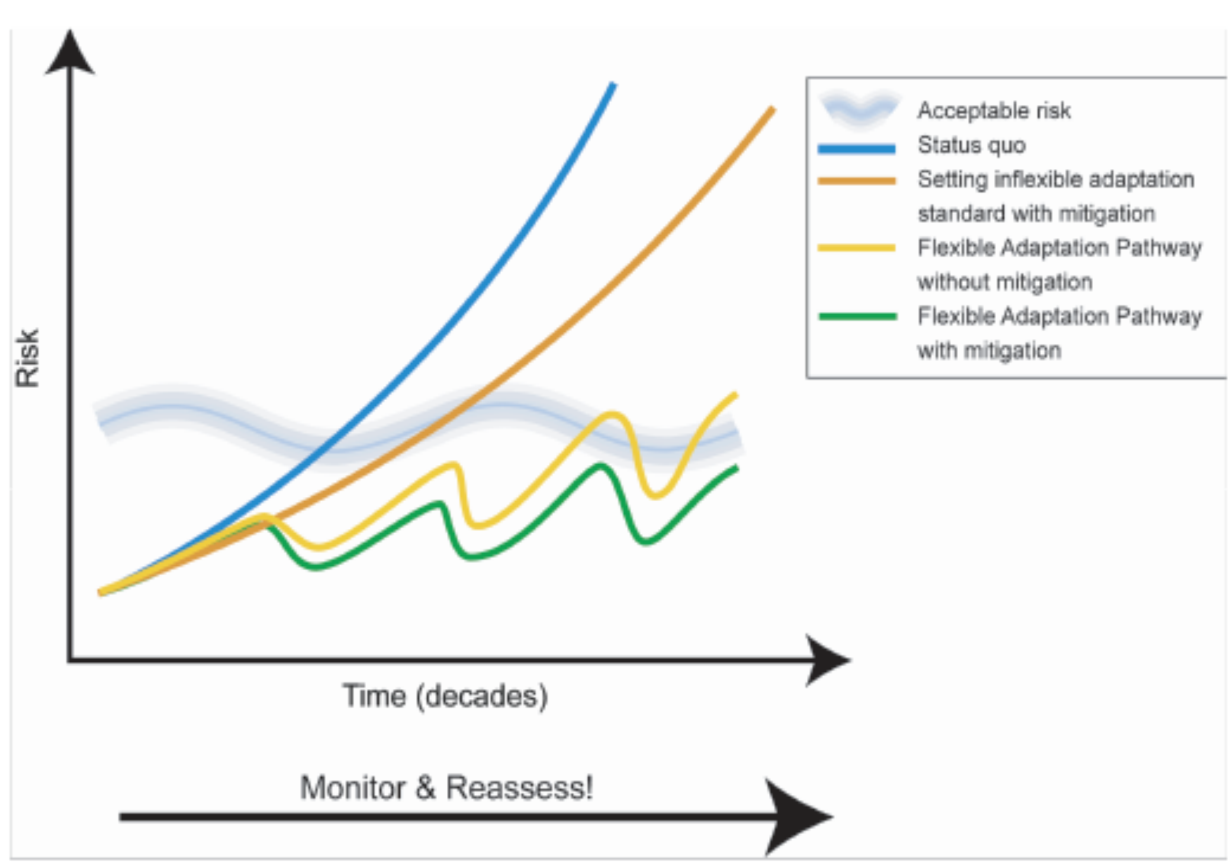
ADAPTATION ASSESSMENT GUIDEBOOK

New York City Panel on Climate Change

Lead Authors

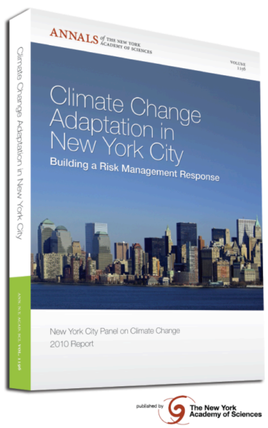
David C. Major (Columbia University), Megan O'Grady (Columbia University)

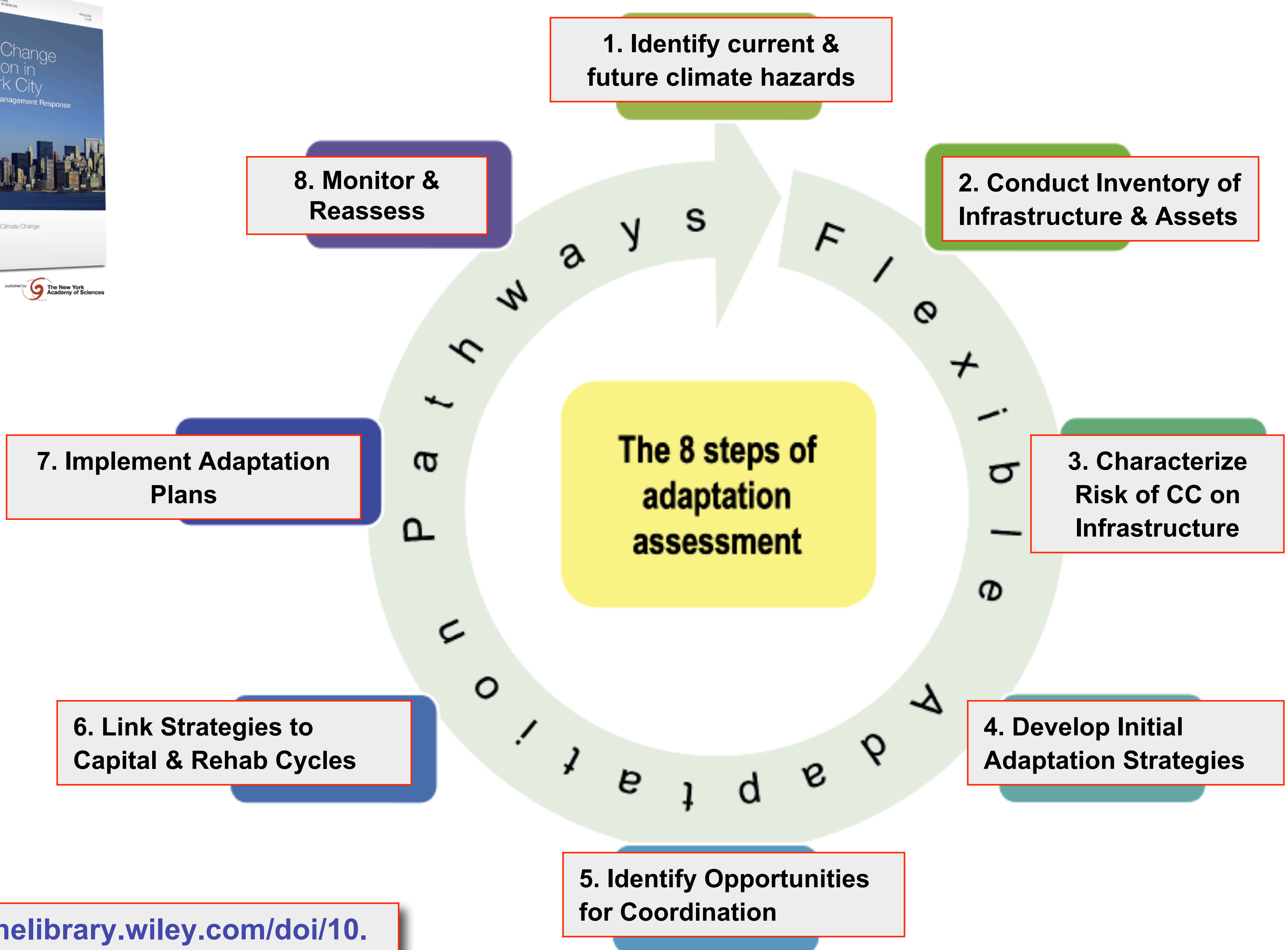
FIGURE 2. Flexible Adaptation Pathways



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

Adaptation Assessment Steps





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


Responding to Climate Change in New York State
Adaptation
Public Health
Water Resources
Climate
Tele-Communications
Coastal Zones
Equity
Economics
ClimAID
Transportation
Ecosystems
Energy
Vulnerability
Agriculture

ClimAID Transportation - CASE STUDY:

"100-YEAR" STORM SURGE HITS METRO-NYC TRANSPORT SYSTEM

Methodology to Estimate Transport Outages, Recovery & Related Economic Losses:

1. **Use the surge elevations of 3 scenarios (S1: 1%/y flood; S2: same +2ft SLR; S3: +4ft SLR).**

2. **Map the flooded portions of the transportation system.**

3. **Compute the volume of floodwaters that enter the tunnels.**

4. **Estimate the times (days) needed to *restore electricity* [E] & and for *logistic set-up* [L] before pumping-out of the tunnels can start.**

Continued:

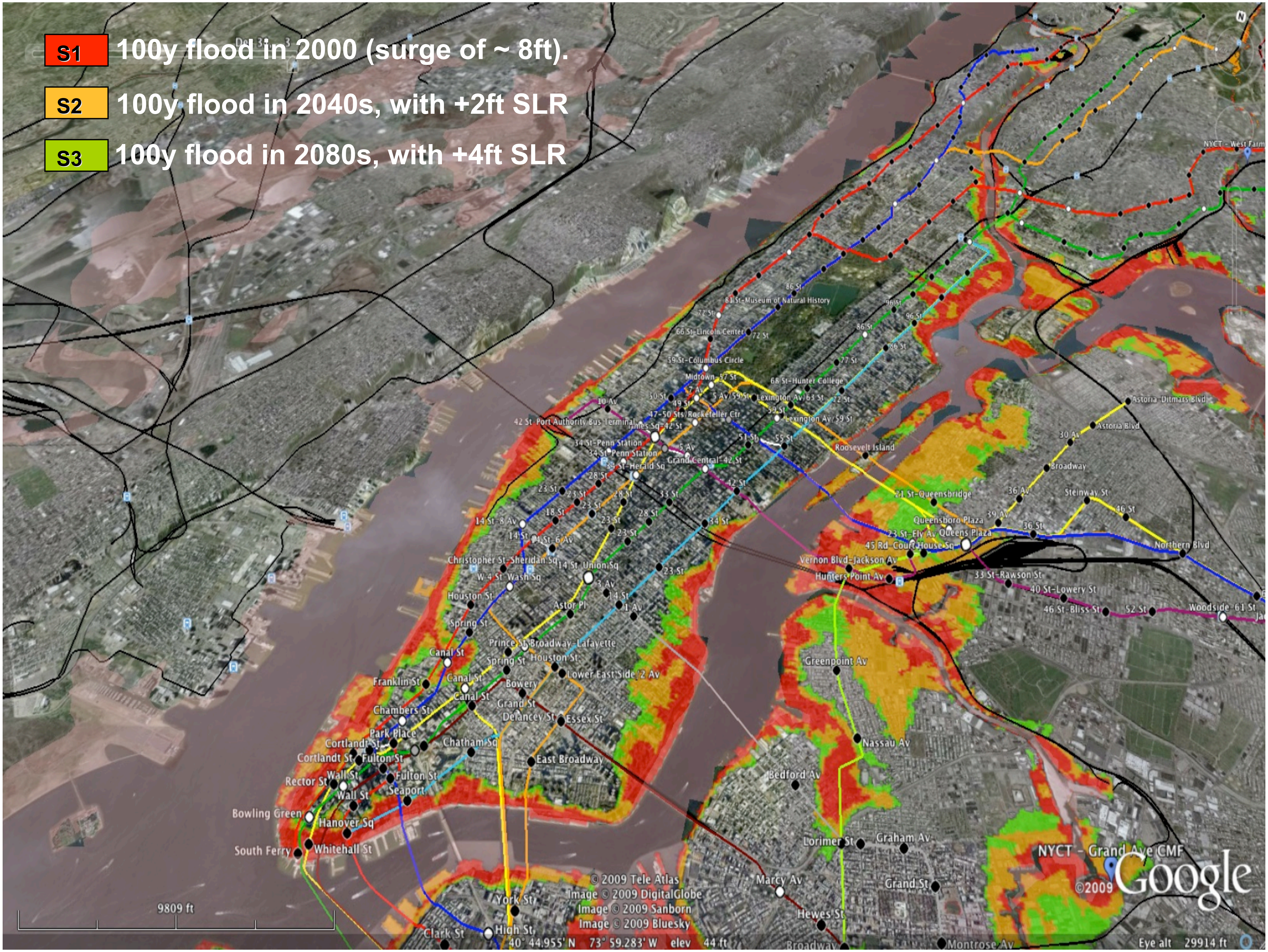
5. **Estimate the pumping times [P] to drain the tunnels (assume ~100 mobile modern pumps !!).**

6. **Estimate post-pumping times [days] to *assess the damage* [A] and carry out the necessary *repairs* [R].**

7. **Combine above times [T90] needed to <u>gradually</u> restore transportation system to 90% of its pre-storm capacity.**

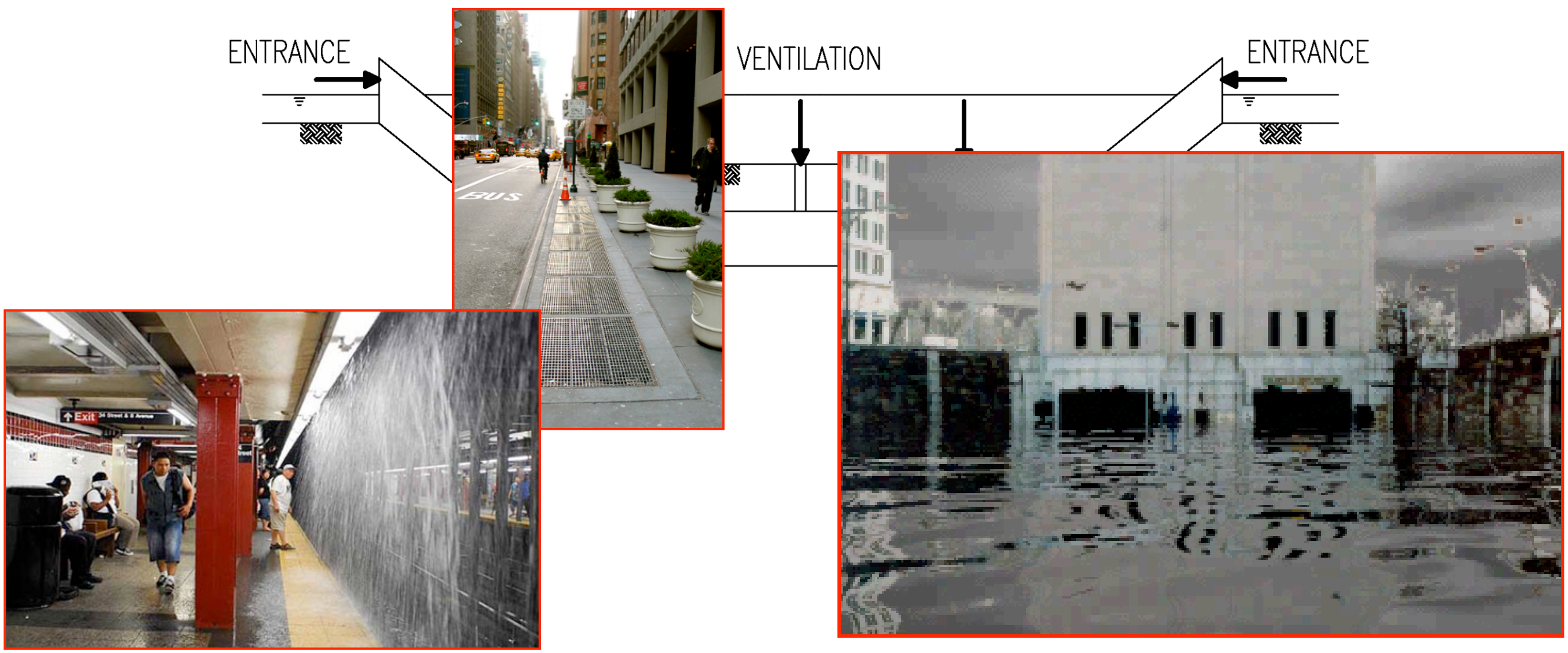
8. **Estimate economic impact of transport outage & restoration times based on pre-storm daily economic output (~ $4 Billion/day)**

9. **Infer lessons for adaptation options to manage these risks.**

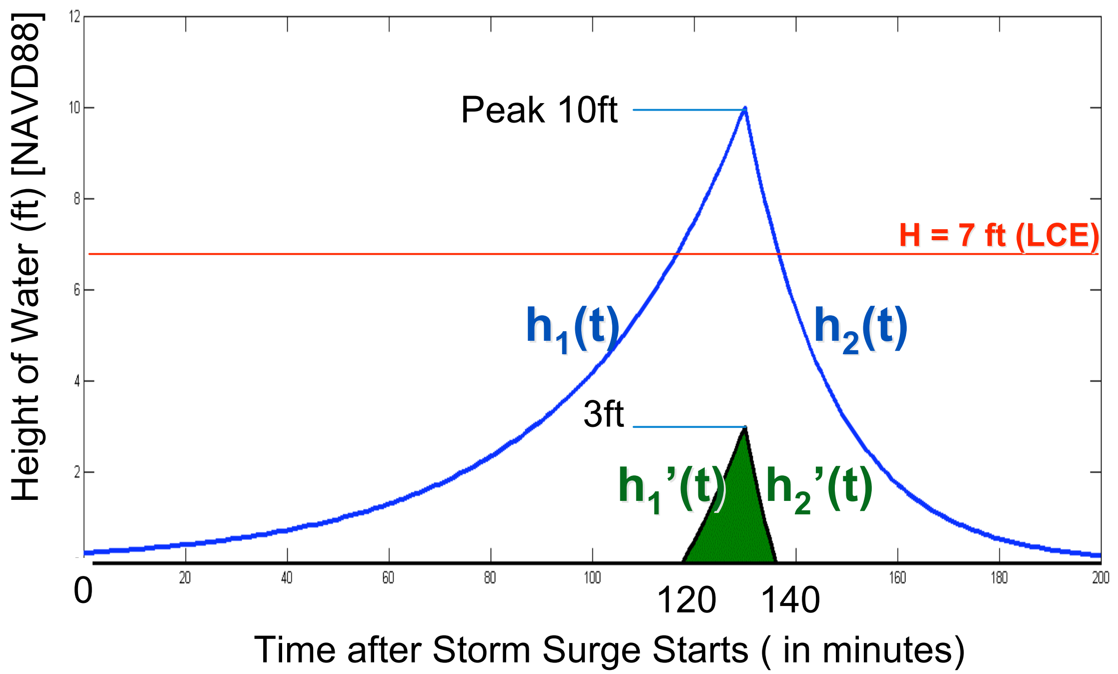

S1 100y flood in 2000 (surge of ~ 8ft).
S2 100y flood in 2040s, with +2ft SLR
S3 100y flood in 2080s, with +4ft SLR
81 St-Museum of Natural History
66 St-Lincoln Center
59 St-Columbus Circle
Midtown-57 St
68 St-Hunter College
Lexington Av/63 St
Lexington Av/59 St
42 St-Port Authority Bus Terminal
Times Sq-42 St
47-50 Sts/Rockefeller Ctr
34 St-Penn Station
34 St-Herald Sq
Grand Central-42 St
Roosevelt Island
21 St-Queensbridge
Queensboro Plaza
23 St-Ely Av
Queens Plaza
45 Rd-Court House Sq
Vernon Blvd-Jackson Av
Hunters Point Av
33 St-Rawson St
40 St-Lowery St
46 St-Bliss St
52 St
Woodside-61 St
Northern Blvd
Astoria-Ditmars Blvd
Astoria Blvd
30 Av
Broadway
36 Av
39 Av
36 St
Steinway St
46 St
14 St-8 Av
14 St
14 St-6 Av
14 St-Union Sq
Christopher St-Sheridan Sq
W 4 St-Wash Sq
Houston St
Spring St
Astor Pl
3 Av
1 Av
Prince St
Broadway-Lafayette
Houston St
Lower East Side-2 Av
Canal St
Franklin St
Bowery
Grand St
Delancey St
Essex St
Chambers St
Park Place
Chatham Sq
East Broadway
Cortlandt St
Fulton St
Wall St
Rector St
Seaport
Bowling Green
Hanover Sq
South Ferry
Whitehall St
Greenpoint Av
Nassau Av
Bedford Av
Lorimer St
Graham Av
Marcy Av
Grand St
Hewes St
York St
High St
Clark St
Montrose Av
NYCT - Grand Ave CMF
NYCT - West Farms
9809 ft
© 2009 Tele Atlas
Image © 2009 DigitalGlobe
Image © 2009 Sanborn
Image © 2009 Bluesky
40° 44.955' N 73° 59.283' W elev 44 ft
Eye alt 29914 ft
©2009 Google

2 Modes of Water Entry into Tunnels

a) Mostly Vertically via Subway Ventilation and Entrances
b) Sub-Horizontally into inclined Rail and Road Tunnels



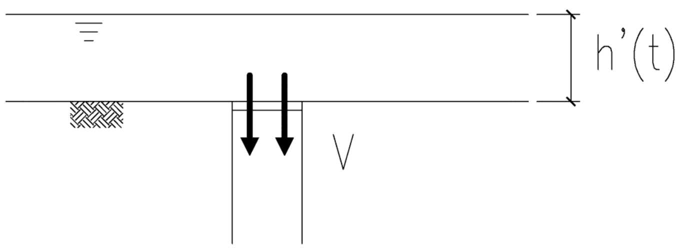
Modified Storm Surge Time-History



H = Lowest Critical Elevation of System (NAVD88)

$h_1'(t) = h_1(t) - H$ $h_2'(t) = h_2(t) - H$

Vertical Flow through subway entrances & ventilation grates



Average Flow Velocity (ft/s)

$$V_i(t) = \sqrt{2gh_i{}'(t)}$$

g = gravitational constant

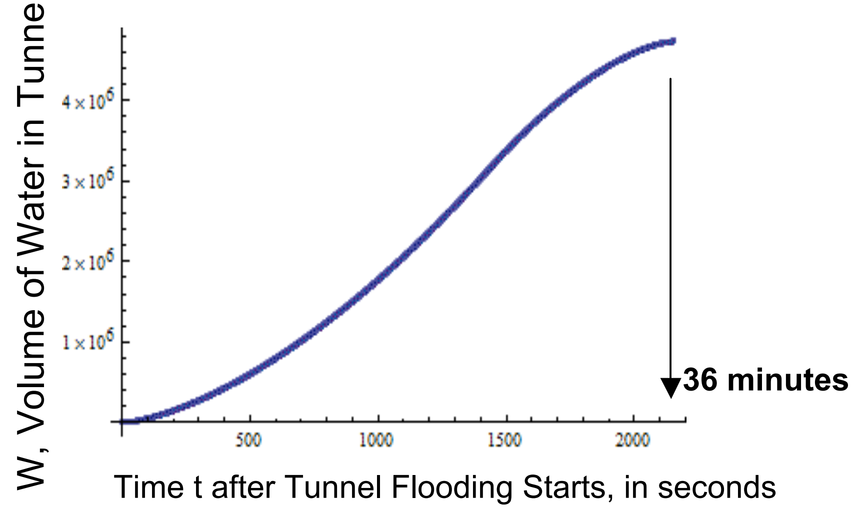
Average Flow Rate (ft³/s)

$$Q_i(t) = A_o V_i(t)$$

A_o = total area of openings (ft²)

W, Volume of Water Entering Opening Area A_o

$$W = \int Q(t)\,dt = \int A_o V(t)\,dt$$



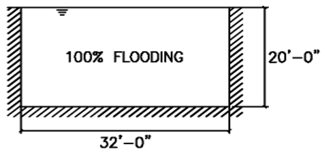
Vertical Influx Example

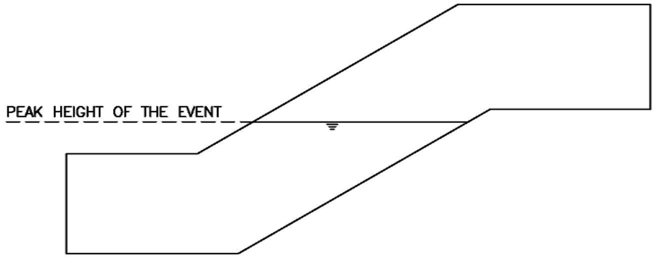
- State St. N of South Ferry Station (#1 Line)
- NAVD88 LCE elevation of ventilation area is 5’ (head: h_{max} = 10’surge - 5’LCE = 5’ max. head)
- Opening area: 48 ft^2 from grates, 150 ft^2 from stairway entrances (A_o=198 ft^2)
- Event duration of 36 minutes
- 17.9 ft/s peak flow *velocity*
- 3,550 ft^3/s peak flow *rate, all openings*
- Total volume of flooding 4,700,000 cf

Assumptions in Methodology

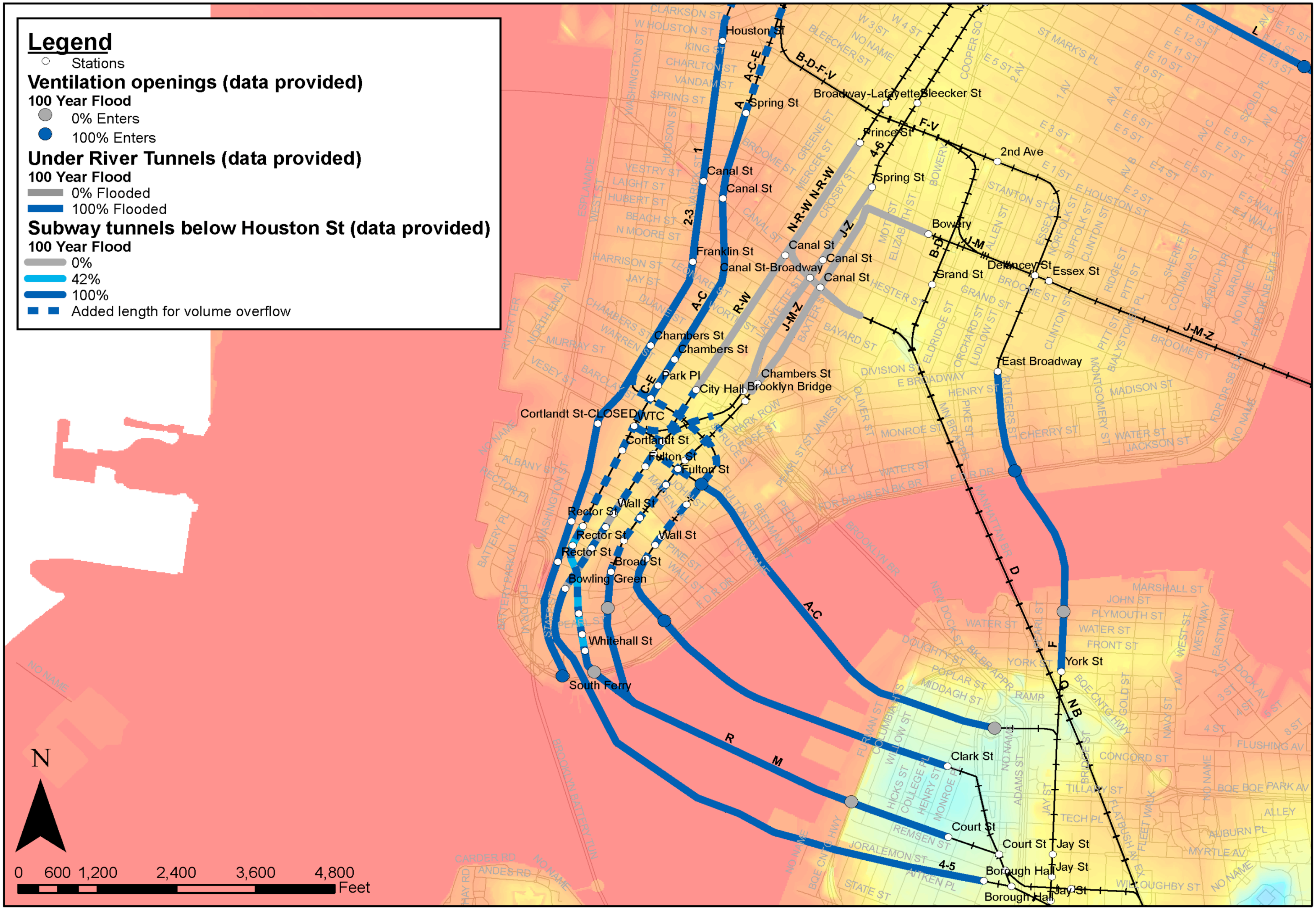
- **Once the water fills its corresponding tunnel section 100%, the overflow volume is divided by the tunnel cross-sectional area to get the length of adjacent tunnels being flooded** (only below or up to exterior water line).

- **No debris blocking the open area of the ventilation, the entire open area is used to compute unhindered flow.**

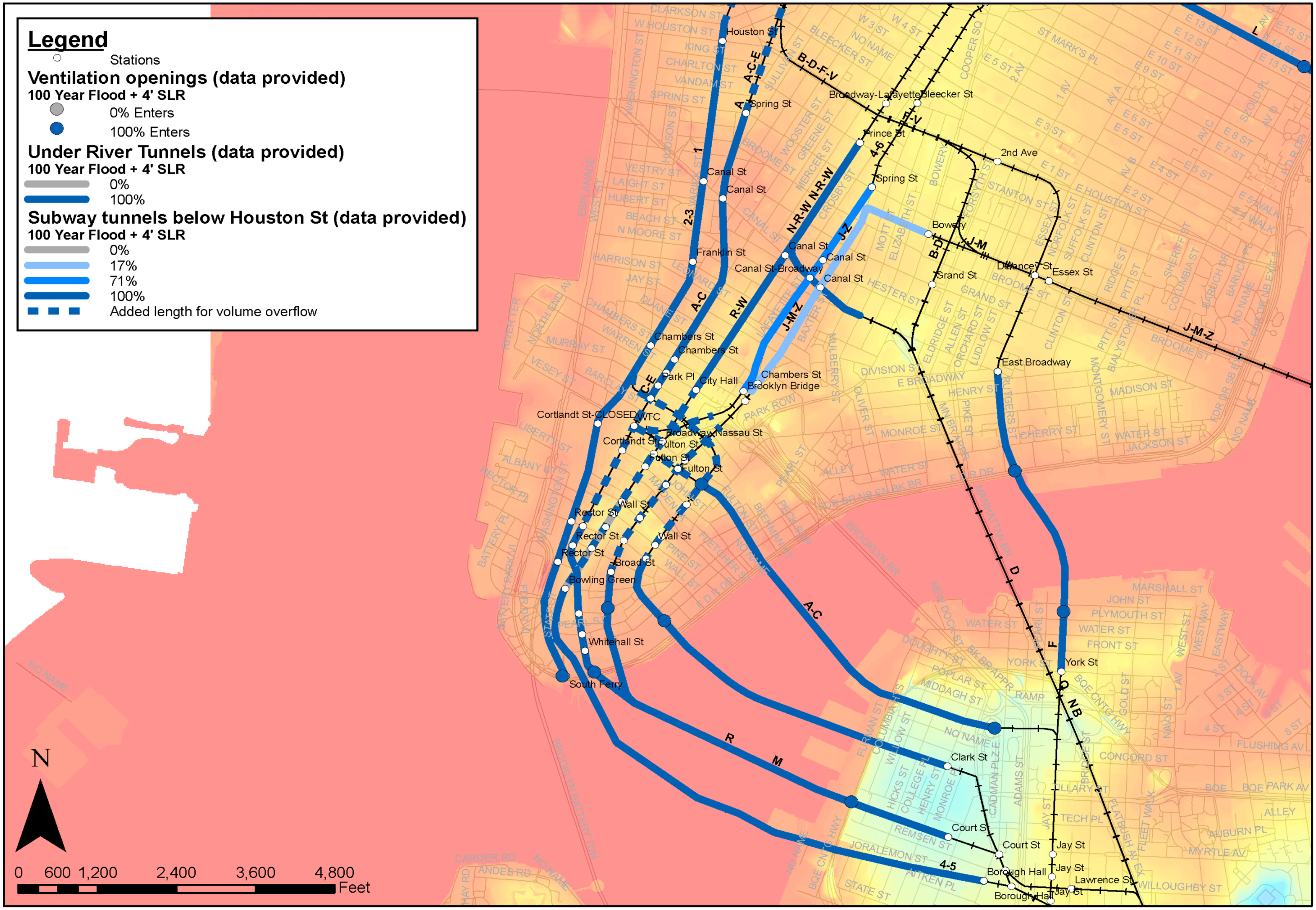




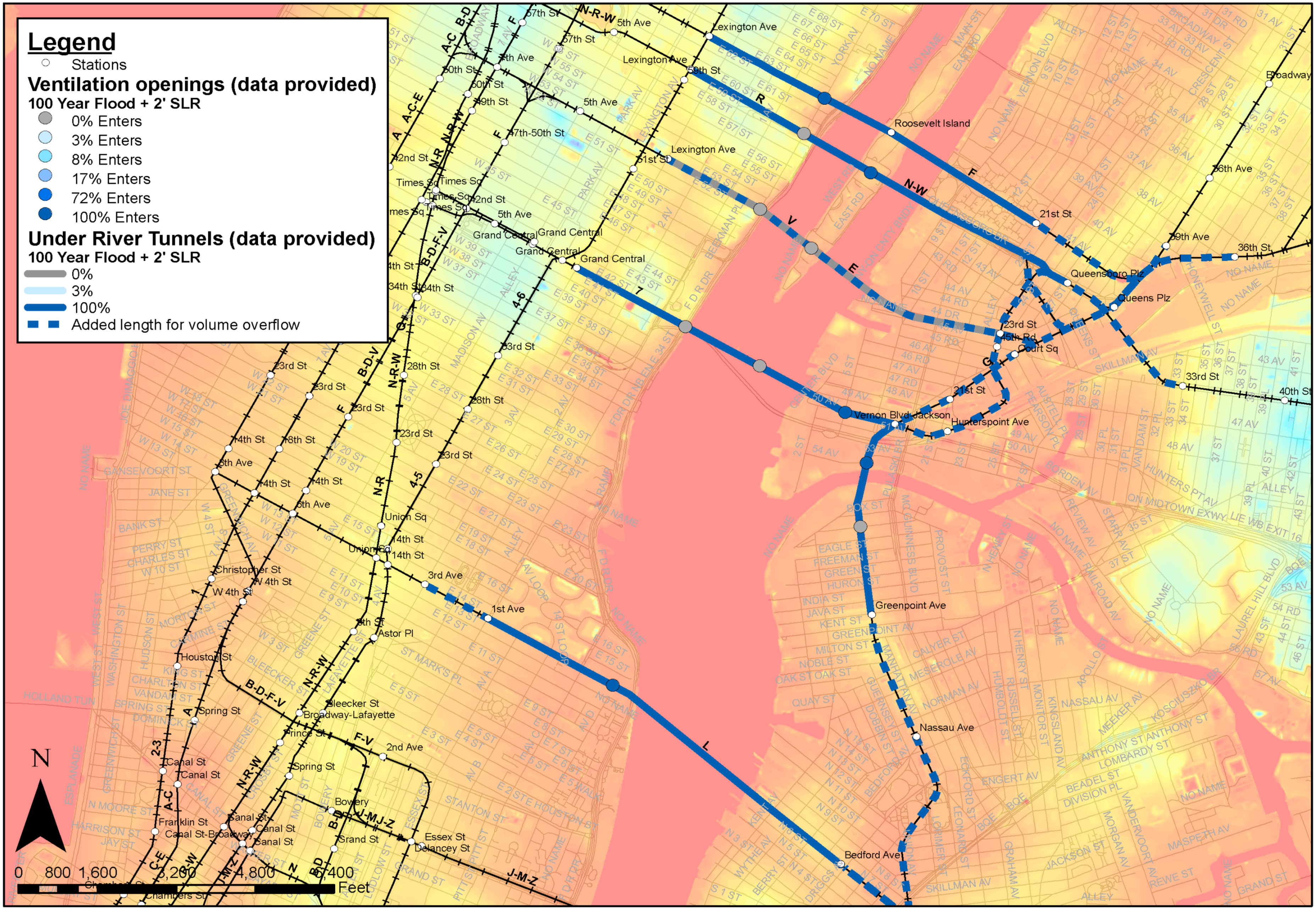
Flooded Subway and Under River Tunnels, Lower Manhattan, 1% Flood (length overflow)



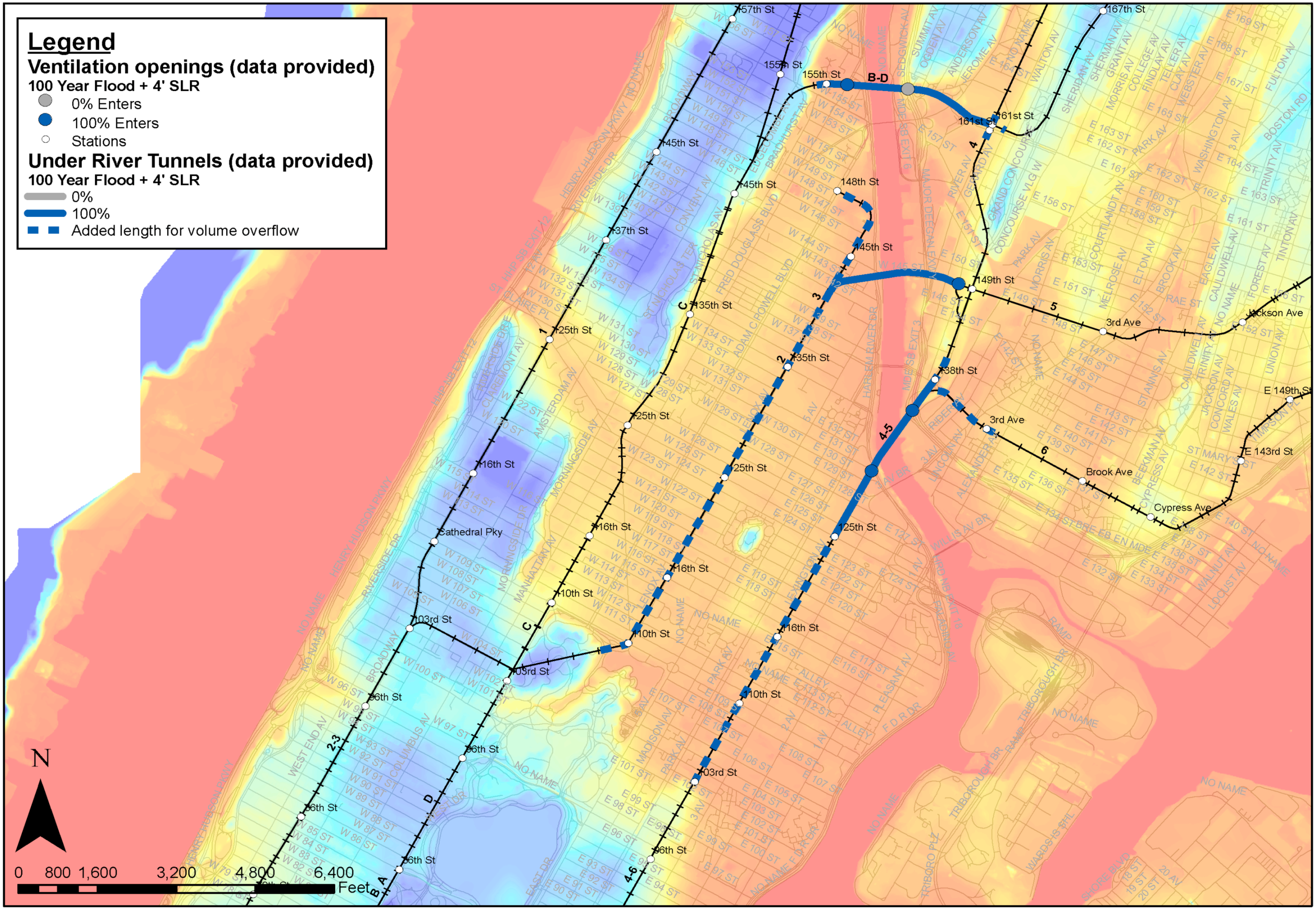
Flooded Subway and Under River Tunnels, Lower Manhattan, 1% Flood + 4' SLR (length overflow)

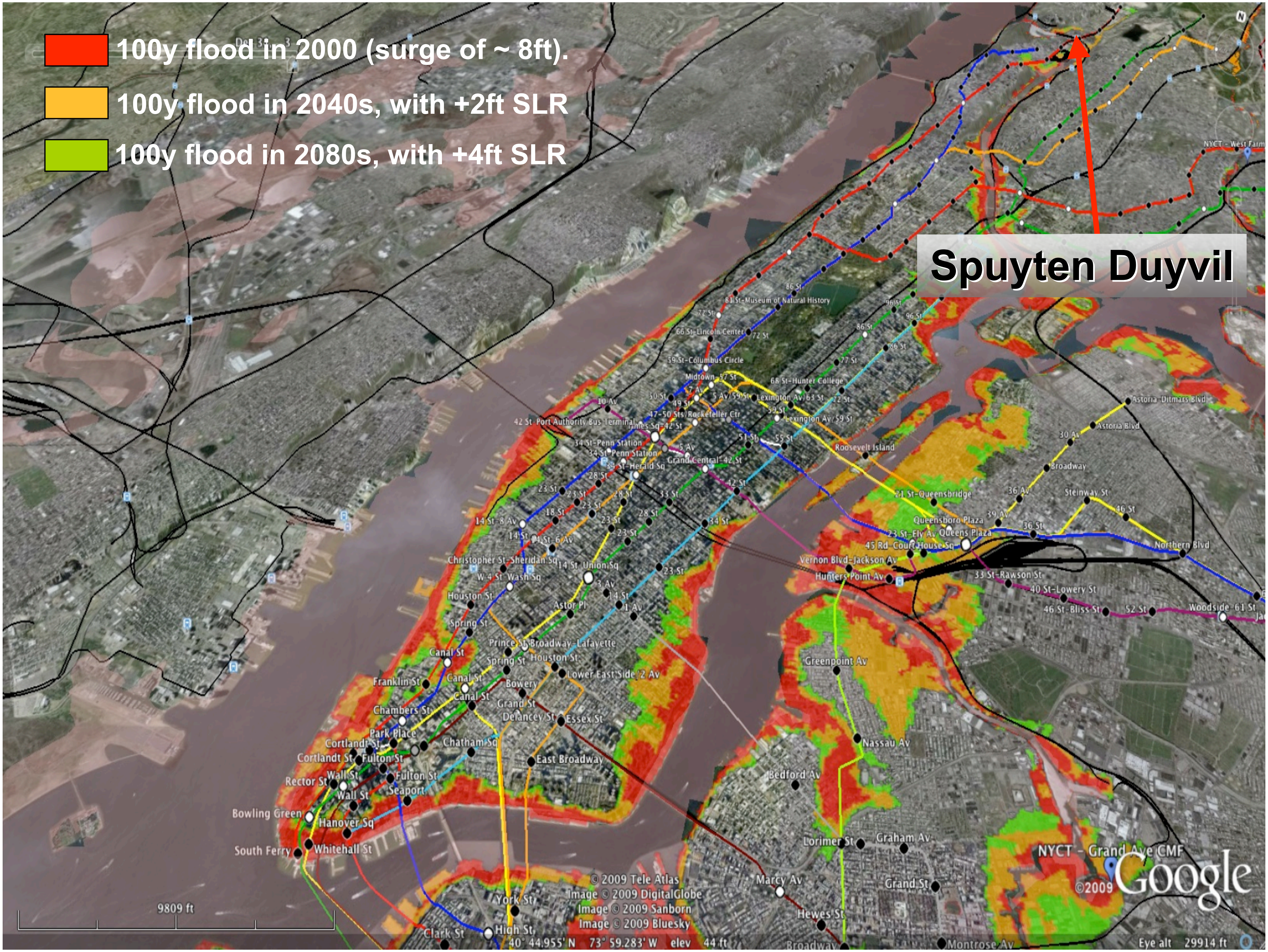


Flooded Under River Tunnels, Midtown, 1% Flood + 2' SLR (length overflow)



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




100y flood in 2000 (surge of ~ 8ft).
100y flood in 2040s, with +2ft SLR
100y flood in 2080s, with +4ft SLR
Spuyten Duyvil

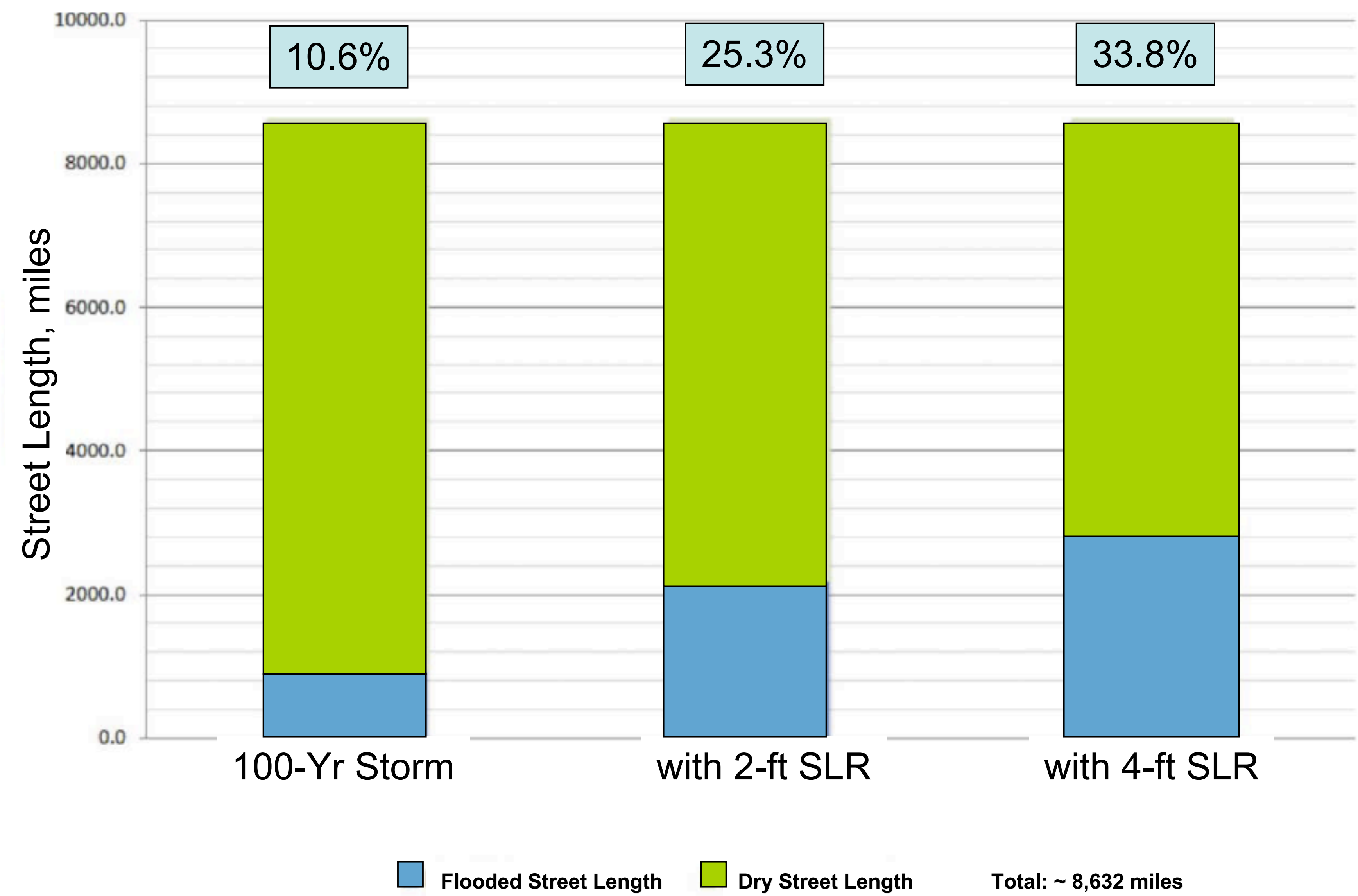
Rail Track Elevation, LCE=6.6'; 100-yr BFE Z=8' at MTA's Metro-North Spuyten Duyvil Rail Station along the Harlem River.

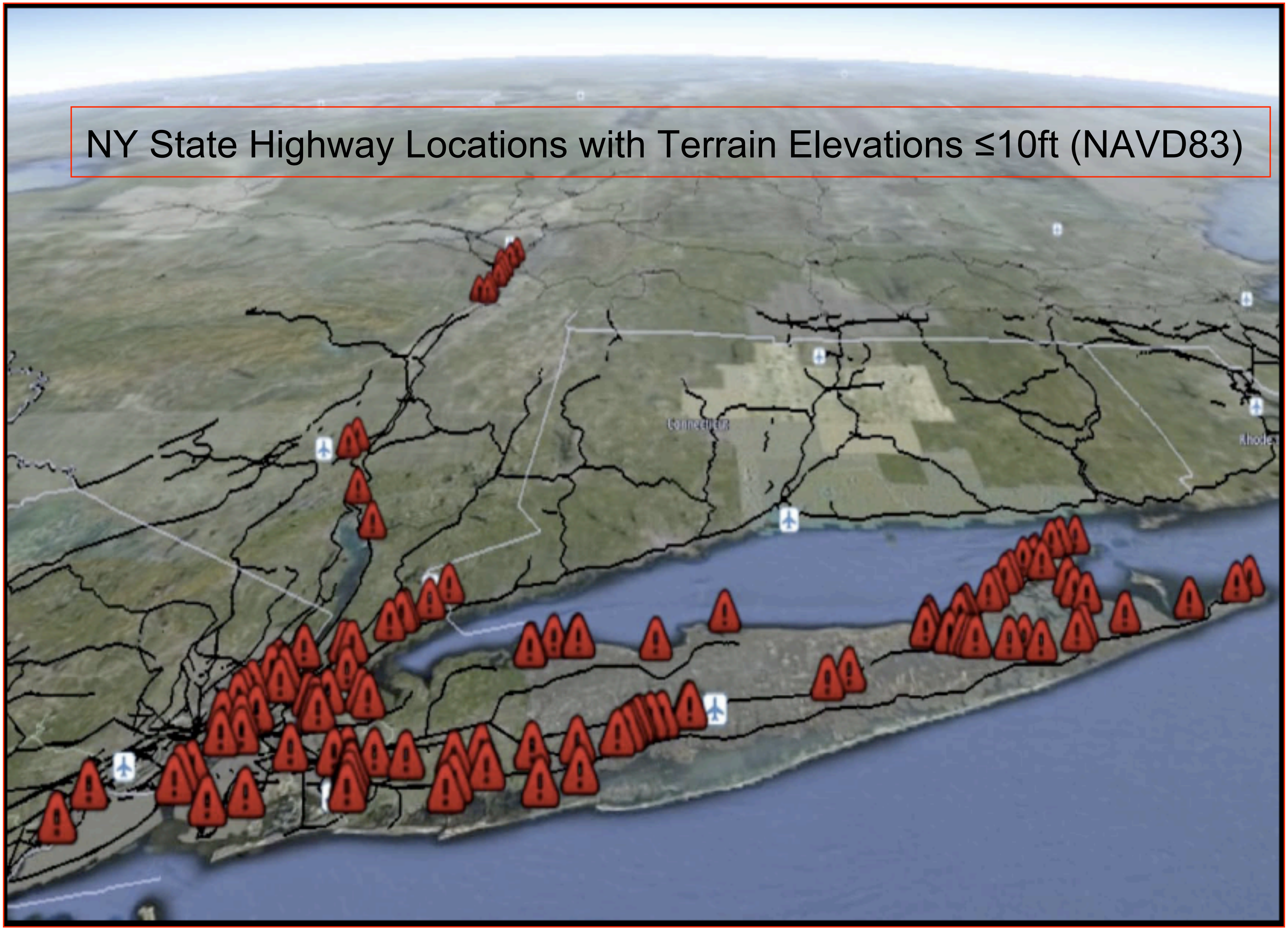
Flooding of Road Tunnels

(2 Examples, Without Adaptation or Protective Measures)

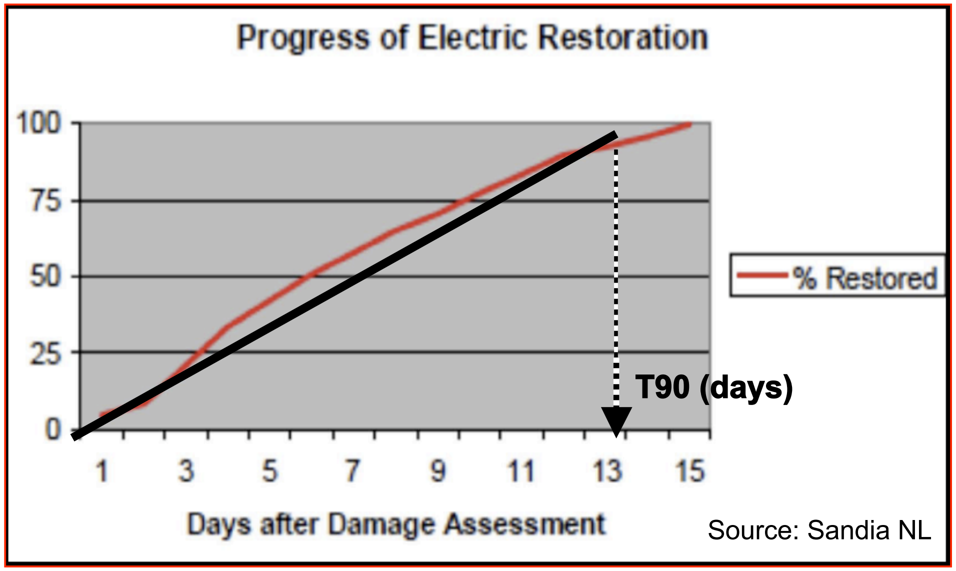
	FLOOD ESTIMATES (by % of Tunnel Volume).					
	Brooklyn-Battery			Queens Midtown		
	100y	100y+2ft SLR	100y+4ft SLR	100y	100y+2ft SLR	100y+4ft SLR
Entrances	36%	167%	254%	0%	22%	105%
Ventilations	0%	3%	49%	0.3%	4%	45%
Total	36%	170%	303%	0.3%	26%	150%

NYC Street Length (miles) and % Flooded, for Three Flood Scenarios




NY State Highway Locations with Terrain Elevations ≤10ft (NAVD83)

- What is the expected **impact/damage** from the flooding of the transportation infrastructure ?
- **How long** will it take for the various components of infrastructure to have their **services restored** ?
- What will be the **economic losses** from the trans-portation outages and extended restoration times ?



D Duration of Storm / Flood

E Time to Restore Electric Power

L Time for Logistic Set-up

P Time to Pump out Tunnels

A Time Assessing Damage in Tunnels

R Time for Repairs & Cleanup

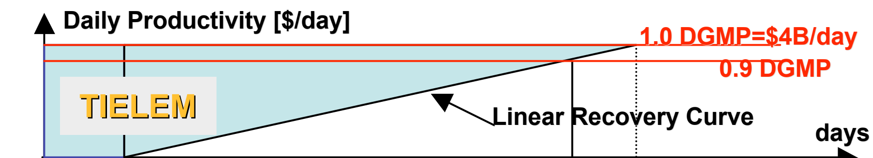
$T90\ (days) = Max\{D, E, L|P>0\} + Max\{P, A, R\} \geq 1$

	1	2**	3	4	5
	TYPE OF DELAY		1%/y BFE	BFE +2 ft	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 42nd Str 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 63rd StrE-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**

TIELEM = **Time Integrated Economic Losses** for the **Entire Metropolitan Region**

DGMP = **Daily Gross Metropolitan Product=$4B/day**

TIELEM =DGMP[T90min+½(T90max–T90min)100/90]



	T90min:	T90max:
S1:	**1**	**21**
S2:	**1**	**25**
S3:	**2 days**	**29 days**

Combined economic and physical-damage Losses for the New York City Metropolitan region for a 100-year storm surge, for three sea level rise scenarios (2010 assets and 2010-dollar valuation).

Scenario	**TIELEM ($ billion)**	**Physical Damage ($ billion)**	**Total Loss ($ billion)**
S1, current sea level 2100	48	10	**$58**
S2 (2-foot rise in sea level) 2040s	57	13	**$70**
S3 (4-foot rise in sea level) 2080s	68	16	**$84**

Multipliers for 40 and 80 year time horizons as a function of growth rate *r* when p=2 (i.e. add each year 2% of *initial* asset value).

Effective Economic Growth Rate *r* (%/year):	**0.0**	**1.50**	**1.75**	**2.00**
S2-TIELEM Multiplier for 40 Years:	1.8	2.91	3.16	3.44
S3-TIELEM Multiplier for 80 Years:	2.6	6.39	7.50	8.83

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For Transportation & Specifically the Subway System, what measures would it take to avoid such losses?

1. In all current and future flood zones, seal all ventilation street grates and replace passive 'open' ventilation with forced 'closed' ventilation. This requires new fan plants, and uses more energy.

2. In all flood prone zones, provide safe flood gates at all entrances and ventilation shafts; and/or safer: surround all entrances and openings by sufficiently high berms and/or levees: "Taipei-Solution"- Go up before you step down !

3. What are the Costs? Needs engineering studies, but costs are likely to be at least 25% of the expected avoided losses: **i.e. in excess of $ 15 to 20 Billion ?**

For Transportation, and Specifically the Subway System, what measures should be undertaken to avoid such losses?

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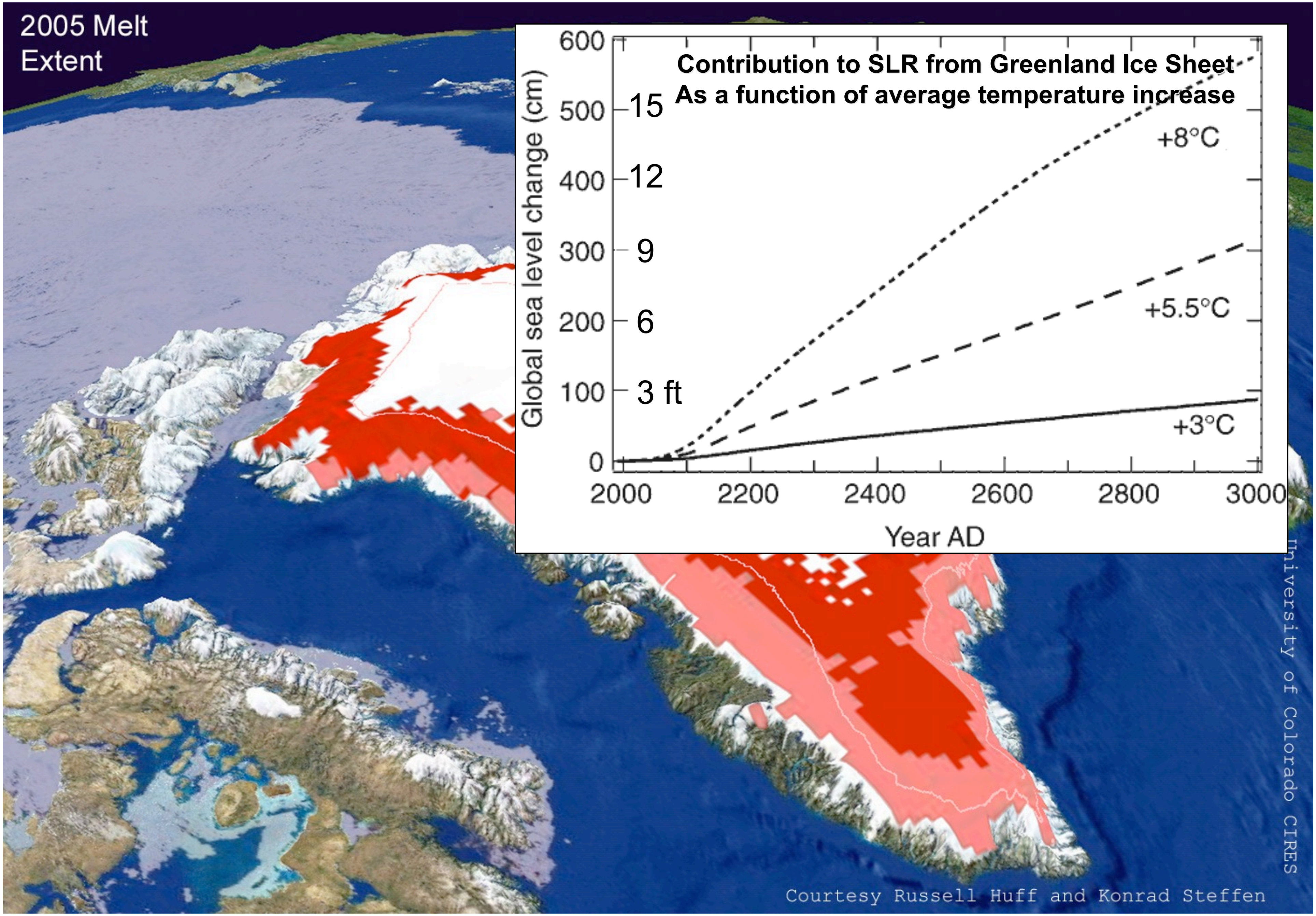
Structural "Solution": 3 or 4 Barriers. Probably Unsustainable. Why?


London's Thames Barriers


2005 Melt Extent
Contribution to SLR from Greenland Ice Sheet
As a function of average temperature increase
Global sea level change (cm)
600
500
400
300
200
100
0
15
12
9
6
3 ft
+8°C
+5.5°C
+3°C
2000
2200
2400
2600
2800
3000
Year AD
University of Colorado CIRES
Courtesy Russell Huff and Konrad Steffen

Risk Management Tools: Minimizing the Risk via Mitigation and Adaptation Measures (Let's use the Risk Equation and GIS-based Models!) :

Risk = Sum (Hazard x Assets x Vulnerability)

Mitig.: Reduce GW + SLR Hazards

Adapt.: Land Use Planning & Zoning,
Considerate Placements of new Assets,
Relocation of Essential Assets.
Levees & Dams (?).
Equity Issues.

or by **Risk = Sum (Hazard x Assets x Vulnerability)**

Adapt.: Good Engineering, Construction Quality-Control,
Codes and Code Enforcement, Retrofitting,
Raising Assets in Place
Reinforcing Levees and Pump Stations

Response Options:

1) Do Nothing: => More GHG, CC, Global Warming & Sea Level Rise, Storm Surges => <u>Greater Hazards</u>! => <u>Higher, More Frequent CC-Related Losses</u>

2) <u>Rely on Insurance and/or Federal Disaster Relief Aid</u>

- Limitations on Commercial Wind Insurance
- More Restrictive Federal Flood Insurance ("3-times: out")
- Both more expensive - less available
- Higher Deductibles, Lower "Ceilings"
- Tighter Federal Disaster Relief Aid to Local Governments, Businesses & Citizens (see New Orleans)

3) <u>Adaptation Measures/Options:</u>

- Short-term: Early Warnings, Evacuation ('Only' Saves Lives)
- Emergency & Operational Preparedness.
- Assess & Avoid Growth in Hazard Zones, Retreat from Low Coasts
- Restore and Preserve Wetland, and Create Vegetated Buffer Areas / Parks.
- Raising & Hardening Structures (Unsustainable Barriers??).
- Increase Peak Capacity (Road Drainage / Storm Sewer / Treatment Plants / Water & Energy Supply). Reduce Demand.
- 'Flexible' / Adaptable Urban Design/Planning.

Response Options (cont.):

4) For Individual Building Projects

- Flood Proofing (Basements, Put Infrastructure far above Ground, Raise Entrances, Install Floodgates, Raise Entire Structures, ….).
- Reduce Run-off; Build Green Roofs; Capture Rain/Storm-Water
- Increase Insulation, Decrease Air Leakage to Increase AC Efficiency to cope with Higher Peak Temperatures.

5) City / Urban / Landuse Planning

- Reduce Heat Island Effects - Trees, Parks, Green Roofs, Lighter Roadways
- Reduce Storm Runoff - Infiltration
- Rezone Waterfront as Storm Surge Buffer Zones
- Adjust FEMA FIRM for SLR and New Storm/Surge Frequencies
- Modify Building Code applicable in Current & Future Flood-Prone Areas.
- Flood-Prove Infrastructure - ?? - NYCT, Sewer - $$
- Protect Entire “Blocks” or entire NY Harbor Estuary - Latter Unsustainable ?

6) Smart Policies ….e.g. PlaNY2030 / NPCC / ClimAID

- Capital Investments into *CC-Mitigative* & *Adaptive* Infrastructure & Landuse are Part of a Smart Growth Path.
- NYC can make these Investments to Achieve Short-term Gains for ***Today’s*** Communities (Safety, Health, Quality of Live, ‘Green City’), but also Leave in Place a Better Legacy for the City’s ***Future*** and Coming Generations.

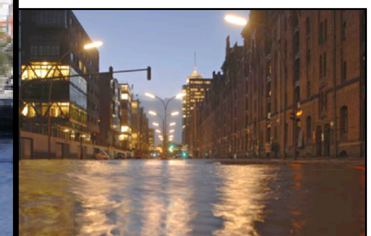
The good Message is

For every $1 invested in Hazard Loss Mitigation & Prevention There is a Return of $4 Saved in NOT Incurred Losses.

National Institute of Building Science
Multi-hazard Mitigation Council
(NIBS/MMC) Study "Mitigation Saves":

http://www.nibs.org/MMC/MitigationSavingsReport/natural_hazard_mitigation_saves.htm

HafenCity/Harbor City **Hamburg**



http://green-changemakers.blogspot.com/2010/09/hafencity-case-study-on-future-adaptive.html

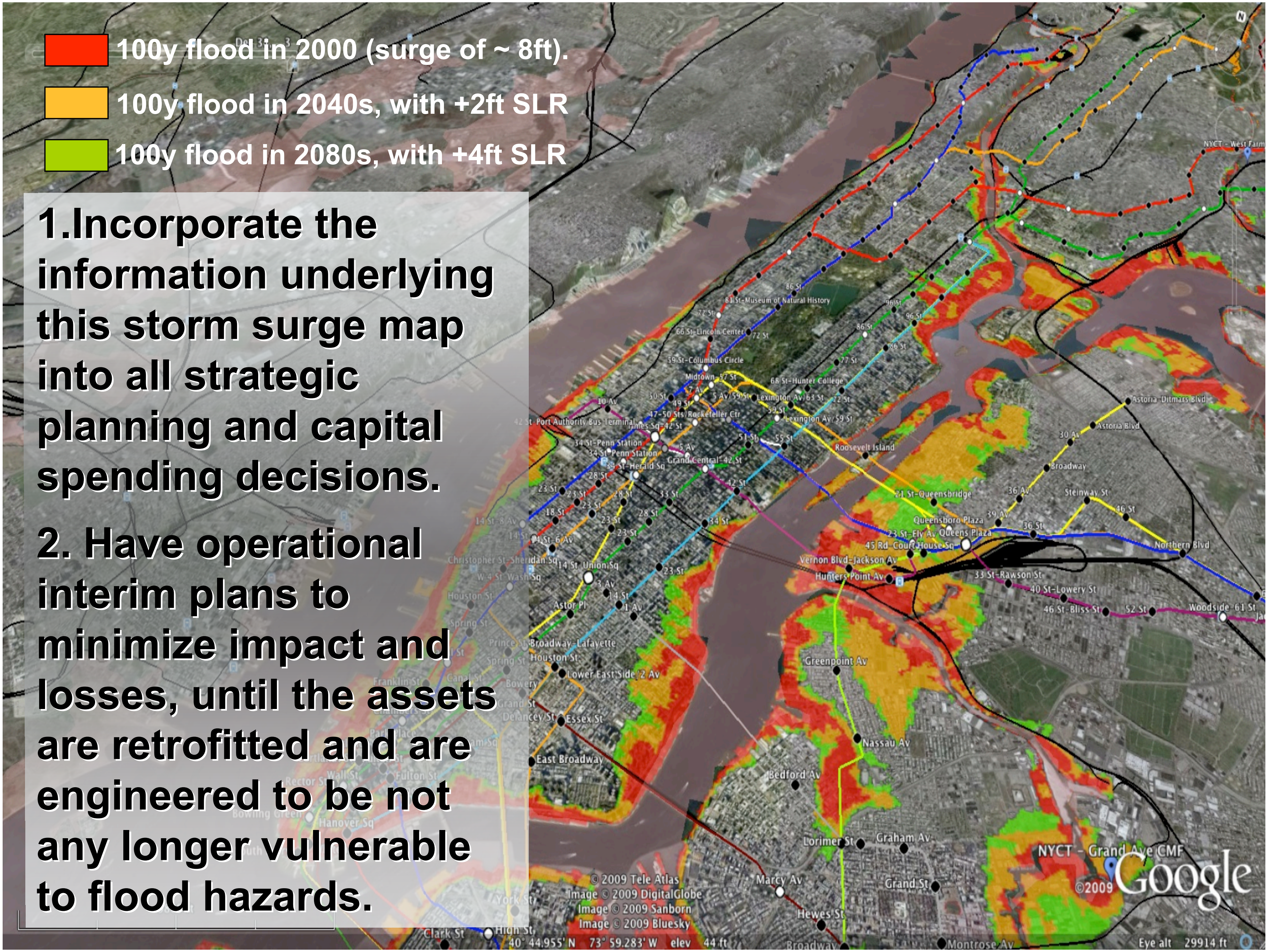
100y flood in 2000 (surge of ~ 8ft).

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

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

1.Incorporate the information underlying this storm surge map into all strategic planning and capital spending decisions.

2. Have operational interim plans to minimize impact and losses, until the assets are retrofitted and are engineered to be not any longer vulnerable to flood hazards.




Oh, crap! Was that TODAY?
REGAN

Thank You !