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.

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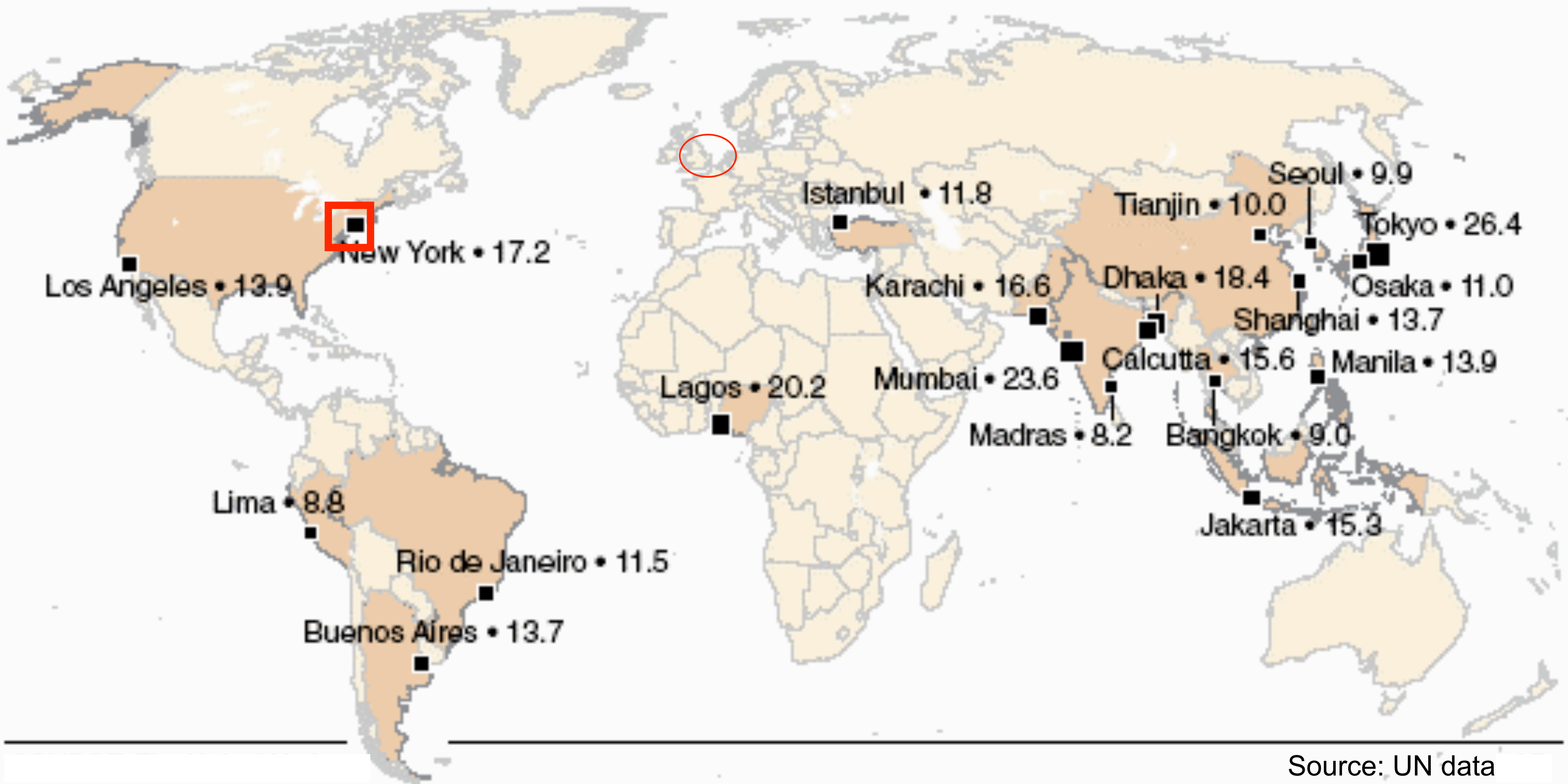
Overview of Topics:

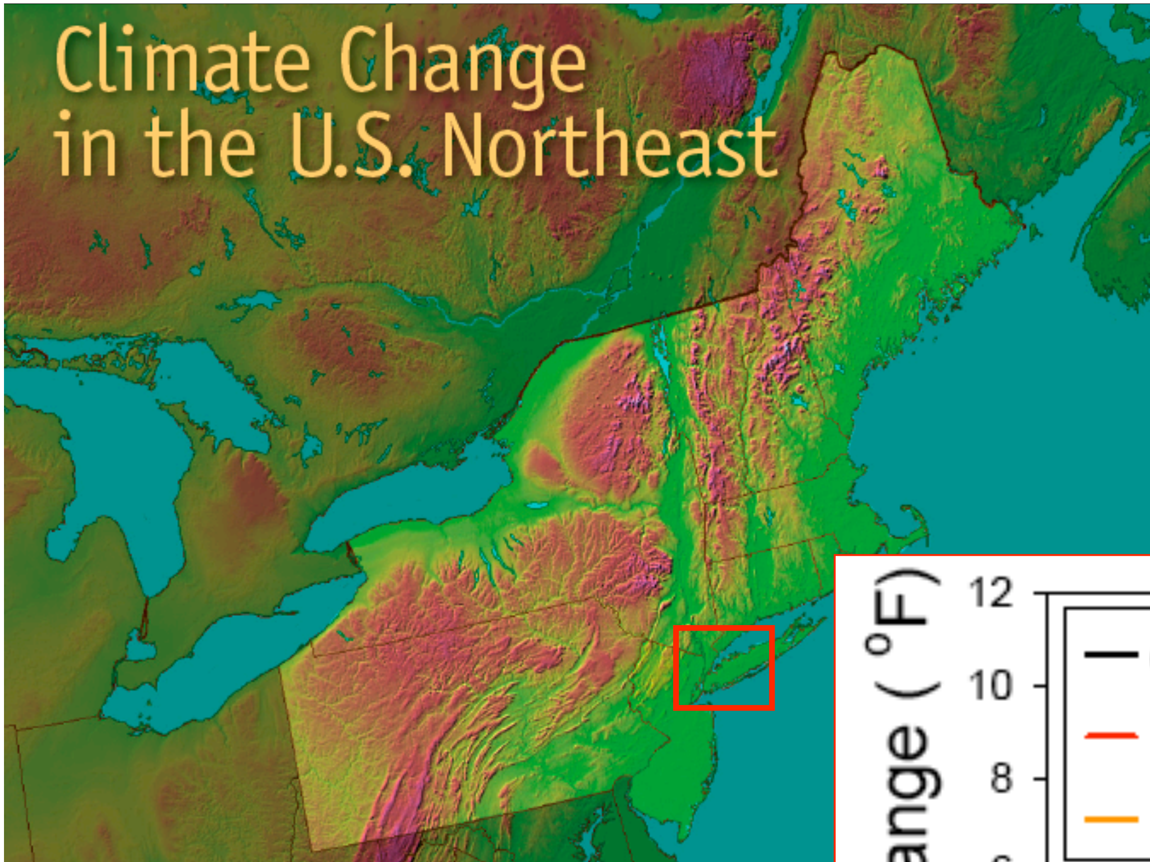
- NYC's Expected Climate Change (21st Century)
  - Temperature
  - Precipitation
  - Storms (Hurricanes, Nor'easter's, Winterstorms, Windstorms)
  - Sea Level Rise (SLR) & Coastal Storm Surge Inundations
- NYC's Infrastructure Exposed to the CC Hazards, and its Vulnerabilities.
- Risk (Expected Future $-Losses) due to CC
- Options & Costs to Reduce NYC's CC Risks.

The Global Context:

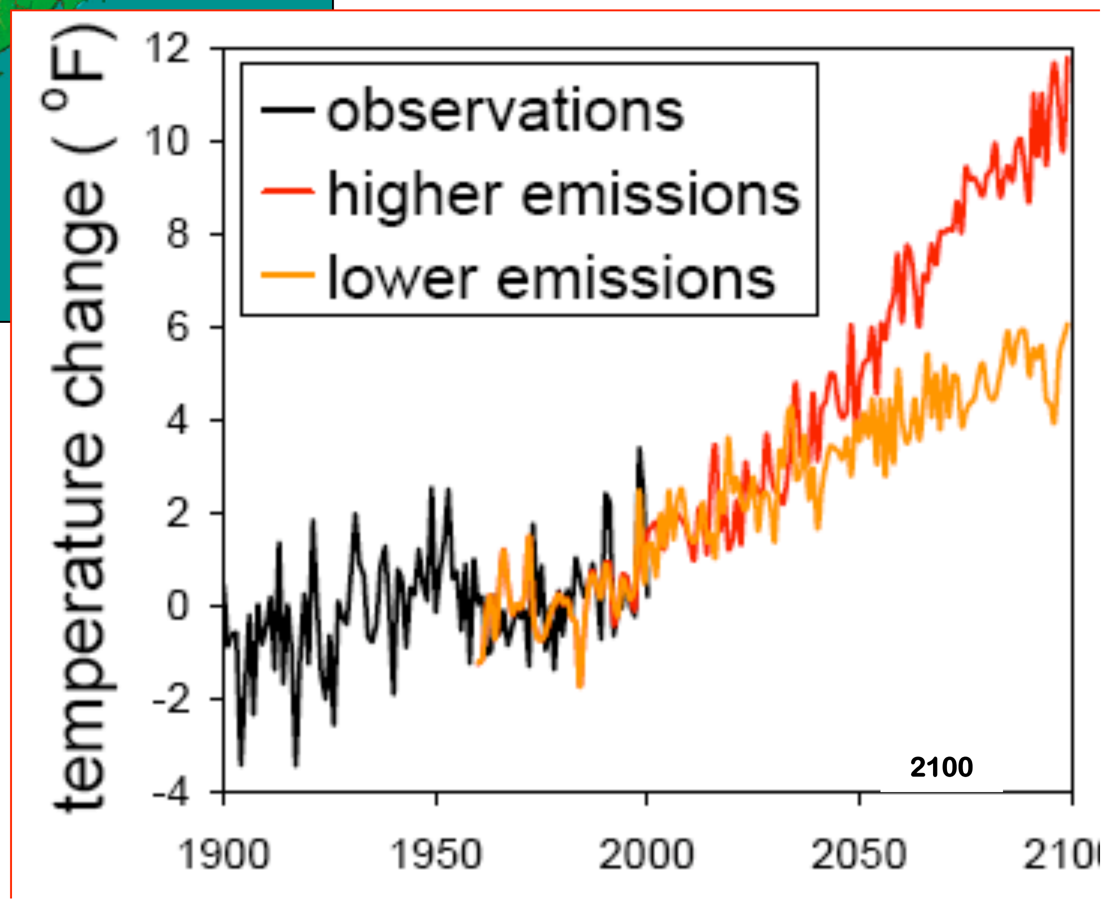
Coastal urban agglomerations with populations more than 8 million in 2010



Source: UN data

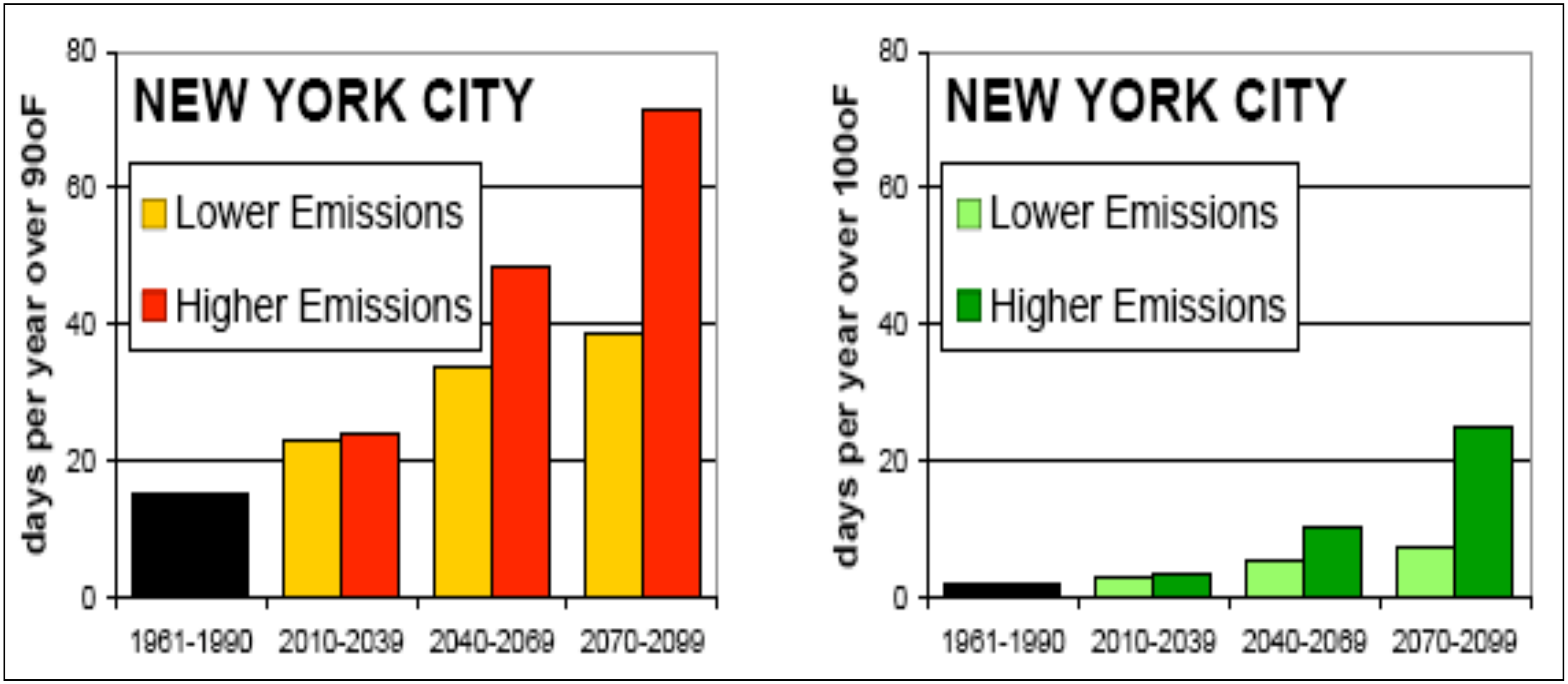


http://www.climatechoices.org/assets/documents/climatechoices/NECIA_climate_report_final.pdf

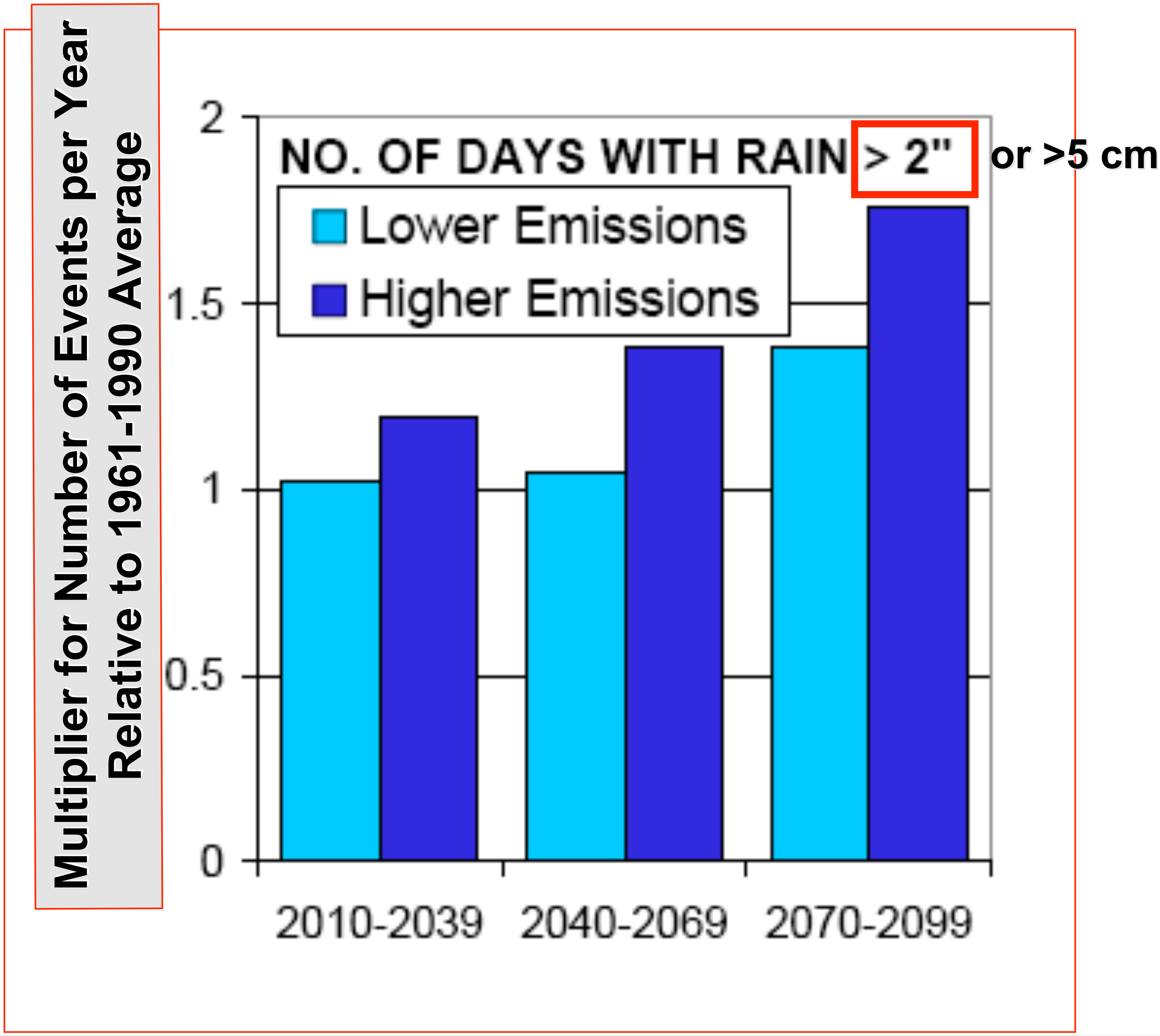


No. of days >90ºF (32ºC)

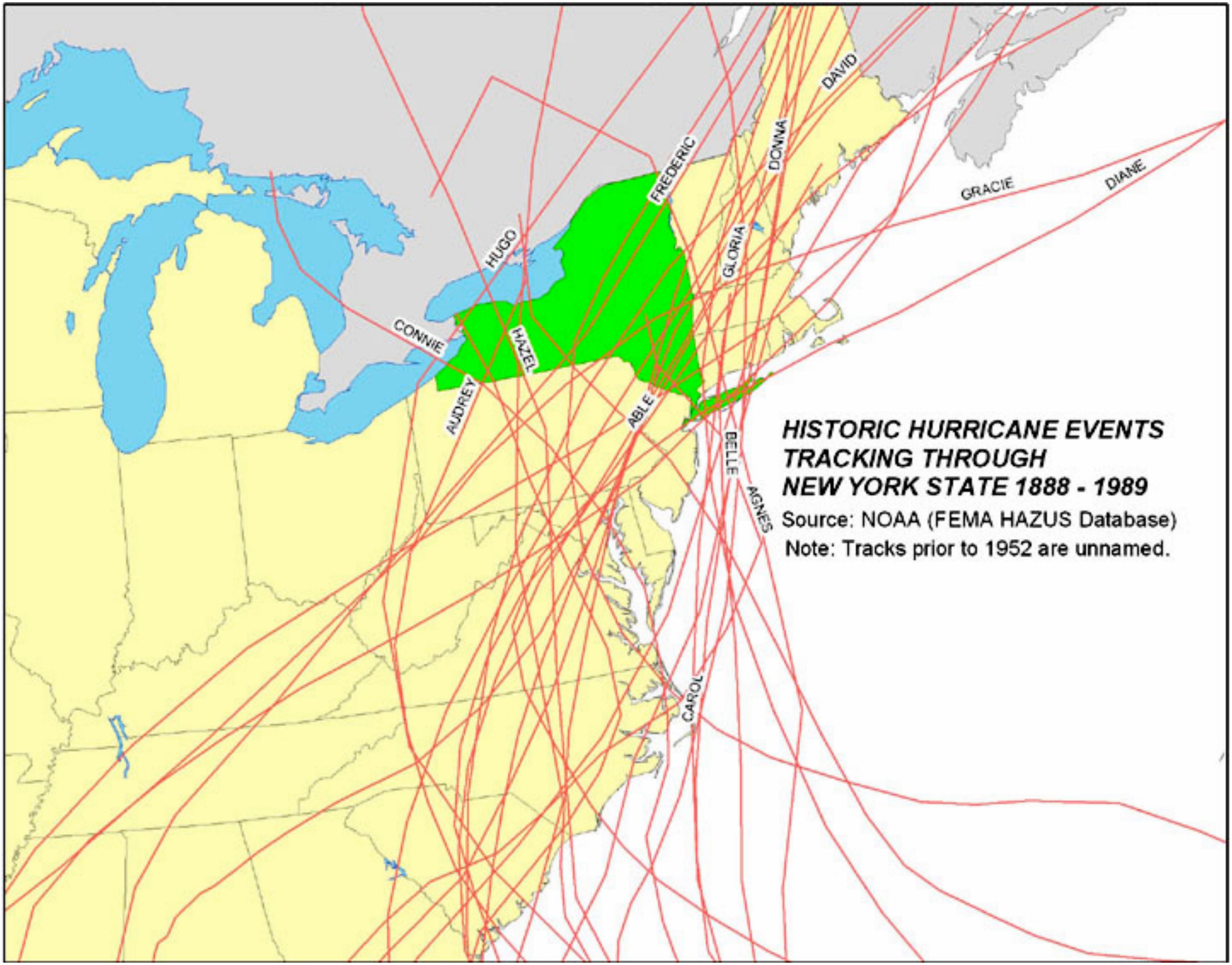
No. of days >100ºF (38ºC)

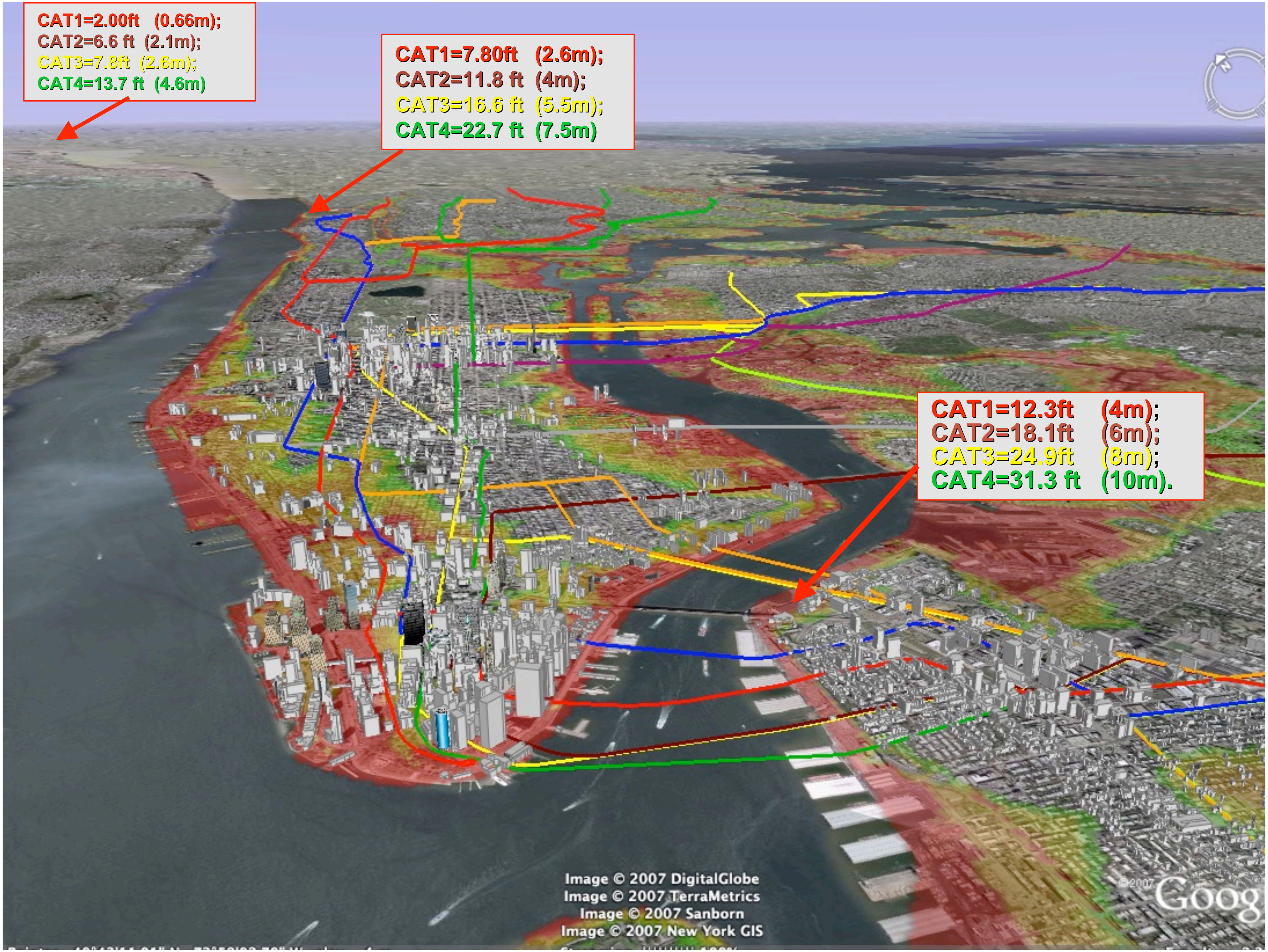


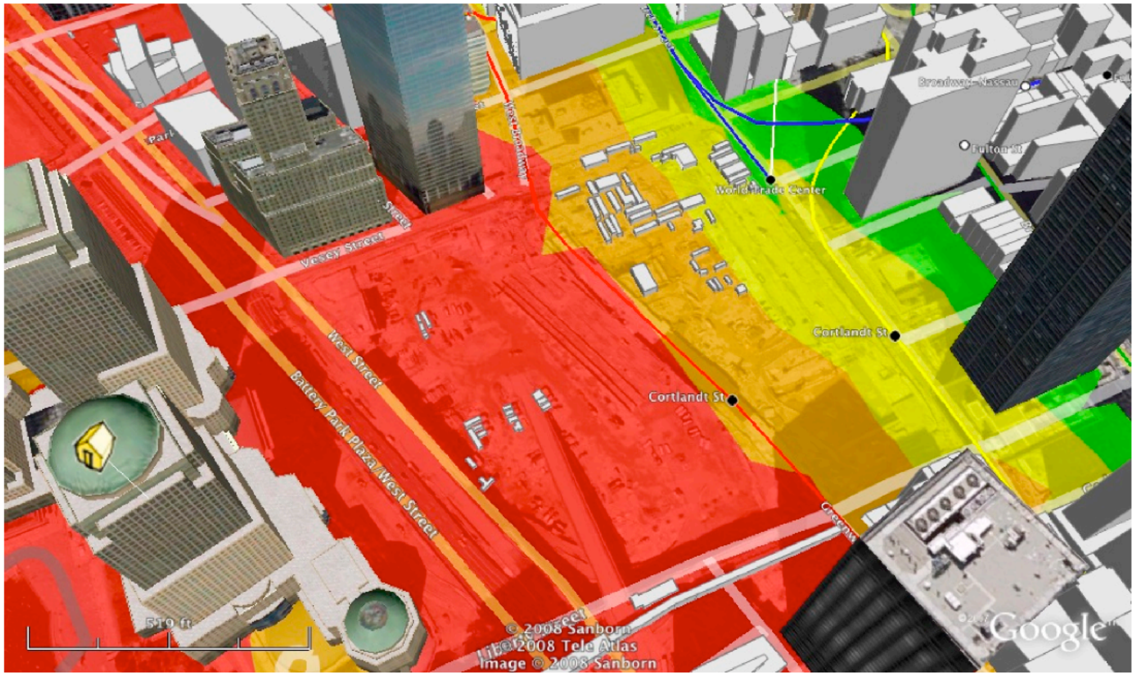
=> more air conditioning, heat strokes, energy, CO2, more warming !



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


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.

GIS-based Risk Assessment Tool 'HAZUS - MH'

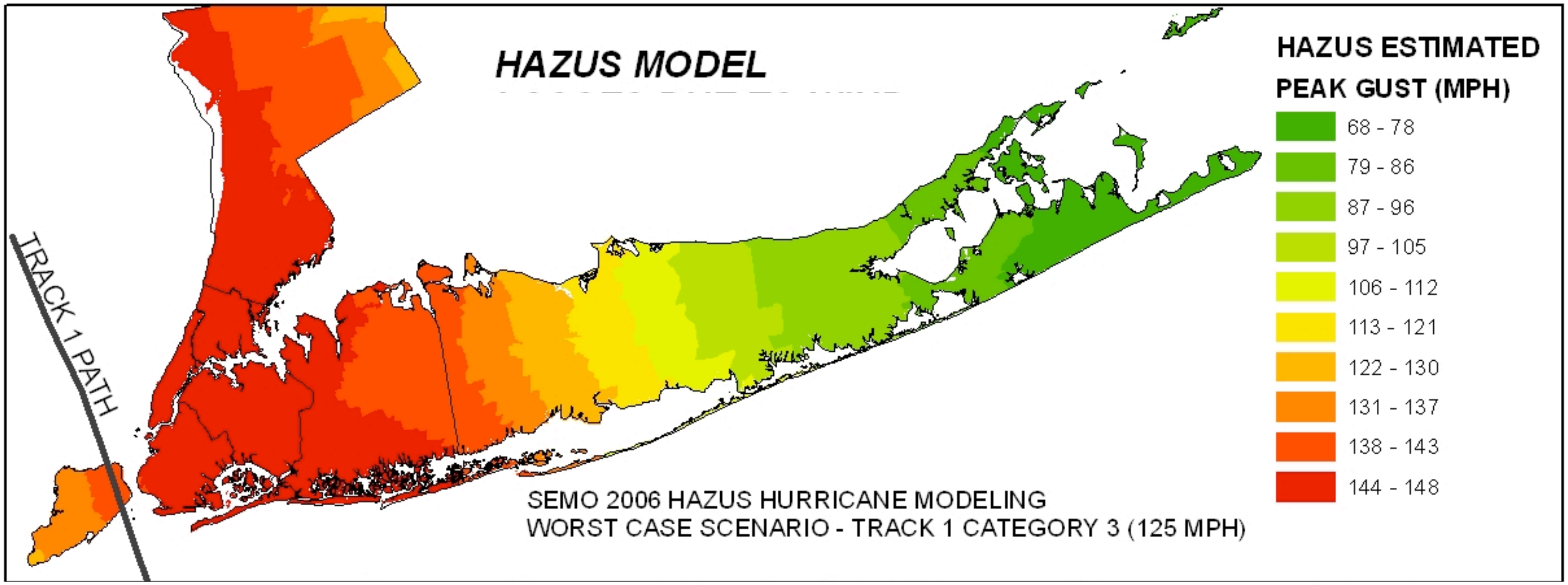
(FEMA's "*Hazards in the United States - Multi Hazards Version*": Earthquakes, Wind, Flood).

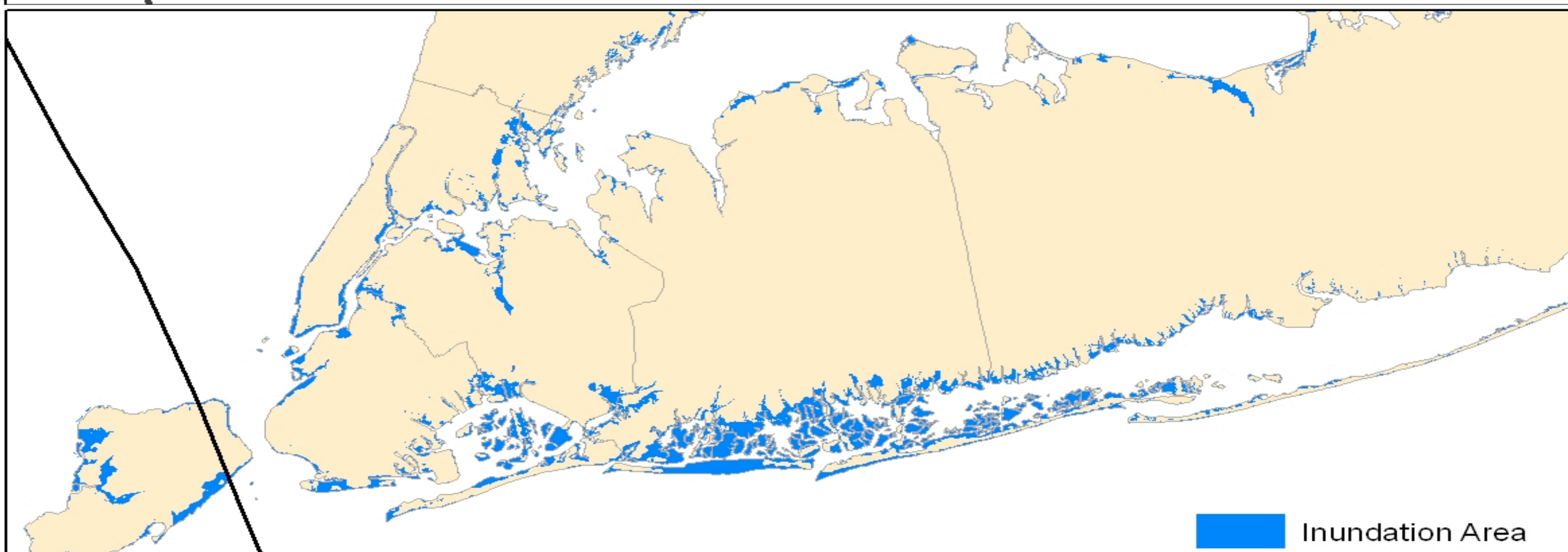
Risk = **Sum** (**Hazard** x **Assets** x **Vulnerability**)

$ / 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.

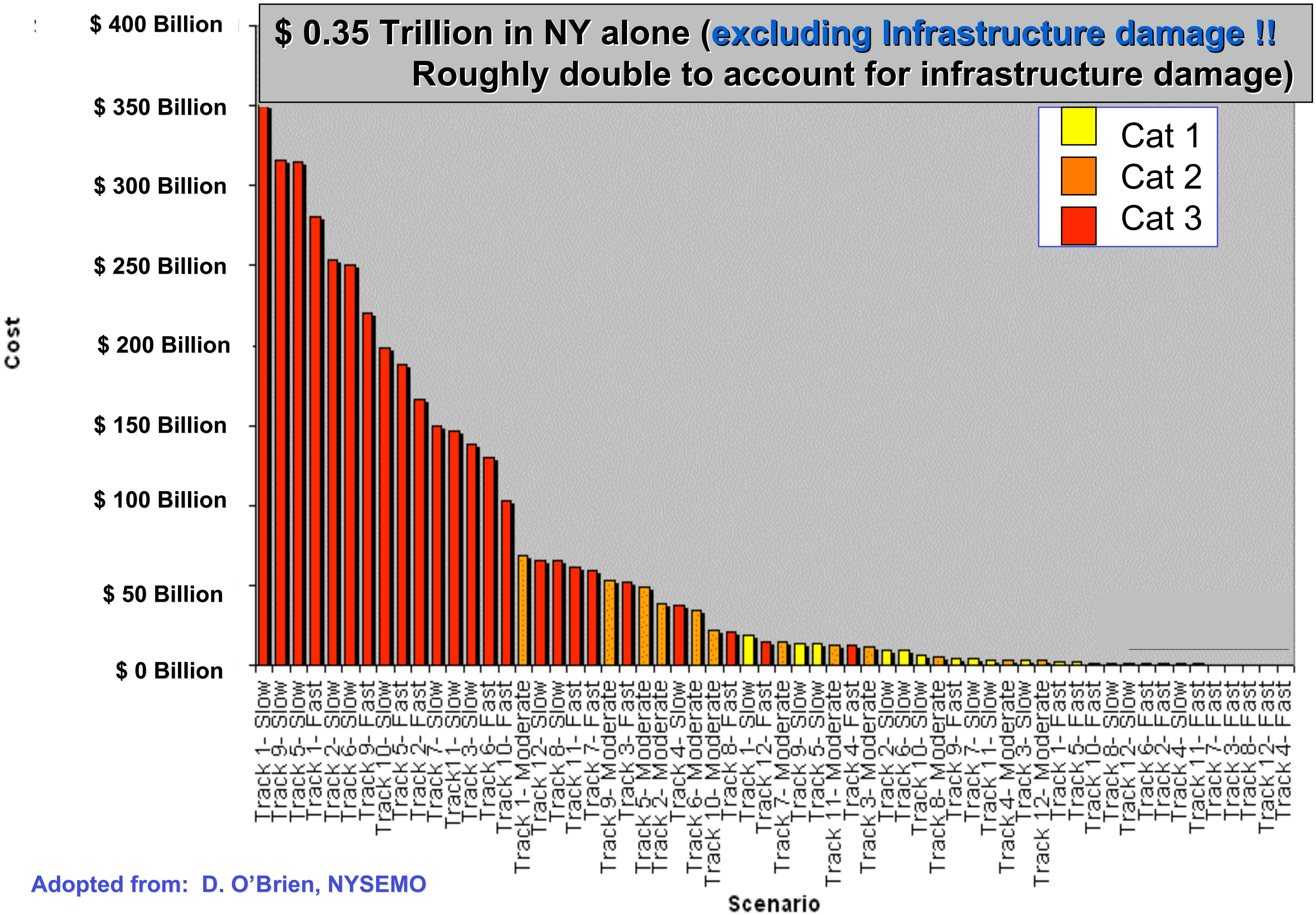
HAZUS-MH also has a Built-in Economic Model for Damage-Related, indirect Economic Losses; e.g. for Losses related to building damage and closure; but its default version is weak in assessing vulnerabilities of infrastructure systems. Requires user input for infrastructure assets and their vulnerabilities.





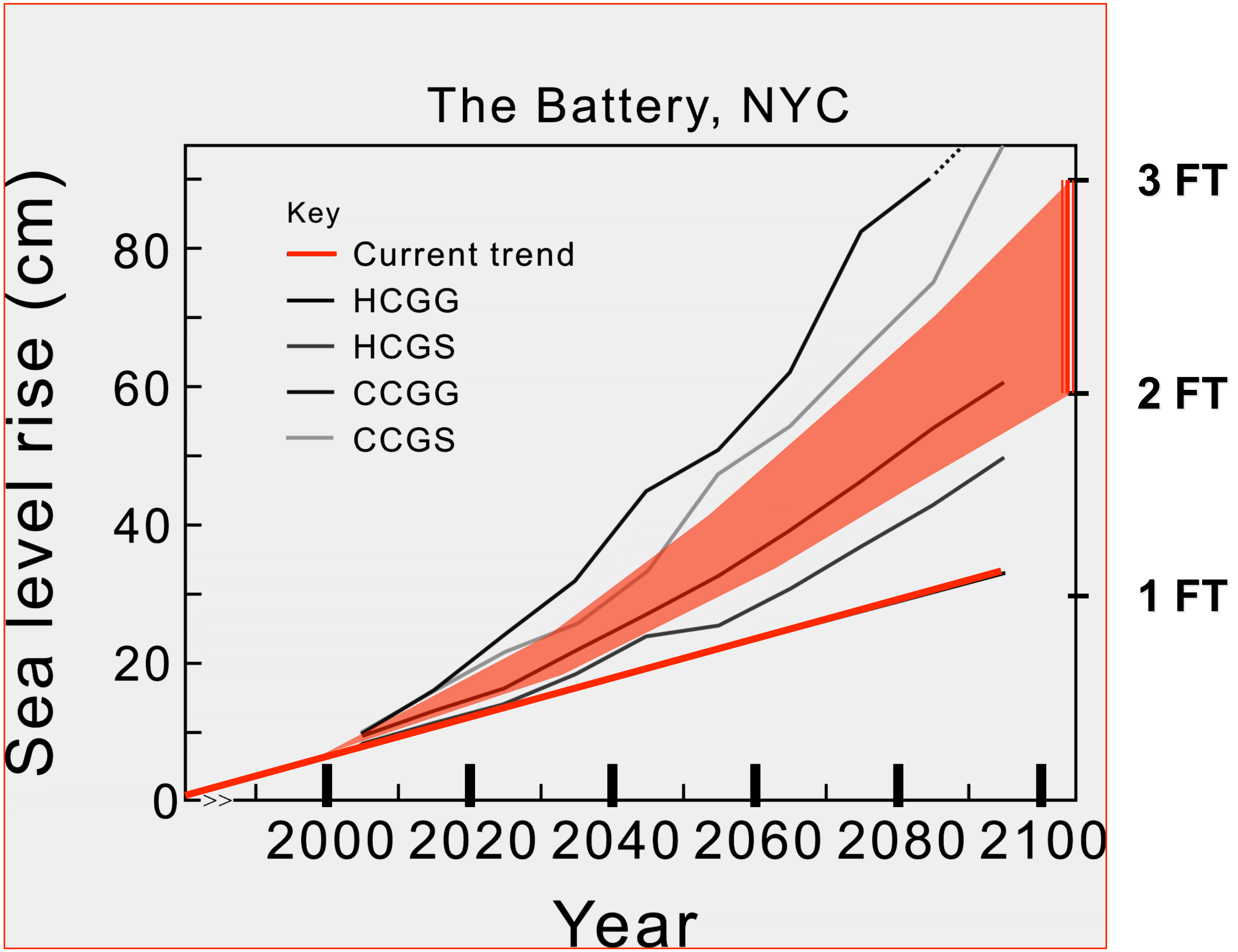
NOAA SLOSH MODEL: Surge Heights Translated into Inundated Areas by Dan O'Brien, NYSEMO

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



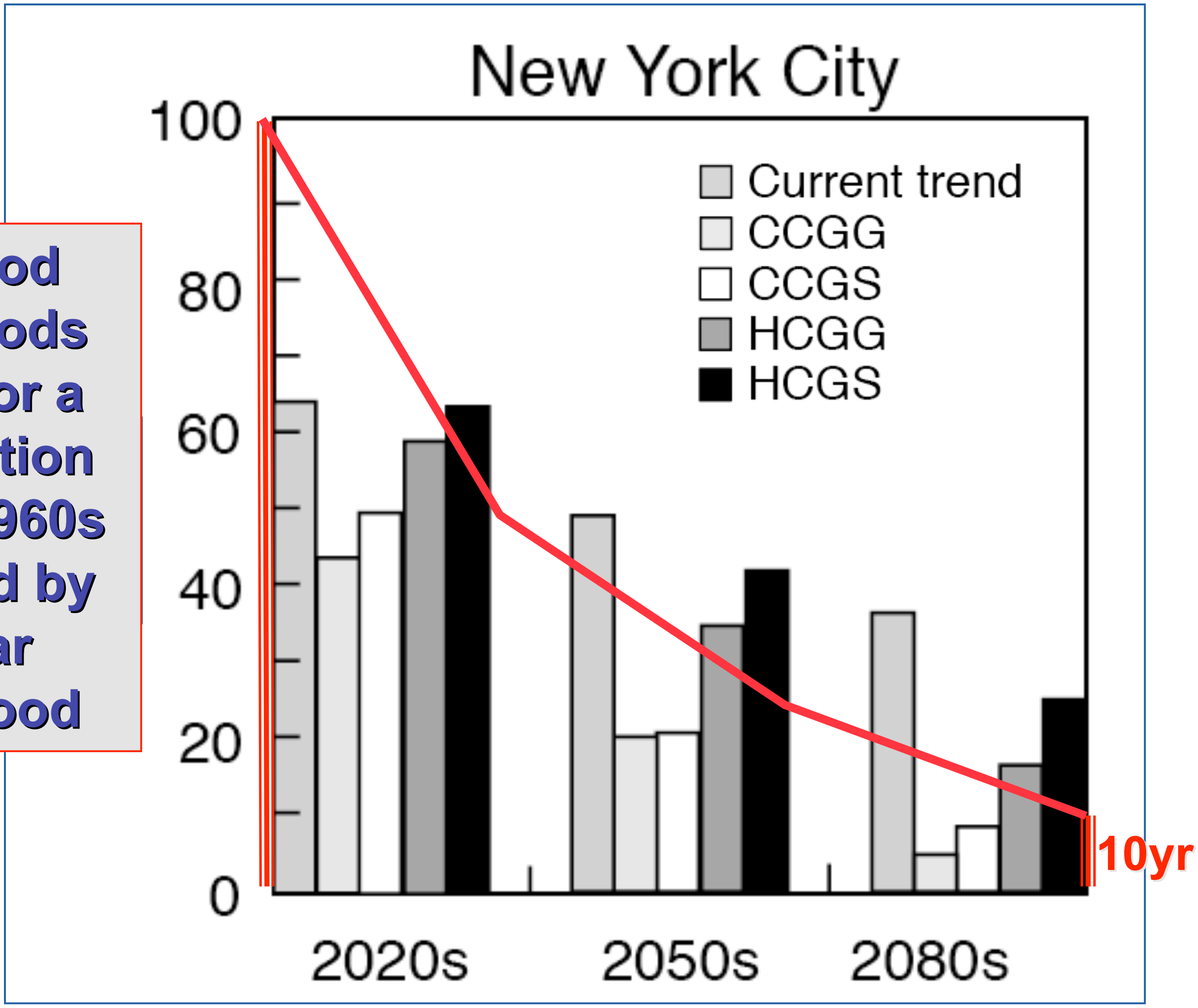
Adopted from: D. O'Brien, NYSEMO

Sea Level Rise Makes a Bad Situation Worse !



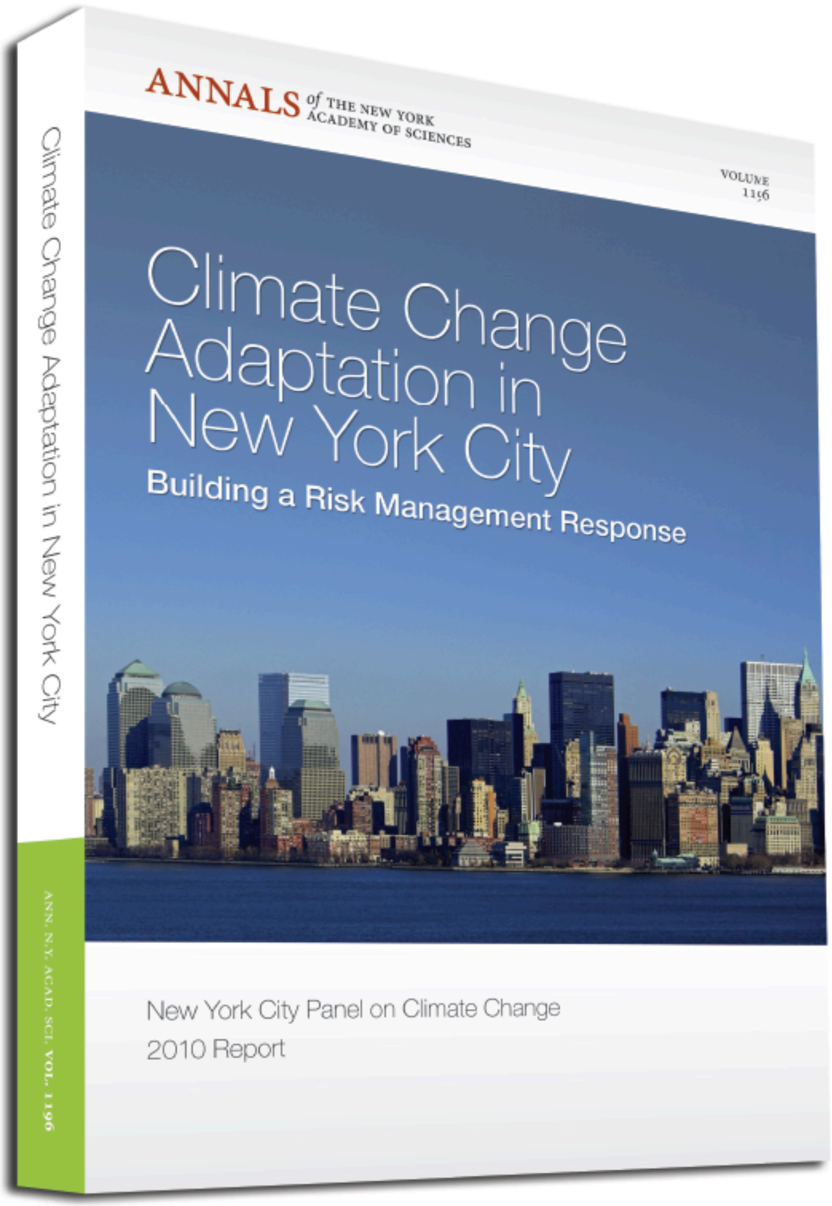
Reduction in Return Period of the 100-Year Flood due to Sea Level Rise Only (Constant Storm Frequency).

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

In 2008 Mayor Bloomberg appointed the NPCC, NYC Panel on Climate Change



published by The New York Academy of Sciences

Annals of the New York Academy of Sciences

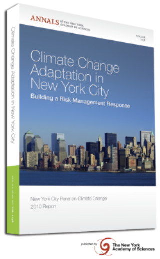
Volume 1196,

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

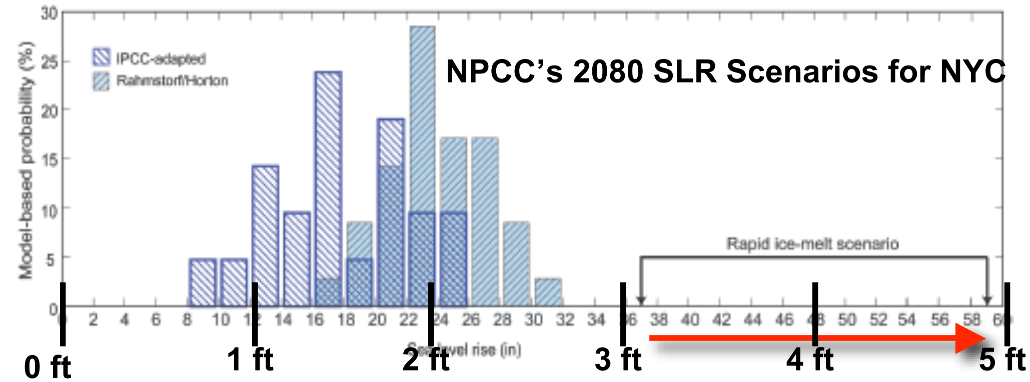
New York City Panel on Climate Change

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]

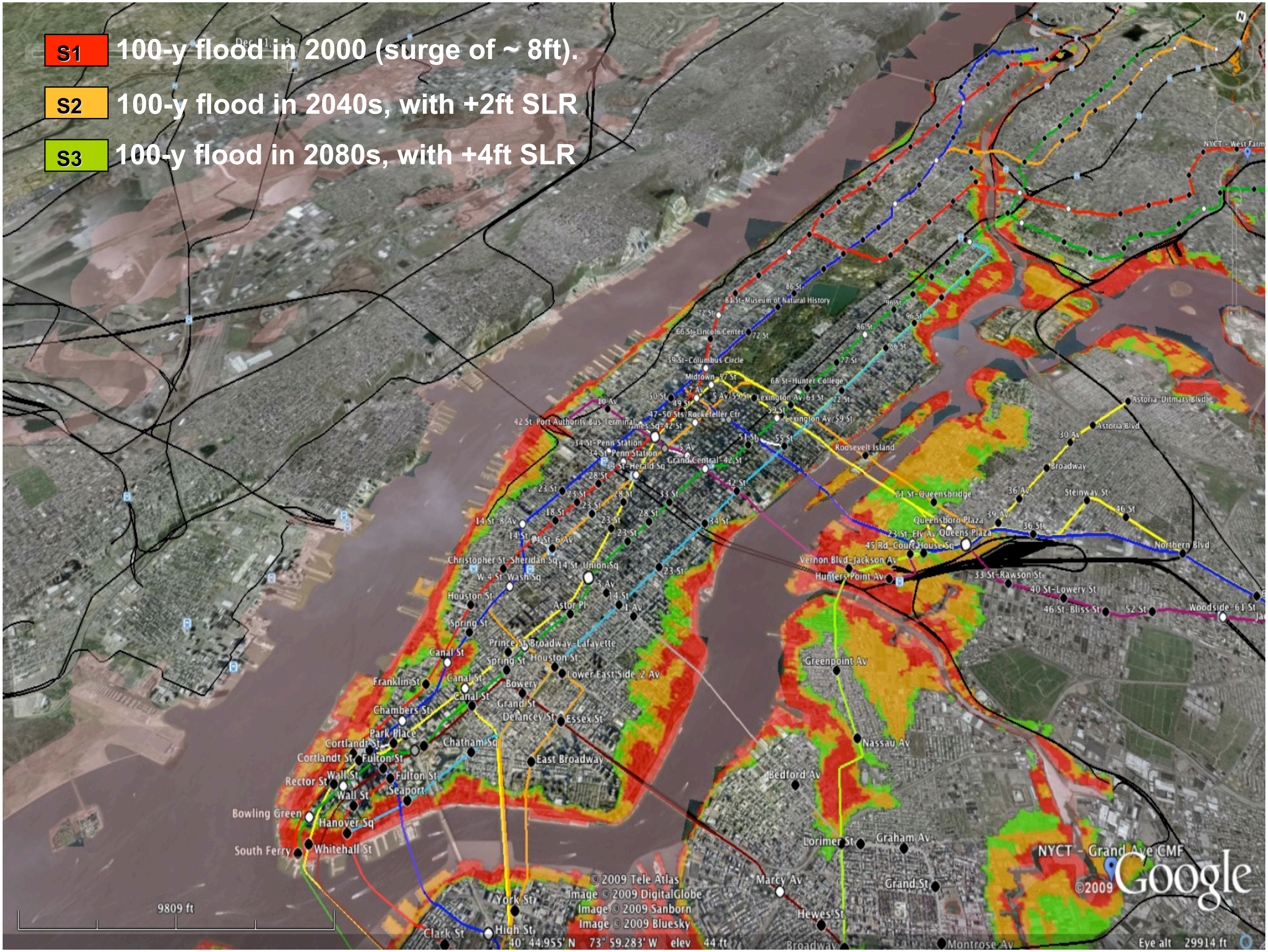
Sources: CCSR, 2008; IPCC, 2007; Horton et al., 2008.

~4 ft **~5 ft**

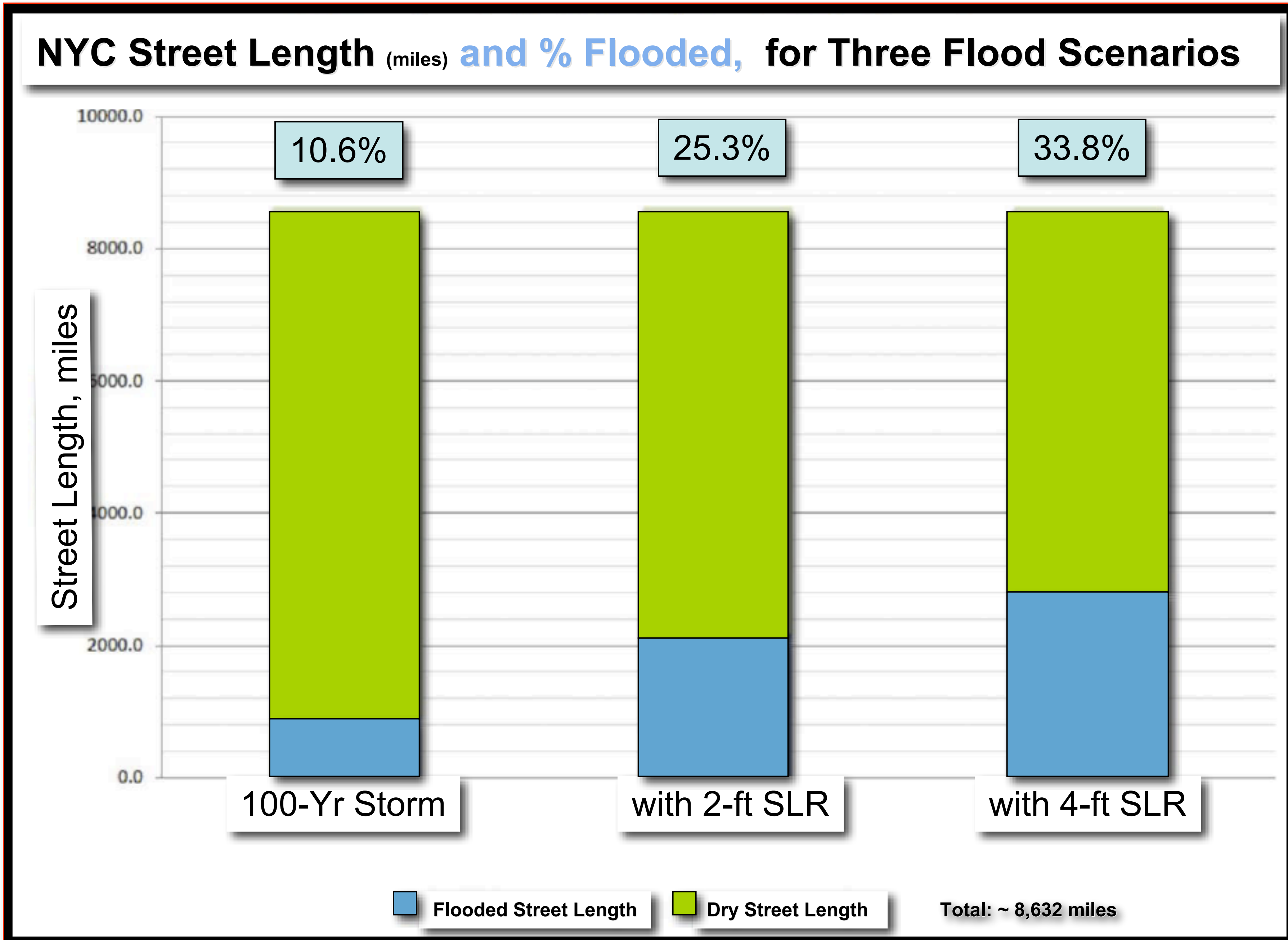
NYSERDA-Sponsored **ClimAID** Project

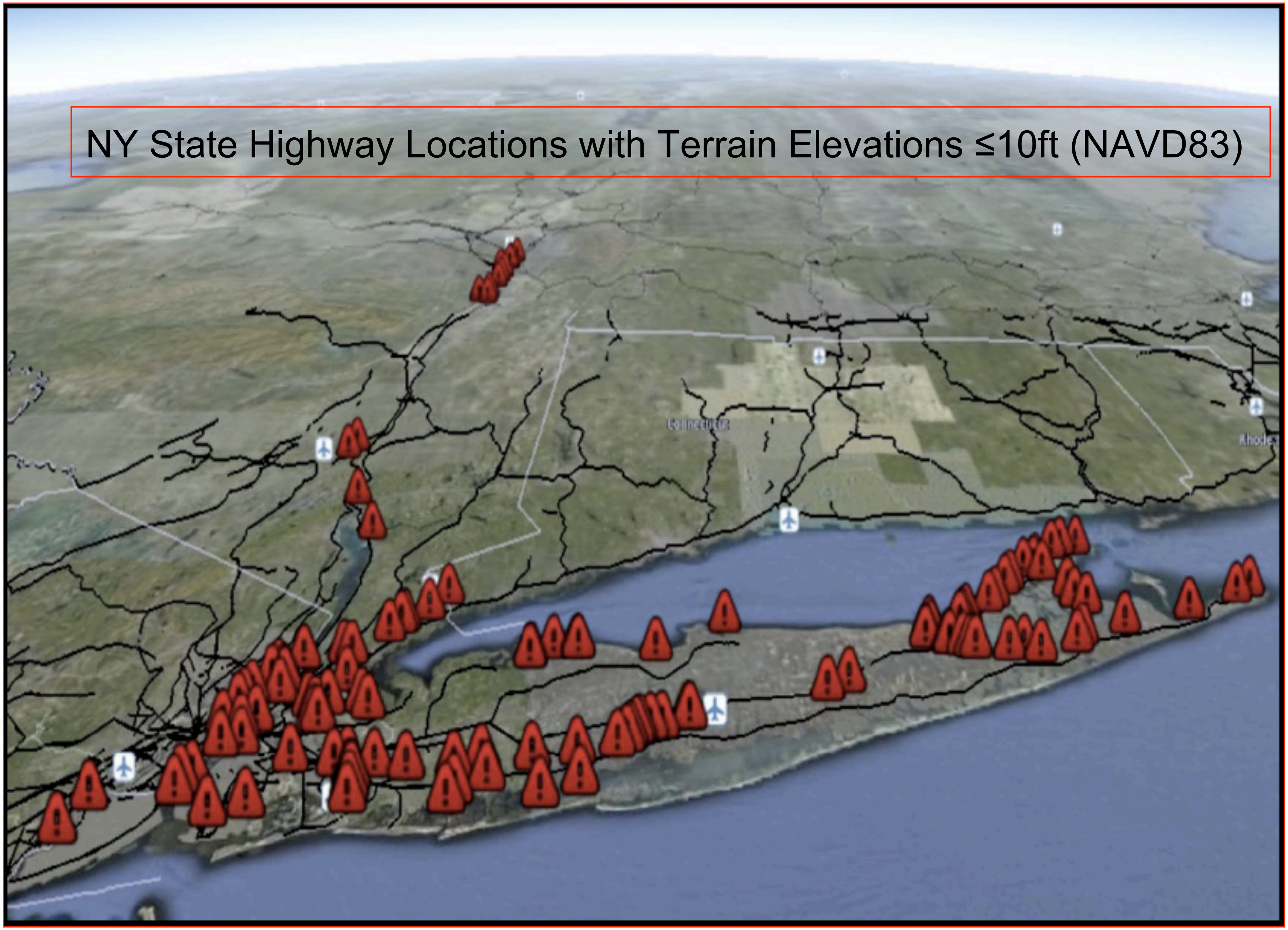
2008-2011

http://www.nyserda.org/programs/environment/emep/clim-aid-synthesis-draft.pdf



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
© 2009 Tele Atlas
Image © 2009 DigitalGlobe
Image © 2009 Sanborn
Image © 2009 Bluesky
©2009 Google

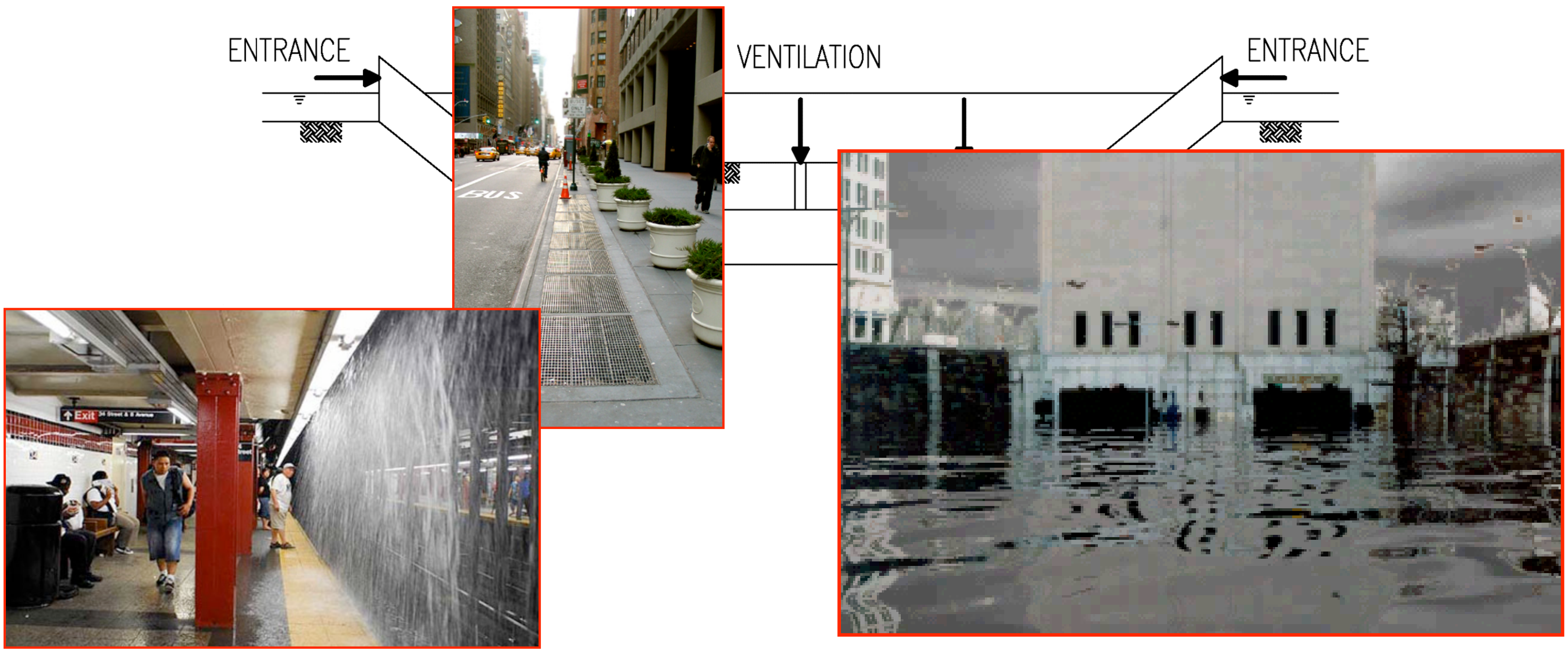

NYC Street Length (miles) and % Flooded, for Three Flood Scenarios
10000.0
8000.0
6000.0
4000.0
2000.0
0.0
Street Length, miles
10.6%
25.3%
33.8%
100-Yr Storm
with 2-ft SLR
with 4-ft SLR
Flooded Street Length
Dry Street Length
Total: ~ 8,632 miles


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

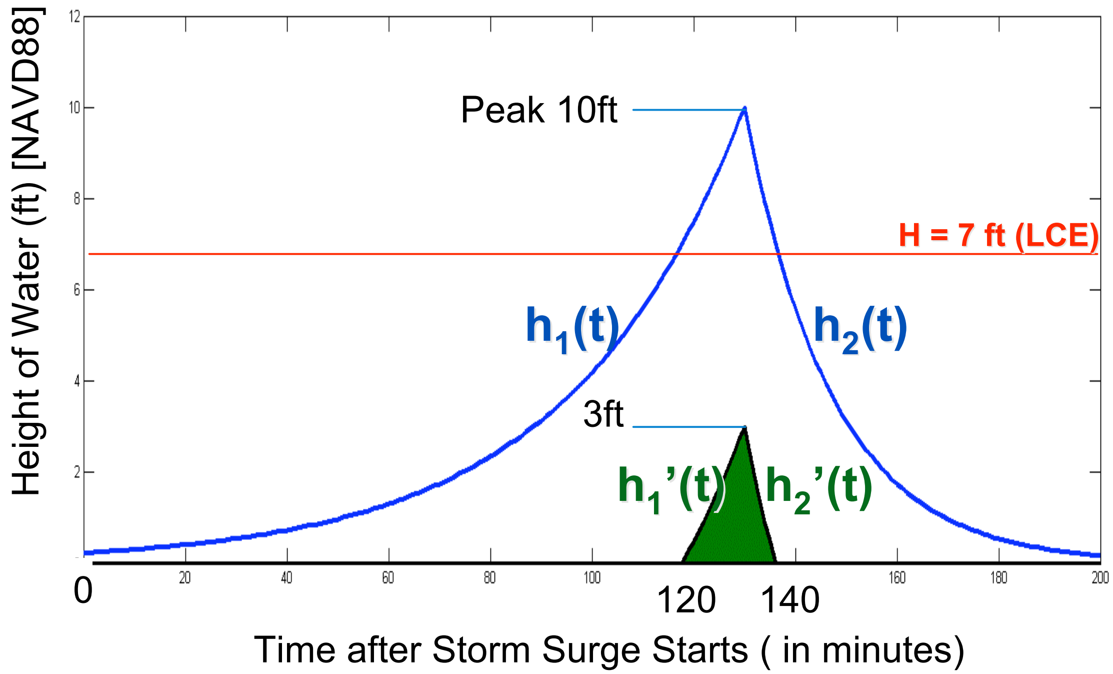
Flood Risks to Subway and Road Tunnels from 100-y Coastal Storm Surge

2 Modes of Water Entry into Tunnels

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



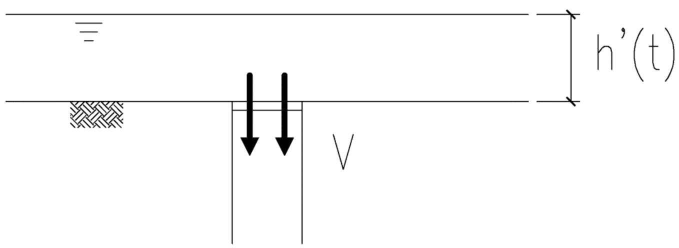
Modified Storm Surge Time-History



H = Lowest Critical Elevation of System (NAVD88)

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

Vertical Flow through subway entrances & ventilation grates



Average Flow Velocity (ft/s)

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

g = gravitational constant

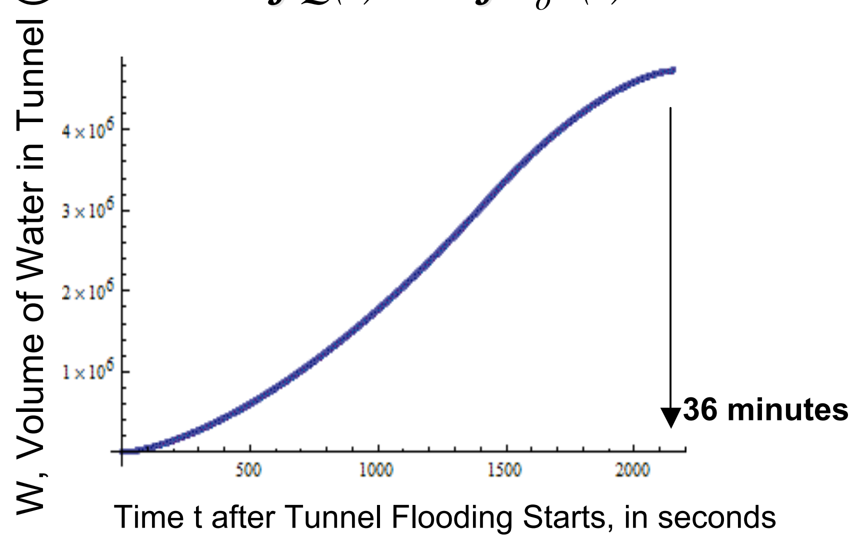
Average Flow Rate (ft³/s)

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

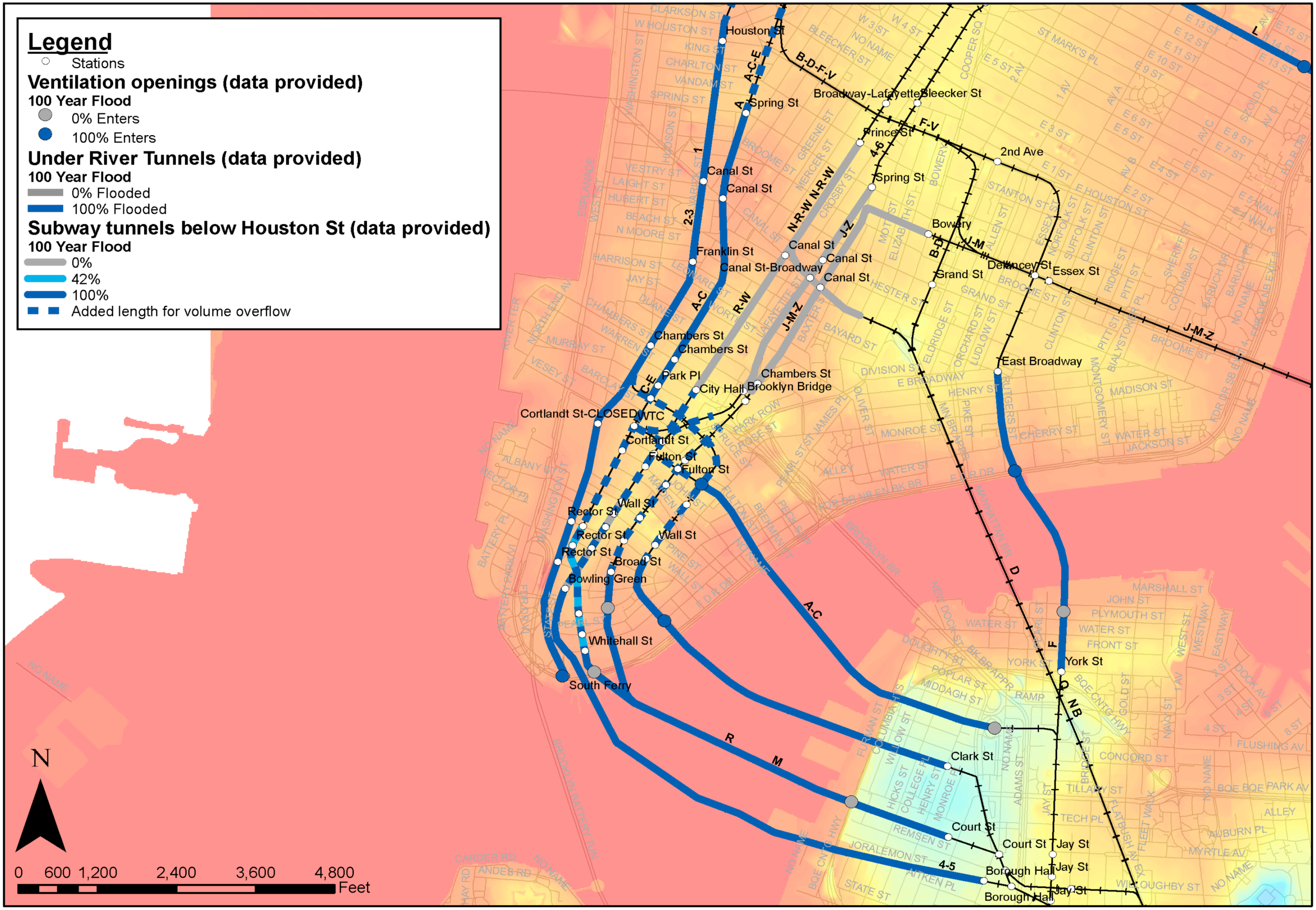
A_o = total area of openings (ft²)

W, Volume of Water Entering Opening Area A_o

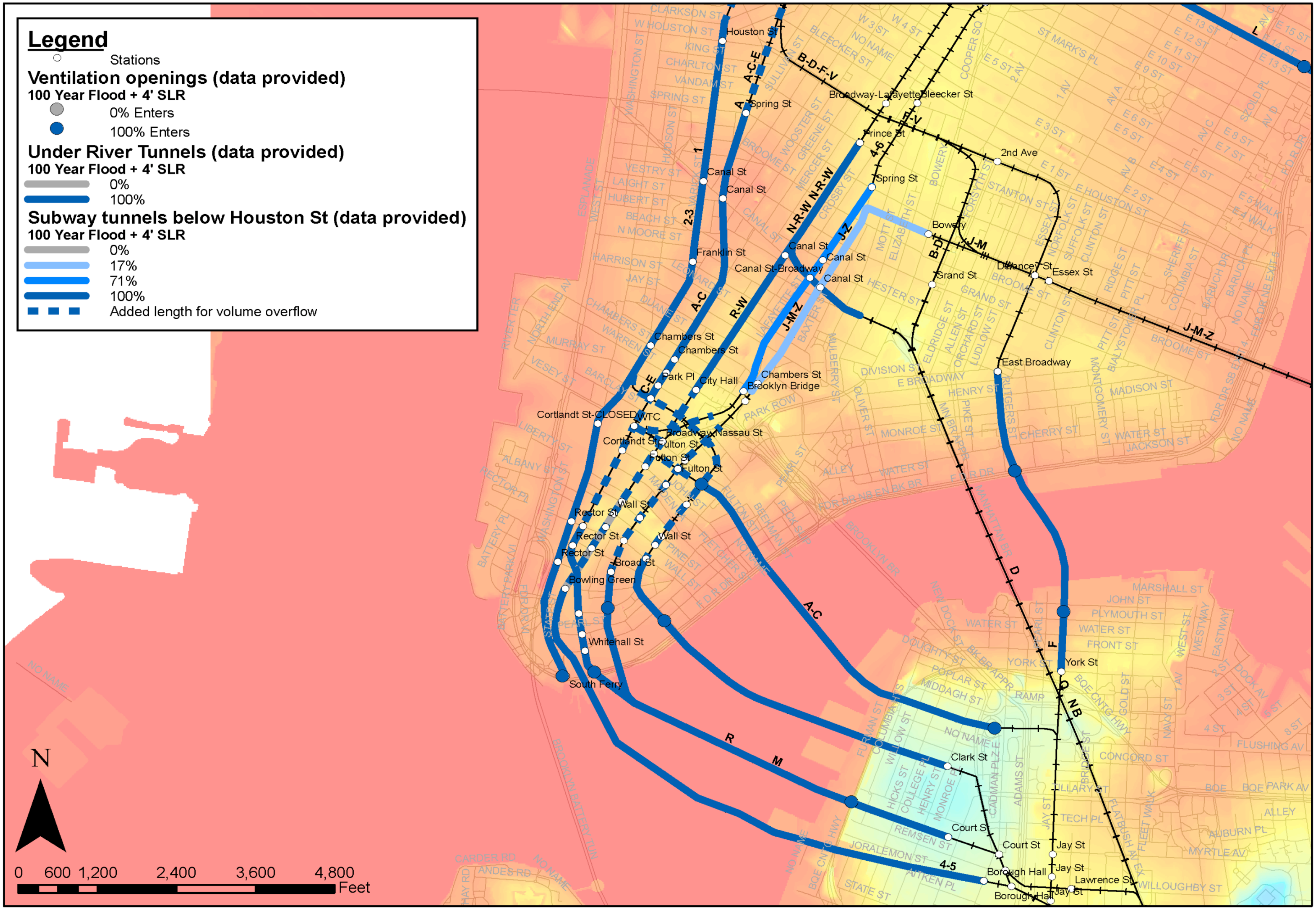
$$W = \int Q(t)\,dt = \int A_o V(t)\,dt$$



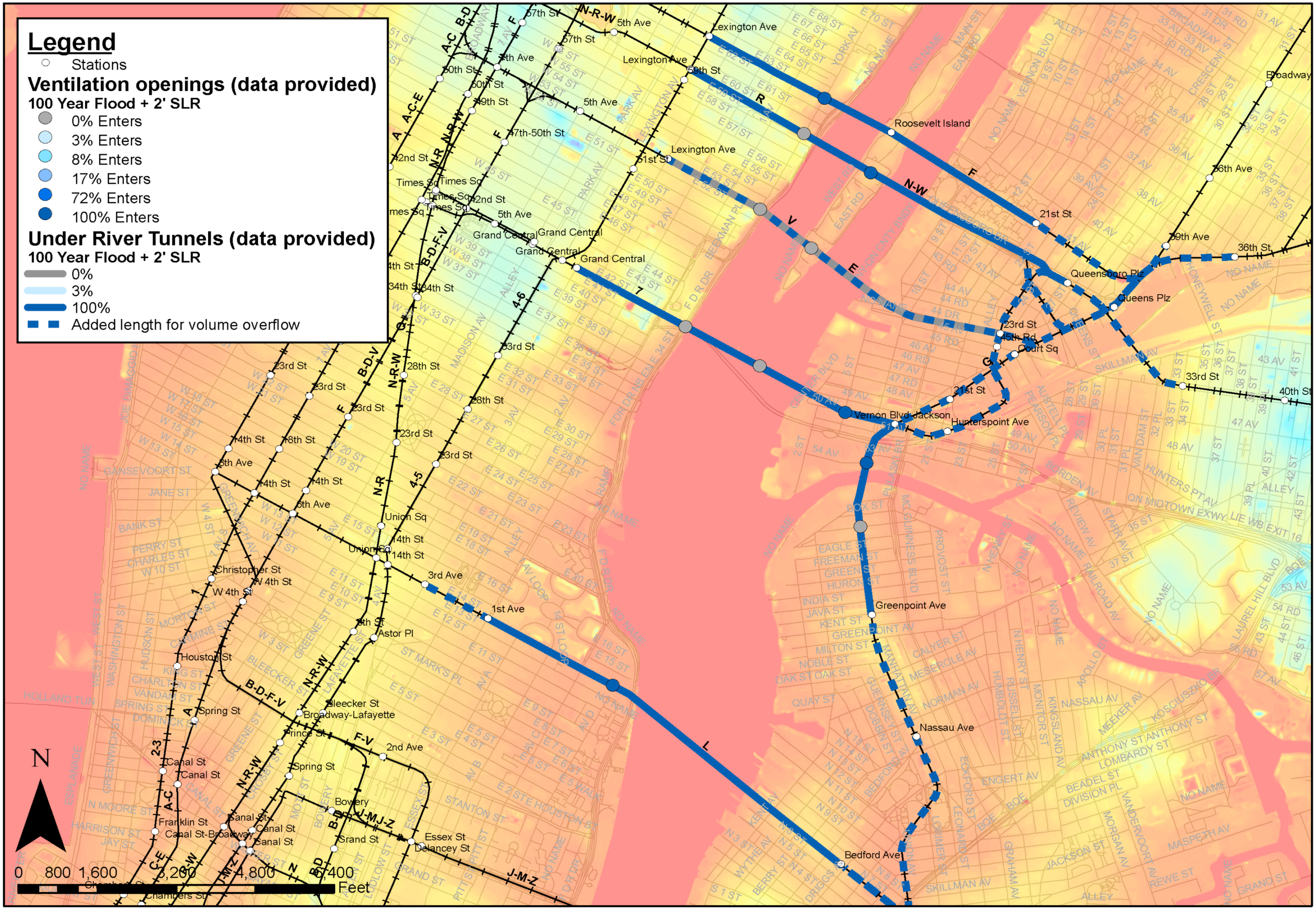
Flooded Subway and Under-River Tunnels, Lower Manhattan, 1% Flood (length overflow)



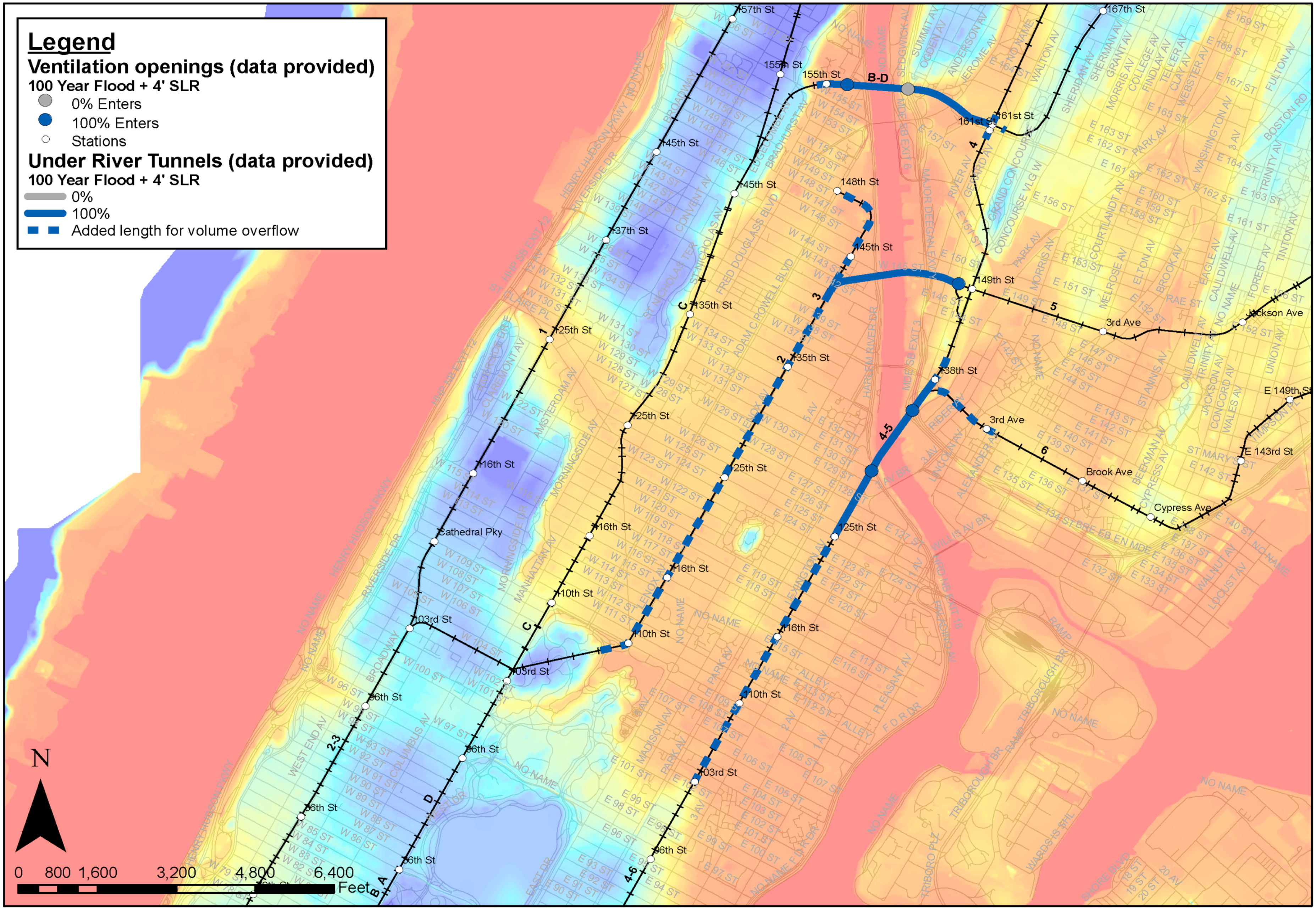
Flooded Subway and Under River Tunnels, Lower Manhattan, 1% Flood + 4' SLR (length overflow)



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



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



- What is the expected **direct 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 transportation outages and extended restoration times ?

Combined (economic + physical-damage) Losses for the New York City Metropolitan region for a 100-year storm surge, for three sea level rise scenarios S1, S2, S3 (for 2010 assets with 2010-dollar valuation); and assuming linear recovery of economy over the minimum outage time of the subway system for (S1) 21 days, (S2) 25 days, and (S3) 29 days, respectively.

Scenario	Economic Losses from Outage ($ billion)	Direct 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-Loss Multiplier for 40 Years:	**1.8**	**2.91**	**3.16**	**3.44**
S3-Loss Multiplier for 80 Years:	**2.6**	**6.39**	**7.50**	**8.83**

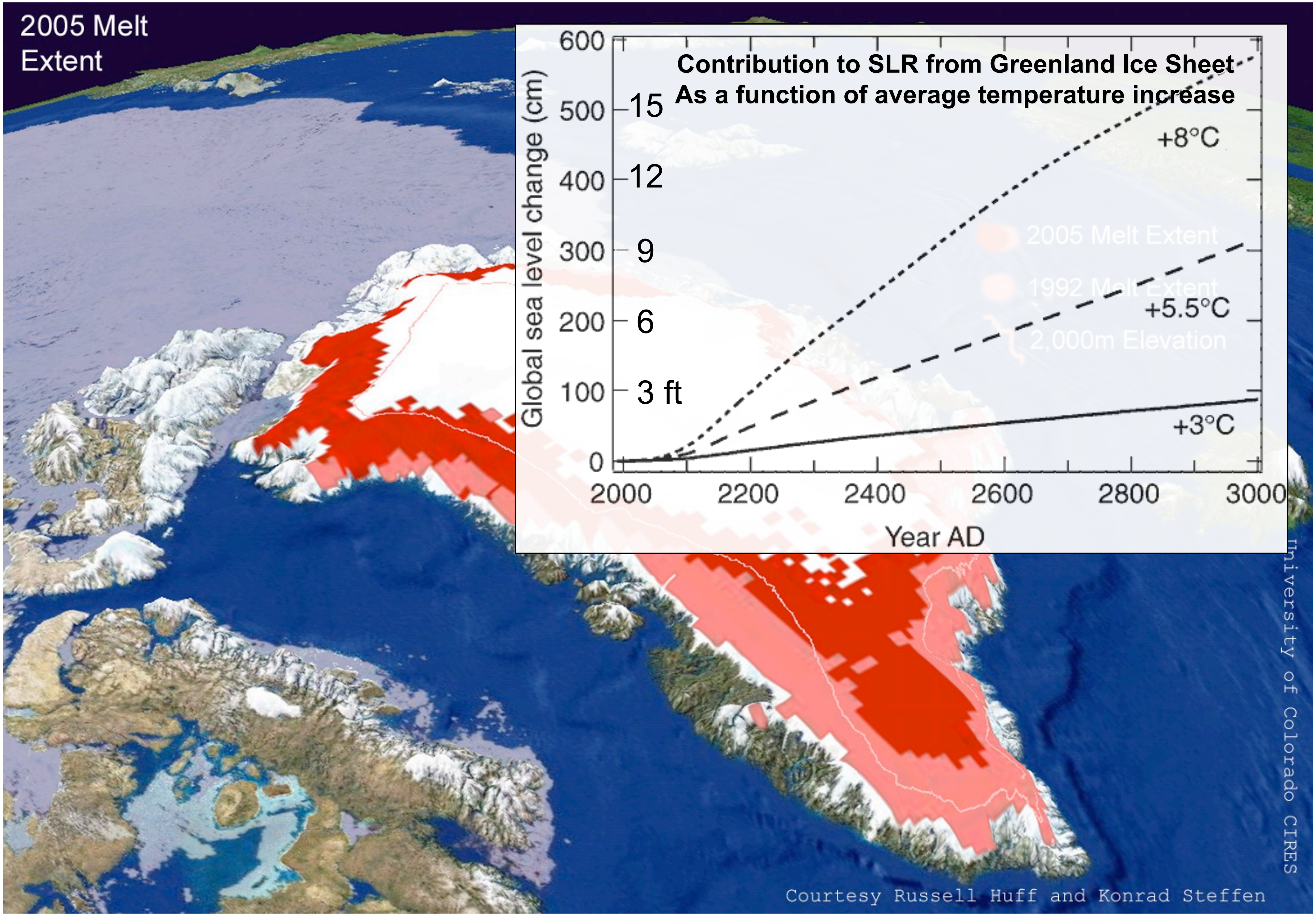
For Transportation, and Specifically the Subway System, what measures should be undertaken to avoid such losses?

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 !

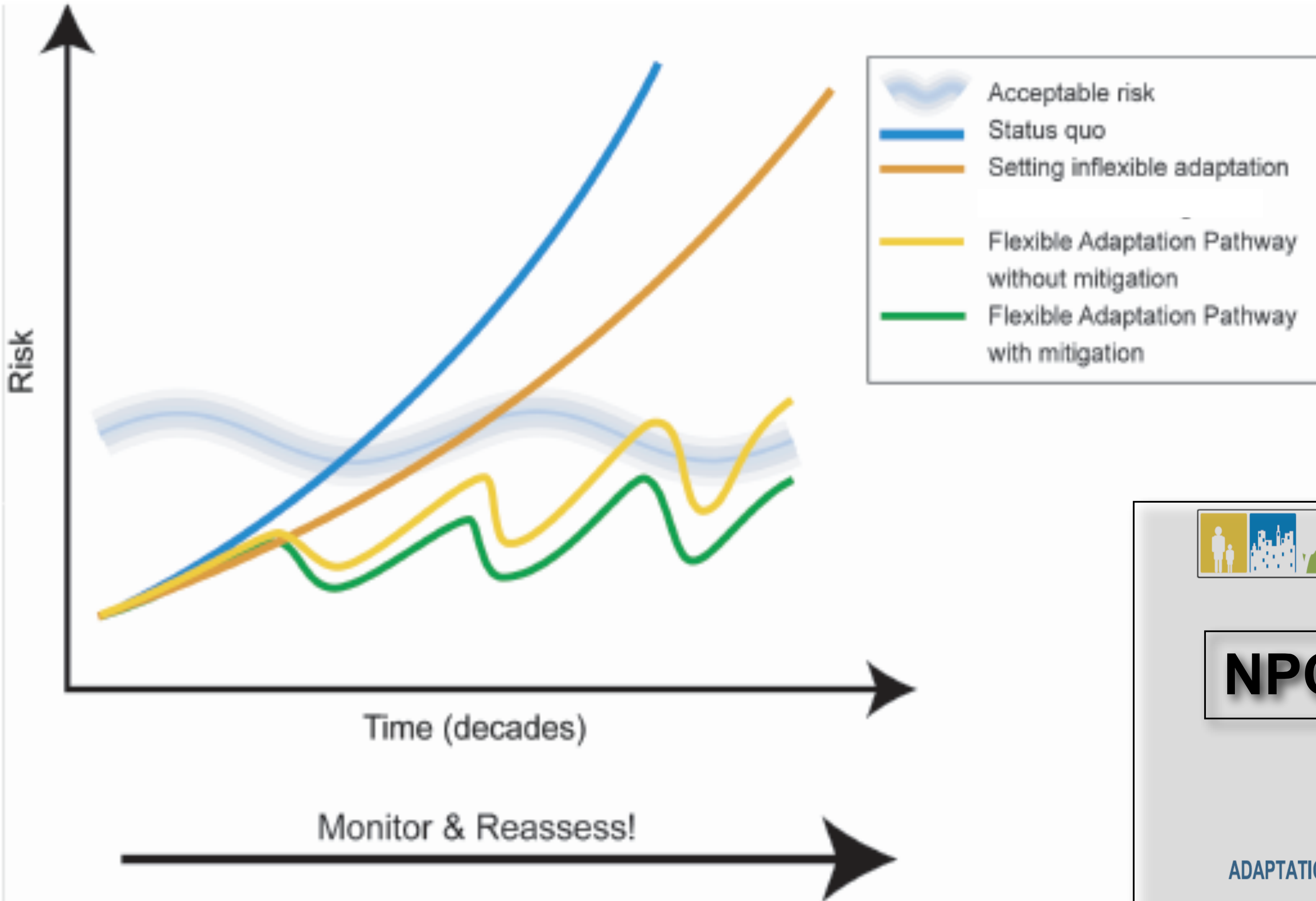
3. What are the Costs? Needs engineering studies, but costs are likely to be at least 25% of the expected avoided losses: **i.e. in excess of $ 15 to 20 Billion ?**

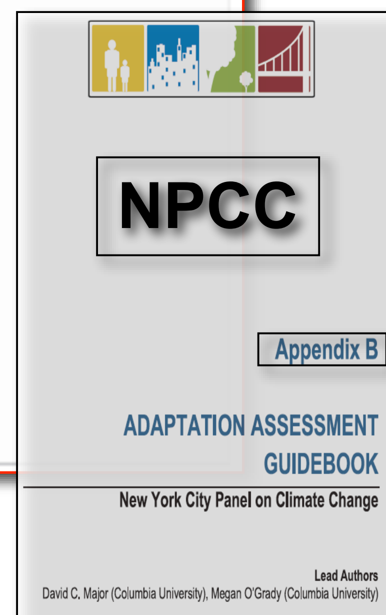
Structural "Solution": 3 or 4 Barriers. Probably Unsustainable. Why?



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
2005 Melt Extent
1992 Melt Extent
2,000m Elevation
2000
2200
2400
2600
2800
3000
Year AD
University of Colorado CIRES
Courtesy Russell Huff and Konrad Steffen

FIGURE 2. Flexible Adaptation Pathways




NPCC

Appendix B

ADAPTATION ASSESSMENT GUIDEBOOK

New York City Panel on Climate Change

Lead Authors

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

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

The good Message is

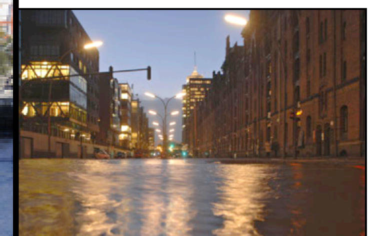
(from MMC Study, see below):

For every $1 invested in Disaster Loss Mitigation & Prevention there is, on Average, a Return of ~$4 Saved in NOT Incurred Losses.

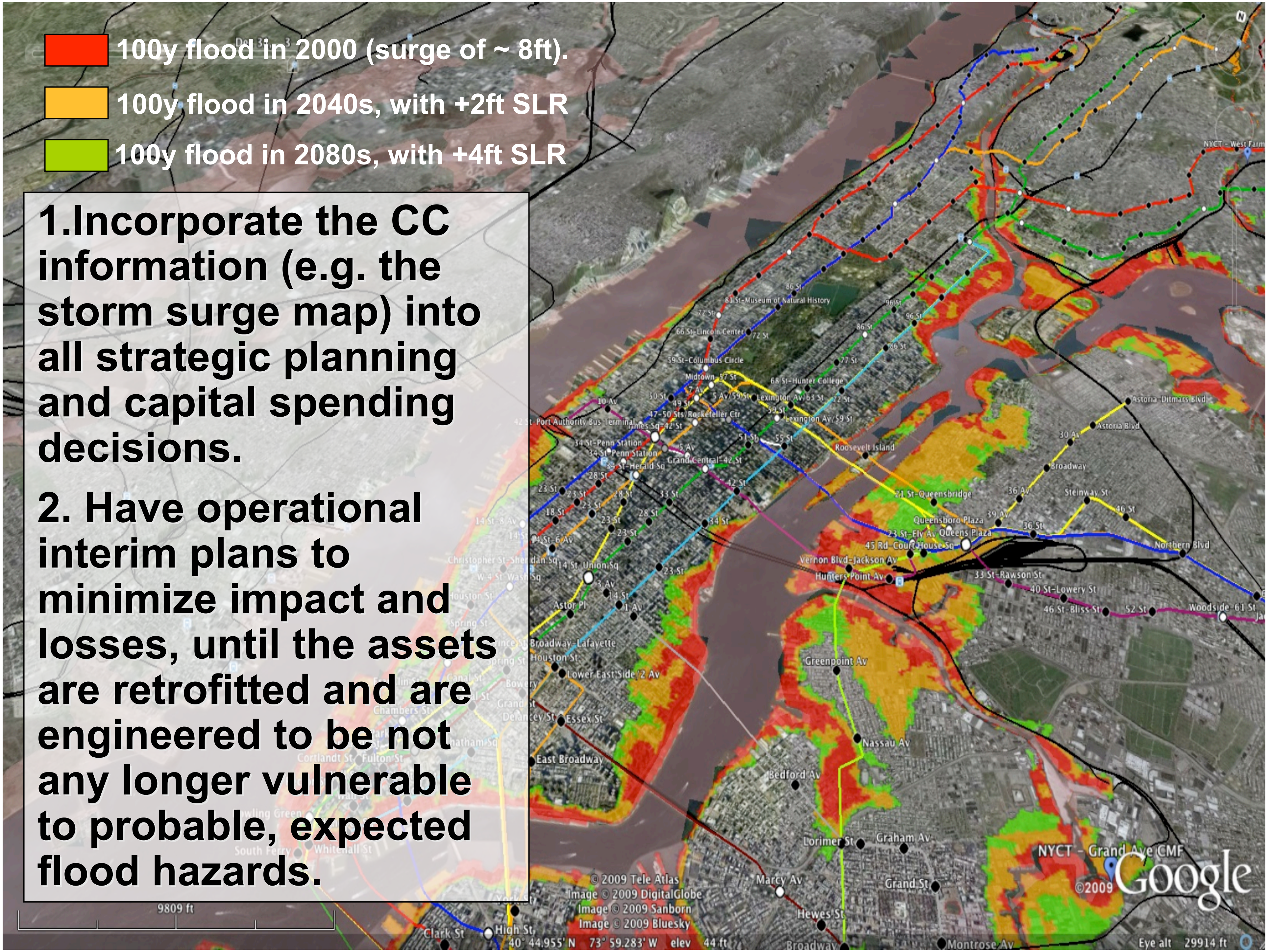
National Institute of Building Science
Multi-hazard Mitigation Council
(NIBS/MMC) Study "Mitigation Saves":

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



1. Incorporate the CC information (e.g. the 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 probable, expected flood hazards.


Oh, crap! Was that TODAY?
REGAN

Conclusions (Repeat from Lecture 4):

1. Hazard Assessments for Critical Structures must strive for the Longest Possible Records to catch Low-Probability / High-Consequence Events (that make up the "Tails" of Probability Distributions).
2. Systematic Monitoring of New Geo-Science Findings that can be Relevant to Updating Disaster Hazards and Risks Is an Essential Government Function
3. Decision Makers and Regulators need to have Protocols in Place, and Prudently Exercise them, to Incorporate these New Findings in a Timely, Socially Responsible, and Effective Way


Thank You !
FRAUNCES
TAVERN