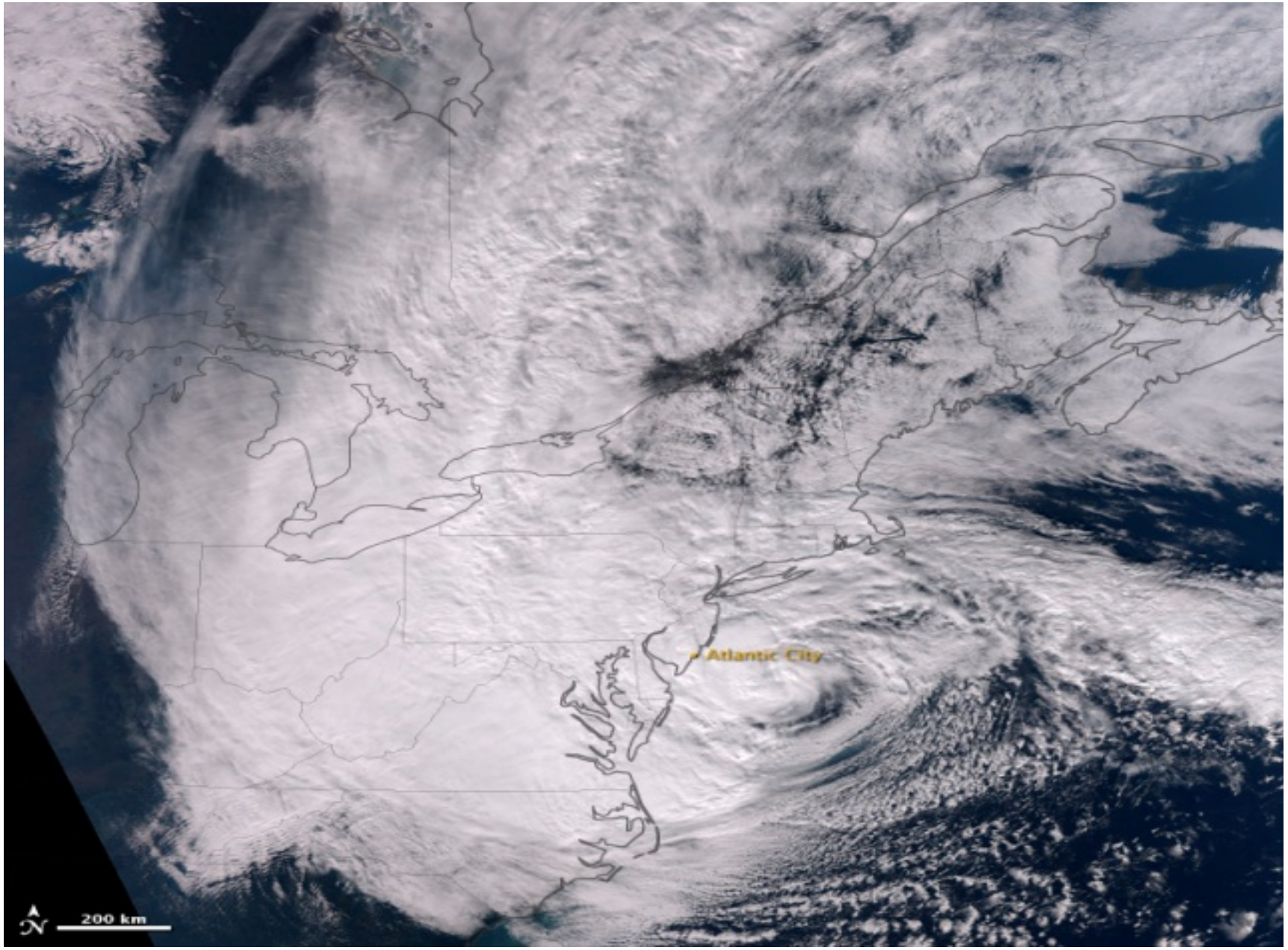
Integrated Climate Change Impacts Assessment: Lessons Learned from Hurricane Sandy (and Hurricane Irene)

William Solecki, CUNY – Hunter College

EMF Summer Workshop

Snowmass, CO 22 July – 2 August

Hurricane Sandy, 28 October 2012

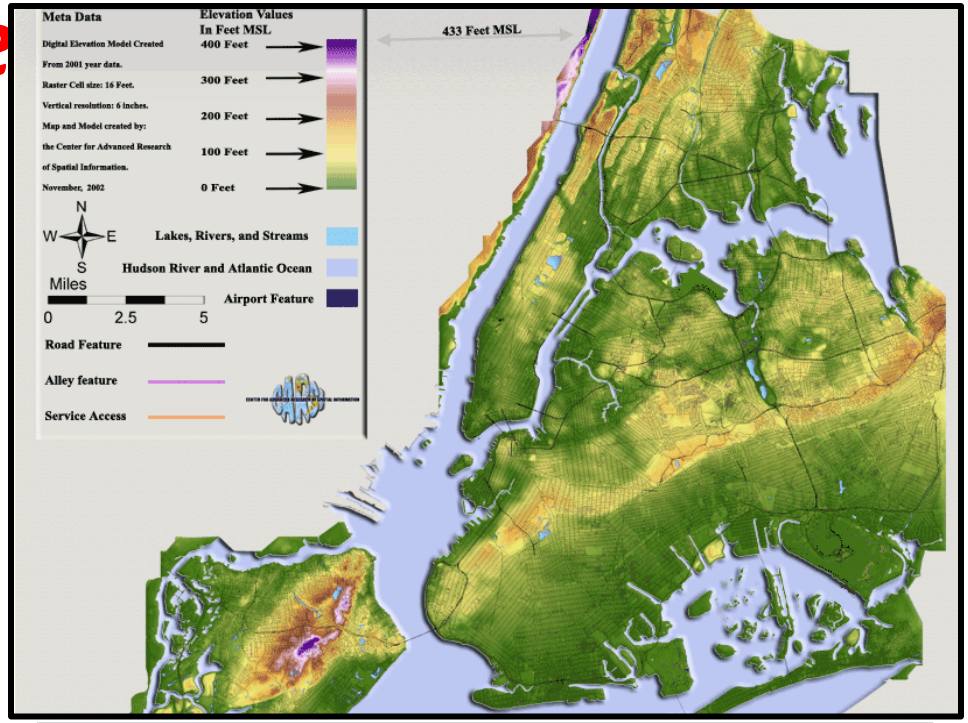


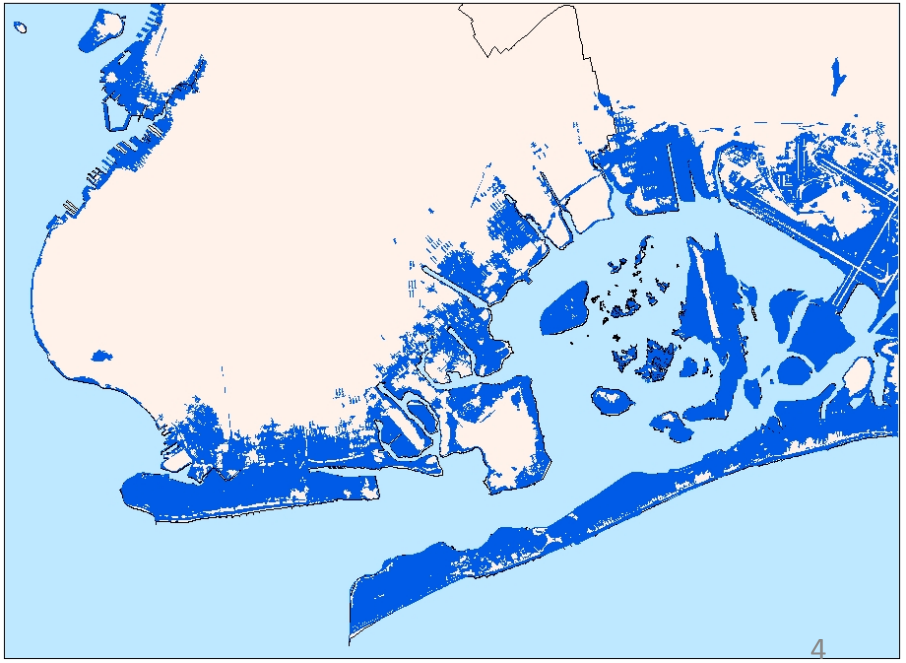
Source: NOAA

Source: PlaNYC 2013

What Does Hurricane Sandy Mean?

- New York City is prone to losses from weather-related disasters.
  - Top 10 in population vulnerable to coastal flooding
  - Second only to Miami in assets exposed to coastal flooding
- What did it reveal about exposure and vulnerability?; What does it mean about disaster risk reduction and climate change adaptation?; Will it signal a change in policy?





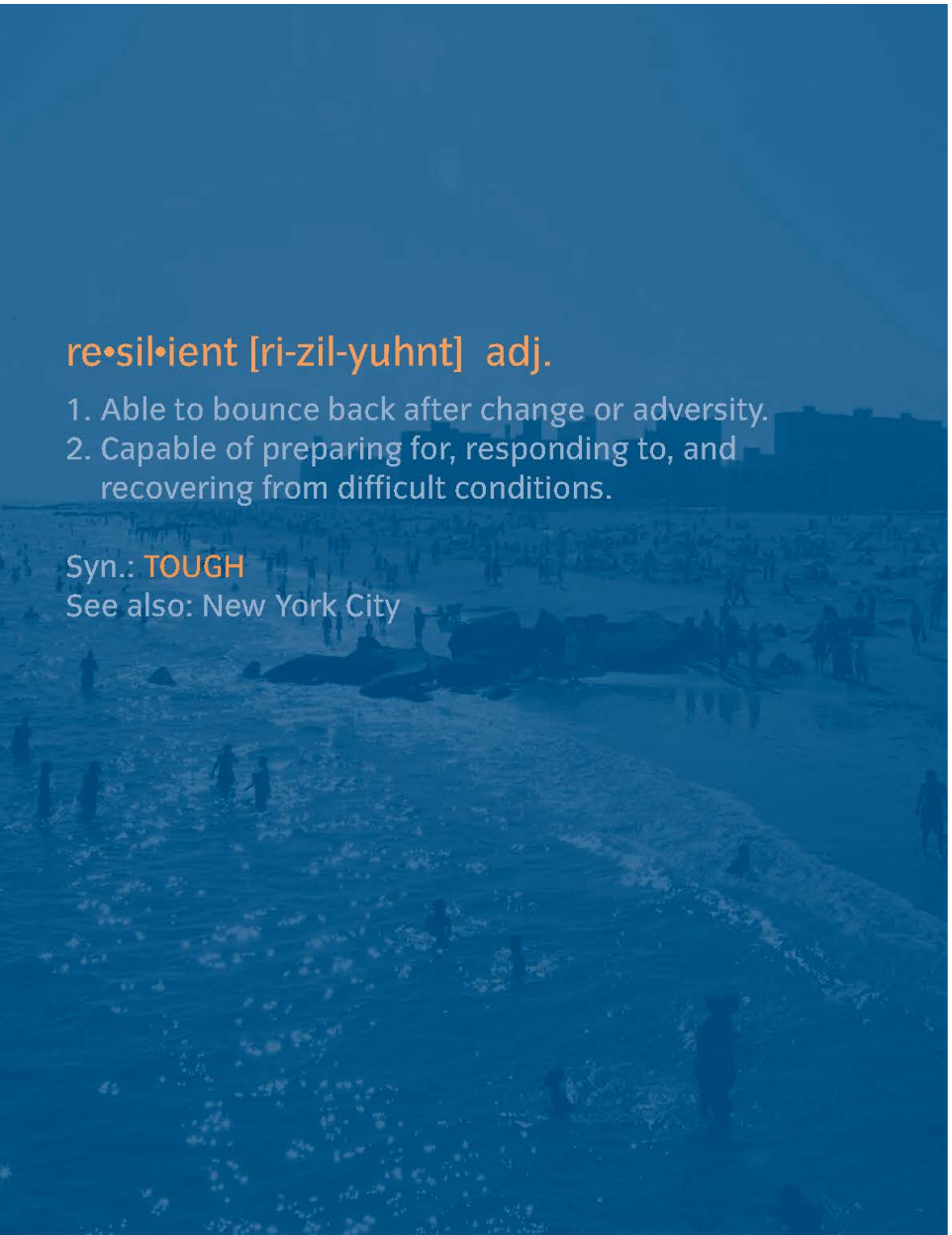
Observed Inundation – Hurricane Sandy

Disaster Response and How Might Hurricane Sandy Points to Wider Transitions and Transformations

- *After a disaster, response typically* is focused on addressing failures and cost-benefit calculations in the context of future risk probability
- Hurricane Sandy response also is often discussed in the context of climate change
- Movement from disaster recovery to disaster rebuilding and resilience
- Change in conceptualization of extreme events
  - From discrete acute events to events as part of a chronic process
  - Looking into future dynamics as much as the present and past
- The question is being asked whether climate change impacts will be like other urban environment-related crises

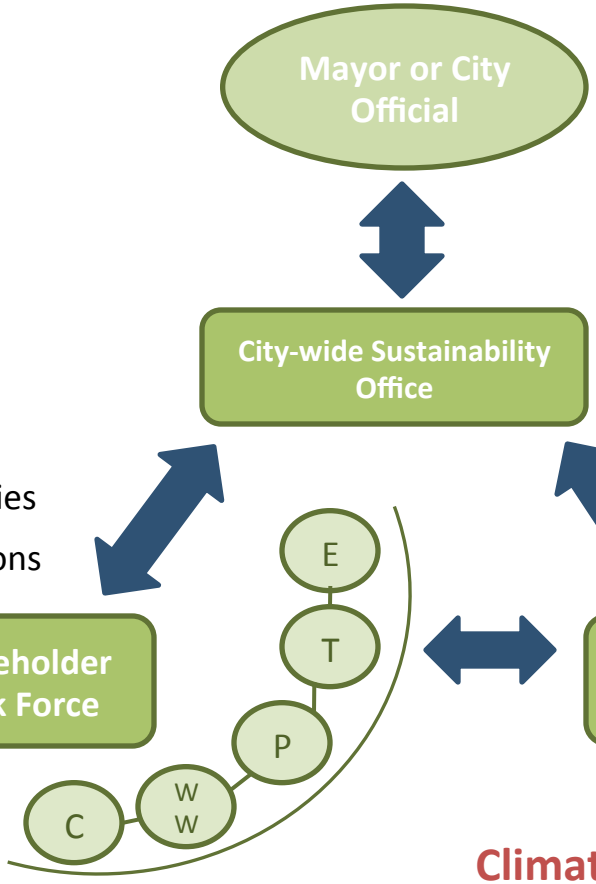
PlaNYC 2013 – Released 11 June 2013

Preface of PlaNYC 2013



This report is dedicated to the 43 New Yorkers who lost their lives during Sandy, and to the loved ones they left behind. It is also offered in recognition of those whose homes, businesses, and communities were damaged during the storm and who are working to rebuild. The City stands in solidarity with all of them as it makes plans to strengthen New York so that future climate events do not have the same devastating effects.

New York City Climate Adaptation Process



High-Level Buy-In

Coordinating Role

Critical Infrastructure

Stakeholders

- City Agencies
- Regional Authorities
- Private Corporations

Expert Knowledge Providers

- University scholars and private sector experts
- Social, biological, and physical scientists
- Legal and insurance experts
- Risk management professionals

Integration across Sector-specific Working Groups

- Energy (E)
- Transportation (T)
- Policy (P)
- Water & Waste (WW)
- Communications (C)

Climate Risk Information

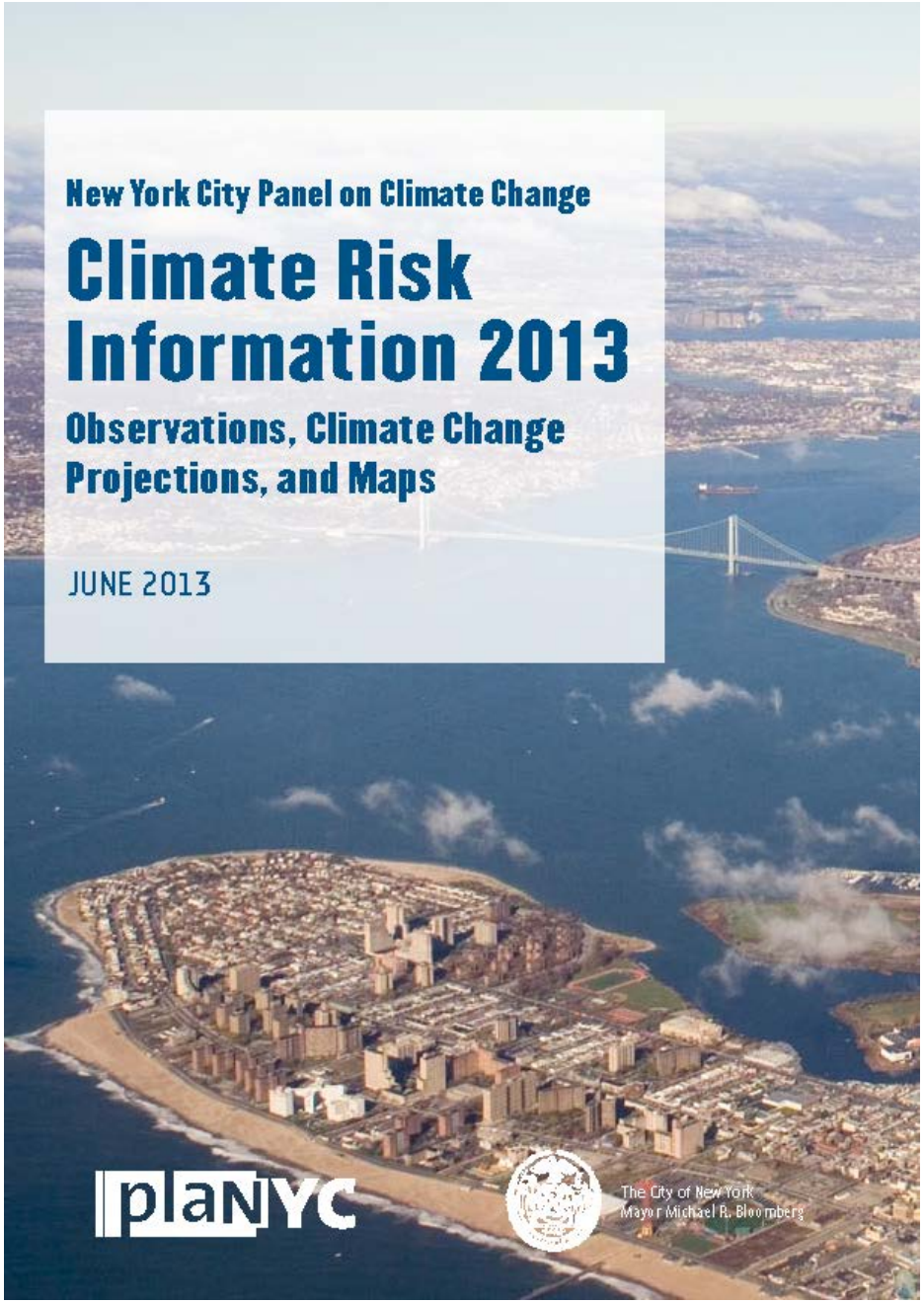
Adaptation Assessment Guidelines

Climate Protection Levels

Source: NPCC, 2010

NYC Special Initiative for Rebuilding and Resiliency

- Addresses how to rebuild New York City to be more resilient in the wake of Sandy but with a long-term focus on:
  - 1) how to rebuild locally; and
  - 2) how to improve citywide infrastructure and building resilience
- A comprehensive report in June 2013 addresses these challenges by investigating three key questions:
  - What happened during and after Sandy and why?
  - What is the likely risk to NYC as the climate changes and the threat of future storms and severe weather increases?
  - What to do in the coastal neighborhoods and citywide infrastructure

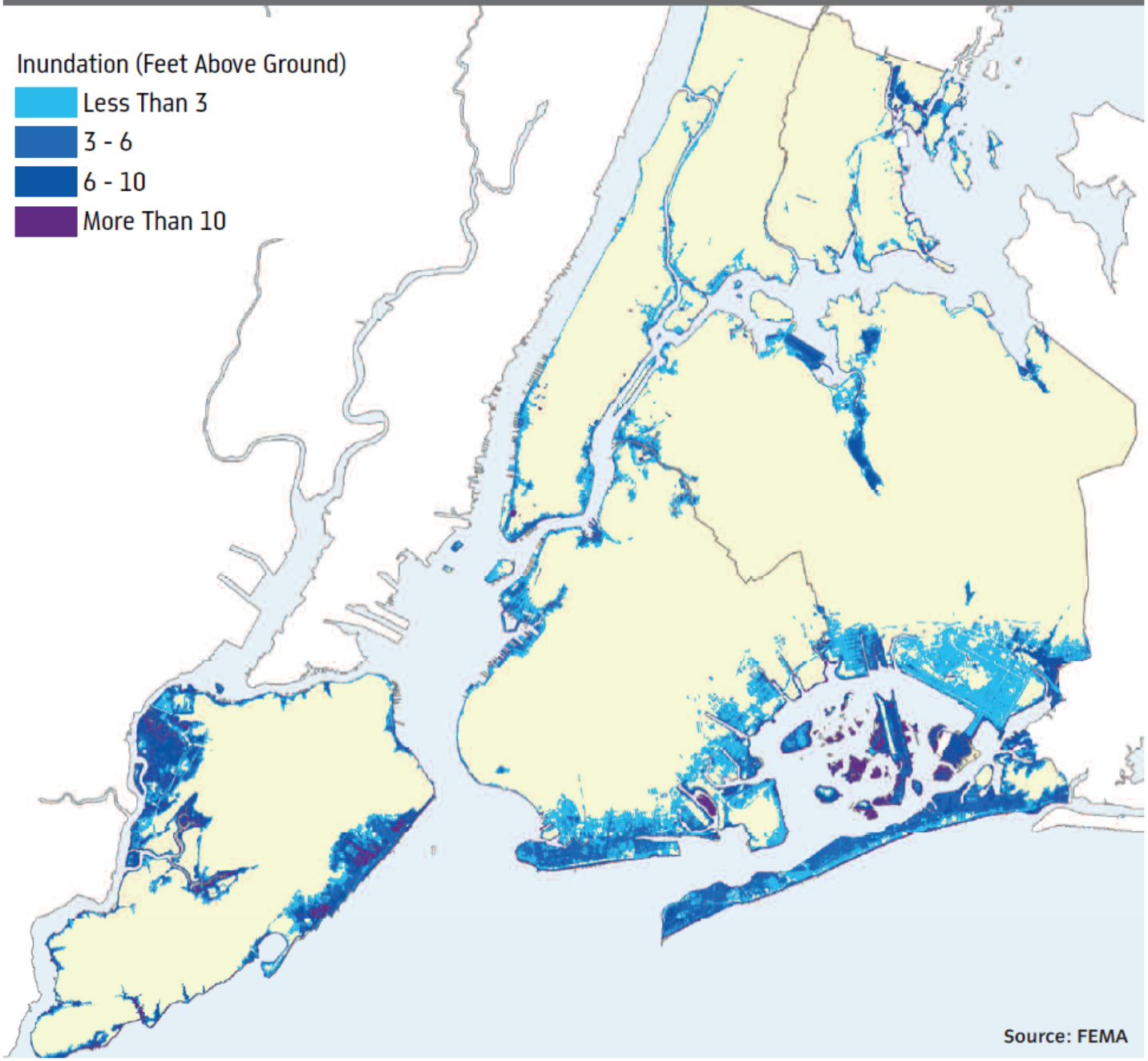


Released 11 June 2013;
available at CUNY Institute for Sustainable Cities (CISC) website – www.cunysustainablecities.org

Provides the updated climate science information and foundation for PlaNYC 2013

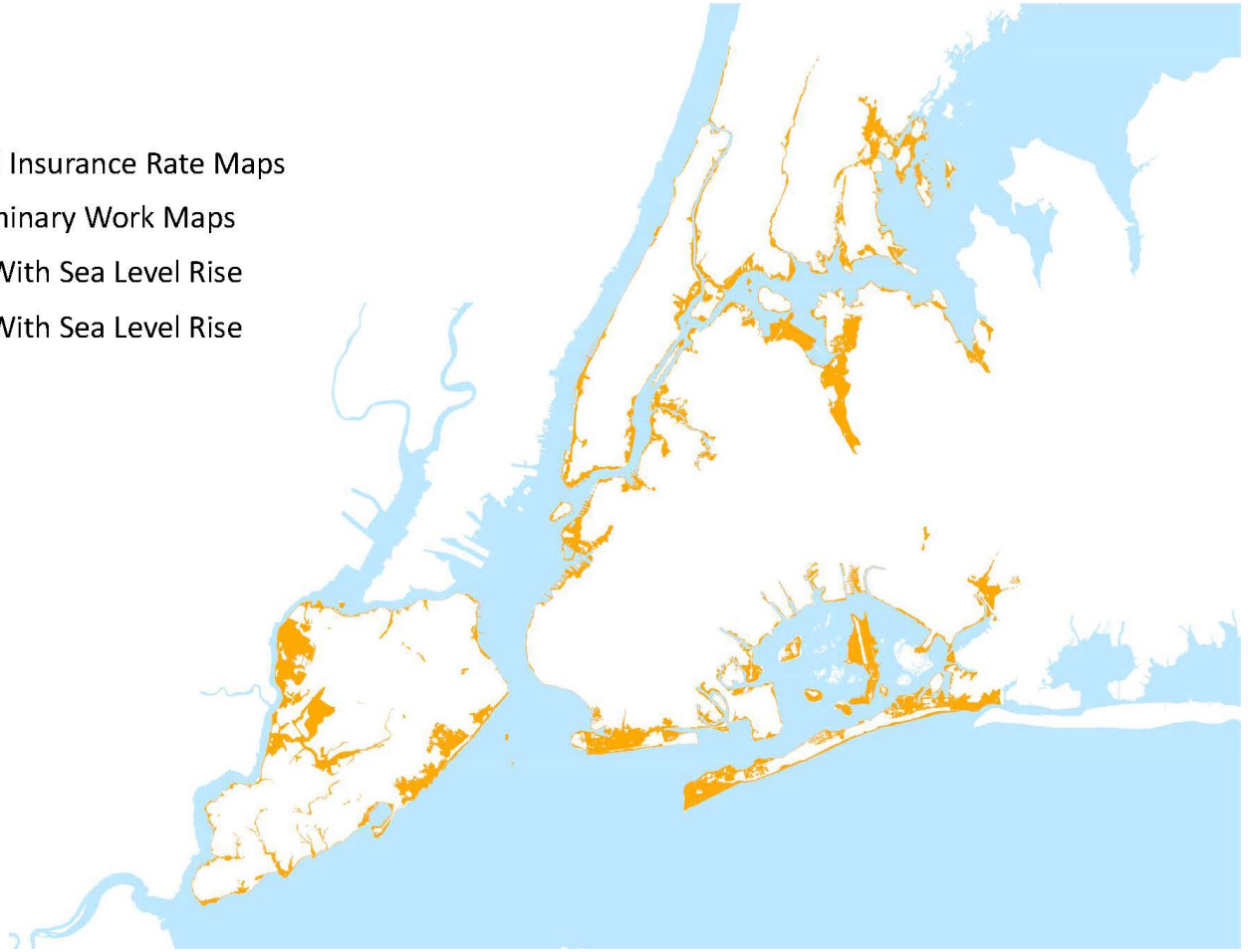
Storm Surge – Now and Future

Sandy Inundation



100-Year Flood Plains

- **1983** – FEMA Flood Insurance Rate Maps
- **2013** – FEMA Preliminary Work Maps
- **2020s** – Projected With Sea Level Rise
- **2050s** – Projected With Sea Level Rise



Source: PlaNYC 2013

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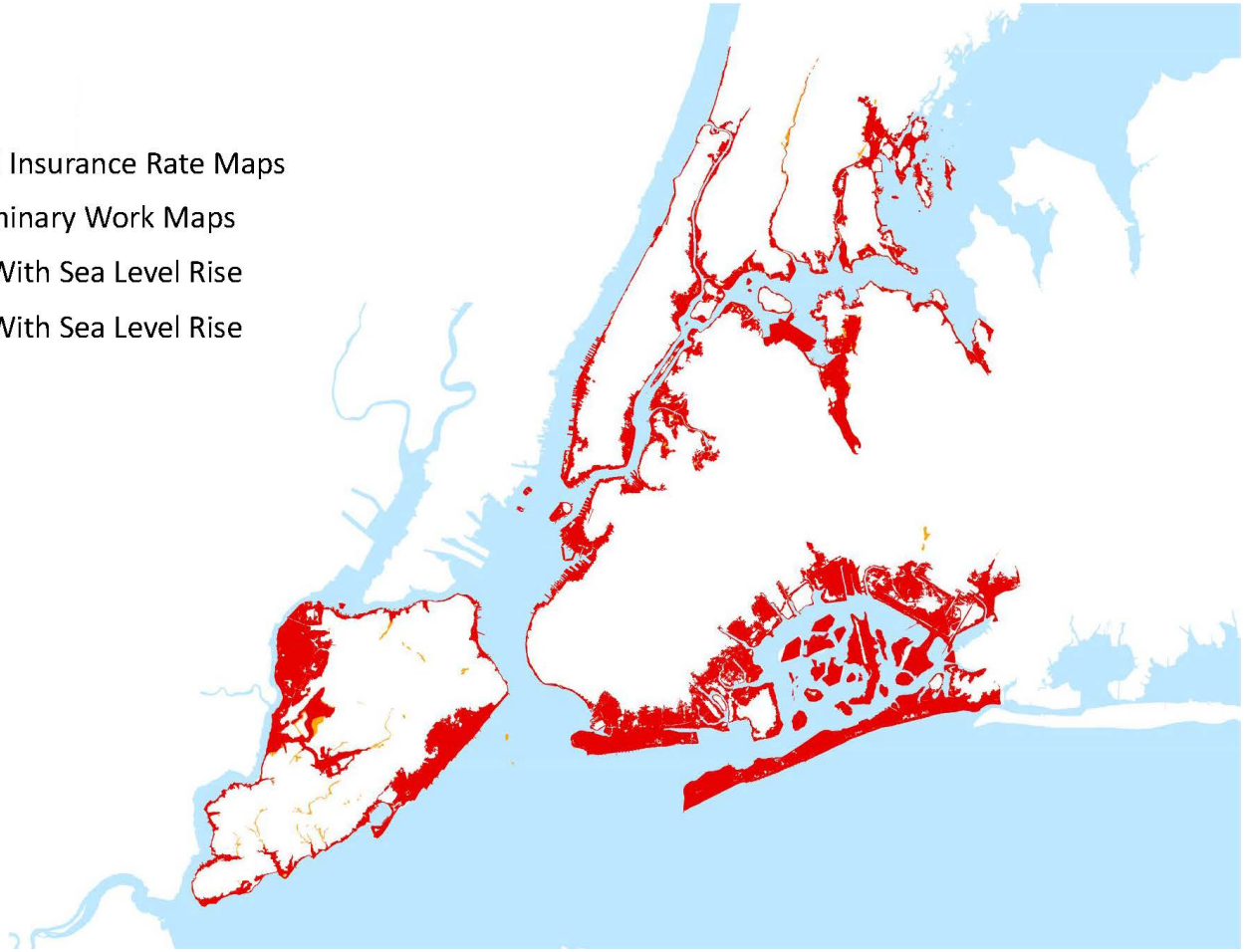

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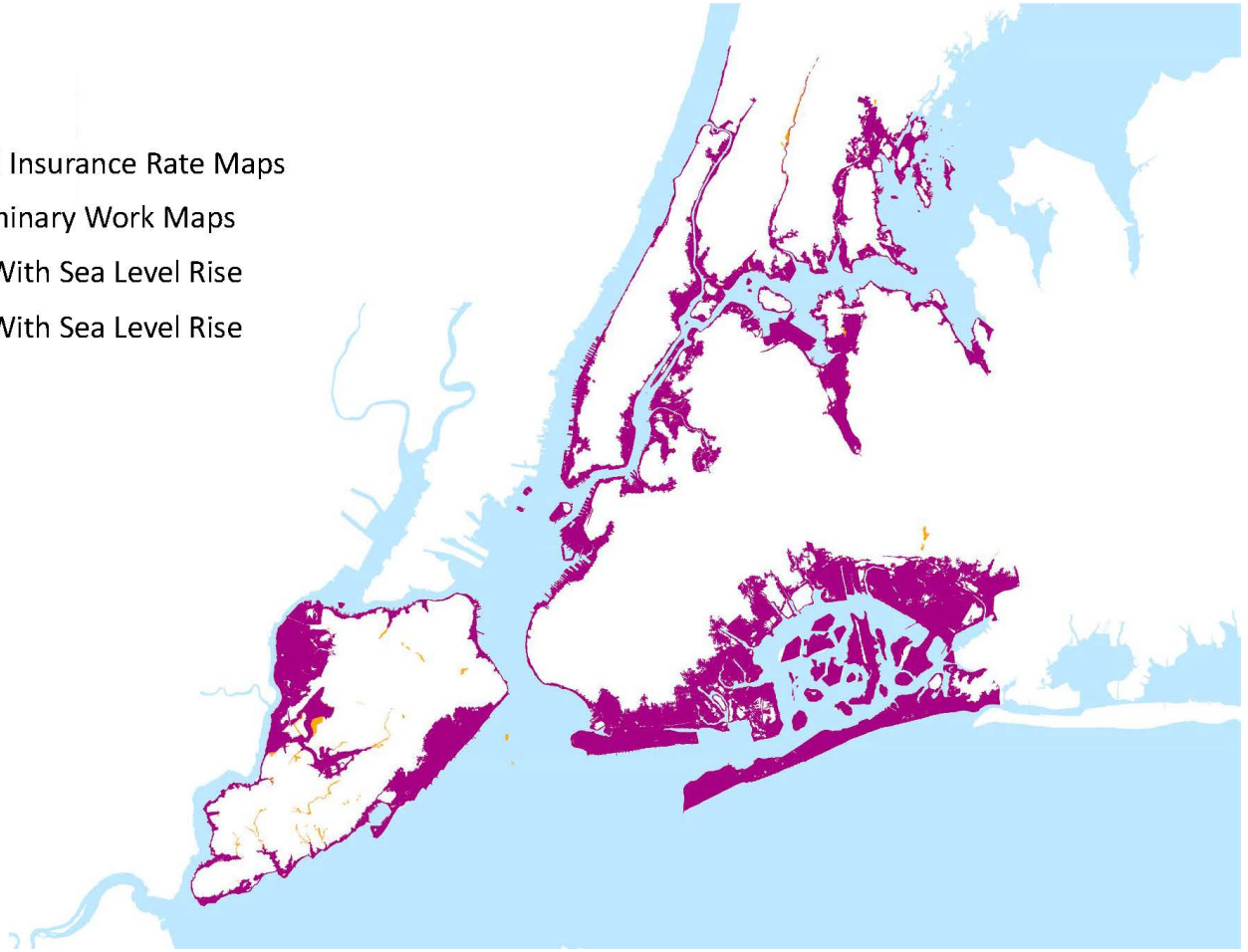
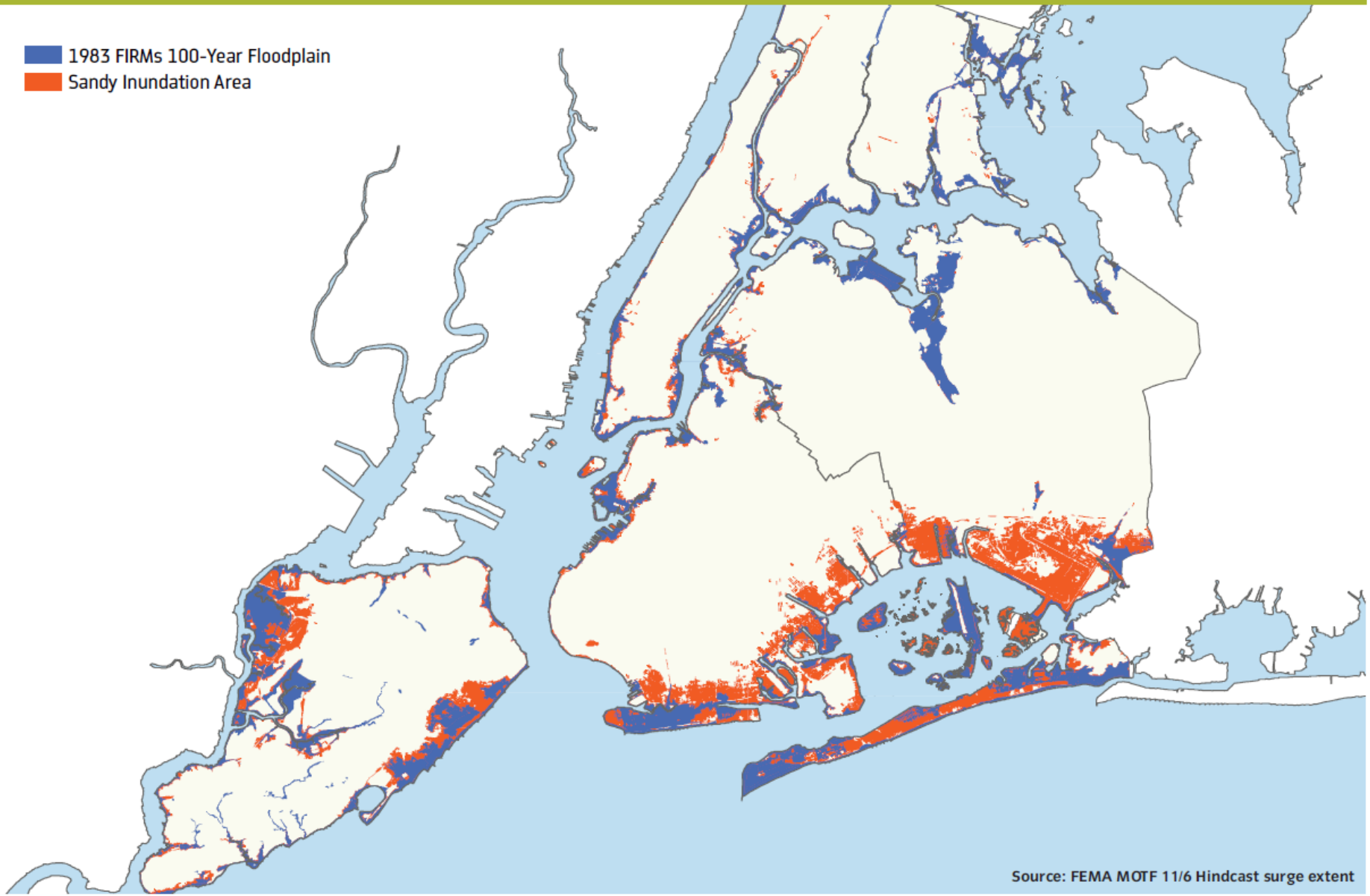


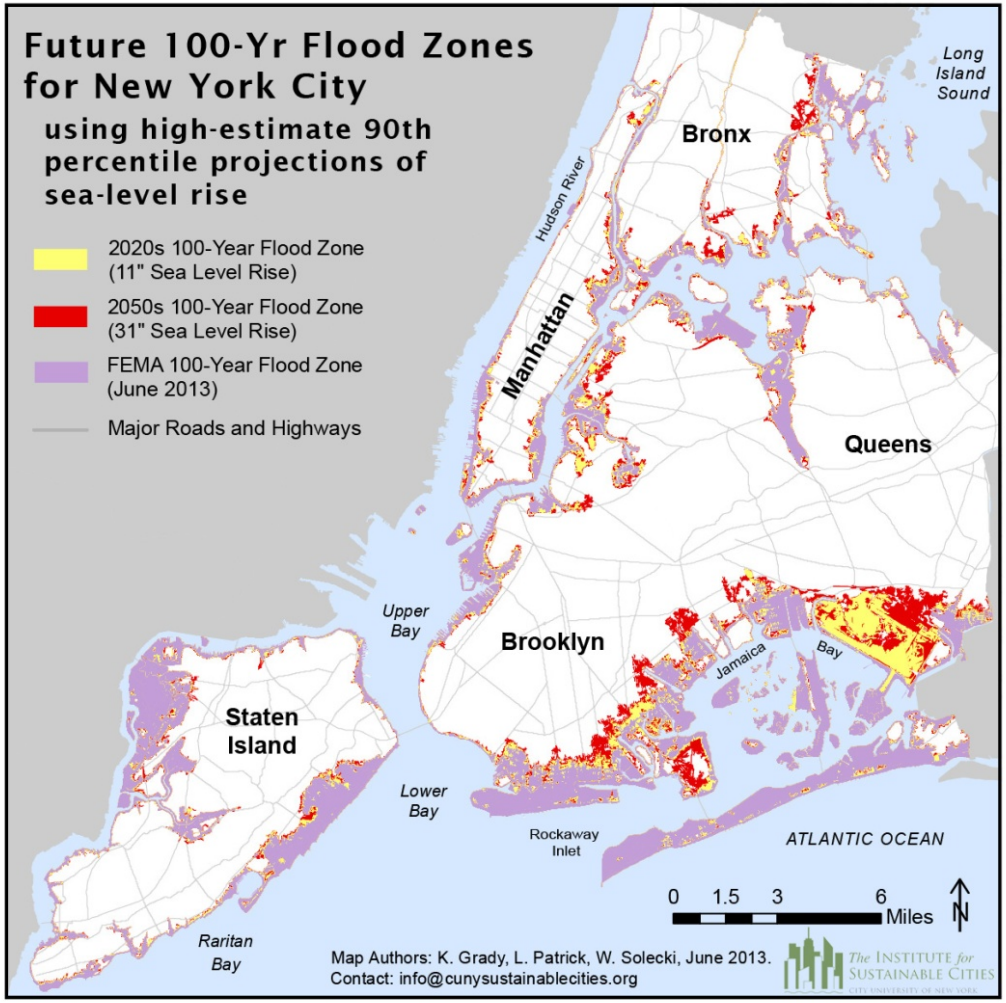
Source: PlaNYC 2013

Comparison of 100-Year Floodplain in 1983 FIRMs and Sandy Inundation Area



Impacts and Associated Vulnerabilities

Urban Lifelines and Infrastructure System Failures

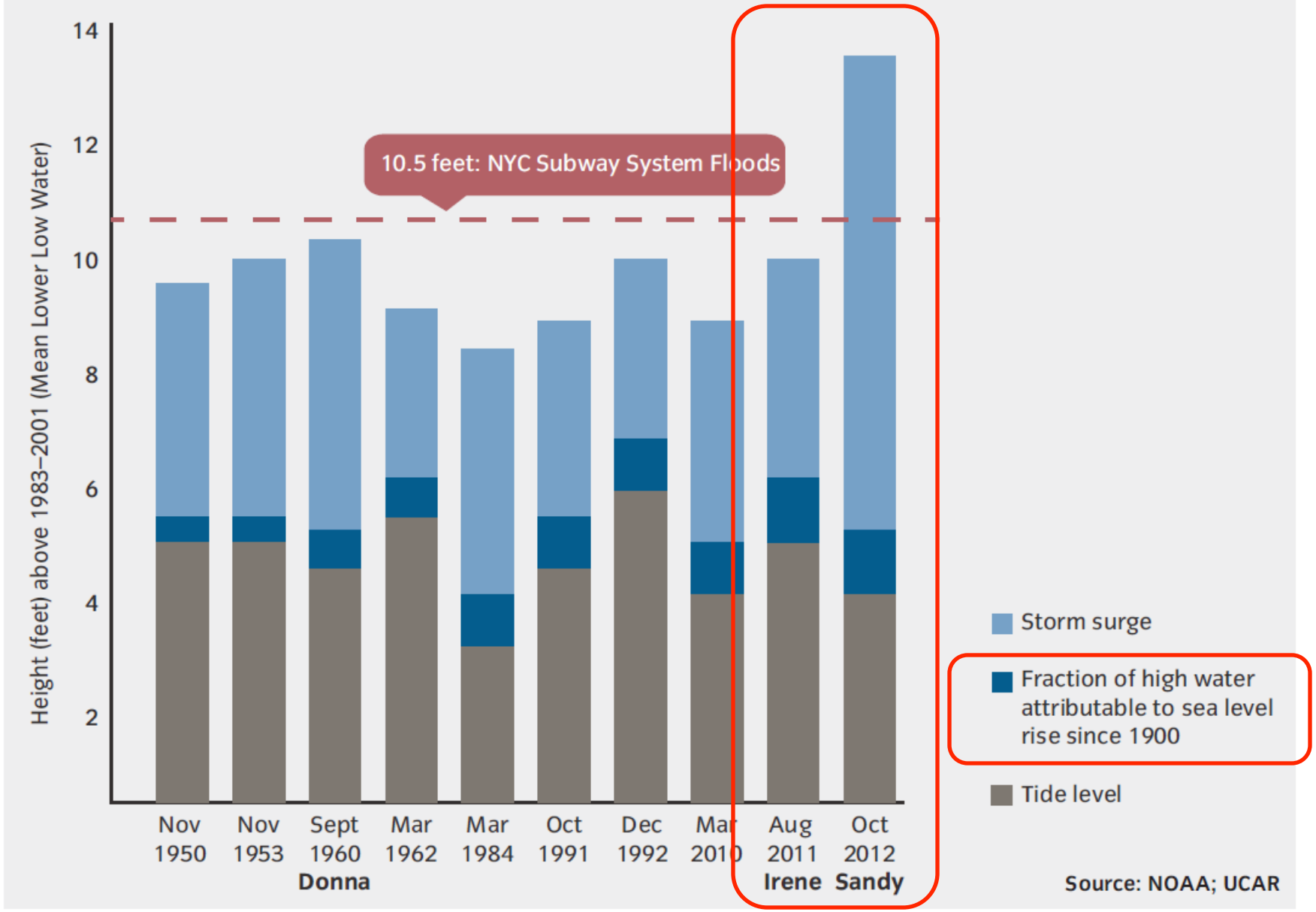


- Water Supply
- Electricity
- Transportation
- Gasoline Supply
- Pharmacy – Drug Supply

General Observations about Impacts and Vulnerabilities

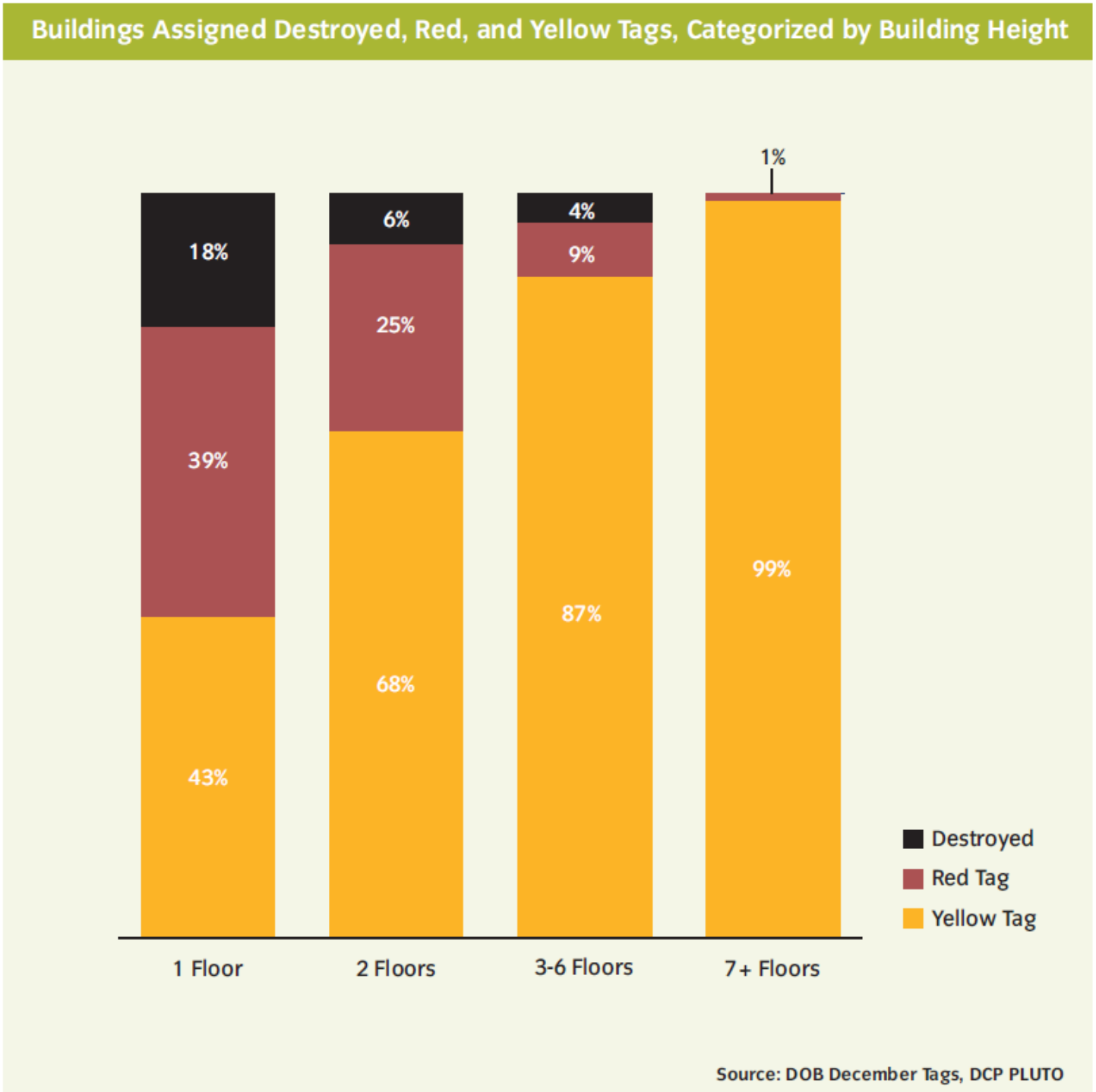
- Cascading system impacts
- Uneven geography – not all on the coast, but most impactful on coast
- Role of ecosystem protection opportunities – lost and found – e.g. wetlands
- Highly complex systems require significant redundancy and context specific vulnerabilities – e.g. health care system
- Data rich assessment – smart city context yielding critical data – challenge is how to use it
- A lot more impact and vulnerability work to be done

High-Water Events in Lower Manhattan



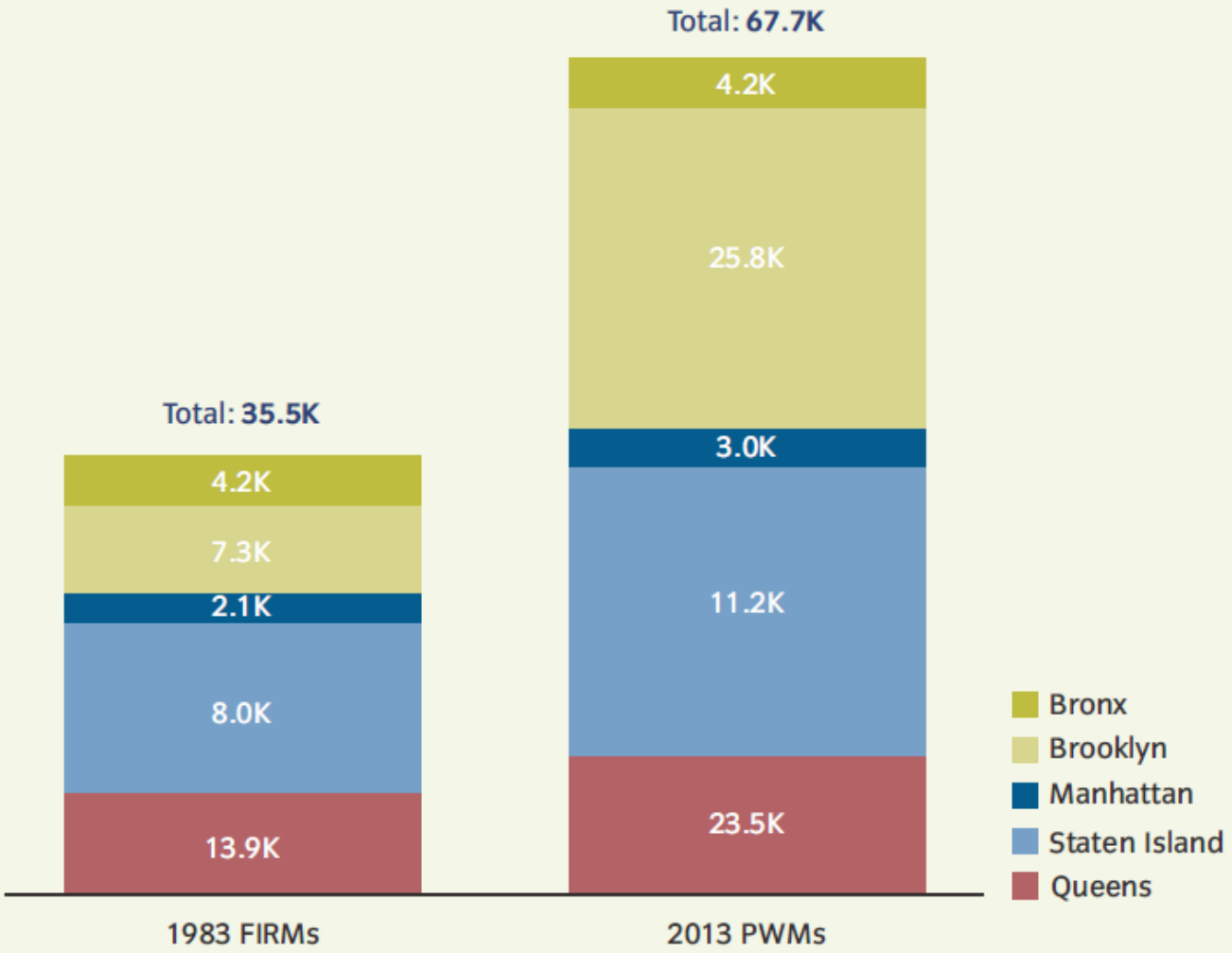
http://www.theatlantic.com/infocus/2012/11/hurricane-sandy-one-week-after-landfall/100399/

Cascading Vulnerability Pathways



Types of Buildings Impacted

Expansion of the Number of Buildings in the 100-Year Floodplain

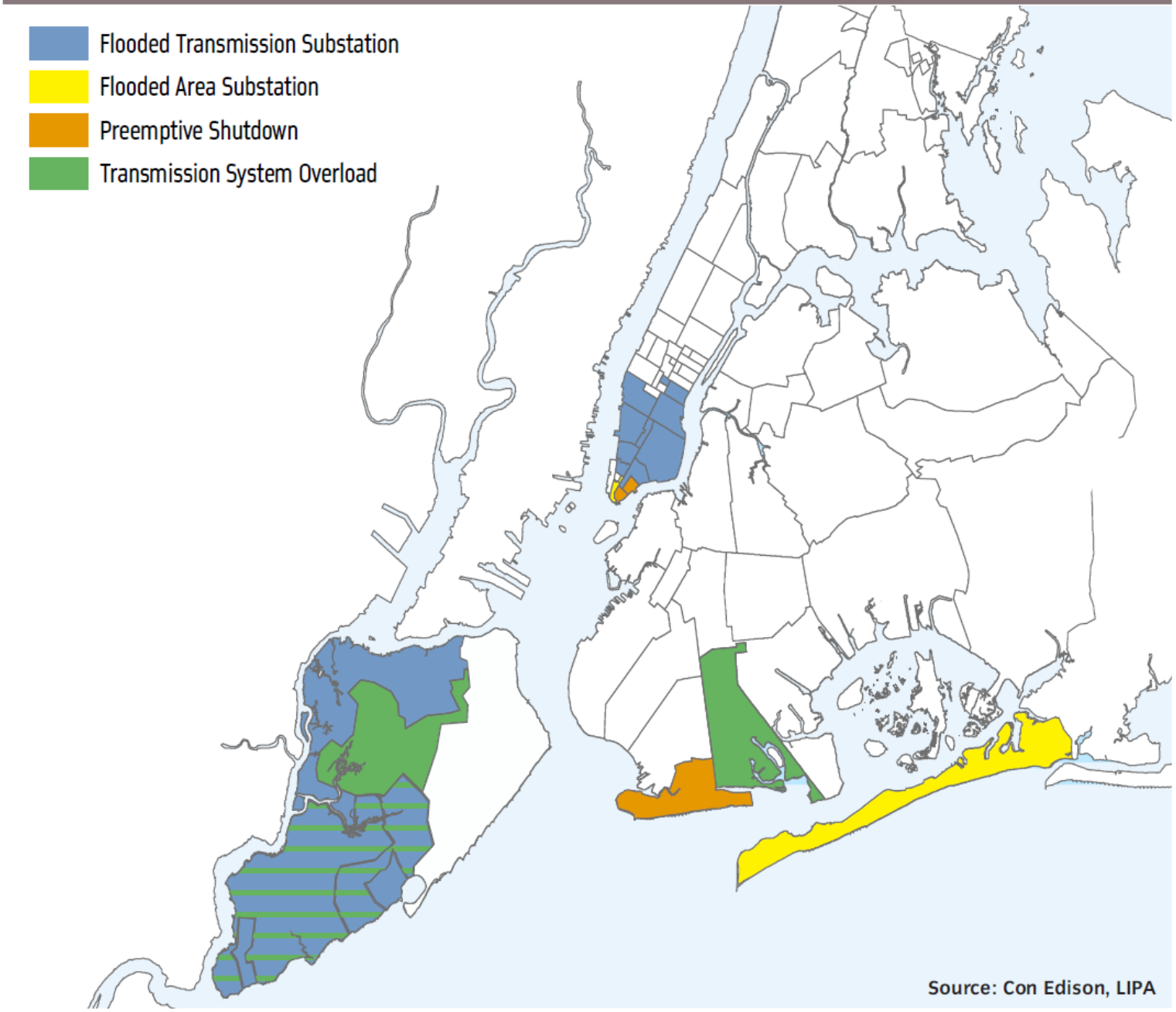


Source: DCP, FEMA

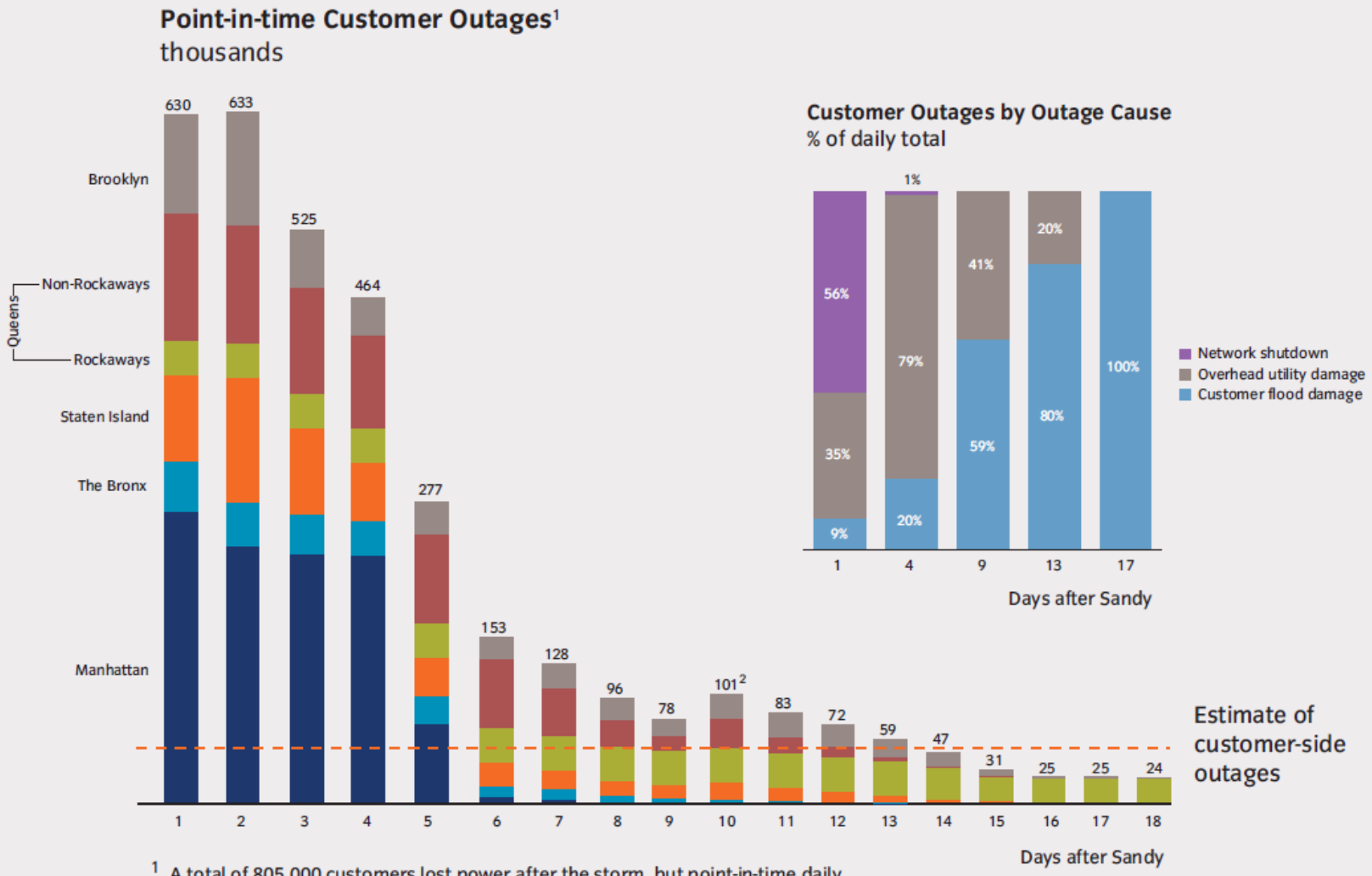
Approximately 1,000,000 building and related structures in New York City

Electrical Power Generation and Distribution

Electric Network Shutdowns During Sandy by Cause



Electrical Outage Restoration

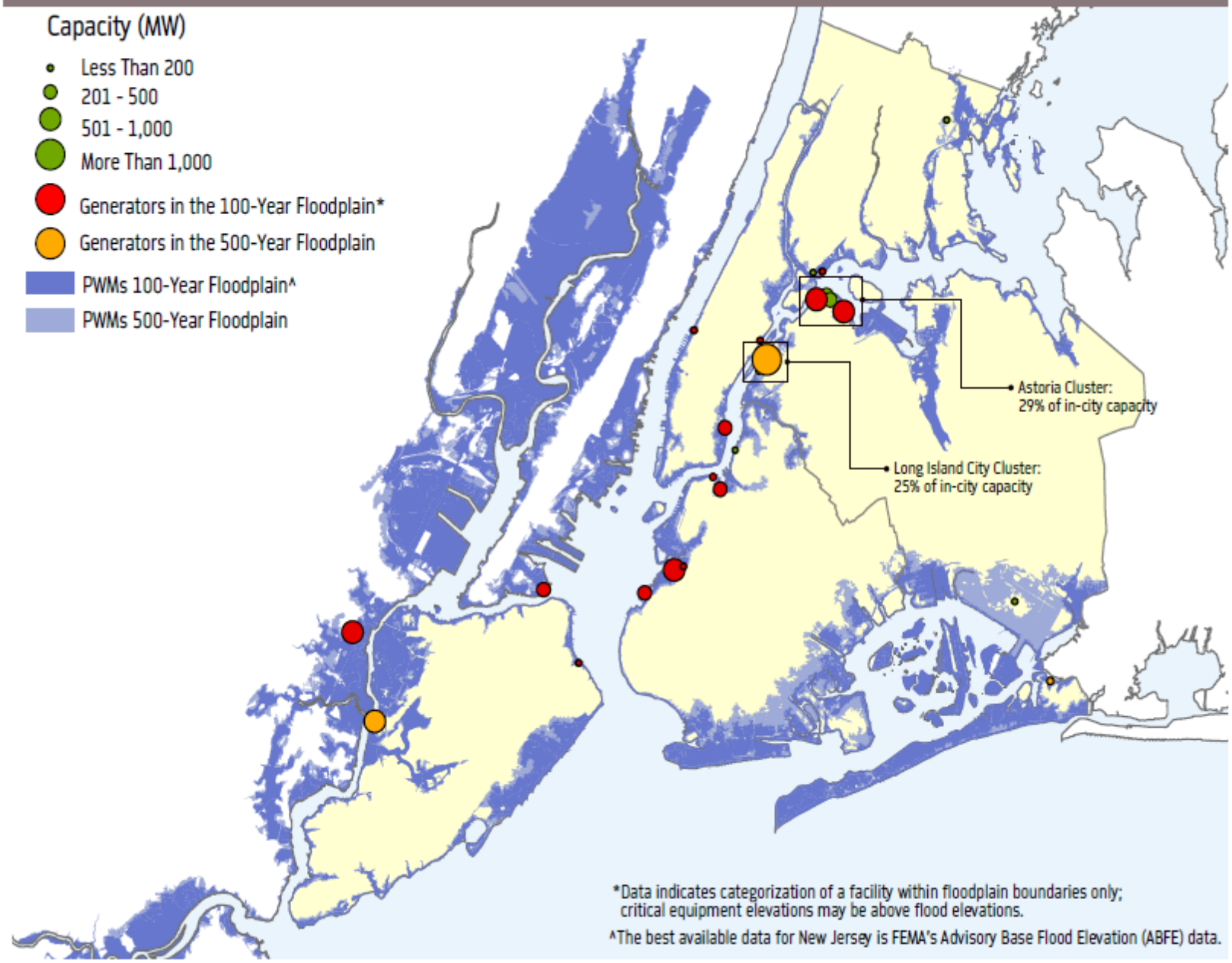


[1] A total of 805,000 customers lost power after the storm, but point-in-time daily estimates are lower because accounts went on and offline at different times

[2] Increase in customer outages due to the impact of nor'easter on Nov. 7

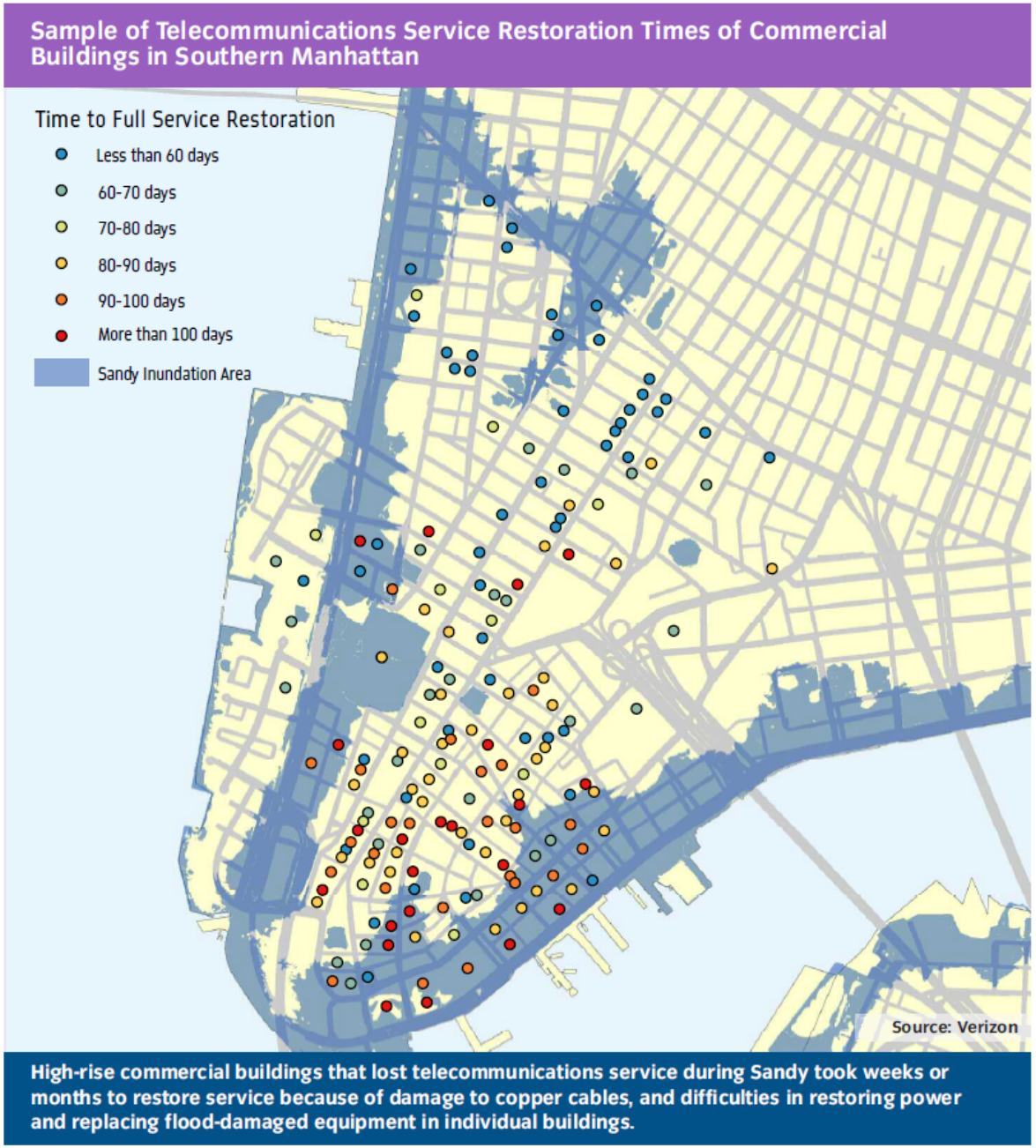
Source: Con Edison, LIPA

In-City Electric Generating Facilities in the Floodplain



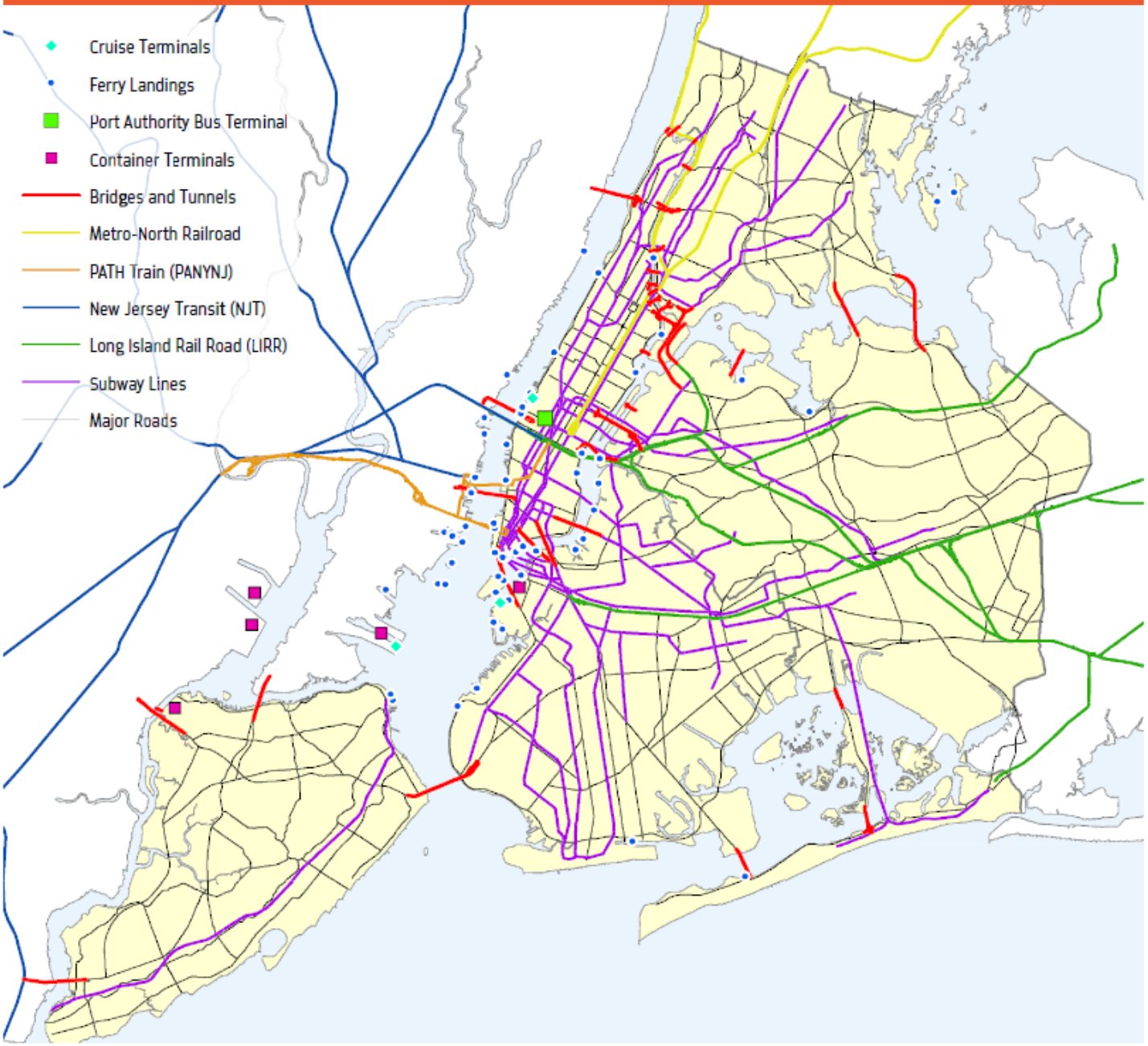
Source: FEMA, OLTPS

Telecommunications

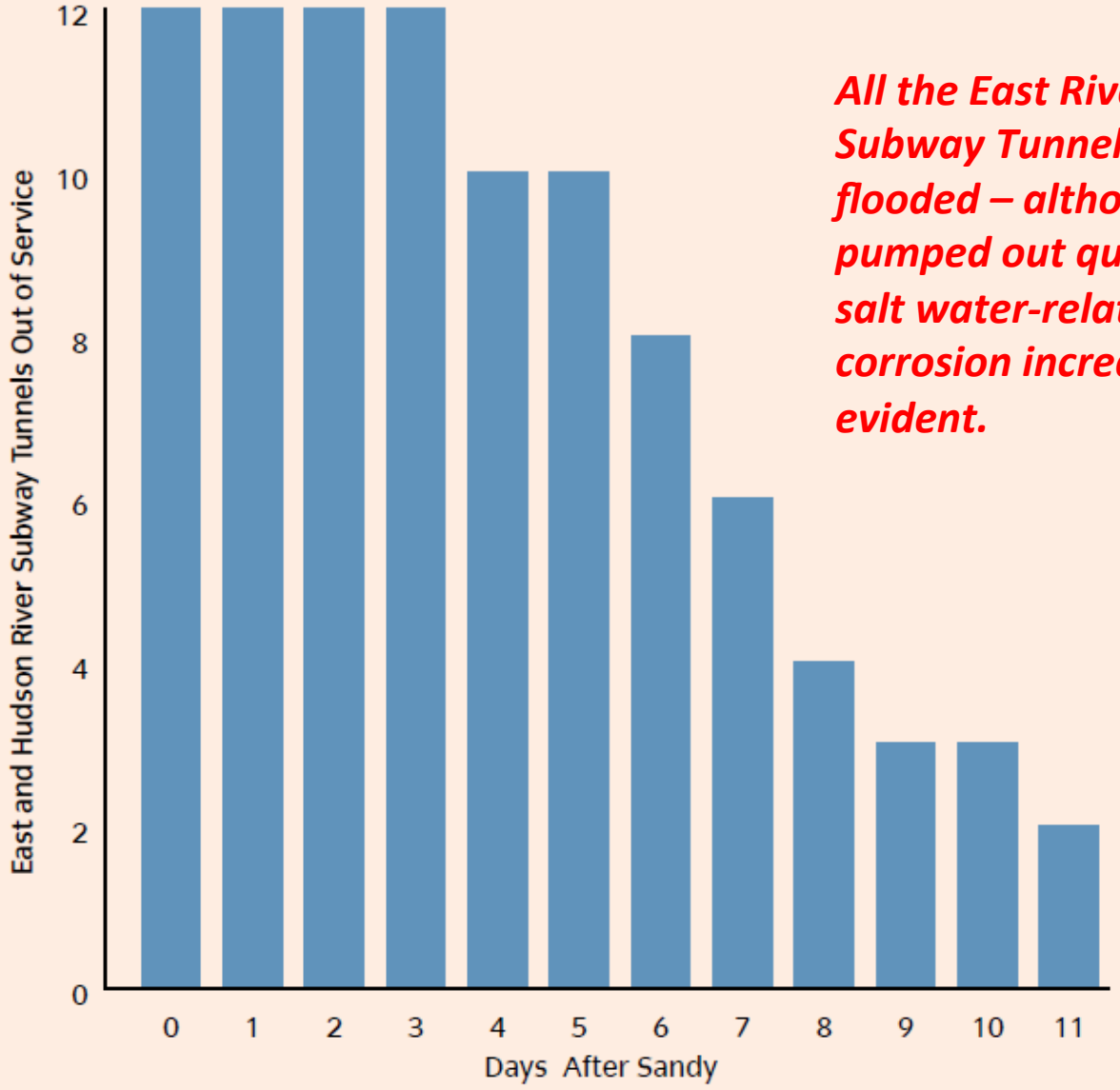


Transportation

Regional Transportation Network



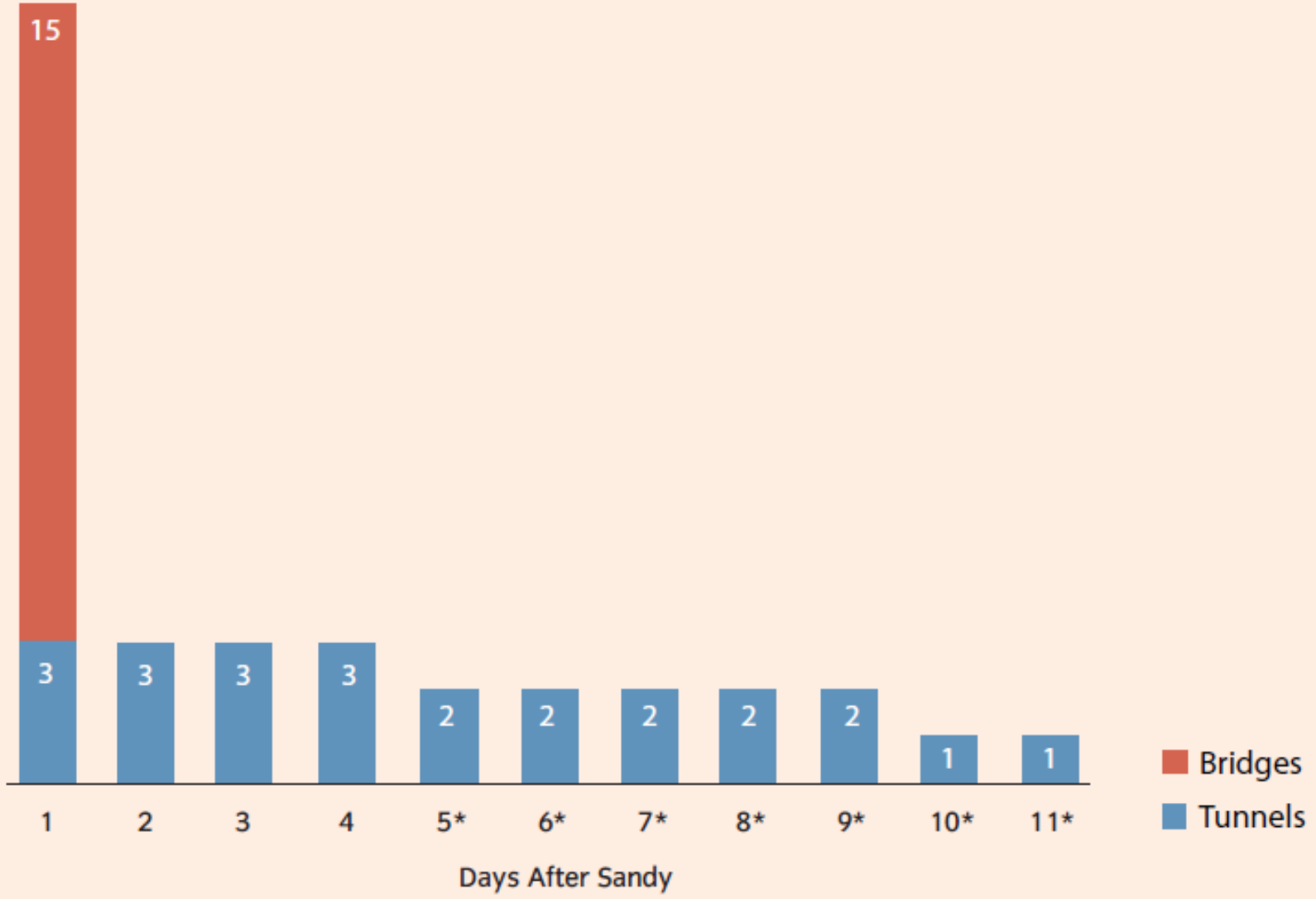
Subway Tunnel Closures After Sandy



All the East River Subway Tunnels flooded – although pumped out quickly salt water-related corrosion increasingly evident.

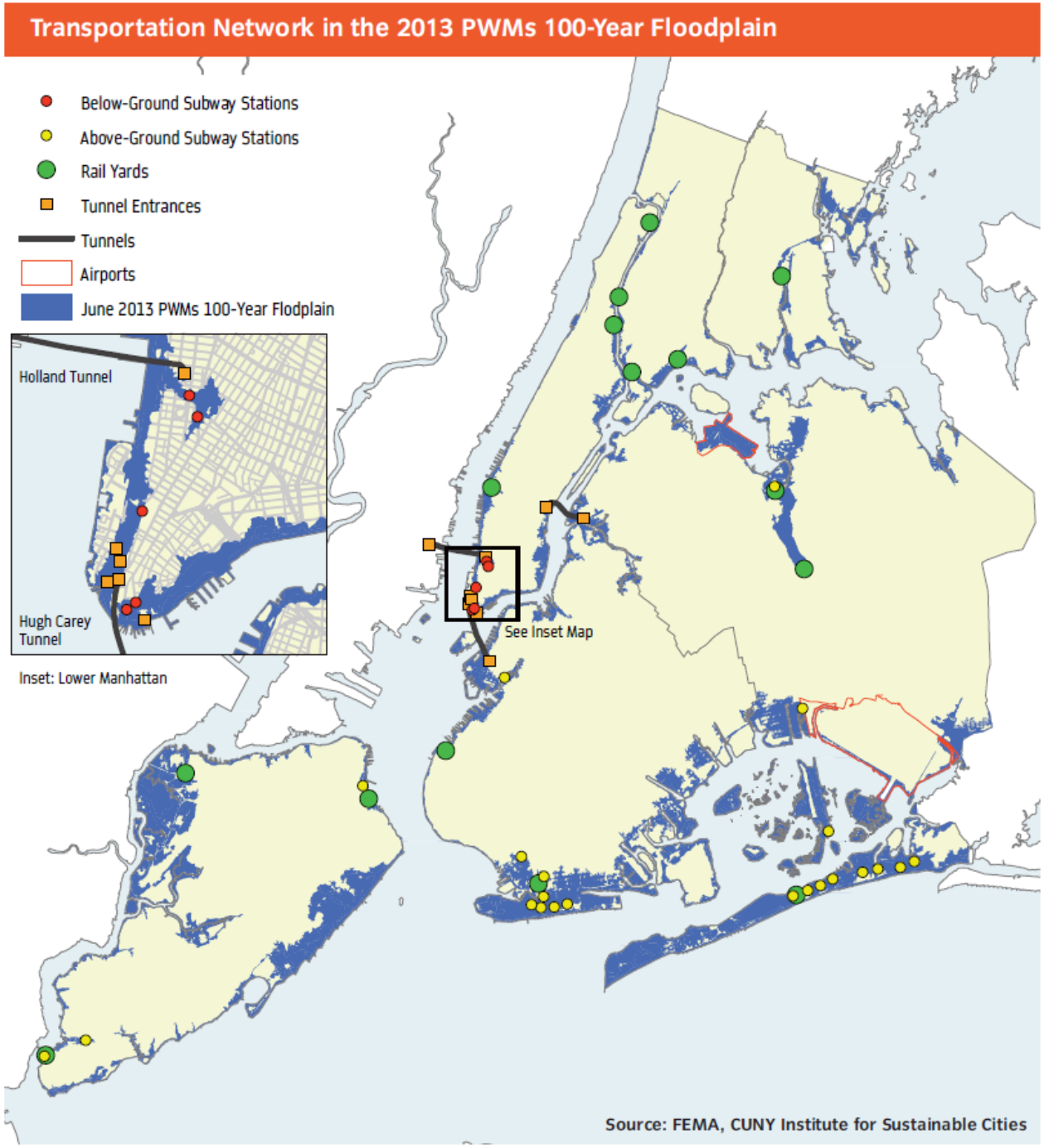
Source: NYCDOT, MTA, and Port Authority of NY & NJ

Major Vehicular Bridge and Tunnel Closures After Sandy



*partial tunnel closures continued due to ventilation system damage

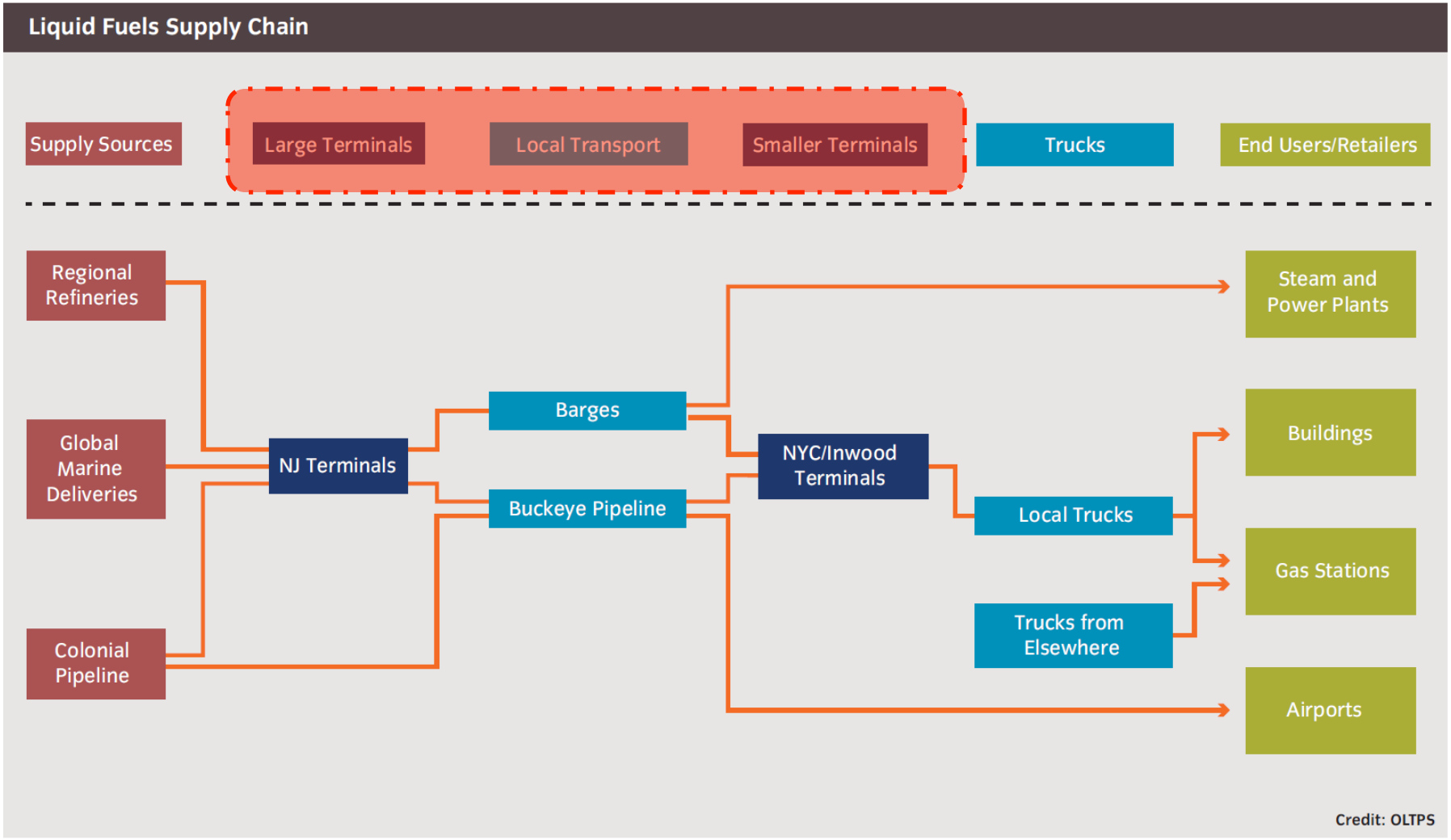
Source: NYCDOT, MTA, and Port Authority of NY & NJ



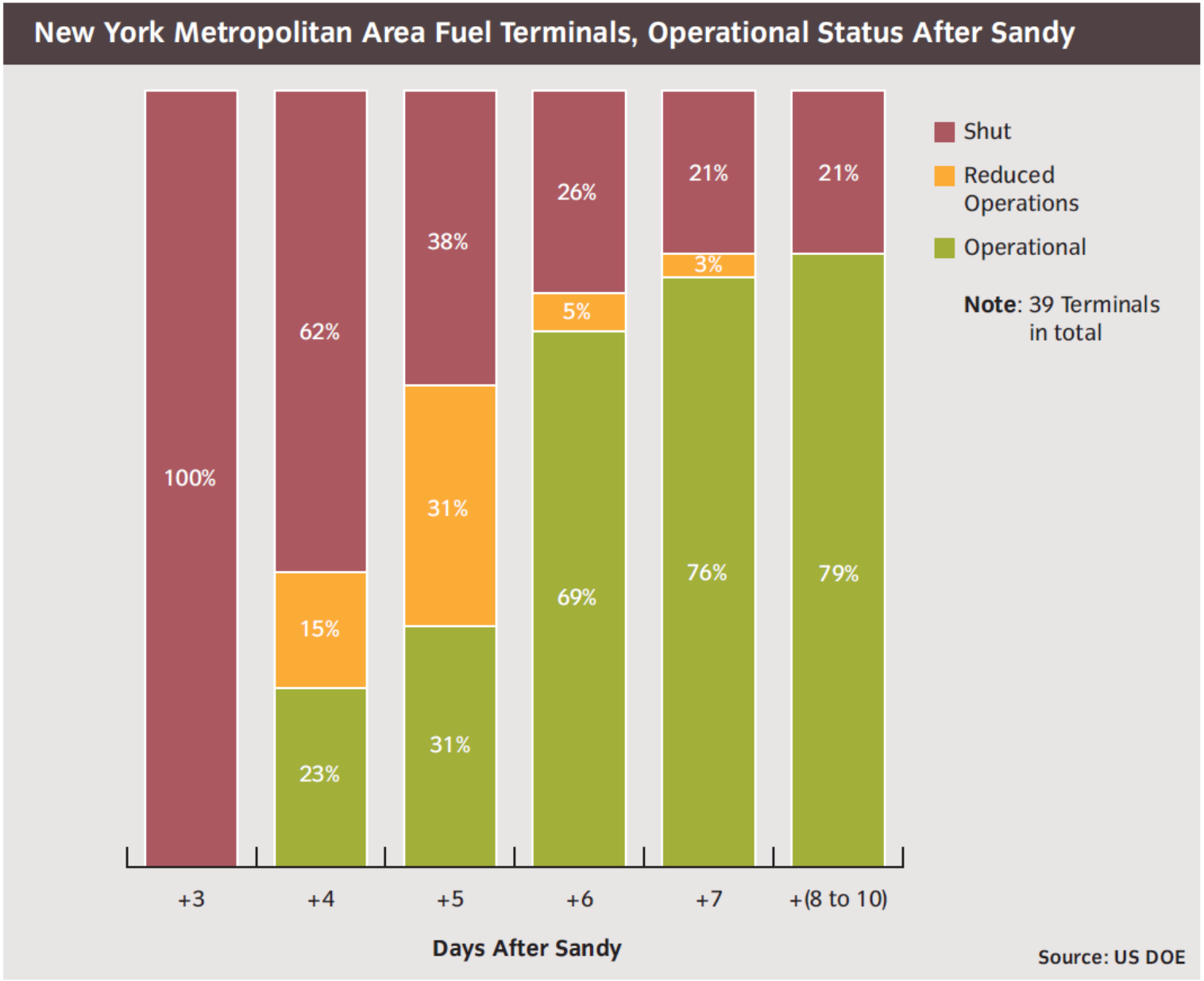
Does not include at-risk roads and rails.

Liquid Fuel Terminals and Gas Shortages

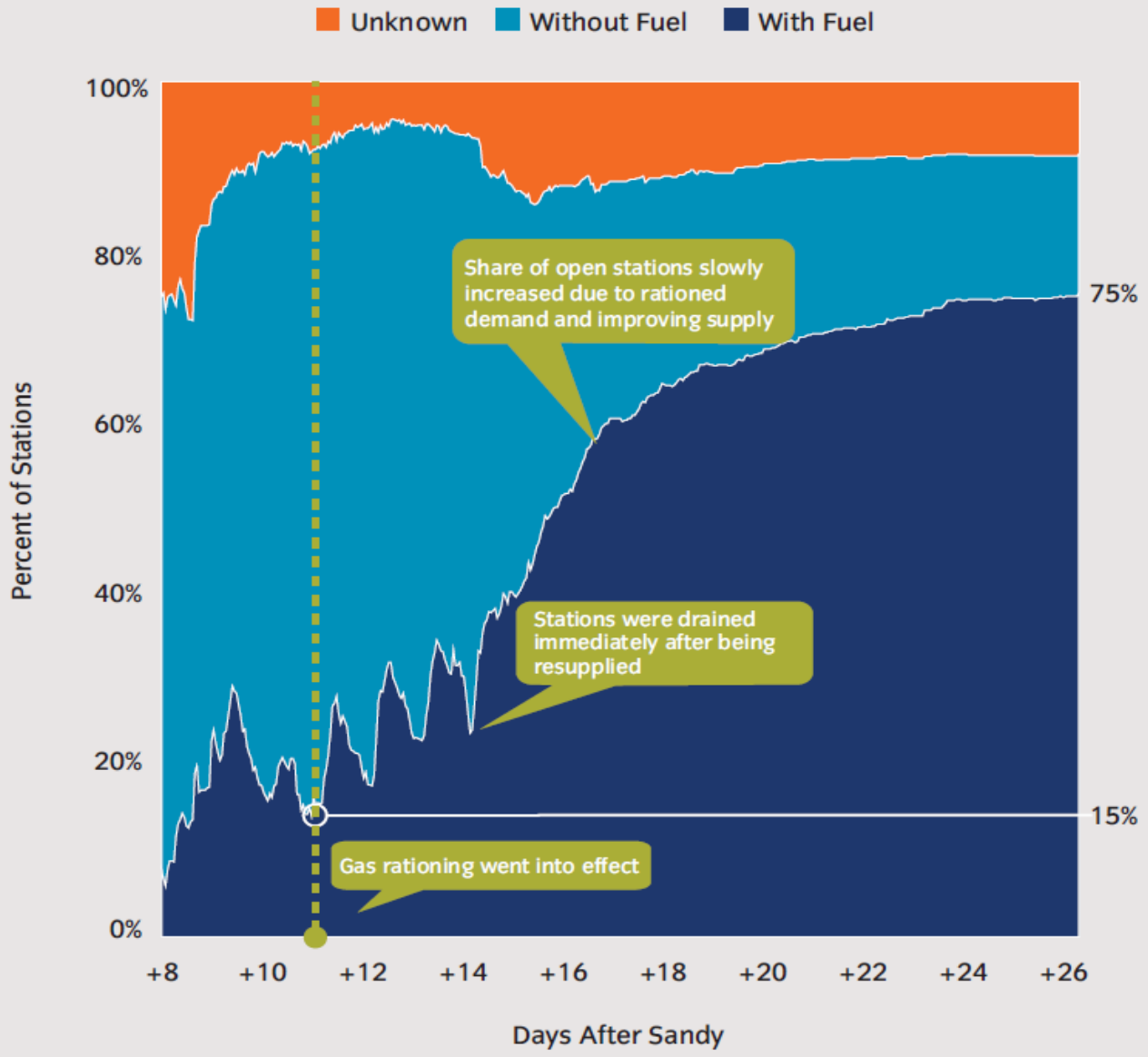
Liquid Fuels Supply Chain for New York City



Fuel Terminals

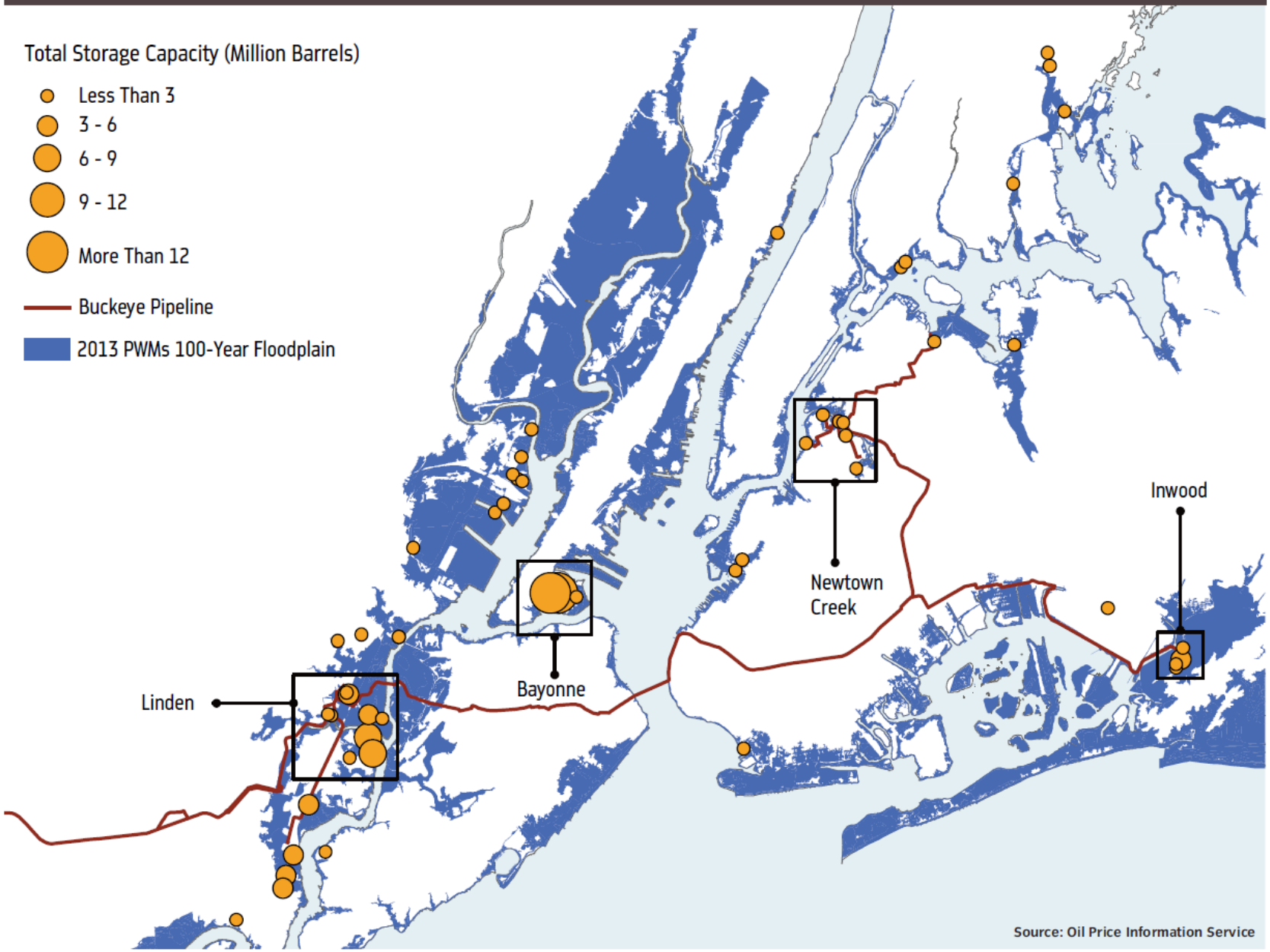


New York City Gas Stations by Point-in-Time Operational Status



Source: Gasbuddy.com

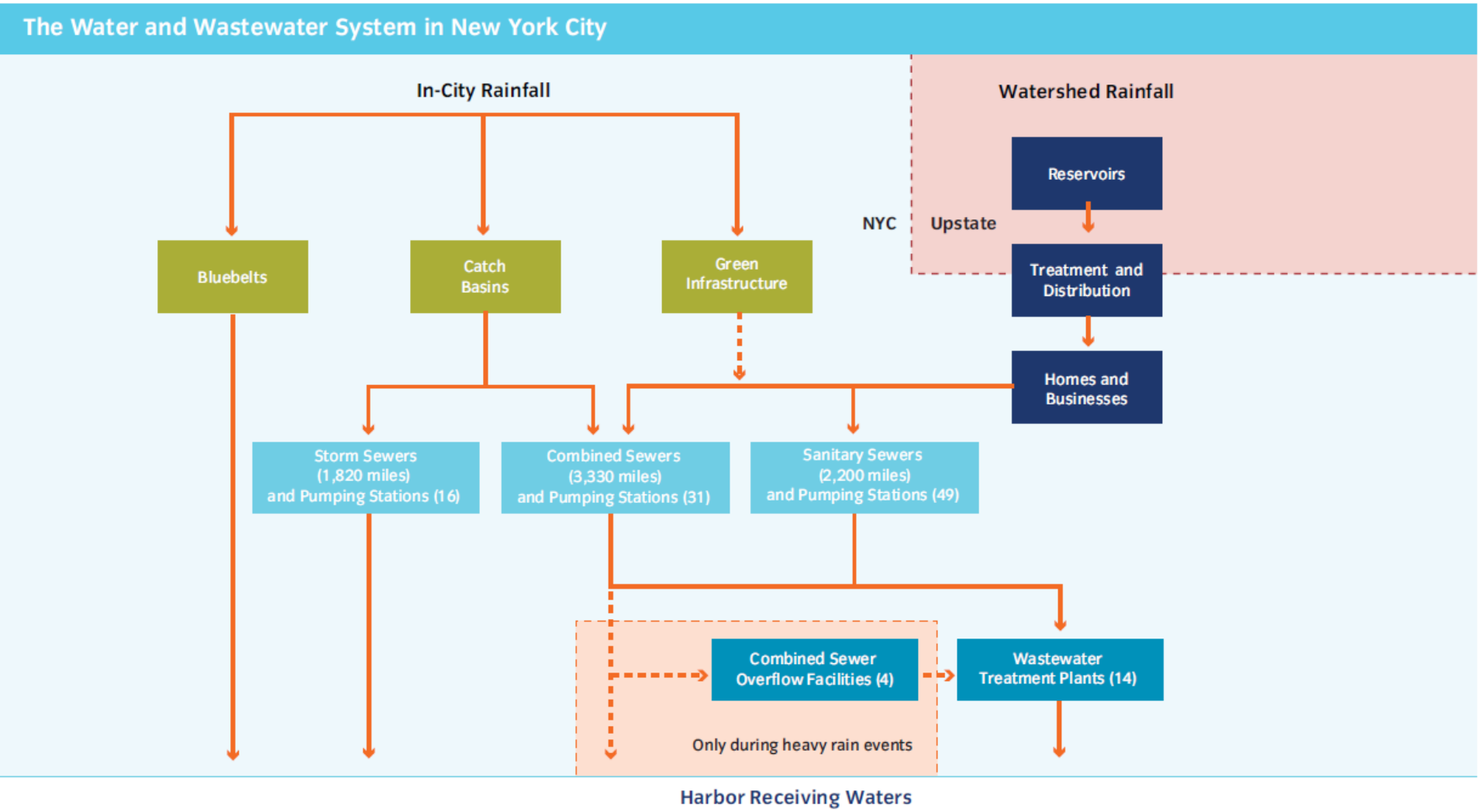
Regional Liquid Fuel Terminals



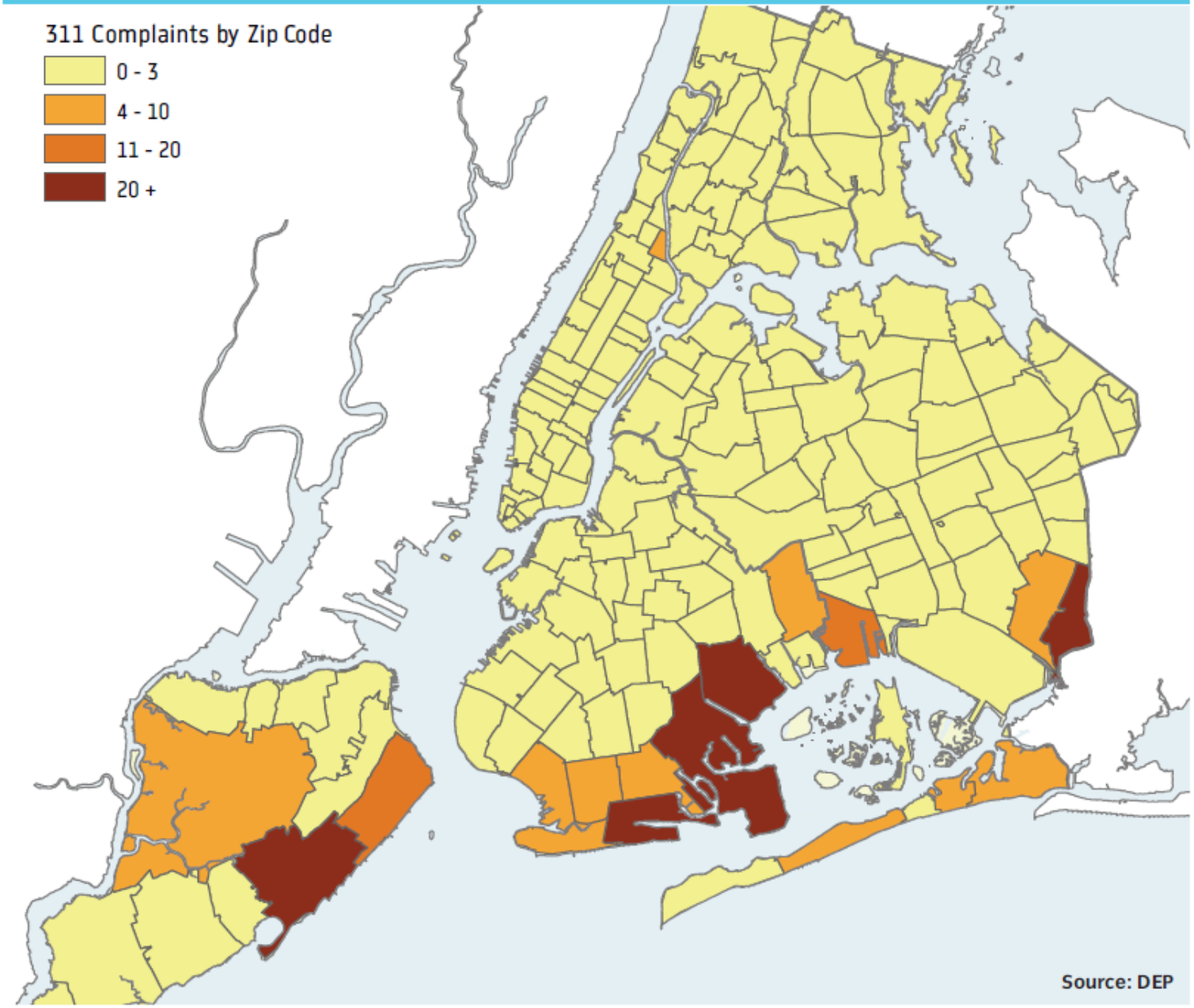
Water and Wastewater Supply

Hurricane Sandy was not a major rain event for New York City

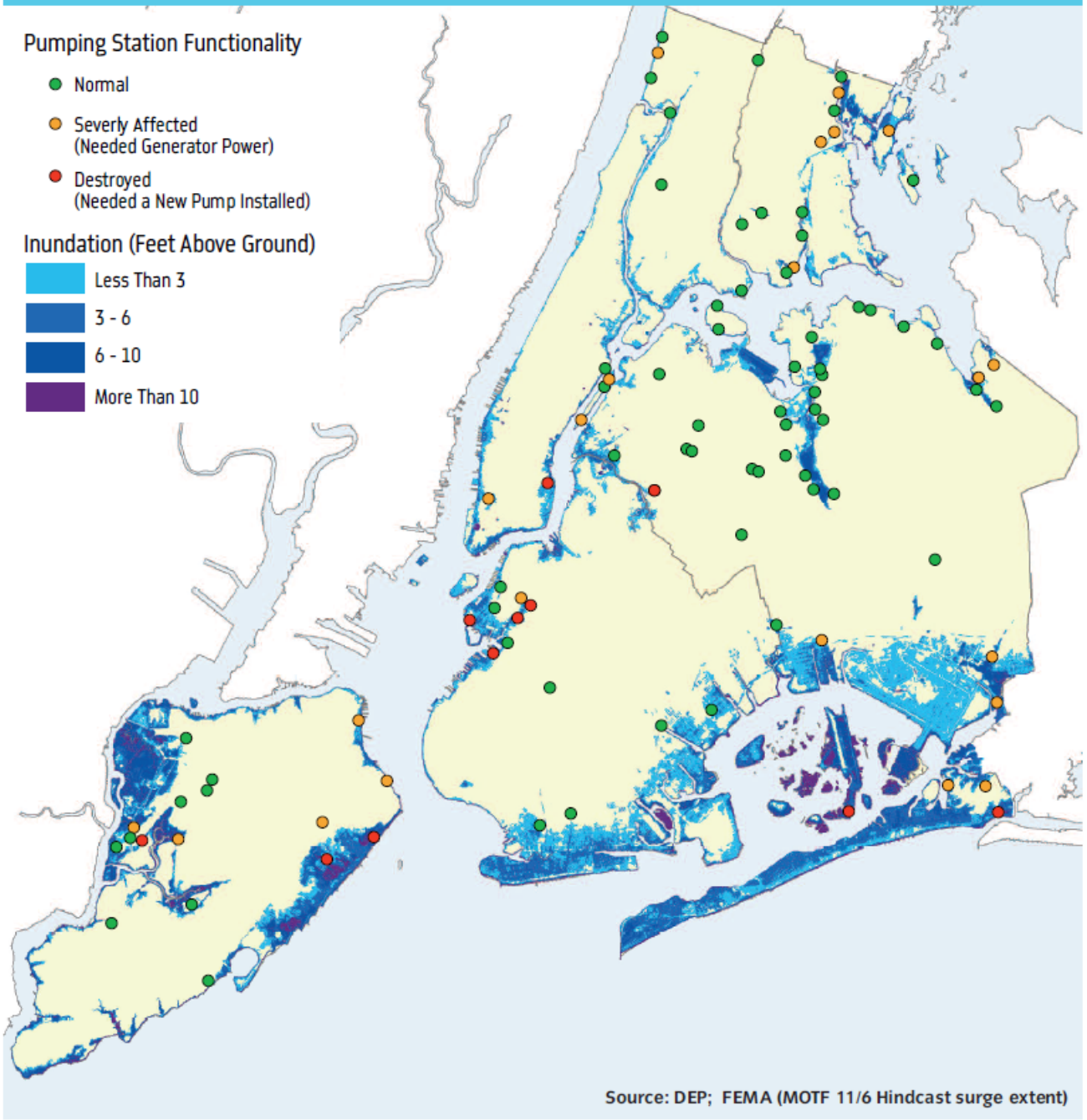
Water and Wastewater System



Confirmed Sewer Backup and Street Flooding Complaints Oct. 30 - Nov. 1, 2012



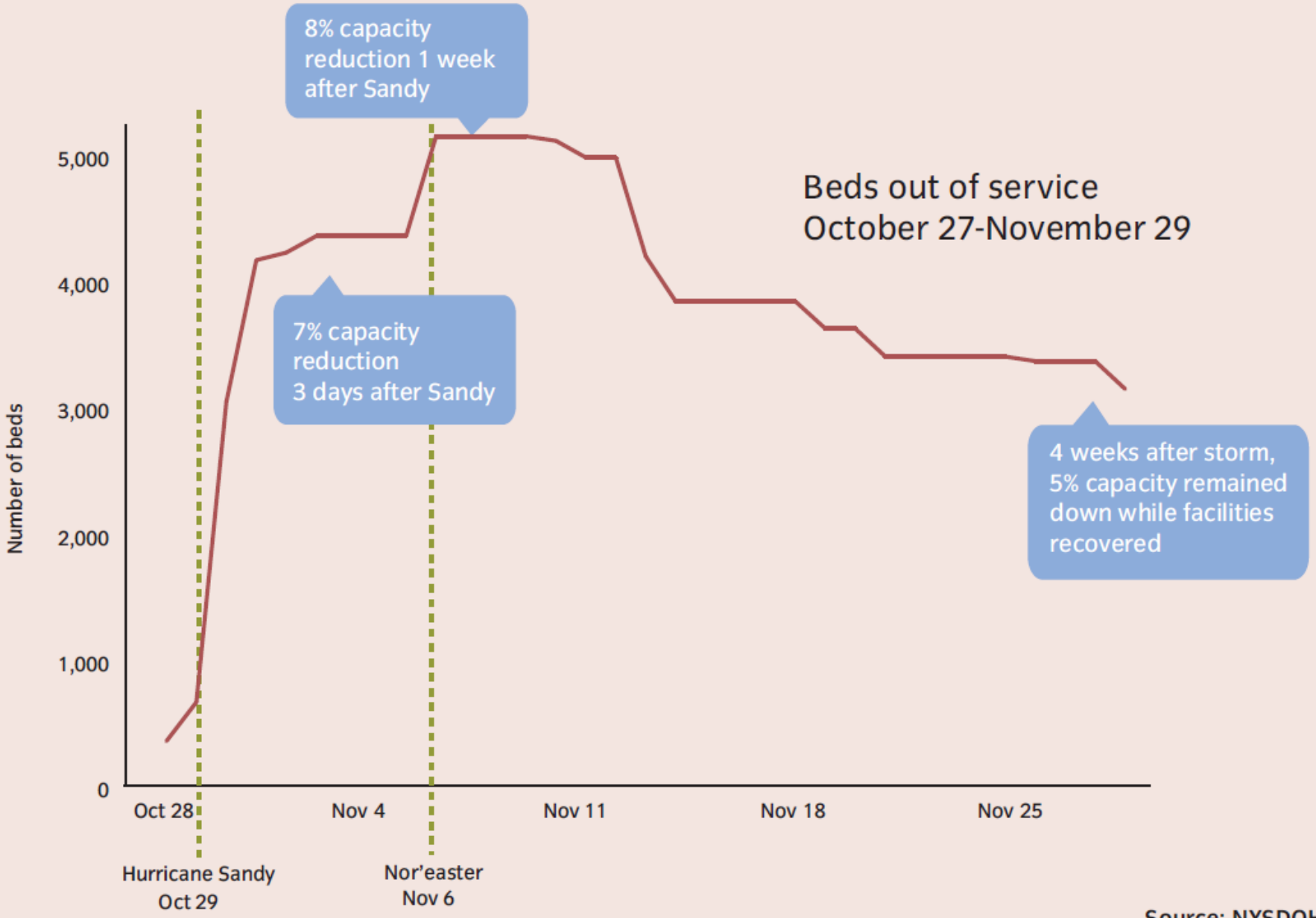
Pumping Stations Affected By Sandy



Source: DEP; FEMA (MOTF 11/6 Hindcast surge extent)

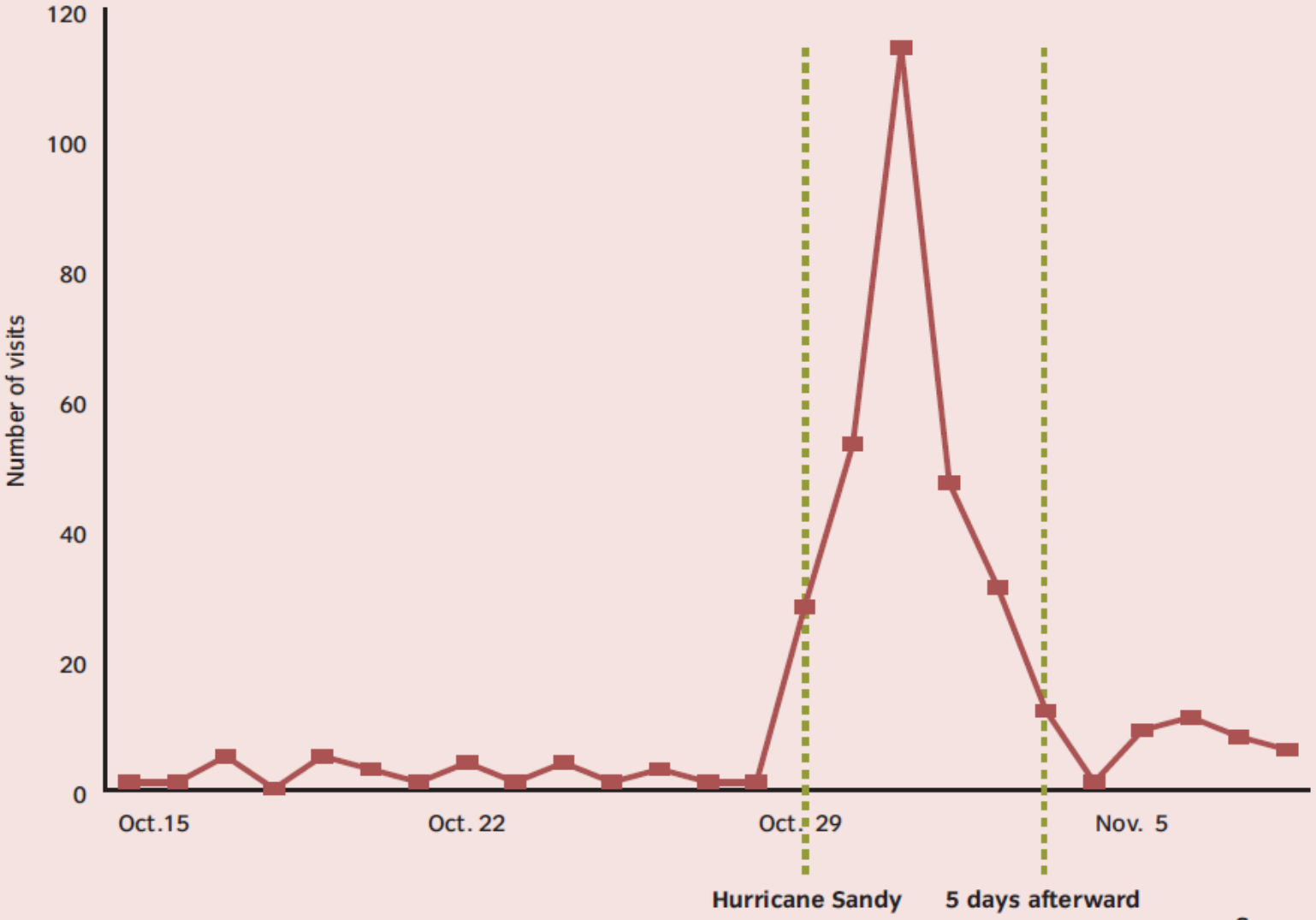
Social Vulnerability

Citywide Bed Capacity Reductions in Nursing Homes and Adult Care Facilities



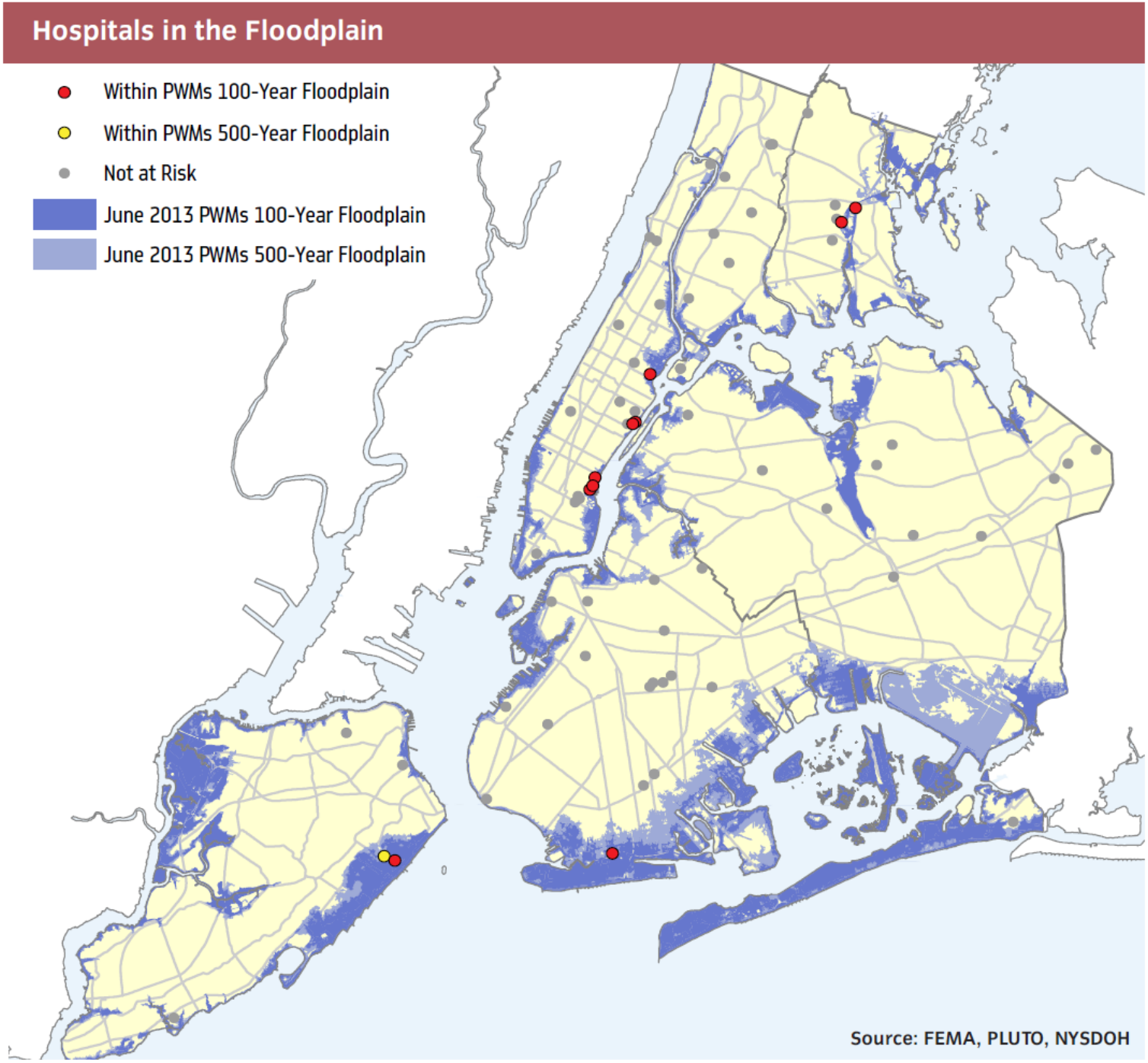
Source: NYSDOH

Citywide Emergency Department Visits Needing Dialysis

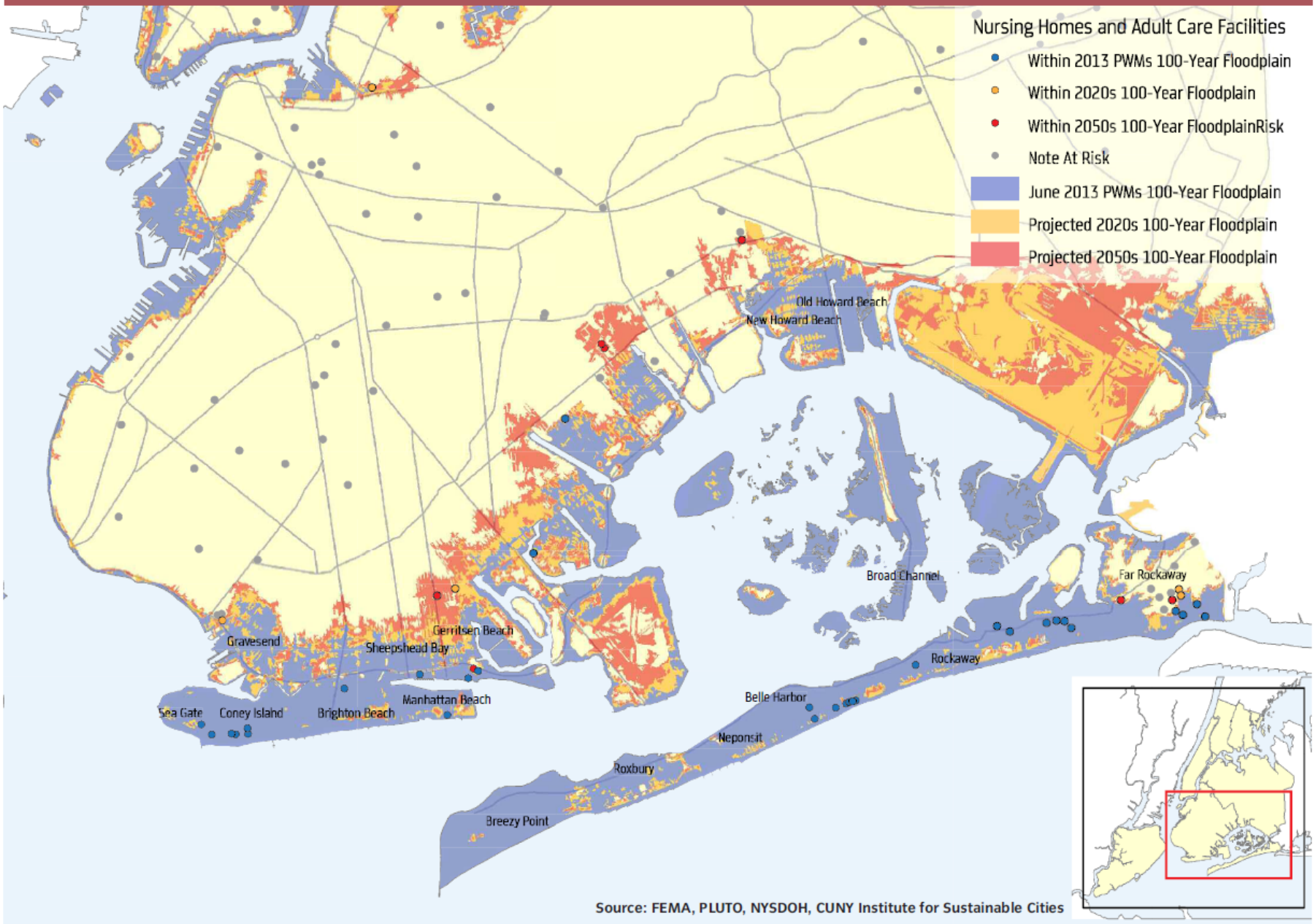


Source: DOHMH

Hospitals in the Floodplain

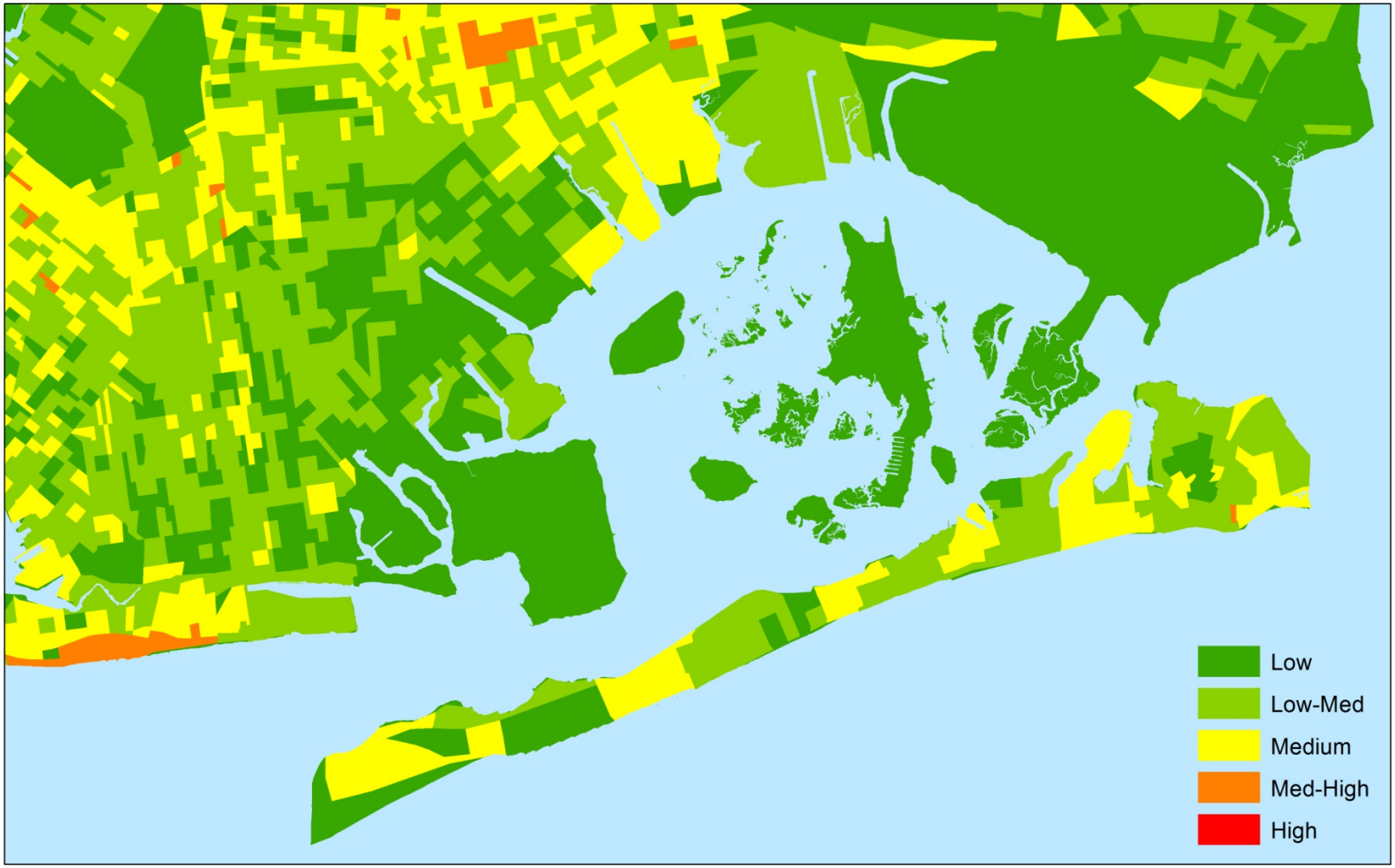


Nursing Homes and Adult Care Facilities in Southern Brooklyn and South Queens

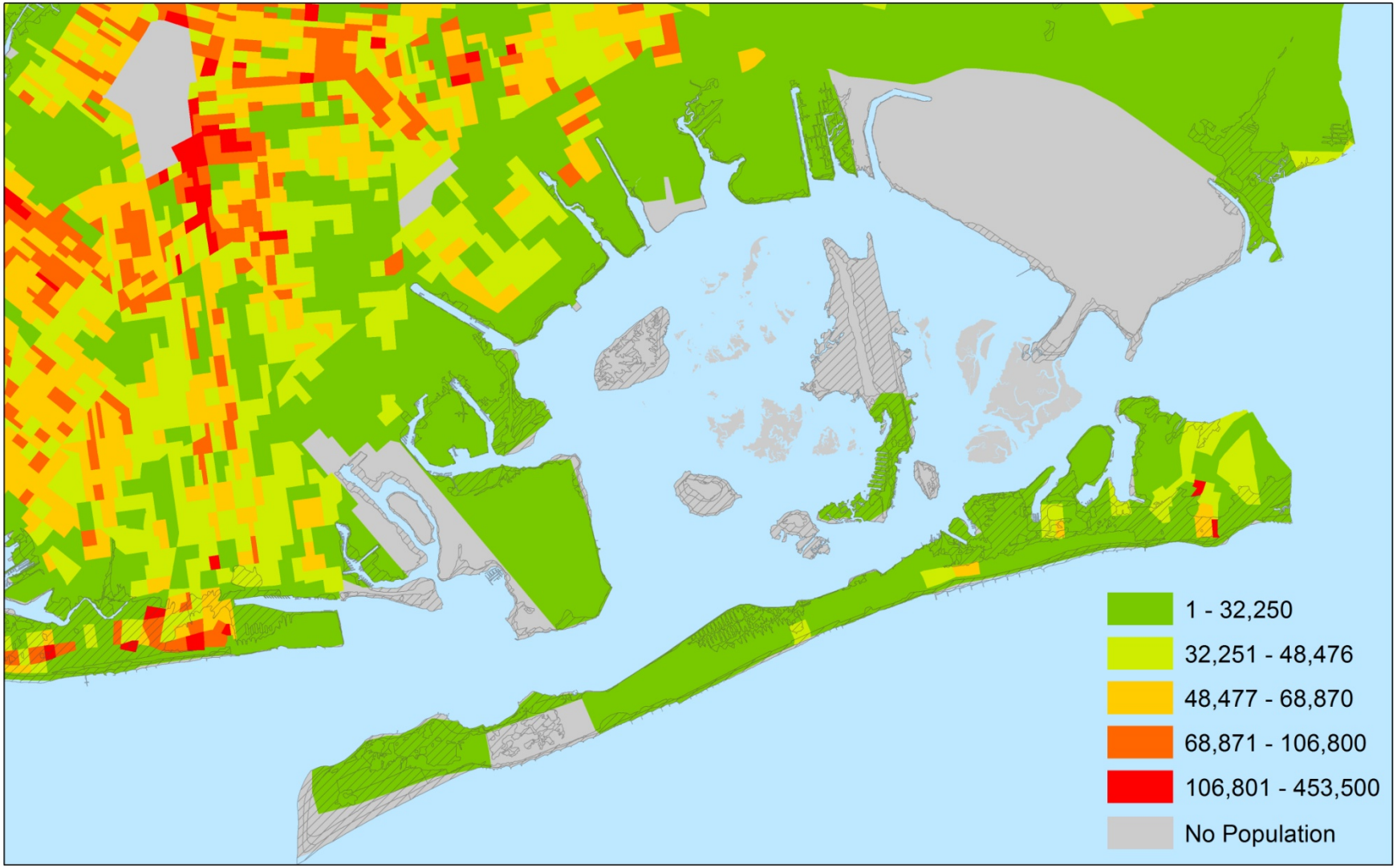


Source: FEMA, PLUTO, NYSDOH, CUNY Institute for Sustainable Cities

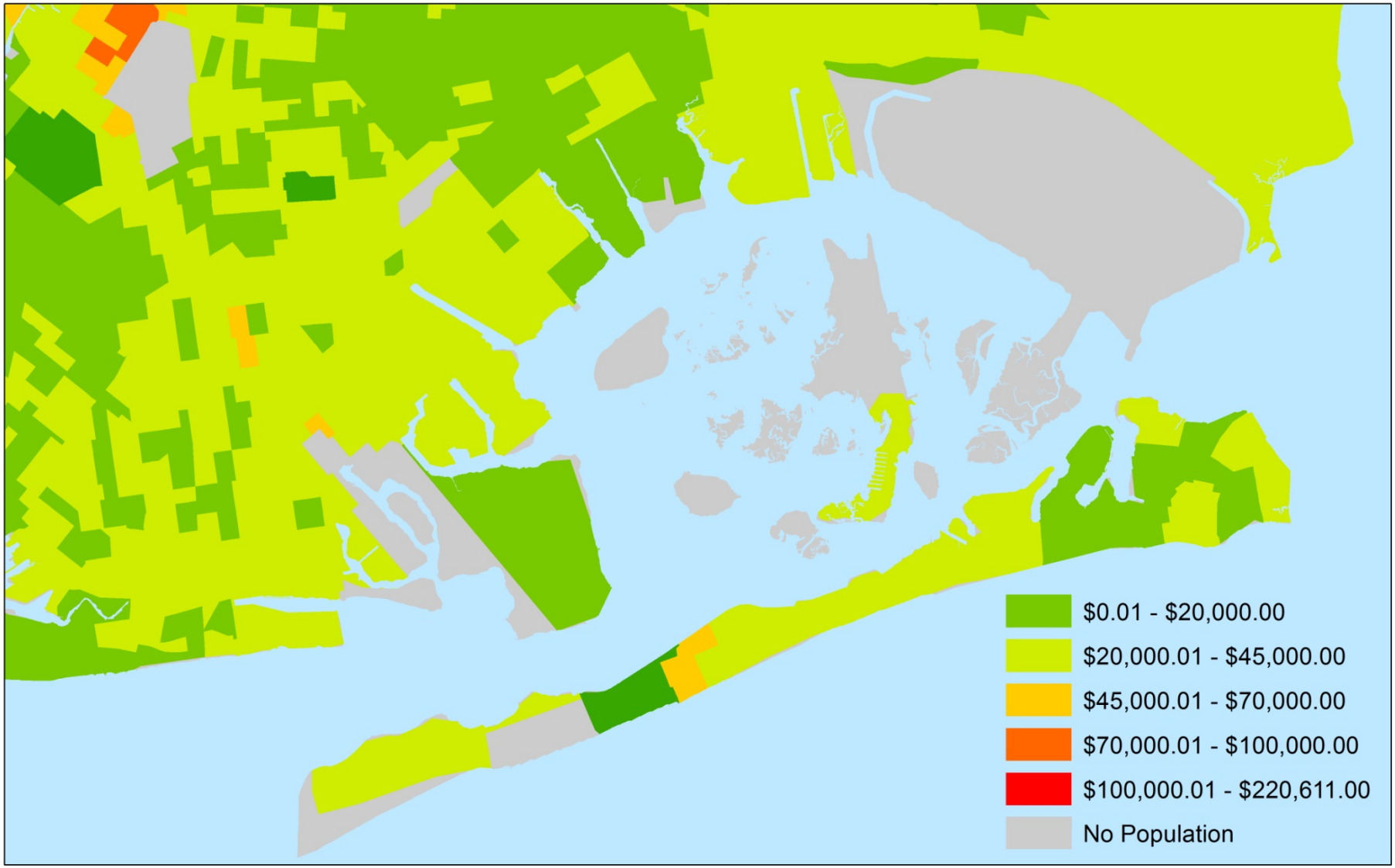
Social Vulnerability around Jamaica Bay



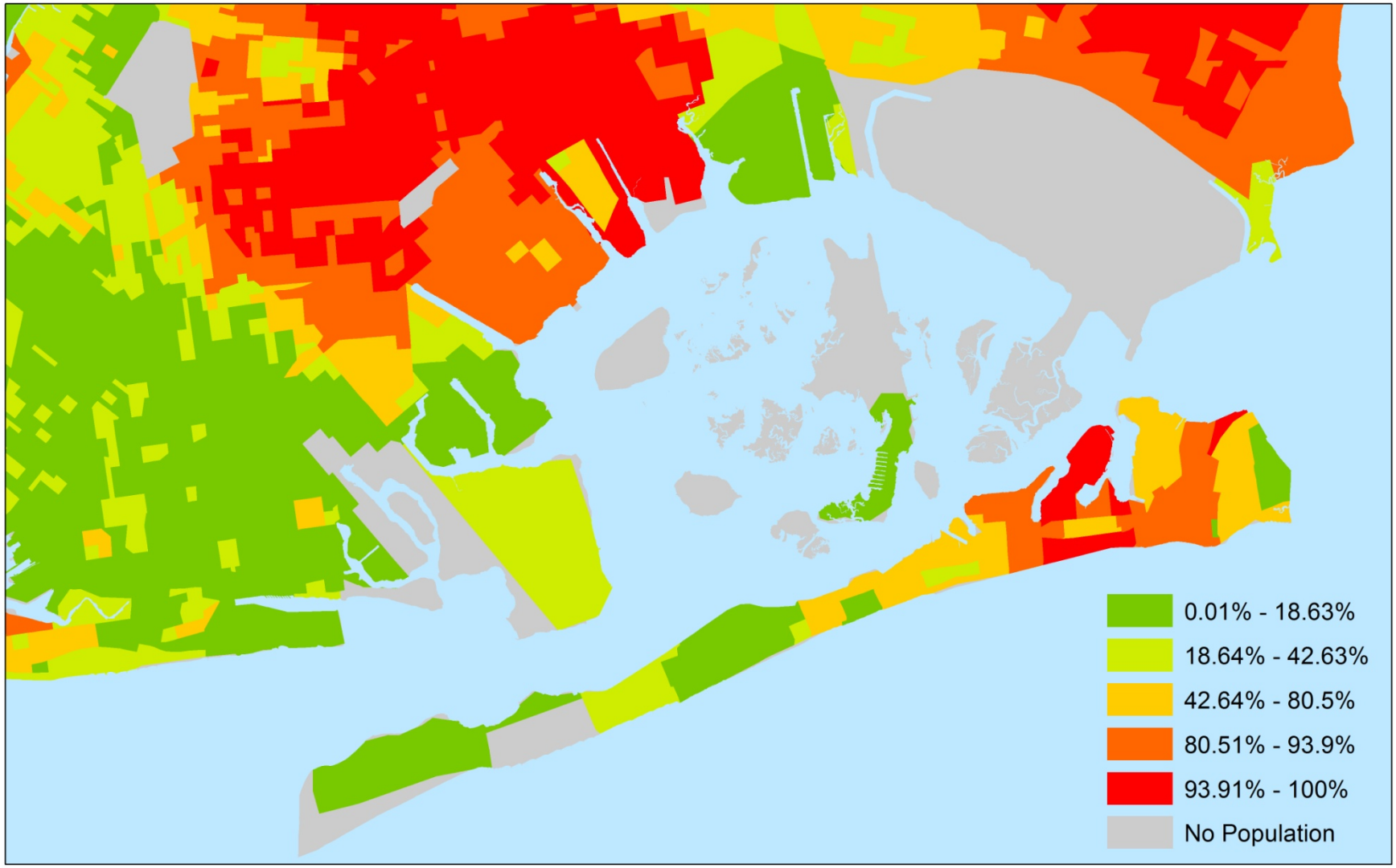
Population Density – per sq. mile by US Census Block Group – 2010

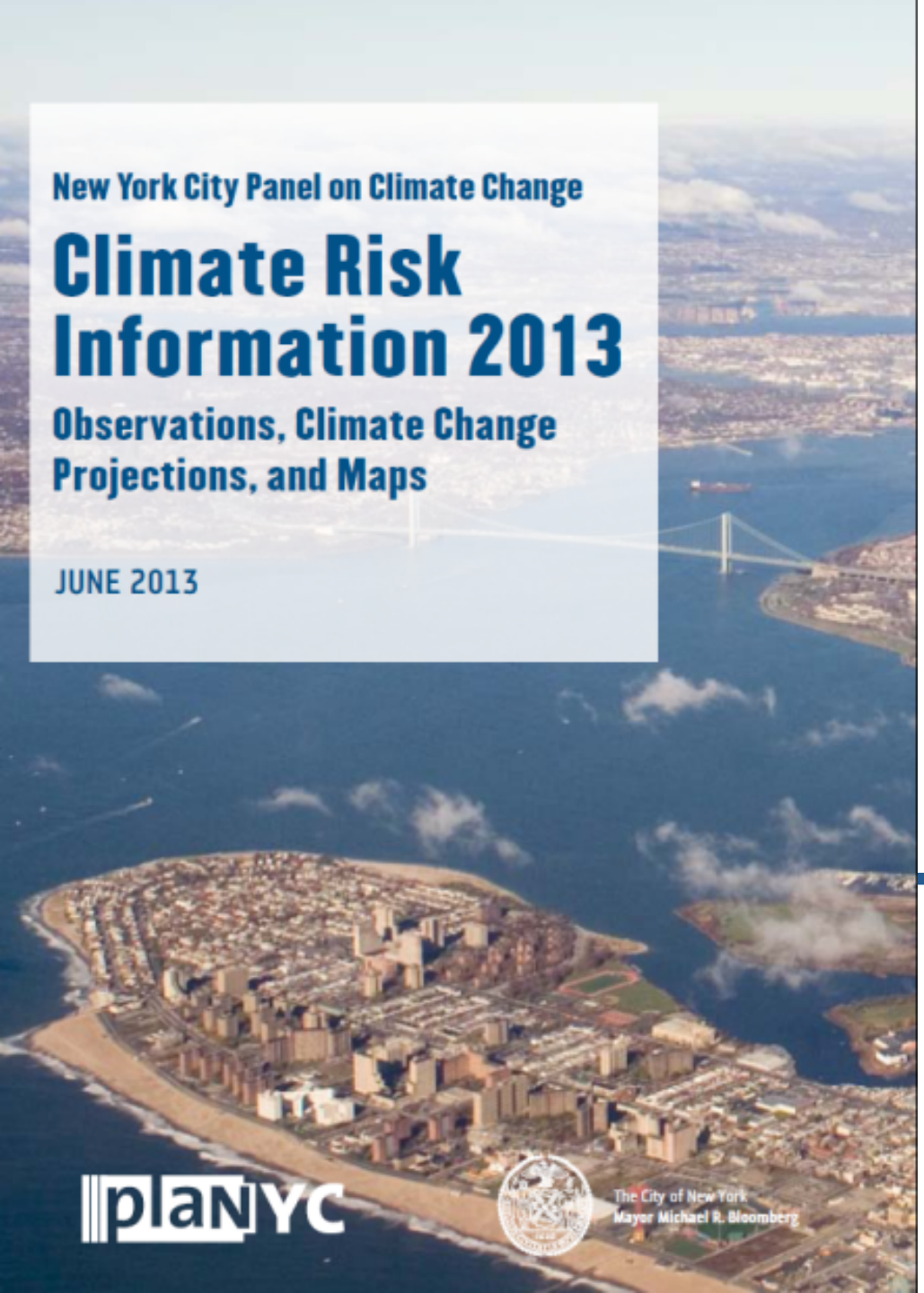


Median Household Income by US Census Tract – 2010



Percent Minority by US Census Block Group – 2010



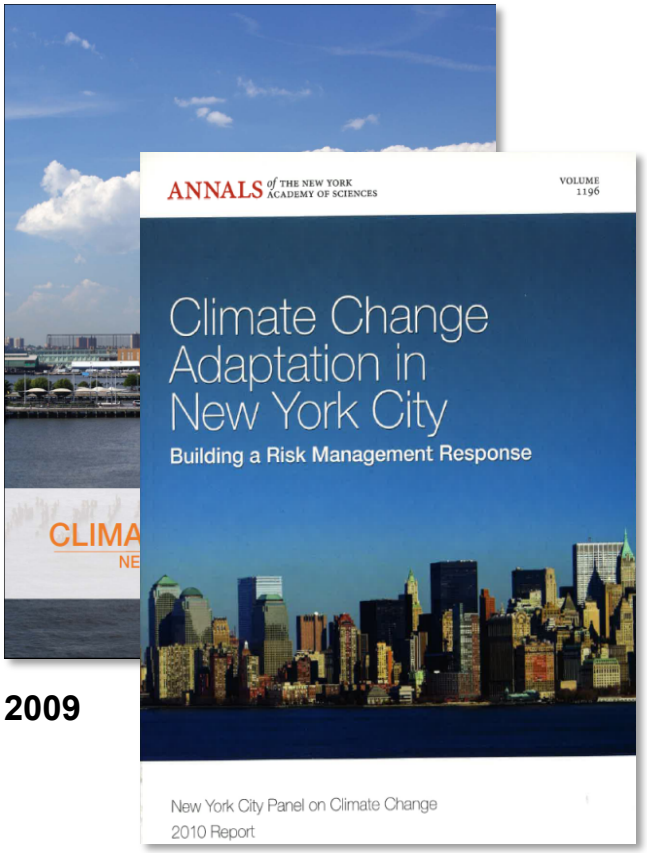


NYC PANEL ON CLIMATE CHANGE

PlaNYC

First New York City Panel on Climate Change

Mayor Bloomberg convened the NPCC in 2008 to identify future climate risks facing NYC



2009

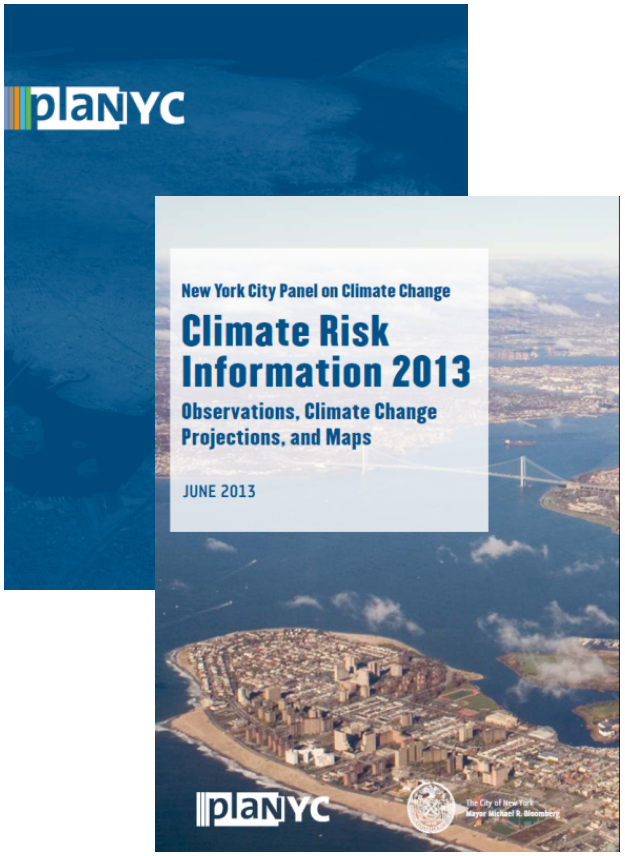
2010

Institutions Represented

- NASA Goddard Institute for Space Studies
- CUNY Institute for Sustainable Cities, Hunter College
- CUNY, NYC College of Technology
- SUNY, Stony Brook
- Swiss Re
- Accenture
- Columbia University, Earth Institute
- Rutgers University
- Wesleyan University - Gary Yohe
- New York University

Second New York City Panel on Climate Change

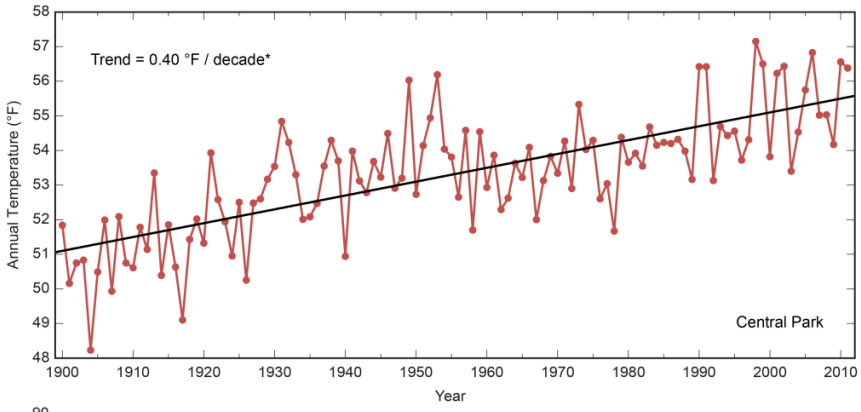
After Hurricane Sandy, Mayor Bloomberg re-convened the NPCC in January to provide updated climate risk information for the Special Initiative for Rebuilding and Resiliency (SIRR)

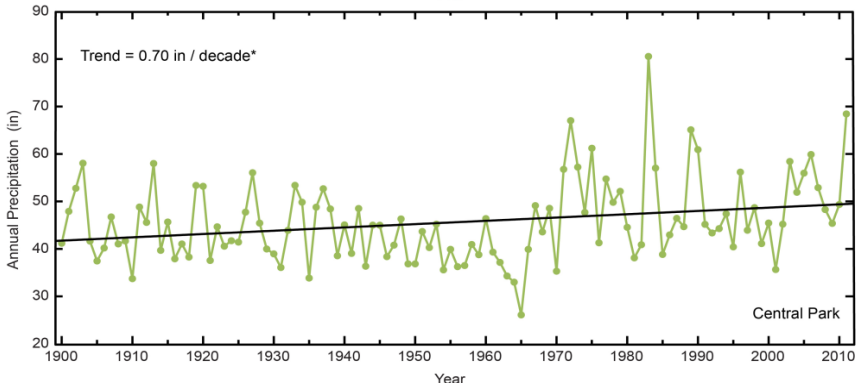


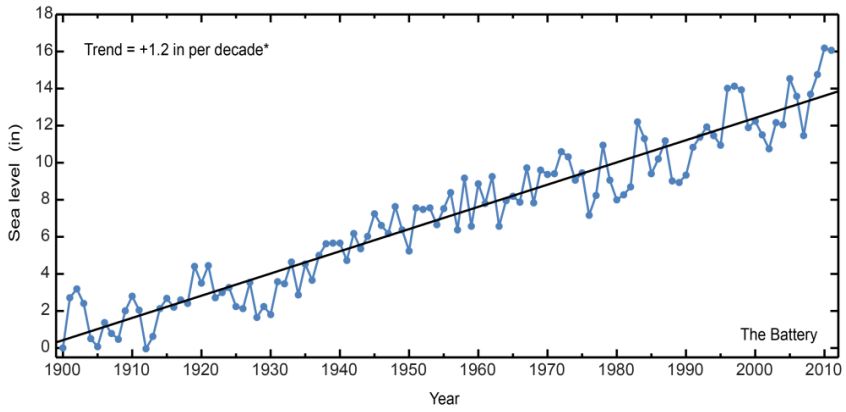
- The 2013 NPCC Climate Risk Information Report (CRI) provides new climate change projections and future coastal flood risk maps for New York City

- Both "A Stronger, More Resilient New York" and CRI reports released on June 11, 2013

NPCC2 Observed Trends







* All trends significant at the 99% level

NPCC2 CRI, 2013

Temperature

Mean annual temperature in New York City has increased 4.4°F from 1900 to 2011.

Precipitation

Mean annual precipitation has increased 7.7 inches from 1900 to 2011 (a change of 1.4 percent per decade). Year-to-year precipitation variability was greater from 1956 to 2011 than from 1900 to 1955.

Sea Level

Sea level in New York City (at the Battery) has risen 1.1 feet since 1900.

Extreme Events

Very difficult to determine trends on local scales

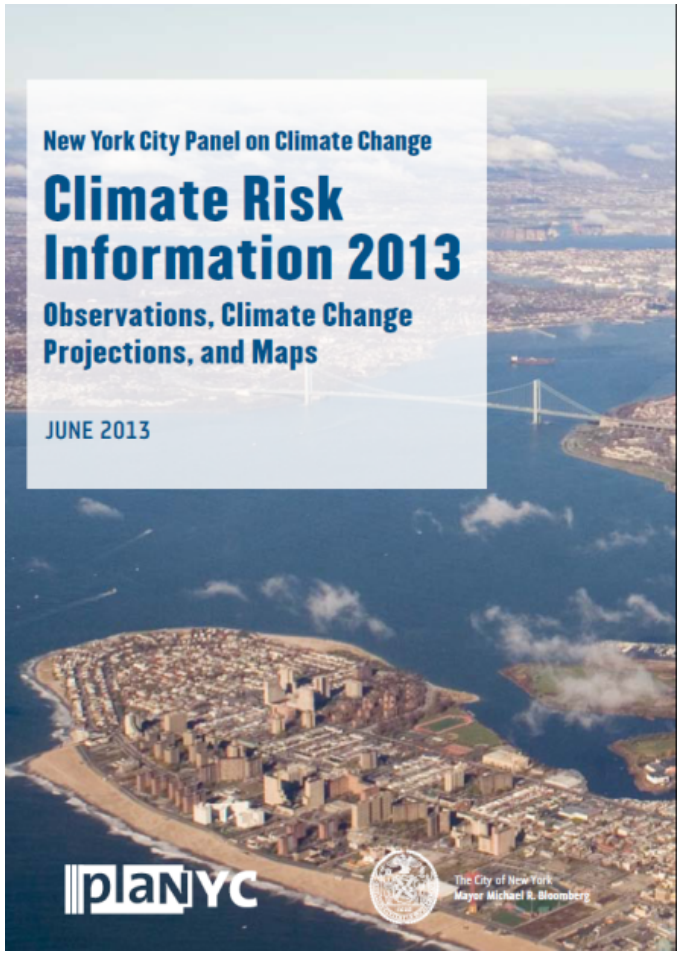
75% increase in heaviest rain events in Northeast in last 50 yrs

Increase in strength of hurricanes and in number of the most intense hurricanes in North Atlantic since early 1980s

Key Findings for Future Projected Changes

Recently released climate change projections…

- illustrate a broad-based acceleration of climate change in coming decades
- show significant climate risks for New York City, especially heat waves, extreme precipitation events, and coastal flooding
- valid for New York City ***and*** the metropolitan region
- Compared to 2009 projections:
  - No dramatic shifts or changes with respect to any one specific climate risk metric or variable
  - Small increases in some variables and timeslices

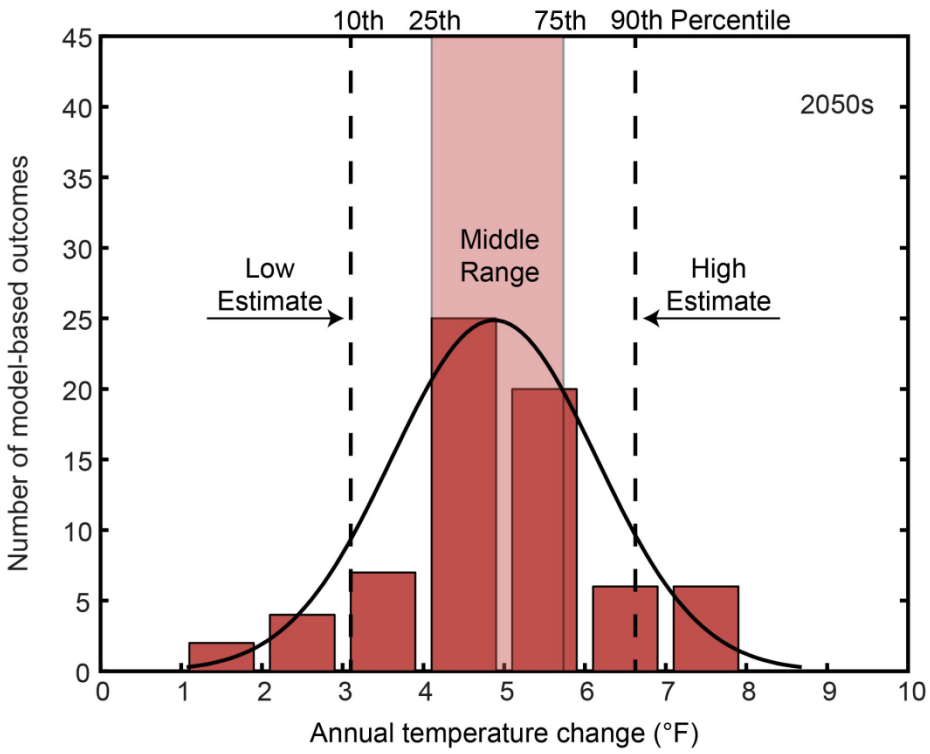


Uncertainty and Risk Management

Projections are presented in a way that facilitates risk-based decision-making

- Accomplished by:
  - Using ranges of model-based outcomes and likelihoods based on scientific literature
  - Presenting outcomes based on climate model results and different future greenhouse gas emissions
- Note that model-based outcomes do not encompass the full range of possible futures

Model-based range of outcomes for 2050s temp. change[1]



[1] Presented relative to the 1971 - 2000 base period. Based on 35 global climate models and 2 representative concentrations pathways. The 10th, 25th, 75th, and 90th percentiles of the distribution are presented.

Methods for Temperature and Precipitation

- **Variables**
  - Mean annual changes
  - Changes in extreme events

- **Quantitative projections based on global climate model simulations**

- **Coupled Model Intercomparison Project Phase 5 (CMIP5)**
  - 35 global climate models (GCMs)
  - 2 representative concentration pathways (RCP4.5, RCP8.5)
  - Timeslices: 2020s and 2050s
  - 1 ensemble member per GCM
  - Single gridbox downscaling (Horton et al., 2011)

- **Qualitative projections based on peer-reviewed scientific literature**

Mean Annual Changes

The projections show accelerating change and broad consistency with previous NPCC projections

Air temperature[1] Baseline (1971-2000): 54° F	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020s	+ 1.5°F	+ 2.0°F to 2.8°F	+ 3.2°F
2050s	+ 3.1°F	+ 4.1°F to 5.7°F	+ 6.6°F

Precipitation[1] Baseline (1971-2000): 50.1 inches	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020s	-1 percent	+ 1 to + 8 percent	+ 11 percent
2050s	+ 1 percent	+ 4 to + 11 percent	+ 13 percent

[1] Based on 35 GCMs and 2 Representative Concentration Pathways. Baseline data from NOAA National Climatic Data Center (NCDC) United States Historical Climatology Network (USHCN), Version 2 (Menne et al., 2009). 30-year mean values from model-based outcomes.

Extreme Events

			2020s			2050s		
		Baseline (1971-2000)	Low-estimate	Middle range	High-estimate	Low-estimate	Middle range	High-estimate
Heat waves[1] [2] and cold weather events	Number of days/ year with maximum temperature at or above 90°F	18	24	26 to 31	33	32	39 to 52	57
	Number of heat waves/year	2	3	3 to 4	4	4	5 to 7	7
	Average heat wave duration (in days)	4	5	5 to 5	5	5	5 to 6	6
	Number of days/ year with minimum temperature at or below 32°F	72	50	52 to 58	60	37	42 to 48	52
Intense Precipitation[1]	Number of days/ year with rainfall at or above 2 inches	3	3	3 to 4	5	3	4 to 4	5

[1]Based on 35 GCMs and two Representative Concentration Pathways. Baseline data are from the NOAA NCDC USHCN, Version 2 (Menne et al., 2009). 30-year mean values from model-based outcomes.

[2]Heat waves are defined as three more consecutive days with maximum temperatures at or above 90°F.

Extreme Events

The NPCC developed qualitative projections where future changes are too uncertain to provide local quantitative projections

	Spatial Scale of Projection	Direction of Change by 2050s	Likelihood[1]	Sources
Tropical Cyclones				
Total number	North Atlantic Basin	Unknown	--	--
Number of intense hurricanes	North Atlantic Basin	Increase	More likely than not	USGCRP, 2013; IPCC, 2012
Extreme hurricane winds	North Atlantic Basin	Increase	More likely than not	USGCRP, 2013; IPCC, 2012
Intense hurricane precipitation	North Atlantic Basin	Increase	More likely than not	USGCRP, 2013; IPCC, 2012
Nor'easters	NYC area	Unknown	--	IPCC 2012; Colle et al. 2013

Number of intense hurricanes in the North Atlantic Basin will more likely than not increase

[1] Probability of occurrence and likelihood defined as (IPCC, 2007): Virtually certain; >99% probability of occurrence, Extremely likely; >95% probability of occurrence, Very likely; >90% probability of occurrence, Likely; >66% probability of occurrence, More likely than not; >50% probability of occurrence, About as likely as not; 33 to 66% probability of occurrence.

Methods for Sea Level Rise

- **Developed single range**
  - Included future changes in polar ice sheets
- **Updated model-based components with CMIP5**
  - 24 Global Climate Models
  - 2 Representative Concentration Pathways (RCP 4.5 and RCP 8.5)
- **Revised meltwater and land-subsidence terms**
- **Added additional components**
  - Land water storage
  - Gravitational, isostatic, rotational ('fingerprint') term

Sea Level Rise Projections

Newly-released sea level rise projections account for processes not well reflected in global climate models, including the possibility of rapid ice loss

- High estimate projections are higher than the Panel's 2009 "Rapid-ice melt" Scenario
- Sea level rise for New York City is projected to exceed the global average

Sea level rise[1] Baseline (2000-2004) 0 inches	Low-estimate (10th percentile)	Middle range (25th to 75th percentile)	High-estimate (90th percentile)
2020s	2 inches	4 to 8 inches	11 inches
2050s	7 inches	11 to 24 inches	31 inches

[1] Based on 24 GCMs and 2 Representative Concentration Pathways.

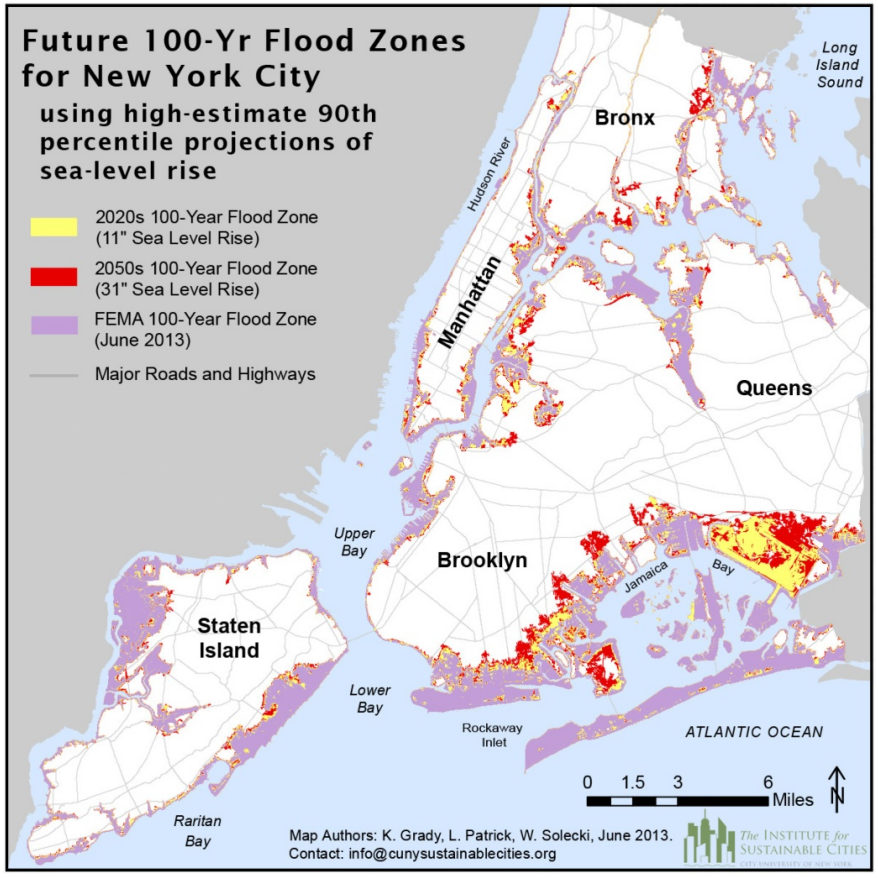
Coastal Flood Heights and Recurrence

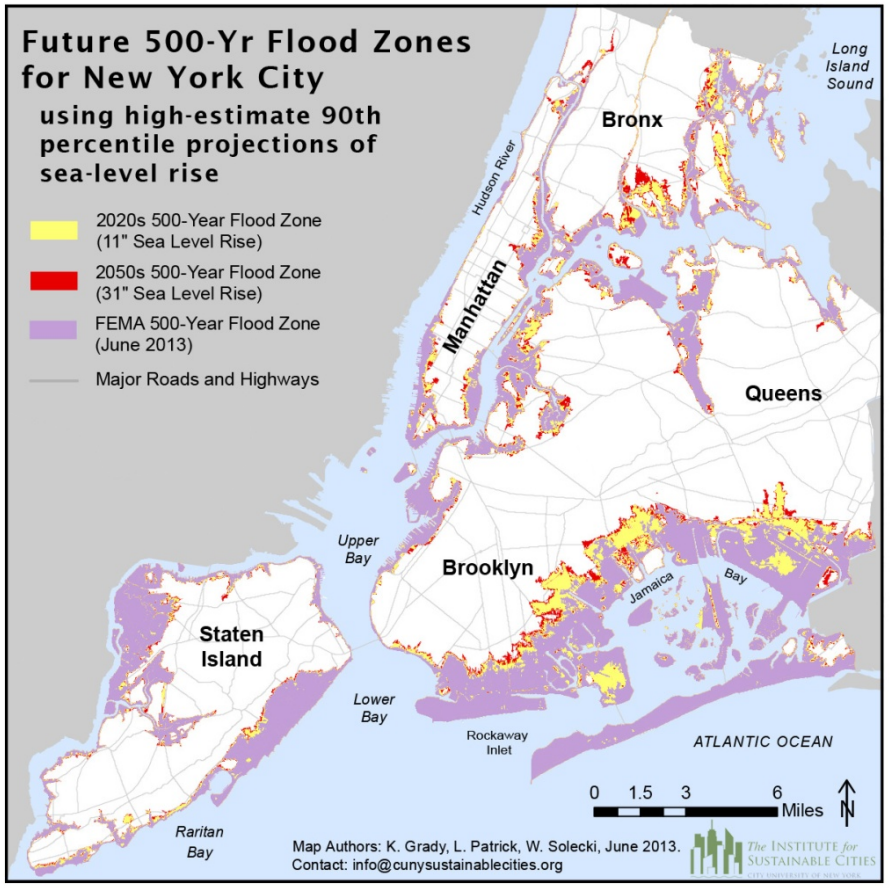
Coastal flooding is very likely to increase in frequency, extent, and height due to higher sea levels

			2020s			2050s		
		Baseline	Low-estimate	Middle range	High-estimate	Low-estimate	Middle range	High-estimate
Coastal Floods at the Battery[1]	Annual chance of today's 100-year-flood	1.0 %	1.1 %	1.2 to 1.5 %	1.7 %	1.4 %	1.7 to 3.2 %	5.0 %
	Flood heights associated with 100-year flood (stillwater + wave heights)	15.0 feet	15.2 feet	15.3 to 15.7 feet	15.8 feet	15.6 feet	15.9 to 17 feet	17.6 feet

[1]Estimates in the top row refer to the values for projected sea level rise. Low-estimate indicates 10th percentile, middle range indicates 25th to 75th percentile, and high-estimate indicates 90th percentile. Flood heights for the 2020s and 2050s are derived by adding the sea level rise projections for the corresponding percentiles to the baseline values. Flood heights are referenced to the NAVD88 datum.

Future Coastal Flood Risk Maps – Became a Critical Component of SIRR



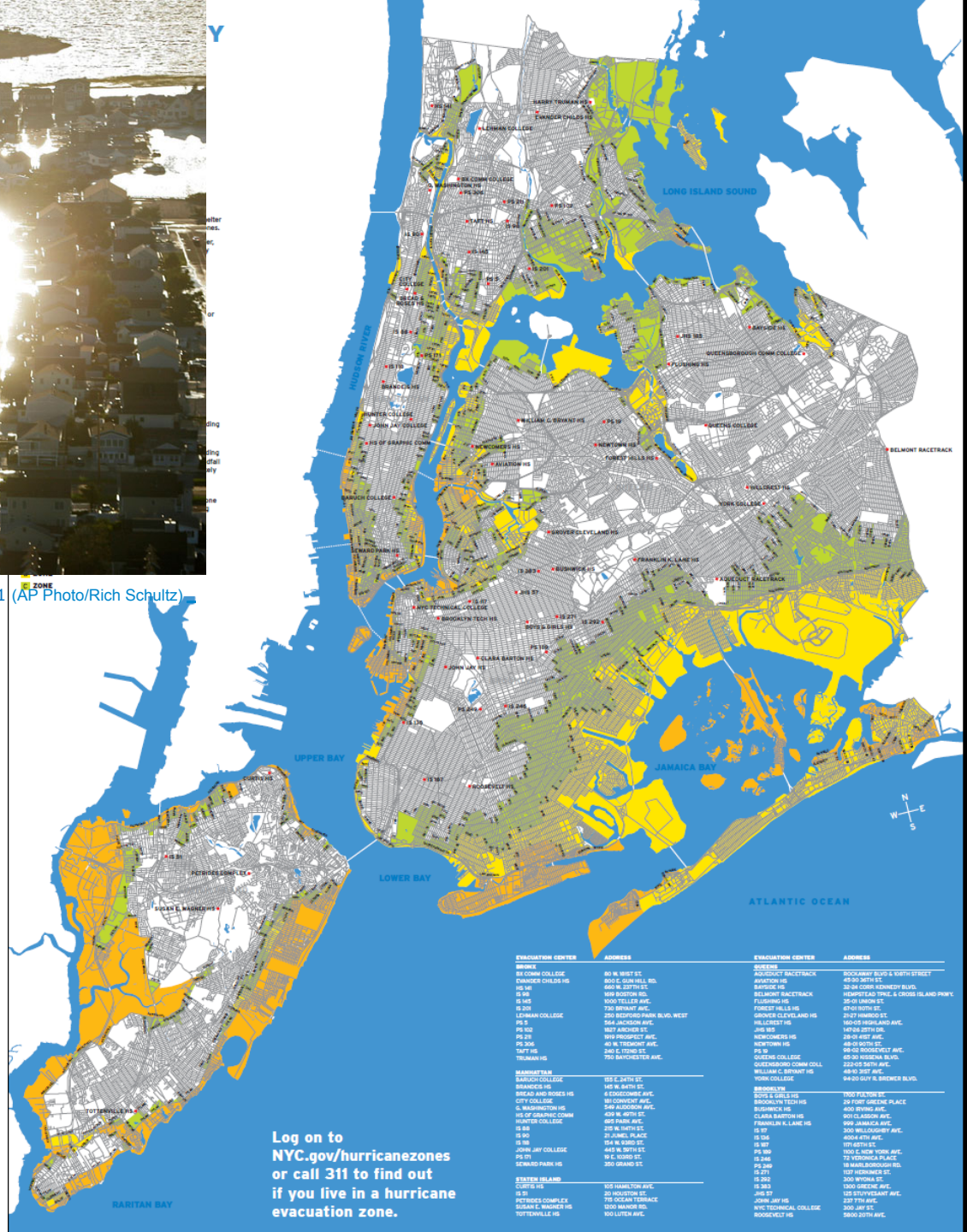


The potential areas that could be impacted by the 100-year and 500-year floods in the 2020s and 2050s based on projections of the high-estimate 90th percentile sea level rise scenario

Vulnerability and Adaptation Implications of Hurricane Irene and Tropical Storm Lee

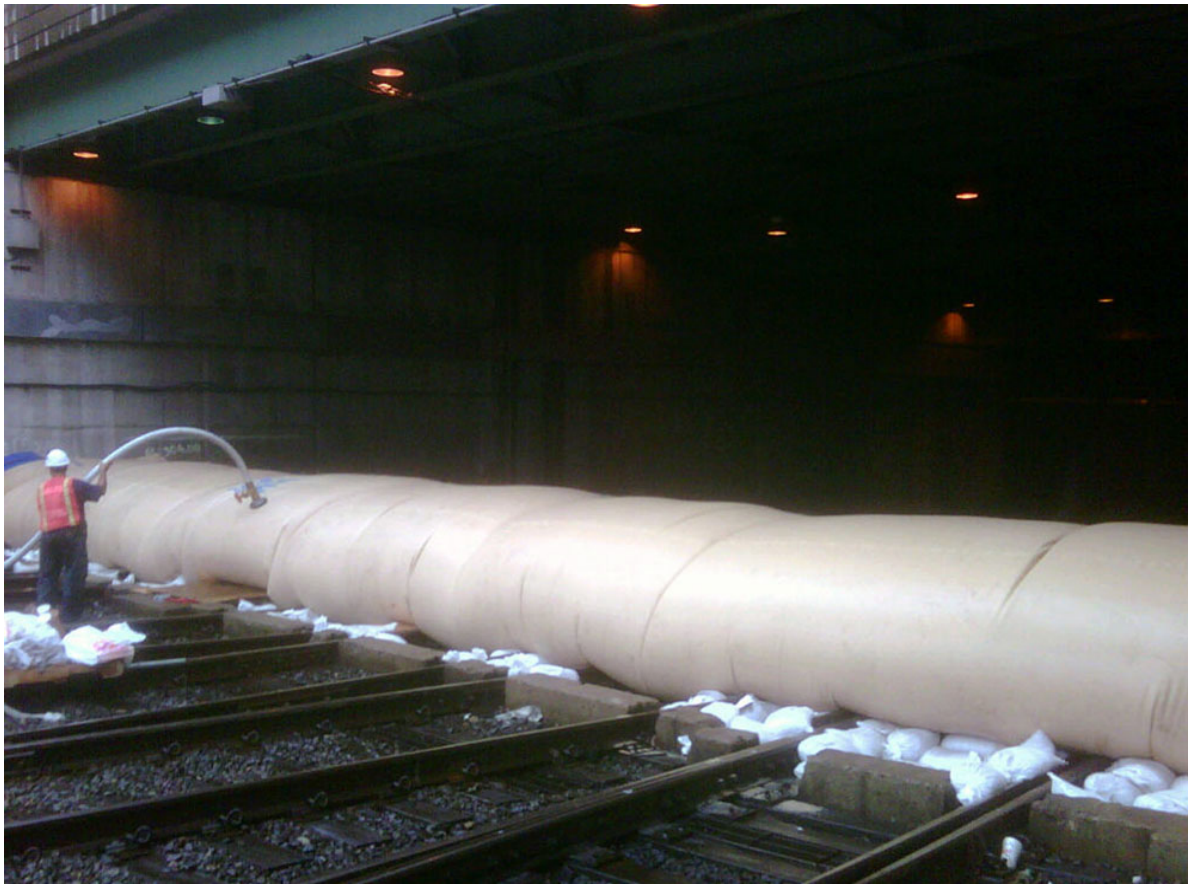
Long Beach Island, New Jersey, are flooded after Hurricane Irene, August 2011 (AP Photo/Rich Schultz)

Hurricane Irene in late August 2011 – 1st ever mandatory evacuation (orange colored zone)



Urban Sectors and Services Impacts and Vulnerabilities

- Water and waste water
- Energy
- Transportation
- Telecommunications
- Built Environment
- Coastal Zones
- Public health

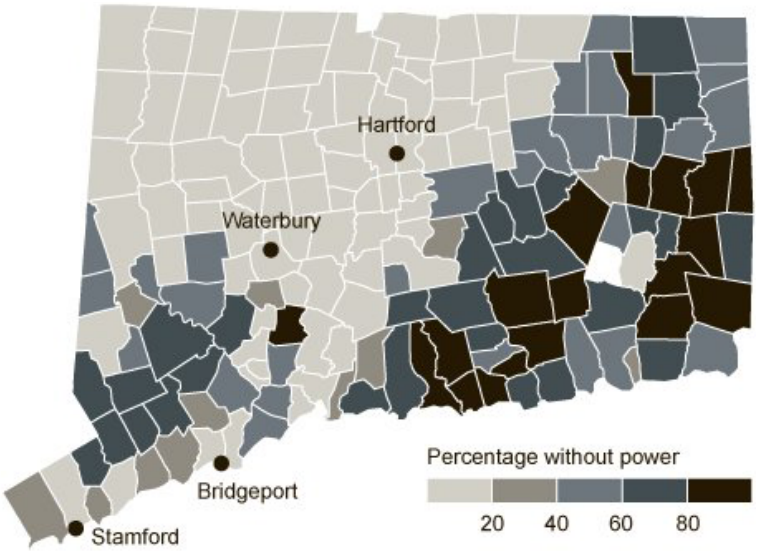


An New York State Metropolitan Transportation Authority employee fills an "AquaDam," placed across the Long Island Rail Road tracks at New York City's Penn Station, on Saturday, August 27, 2011. The temporary barrier was installed to help keep flood waters stirred up by Hurricane Irene out of Penn Station's tunnels.

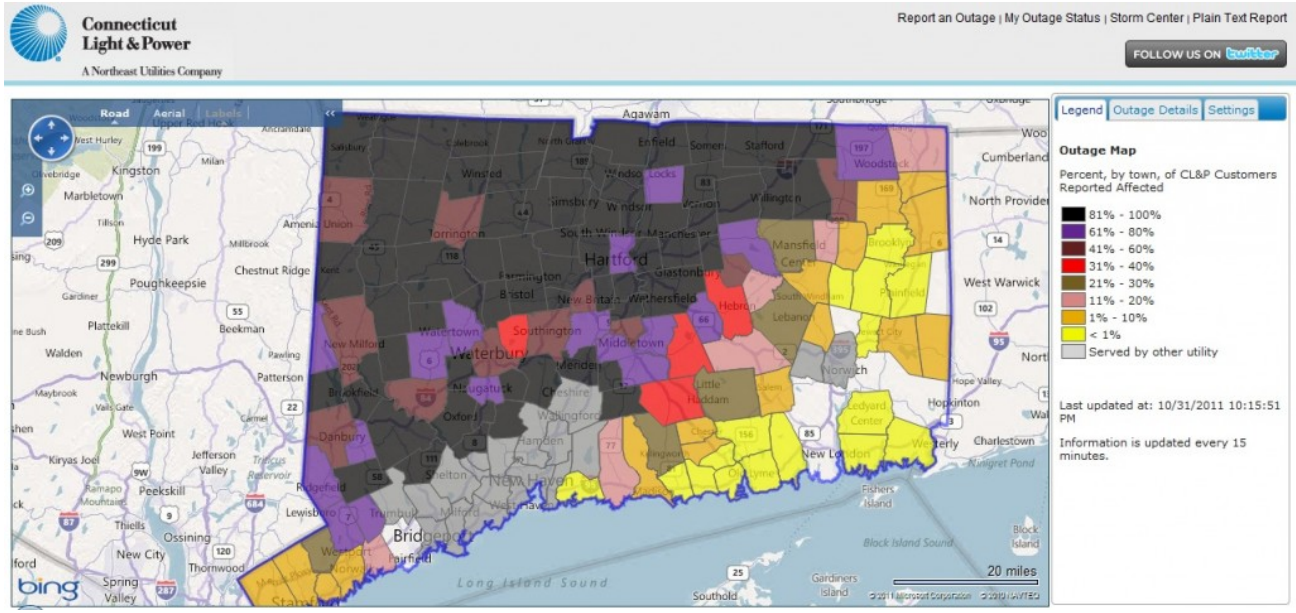
(AP Photo/NY Metropolitan Transportation Authority, John Kettel)

Key Impacts and Vulnerabilities - Energy

- Exurban loss of power and blackouts, wind storms lead to extensive service disruption
- Energy infrastructure and pipelines vulnerability

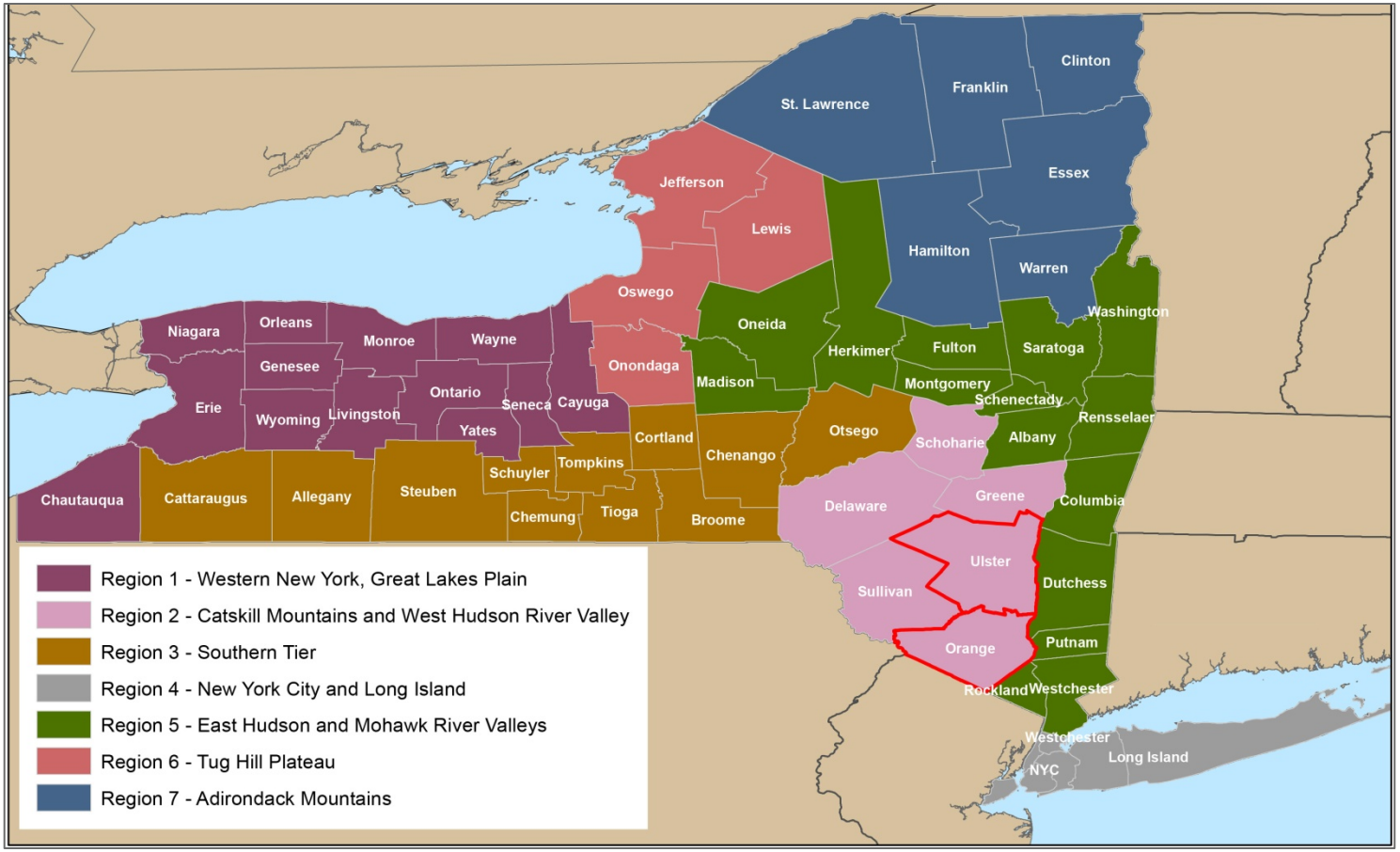


Percent without power – Sept. 1, 2011 – after Hurricane Irene



Percent without power – Oct. 31, 2011 – after Nor'easter Snow Storm

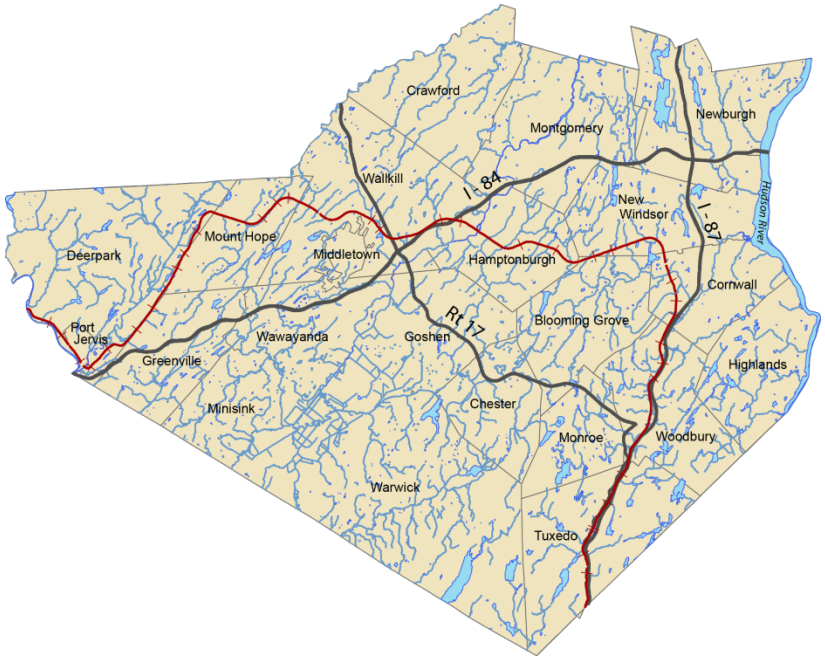
Irene and Lee Impacts on Two Exurban Counties in New York State



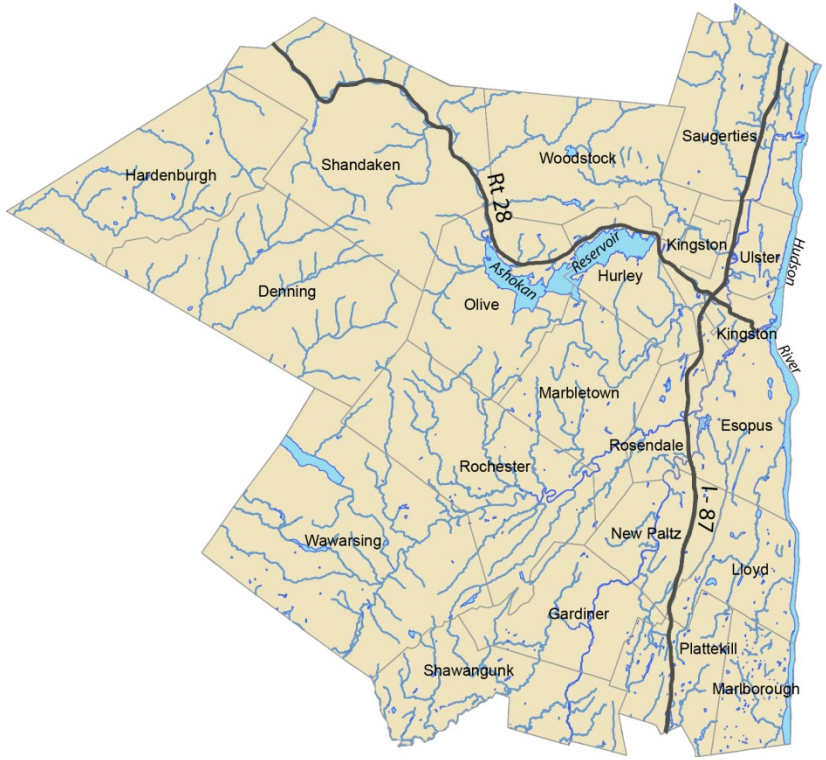
Orange and Ulster Counties, situated in the Greater Catskills and West Hudson Valley area (regions defined by *NYSERDA ClimAID* report)

Study Counties

A) Orange County NY showing major waterways, county towns and villages. Metro North's Port Jervis line is highlighted in Orange County in red.



B) Ulster County showing major waterways, county towns and villages.



Emergent Vulnerabilities

- **The transportation, tourism and agricultural sectors were the most heavily impacted by the flooding.** The vast majority of the impacts and costs were the result of flooding and river scourging. Little wind or other weather related damage was observed.

- **Emergent (i.e., new or previously not recognized) vulnerabilities and new patterns of flood exposure were present.** Flooding took place in areas where it had not previously flooded or not flooded in the memory of local interviewees. Damage occurred in higher elevation areas that are not floodplains. A number of people noted that the predicted return interval for floods appears not to be a good indicator of actual frequency.

- **Newly revealed infrastructural weaknesses**. Some of the most noteworthy flood damage in upland areas occurred as the result of flooding of roadside ditches, where the volume of water present vastly exceeded capacity leading to road washouts.

Emergent Vulnerabilities

- **Many properties that had never experienced flooding before were flooded as the result of the Irene and/or Lee.** A new pattern of flood exposure and new uncertainties in real estate markets could emerge. Although the effect of the storm events on housing and real estate values in the region is difficult to disentangle from the general economic downturn that has affected values in the region over the past several years, anecdotal evidence suggests that a decline in sales prices occurred in areas that were flooded, including properties that were flooded for the first time.

- **Effects on availability of affordable housing.** Loss of affordable housing in the region as the result of the flooding was a concern. Affordable housing in the region is already limited and some of this housing (e.g., a trailer park in Ulster County) was washed out by flooding and not expected to be rebuilt. Given the possibility of significant increases in flood insurance costs, the potential for higher cost and reduced availability of affordable housing is another type of emergent vulnerability.

Damage to the Port Jervis line in Orange County. Source: MTA

Looking North on Wallkill River – Pellets Island area

Community Response and Adaptation

Trees cleared along Wallkill River “high flow” channel near Pellets Island in Orange County

Conclusions: Connections to Integrated Assessment Modeling

- Timing of impacts
- Rate of change
- Emergent vulnerabilities
- Risk, uncertainties, cost curves
- Actionable science – relevant to engineering world
- Uneven distribution of impacts and vulnerabilities
- Urban system complexity – opportunity and challenge
- Defining indicators and monitoring schemes

Post Hurricane Sandy Adaptation Emerging Challenges and Opportunities

- Baseline climate science data (and modeling if possible)
- Rapid assessment strategy of impacts, vulnerabilities, opportunities for increased resiliency
- Long term goal (e.g. resilience) as frame for action
- Interagency cooperative (within govt. and across governments)
- Integrate new risk and hazard measures (in conjunction with traditional measures – e.g. 1% maps)
- Climate protection levels – access codes, standards, and regulations, and monitoring and indicators for climate change robustness
- System perspective – for identifying tipping points/cascade impacts and vulnerabilities
- Climate science data and mapping uncertainties (besides cost uncertainties)
- Greater transparency of data analysis and data interpretation
- Promote greater post extreme event learning – pushing open the policy window

Conclusion – Recent Hurricane in NYC metropolitan region seem to be revealing emerging vulnerabilities to climate change

(photo source F. Montalto)

Hurricane Sandy Damage in Oakwood Neighborhood (Staten Island, NY)

Thank You. wsolecki@hunter.cuny.edu