CHANGE AGENTS FOR RESILIENT INFRASTRUCTURE

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Cornell University

PEER

RESILIENT INFRASTRUCTURE

CORNELL UNIVERSITY

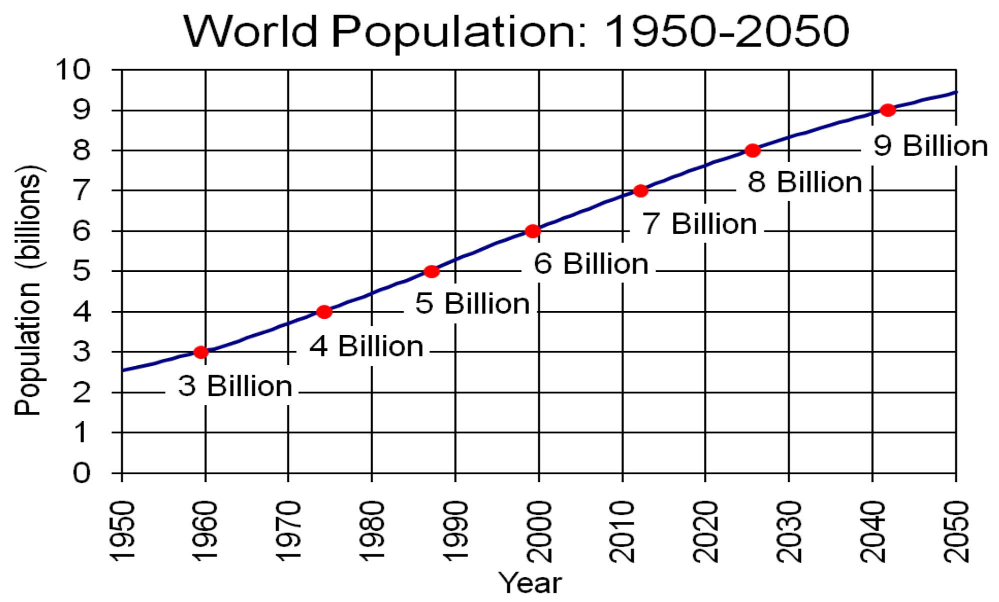
TOPICS

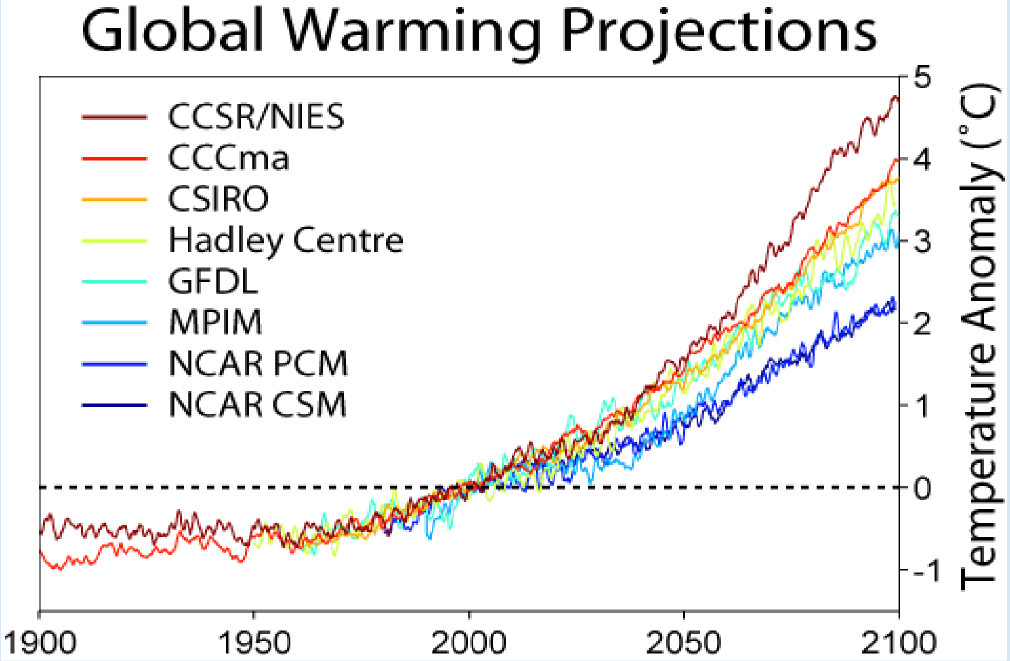
- Global Hazards
- WTC Disaster & Hurricane Katrina
- Hurricane Sandy
- L Line Tunnel

TOPIC

- **Global Hazards**

GLOBAL TRENDS





DISASTER DU JOUR

3
- 2004 Sumatra-Andaman EQ & Tsunami

228,000 dead

- 2005 Hurricane Katrina

6
- 2010 Maule Earthquake
- 2010 Haiti Earthquake

~ 120,000 dead

- 2010-11 Canterbury Earthquake Sequence

4
- 2011 Tohoku Earthquake & Tsunami

16,000 dead

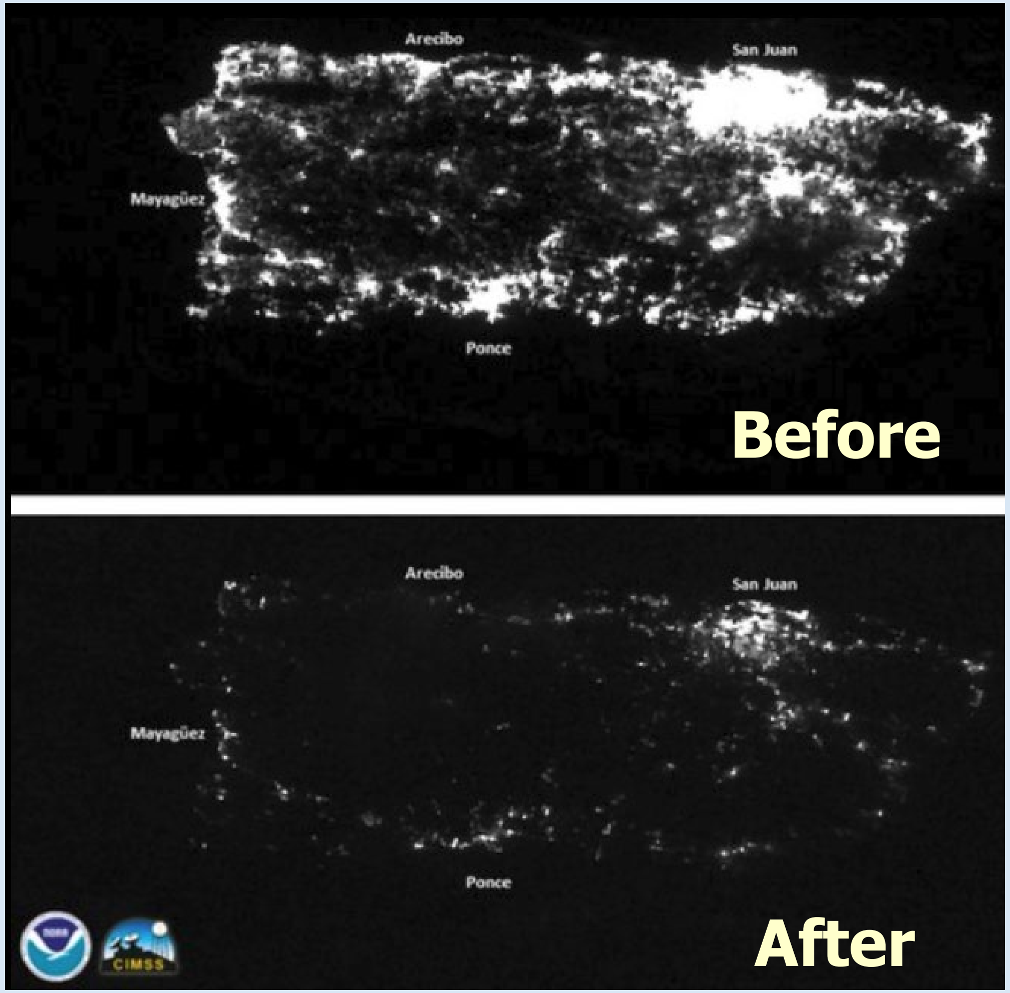
- 2012 Hurricane Sandy
- 2013 Typhoon Haiyan

DISASTER DU JOUR 2017

- Hurricane Harvey
- Hurricane Irma
- Chiapas Earthquake
- Hurricane Maria
- Mexico City Morelos Earthquake
- Sonoma Santa Rosa Fires

HURRICANES HARVEY, IRMA, AND MARIA

- HURRICANE HARVEY $ 125 B
- HURRICANE IRMA $ 50 B
- HURRICANE MARIA $ 90 B



TOPIC

- **WTC Disaster/Hurricane Katrina**

EVOLUTION OF POLICY

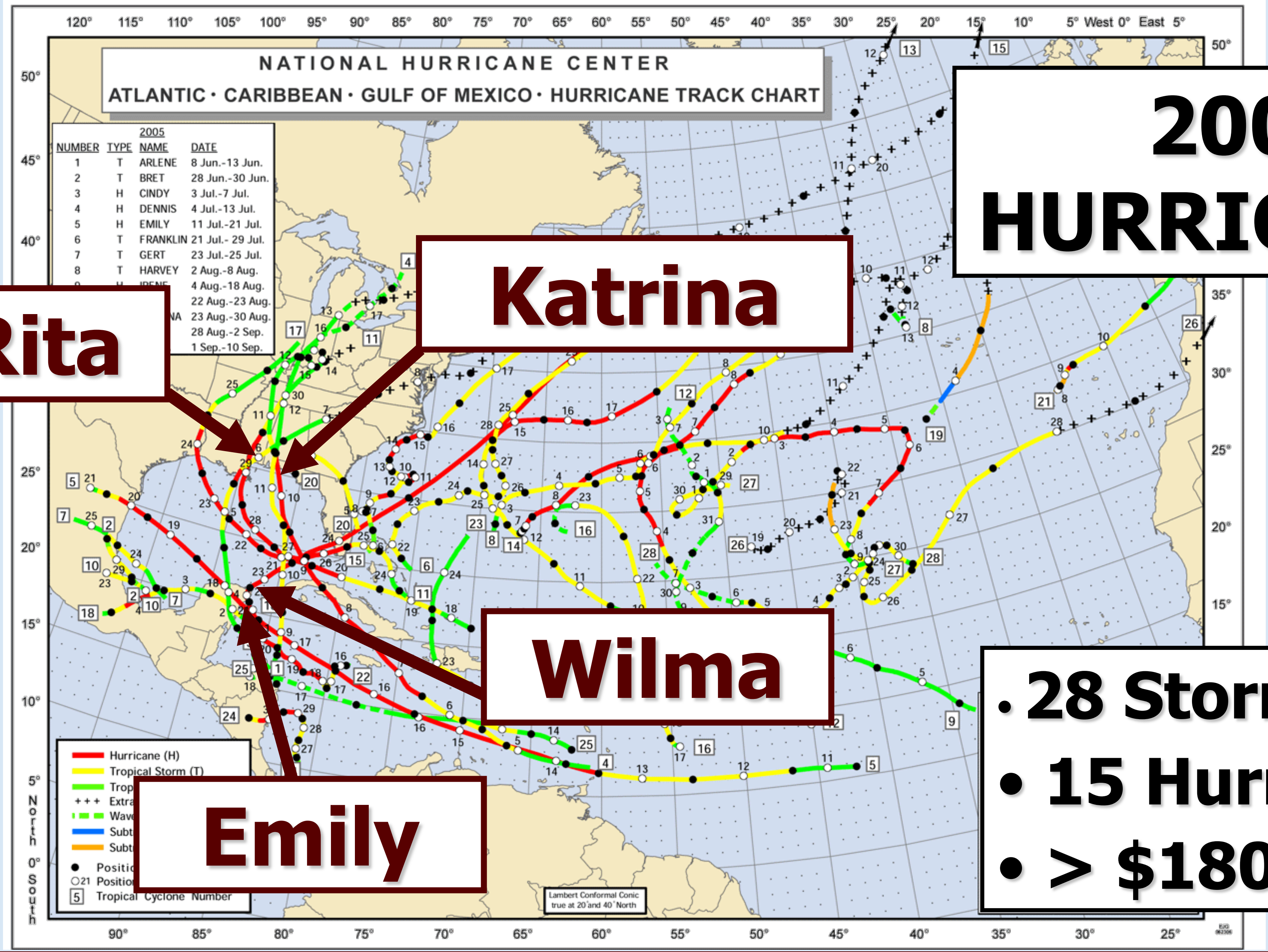
SEPTEMBER 11

- Protection of Critical Infrastructure

Hurricane Katrina:

- Resilient Communities

2005 HURRICANES



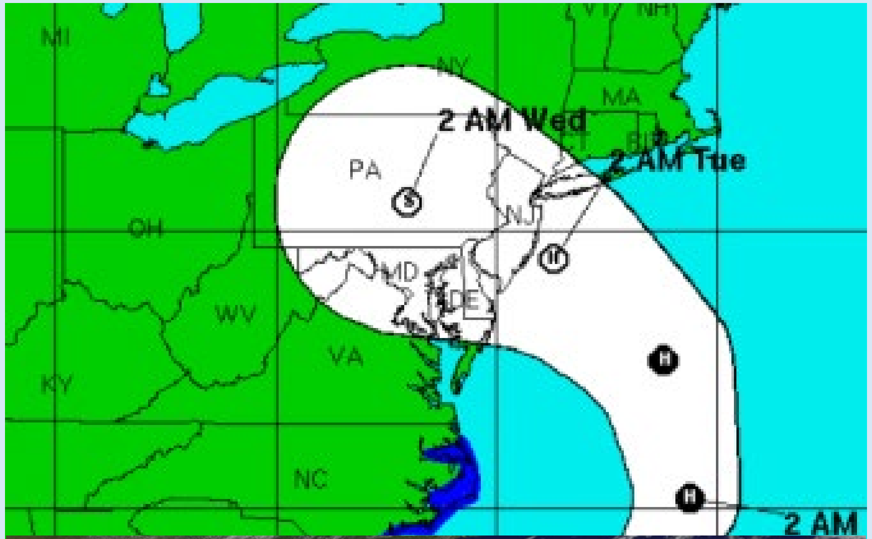
- 28 Storms
- 15 Hurricanes
- > $180 Billion

TOPIC

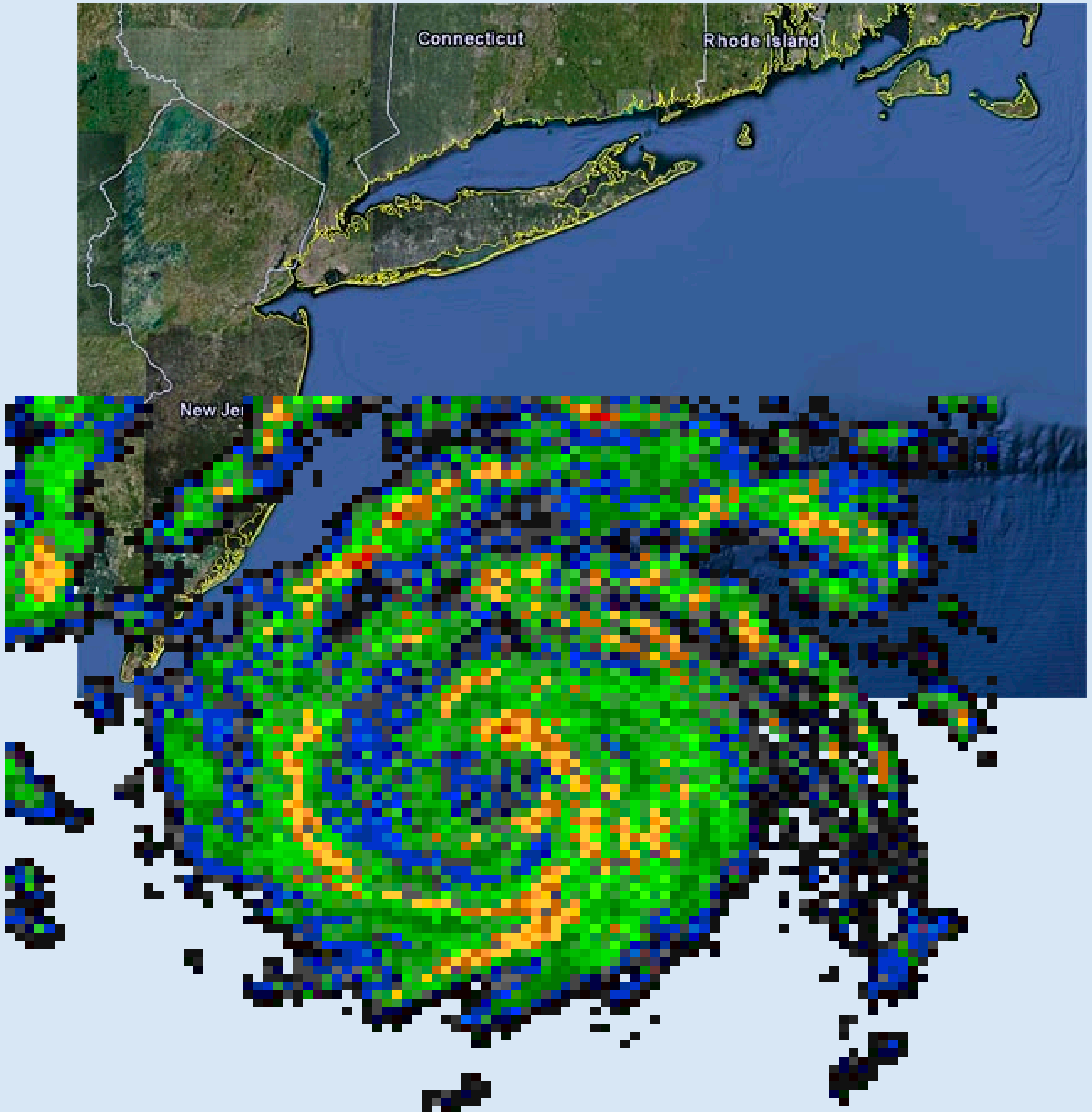
- **Hurricane Sandy**

HURRICANE SANDY (2012)

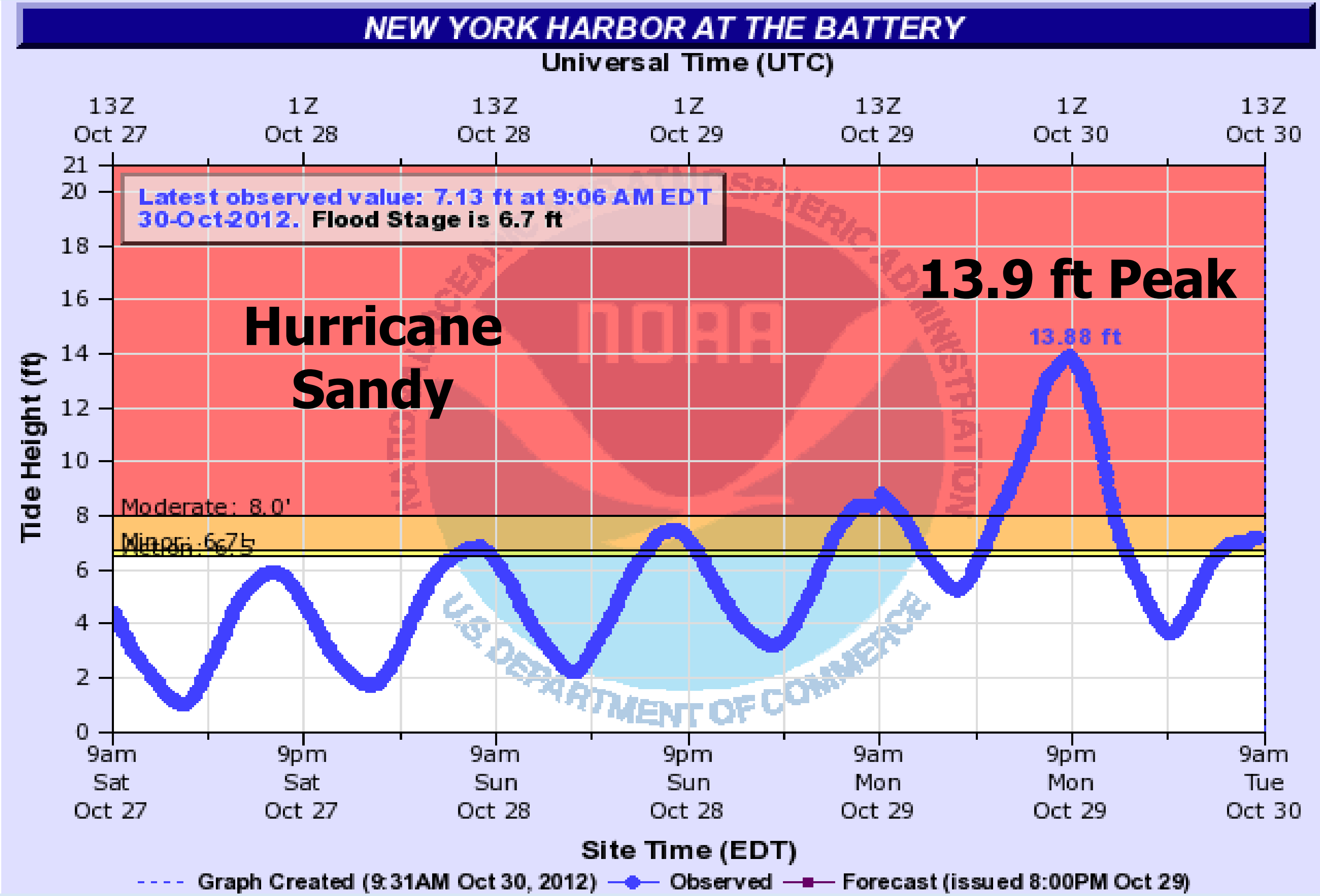
- **159 Killed in US**
- **$68 Billion Property and Business Losses (Sandy Task Force)**
- **8.5 Million Homes & Businesses Without Power**
- **NYC Evacuation & Shutdown of MTA & Public Transport**
- **Wall Street Shut 2 Days**
- **Record Flooding (Surge)**
- **Direct Hit**



SUPERSTORM SANDY



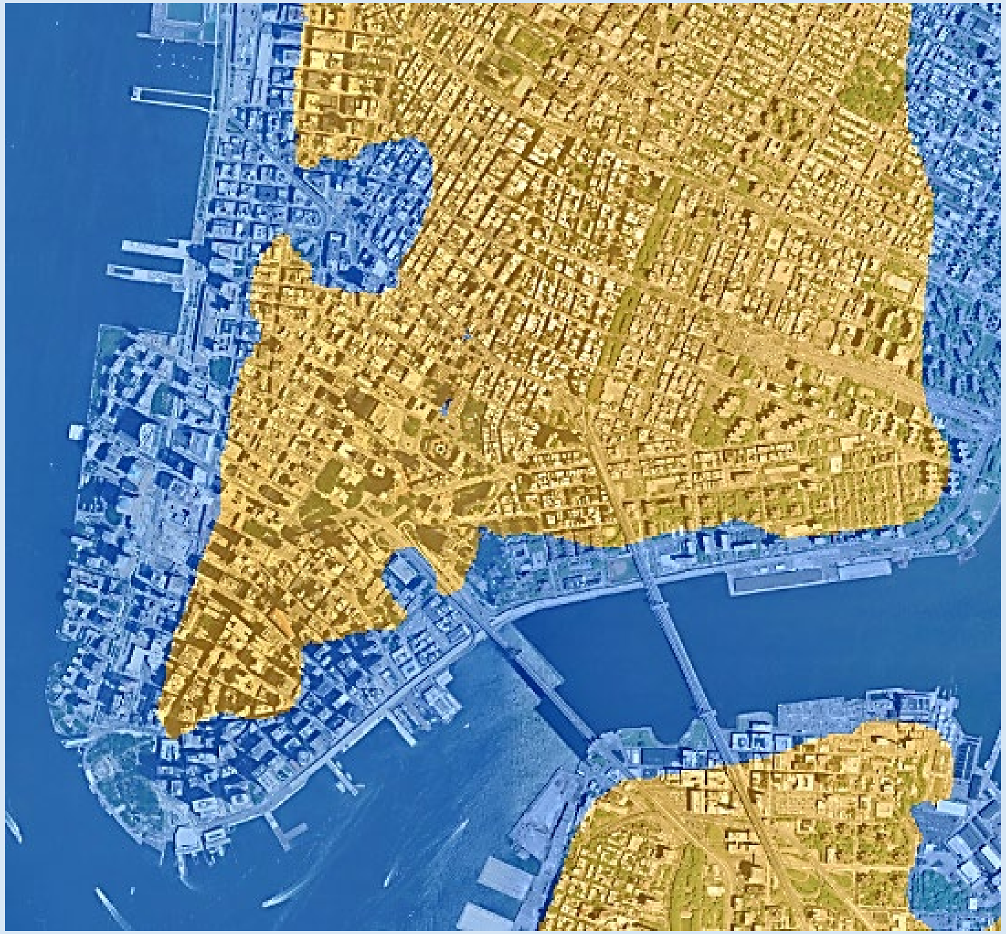
STORM SURGE AT BATTERY



13.9 ft (4.23 m) - 2.0 ft ~ 11.9 ft (3.62 m) Surge

HURRICANE SANDY INNUNDATION

HURRICANE SANDY INNUNDATION



HURRICANE SANDY INNUNDATION

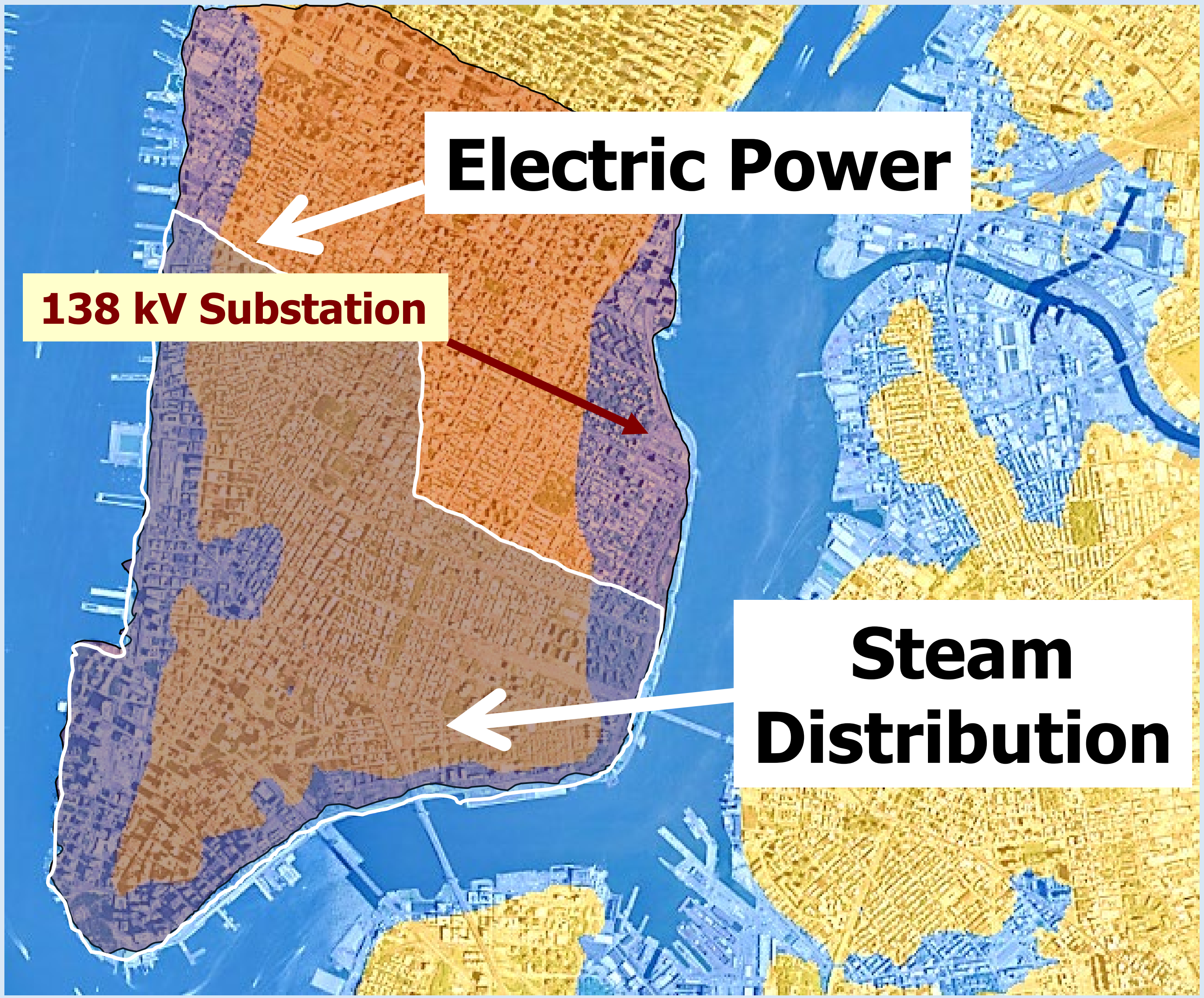
Flooded Tunnels

- 7 Subway Tunnels
- Brooklyn Battery
- Midtown Tunnel
- PATH Tunnels
- Holland Tunnel
- Amtrak East River
- Amtrak North River

HURRICANE SANDY INUNDATION

NYC Steam System

- **105 mi. (170 km)**
- **10 – 30 in. (250 – 750 mm) dia.**
- **400 psi. (2.8 MPa) transmission**
- **140 – 180 psi (1 -1.25 MPa) distribution**
- **415 – 475° F (~ 230° C)**



2007 Steam Line Explosion

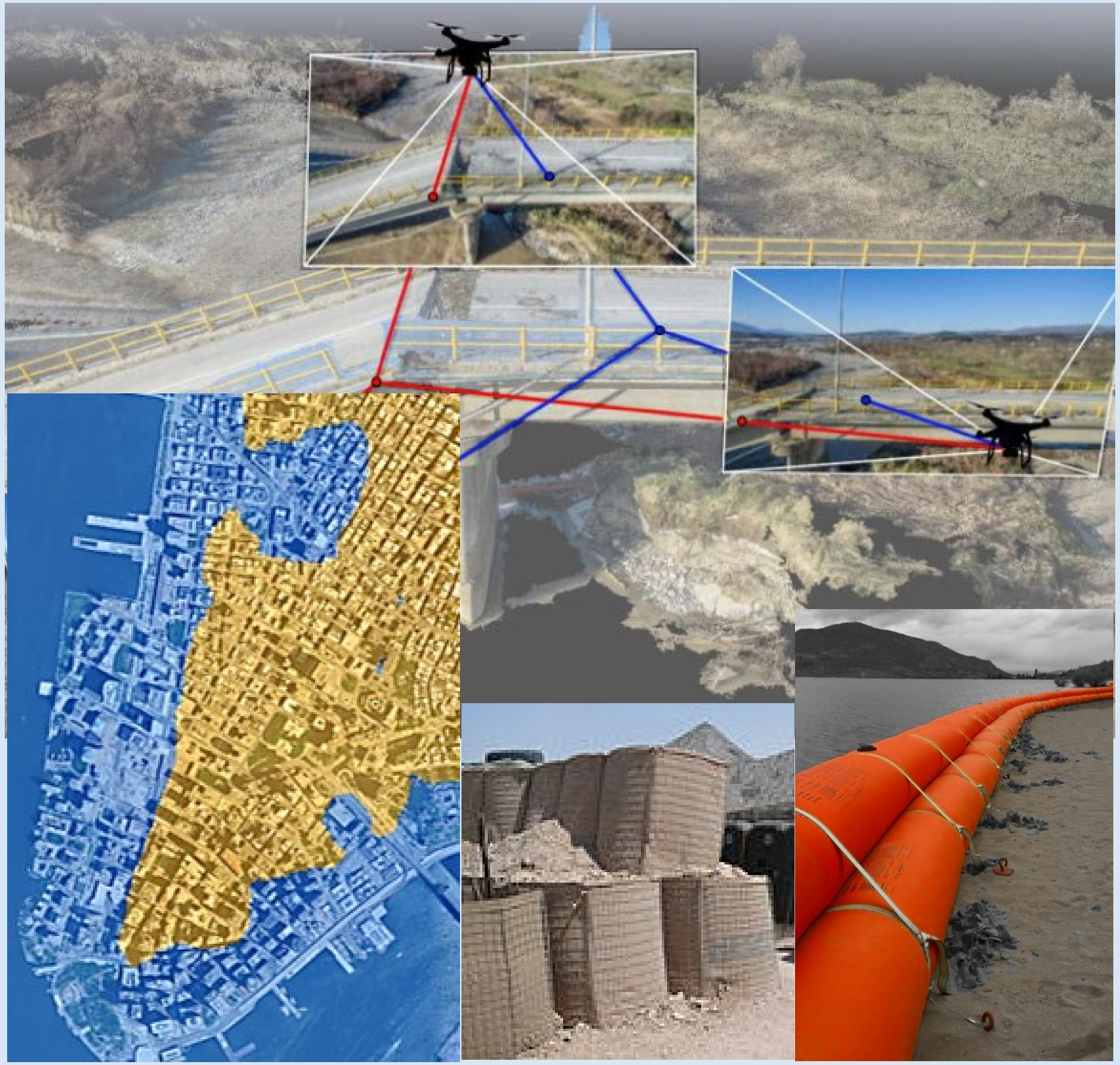
"There is no reason to believe this is anything other than a failure of our infrastructure." - **Mayor Bloomberg**

LESSONS FROM HURRICANE SANDY

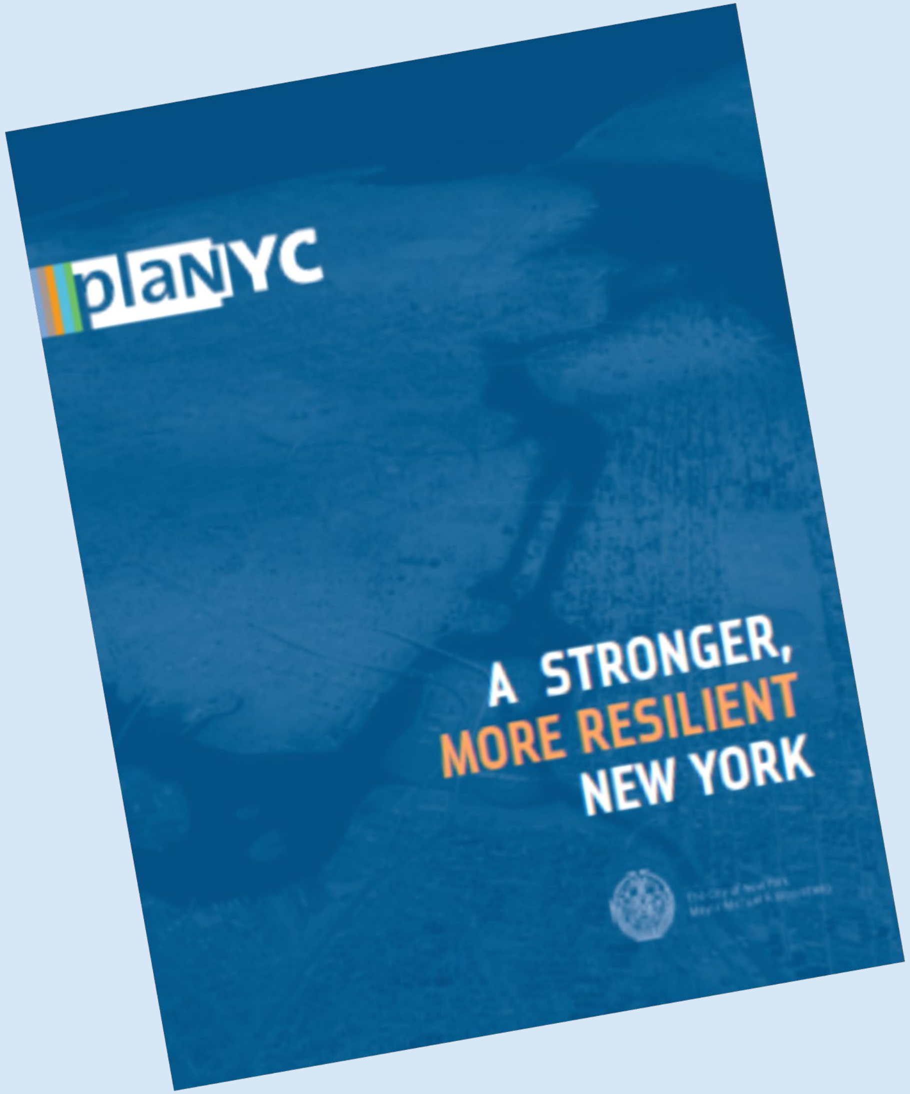
- **Long Tail Recovery**
- **Protect Against Tunnel Flooding**
  - **Doors, dikes, and diversions**
- **Back-up Power for Water Supply on Buildings**
- **Remove Diesel Generators from Basements and Secure Fuel Tanks and Fuel Lines**

TECHNOLOGY FROM HURRICANE SANDY

- UAV Equipment and Structure from Motion Photogrammetry
- BIM for Flood Zones
  - 3-D Community Models
  - Topography & Bathymetry
- Deployable Flood Protection
  - HESCO Bastions
  - Tiger Dams

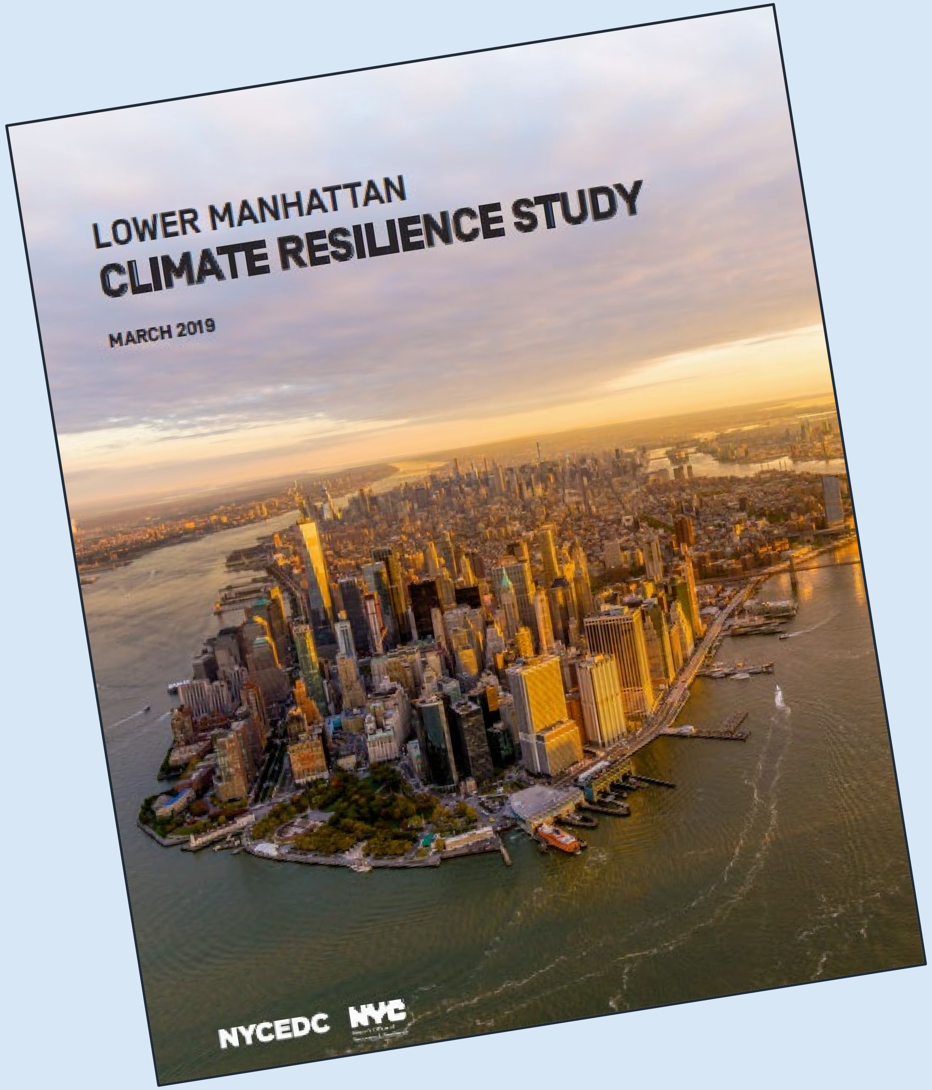


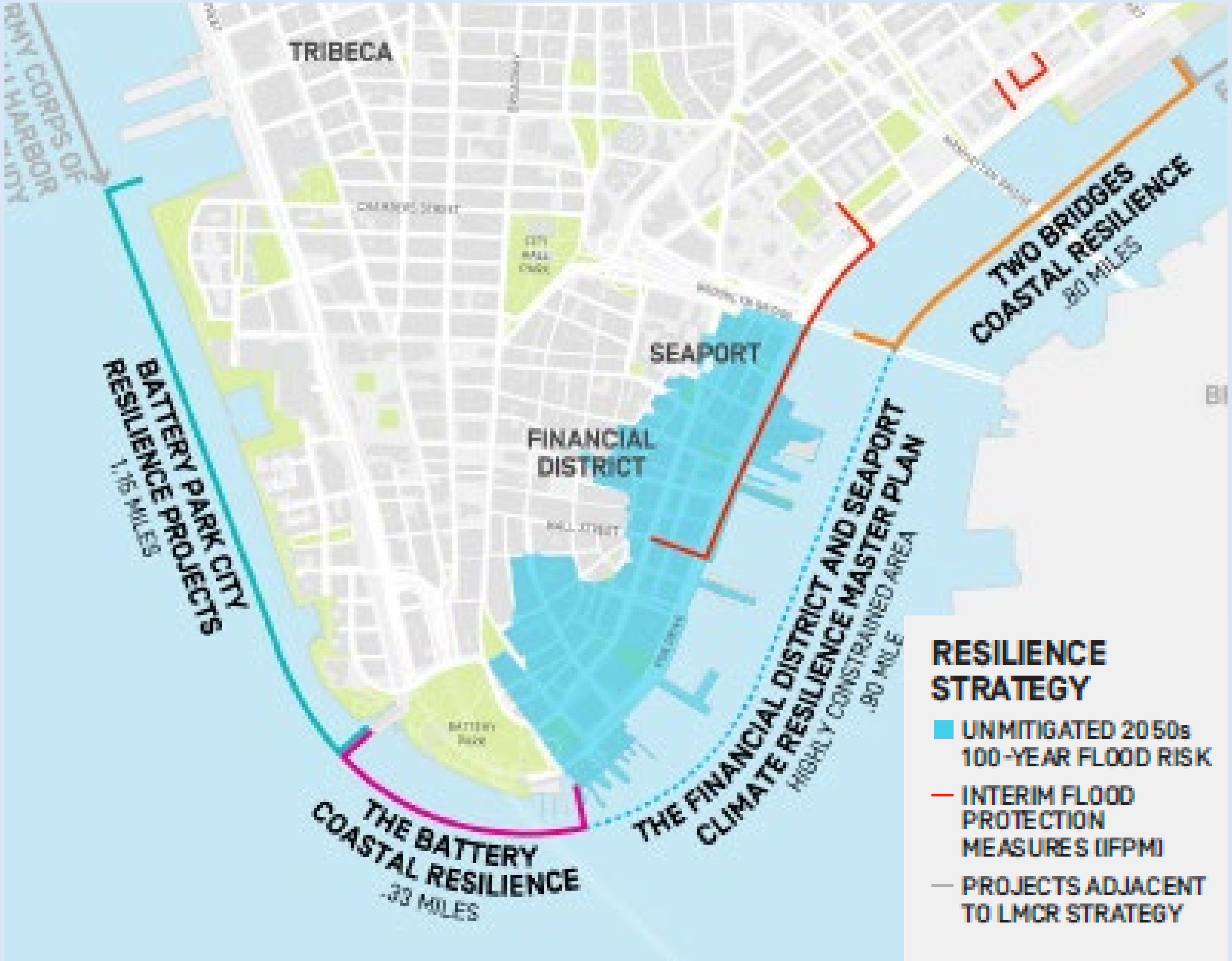
NEW YORK CITY RESILIENCE PLAN



- Authorized by Mayor Bloomberg
- Hurricane Sandy Effects
- Science of Coastal Flooding
- Engineering Options
- Community Plan by Neighborhoods

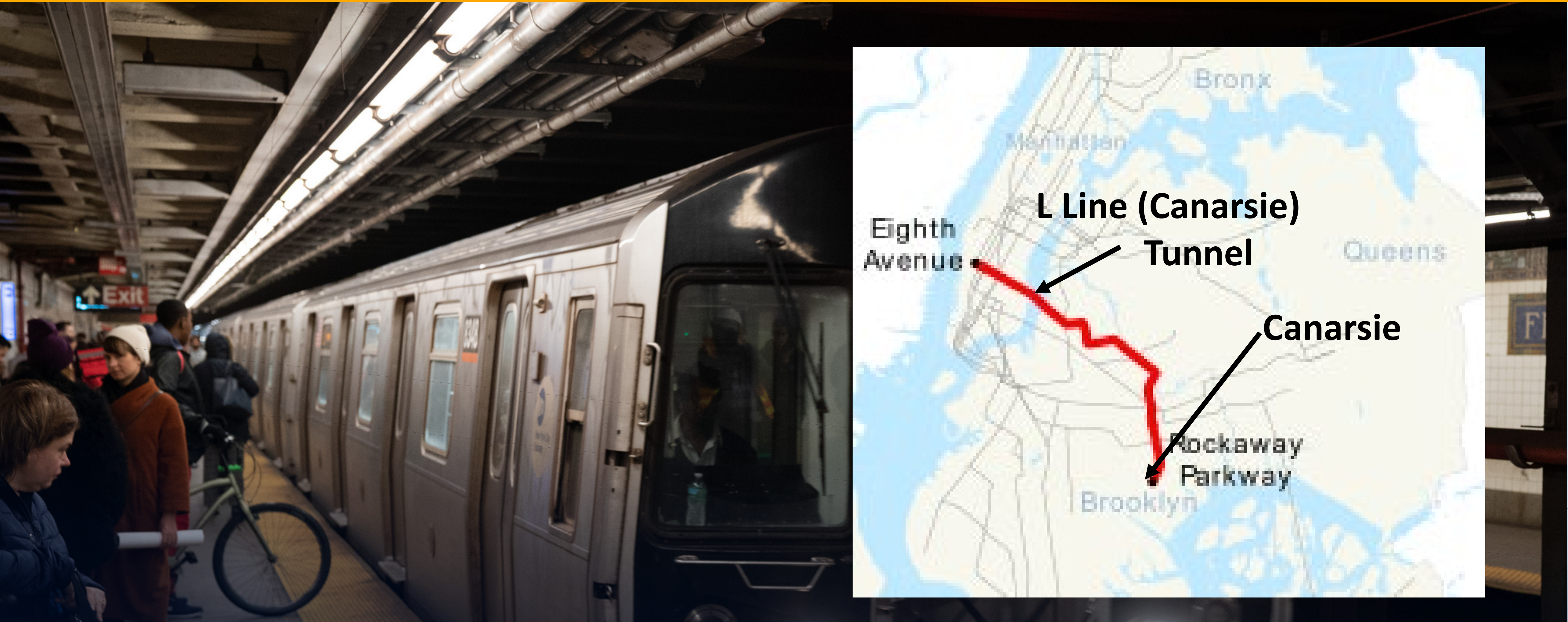
LOWER MANHATTAN CLIMATE RESILIENCE





TOPIC

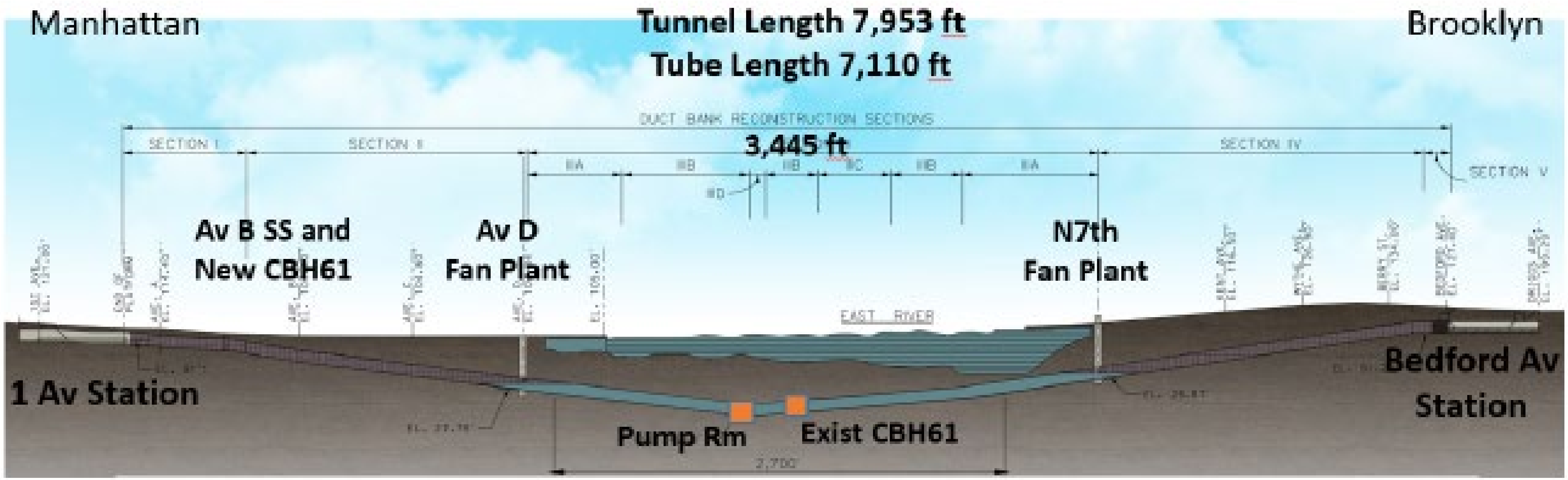
- **L Line Tunnel**



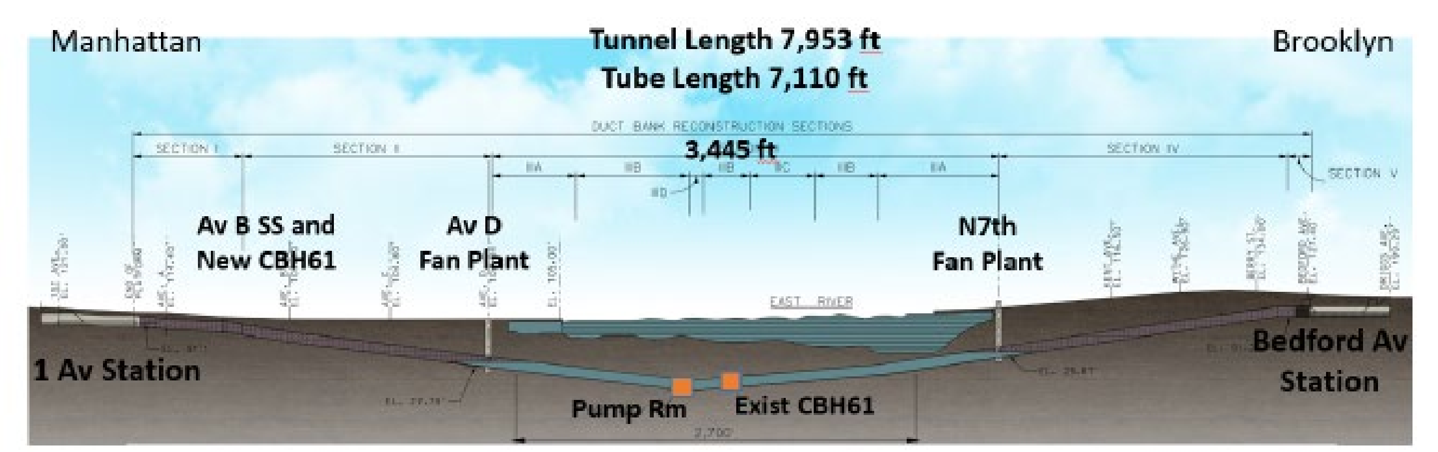
The L Train Tunnel is 1.5 miles (2.4 km) long and over 100 years old stretching from 1st Ave Station in Manhattan to Bedford Ave Station in Brooklyn...

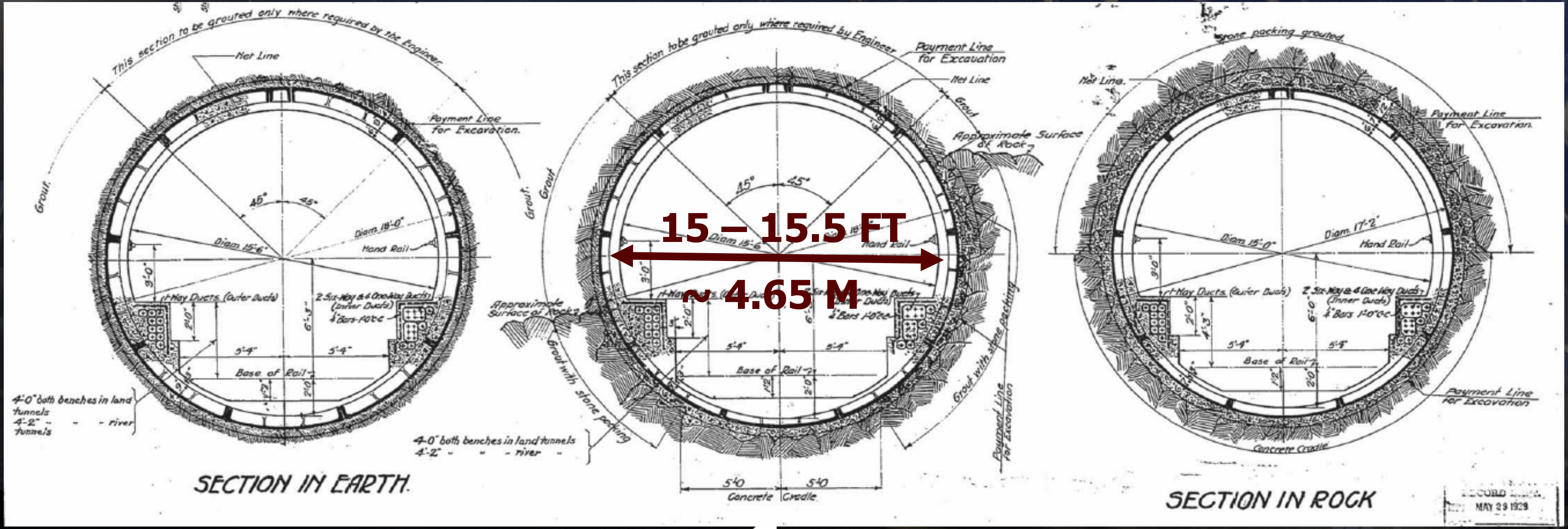

In 2012, Hurricane Sandy filled the tunnel
with salt water, from the Avenue D Fan Plant
to the North 7th Street Fan Plant...

L Train Tunnel Profile and Sections



L Train Tunnel Profile and Sections

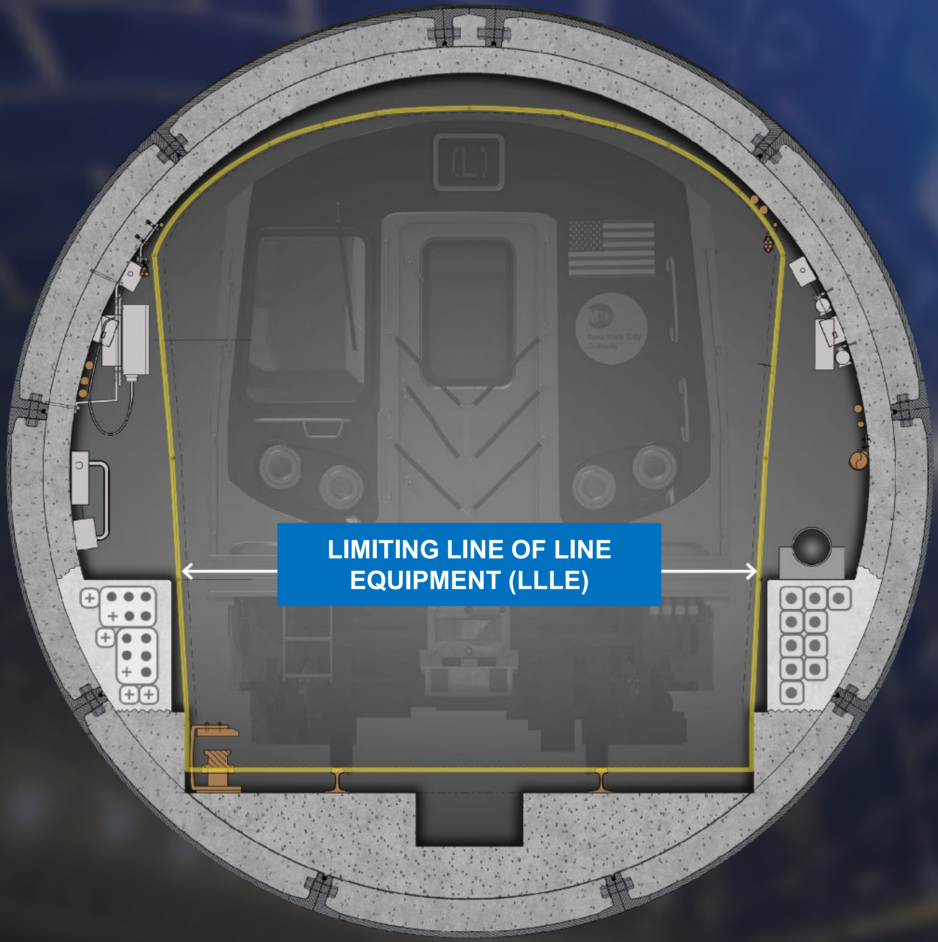




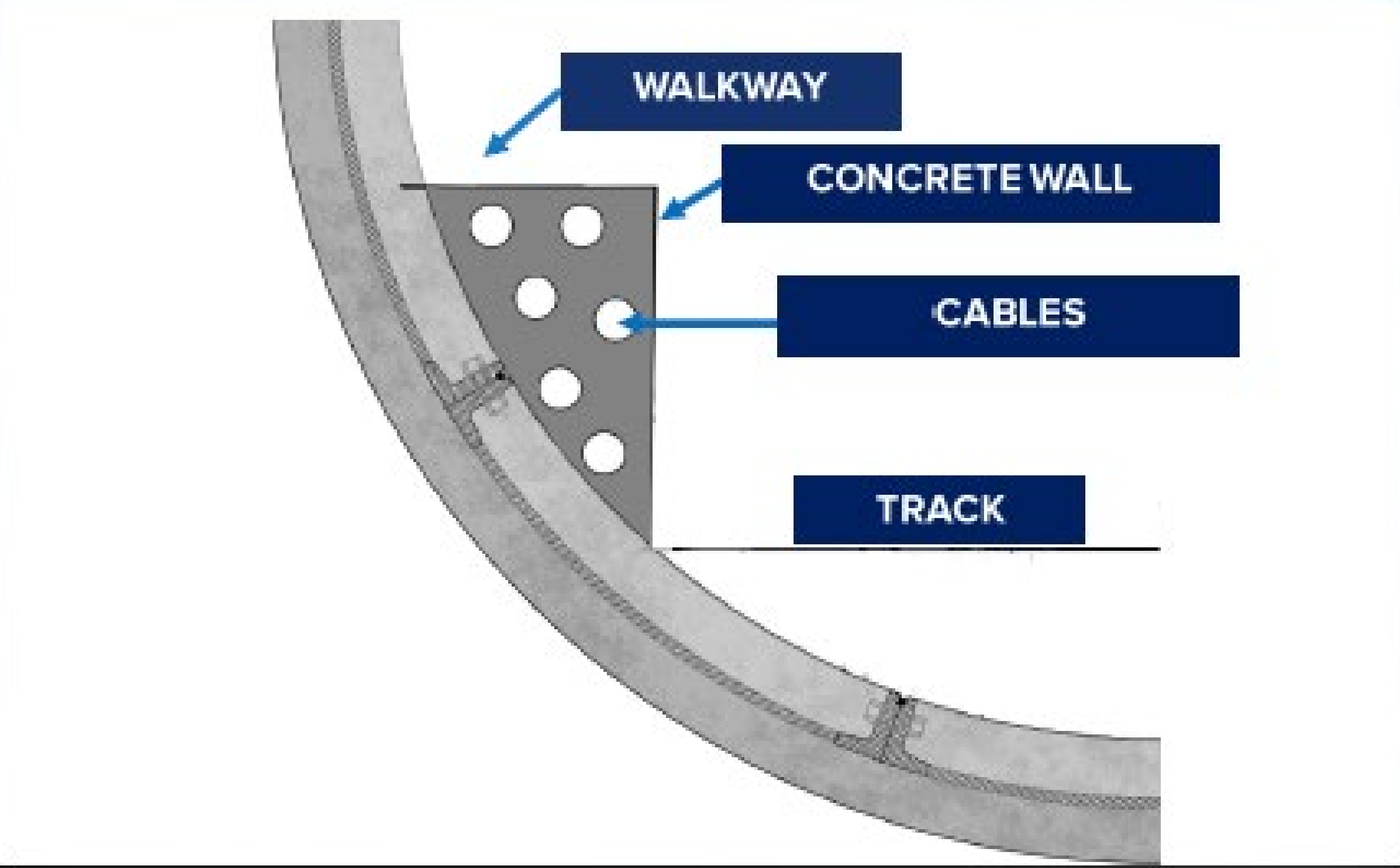
NEW YORK STATE EXCELSIOR EVER UPWARD

WHAT IS THE BENCHWALL?

- Holds and protects cables, which decades ago were less stable and did not have state-of-the-art fireproofing materials.
- Provides access/egress walkway for workers or, in the event of an emergency, for train passengers and first responders.



CUTAWAY OF BENCHWALL



BENCHWALL CONDITIONS:

SOME PORTIONS CRUMBLING, SOME WEATHERED, OTHER PORTIONS STABLE

Example of cement benchwall in good condition.

Concrete deterioration: alkalai silica reaction

Much of the benchwall was planned to be removed by hand a laborious, time-consuming process — to avoid damage to the century-old tunnel concrete lining…

An expert review team was organized

from Cornell and Columbia engineering schools to do a final review of the plan ahead of the L Train shutdown.

REVIEW TEAM

Mary Boyce, Dean of Engineering, Morris C. And Alma Schapiro Professor, Columbia University

Lance Collins, Joseph Silbert Dean of Engineering, Cornell University

George Deodatis, Santiago and Robertina Calatrava Family Professor of Civil Engineering, Columbia University

Peter Kinget, Bernard J. Lechner Professor of Electrical Engineering, Columbia University

Andrew Smyth, Professor of Civil Engineering, Columbia University

Tom O'Rourke, Thomas R. Briggs Professor of Engineering, Cornell University

RECOMMENDATION SUMMARY

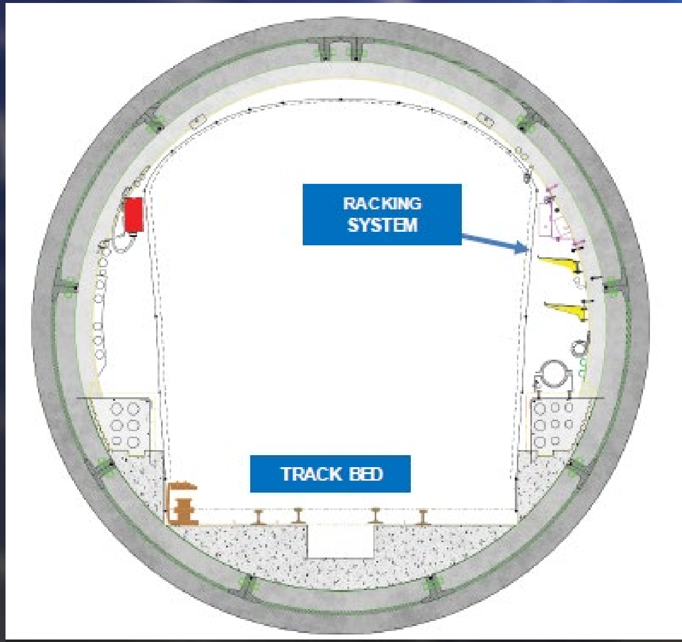
1. Implement a new power and control system.
2. Decouple power cable housing from benchwall.
3. Implement racking system for cables.
4. Jacket cables with low smoke, zero halogen fireproof material.
5. Abandon all old cables in benchwall.
6. Leave benchwall unless structurally compromised and fortify using fiber reinforced polymer. Remove unstable benchwall.
7. Install “smart” sensor systems to monitor benchwall integrity.
8. Install elevated walkway where benchwall removed.
9. Increase flood resilience measures.
10. Enhance public safety.

RECOMMENDATIONS

Cables

- Decouple power cable housing from benchwall.

- Implement racking system to suspend cables on the side of the tunnel. Place negative returns on the track bed.



- Jacket cables with zero halogen fireproof material successful in the airline/aero-space industry and satisfies NFPA 130 fire code

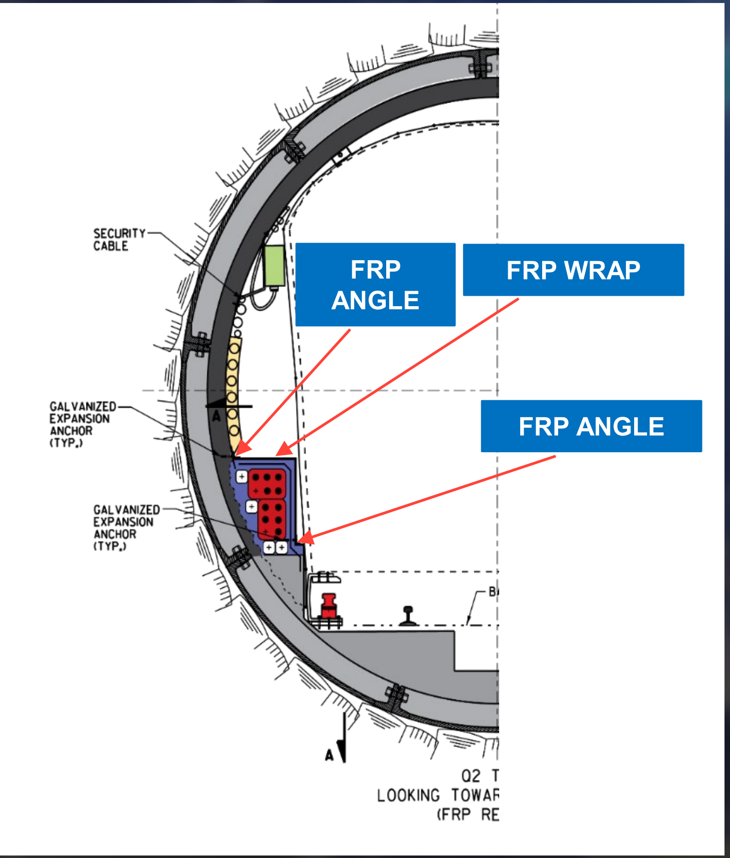
RECOMMENDATIONS

Benchwall

6. a. Leave benchwall where structurally stable.

   b. Fortify weakened structure with fiber reinforced polymer (FRP) wrap and strapping, reducing the need for continual fixes.

   c. Remove unstable benchwall.

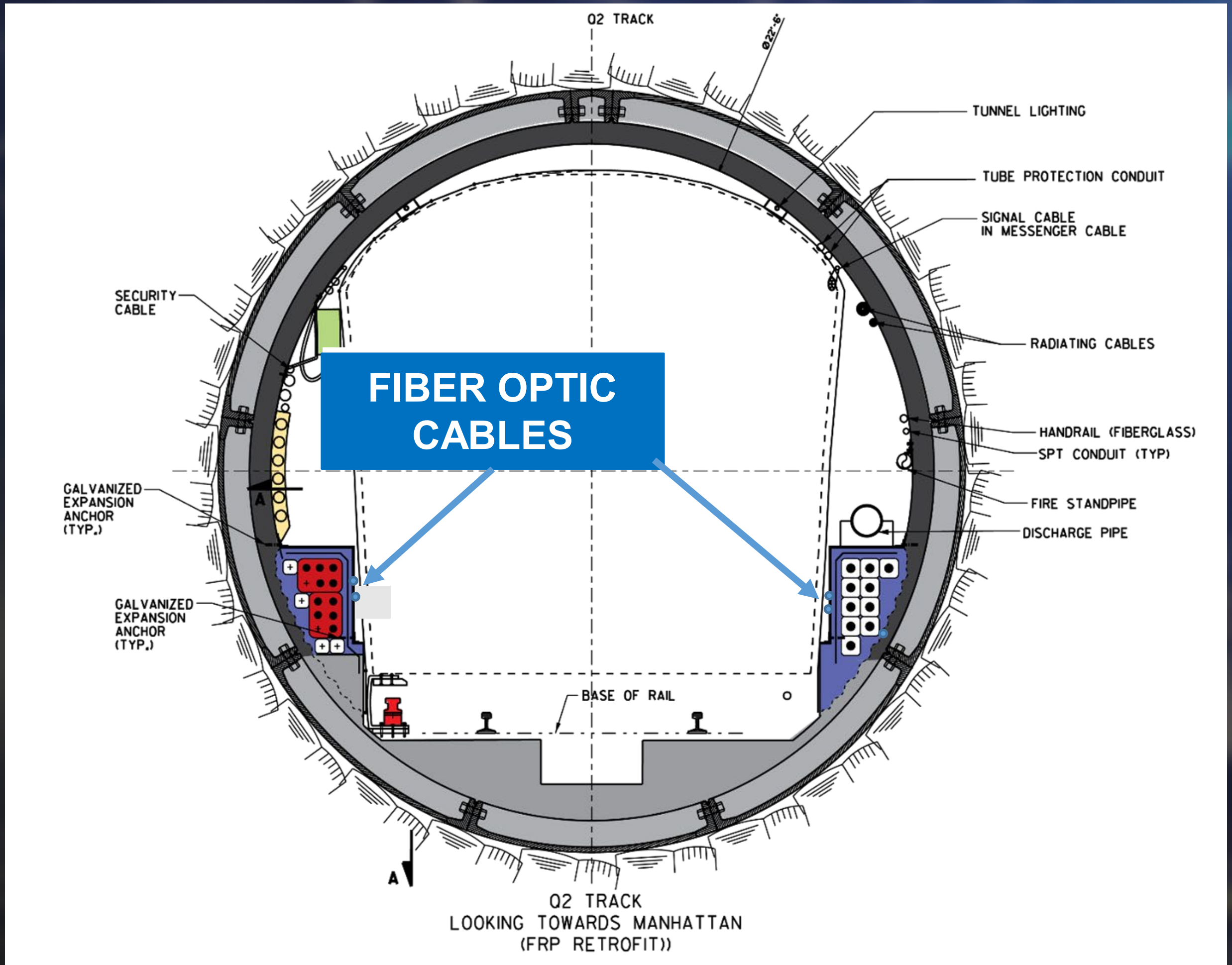


RECOMMENDATIONS

Smart Sensors

7. a. Install “smart” fiber optic sensor cables along remaining benchwall to detect shifts or cracks in benchwall.

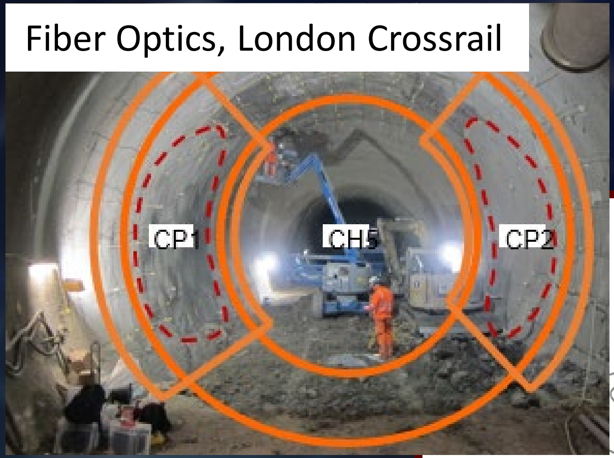
   b. Use high resolution LiDAR to monitor for benchwall deformation.

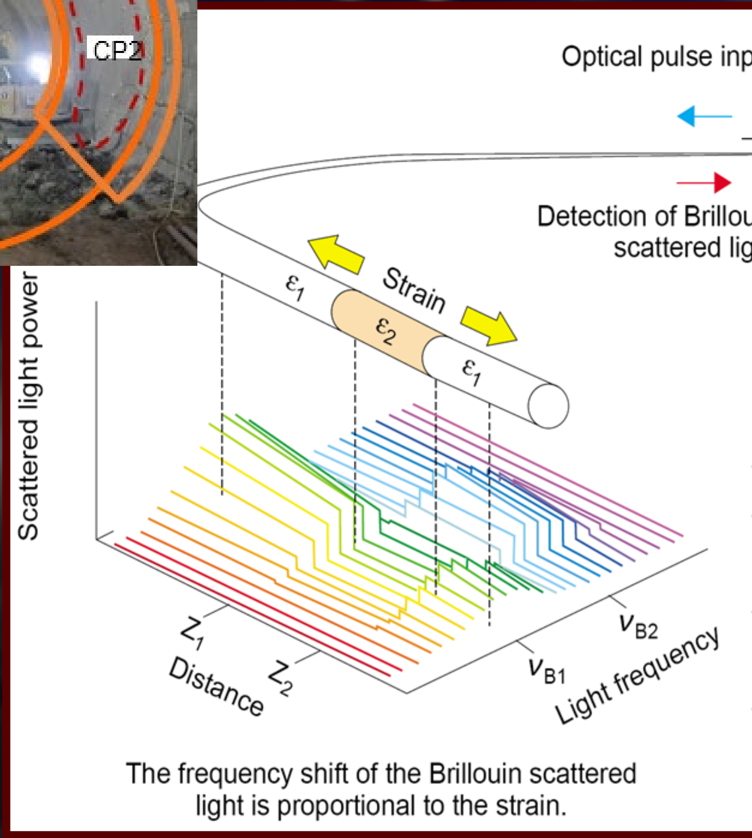


SMART TUNNEL TECHNOLOGY

Proven Technolgy

- Fiber Optics
- High Resolution LiDAR





- **Distance range ≈10-30 km**
- **Readout resolution = 0.05m**
- **Gauge length resolution = 0.2-1m**
- **Strain Resolution = 10-30 me**

RECOMMENDATIONS

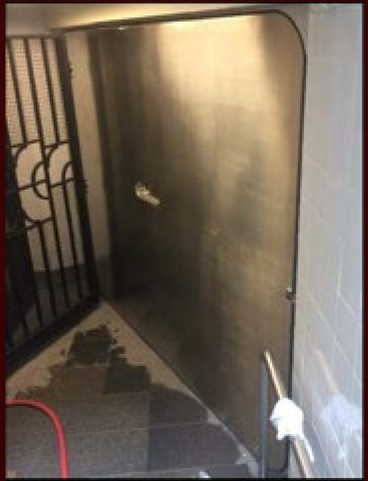
Resilience

9. Increase tunnel resilience against flooding:
    a. Increase pump capacity as currently planned.
    b. Install a permanent generator to power pumps, providing redundancy to power sources from both Manhattan and Brooklyn. Explore natural gas vs. diesel fuels.
    c. Consider watertight submarine-type gates (similar to QMT and BBT).
    d. Consider sealing capability for all openings on the L-line from 1st Ave station to Bedford Ave station, depending on critical elevation.

Watertight gate closure at the Queens Midtown Tunnel

FLOOD ZONE PROTECTION

Mecanical closure devices



Marine doors

Watertight hatch doors

Watertight manhole inserts

RECOMMENDATIONS

Safety

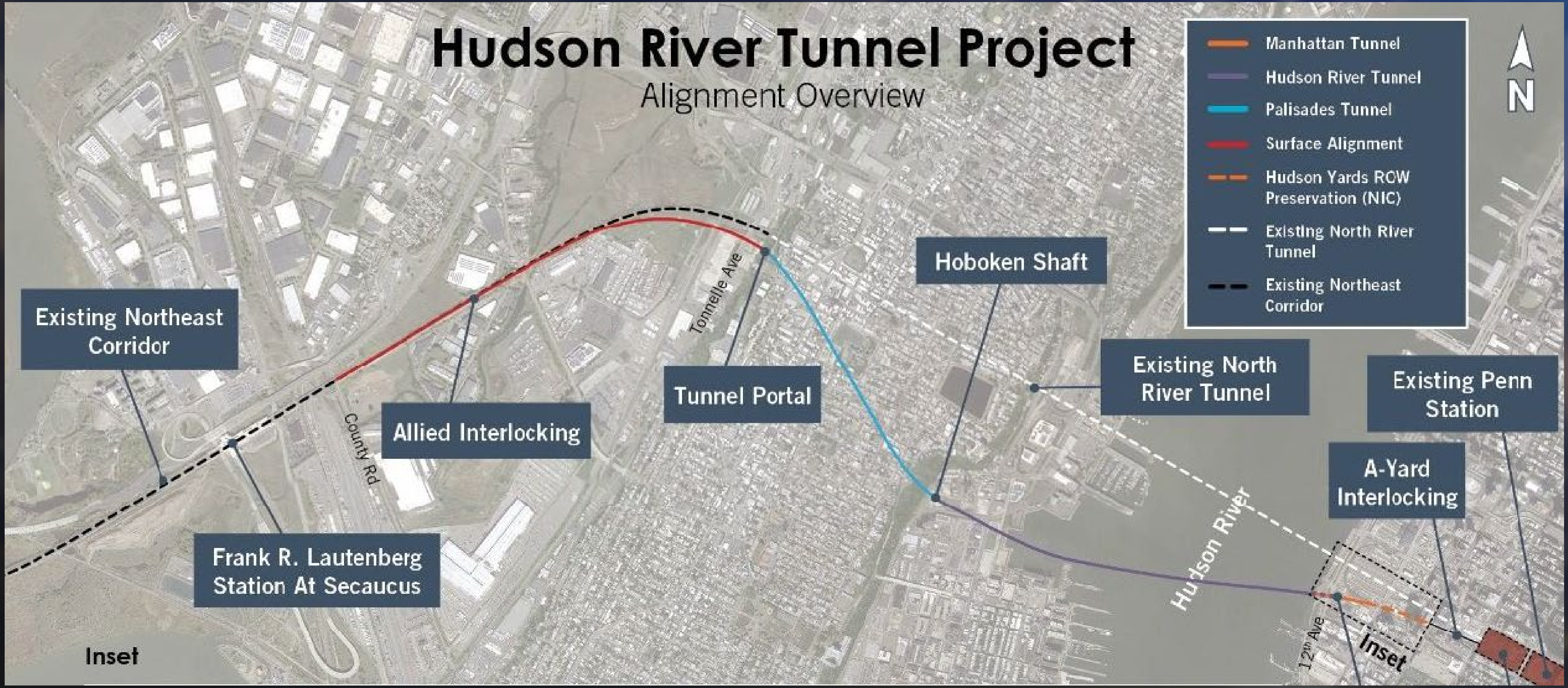
10. Enhance public safety:

    a. Detailed evaluation of control options for dust and airborne silica with an assessment of their impact on construction schedule.
    b. Enlisting an independent environmental firm to monitor air quality and report directly to NYC Transit.
    c. Ongoing structural condition monitoring with smart tunnel technology.

THIS MEANS...

- No closure of service is necessary with this new design.
- Work can be completed with weekend and nighttime closures of ONLY ONE TUBE at a time leaving the other to run trains in both directions.
- This new system design approach can be potentially applied to other projects, such as the Second Ave. Phase 2 and Amtrack Tunnels.

GATEWAY PROJECT



LESSONS FOR RESILIENT INFRASTRUCTURE

- It takes a village to build infrastructure
- Change agents vs agencies that don't change
- Innovation through integration
- Build back better
- Fusion of innovative financing, emerging technology, and community engagement

ENGINEERING FOR DISASTER RESILIENCE

- **Summer 2019 Issue of *The Bridge***
- **National Academy of Engineering Flagship Publication**
- **Resilient Infrastructure**
- **https://www.nae.edu/21020/Bridge**