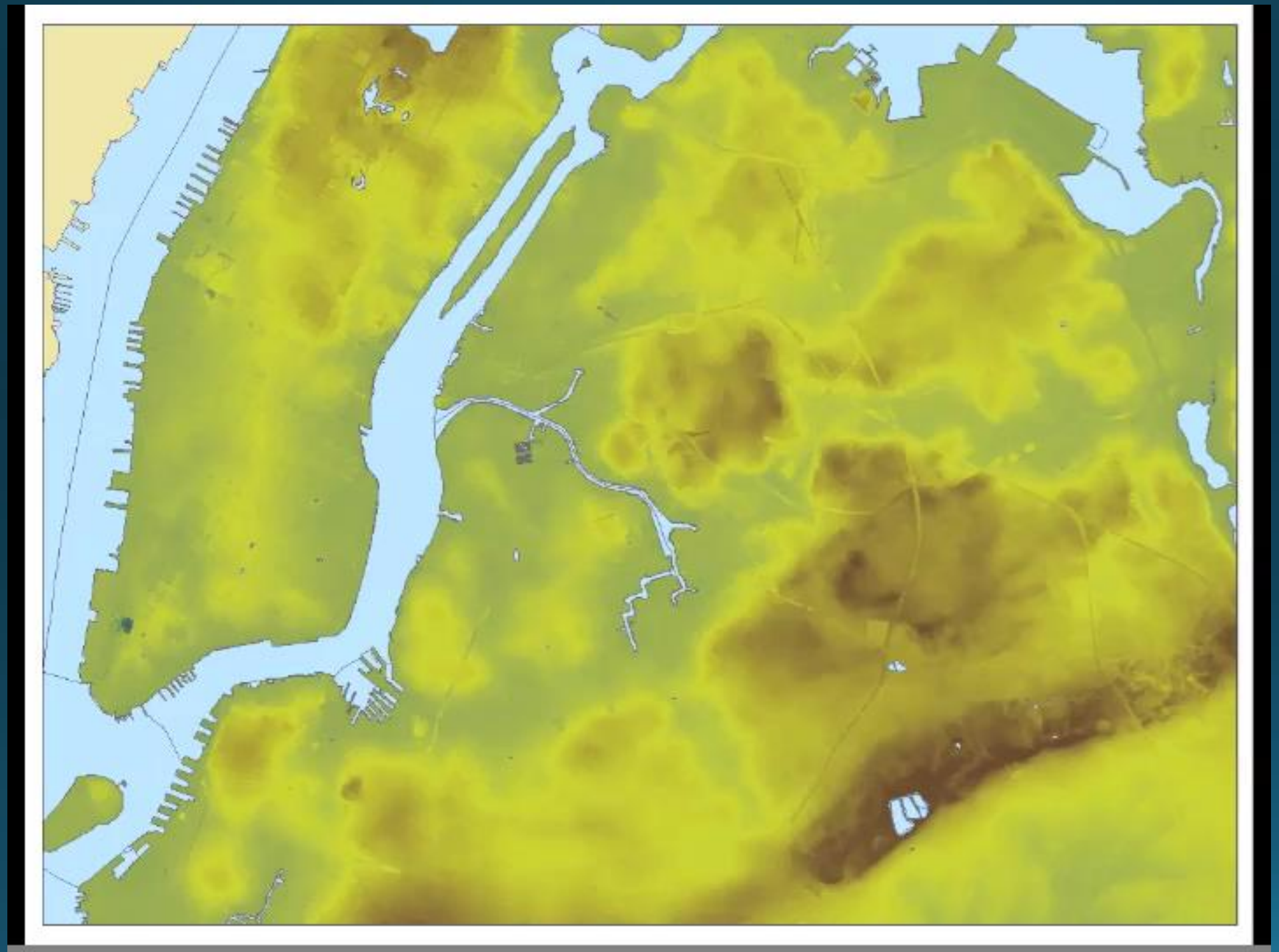
Objectives (2.1)

1. Case Study of Hurricane Irene and super storm sandy Impact on the Transportation Infrastructure in NYC
2. Peak Water Levels and FEMA 100 year return period with respect to transport infrastructure (Roads Rails, Ports and Airports)
3. Formulation of failure modes due to the interactions and thresholds for impact
4. Assessing Vulnerability of the Road Network, and potential Inundation of Transportation Infrastructure
5. Reporting

Sally Watkins, CUSP NYU
Naresh Devineni, CUNY

NYS RISE (task 2.1)



1.2 Super Storm Sandy Impact on Transportation

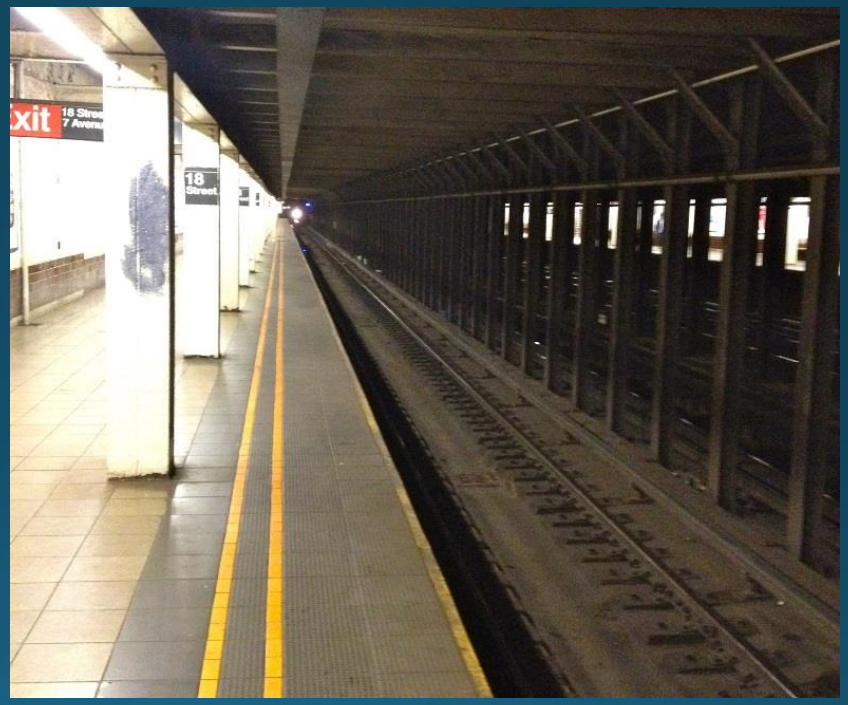
Asset	In Sandy Inundation Area	Not in Sandy Inundation Area	Percent Inundated
Airports	2	0	100%
Subway Stations	31	459	6.3%
Rail Stations	9	33	21.4%
Bus Depots	6	24	20.0%
Bridges	29	41	41.4%
Tunnels	3	1	75.0%
Major Roads	235	652	36.0%

Source: OEM, based on FEMA MOTF Hindcast data.

Overview

- Determined stations flooded by Sandy
  - MOTF Hindcast + Stations Map
- To better assess vulnerability, stations ranked by importance.
  - Importance is measured based on number of swipes a station used.
- Mapped stations on hurricane flood zones to determine which were inundated.
  - Flooding was determined using data from SLOSH Model.

Stations should not be equally weighted!



Station Ranks

- Analyzed fare data in subways to establish rank.
- Stations with more swipes were determined to be more important.
- Map of weighted stations superimposed on Sandy flood zones illustrate the high risk subway stations
- Systematic effects to consider upon completion of full transit network analysis:
    - Transfer hubs
    - Local reroutes
    - Station density
    - Station elevation

MTA NYC Transit

Fare Data / Turnstile Usage Data

NYC Open Data – MTA Data

- **Fare Data**
  - The number of MetroCard swipes by customers entering each station
  - Every week
  - Since June 12, 2010
  - The New York City Subway, PATH, AirTrain JFK and the Roosevelt Island Tram
- **Turnstile Usage Data**
  - Entry/exit register values for Each turnstile
  - Every 4 hours
  - Since May 05, 2010
  - The New York City Subway, PATH, AirTrain JFK and the Roosevelt Island Tram

Data Reduction/Cleaning

Total Data

- **552** Remote Station
- 194 Time Stamp
- 23 Data Field

→

Potentially Impacted Stations

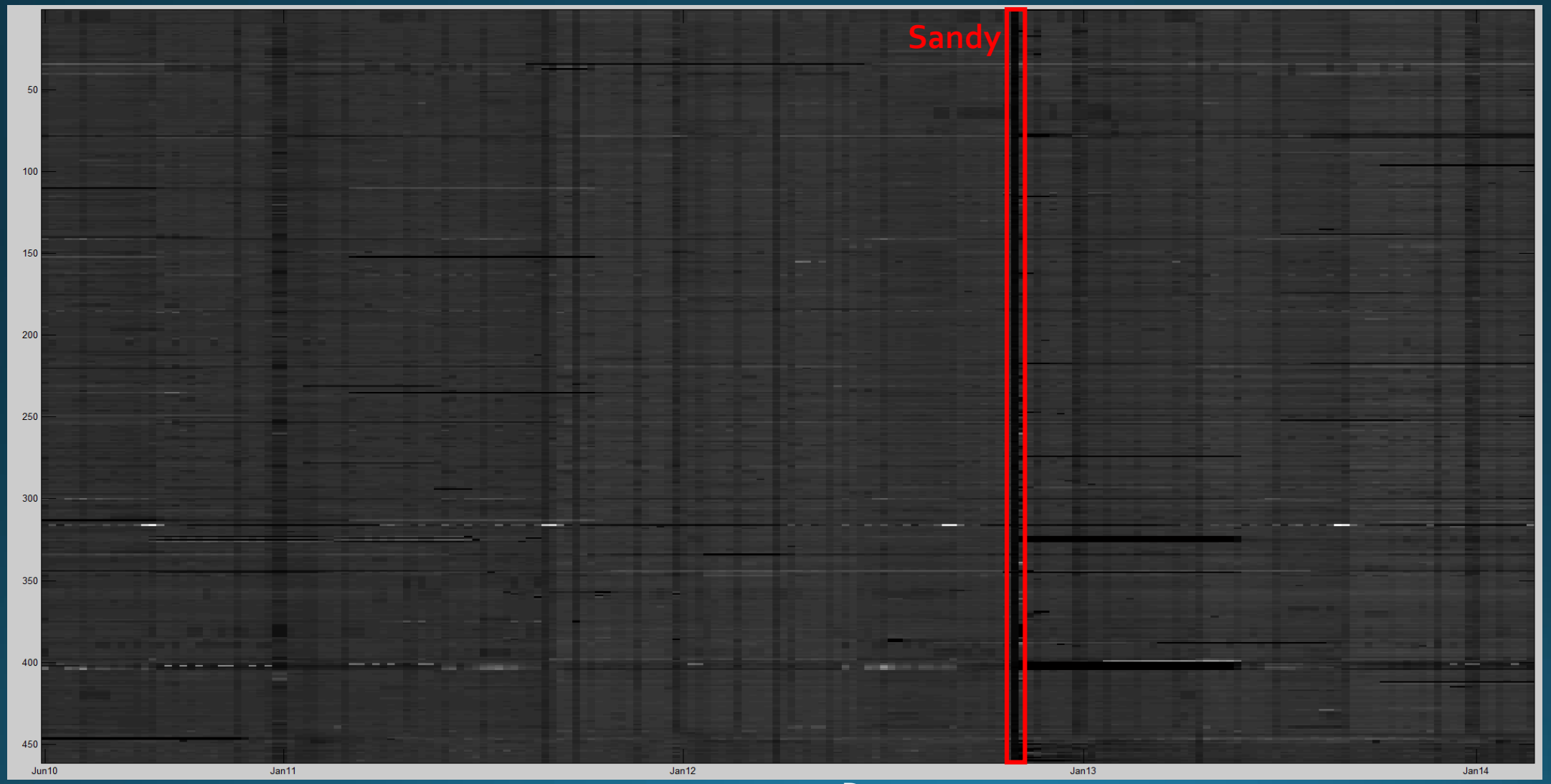
- **461** Remote Station
- 194 Time Stamp
- 23 Data Field

→

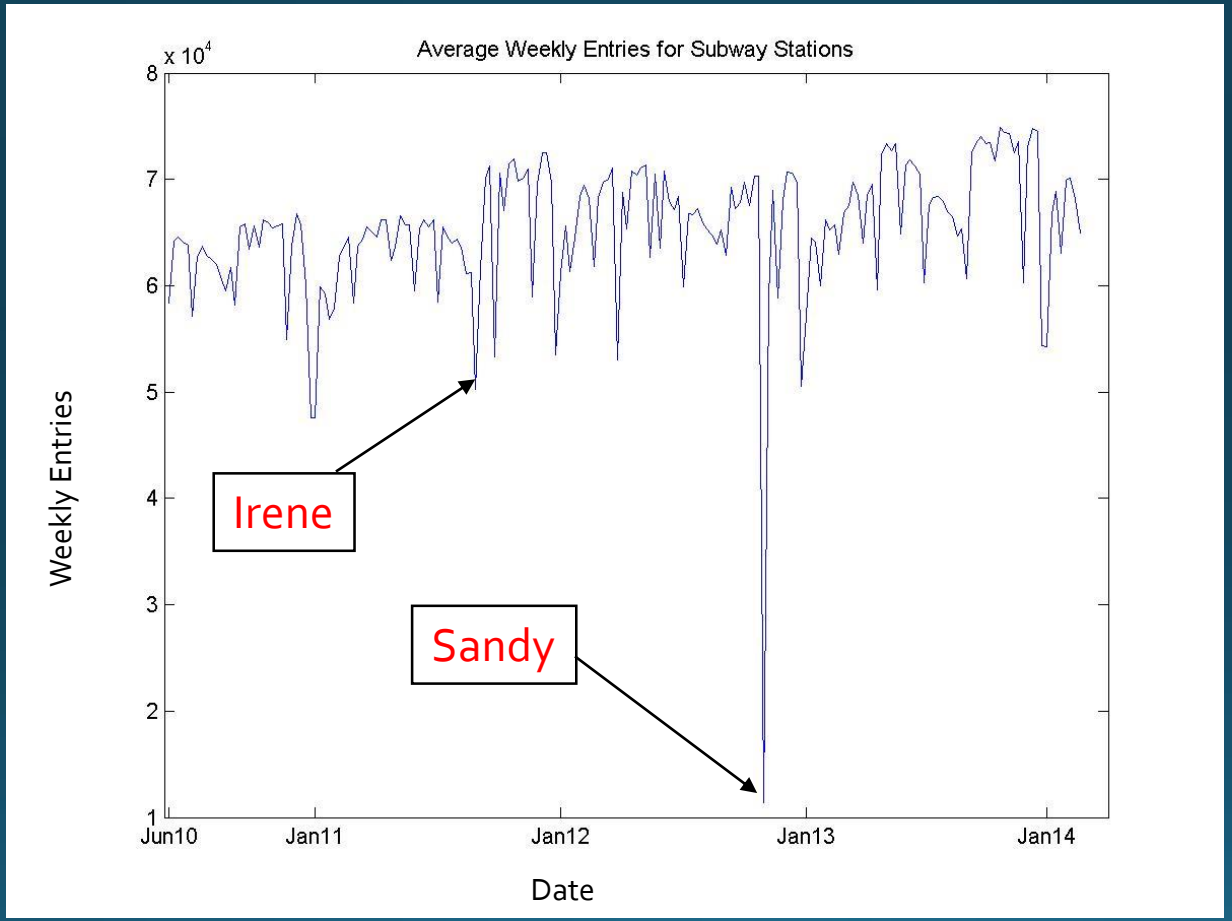
Geo-Referenced Stations

- **442** Remote Station
- 194 Time Stamp
- 23 Data Field

Normalized Weekly Entries Intensity Map

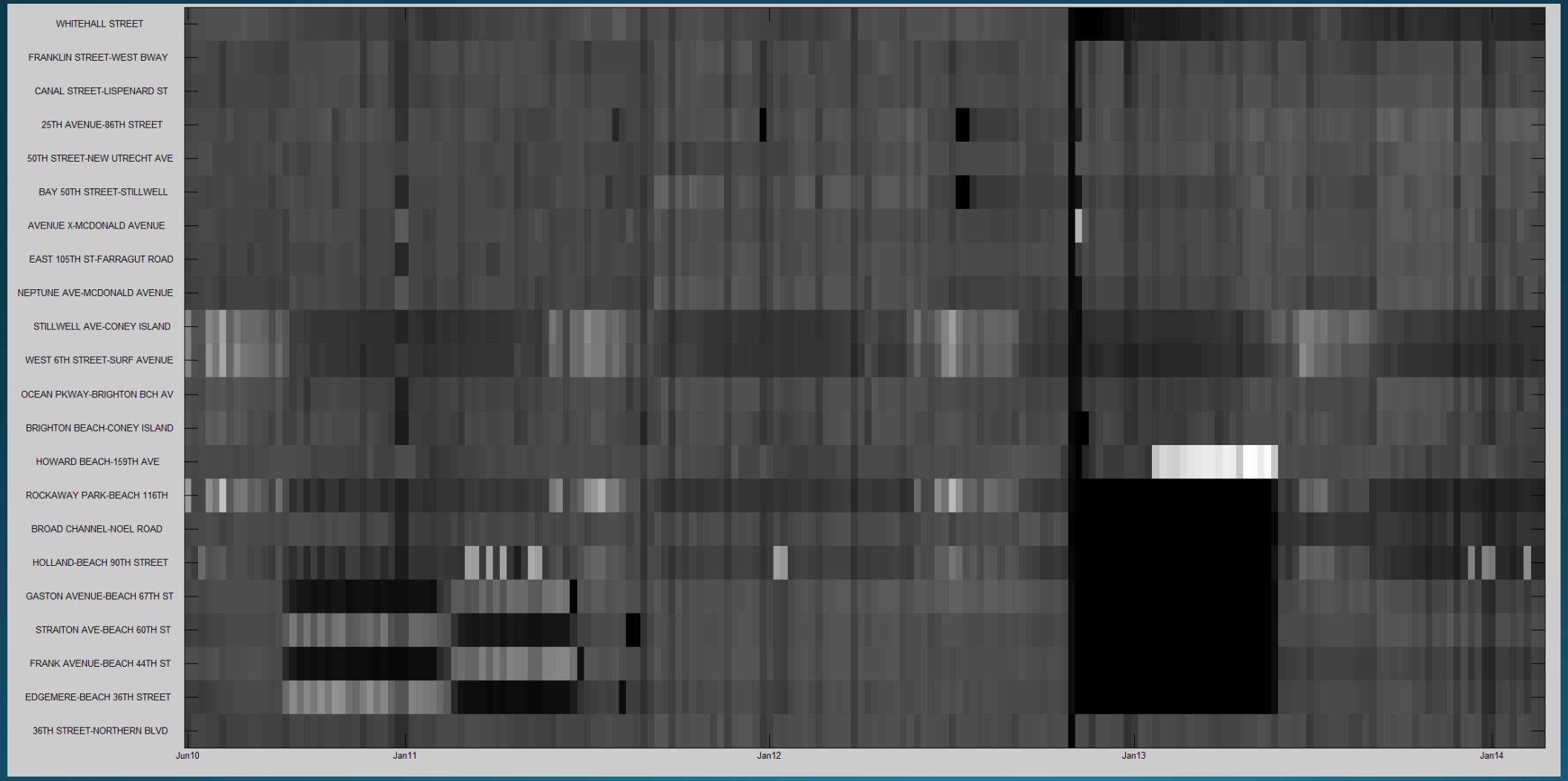


Average Weekly Entries



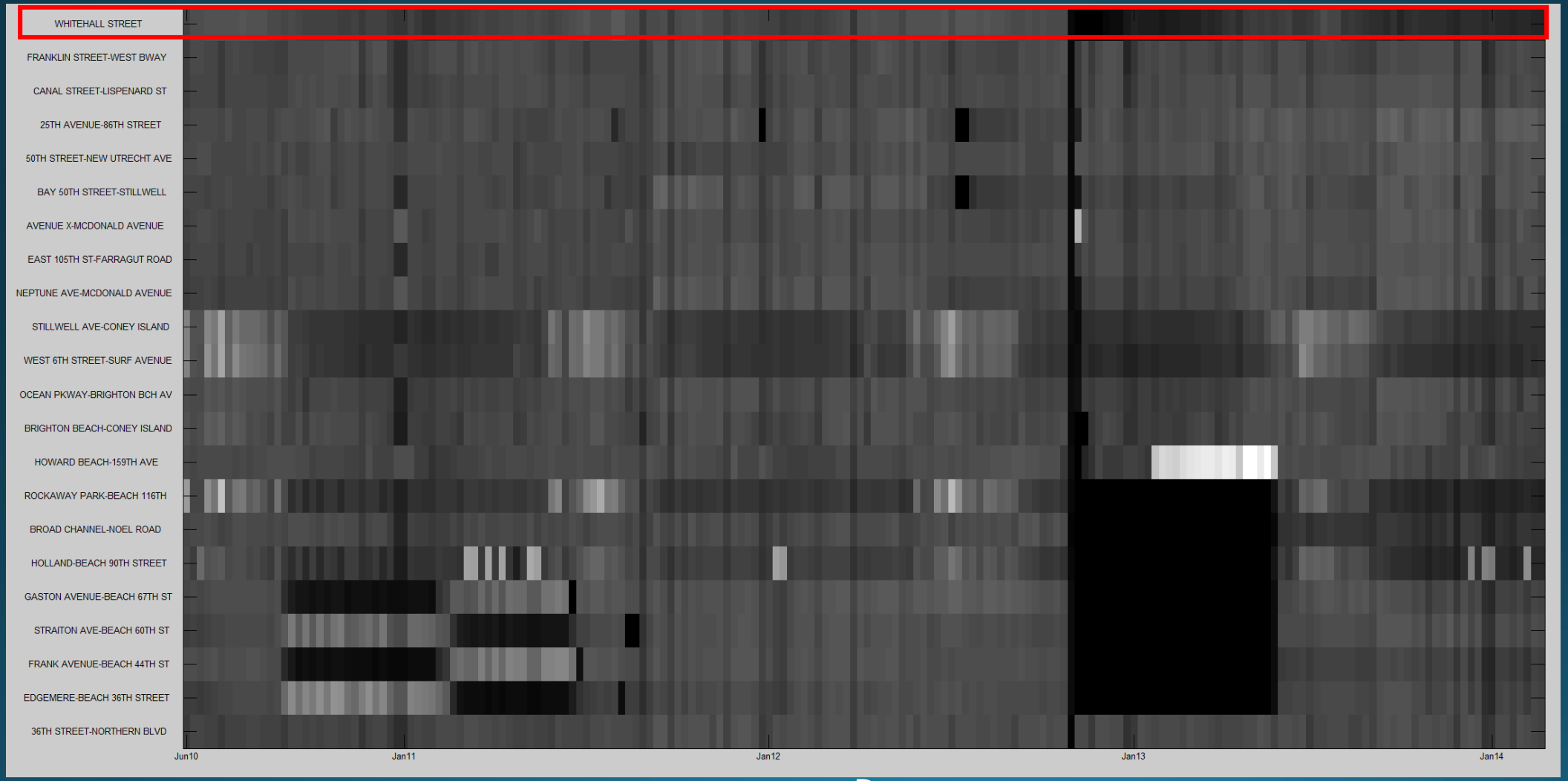
Normalized Weekly Entries Intensity Map

(Affected by Sandy-Sorted by distance from Whitehall Station)



Normalized Weekly Entries Intensity Map

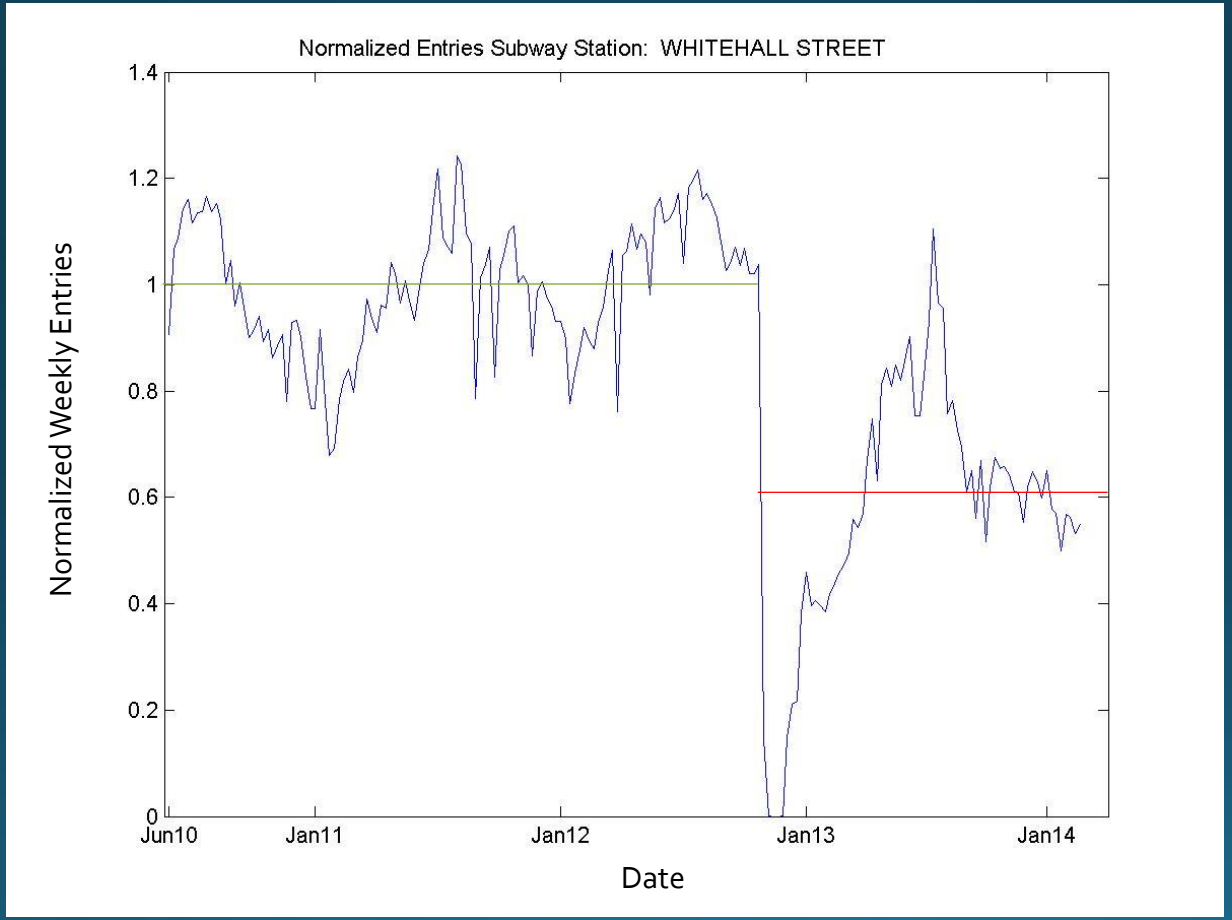
(Whitehall Station)

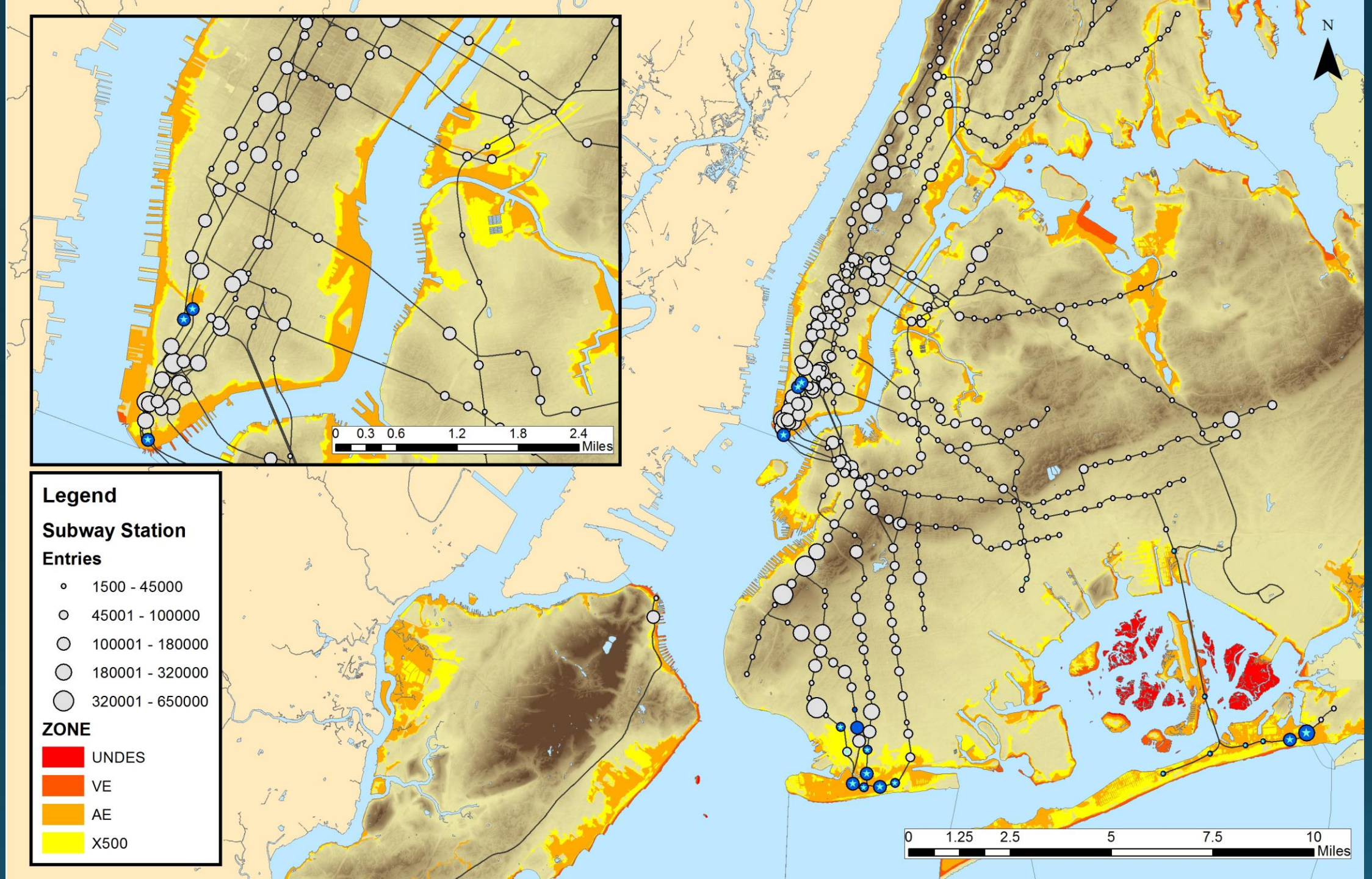


Remote Station

Date

Normalized Weekly Entries
(Whitehall Station)




N
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Miles
Legend
Subway Station
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45001 - 100000
100001 - 180000
180001 - 320000
320001 - 650000
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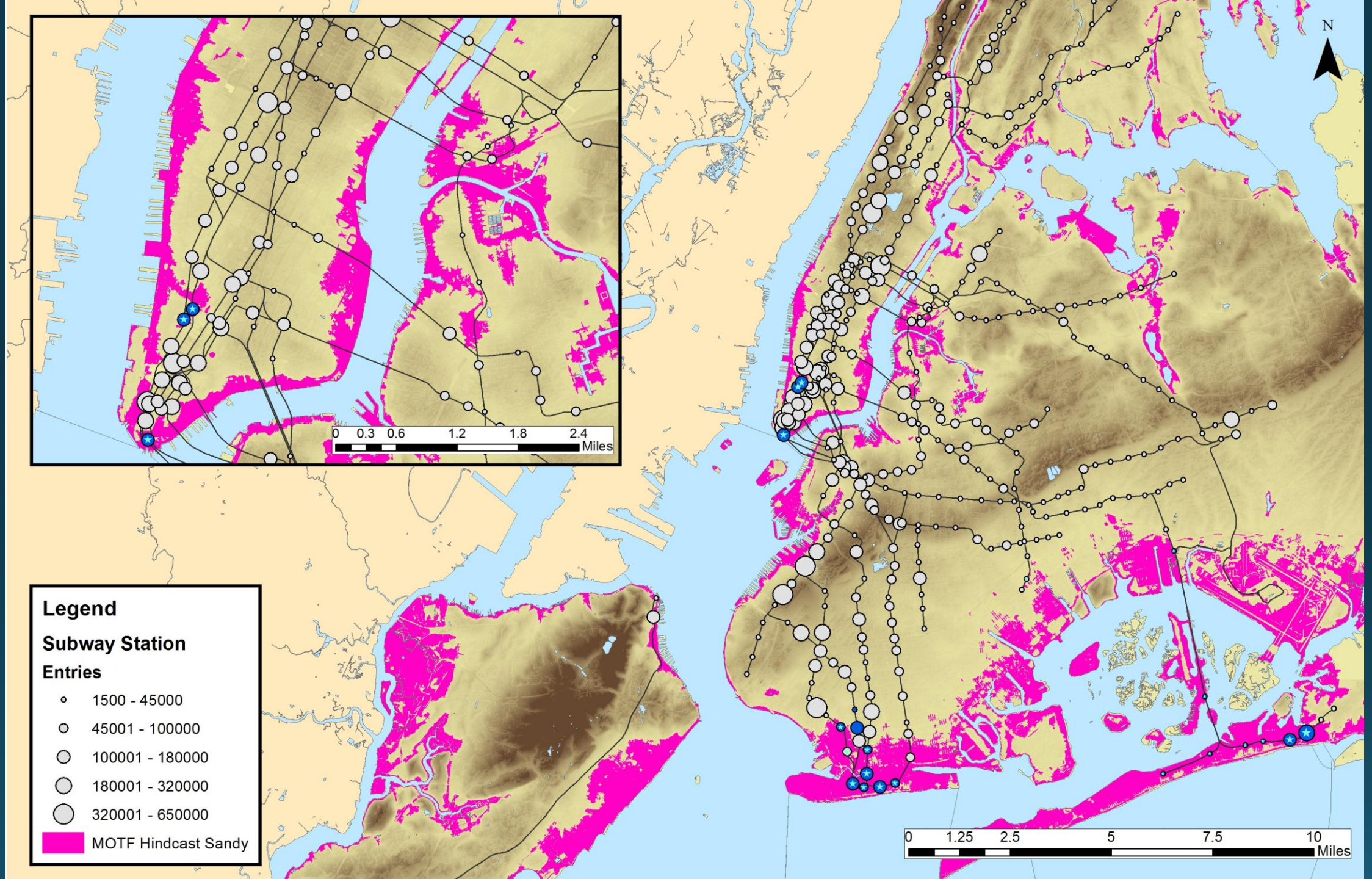
Miles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Miles
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Miles
Legend
Subway Station
Entries
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45001 - 100000
100001 - 180000
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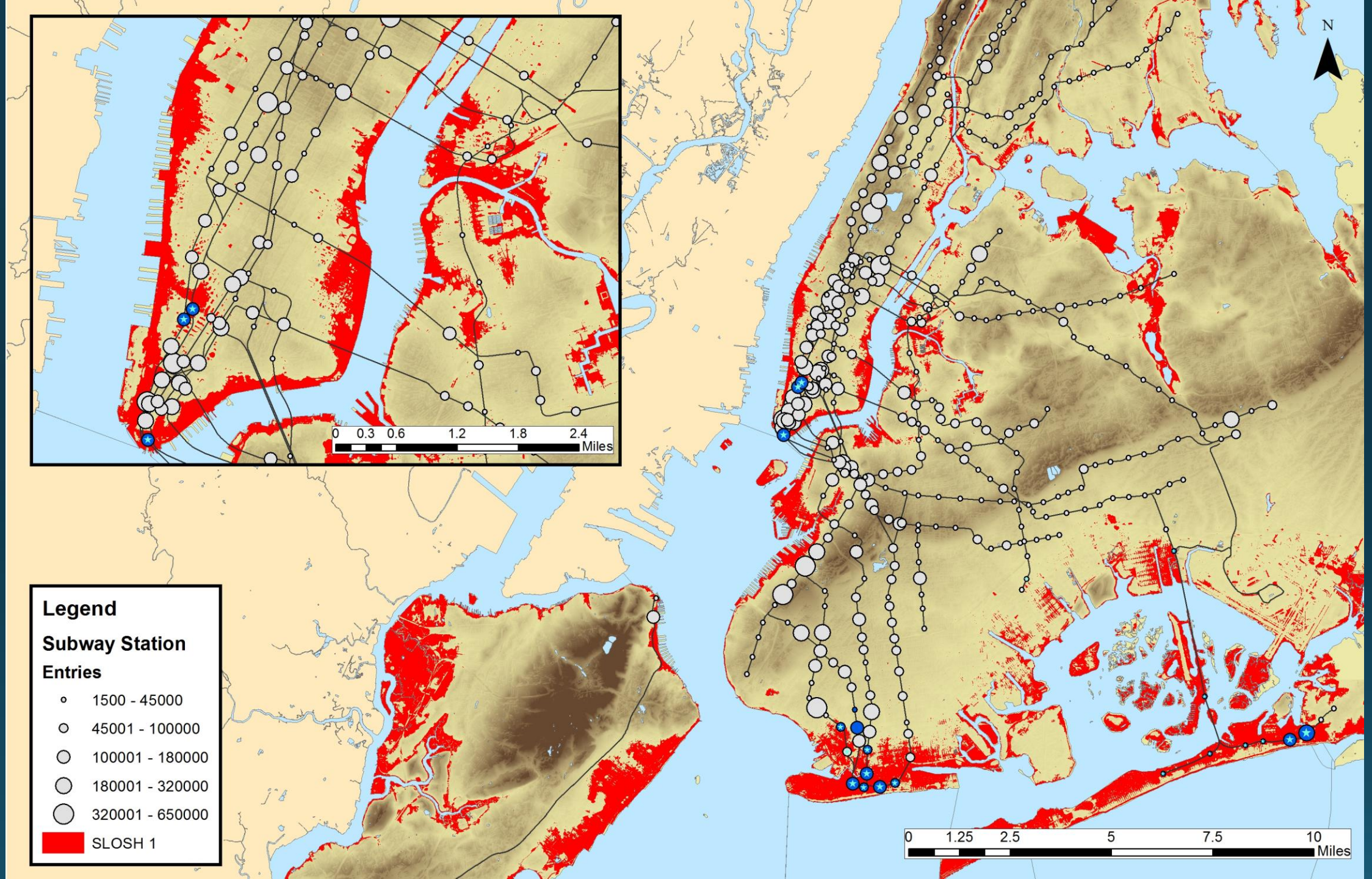
320001 - 650000
MOTF Hindcast Sandy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Legend
Subway Station
Entries
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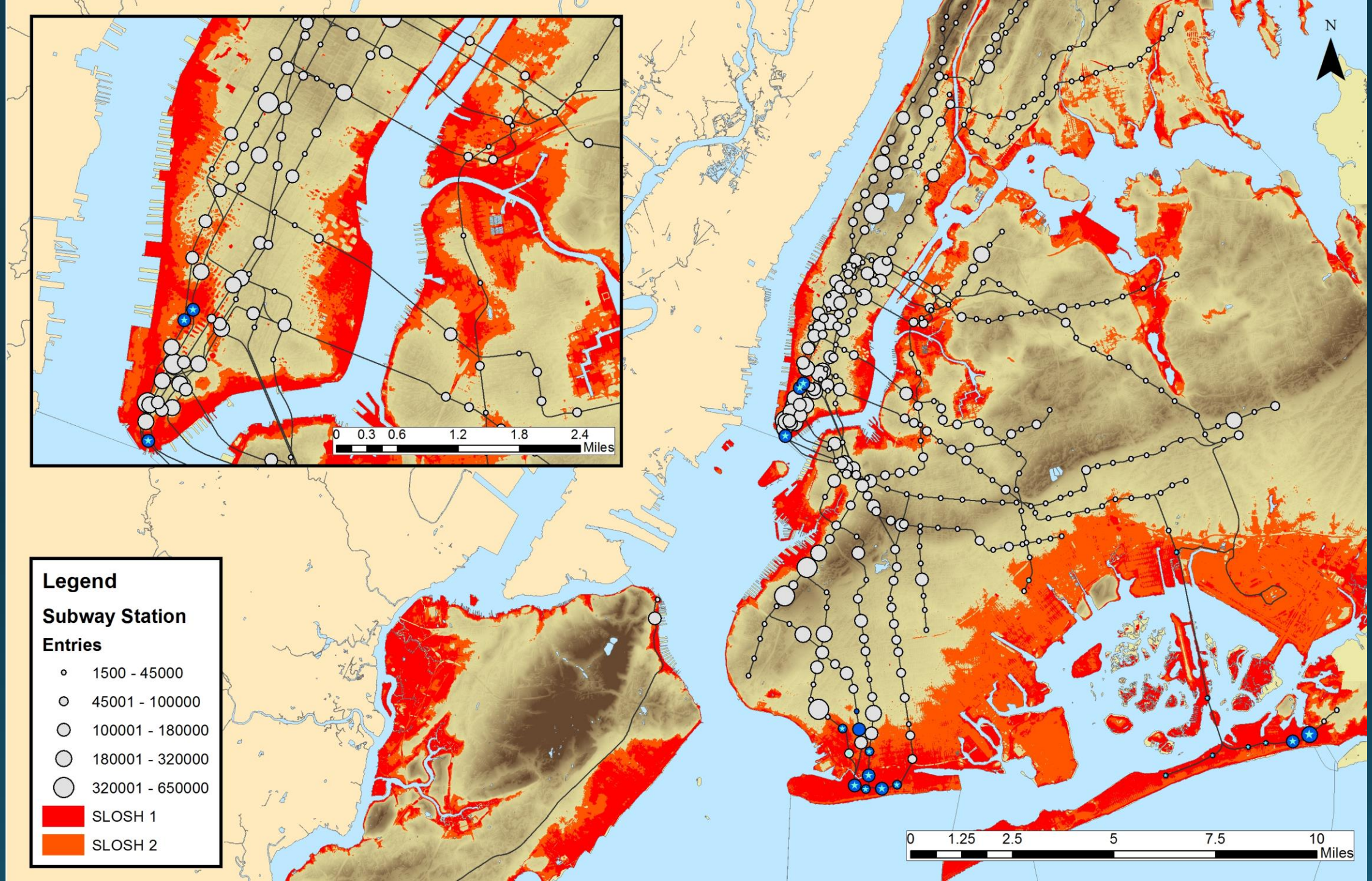
100001 - 180000
180001 - 320000
320001 - 650000
SLOSH 1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Miles
Legend
Subway Station
Entries
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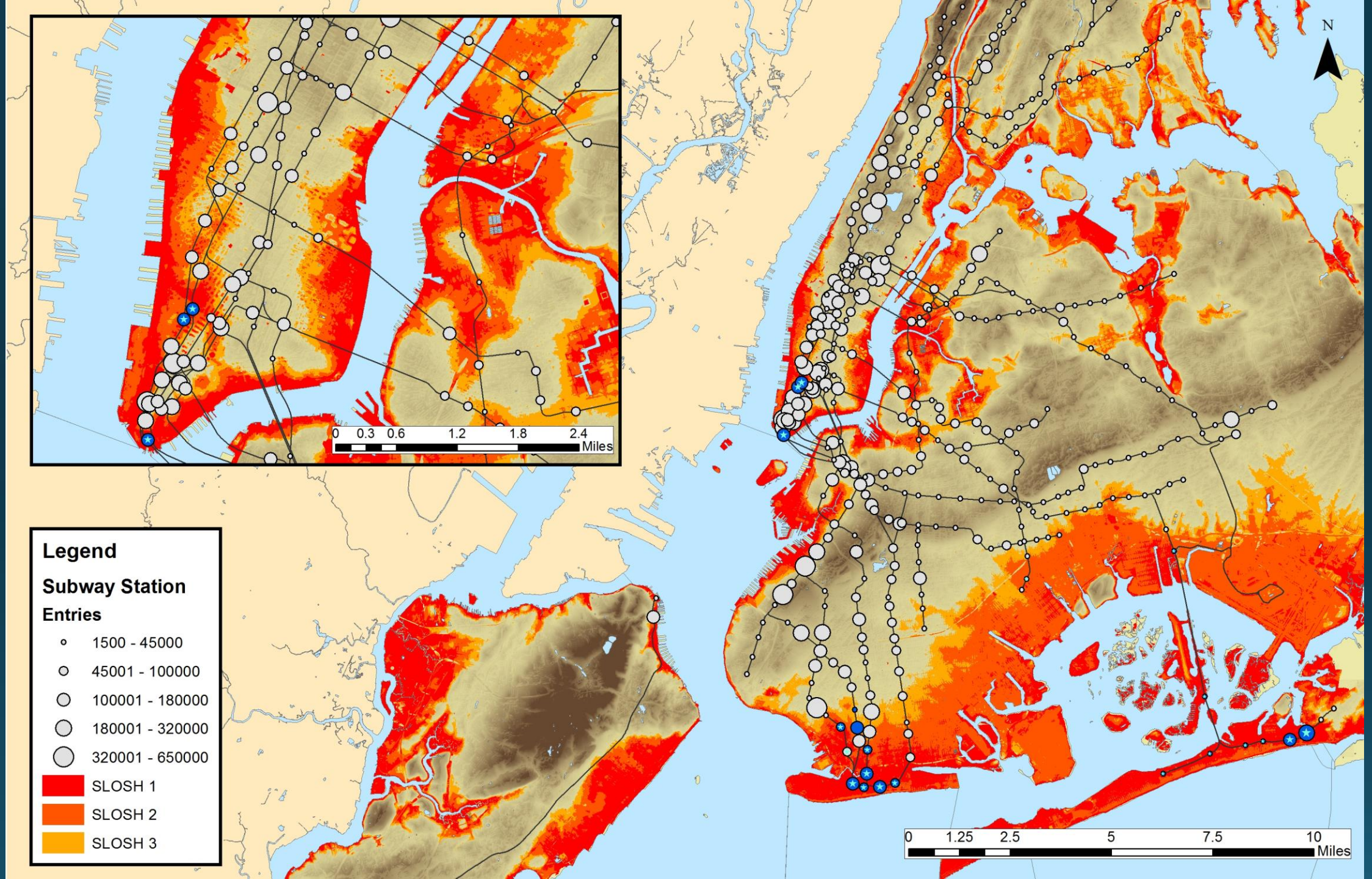
180001 - 320000
320001 - 650000
SLOSH 1
SLOSH 2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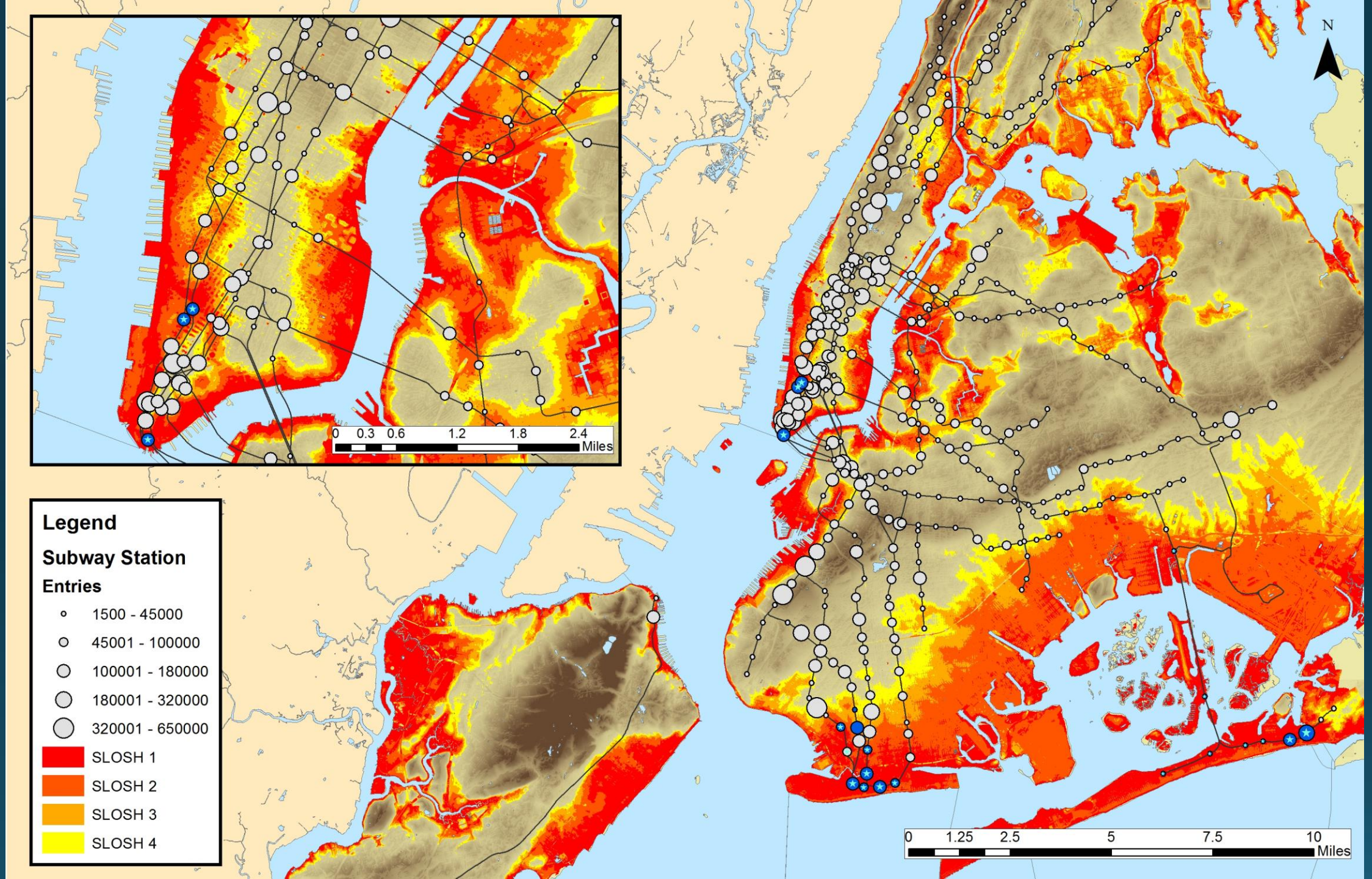
320001 - 650000
SLOSH 1
SLOSH 2
SLOSH 3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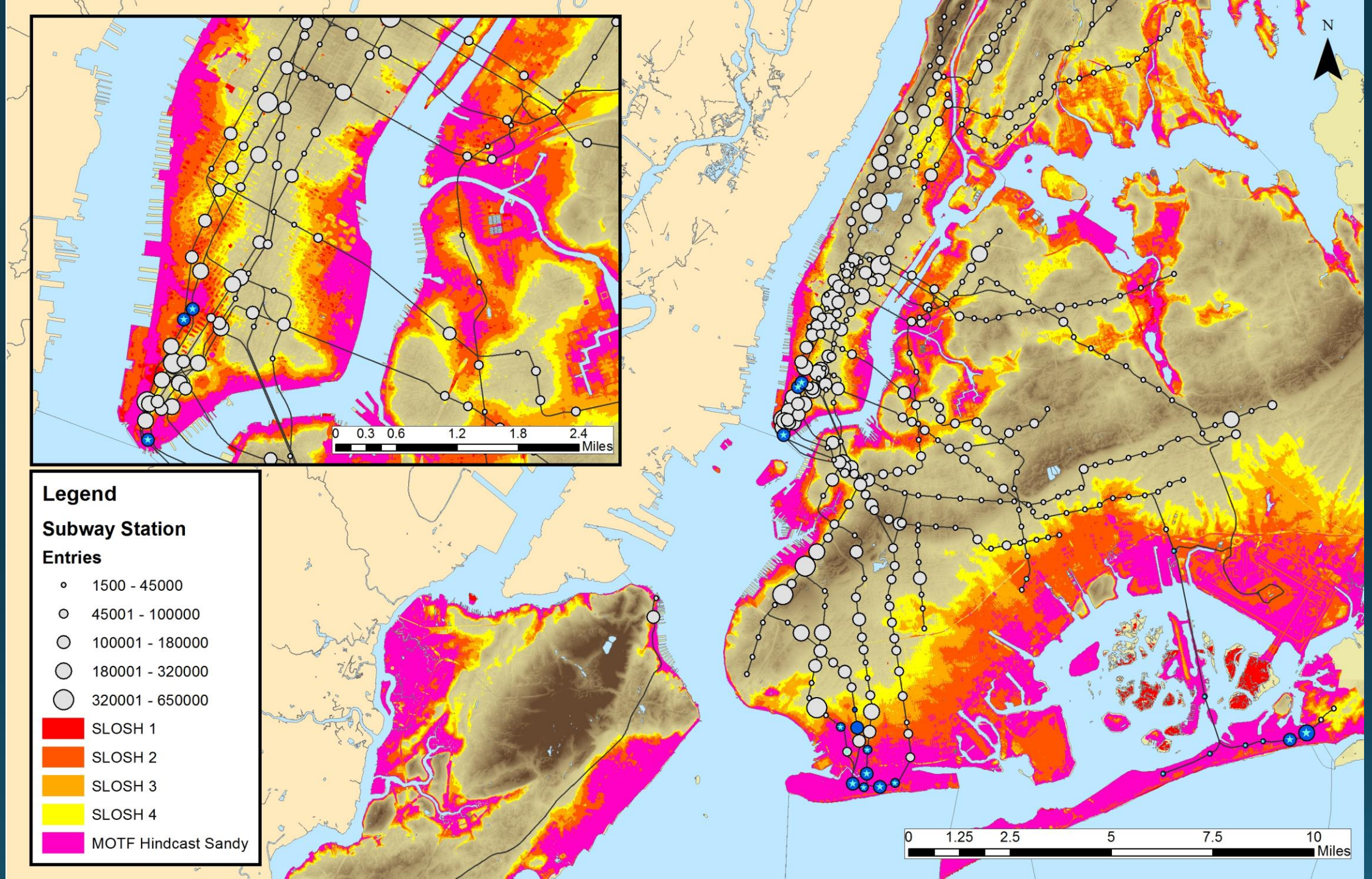
SLOSH 2
SLOSH 3
SLOSH 4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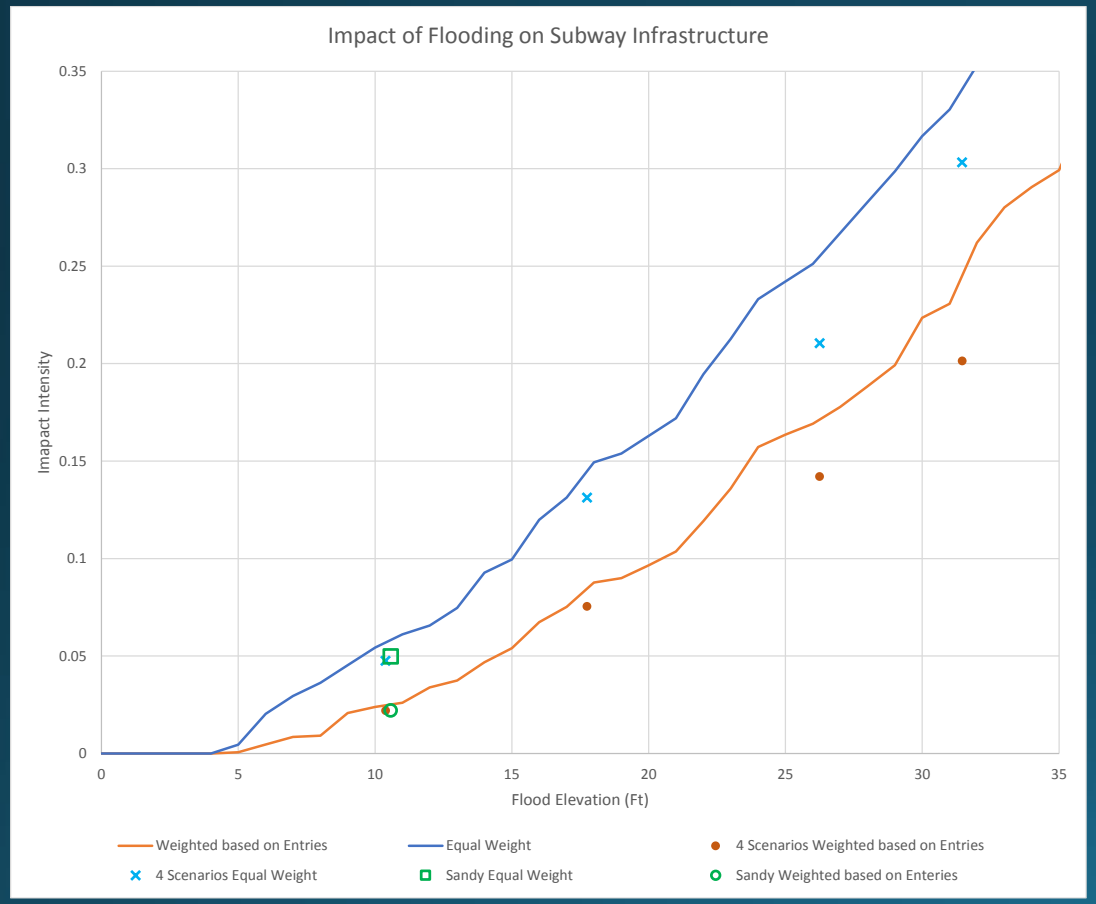
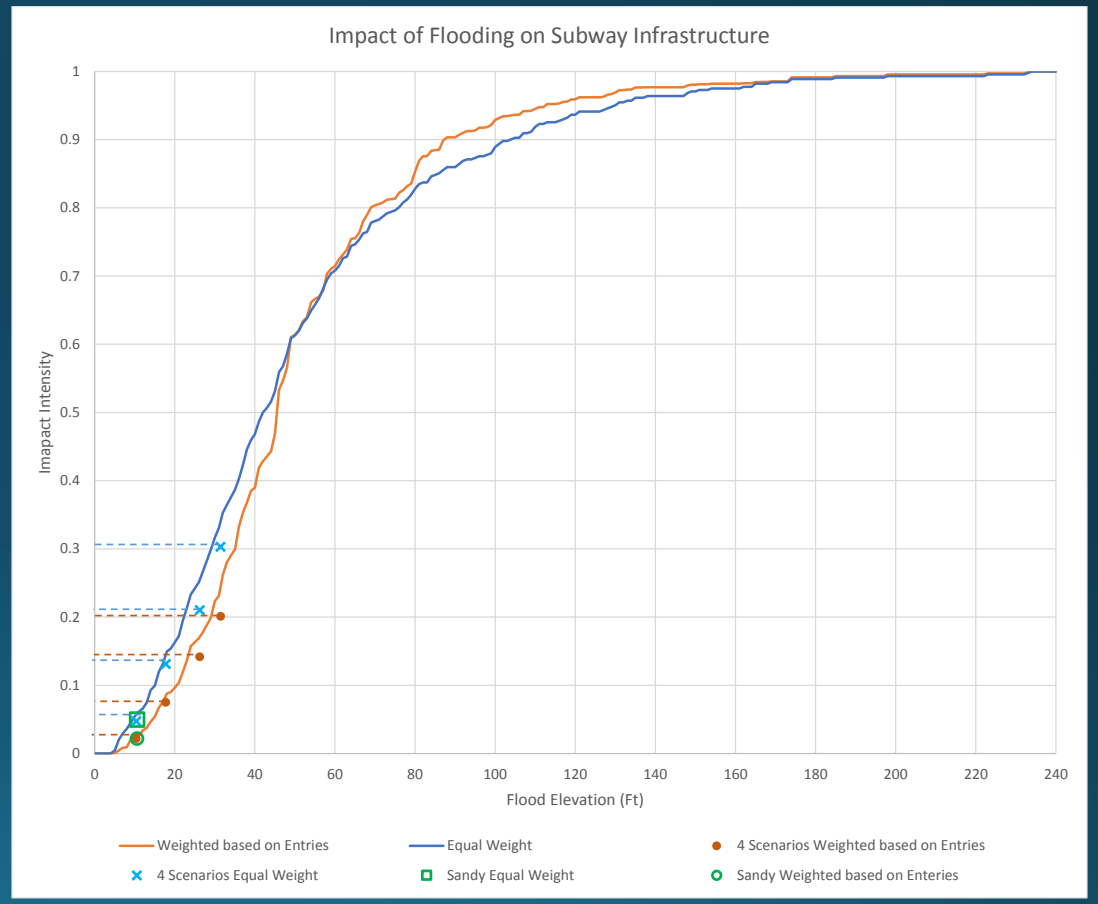
SLOSH 1
SLOSH 2
SLOSH 3
SLOSH 4
MOTF Hindcast Sandy
0 1.25 2.5 5 7.5 10
Miles

What if!?

Intensity of Flood



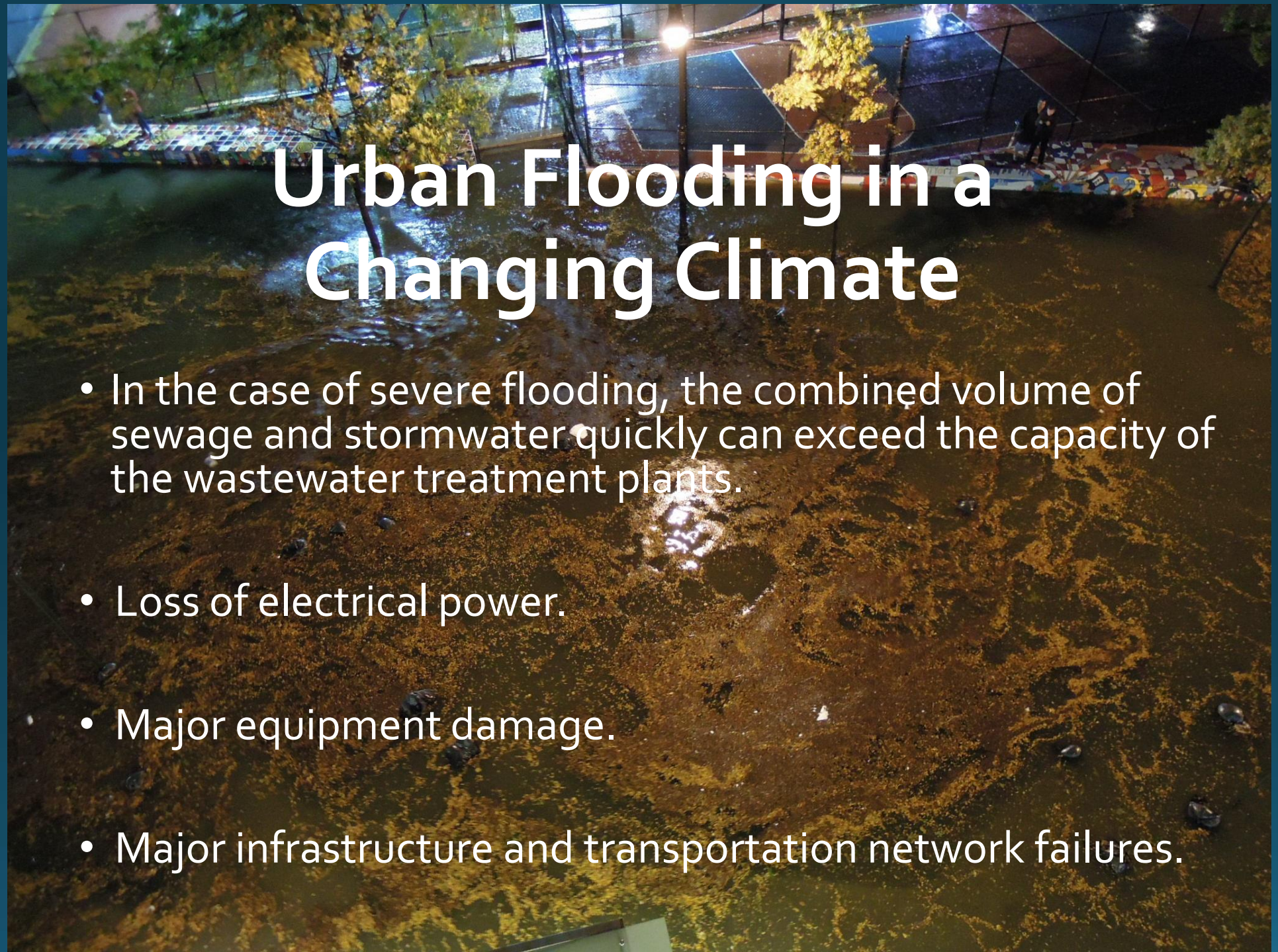


Looking Forward

- Full transit network model
- Time series trend extraction and analysis
- Pre-/post-Sandy impact analysis on station ridership
- Reroute possibilities and integration of exit data for improved understanding of resiliency
- High Risk Area identification
  - Water corridor identification
  - Mitigation methods

References / Sources

- NYC Open Data
- NYS GIS Clearinghouse
- CUSP Data Warehouse
- NYC Panel on Climate Change – Climate Report
- New York City Hazard Mitigation Plan – OEM



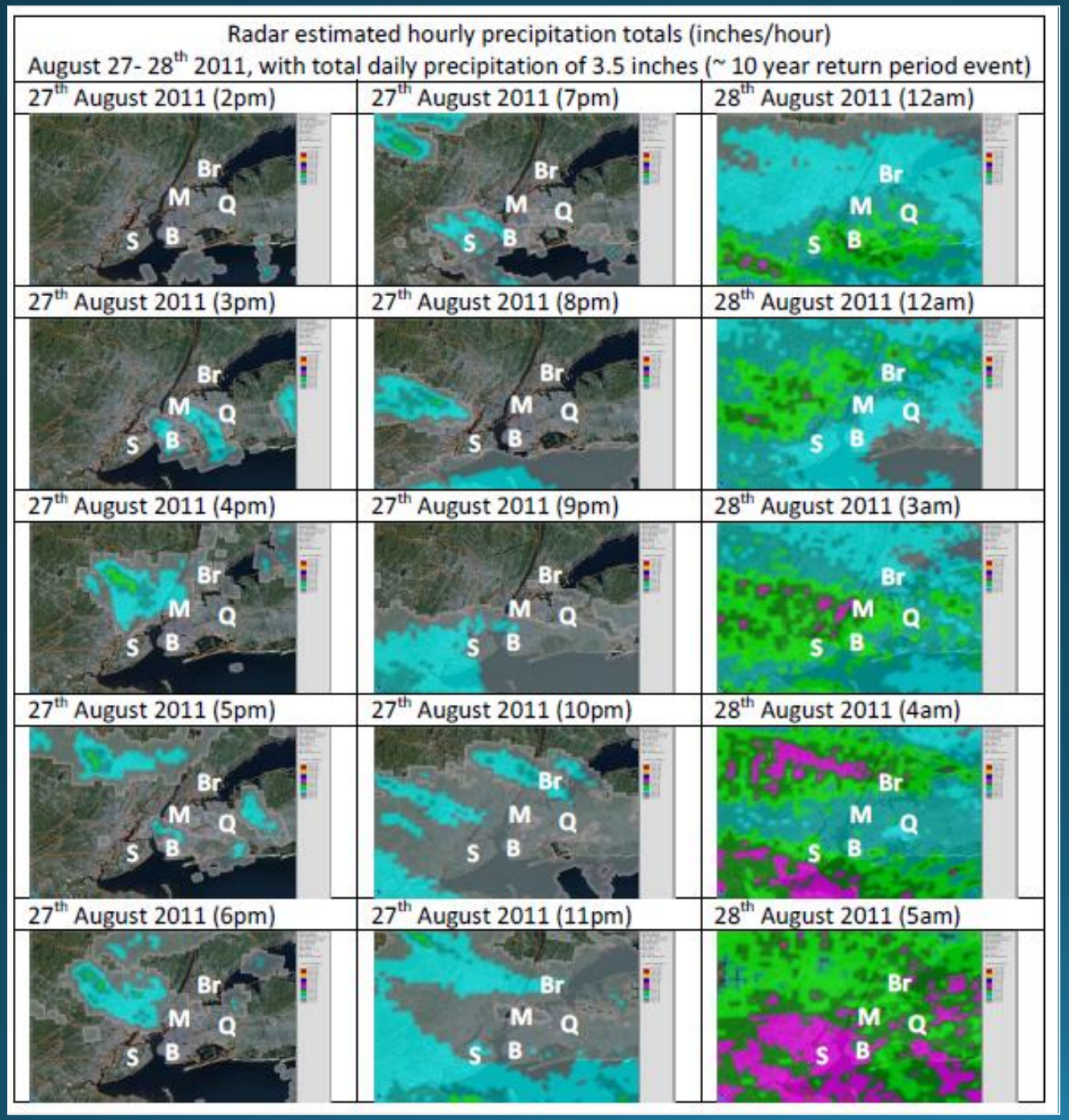
Urban Flooding in a Changing Climate

- In the case of severe flooding, the combined volume of sewage and stormwater quickly can exceed the capacity of the wastewater treatment plants.
- Loss of electrical power.
- Major equipment damage.
- Major infrastructure and transportation network failures.

Radar Technology

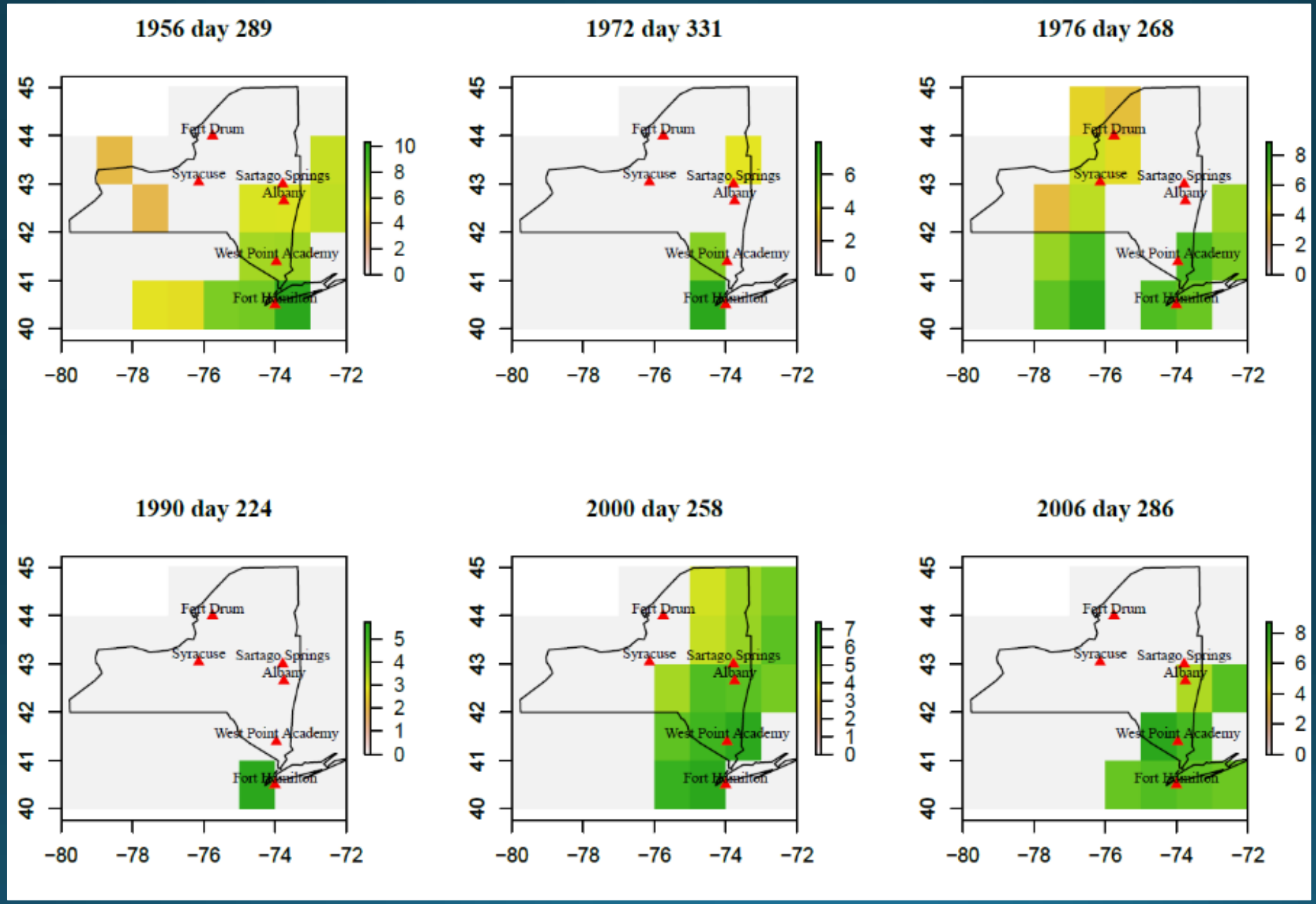
- A very high resolution space and time data set is available in much of the USA for precipitation.

- These spatio-temporal fields can provide a basis for **improved design estimates** and for developing **stochastic scenarios for evaluating the critical links** in an urban hydrologic network and transportation systems.



T-year RP, N-hour duration events spatial field

Where should which type of infrastructure be put needs to be informed by space-time fields



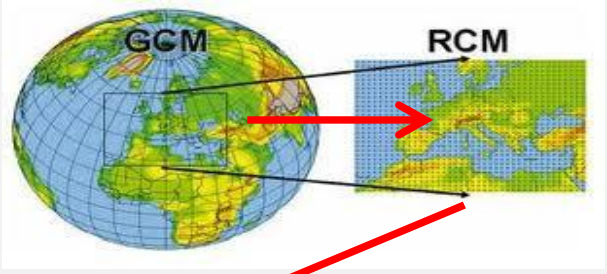
Long duration Floods

Questions

1. How best can rainfall intensity for specified duration and return period be estimated using multiple sources of data while preserving spatial and temporal structures?

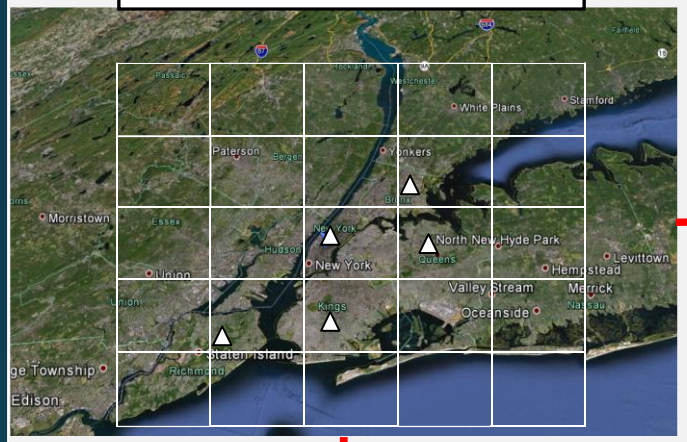
2. How best can **spatio-temporal rainfall fields** corresponding to a rainfall duration and return period be generated to inform design and reliability estimation?

State Variables from Large Scale Climate

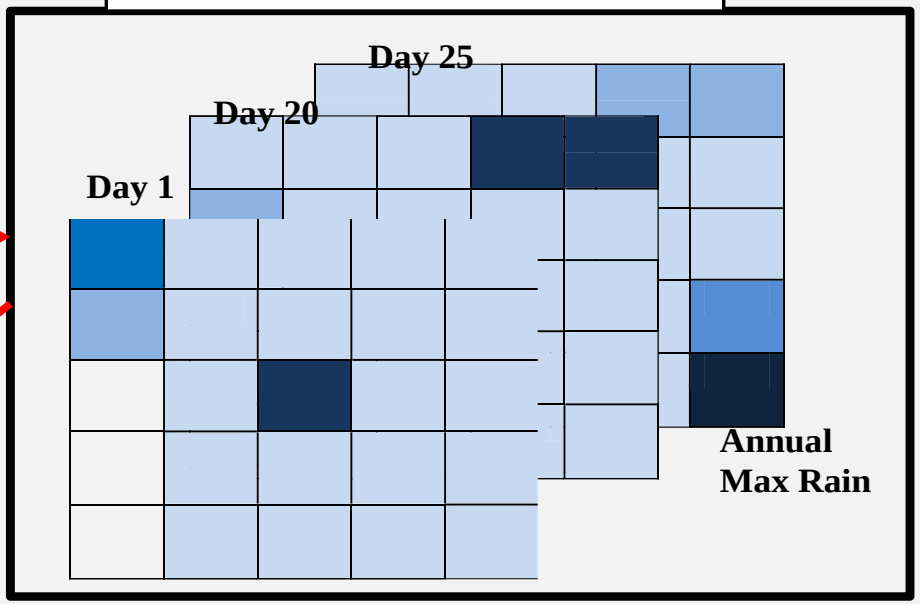


Regional Climate Variables

Data Fusion
Radar + Gauge



Rainfall Extreme Event Fields



Hierarchical Model
Space-Time Rainfall Process Model

Bayesian Inference
$f(Y|\theta)f(\theta|X,C)f(X)f(C)$

Simulation of the Field

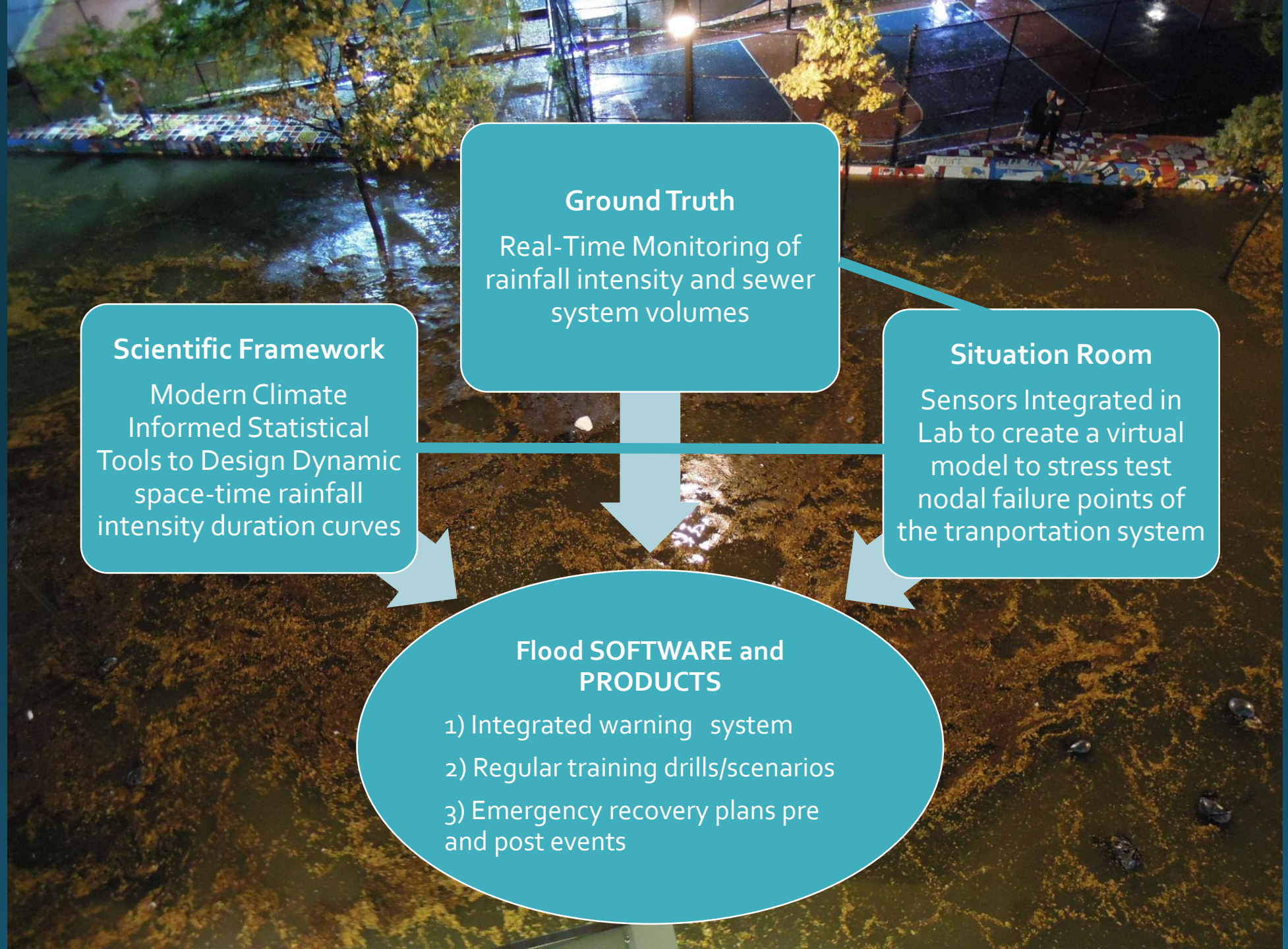
Risk and Performance Analysis

$$\log(\boldsymbol{Y}_i^t) \sim N(\boldsymbol{\mu}_i^t, \boldsymbol{\Sigma}_y) \quad \ldots (1)$$

$$\boldsymbol{\mu}_i^t = \boldsymbol{C}_j^t \boldsymbol{\beta} + \mathbf{X}\boldsymbol{\gamma} \quad \ldots (2)$$

$$\boldsymbol{\beta} \sim MVN(\boldsymbol{\mu}_{\boldsymbol{\beta}}, \boldsymbol{\Sigma}_{\boldsymbol{\beta}}) \quad \ldots (3)$$

$$\Sigma(\mathrm{i},\mathrm{j}) = \Psi(||s_i - s_j||; \boldsymbol{\psi}) \quad \ldots (4)$$


Ground Truth
Real-Time Monitoring of rainfall intensity and sewer system volumes
Scientific Framework
Modern Climate Informed Statistical Tools to Design Dynamic space-time rainfall intensity duration curves
Situation Room
Sensors Integrated in Lab to create a virtual model to stress test nodal failure points of the tranportation system
Flood SOFTWARE and PRODUCTS
1) Integrated warning system
2) Regular training drills/scenarios
3) Emergency recovery plans pre and post events

Thank you.

Questions / Comments