

*Assessing the “Riskscape” -  
Exposure and Vulnerability from  
Current and Projected Coastal Flooding in  
New York City*

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# *Flood Hazard in New York City - Background of Problem:*

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- 600 Miles of coastline in NYC;
- >15% of NYC's land area is within FEMA's 100-year flood zone (pre-Sandy maps);
- Frequent storms, nor'easters, hurricanes, increasing in frequency with global climate change;
- Probable future sea level rise;
- Much of NYC is at, or only slightly above, sea-level;
- Large proportion of NYC's population live within the flood zone;
- Risk to critical infrastructure: underground utilities, transportation network (subways), hospitals, etc.
- City of islands, hard to evacuate.

# *The Importance of Estimating Vulnerable Populations:*

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Emergency management and disaster preparation, planning, mitigation, and recovery require accurate estimation of potentially at-risk populations and sub-populations, yet census data alone do not necessarily yield sufficiently detailed knowledge of population location and distribution, particularly in large, hyper-heterogeneous urban areas like New York City. Additionally, specific sub-populations (i.e., racial/ethnic minorities) may be at higher risk, (Blaikie et al, 1994; Cutter, 2006; Fielding and Burningham, 2005; Fothergill et al, 1999; Mitchell, 1999), yet minority sub-populations remain under-counted by existing methods of calculating potentially exposed or impacted populations.

# *Disaggregating Population Data through Dasymetric Mapping and Expert Systems:*

<b>Areal Units in New York City</b>		
<b>Unit</b>	<b>Number</b>	<b>Average Number of Units per Tract</b>
<b>Census Tracts</b>	<b>2,217</b>	<b>1.00</b>
<b>Census Block Groups</b>	<b>5,733</b>	<b>2.59</b>
<b>Tax Lots</b>	<b>847,153</b>	<b>382.12</b>

## *Dasymetric Mapping*

Utilizes tax-lot level information (e.g. residential area or number of residential units) as ancillary data to disaggregate census population at high spatial resolution in a densely populated, hyper-heterogeneous urban environment such as New York City.

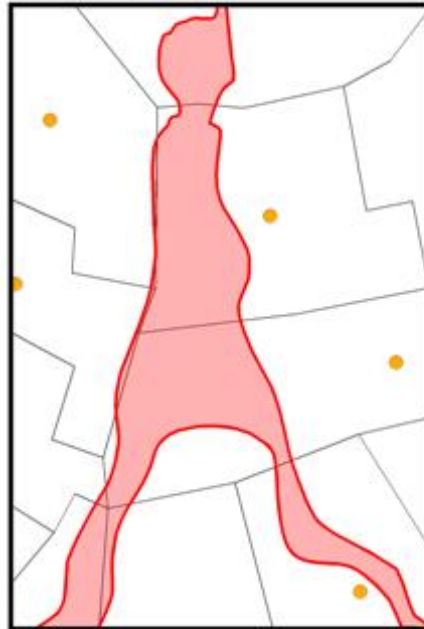
## *Expert System* (Rule-based decision-making system)

Employs an 'expert system' to determine the more accurate ancillary data set (e.g. residential area or number of residential units).

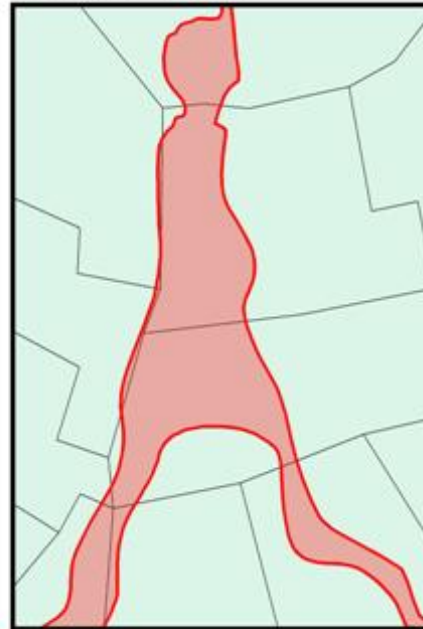
# Cadastral-based Expert Dasymetric System (CEDS)

A comparison of a small area in Staten Island, showing the number of people within the 100-year flood plain. Not only are the population counts not the same amongst the three methods, but the populations being estimated are not the same people.

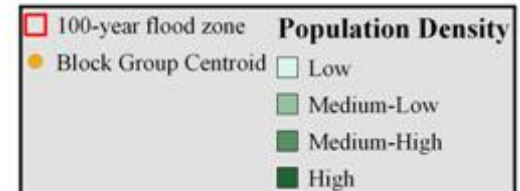
**Centroid Method:**  
0 people at risk



**Areal Weighting:**  
872 people at risk



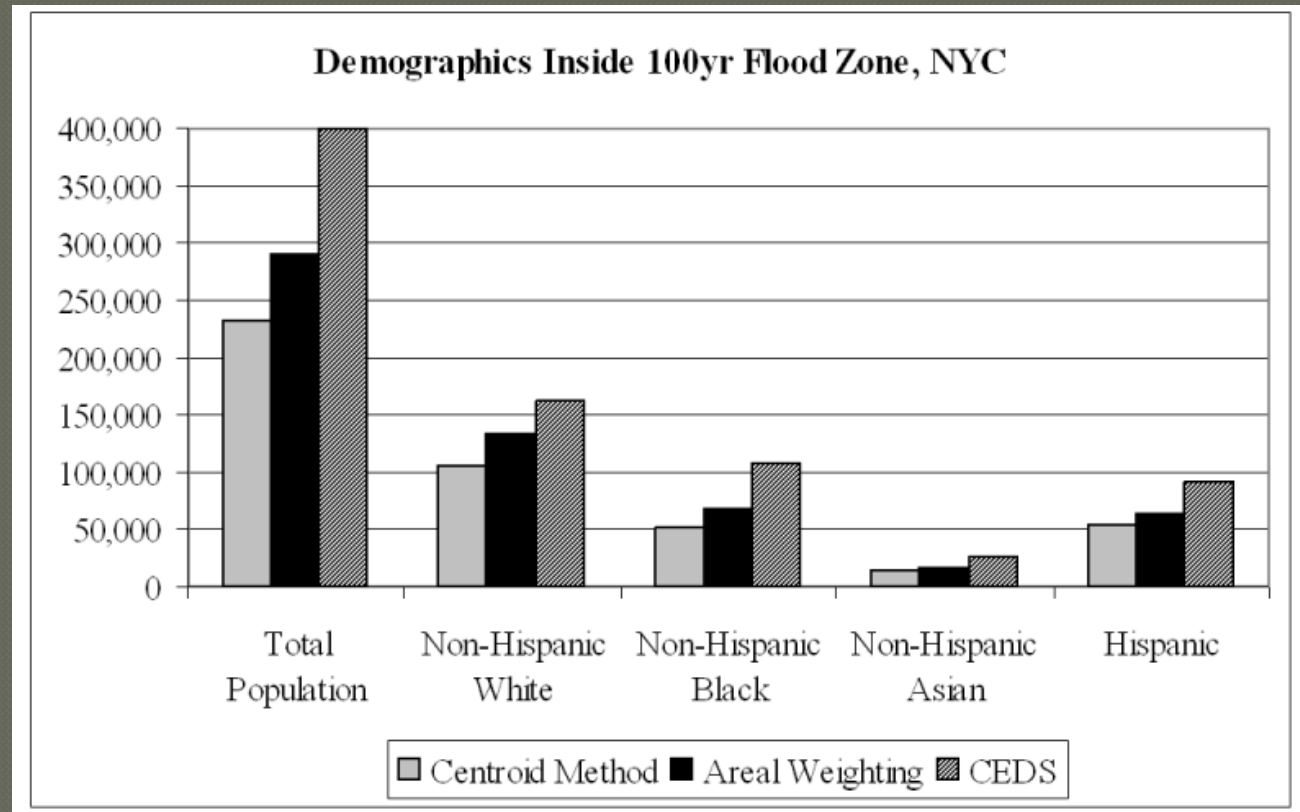
**CEDS:**  
1,154 people at risk



Source: Maantay, J.A.,  
Maroko, A.R., 2009.  
Mapping Urban Risk: Flood  
Hazard, Race, and  
Environmental Justice in  
New York City. *Applied  
Geography*, 29:111-124.

# Population Estimation: Comparison of Methods

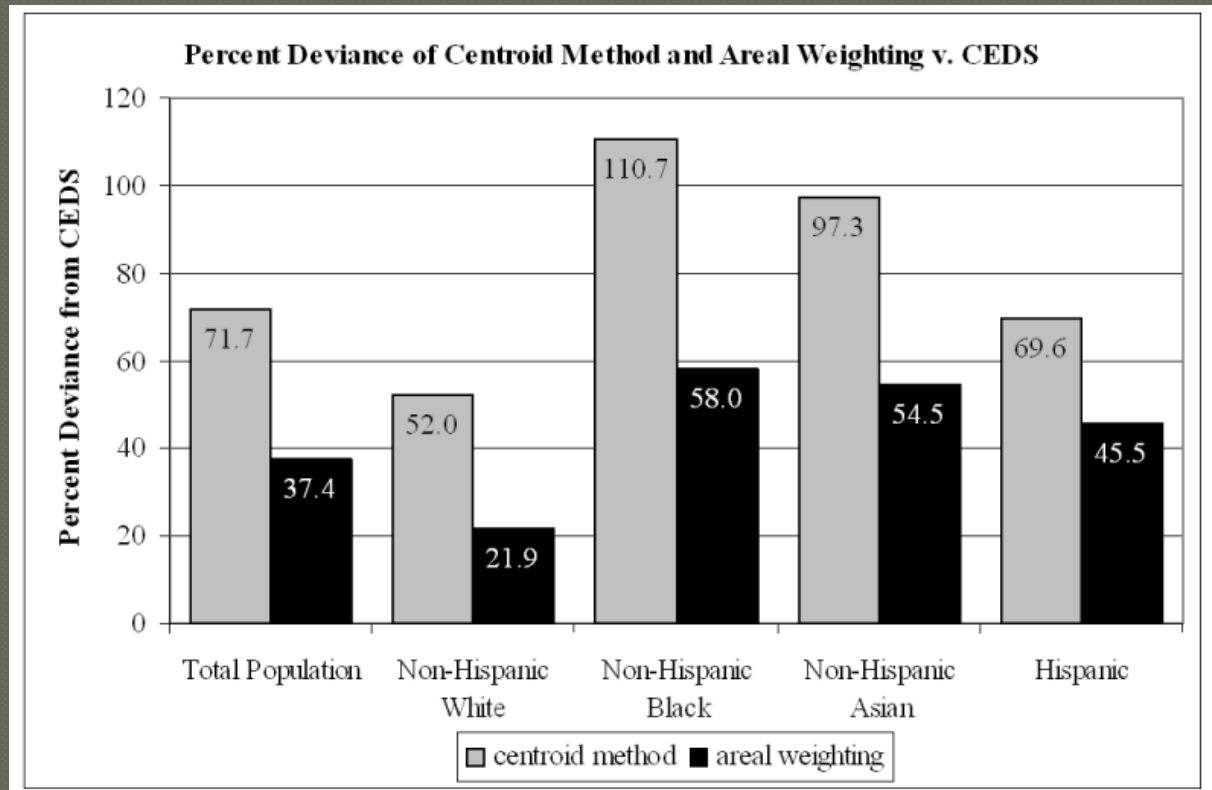
In the results for the entire city, the centroid containment method and areal weighting undercounted the total population potentially affected by the 100-year flood by 72% and 37% respectively, when compared to the CEDS-derived population.



Source: Maantay, J.A., Maroko, A.R., 2009. Mapping Urban Risk: Flood Hazard, Race, and Environmental Justice in New York City. *Applied Geography*, 29:111-124.

# Environmental Justice Implication of Under-Counting

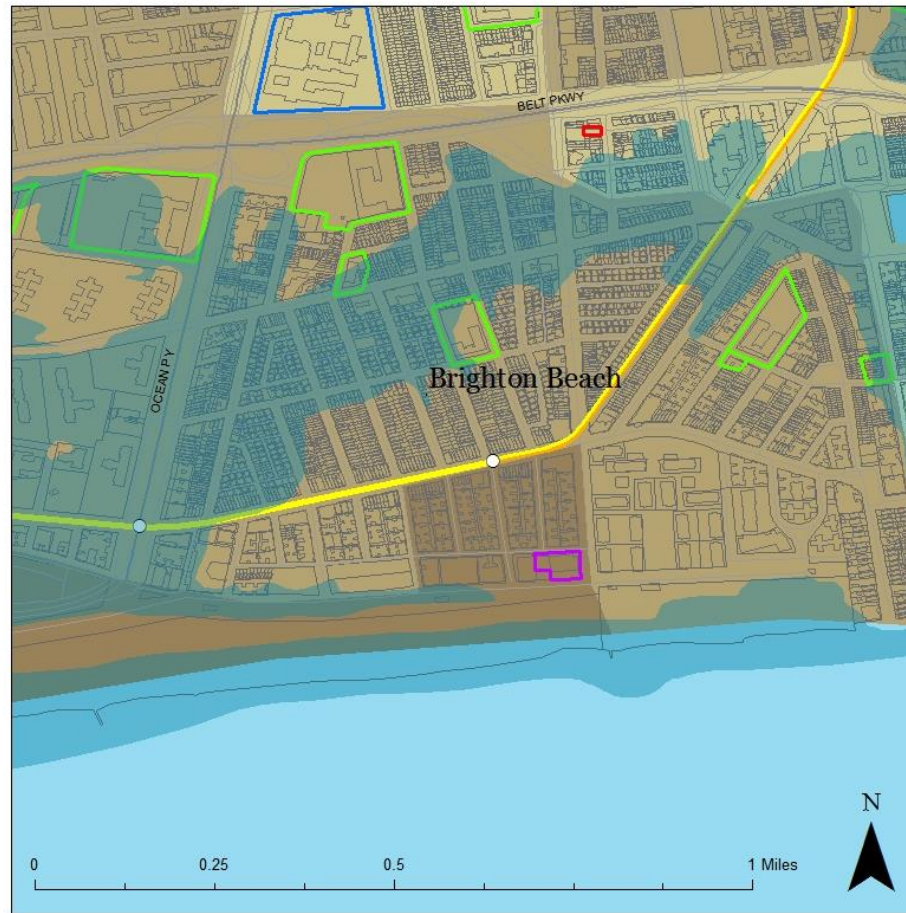
The underestimation by the centroid containment and the areal weighting methods was not consistent across racial/ethnic groups. For instance, areal weighting undercounted non-Hispanic whites by 22%, but non-Hispanic blacks were undercounted by 58%. The centroid containment method undercounted non-Hispanic whites by 52%, while non-Hispanic blacks were undercounted by 111%.



Source: Maantay, J.A., Maroko, A.R., 2009. Mapping Urban Risk: Flood Hazard, Race, and Environmental Justice in New York City. *Applied Geography*, 29:111-124.

# Hazard Vulnerability Index (NYCHVI):

NYCHVI (Hazard Vulnerability Index) is based on CDC's GRASP Model, and assigns an index value to each census tract in NYC, reflecting a composite of population vulnerability indicators, including poverty status, disabled status, age cohorts, several health variables, race/ethnicity, and linguistic isolation.



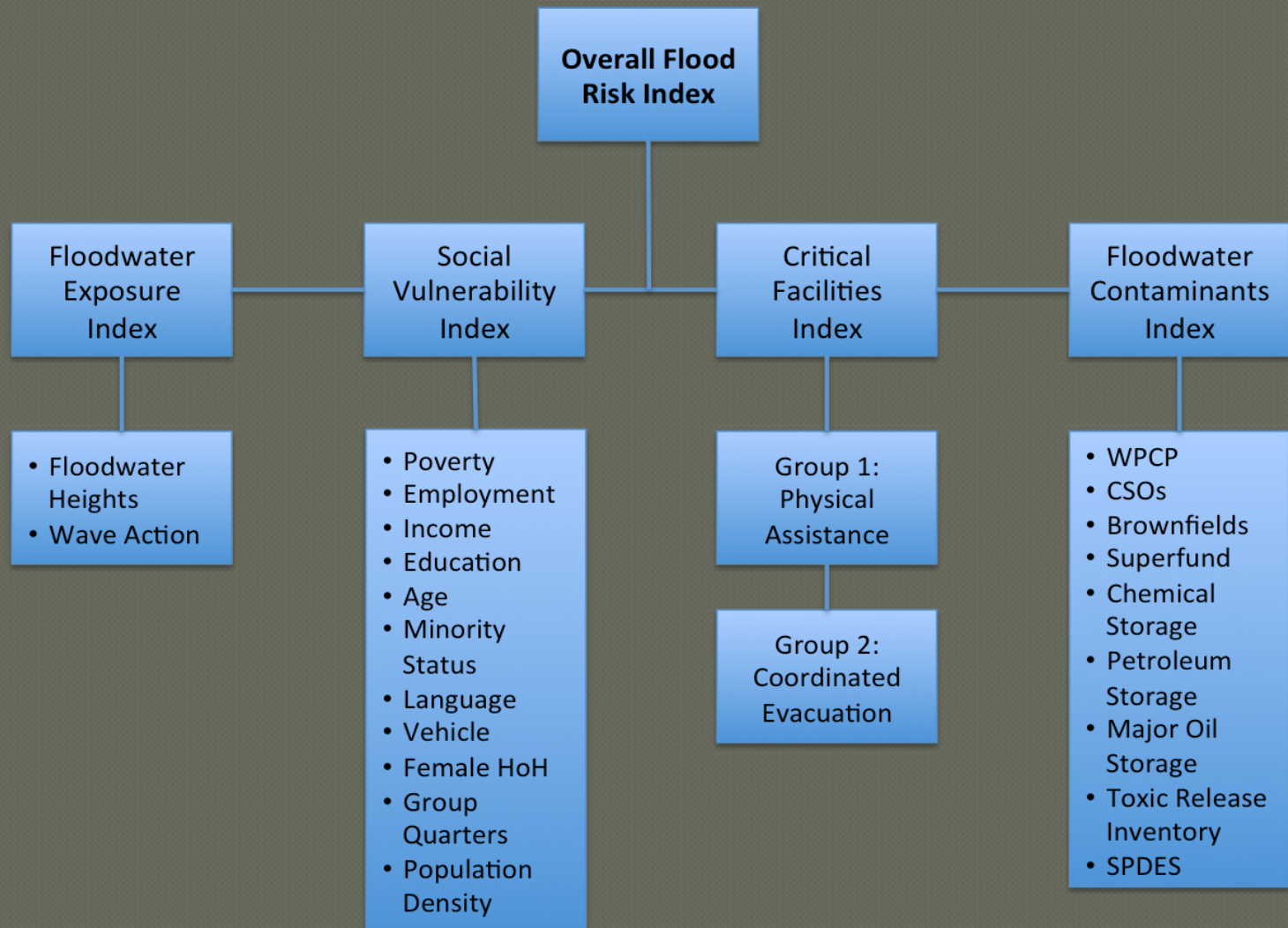
Human Vulnerability Assessment (HVA) with 100 Year Flood Area Overlay for Brighton Beach, Brooklyn, NY



- 100 Year Flood Arm
  - Subway Stop
  - B/Q Subway Line
  - Q Subway Line
  - Hospitals
  - Daycare Centers
  - Schools
  - Fire Stations
- Number of HVA Flags
- 0
  - 1-3
  - 4-6
  - 7-9
  - 10-12
  - 13-15

Source: Maantay, J.A., Maroko, A.R., and Culp, G., 2010. Using Geographic Information Science to Estimate Vulnerable Urban Populations for Flood Hazard and Risk Assessment in New York City, in Showalter, P., and Lu, Y. eds., *Geotechnical Contributions to Urban Hazard and Disaster Analysis*. Springer-Verlag. Map by G. Culp

# Developing a Flood Risk Index:



# *Modeling Risk, Exposure, and Vulnerability:*

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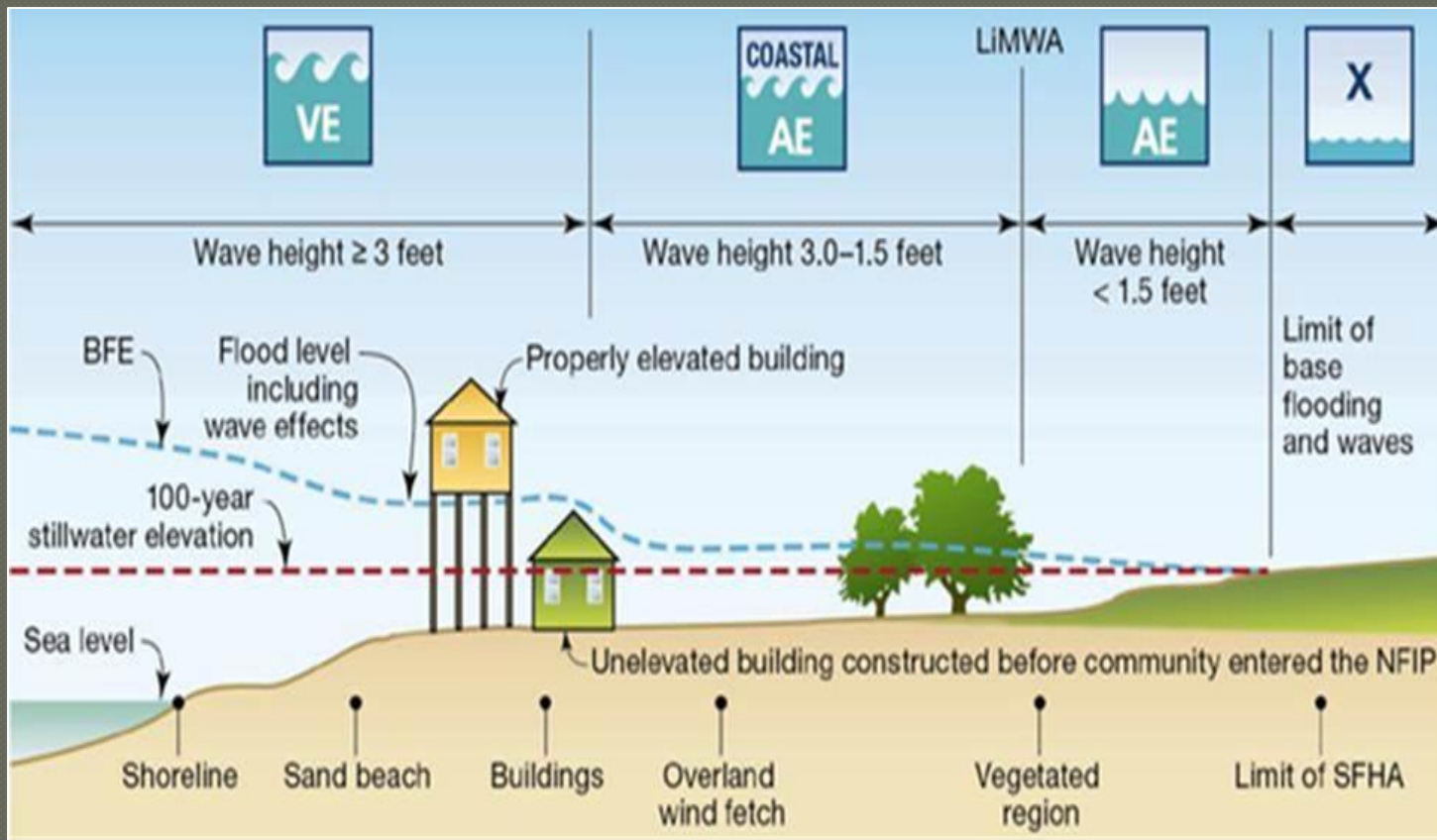
Four separate indices were constructed, to capture:

- Exposure to floodwater heights and wave action;
- Exposure to floodwater contaminants;
- Social vulnerability to flooding; and
- Critical facilities at-risk to flooding.

Six flood scenarios were examined:

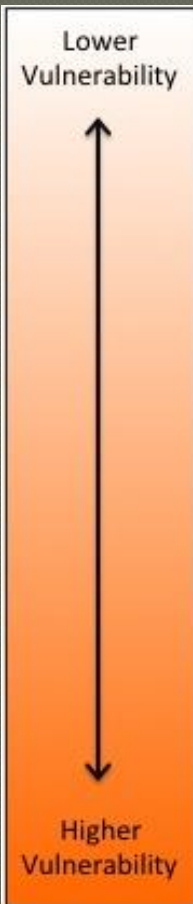
- 100-year and 500-year flood plain extents, based on FEMA's 2013 Work Maps for NYC;
- 100-year and 500-year flood plain extent projected for 2020, based on NPCC's 90<sup>th</sup> percentile projections;
- 100-year and 500-year flood plain extent projected for 2050, based on NPCC's 90<sup>th</sup> percentile projections.

# Floodwater Exposure Index:



A coastal profile showing the transition of FEMA designated flood zones from the ocean (left) moving onshore to the limit of the 100-year flood and beyond. The Special Flood Hazard Area contains Zones VE and AE. Zone X indicates areas beyond the 100-year flood zone that may be subject to the 500-year flood. *Source: FEMA*

# Flood Extent and Severity:

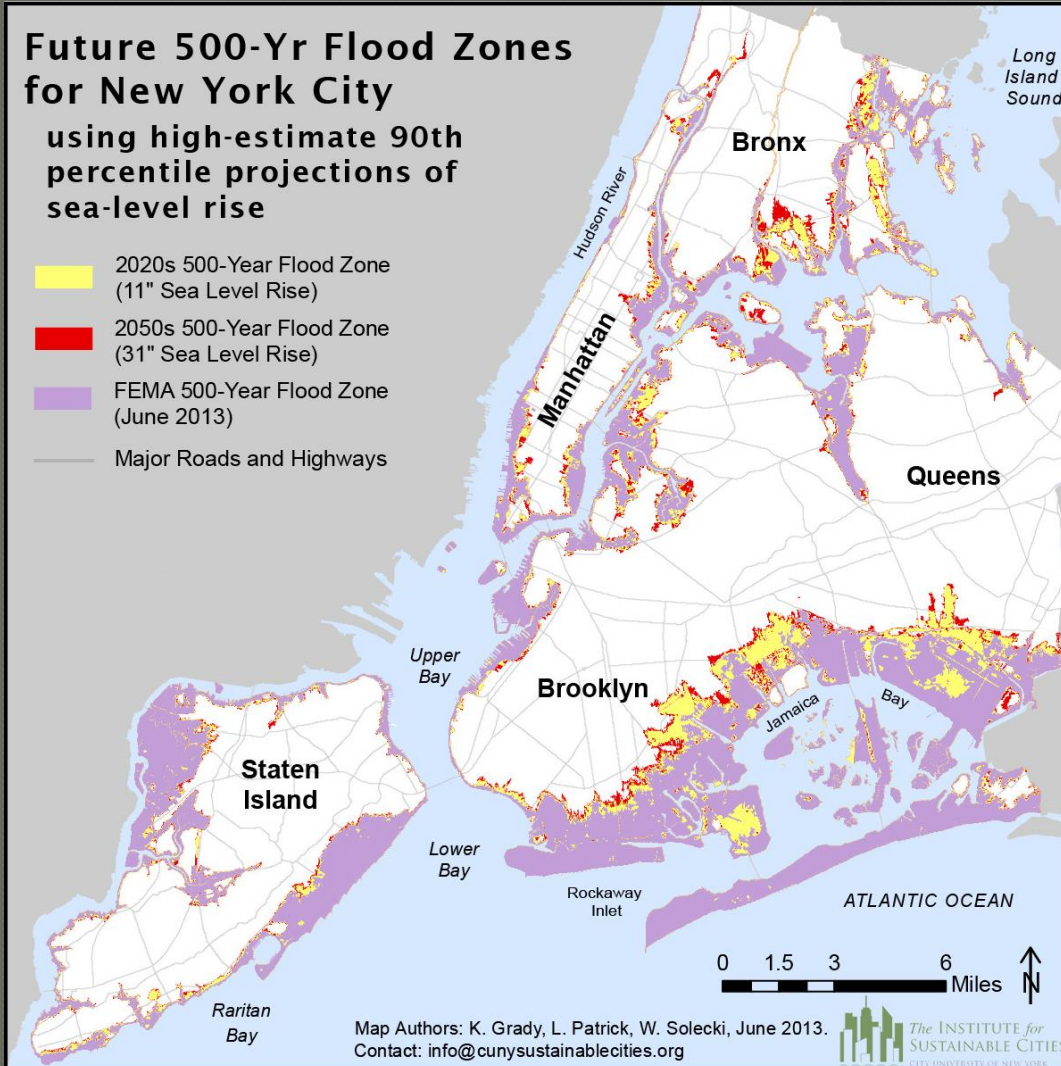
	<b>Rank 1</b> - Projected 500-Year Flood, 2050s
	<b>Rank 2</b> - Projected 500-Year Flood, 2020s
	<b>Rank 3</b> - Projected 100-Year Flood, 2050s
	<b>Rank 4</b> - Projected 100-Year Flood, 2020s
	<b>Rank 5</b> - FEMA Shaded X Zones FEMA Shaded X areas are located between the limits of the current 100-Year and 500-Year floods. High velocity wave action is not a factor.
	<b>Rank 6</b> - FEMA AE and AO Zones, BFE < 10 ft FEMA AE Zones are subject to shallow flooding (average depths between 1 and 3 feet) in the current 100-Year flood. High velocity wave action is not a factor. The base flood elevations in these tax lots are less than 10 feet.
	<b>Rank 7</b> - FEMA AE Zones, BFE 10 ft FEMA AE Zones are subject to the current 100-Year flood. High velocity wave action is not a factor. The base flood elevations in these tax lots are equal to 10 feet.
	<b>Rank 8</b> - FEMA AE Zones, BFE > 10ft FEMA AE Zones are subject to the current 100-Year flood. High velocity wave action is not a factor. The base flood elevations in these tax lots are greater than 10 feet.
	<b>Rank 9</b> - FEMA VE Zones FEMA VE Zones are subject to the current 100-Year flood and also exposed to storm-induced breaking waves greater than 3 feet in height (high velocity wave action).

Ranking of NYC tax lots based on their potential to experience high storm surge elevations and high velocity wave action. The higher the rank the greater the exposure to flood waters and the greater the physical vulnerability of the residential population. The 10ft BFE was chosen as the break value in the AE zones (zones subject to shallow flooding of 1 - 3 feet) based on the distribution of the base flood elevation data.

# 500-Year Flood Plain Extent: Current, 2020, 2050

## Future 500-Yr Flood Zones for New York City using high-estimate 90th percentile projections of sea-level rise

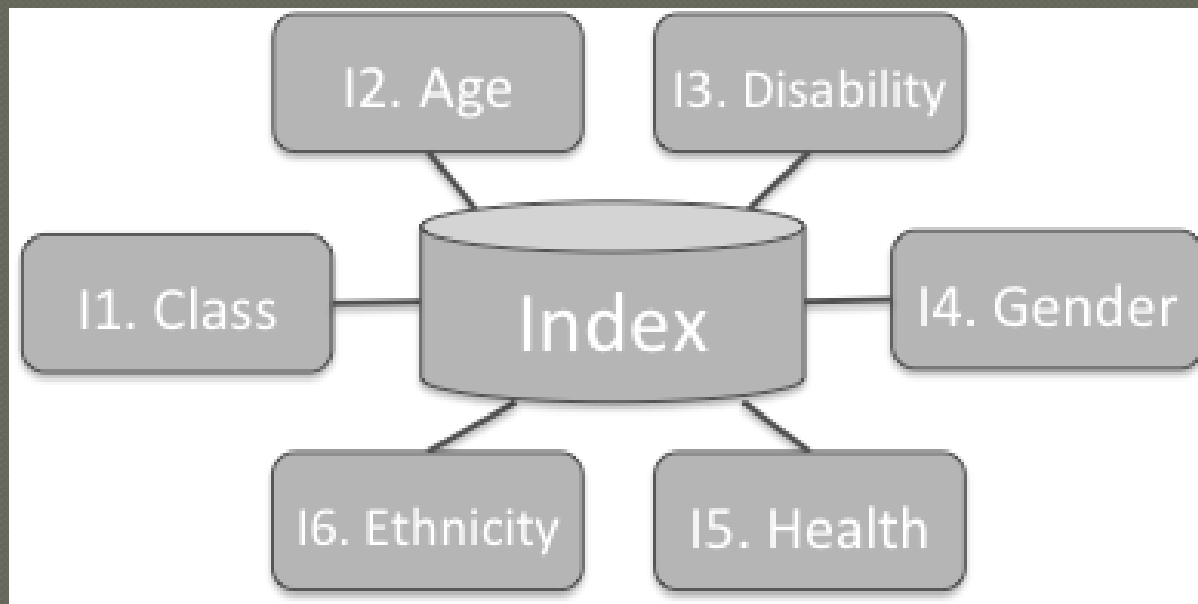
- 2020s 500-Year Flood Zone (11" Sea Level Rise)
- 2050s 500-Year Flood Zone (31" Sea Level Rise)
- FEMA 500-Year Flood Zone (June 2013)
- Major Roads and Highways



The potential future 500-year floodplains in New York City using a component-by-component approach to sea level rise projections.

Source: New York City Panel on Climate Change (NPCC), 2013. Map by K. Grady, L. Patrick, and W. Solecki

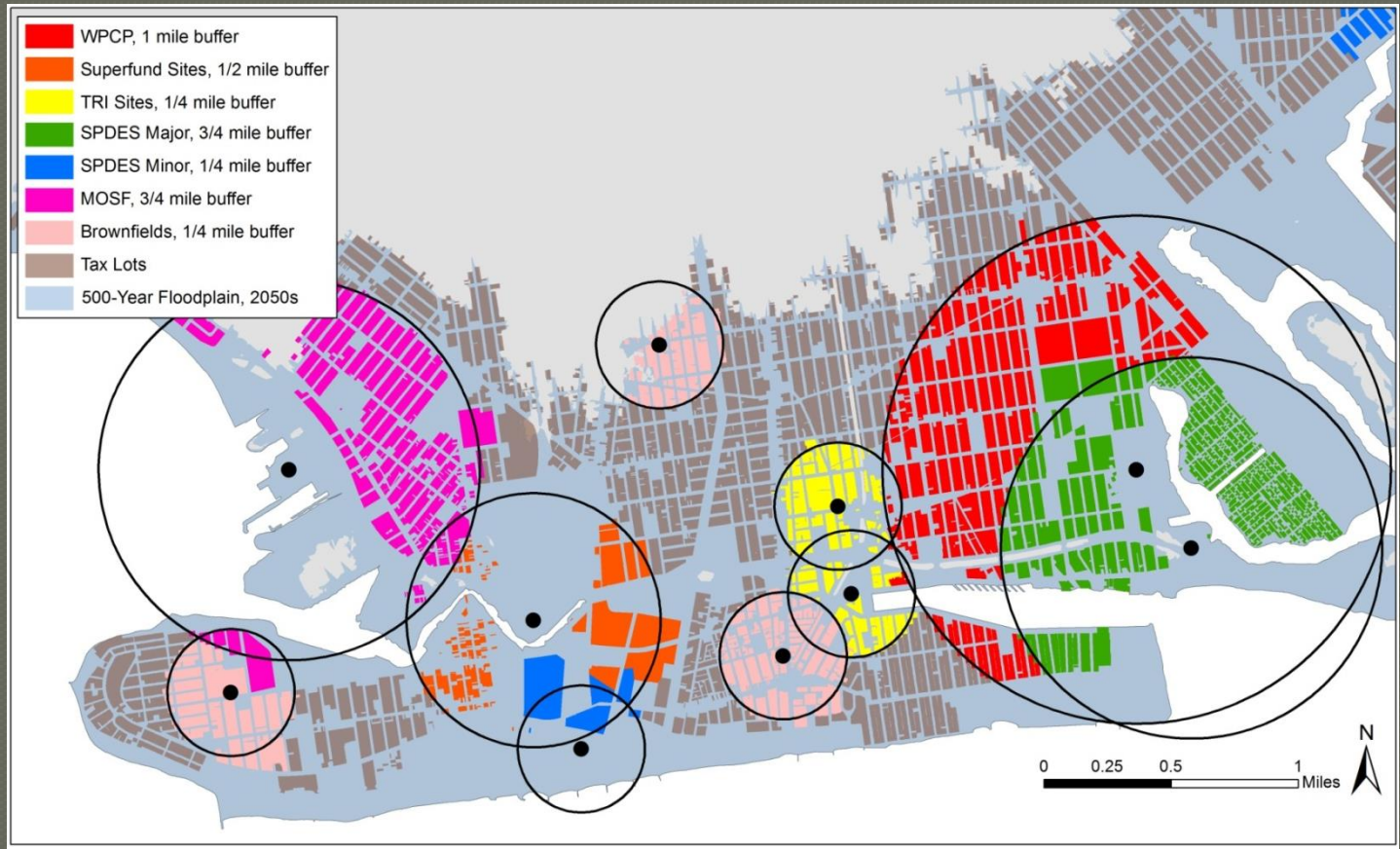
# *Social Vulnerability Index:*



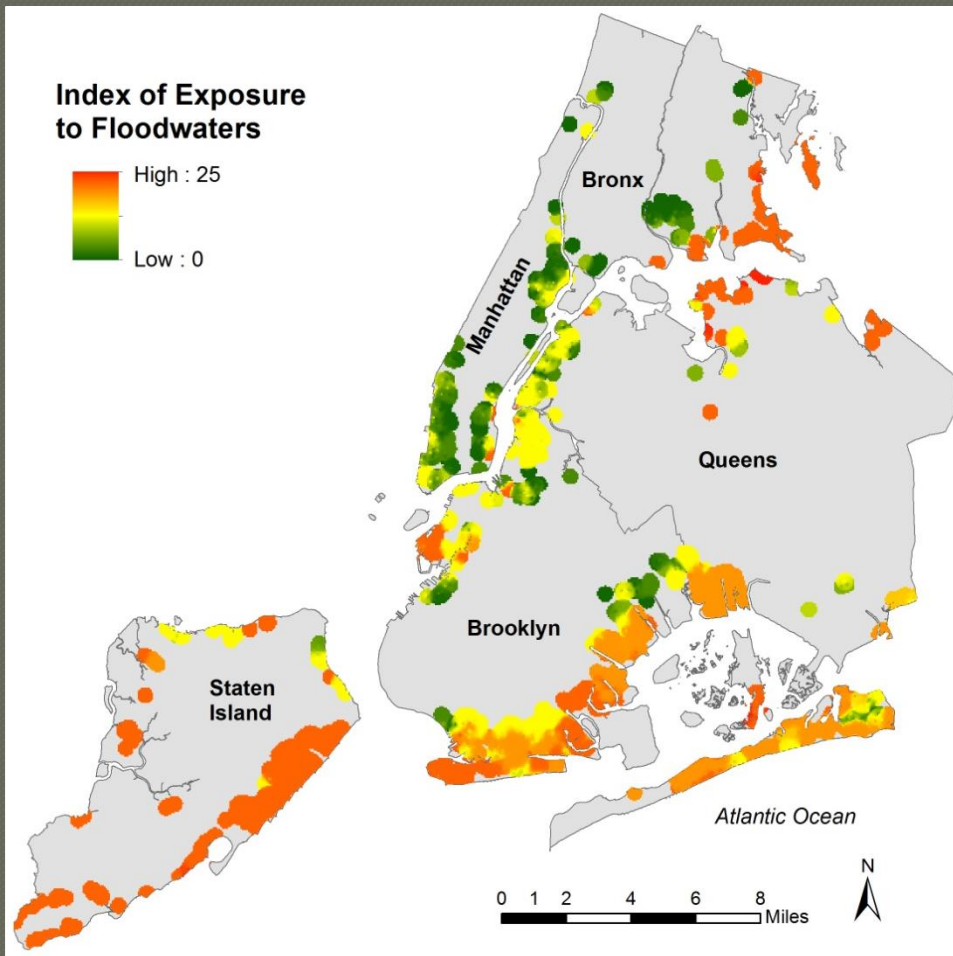
A model of deductive design for the construction of vulnerability indices. Each indicator (I.1. – I.6.) is transformed, normalized, and aggregated without weights to form the index. *Reprinted from Tate (2012).* The Social Vulnerability Index includes 14 variables in the following domains: socioeconomic status, household structure and disability, minority status and language, and group housing and transportation .

# Exposure to Floodwater Contaminants:

Sources of potential floodwater contaminants in south Brooklyn, their buffer zones, and the tax lots at risk. The 500-year floodplain for the 2050s is in blue.



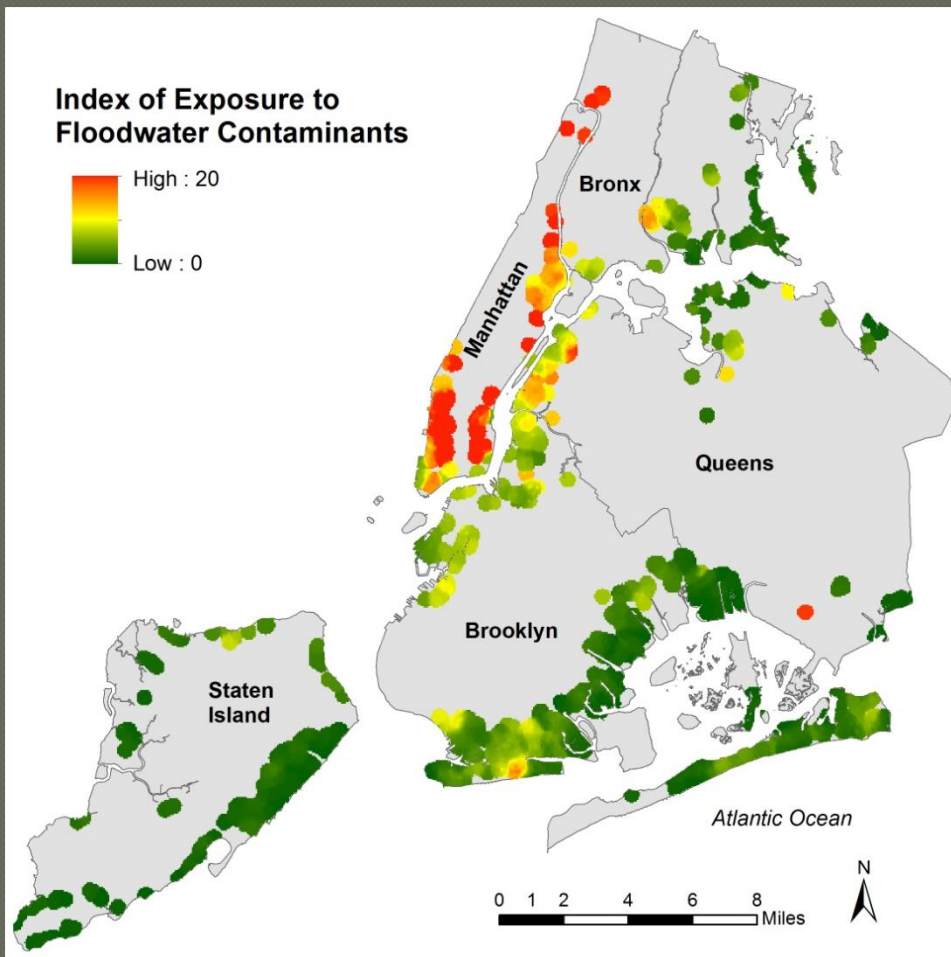
# Index of Exposure to Floodwaters:



The index of exposure to floodwaters for New York City. Data for the index was generated at the tax lot level and the map surface was interpolated via inverse distance weighting. Tax lots without a residential population were not included.

Map: L. Patrick, 2015

# Index of Exposure to Floodwater Contaminants:

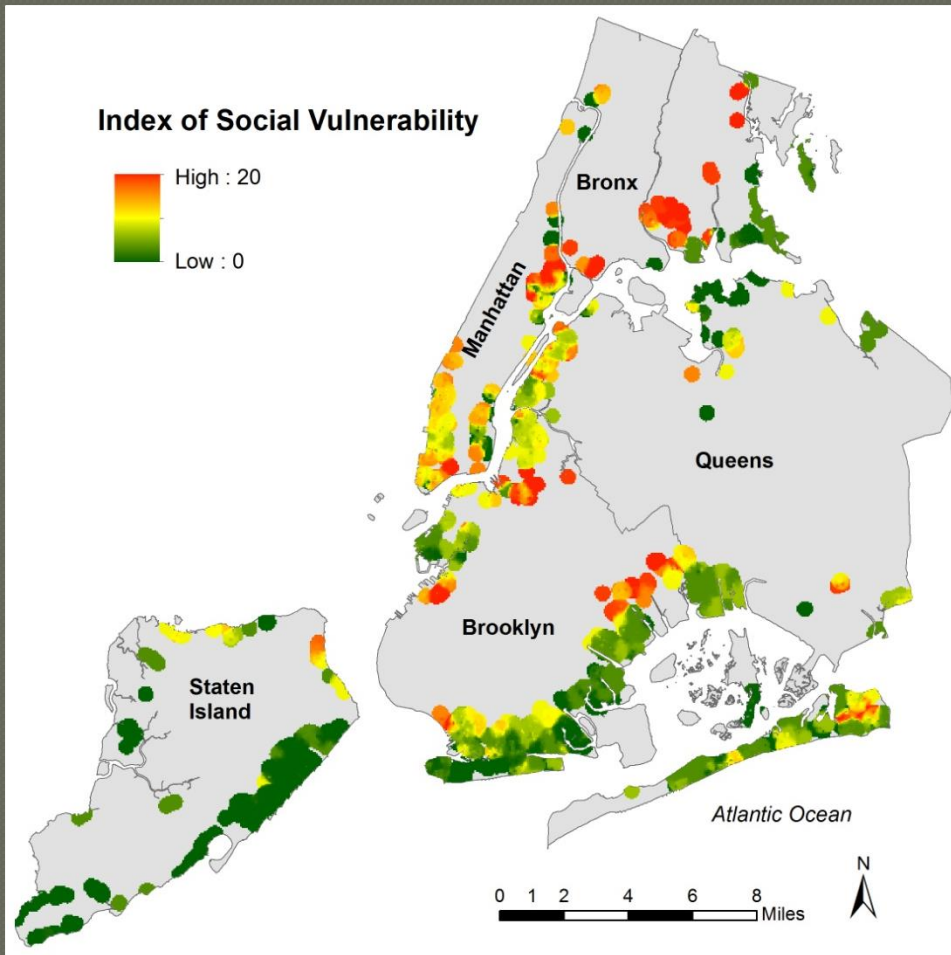


The index of exposure to floodwater contaminants for New York City. Data for the index was generated at the tax lot level and the map surface was interpolated via inverse distance weighting. Tax lots without a residential population were not included.

Map: L. Patrick, 2015

# Index of Social Vulnerability

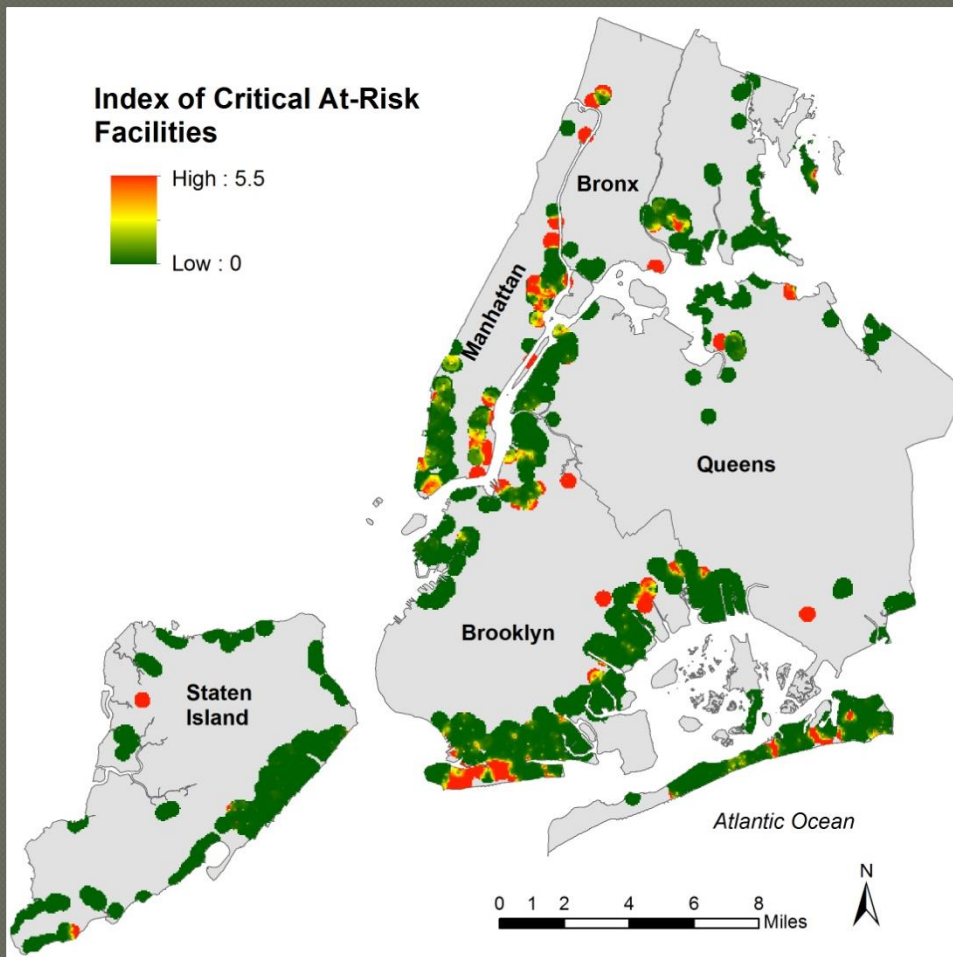
The index of social vulnerability for New York City. Data for each index was generated at the tax lot level and the map surfaces were interpolated via inverse distance weighting. Tax lots without a residential population were not included.



Map: L. Patrick, 2015

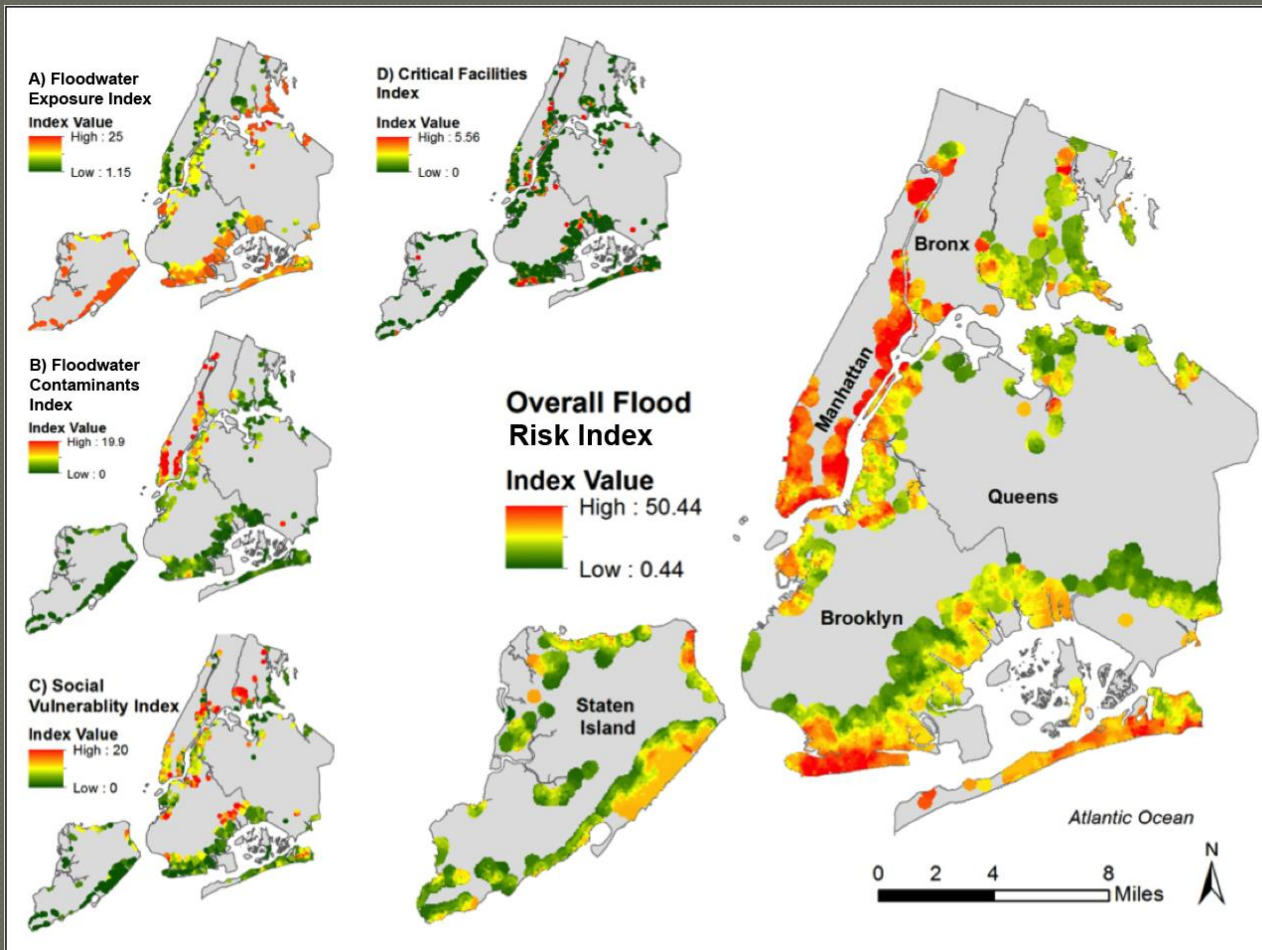
# *Index of Critical At-Risk Facilities*

The index of critical at-risk facilities for New York City. Data for each index was generated at the tax lot level and the map surfaces were interpolated via inverse distance weighting. Critical facilities include those requiring complex evacuation, or whose residents require physical assistance, such as hospitals, nursing homes, daycare centers, schools, homeless shelters, correctional facilities, or high rise buildings.



Map: L. Patrick, 2015

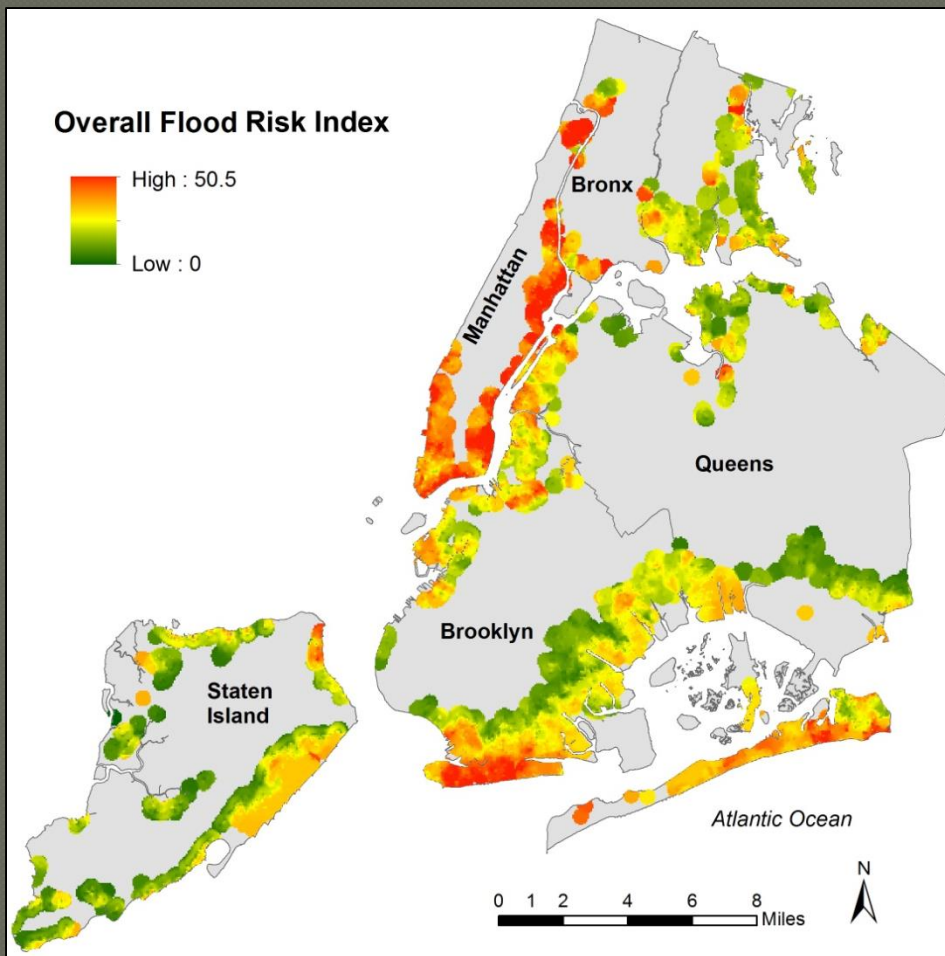
# The Combined Risk Index:



The index of exposure to floodwaters (A), the index of exposure to floodwater contaminants (B), the social vulnerability index (C), the index of at-risk critical facilities (D), and the overall flood risk index.

Map: L. Patrick, 2015

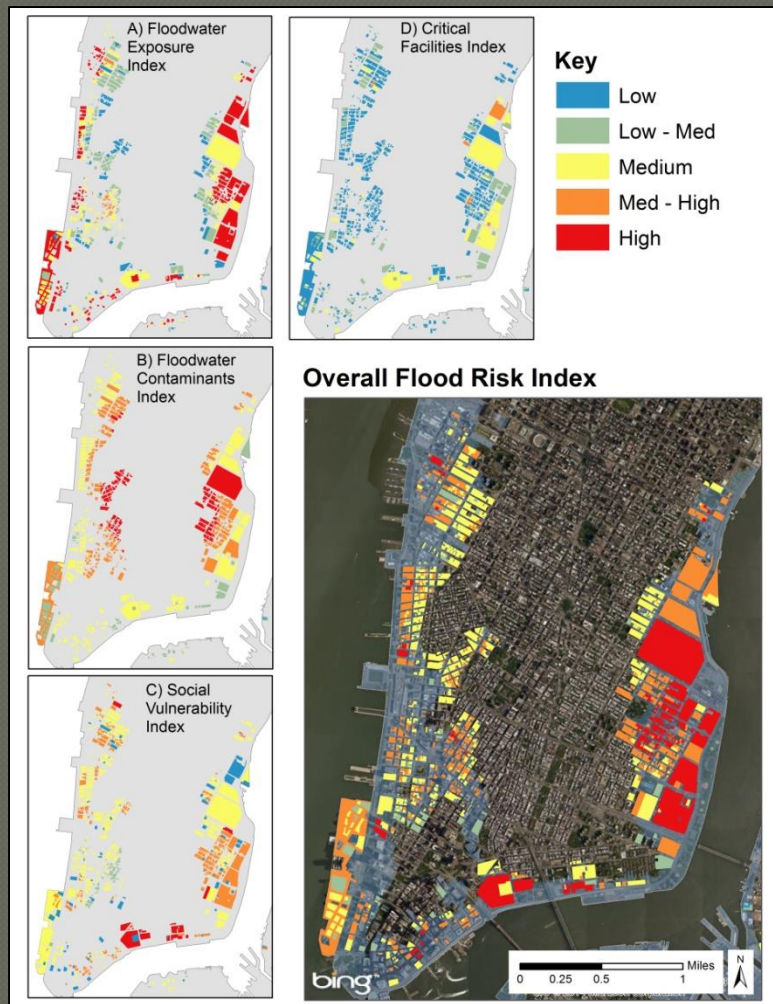
# Overall Flood Risk Index:



The overall flood risk index for New York City is calculated from the combination of the following four indices: the index of exposure to floodwaters, the index of exposure to floodwater contaminants, the social vulnerability index, and the index of at-risk critical facilities. The index surface was interpolated using inverse distance weighting. Tax lots without a residential population were included.

Map: L. Patrick, 2015

# Lower Manhattan Case Study Area:

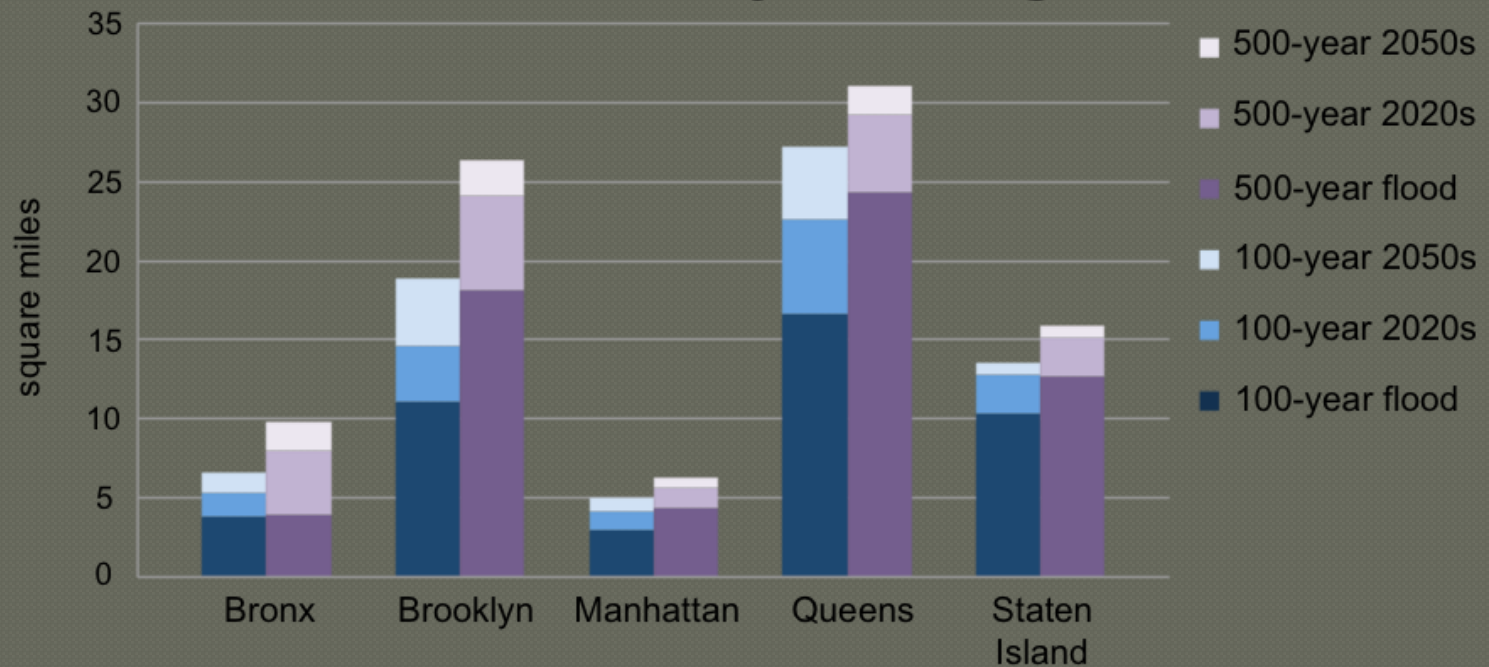


The floodwater exposure index (A), floodwater contaminants index (B), social vulnerability index (C), critical facilities index (D), and the overall flood risk index (right) for lower Manhattan. Tax lots are ranked from low (blue) to high values (red), and the 500-year flood zone for the 2050s is shown in transparent blue (right).

Map: L. Patrick, 2015

# Flood Extent in Square Miles for Six Flood Scenarios:

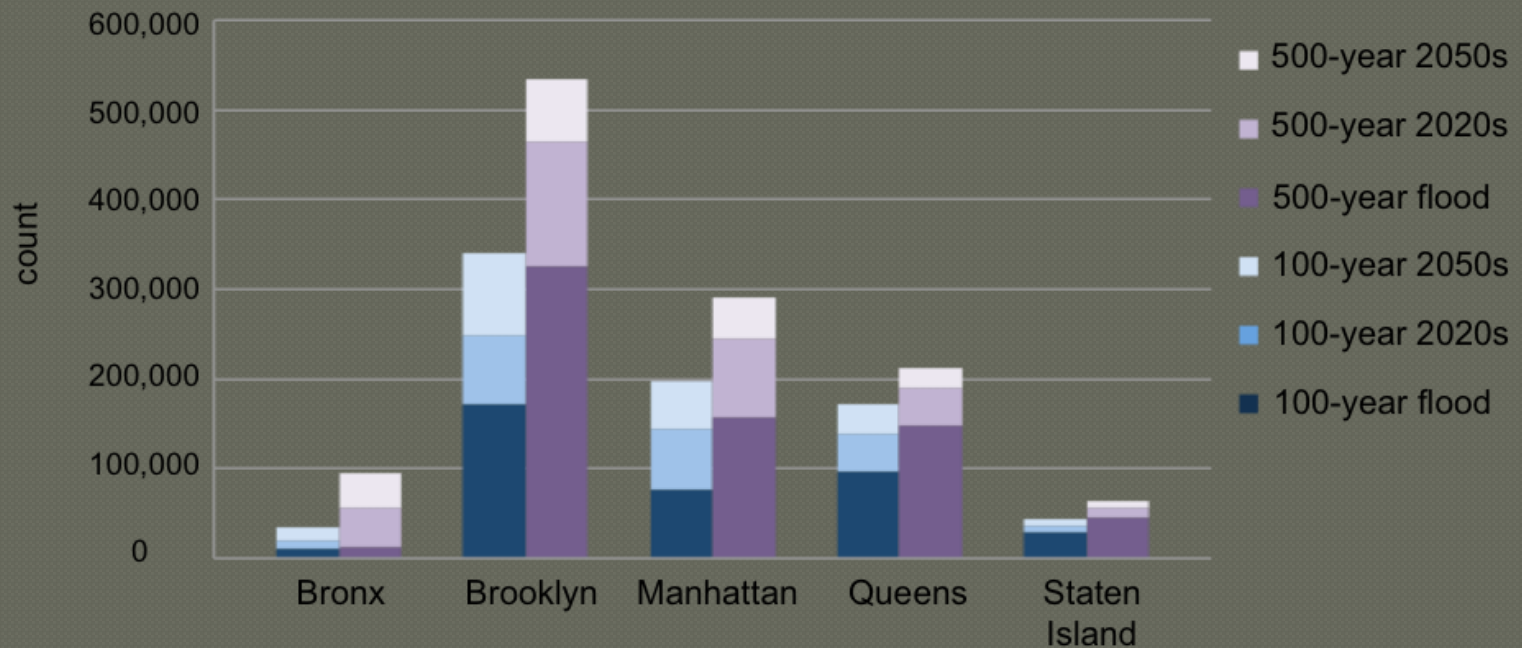
## Flood Area by Borough



Area in square miles of the current and future 100- and 500-year flood zones for the five boroughs of New York City. The purple bars represent 500-year flood scenarios and the blue bars represent 100-year flood scenarios.

# At-Risk Population Estimates for Six Flood Scenarios:

## Population At-Risk by Borough



Residential population at-risk to the current and future 100- and 500-year flood zones for the five boroughs of New York City. The purple bars represent 500-year flood scenarios and the blue bars represent 100-year flood scenarios.

Source: 2010 U.S. Census.

## *Policy Implications:*

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- Exposure and vulnerability index can be used to locate the most vulnerable parts and populations of NYC, for purposes of pre-disaster planning, management, and mitigation, as well as recovery efforts.
- Land use planning, zoning, and other public and private development efforts can take into account the vulnerability index results in assessing proposals for new development and policy initiatives, in order to better protect the most vulnerable populations and natural and built infrastructure.
- City resources can be distributed more equitably, and allocated in proportion to the actual risk anticipated to be borne by vulnerable populations and natural and built infrastructure due to potential hazards.

# *Acknowledgements:*

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