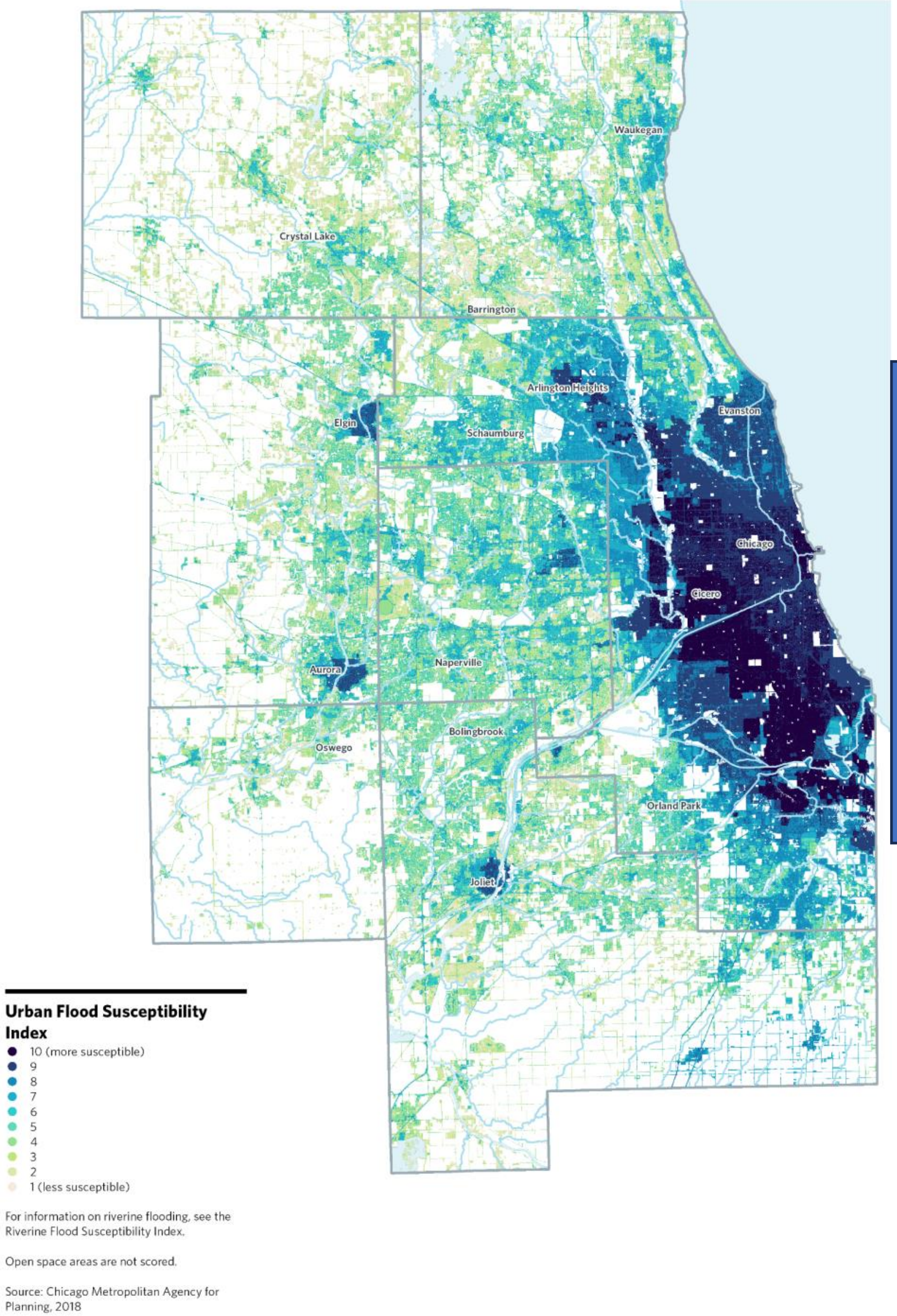

National Science Foundation

Stormwater Inequity in Urban Areas: Citizen Science, Sensor Data, and Policy Analysis

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7/15/2024

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Project Objectives

1. Improve **citizen science** and **citizen education** about water infrastructure.

2. Address **water infrastructure differences** between **socio-economically disparate communities**.

3. Identify **viable policy options** using both **economic** and **policy analysis**.

Figure: Students at Chicago’s Whitney M. Young Magnet High School were introduced to water quality tests, including **turbidity testing**, **coliform testing**, and **dissolved oxygen testing**.

Source: IIT Water, *Citizen Science*. https://iitwater.com/index.php/citizen-science/

Stormwater Management History of Chicago

- **Stormwater volumes in Chicago are projected to increase**

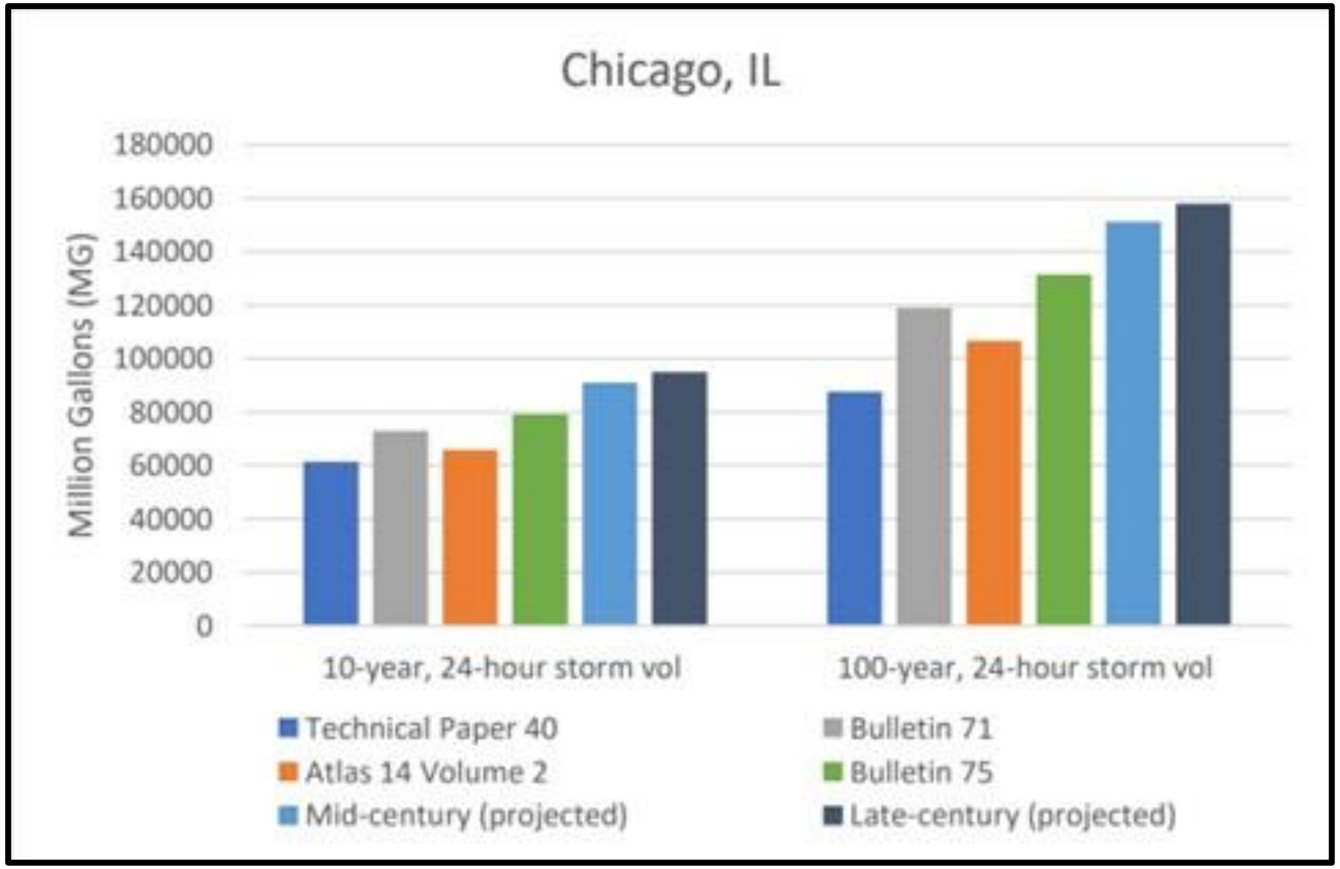
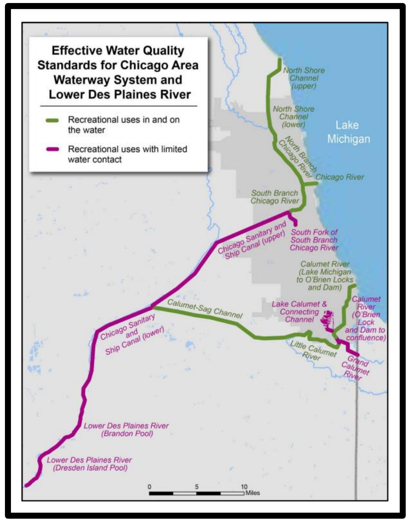


Figure: Projected increase in stormwater volumes in Chicago.
Source: Center for Neighborhood Technology

Stormwater Management History of Chicago

SWM Strategy: PAST
Diversion

- Channels built to reverse the flow of the Chicago River and ***divert*** the flow of sewers from Lake Michigan to the Mississippi River.



SWM Strategy: PRESENT
Treatment

- Sewage treatment plants were added to supplement the channel system. By 1970, Chicago had the largest sewage treatment facilities in the world.

SWM Strategy: FUTURE
Source Level Control

- Best Management Practices (BMPs) are a comprehensive approach toward SWM. The goal is to reduce the ***quantity*** and improve the ***quality*** of urban stormwater runoff at its source.

Green Alley Construction in Chicago

- Chicago's 50 wards (legislative district of Chicago's City Council) are allocated a single new green alley construction per year.

- Variation in geographic size of wards and rates of flood complaints within them has rendered the implementation strategy ineffective and inequitable.

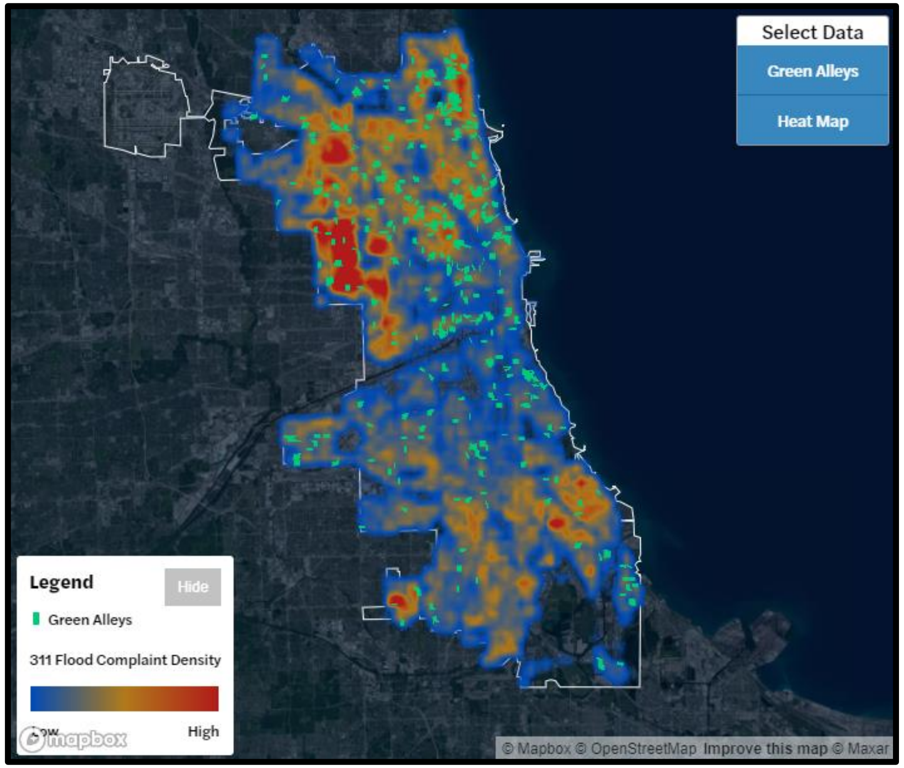


Figure: 311 Flood Complain Density and Green Alley locations in the City of Chicago

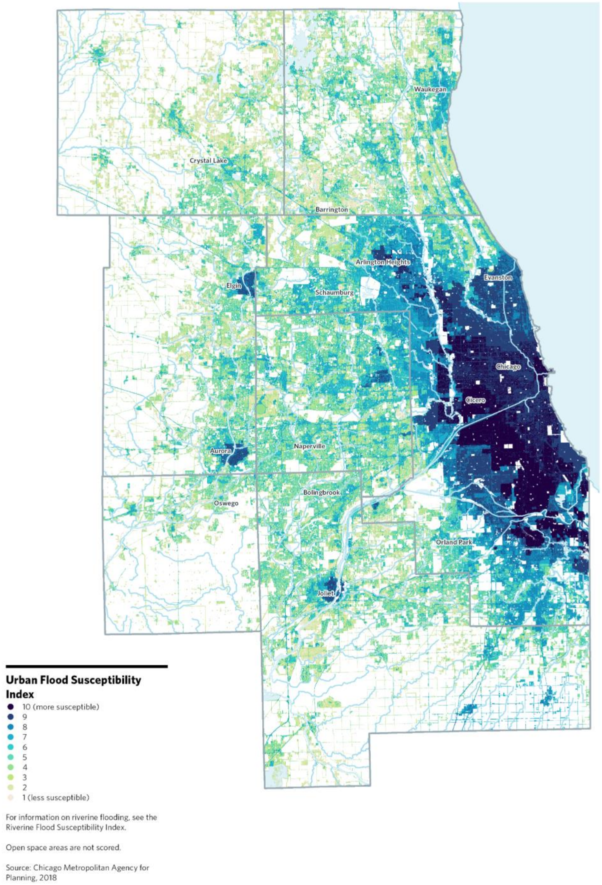
Source: Illinois Answers, *'Green Alleys' Help Prevent Flooding, But Vulnerable Neighborhoods Must Wait in Line.* https://illinoisanswers.org/2024/04/18/chicago-green-alleys-prevent-flooding-but-vulnerable-neighborhoods-must-wait/

Urban Planning Approach for Equitably Implementing Green Infrastructure

- Municipalities must "recognize and evaluate urban flooding as a potential environmental justice concern – and work to remedy this concern with an equity impact analysis of stormwater infrastructure investments" *– Center for Neighborhood Technology (CNT)*
- "Equity-related data should inform flood resilience investment decisions" *– Chicago Metropolitan Agency for Planning (CMAP)*
- Our Approach: **Flood Susceptibility Mapping**
  - CMAP's Flood Susceptibility Index (FSI)
  - CDC's Social Vulnerability Index (SVI)

Flooding Susceptibility Index (FSI)

- Developed by CMAP in 2017 to help focus stormwater planning efforts, may be helpful in coordinating actions of partners
- **Methodology: Frequency Ratio Approach**, statistical method based on relationship between distribution of reported flood locations and flooding-related factors
- **FR** is one of the most widely adopted and popular methods for natural hazard susceptibility assessment



Flooding Susceptibility Index - Factors

- **Topographic Wetness Index (TWI)**
- **Combined sewer service areas**
- **Elevation differential between property and nearest Base Flood Elevation (BFE)**
- **Percentage impervious cover**
- **Age of first development**
- **Precipitation variation**

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Frequency Ratio

Flooding-related factor	Data Input	Description	Categories	Percent of Study Area	Percent of Flooding Locations	Frequency Ratio
Combined sewer service area	Combined Sewer Service Area boundaries, received from MWRD and municipalities	Potential risk of flooding caused by a connection to a combined sewer system	Present	15.75%	69.55%	4.41
			Absent	84.25%	30.43%	0.36

$$\frac{\text{69.55\% of flooding locations in “Present” category}}{\text{15.75\% of study area is “Present” category}} = \text{FR of 4.41}$$

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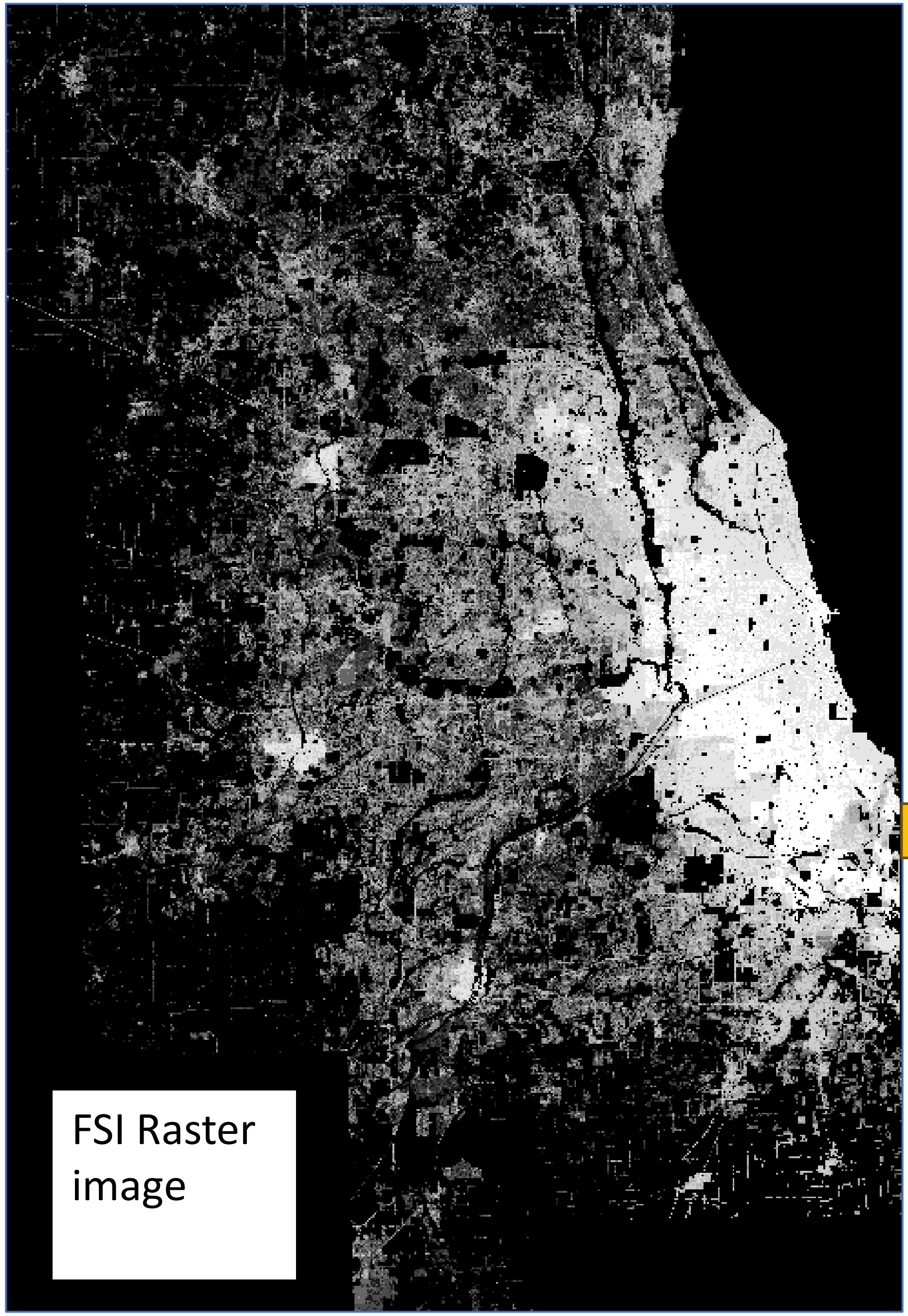
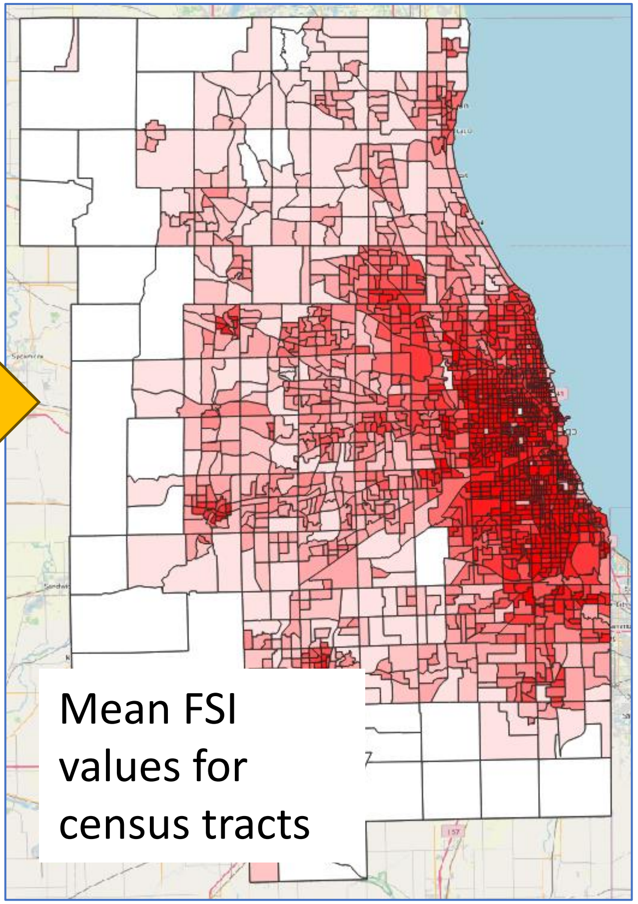
Flooding Susceptibility Index Mean FSI Value: Zonal Statistics





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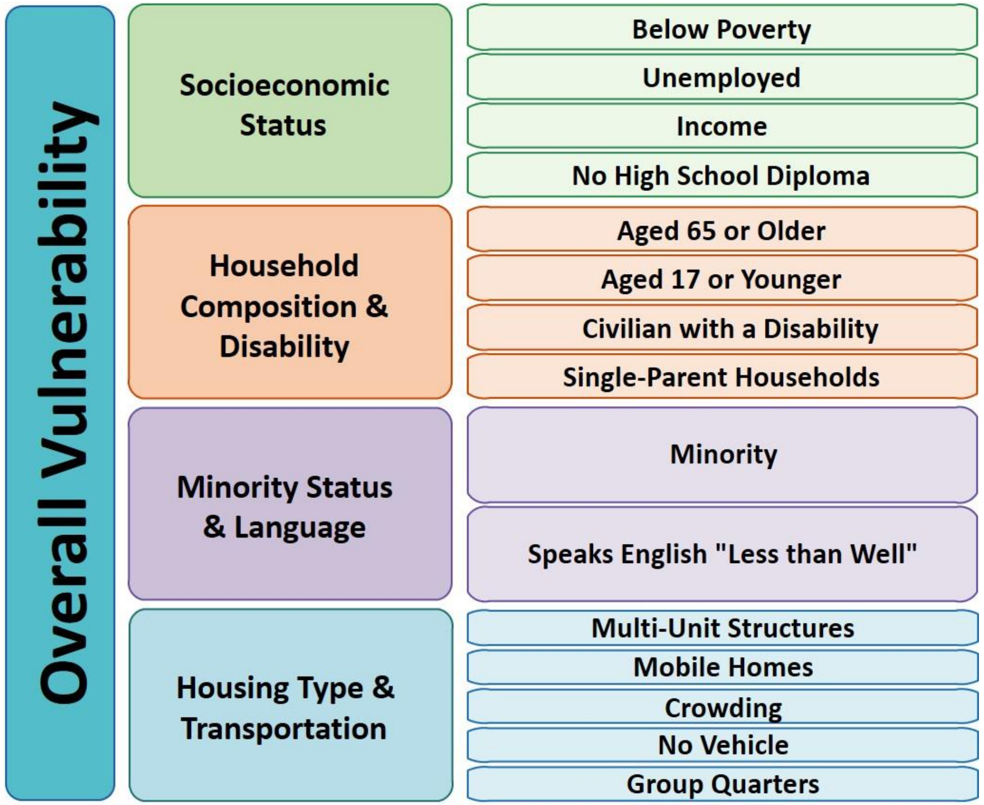
GIS Assessment of Socio-Economic Data

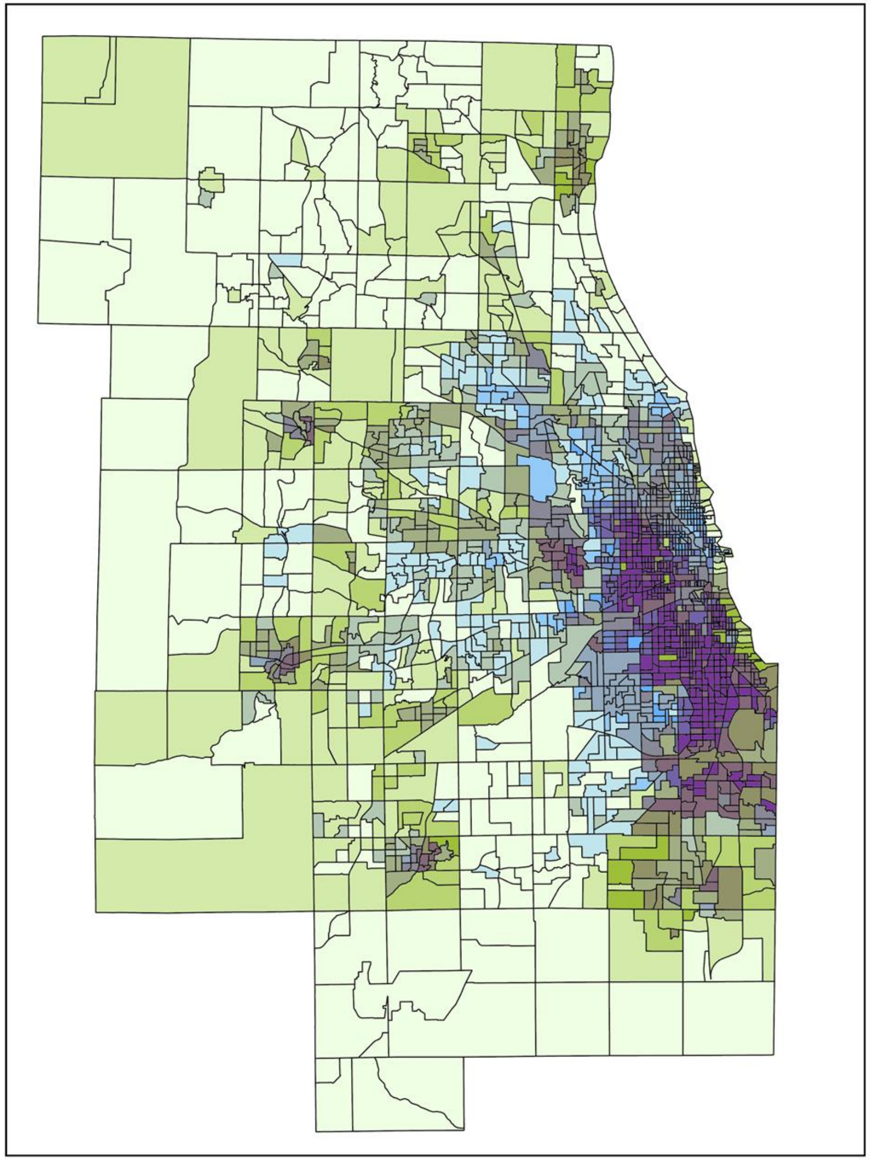


- **CDC's Social Vulnerability Index:** The SVI uses Census data to determine the relative social vulnerability to identify communities that need support before, during, and after hazardous events.
- **SVI Flags:** Census tracts in the top 10%, i.e., at the 90 the percentile of values, are assigned a flag to indicate high vulnerability.
- **FSI Flag:** Census tracts in the top 10% of mean FSI scores are assigned a flag to indicate high flood susceptibility

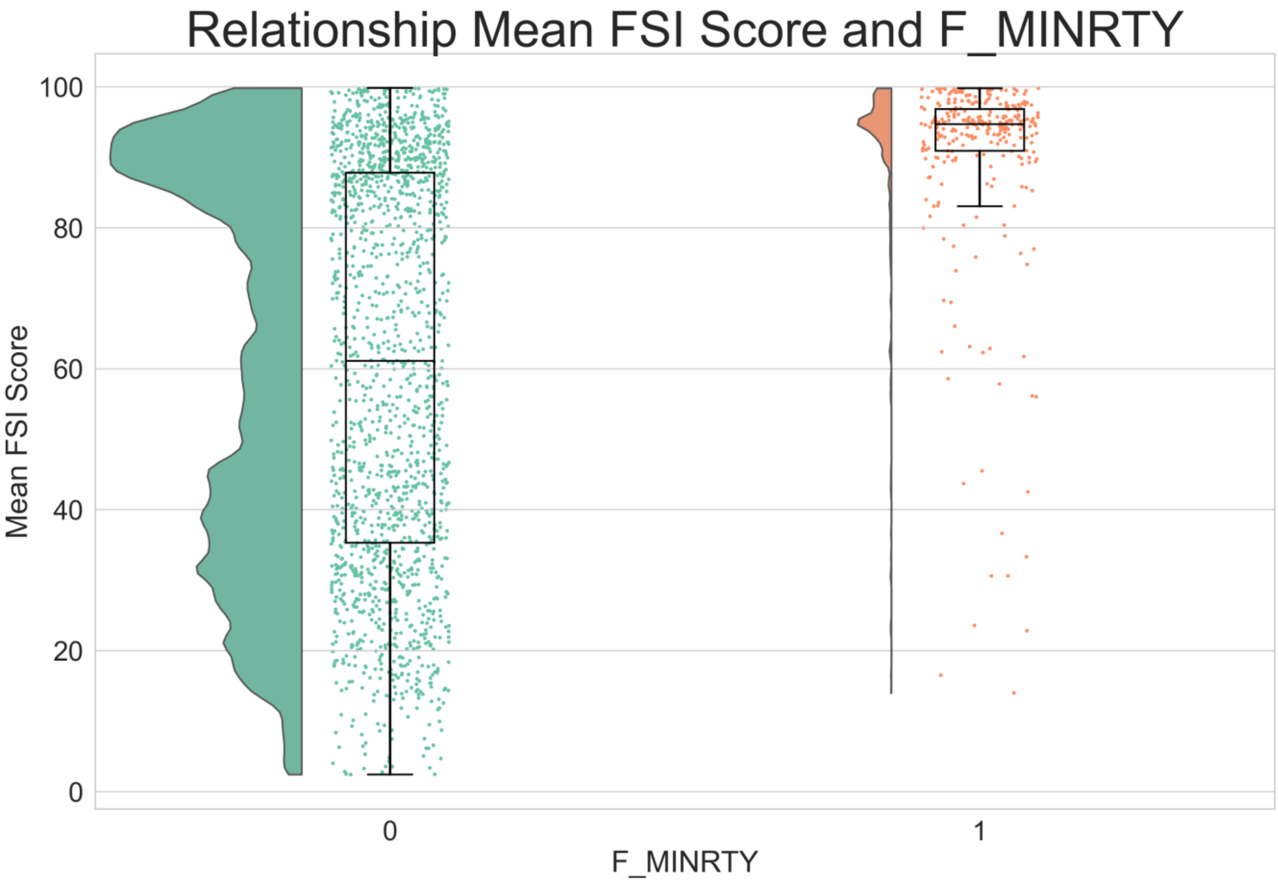
Figure: Fifteen variables and four themes described by the SVI

Source: CDC, *Overall Social Vulnerability.* https://www.atsdr.cdc.gov/placeandhealth/svi/overall-social-vulnerability.html

Visualizing FSI and SVI



Bivariate Choropleth Map for Flood Susceptibility and Social Vulnerability



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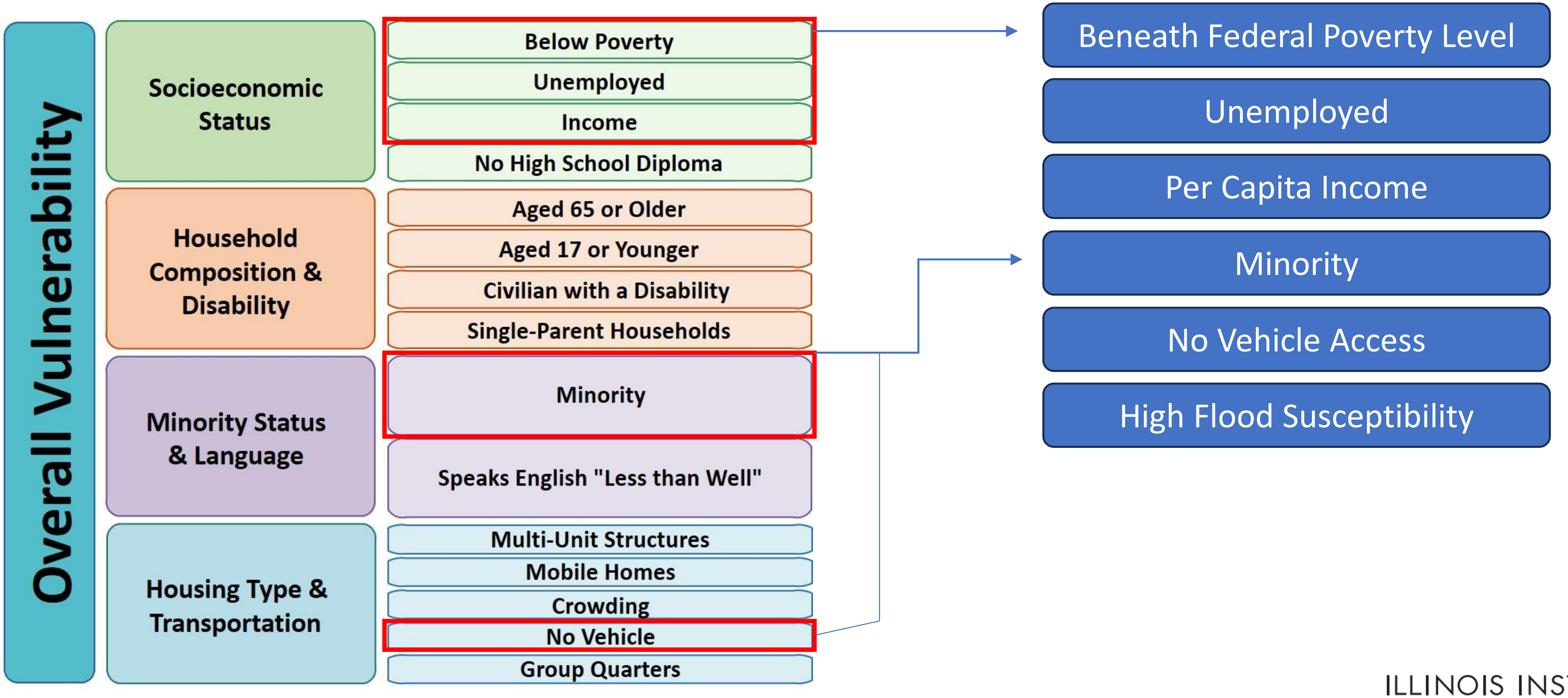
Flag	Description	Median FSI Score		Difference	Mann-Whitney p-Value
		Without Flag	With Flag		
F_POV	Beneath Federal Poverty Level	6.588	9.317	**2.729**	2.735e-32
F_UNEMP	Unemployed	6.363	9.400	**3.036**	3.157e-51
F_PCI	Per Capita Income	6.423	9.406	**2.982**	1.839e-47
F_NOHSDP	No High School Diploma	6.447	9.096	2.649	1.412e-29
F_AGE65	Aged 65 and Older	7.479	4.3551	-2.928	7.682e-07
F_AGE17	Aged 17 and Younger	7.131	8.046	0.916	0.00133
F_DISABL	Persons with Disability	7.030	9.318	2.288	1.125e-11
F_SNGPNT	Single Parent Households	6.600	9.300	2.699	2.176e-29
F_MINRTY	Minority	6.111	9.472	**3.360**	1.208e-82
F_LIMENG	Limited English Speaking	6.337	8.929	2.592	3.089e-30
F_MUNUIT	Multi-Unit Housing	7.058	7.894	0.835	0.278
F_MOBILE	Mobile Homes	7.332	4.521	-2.812	6.596e-05
F_CROWD	Crowded Households	6.707	8.517	1.811	6.015e-13
F_NOVEH	No Vehicle	6.369	9.193	**2.824**	8.445e-32
F_GROUPQ	Institutionalized Group Quarters	7.221	7.635	0.414	0.714

Socioeconomic Status
Minority Status & Language
Lower Median FSI Score w/ Flag
Household Composition & Disability
Housing Type & Transportation
Higher Median FSI Score w/ Flag

GIS Assessment of Socio-Economic Data



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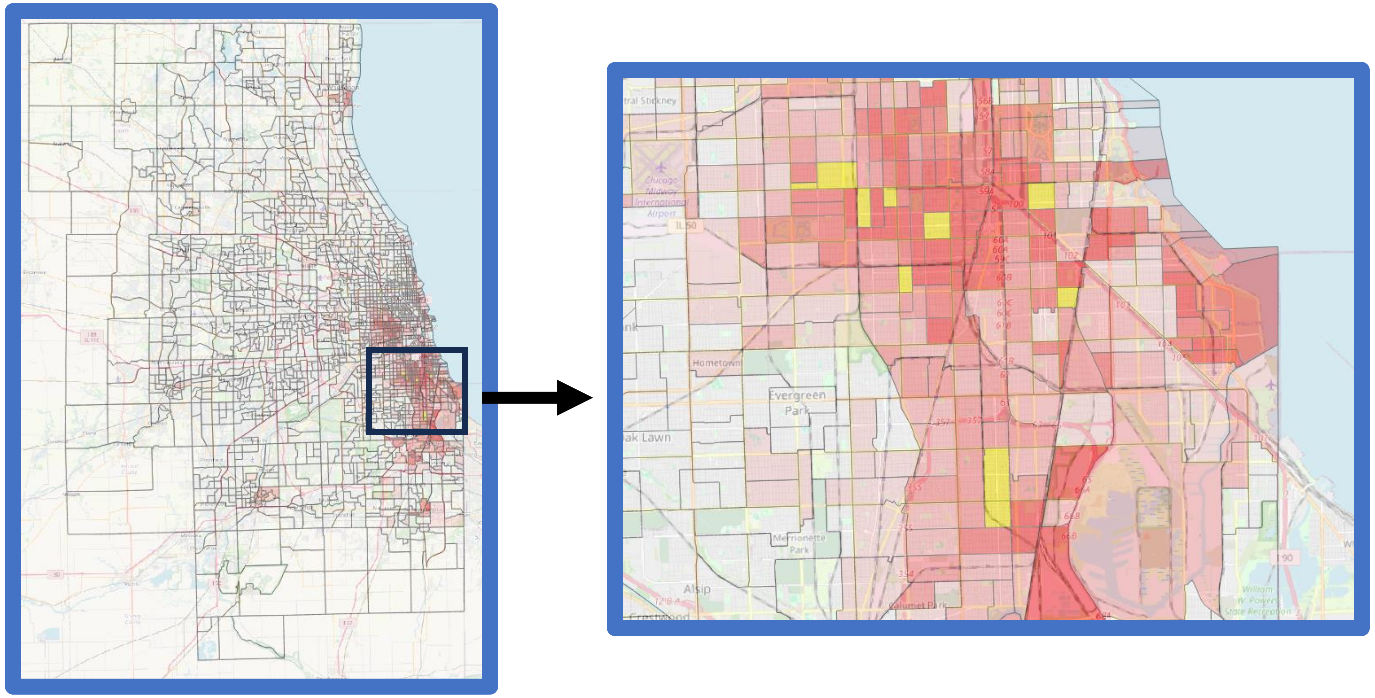
Summing FSI & SVI Flags

- Of the 1983 census tracts in this analysis, 11 (~0.5%) census tracts held all six combined FSI and SVI flags. These census tracts were located primarily on the south and near southwest sides of Chicago.



Number of combined FSI and SVI flags:

0 1 2 3 4 5 6

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Stormwater Sensor Data

- To study and investigate the capabilities of stormwater infrastructure to manage runoff from extreme rainfall events, our project aims to:
  - Monitor the water level in stormwater manholes
  - Provide insight into the amount of runoff collected in the stormwater infrastructure
- Essential data will be collected to address the challenges posed by climate change and rapid urbanization
- **Method**:
  - Low-cost sensors utilized to measure variation in water levels at multiple sites to establish reliable and potentially generalizable results

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Equipment and Materials

- **Waterproof ultrasound distance sensor**
  - Measures water depth in a channel by emitting ultrasonic waves and detecting their reflection from the water surface
  - Provides accurate, non-contact measurements of the distance from the sensor to the water
  - Crucial for monitoring and analyzing water levels in hydraulic studies

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Equipment and Materials

- **RoamWiFi Hotspot**
- **Solar Charger Power Bank**
- **Arduino uno WIFI R4**
- **Lithium Ion Battery**

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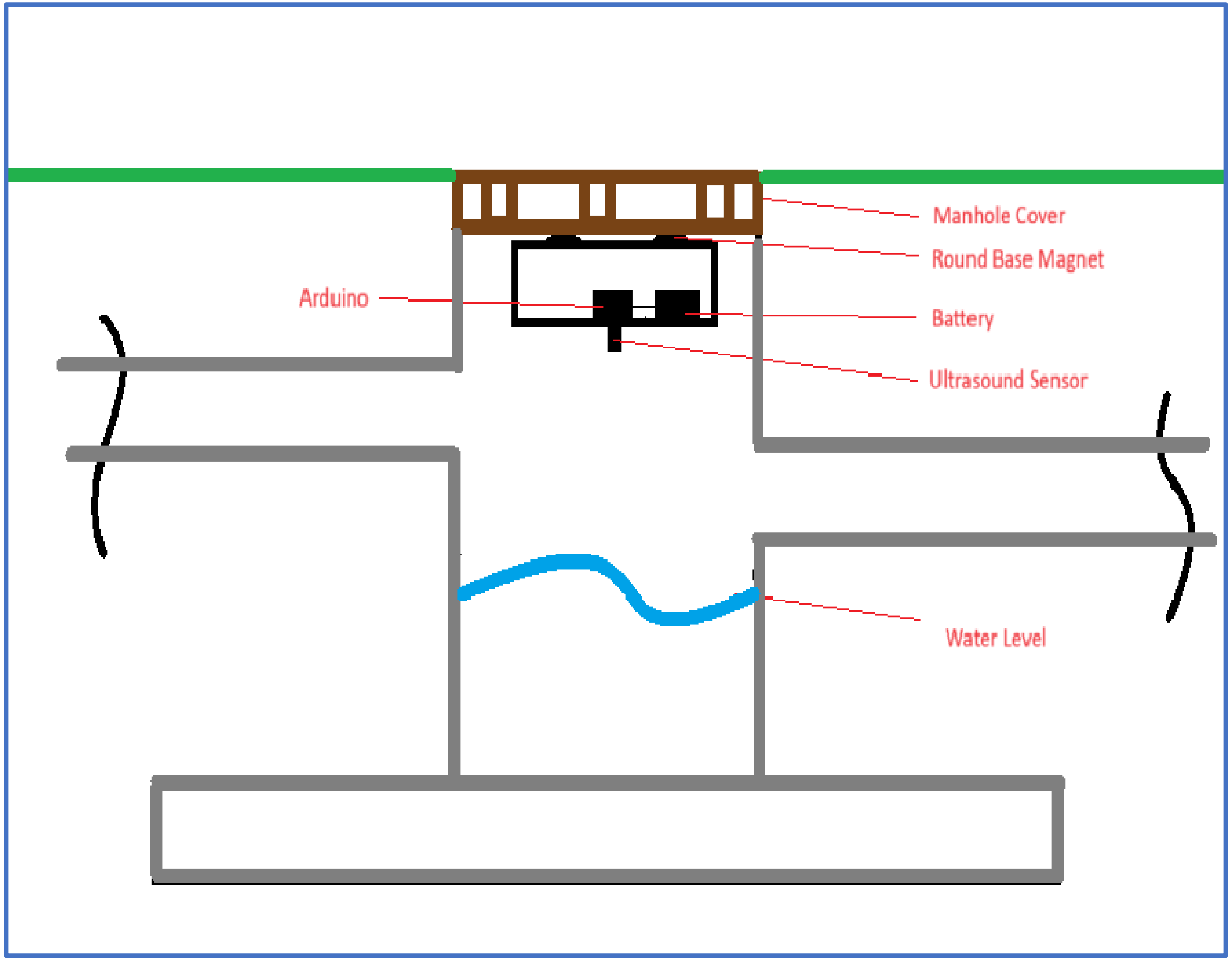

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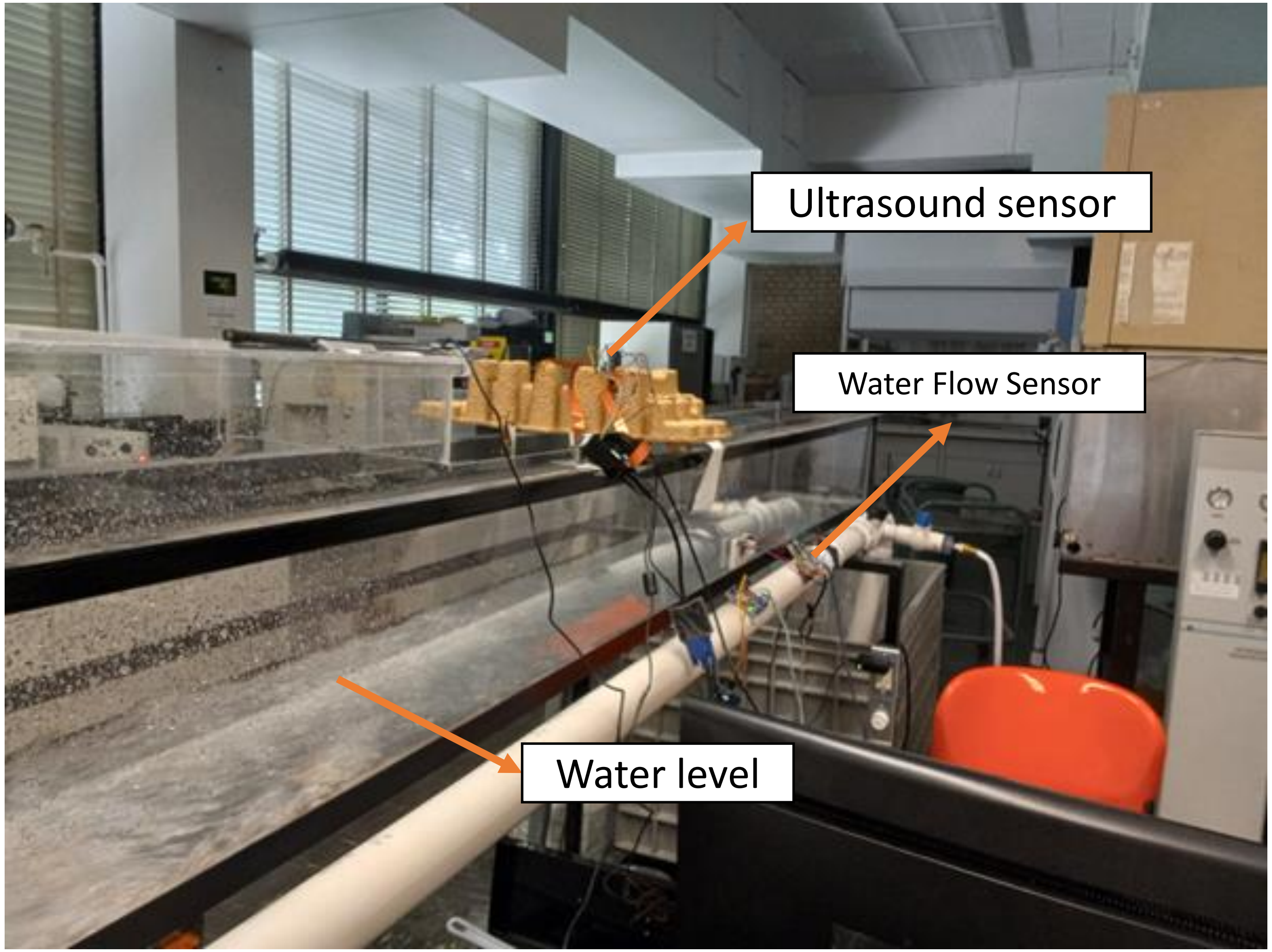
Lab Scale Experiment



Lab Scale Experiment

- Results displaying variation of flow rate and water depth in the flume

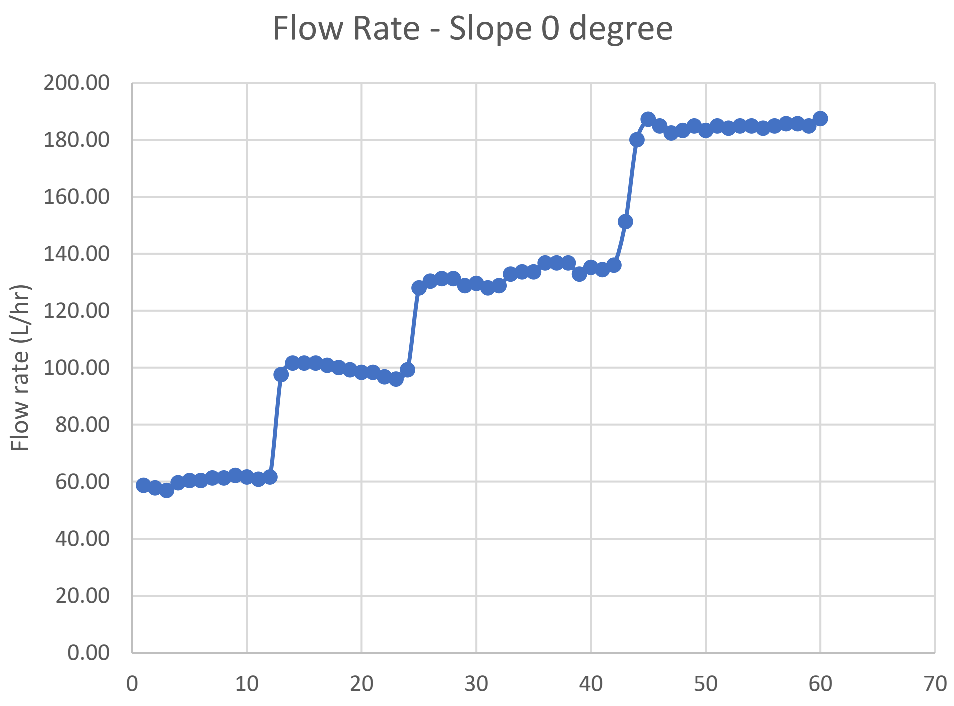


Chart 1

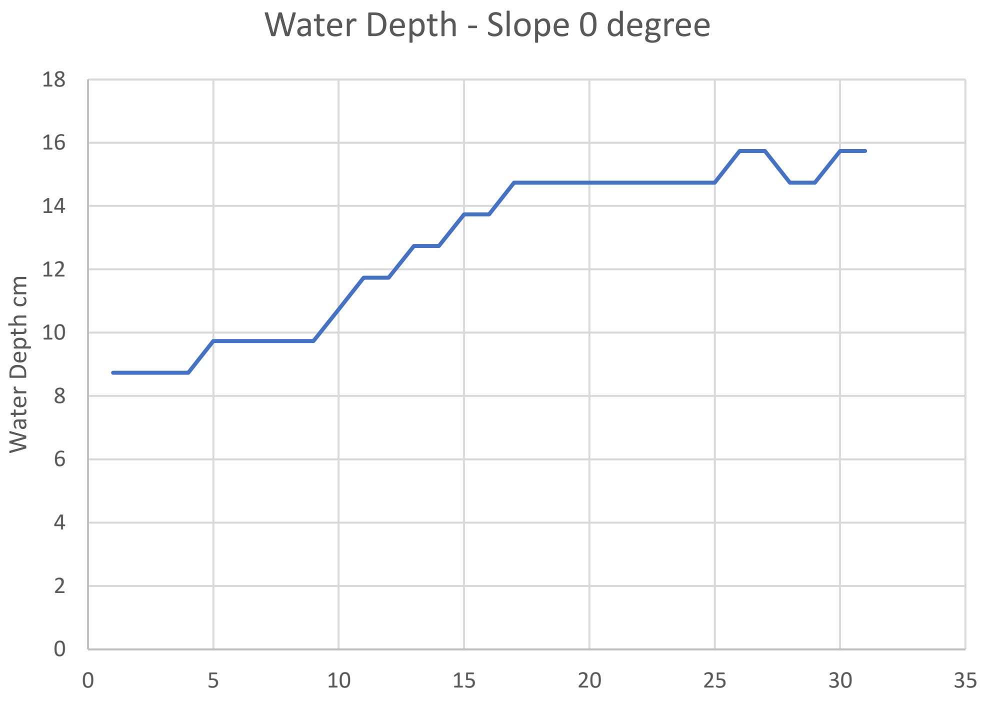
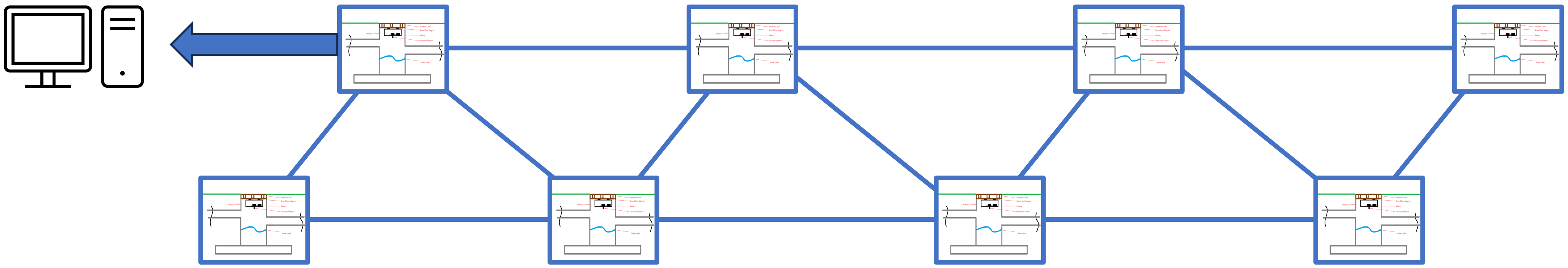


Chart 2

Stormwater Management Applications

- Valves and pumps are turned on in stormwater management infrastructure networks
- Network of sensors could inform sewer conditions and the timing of opening/shutting valves and pumps
- Data can be used to improve modelling



Conclusion

- **Flood susceptibility mapping (FSM)** is a reliable method for identifying regions more susceptible to flooding.
  - Combining **flood susceptibility** with **demographic data** should be the updated standard for the identification of regions for stormwater management intervention.
- Runoff prediction is crucial, especially during the design phase of stormwater infrastructure
- We must have the capacity to handle runoff from extreme rainfall events, and **machine learning** (ML), a branch of artificial intelligence, will be implemented for making predictions about capacity

Next Steps

- **Next Steps:**
  - Reproduce FSM for other urban areas.
  - Relate socioeconomic and built environmental factors and green infrastructure.
  - Quantify the relationship between flood risks and income levels.
  - Develop ML models to forecast runoff based on the triangulation of climatic and hydrologic data.

Supplemental Slides

Deployment of a Mobile Stormwater Monitoring App for Crowdsourced Data Collection

Welcome to The Flood Report!

We are excited to have you here. Our application is designed to help you report incidents efficiently and effectively. You can easily submit reports of various incidents, which will then be displayed on interactive maps and detailed lists. This allows you to track and monitor incidents in real-time, ensuring you stay informed and can take appropriate actions. Explore our features to see how we can assist you in managing and responding to incidents promptly.

Sign up today to get started or log in if you already have an account.

Sign Up | Log In

Available on iOS and Android

Download our app from the App Store or Google Play.

Download on the App Store | Get in on Google Play

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Objective 1: Citizen Science

- **Task 1.1:** deployment of a mobile stormwater monitoring app for crowdsourced data collection.
- **Task 1.2:** implementation of stormwater sensors for comparison with crowdsourced observations.
- **Task 1.3:** application of an in-person training and testing program for water quality samples.
- **Task 1.4:** assessment of the role of citizen science programs to improve water infrastructure management.

Objective 2: Infrastructure Differences

- **Task 2.1:** develop an urban planning approach for equitably implementing green infrastructure.
- **Task 2.2:** analyze existing flood inundation risks in low-income areas.
- **Task 2.3:** determine the geospatial relationships between socioeconomic and built environmental factors and green infrastructure.
- **Task 2.4:** quantify the relationship between flood inundation risks and income levels in the present climate.

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Objective 3: Policy Options

- **Task 3.1: Policy Innovation:** identify economic and political factors providing stormwater flood-related relief to Chicago residents
- **Task 3.1.1: Economic Analysis:** extended cost-benefit analysis and cost-effectiveness analysis will be used to identify and measure monetary and non-monetary costs and benefits
- **Task 3.1.2: Political Analysis:** political analytical models will assess the feasibility of policy options, including the status quo
- **Task 3.2: Strategic Planning:** stakeholder workshops will be held including representatives from environmental and social organizations to explore future actions and next steps

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In-Person Training and Testing Program for Water Quality Samples

Figure: Students from Chicago Public Schools were introduced to water quality tests at IIT's College of Civil, Architectural, and Environmental Engineering, including **turbidity testing**, **coliform testing**, and **dissolved oxygen testing**.

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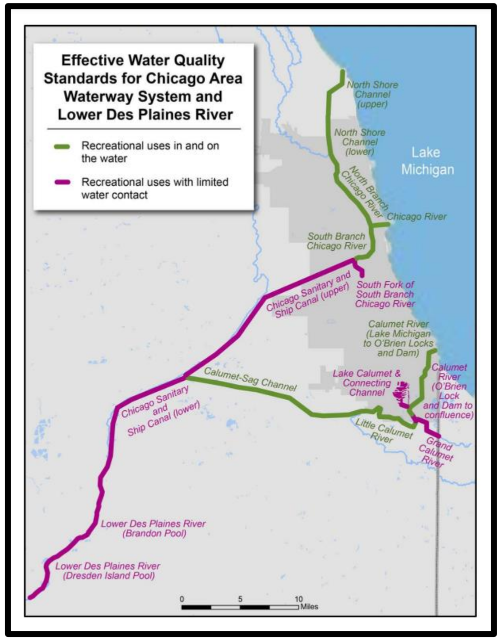
Stormwater Management History of Chicago

- **SWM Strategy, *PAST (1822-1922)*:** Diversion
- **Metropolitan Water Reclamation District (MWRD)** constructed channels to reverse the flow of the Chicago River and ***divert*** the flow of sewers from Lake Michigan to the Mississippi River.



- Channel system is fixed-capacity and was outpaced by residential and industrial growth.

Figure: Chicago Area Waterway System (CAWS).

Source: US EPA, *Chicago Area Waterway System/Chicago River.* https://www.epa.gov/il/chicago-area-waterway-system-chicago-river

Stormwater Management History of Chicago

- **SWM Strategy, *PRESENT (1922-Present)*:** Treatment
- **Sewage treatment plants** were added to supplement the channel system. By 1970, Chicago had the largest sewage treatment facilities in the world.

Figure: Stickney Water Reclamation Plant, the largest wastewater treatment facility in the world.

Source: US Water Alliance, *One Water Spotlight: Stickney Water Reclamation Plant.* https://uswateralliance.org/resources/one-water-spotlight-stickney-water-reclamation-plant/

Stormwater Management History of Chicago

- **SWM Strategy, *PRESENT (1922-Present)*:** Treatment
- **The Tunnel and Reservoir Plan (TARP)** was implemented to capture and store sewage that would otherwise overflow from sewers into waterways in rainy weather.

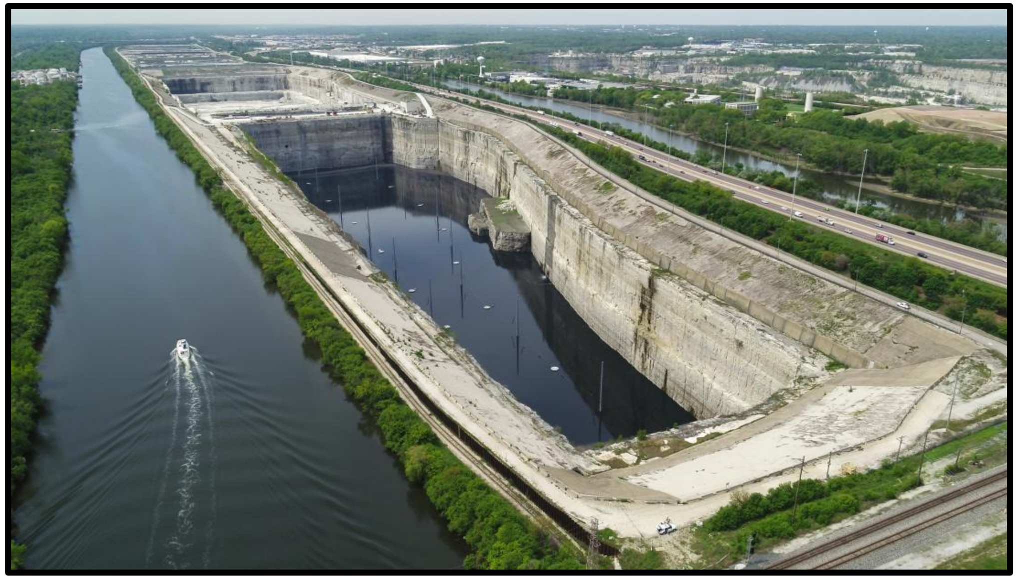


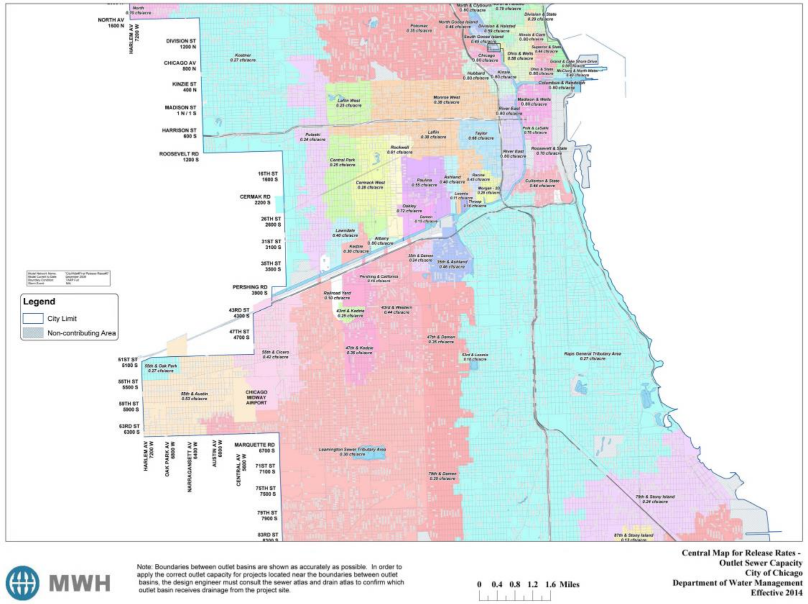
Figure: The McCook Reservoir is located between the Chicago Sanitary and Ship Canal (left) and the Des Plaines River (right).
Source: MWRD, *Tunnel and Reservoir Plan.* https://mwrd.org/what-we-do/tunnel-and-reservoir-plan-tarp

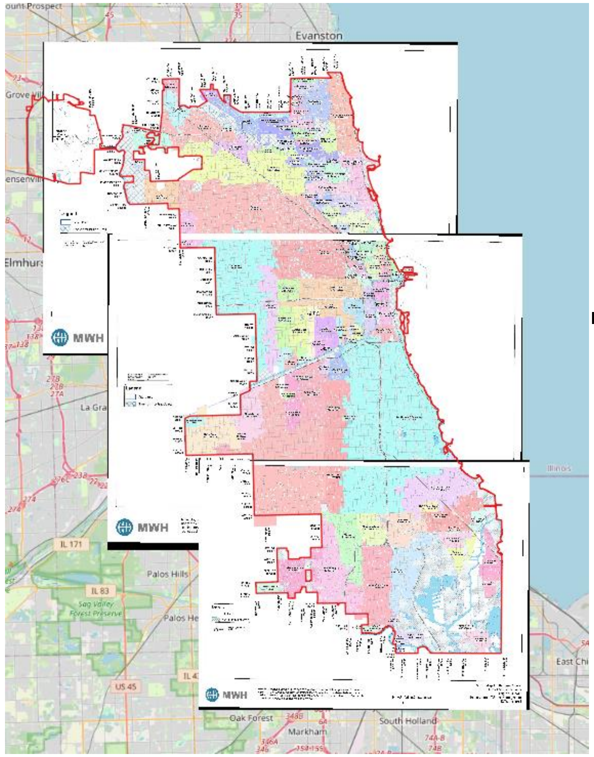
Stormwater Management History of Chicago

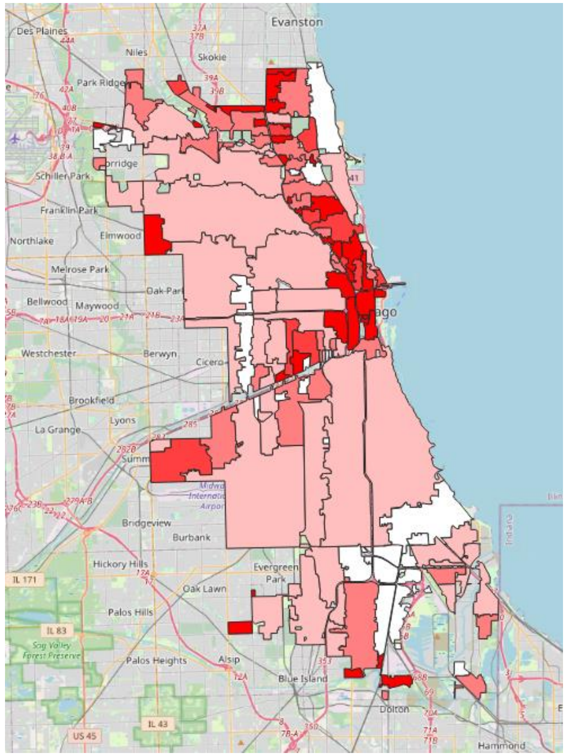
- **SWM Strategy, *FUTURE (Present-On)*:** Source Level Control
- **Best Management Practices (BMPs)** are a new, comprehensive approach toward SWM. The goal is to reduce the ***quantity*** and improve the ***quality*** of urban stormwater runoff at its source.
- For example, **Rain Gardens (Bioretention Cells):** Native plants with deep root systems provide great absorptive capacity.

Figure: Rain gardens are used at the Green bungalows and in parkways around the City of Chicago. The photo depicts a rain garden using native plants.
Source: City of Chicago, *Bioinfiltration: Rain Gardens.* https://www.chicago.gov/city/en/depts/water/supp_info/conservation/green_design/bioinfiltration_raingardens.html

FSM: Frequency Ratio

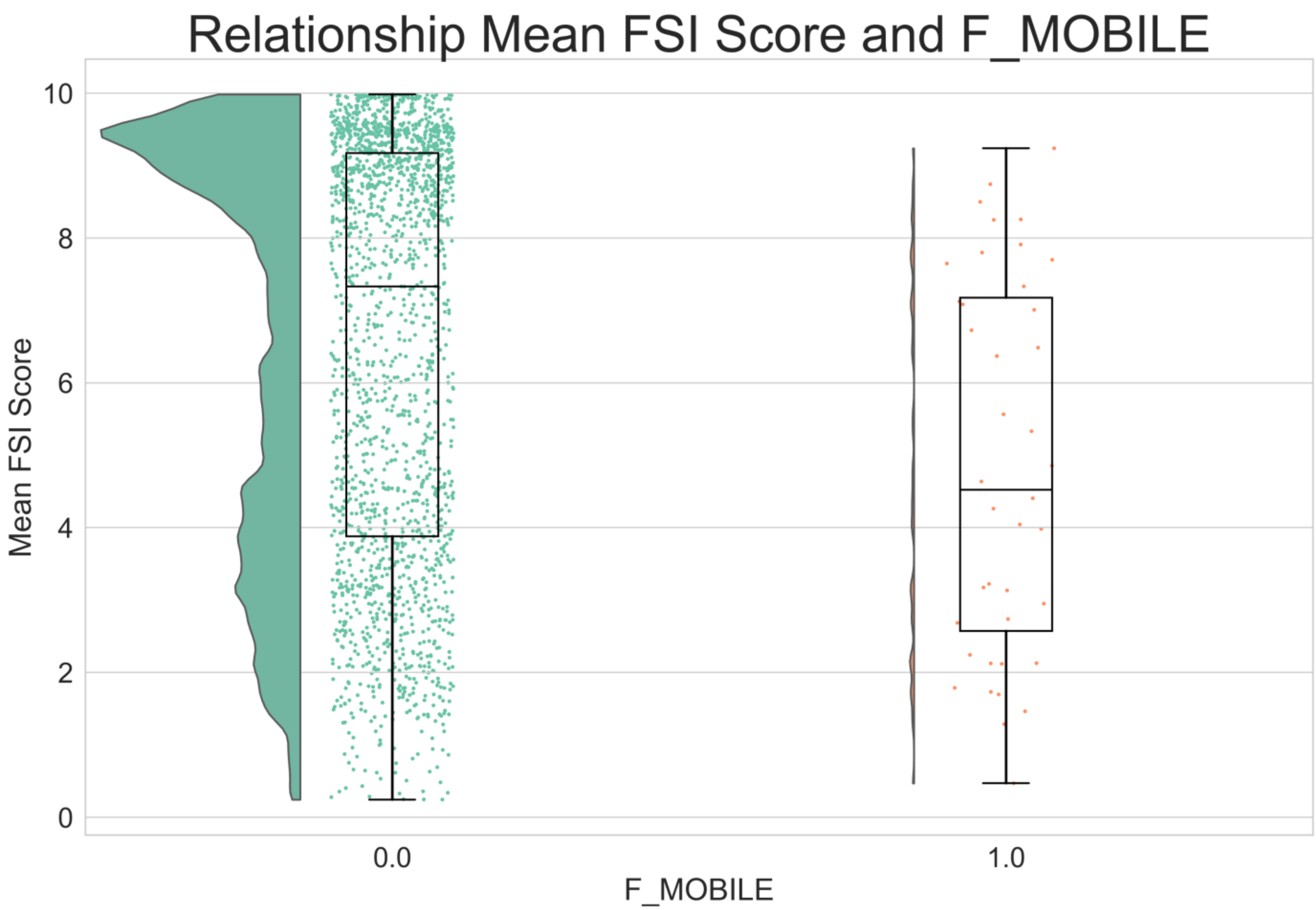






Figures: Individual sheets of MWH outflow capacity maps georeferenced to city boundary and polygons traced in QGIS

Mobile Homes Flag



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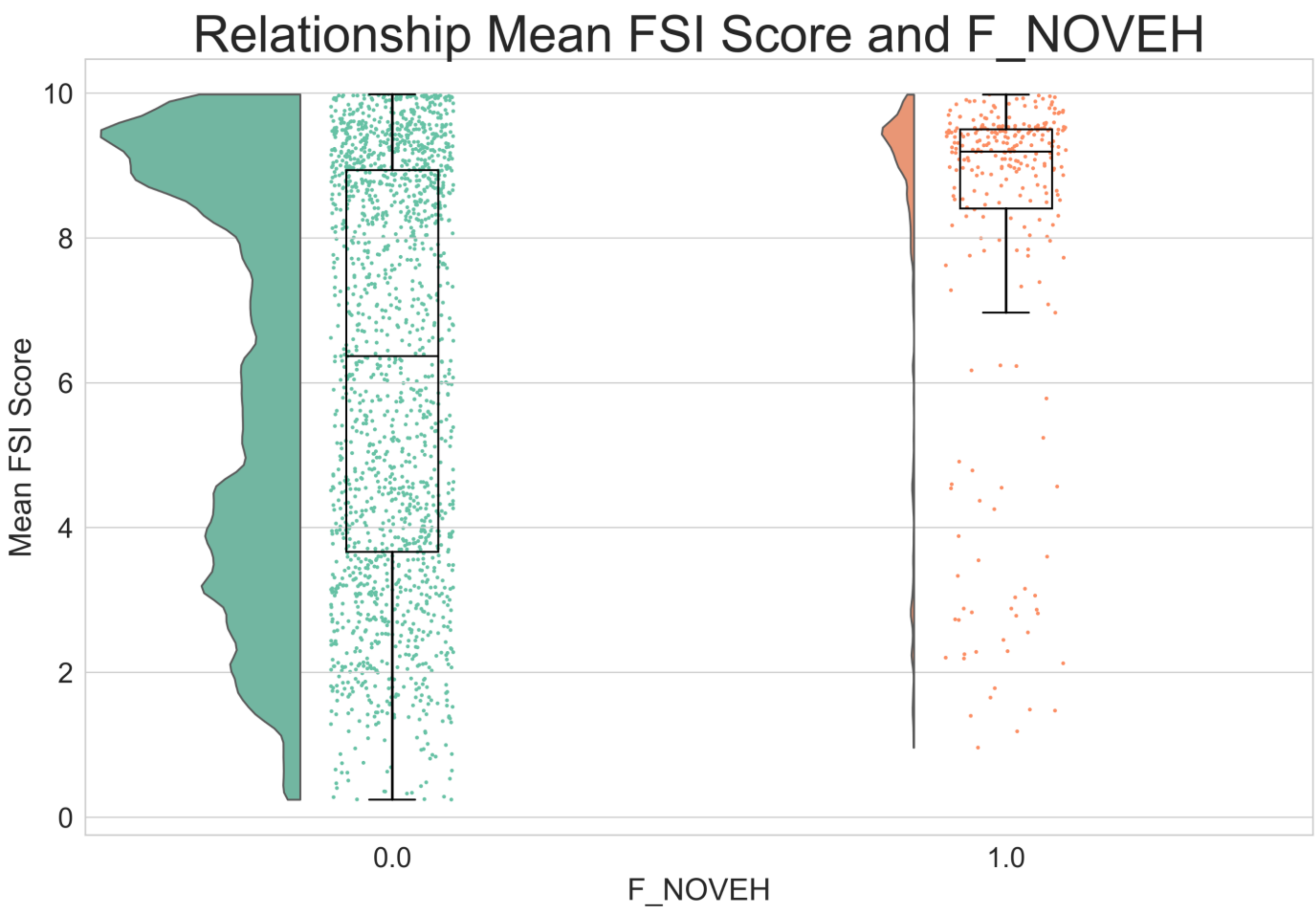
No Vehicle Access Flag



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Beneath Federal Poverty Level Flag

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Data Collection and Analysis

- Data collected and monitored during storms
- Variation in water level analyzed alongside the storm's intensity to understand the behavior of the stormwater infrastructure
- **Outcome:** provide an approximate view of the runoff amount in the system