PRIORITIZING URBAN AREAS FOR THE DEPLOYMENT OF HYPER-LOCAL FLOOD SENSORS USING STAKEHOLDER ELICITATION AND RISK ANALYSIS - SUPPLEMENTARY INFORMATION

Riccardo Negri[1], Luis Ceferino[2], and Gemma Cremen[3]

[1]PhD Candidate in Urban Systems, Civil and Urban Engineering Department, New York University. Email: r.negri@nyu.edu

[2]Civil and Environmental Engineering, University of California, Berkeley

[3]Civil, Environmental, and Geomatic Engineering Department, University College London

ANSWERS TO QUESTION #1: PROPOSED USES FOR SENSOR DATA

Tables 1–4 list all the possible uses for sensor data suggested during the elicitation process by stakeholders. We categorized specific use cases into broader use categories, also indicating the stakeholders that could benefit from these uses.

ANSWERS TO QUESTION #2: PROPOSED USE-CASE METRICS

Table 5 lists all the metrics associated with use cases that were proposed by stakeholders during the elicitation process. At the end of the discussion, we associated each metric with the use cases that they could serve.

ANSWERS TO QUESTION #3: PROPOSED SOCIAL VULNERABILITY METRICS

Table 6–7 list all the metrics associated with social vulnerability that were proposed by stakeholders during the elicitation process. At the end of the discussion, we organized them into four broad categories: Socio-Economic and Demographic Factors, Access to public services and infrastructure, Community engagement and Risks from compounding hazards.

QUANTIFICATION OF SELECTED METRICS

Tables 8 and 9 list the 16 metrics that were selected by stakeholders for the subsequent prioritization of deployment areas for sensors. In the prioritization process, Social Vulnerability Metrics were multiplied by the expected number of residents affected by flooding. To estimate the number of residents living in each building, we used the following data: Primary Land Use Tax Lot Output - Map (MapPLUTO), Building Footprints and Census data (U.S. Census Bureau. (2021). Table S101. American Community Survey, 5-Year Estimates). Tables 8 and 9 also list the data sources and data types used for metrics quantification.

AHP COEFFICIENTS

Tables 10 and 11 list the importance factors obtained from AHP that are associated with each metric. Since some metrics were excluded due to unavailable data, we rescaled the importance factors to sum to one.

List of Tables

TABLE 1. Use cases for emergency response and recovery planning

BROAD USES	SPECIFIC USE CASES	POSSIBLE STAKEHOLDERS
(1) Emergency response and recovery planning	◇ Sending/receiving flood alerts to residents and tourists ◇ Coordinating flood-related evacuations ◇ Guiding resource allocation (before, during or after an event) ◇ Guiding post-event recovery activities ◇ Monitoring flood risk for critical facilities (e.g., hospitals and fire stations) ◇ Monitoring flood levels near residential buildings with basement dwellings and located in areas of low topographic elevation	Emergency responders, Resident representatives

TABLE 2. Use cases for Monitoring, protecting, managing and planning infrastructure and public services

BROAD USES	SPECIFIC USE CASES	POSSIBLE STAKEHOLDERS
(2.a) Monitoring, managing and planning flood-mitigation infrastructures	◇ Monitoring and automating flood control systems (e.g., pumps, flood gates and other protection systems) ◇ Signaling when catch basins need to be cleaned ◇ Detecting poor conditions/failure in stormwater and/or combined stormwater-sewage drainage systems ◇ Monitoring the effectiveness of flood mitigation projects (e.g. green infrastructure) ◇ Planning, prioritizing, and designing new flood mitigation projects	Government agencies working on flood-mitigation infrastructure, Engineering consultants.
(2.b) Protecting, managing and planning other types of infrastructures and public services	◇ Informing public services on floods (e.g., schools, street garbage collection, snow plows) ◇ Monitoring the flooding of critical infrastructure during and after an event (e.g., energy, wastewater) ◇ Identifying flooded areas to assess potentially damaged public infrastructure after a flooding event ◇ Monitoring the impact of new urban development on flooding	Government agencies involved in infrastructure management and public services, Engineering consultants.
(2.c) Monitoring and managing transportation infarstructure	◇ Rerouting private and public transportation (e.g., bus lanes) during a flooding event ◇ Monitoring street entrances to subway transportation networks during a flooding event	Government agencies working on transportation infrastructure, Engineering consultants.

TABLE 3. Use cases for Documenting past floods and increasing risk awareness

BROAD USES	SPECIFIC USE CASES	POSSIBLE STAKEHOLDERS
(3) Documenting past floods	◇ Providing evidence to receive financial aid for building upgrades related to flood-risk mitigation ◇ Providing evidence to support applications for post-storm financial assistance ◇ Providing evidence to receive public funding for flood-risk protection and mitigation infrastructure ◇ Raising flood-risk awareness among residents ◇ Communicating flood-related information to the community	Resident representatives.

TABLE 4. Use cases for Characterizing flood hazard and risk

BROAD USES	SPECIFIC USE CASES	POSSIBLE STAKEHOLDERS
(4.a) Characterizing flood hazard	◇ Developing and validating flood models coupled with weather and/or tide events (e.g., providing a better understanding of the relationship between rainfall and local flood extent) ◇ Developing dynamically updated flood maps for recorded events ◇ Recording tidal flooding ◇ Identifying modified trends in floods due to climate change and urbanization	Researchers, Engineering consultants.
(4.b) Characterizing flood risk	◇ Mapping (quantifying) the spatial and temporal impact of a storm across multiple interdependent infrastructure systems (transportation, housing, power) and multiple communities ◇ Improving the forecasting of flood impacts on cities ◇ Informing the real estate market on flood-related risks ◇ Identifying insurance gaps related to flood protection (e.g., identifying neighborhoods with flood exposure but without flood insurance, or where the flood risk is underestimated) ◇ Updating catastrophe risk models for estimating flood-related insurance losses ◇ Acting as a trigger for parametric insurance policies	Insurance and real estate companies, Researchers, Engineering consultants.

TABLE 5. Proposed Use-Case Metrics

METRICS	POSSIBLE USES
◇ Number of residents, workers, and daily visitors	(1), (2.a)
◇ Number of buildings not compliant with updated building code regulations	(1), (2.a), (3), (4.b)
◇ Number of basement dwellings	(1), (2.a), (3), (4.b)
◇ Number of emergency and evacuation routes	(1)
◇ Number of major catch basins and sewer collectors	(2.a)
◇ Number of flood mitigation infrastructure projects (e.g., green infrastructure)	(2.a)
◇ Number of critical infrastructure facilities (e.g., energy, communications, wastewater facilities)	(2.b)
◇ Number of essential community services (e.g., supermarkets, schools, community centers)	(1), (2.b)
◇ Number of planned or recently completed infrastructure projects (e.g., new buildings) that significantly alter the flooding potential of their surroundings	(2.b)
◇ Number of polluted sites (e.g., Brownfield land)	(2.b), (4.b)
◇ Vehicular and foot traffic along transportation routes (private and public)	(1), (2.c)
◇ Number of bus and subway stations	(2.c)
◇ Level of uncertainty in flood model predictions (e.g., mismatch between flood reports and modeled flooding)	(4.a)
◇ Area of historical waterways, wetlands, and marshlands	(4.a)
◇ Flow accumulation coefficient based on topography	(4.a)
◇ Historical number of flood-related emergency response incidents	(4.a), (4.b)
◇ Historical number of citizen-reported flood incident data (e.g., records from the 311 reporting system)	(4.a), (4.b)
◇ Historical number of documented flood-induced interruptions to transportation routes	(2.c), (4.a), (4.b)
◇ Historical number of applications for post-flood assistance	(1), (4.a), (4.b)
◇ Historical number of flood insurance claims	(3), (4.a), (4.b)
◇ Anecdotal evidence of flooding (e.g., historical number of reports from public media)	(4.a), (4.b)
◇ Amount of documented damages to public infrastructure	(4.b), (2.b)
◇ Number of buildings without flood insurance	(3), (4.b)

TABLE 6. Proposed Social Vulnerability Metrics – Socio-Economic and Demographic Factors

CATEGORY	METRICS
Socio-Economic and Demographic (SED)	◇ Social Vulnerability Index ◇ Percentage of non-documented households ◇ Level of community marginalization (e.g., living in Redlined areas) ◇ Median household income ◇ Percentage of people with disability and medical issues ◇ Median household wealth/savings ◇ Percentage of households with children and elders ◇ Average dwellings occupancy (i.e., average number of household members per square foot) ◇ Percentage of homeless people ◇ Literacy rate ◇ Percentage of non-native English speakers ◇ Percentage of single-person households ◇ Level of segregation (economic, racial) ◇ Median flood insurance premium relative to median household income ◇ Percentage of denied flood insurance claims ◇ Median housing costs relative to median household income ◇ Percentage of households using food stamps

TABLE 7. Proposed Social Vulnerability Metrics – Other categories

CATEGORY	METRICS
Access to public services and infrastructure	◇ Number of emergency response facilities per capita ◇ Average emergency response time (i.e., length of time between an emergency call and the emergency being addressed) ◇ Accessibility to private and public transportation ◇ Transportation connectivity ◇ Amount of government investment in climate-mitigation infrastructure per capita (e.g., green infrastructure projects) ◇ Number of essential public services (e.g., schools, markets, evacuation centers) per capita ◇ Level of social isolation/civil capacity (e.g., number of senior or community centers per capita) ◇ Number of senior housing and naturally occurring retirement communities ◇ Number of shelters for homeless people ◇ Percentage of locally-owned businesses compared to national or international chains (across all business sectors).
Community engagement	◇ Usage of the 311 reporting system by residents ◇ Voter turnout ◇ Stewardship engagement level ◇ Number of advocacy groups per capita ◇ Number of community-based flood monitoring groups
Risks from compounding hazards	◇ EPA Environmental Justice Index ◇ NYC Displacement Risk Index ◇ Level of compound risk (e.g., compound risk from flooding and heat)

TABLE 8. Selected metrics, data origins and data type – Use-Case Metrics

METRIC	DATA ORIGIN	DATA TYPE
v_1	NOAA Fisheries and National Ocean Service - InPort - https://www.fisheries.noaa.gov/inport/ - Electric Power Substations	Electricity substations are mapped as point features.
v_2	NYC Office of Technology and Innovation (OTI) - NYC Open Data - https://opendata.cityofnewyork.us/ - Primary Land Use Tax Lot Output - Map (MapPLUTO) / Building Footprints	Buildings with their number of residential units are mapped as polygons.
v_3	New York State - Open NY - https://data.ny.gov/ - NYS Traffic Data Viewer	Roads, streets, and highways are mapped as segments, with their Annual Average Daily Traffic.
v_4	NYC Office of Technology and Innovation (OTI) - NYC Open Data - https://opendata.cityofnewyork.us/ - 311 Service Requests from 2010 to Present; Primary Land Use Tax Lot Output Map (MapPLUTO)	Tax lots are mapped as polygons. 311 reports are mapped as points.
v_5	New York State - Open NY - https://data.ny.gov/ - Turnstile Usage Data: 2022	Subway stations are mapped as point features with their AAR.
v_6	NYC Office of Technology and Innovation (OTI) - NYC Open Data - https://opendata.cityofnewyork.us/ - DEP Green Infrastructure	Green infrastructure projects are represented as square polygons, each with an area corresponding to their actual size.
v_7	New York State - Open NY - https://data.ny.gov/ - Environmental Remediation Sites Map	Environmental remediation sites are mapped as point features
v_8	Proxy not included in the case study because of lack of data	N/A

TABLE 9. Selected metrics, data origins and data type – Social Vulnerability Metrics

METRIC	DATA ORIGIN	DATA TYPE
v_9	Centers for Disease Control and Prevention / Agency for Toxic Substances and Disease Registry - https://www.atsdr.cdc.gov/placeandhealth - Social Vulnerability Index	Social Vulnerability Index (SVI) from the Centers for Disease Control and Prevention (CDC). Provided as percentile index.
v_{10}	NYC Department of City Planning (DCP) - Capital Planning Explorer - https://capitalplanning.nyc.gov/ - Education, Child Welfare, and Youth	Public schools are mapped as points with their total floor area. Each census tract is assigned the total area of public schools located within its boundaries, which is then divided by the total population of the tract to normalize the data. To account for potential school access extending beyond these boundaries, an 800-meter buffer is applied around each tract. For schools that overlap multiple tracts, their floor area is distributed proportionally among the tracts based on population. Finally, tracts are ranked by school area per capita and assigned percentile values.
v_{11}	Proxy not included in the case study because of lack of data	N/A
v_{12}	NYC Department of City Planning (DCP) - Capital Planning Explorer - https://capitalplanning.nyc.gov/ - Health and Human Services	Health and Human Service centers are mapped as points. A method similar to that used for v_{10} is employed to estimate the number of Health and Human Service centers per capita. Tracts are ranked by this estimate and assigned percentile values.
v_{13}	Environmental Protection Agency (EPA) - Environmental Justice Screening and Mapping Tool - https://www.epa.gov/ejscreen - Environmental Justice Index	Environmental Justice Index from the Environmental Protection Agency (EPA). Provided as percentile index.
v_{14}	NYC Office of Technology and Innovation (OTI) - NYC Open Data - https://opendata.cityofnewyork.us/ - 311 Service Requests from 2010 to Present; Primary Land Use Tax Lot Output Map (MapPLUTO)	Tax lots are mapped as polygons. 311 reports are mapped as points.
v_{15}	Proxy not included in the case study because of lack of data	N/A
v_{16}	Proxy not included in the case study because already considered in the Social Vulnerability Index	N/A

TABLE 10. Selected metrics and AHP importance factors (before/after excluding some of the metrics) – Use-Case Metrics

METRIC	AHP IMPORTANCE FACTOR	AHP IMPORTANCE FACTOR (AFTER EXCLUDING SOME OF THE METRICS)
v_1 - Number of electricity substations	0.172	0.184
v_2 - Number of residential units in pre-1961 buildings	0.171	0.183
v_3 - Annual Average Daily Traffic for vehicular traffic along roads and highways	0.170	0.182
v_4 - Discrepancy between Flood Maps and Flood Reports: Areas where Flood Reports Exceed Flood Maps Predictions	0.118	0.127
v_5 - Subway stations average annual daily ridership	0.108	0.116
v_6 - Spatial extent of public green infrastructure projects	0.104	0.111
v_7 - Number of Environmental Remediation Sites	0.091	0.097
v_8 - Proxy not included in the case study because of lack of data	0.065	0.000

TABLE 11. Selected metrics and AHP importance factors (before/after excluding some of the metrics) – Social Vulnerability Metrics

METRIC	AHP IMPORTANCE FACTOR	AHP IMPORTANCE FACTOR (AFTER EXCLUDING SOME OF THE METRICS)
v_9 - Social Vulnerability Index	0.195	0.282
v_{10} - Floor area of public schools per capita	0.169	0.244
v_{11} - Proxy not included in the case study because of lack of data	0.150	0.000
v_{12} - Number of Health and Human Services centers per capita	0.126	0.182
v_{13} - Environmental Justice Index	0.102	0.147
v_{14} - Discrepancy between Flood Reports and Flood Maps: Areas where Flood Maps Predictions Exceed Flood Reports	0.101	0.145
v_{15} - Proxy not included in the case study because of lack of data	0.096	0.000
v_{16} - Proxy not included in the case study because already considered in the Social Vulnerability Index	0.060	0.000