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DEVELOPING A FRAMEWORK TO OPTIMIZE FLOODNET SENSOR DEPLOYMENTS AROUND NYC FOR EQUITABLE AND IMPACT-BASED HYPER-LOCAL STREET-LEVEL FLOOD MONITORING AND DATA COLLECTION

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16. Abstract

This report culminates a year-long study on flood-monitoring sensor deployment in urban areas, with a specific application to the deployment of FloodNet sensors in New York City. The study presents a comprehensive method developed over the course of the year, which is based on two key components: stakeholder needs and equity considerations. Initially, the report describes the stakeholder elicitation process in which we engaged experts and urban stakeholders to identify metrics that would guide sensor deployment. These metrics were then subjected to the Analytical Hierarchy Process (AHP) to weight their relative importance. Different flooding scenarios were considered using available flood maps, with a particular focus on pluvial flooding. In the data analysis and metrics quantification stage, each identified metric was associated with a quantifiable proxy using publicly available data. Some metrics, however, were excluded due to lack of available data at the required geographic granularity. The metrics for stakeholders' needs and equity were then normalized and weighted using AHP-derived factors, aggregated within each set, and combined to derive a final prioritization metric for each Census Tract. This enabled the ranking of NYC Census Tracts for sensor deployment. Radar charts were used to illustrate the influence of each metric on the final combined metric, revealing that stakeholder metrics, specifically the presence of electricity substations, were most influential in the prioritization process. The report concludes by discussing the potential for further refinement of the method, such as adding or removing metrics, using different flood maps, and assigning different weights to stakeholder and equity metrics.
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Developing a Framework to Optimize Floodnet Sensor Deployments Around NYC for Equitable and Impact-Based Hyper-Local Street-Level Flood Monitoring and Data Collection

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Executive Summary

This report culminates a year-long study on flood-monitoring sensor deployment in urban areas, with a specific application to the deployment of FloodNet sensors in New York City. The study presents a comprehensive method developed over the course of the year, which is based on two key components: stakeholder needs and equity considerations. Initially, the report describes the stakeholder elicitation process in which we engaged experts and urban stakeholders to identify metrics that would guide sensor deployment. These metrics were then subjected to the Analytical Hierarchy Process (AHP) to weight their relative importance. Different flooding scenarios were considered using available flood maps, with a particular focus on pluvial flooding. In the data analysis and metrics quantification stage, each identified metric was associated with a quantifiable proxy using publicly available data. Some metrics, however, were excluded due to lack of available data at the required geographic granularity. The metrics for stakeholders' needs and equity were then normalized and weighted using AHP-derived factors, aggregated within each set, and combined to derive a final prioritization metric for each Census Tract. This enabled the ranking of NYC Census Tracts for sensor deployment. Radar charts were used to illustrate the influence of each metric on the final combined metric, revealing that stakeholder metrics, specifically the presence of electricity substations, were most influential in the prioritization process. The report concludes by discussing the potential for further refinement of the method, such as adding or removing metrics, using different flood maps, and assigning different weights to stakeholder and equity metrics.

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Section 1 Introduction

Urban flooding represents one of the most pressing challenges of the twenty-first century. With the rate of urbanization increasing globally, built environments continue to intersect and interact with natural hydrological systems in ways that exacerbate the risks and impacts of flooding (Du et al. 2012; Hollis 1975; Sheng and Wilson 2009; Zhou et al. 2019). These risks are not uniformly distributed; they disproportionately impact vulnerable communities who are often ill-equipped to manage such crises (Mohai, Pellow, and Roberts 2009). Moreover, the backdrop of a changing climate, characterized by increased precipitation variability and extreme weather events, only serves to intensify the situation, creating an urgent need for comprehensive solutions.

Flood monitoring stands as a critical component of these solutions, serving as the first line of defense against the escalating crisis. Existing monitoring systems, however, often fall short in their ability to provide timely, accurate, and accessible data necessary to mitigate flood risk (Hultquist and Cervone 2020; School 2018). Current systems struggle with challenges such as coverage gaps, data latency, and integration with existing infrastructure and systems. Moreover, these issues are often compounded by high maintenance costs and logistical challenges in hard-to-reach areas.

One promising development in addressing these challenges has been the advent of inexpensive flood-monitoring sensors (Castillo-Effer et al. 2004; Loftis et al. 2018; Rose et al. 2023; Tien, Lozano, and Chavan 2023). These devices, with their ability to provide real-time, granular data on water levels, promise a new paradigm in flood risk management. They are not only affordable, but they can also be easily deployed and maintained, potentially transforming the way we approach flood monitoring.

Building on the emergence of innovative sensor technologies, a prime example of progress in this area is the FloodNet Project (Silverman et al. 2022). Located primarily in New York City, this project aims to enhance flood-monitoring in neighborhoods that are particularly vulnerable to high tides, storm surges, and other flood-related impacts. This ambitious initiative, a multiyear partnership between New York University, the City University of New York, and various agencies within the City of New York, forms a vital part of wider efforts to bolster flood management strategies. The core aspiration of the FloodNet Project is to enhance flood monitoring capabilities, leveraging state-of-the-art sensor technology. The project employs real-time flood sensors developed by the FloodSense project at NYU and the CUNY Advanced Science Research Center (ASRC). These high-precision sensors are designed to deliver real-time, local data on flooding events and are not only affordable but also offer easy deployment and maintenance.

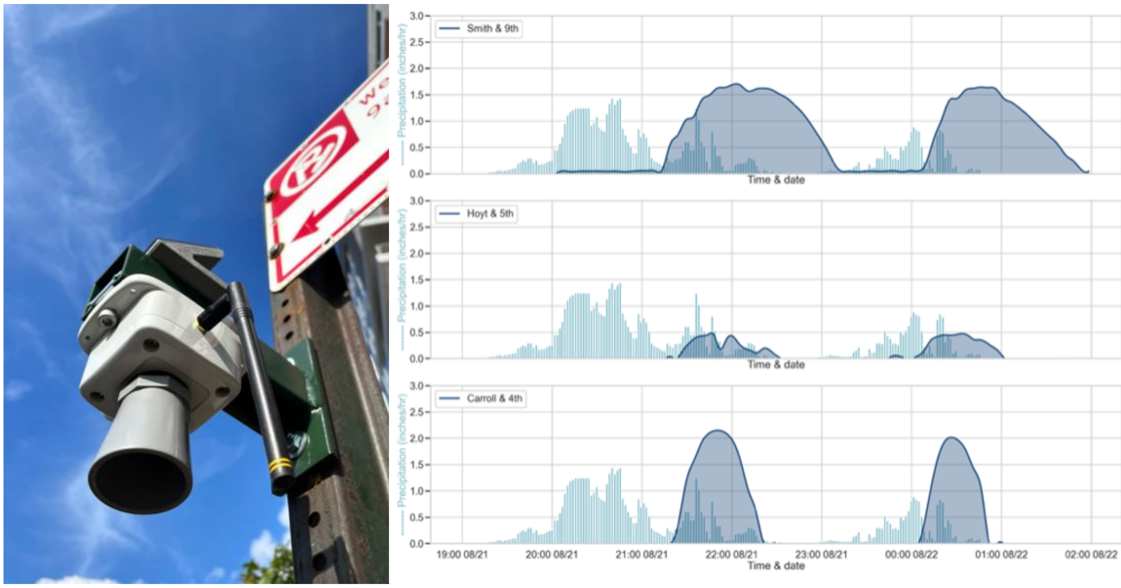


Figure 1 A flood sensor employed by the FloodNet project, and an example of a recording during a flood event

Notwithstanding these advantages, an important issue emerges when the regions requiring monitoring exceed the available number of sensors. This presents a pertinent question: how can we effectively prioritize these deployment locations to maximize benefits for the entire community? The challenge of prioritizing sensor placement is one that needs to be urgently addressed. By answering this question, we can ensure that our limited resources are leveraged effectively, leading to the best possible protection for flood-prone regions and vulnerable communities.

In attempting to frame this problem, it's important to identify the key beneficiaries of an optimized flood-monitoring sensor network. These may include local authorities for planning and disaster management, insurance companies for risk assessment, and most importantly, the residents of flood-prone areas. Furthermore, potential applications of sensor data are not limited to real-time flood monitoring. They could be used for predictive analytics, infrastructure planning, and ecological studies, to name just a few areas.

This report, therefore, proposes a stakeholder-centric approach to the challenge of prioritizing sensor deployment locations. This method is based on an elicitation process involving all possible stakeholders - from local authorities and residents to insurance companies - to define meaningful metrics for comparing different potential deployment locations. A further key element taken into account within this framework is Equity. This dimension holds a pivotal role in strategizing future protective measures against natural calamities (Mohai, Pellow, and Roberts 2009; Sanders et al. 2023). Once these metrics are defined, a subsequent data analysis is performed using available open data to quantify them.

This process does not merely consider static factors such as topographical characteristics and historical flood data, but also factors such as population density and infrastructure vulnerabilities, which may be subject to change over time. By adopting such a dynamic, stakeholder-driven approach, we aim to harness the potential of inexpensive flood-monitoring sensors for the maximum benefit of all community members. This approach has been implemented for a case study in New York City, as a support to the FloodNet Project, providing tangible evidence of its feasibility and effectiveness.

Section 2 Research Objective

Our current study seeks to establish a methodology for assessing and ranking potential locations for the installation of flood-monitoring sensors, especially when the need for monitoring surpasses sensor availability. This methodology involves segmenting the proposed sensor deployment zone into smaller geographic sections, each capable of hosting one or more sensors.

Following this, we identify a range of metrics that can be ascribed to each geographic unit and applied to our ranking strategy. The selection of these metrics is informed through a consultation process that engages experts in urban flooding and other relevant stakeholders. Utilizing open data sources, these identified metrics are subsequently assigned to each geographic unit and integrated using specific weighting factors.

The process of assigning these weights is conducted during the elicitation process, inviting participants to perform a comparative evaluation of each metric using the Analytic Hierarchy Process (AHP), a technique well-recognized in multiple-criteria decision analysis. Our methodology is then operationalized within the FloodNet Project, forming a central element of their upcoming sensor deployment strategy.

Section 3 Literature Review

The task of ascertaining the optimal locations for placing flood-monitoring sensors is a relatively underexplored field, but recent studies have made encouraging strides towards formulating solutions. A notable example is the work of Tien, Lozano, and Chavan (2023), who introduced an innovative multi-parameter optimization strategy that accounts for flood-related variables as well as social vulnerabilities (Tien, Lozano, and Chavan 2023). Their strategy, however, processes each parameter in parallel rather than combining them. This could unintentionally favor regions with well-established infrastructure, even if they are naturally protected from flood hazards due to geographical factors. Also, the optimization parameters in this approach are preset, which overlooks the chance for meaningful collaboration with key stakeholders to select the most relevant metrics.

Research in other areas of sensor deployment has recognized the importance of urban stakeholders, yet they often miss the opportunity for direct engagement with these stakeholders when defining pertinent prioritization metrics (Sun et al. 2019).

Our research proposes an innovative solution that addresses these identified gaps. It does so by examining who stands to gain from flood-monitoring sensors and assessing their specific data needs. Our method stands out by seamlessly integrating flood hazard data with other crucial parameters such as vulnerable population demographics, essential infrastructure, aging structures, and transportation networks. This comprehensive approach ensures that prioritization is driven by a blend of factors that not only appreciate the presence of infrastructure but also directly link it to the corresponding flood risk.

Our work introduces a strategy that offers a transparent and fair approach for determining the priority zones for sensor deployment. By investigating and incorporating the needs of all stakeholders, our strategy presents a practical resource for the FloodNet Project team (and other institutions facing the challenge of prioritizing sensors deployment areas), assisting them in optimizing the placement of the next generation of flood-monitoring sensors.

Section 4 Method

4.1 Elicitation Process

4.1.1 Overview

This chapter describes the process of eliciting information from stakeholders, discussing the critical elements and stages involved. The arrangement of the workshop we organized is illustrated, emphasizing its significant sections and the inquiries presented to attendees to collect necessary data for our prioritization method's application. Moreover, we discuss the range of stakeholders that should be engaged in the elicitation process, along with those who took an active role in our workshop. In conclusion, we explore the utilization of the Analytic Hierarchy Process (AHP), a key component of our approach to assess and rank metrics based on stakeholder feedback.

4.1.2 The Workshop

The initial phase of our methodology involves enlisting stakeholders in the decision-making process to pinpoint priority zones for the deployment of flood-monitoring sensors. This phase engages experts in flood management and urban stakeholders through an elicitation process.

We summoned individuals from diverse spheres including academia, municipal departments, and the private industry. While our methodology advises involving local community members and residents, we suggest conducting their consultation separately from other stakeholders, like city officials, at the onset. This stratagem is intended to sidestep any potential political tensions during the early phases. A detailed breakdown of our workshop attendees is provided below.

Figure 2 Composition of the participants to the elicitation process hosted at NYU as part of the research project

Our workshop saw participation from a total of 45 individuals. These participants were then subdivided into smaller, intimate groups of approximately six to seven people each. Participants were posed three pertinent questions: 1) how they would utilize the data procured from flood-monitoring sensors, considering both their specific requirements and potential applications by others; 2) where they would deploy the sensors, or in other words, which metrics they would employ to compare and prioritize alternate deployment zones; and 3) what additional metrics they would incorporate for an equity-focused prioritization.

Every question posed to the participants was followed by an allotted time for individual responses, after which they shared their thoughts within their respective groups. Subsequently, a representative from each group presented the main ideas to the entire gathering, while a facilitator was actively capturing the points of discussion on a whiteboard.

The output of this phase served to identify a range of metrics, some addressing stakeholders' needs while others targeting equity. These metrics are subsequently assigned weights through the Analytical Hierarchy Process (AHP).

Figure 3 Elicitation process carried out during the Workshop hosted on November 10th 2022

4.1.3 The Three Questions

In our initial section, we hinted at the heart of our stakeholder elicitation structure, anchored on three pivotal questions. The discussions and responses garnered around these queries during the workshop act as invaluable input for subsequent phases of analysis, particularly in designating priority deployment regions. The feedback from questions 2 and 3 underpins the metrics eventually employed to differentiate and rank possible deployment locations. Specifically, the first question is intended to uncover metrics that echo the needs of the stakeholders, whereas the second question is geared towards pinpointing metrics that ensure fair prioritization.

Question 1:
What potential applications do you envision for the flood data harvested from the sensors?

This question encourages the participants to speculate about the various ways different stakeholders might profit from the sensor data. Despite our workshop's primary objective being the discovery of comparative and priority-setting metrics via questions 2 and 3, ruminating on the potential utilities of the sensors lays a crucial foundation for this exploration. Comprehending the diverse applications can contextualize and shape the participants' views on the vital factors to consider when appraising deployment sites. Moreover, participants were prodded to contemplate not only specific utilities related to their individual roles but also to cater to the requirements of other stakeholders, thereby fostering a cooperative mentality centered on the advantages of sharing sensor data.

Question 2:
Where do you suggest the sensors be installed?

This question strives to pinpoint the unique attributes of various urban regions that could double as criteria during the prioritization process. Sample responses might include "Areas with denser populations" or "Along major transportation routes." The results of this question give rise to the priority-setting metrics that mirror stakeholders' needs, which are subsequently employed to differentiate and rank alternate deployment regions in our procedure.

Question 3:
What features of a community would you regard when embedding fairness into the prioritization process?

This question necessitated a deeper clarification before participants could commence formulating responses. Here, our target was to identify community features that, though not directly tied to flooding, could render some communities more susceptible in case of a flood. As a supplementary query, we prodded participants to visualize two distinct communities, equally affected by flooding, and enumerate characteristics that could render one community more prone to the disaster. Responses could potentially include elements like "lower median income" or "higher proportion of single-person households."

Not only do the responses collected during our workshop fuel subsequent analysis and deployment prioritization, they offer a broader view of stakeholder necessities in the context of flood sensor design and data dissemination.

Such insights, for instance, could be harnessed by teams like NYC's FloodNet Project, aiding in their sensor development efforts. Simultaneously, these responses could unveil potential synergies among agencies with diverse needs and expand the stakeholders' pool by identifying new entities that could benefit from sensor data.

In order to ensure effective deployment of sensors, it's vital to interlink the insights gathered from different questions. For example, correlating responses from the first and second questions – understanding sensor utility and deciding their placement – allows for a more strategic sensor deployment.

Thus, the responses obtained from the workshop hold more than just immediate analysis value. When post-processed and organized into tabular form, they can serve as an ongoing resource for future workshops and stakeholder elicitation initiatives. This process constructs a holistic framework that reflects the myriad aspects of stakeholder input, vital for informed flood management.

Upon gathering all responses on a whiteboard, we prompted participants to cast their votes separately for the three most pertinent responses to questions 2 and 3. This enabled us to refine a set of eight metrics per question that respectively encapsulate stakeholders' requirements and considerations of equity.

4.1.4 Analytical Hierarchy Process (AHP)

After distilling the essence of stakeholders' needs and equity metrics from the second and third questions into a concise list of eight key points each, these critical insights were then visualized and shared with the entire group of participants. Moving forward, we ventured into the next crucial stage: ascertaining the relative importance of each metric within its group.

Participants were engaged in a systematic examination of these metrics via a pairwise comparison technique. This process was conducted separately for each category, i.e., once for stakeholders' needs and once for equity metrics. This approach effectively maintains the unique context of each category.

Each pair of metrics underwent a thorough evaluation, receiving a score between 1 and 9. In this context, a score of 1 would imply a balanced importance of both metrics in the pair, whereas a score of 9 in favor of a metric would suggest it holds a significance ninefold greater than its counterpart. Through this method, we could cultivate a more nuanced understanding of the relative importance of each metric within its category, which ultimately formed the basis for our unified prioritization metric.

What is AHP?

In managing complex decision-making scenarios, we adopt the principle of Analytical Hierarchical Process (AHP) (de Brito and Evers 2016; Saaty 1987). This technique, notable for its systematic approach, employs a pairwise comparison mechanism as its initial step. The crux of the AHP is to dissect a compound issue into simpler, manageable segments, thereby illuminating their relative importance when contrasted. Essentially, the AHP sets a rigorous stage for methodical evaluation and ranking of these elements, thereby ensuring that each constituent part receives its due consideration, despite the complexity of the overall problem. This underpins our analytical approach, demonstrating a thorough and strategic understanding of the decision-making process.

Implementing AHP in the Workshop

During the workshop, participants were then acquainted with the chosen metrics through a visual presentation, highlighting the two distinct categories of metrics. Each attendee was given two distinct evaluation sheets, each catering to a different group of metrics. These sheets contained empty matrices that were designed to be filled based on the metrics presented.

The evaluation sheets also came equipped with a built-in mechanism to perform pairwise comparisons. The participants were allowed a solid half an hour to draw their comparisons across both sets of metrics. Given our manageable number of attendees, we took the traditional approach of conducting the process manually. It's noteworthy that larger scale engagements could benefit from automated AHP-oriented software solutions.

The workshop's resources, including the blank evaluation sheets as well as those filled out by the attendees, are accessible as part of the supplementary materials for this report. These resources offer an insightful glimpse into the methods and mechanisms employed during our workshop, and can serve as a guiding template for future research endeavors and stakeholder engagement events.

Post-Processing

For our study, we had the participants' input in digital form as we transcribed their evaluation sheets into an electronic data management system, a spreadsheet for our case. While we had 31 participants complete the comparisons for the metrics pertaining to stakeholder needs, 30 of them provided valid comparisons for metrics relating to equity.

In our subsequent stage of data analysis, the AHP methodology was instrumental in determining the weight each metric carried from each participant's perspective. These individual weightings were then amalgamated through a geometric mean to reach a consolidated weighting for each metric. As a result, we had two sets of importance scores—one for stakeholder needs metrics, another for equity metrics.

While all this may seem straightforward, our data analysis had its complexities. Not every piece of information collected was deemed suitable for analysis. In line with AHP rules, we computed a Consistency Ratio (CR) for each pairwise comparison. An acceptable CR is one that does not exceed 0.10. Therefore, if any pairwise comparison yielded a CR above this threshold, we chose to dismiss that data from our subsequent analysis, a process which resulted in the elimination of some of the collected data.

Combining Stakeholders' Metrics with Equity Metrics

With the assistance of the Analytical Hierarchical Process (AHP), we were able to determine significance values for each metric, both in terms of stakeholders' requirements and equity. This allowed us to integrate the individual metrics within each category, generating two holistic measures, one for each respective area of consideration.

However, the gathered data from the AHP didn't reveal any inherent method to fuse these two synthesized metrics into a singular, overarching measure. As such, the decision was made, during subsequent stages of our analysis, to merge these metrics by assigning them equal weight. It's worth noting that this choice was not based on empirical data, but was rather a product of our discretion.

In applying our framework to real-world contexts, one might consider an additional comparative step between the combined metrics of stakeholders' needs and equity. This would provide an empirical basis for determining the relative importance of these two areas when integrating them into a final, comprehensive measure, thereby ensuring a more objective, data-driven approach.

4.2 Data Analysis

4.2.1 Overview

In the following section, we present our comprehensive methodological framework for strategizing sensor placement. Initially, we focus on the process of matching the right proxies to the metrics identified through our rigorous stakeholder engagement process. Following that, we detail how we procure the requisite data to effectively measure these surrogate metrics.

Subsequently, we move on to the detailed description of our spatial analysis method. In this process, we consolidate flood risk mapping with aggregated Census tract data, creating an effective tool to compare and assess potential deployment areas with distinct characteristics.

We further illustrate the process of merging flood map data from diverse return periods and streamlining each metric through normalization. This phase ensures each metric can be equitably compared on a uniform scale.

Furthermore, we elaborate on how we apply factors derived from the Analytical Hierarchy Process (AHP) to amalgamate the wide array of metrics into a single, holistic score.

4.2.2 Data

In the subsequent section, we enumerate the various data sources utilized in our analysis and outline the specific data preparation procedures employed for each.

Metrics Data

In the subsequent tables, we provide, for each chosen metric, the corresponding data source, where available.

Metric		Proxy	Data source
M1	Presence of critical infrastructure that is susceptible to flood damage/interference (energy, communications, wastewater facilities)	Presence of electricity substations	Homeland Infrastructure Foundation-Level Data (HIFLD)
M2	Vulnerable buildings	Presence of buildings built or ultimately renovated before 1961	New York City Department of City Planning (DCP) Primary Land Use Tax Lot Output (PLUTO)
M3	Major transportation routes (private and public) for vehicles and foot traffic	Annual Average Daily Traffic for vehicular traffic	New York State Department of Transportation (DOT) Traffic Data Viewer
M4	Areas where models have higher uncertainties (Validation spots for flood models, mismatch between flooding reports and modeled flooding)	Proxy not included in the case study because of lack of data	N/A
M5	Subway stations with potential to be impacted by surface flooding	Subway stations annual ridership	Metropolitan Transit Authority (MTA) Open Data Portal
M6	Areas where mitigation measures (e.g. green infrastructure) have been recently completed or planned	Presence and size of public green infrastructure projects under completion	New York City Open Data Portal
M7	Areas with pollution hazards (e.g. toxic releases from polluted sewers)	Presence of Environmental Remediation Sites	New York State Open Data Portal

M8	Areas with a higher number of flood insurance claims	Proxy not included in the case study because of lack of data	N/A

Table 1: List of stakeholders' metrics

	Metric	Proxy	Data source
E1	Social Vulnerability Index	CDC SVI	Centers for Disease Control and Prevention (CDC)
E2	Lack of essential public services (schools, markets, evacuation centers)	Number of schools per capita	New York City Department of City Planning (DCP) Capital Planning Explorer
E3	Locations of compound risk (e.g. flooding and heat waves)	Proxy not included in the case study because of lack of data	N/A
E4	Social isolation/lack of civil capacity (lack of senior or community centers)	Number of community centers per capita	New York City Department of City Planning (DCP) Capital Planning Explorer
E5	Belonging to Environmental Justice Areas	EPA Environmental Justice Index	Environmental Protection Agency (EPA) Environmental Justice Screening and Mapping Tool
E6	Locations at high risk of flooding but low rates of community reports (e.g. 311 calls)	Proxy not included in the case study because of lack of data	N/A
E7	High percentage of non-documented households	Proxy not included in the case study because of lack of data	N/A
E8	High ratio of housing costs over income	Percentage of residents whose housing costs exceed 30% of their income	US Census Bureau - Table B19001 and Table B25088

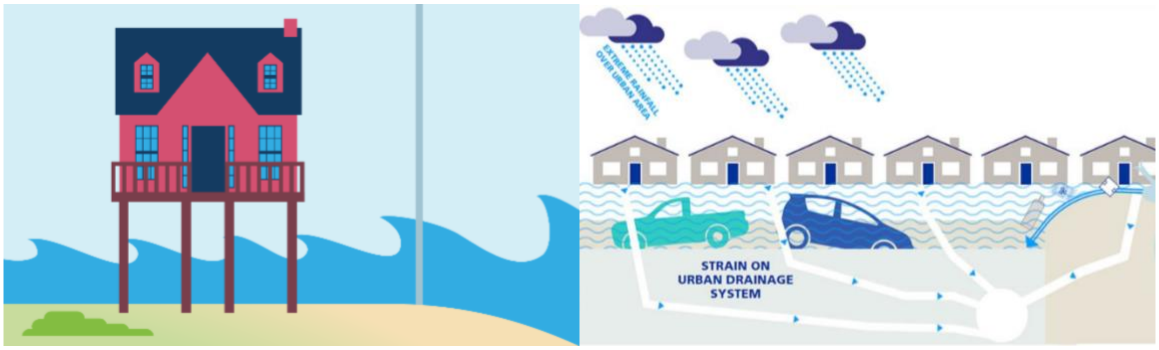
Table 2: List of Equity metrics

Flood Maps

Distinct maps are provided for each type of flood scenario: storm surge, pluvial, and tidal. For storm surges, we reference the Preliminary Flood Insurance Rate Maps (FIRMs) produced by FEMA as part of the National Flood Insurance Program (NFIP). These maps delineate floodplains for the 100-year and 500-year return period events.

In terms of pluvial flooding, the city has developed Stormwater Flood Maps, which illustrate the repercussions of rainfall-induced flooding under both current and future climate conditions. These maps present two scenarios for inland flash flooding: moderate and extreme. The moderate scenario is based on a rainfall intensity of 2 inches per hour. The flood maps incorporate both current and projected sea levels, with future predictions deriving from the findings of the New York Panel on Climate Change. The 2050 moderate scenario projects a sea level rise of 2.5 feet (the 90th percentile estimate for the 2050s), while the extreme 2080 scenario predicts a rise of 4.8 feet (the 90th percentile estimate for the 2080s). Future flooding scenarios take into account the compounded effects of rainfall, potential storm drain blockages, and restricted outflows due to rising sea levels.

Three unique maps are provided: a moderate rain event with the current sea level, a moderate rain event with the anticipated sea level rise in 2050, and an extreme rain event with the projected sea level rise in 2080. These maps distinguish between areas susceptible to deep flooding (1 foot or more) and those prone to nuisance flooding (from 4 inches to 1 foot).



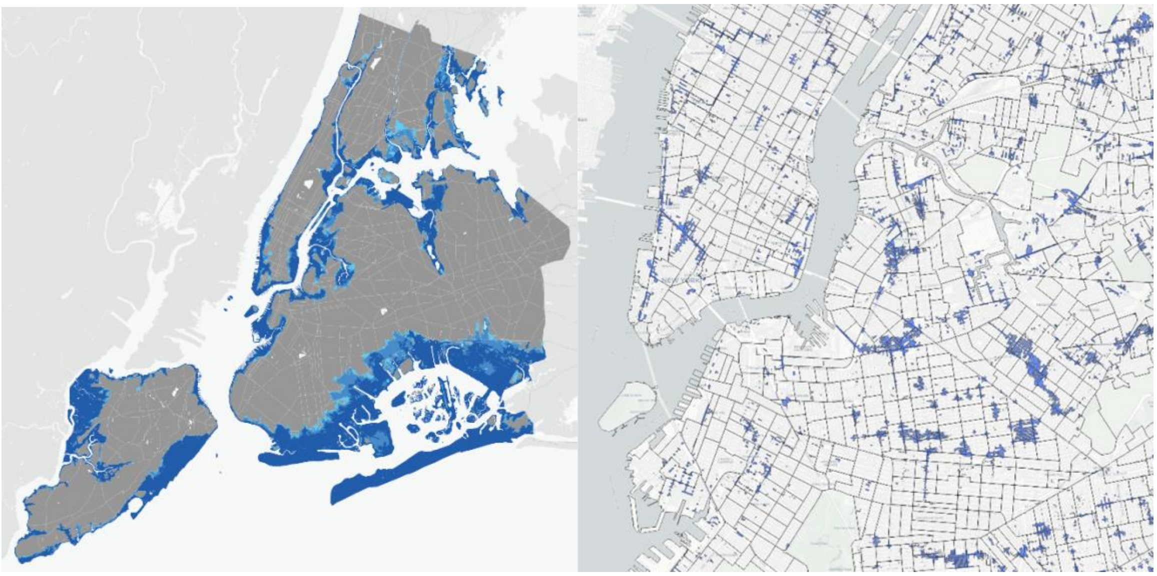


**Figure 4 The two main types of flooding affecting New York City:
Storm Surge (on the left), and pluvial flooding (on the right)**

Regarding tidal flooding, a comprehensive map outlining all currently affected locations is not available. However, NYC does offer maps depicting future high tide levels for the 2020s, 2050s, 2080s, and 2100s. These maps utilize the New York Panel on Climate Change (NPCC) projections for sea level rise (SLR) and apply a modified bathtub approach, as suggested by the National Oceanic and Atmospheric Administration (NOAA). While these maps can provide some guidance in identifying locations prone to recurring tidal flooding, they do not explicitly pinpoint such areas. For a more precise understanding of tidal flooding, additional research and data collection would be necessary, potentially involving community-based initiatives, local flood monitoring, and analysis of historical flood events.

In this study, we've chosen to concentrate our analysis exclusively on pluvial flooding as a demonstration of our proposed method's application.

Geographic units – NYC Census Tracts

Our approach primarily focuses on directing the strategic installation of flood-monitoring sensors by leveraging well-defined evaluation metrics. Here, we undertake a comparison between different potential regions based on these metrics. This process involves harnessing the power of accessible data, which is then assimilated within predefined geographical boundaries.

Taking into account the unique characteristics of our study, we've opted to delineate our geographic parameters based on New York City's Census Tracts. This decision is influenced by our specific goal: to aid the FloodNet initiative in their sensor placement decision-making process. According to the FloodNet's operational structure (Silverman et al. 2022), each sensor shares its data with a proximate gateway, which then forwards this data to a central server. Given that a single gateway is designed to cater to about 5-10 sensors and that its coverage closely approximates a NYC Census Tract, our analysis thereby aids in identifying potential areas for gateway installations within these tracts.

However, it's worth acknowledging that depending on the specifics of the sensor network, the geographic units could be different. For a more adaptive and flexible strategy, a moving window analysis might be a viable alternative. This method systematically scans a predefined area, allowing for a more dynamic assessment of the metrics in question. Despite the potential benefits, such as accommodating local conditions and patterns, this approach might demand more computational resources and lead to increased costs due to its complex nature.

4.2.3 Analysis of the Data

In this section, we outline the process we undertook to analyze the data we accumulated. This includes detailing our strategy for clustering each metric at the level of Census Tracts (which form our chosen geographical units for ranking). Additionally, we explain how we amalgamated the findings from various flood maps, each pertaining to a different return period. Lastly, we describe our approach to metric normalization to ensure compatibility across disparate scales.

Overlap of the Metrics with the Flood Maps and Aggregation at Census Tract Level

For each metric, we overlaid the corresponding data onto the Stormwater Flood Maps, subsequently grouping the information at the Census Tract level. This process is visually depicted in the image below.

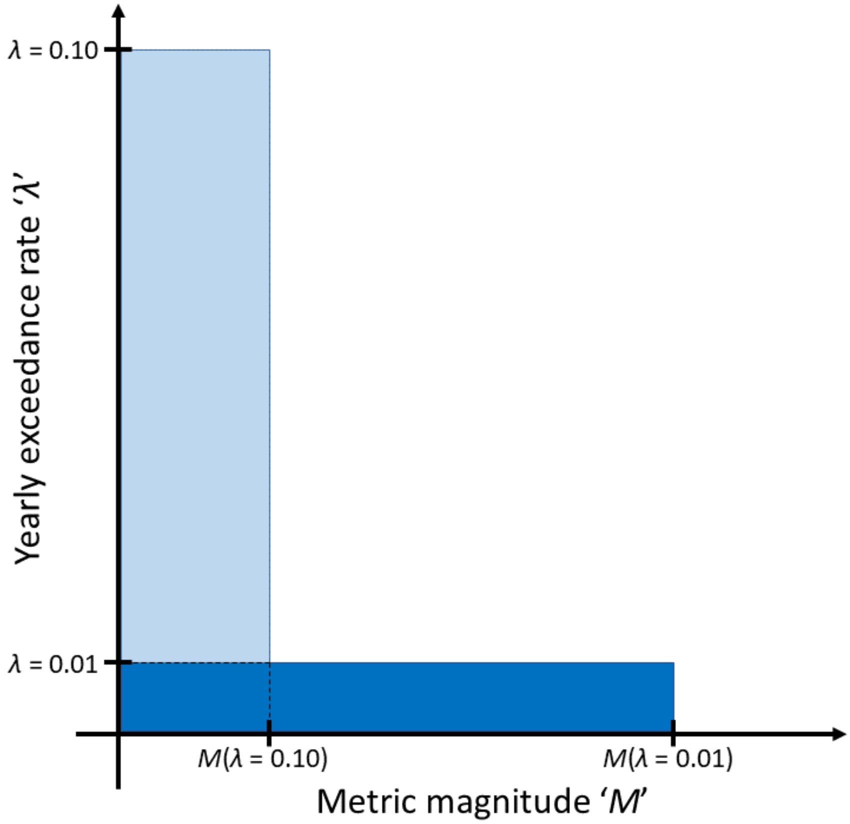
Figure 5 Method for quantifying the selected metrics at Census Tract level

Combining Return Periods

As previously noted, our analysis incorporated the Stormwater Flood Maps that illustrate the risk of pluvial flooding. We utilized two maps for this purpose: one depicting a moderate event, which assumes rainfall of 2 inches within an hour (a scenario with a 10% probability of occurrence in NYC), and the other representing an extreme event, which presumes 3.5 inches of rainfall within an hour (a scenario with a 1% probability of occurrence in NYC). Our combination method is based on the following assumptions:

- For events with an annual exceedance probability (AEP) greater than 0.10 (i.e., events with a return period less than 10 years), all metrics are assumed to be zero.
- For events with an AEP between 0.10 and 0.01 (i.e., events with return periods between 10 and 100 years), the magnitude of each metric is assumed to be equal to the value calculated using the 10-year return period flood map.
- For events with an AEP less than or equal to 0.01 (i.e., events with a return period of 100 years or more), the magnitude of each metric is assumed to be equal to the value calculated using the 100-year return period flood map.

These assumptions can be visually represented in a graph, showing how the metric values change according to the corresponding return periods and their associated annual exceedance probabilities.



Let M_{i-10} represent the magnitude of metric *i* for T = 10 years, and M_{i-100} represent the magnitude of metric *i* for T = 100 years. We calculate the expected yearly magnitude of metric *i* (M_{i-y}) using the following formula:

$$M_{i-y} = (0.10 - 0.01) \cdot M_{i-10} + 0.01 \cdot M_{i-100}$$

Normalization

To reconcile the various metric scales, we normalize each metric to a value ranging from zero to one. This is achieved by dividing each metric by its highest value across all Census Tracts. This step ensures that no individual metric dominates the final consolidated value due to scale disparities.

4.2.4 Metrics Combination

Upon calculating metrics for both stakeholders' needs and equity, we have a total of eleven metrics per Census Tract. The subsequent step entails consolidating these metrics into a singular, comprehensive value, which will enable us to effectively prioritize flood-monitoring sensor deployment areas. The process includes:

Weighting with AHP Factors: We then integrate the importance factors derived from the AHP analysis. For each metric, its normalized value is multiplied by the corresponding AHP importance factor, thereby ensuring that metrics deemed more critical by stakeholders exert a greater influence on the final combined value.

Metrics Aggregation Within Each Set: After weighting the metrics, we aggregate the products within each set (stakeholders' needs and equity) separately. Consequently, each Census Tract is represented by two aggregated metrics: one for the stakeholders' needs set and one for the equity set.

Combining the Two Sets of Metrics: The final step is to amalgamate the two aggregated metrics (stakeholders' needs and equity) into a single metric for each Census Tract. In the absence of elicited preferences regarding the relative importance of stakeholders' needs and equity, we simply calculate the mean of the two aggregated metrics. This process results in a final combined metric for each Census Tract.

4.2.5 Prioritization

With this final combined metric in hand, we can now contrast and prioritize different deployment areas for flood-monitoring sensors, thus completing the prioritization process.

Each Census Tract, now characterized by a unique combined metric, can be prioritized for flood-monitoring sensor deployment. The prioritization process comprises the following steps:

A. Ranking the Census Tracts based on the final combined metric.
B. Determining the number of desired deployment areas.
C. Selecting the requisite number of Census Tracts from the ranked list.

This method establishes a clear and reproducible process for prioritizing deployment areas.

4.3 Use of 311 Data to Address Flood Model Uncertainties and Flood Reporting Biases

This section provides an in-depth analysis that pertains specifically to metrics M4 from the Stakeholders' needs list (Areas where models have higher uncertainties (Validation spots for flood models, mismatch between), and E6 from the Equity set (Locations at high risk of flooding but low rates of community reports). These particular metrics were not incorporated into the primary analysis discussed in preceding sections. Rather, a distinct chapter is allocated for a preliminary examination of the utilization of 311 data in estimating these metrics.

The rationale for excluding these two metrics from the main body of analysis stems from a few factors. Primarily, the methodology required to accurately assess these metrics diverged significantly from the standard procedures implemented in this study. In addition, the intricacies involved in these metrics necessitated a comprehensive examination of 311 data, which warranted separate and dedicated exploration. The purpose of this focused inquiry is to thoroughly understand the potential of 311 data in addressing flood model uncertainties and detecting potential biases in flood reporting within specific communities.

It is anticipated that this specialized investigation will contribute valuable insights into the respective metrics and further underline the significance of 311 data in the context of flood modeling and community reporting studies.

4.3.1 Method Overview

The fundamental structure of our analysis rests upon gauging flood severity at the Census Tract level by employing two sources of data: Stormwater flood maps and flood-related 311 calls. These two measures are subsequently displayed on a scattered plot with each axis representing one of the data sources. Each point within the plot corresponds to a distinct Census Tract.

To analyze the relationship between these two measures of flood severity, we conduct a linear regression analysis, and the resultant regression line is plotted on the graph. This approach aids in discerning any existing linear relationship between the flood intensity as indicated by Stormwater maps and the number of flood-related 311 calls.

In the final stage of this analysis, we isolate Census Tracts that deviate considerably from the regression line. These outliers exemplify areas where the number of 311 calls is either higher or lower than predicted by the flood severity as delineated by the Stormwater flood maps. This deviation indicates potential discrepancies in flood reporting or model uncertainty that warrants further investigation.

4.3.2 Measuring Flood Intensity Using 311 Data

The methodology utilized for our analysis leans heavily on the 311 service requests dataset, a public resource provided by NYC Open Data. Initially, we refined this data set to include only service requests that pertained specifically to flooding, thereby concentrating our focus on flood-related incidents.

To further ensure relevance, we cross-referenced these selected service requests with rainfall intensity data. We identified major rain events as those with an intensity of 1 inch per hour or greater. By doing this, we ensured that the chosen 311 calls correlated with significant rainfall events, offering a more accurate reflection of flood intensity in those specific circumstances.

4.3.3 Measuring Flood Intensity Using the Stormwater Flood Maps

To evaluate flood intensity as per the Stormwater flood model, we implemented an approach involving the combination of the Stormwater flood maps and the NYC tax lot database (Map PLUTO). The initial step was to overlay the flood maps onto the tax lot database, allowing us to identify and tally the count of structures affected by flooding within each Census Tract.

Subsequently, this gathered data was synthesized with the methodology explained in chapter 5.2.3.2. Through this integration, we achieved a composite measure of flood intensity that was based on the count of flooded buildings for the two distinct return periods available.

4.3.4 Comparison Between 311 Data and the Stormwater Flood Maps

In the subsequent phase of our analysis, we graphically depicted each Census tract as a point on a bi-dimensional scatter plot. The horizontal axis represents the volume of flood-related 311 service requests, while the vertical axis indicates the count of buildings considered flooded per the Stormwater flood model.

We then applied a linear regression model to this data and superimposed the resultant regression curve onto the scatter plot. Points that deviate significantly from the regression line could signify areas where the model's flood predictions are either underestimations or overestimations. Such deviations could illuminate areas of uncertainty within the model's predictions (correlating to metric M4).

Alternatively, significant divergences could indicate regions where the 311 reporting system is underutilized, thus bringing to light potential equity issues that warrant further exploration.

Section 5 Results

In this chapter, we present the results of our analysis. We report the outcomes of our workshop, showing the answers that emerged during the elicitation process, and the results of the data analysis carried out for New York City. Finally, we present the results of the comparison between 311 data and the Stormwater flood maps.

5.1 Elicitation Process

In this section, we unfold the findings from our workshop session. We initially lay out the feedback gathered concerning the three posed questions, regarding the use of sensors data, their ideal deployment areas, and how equity can guide the prioritization process. Subsequently, we delve into the data obtained from the Analytical Hierarchy Process (AHP), highlighting the weights assigned to each of the identified key parameters.

5.1.1 Possible uses for the sensors

In this segment, we focus on the initial component of our workshop: assessing the prospective applications of sensor-gathered flood data as envisioned by the participants. This exploration, though peripheral to the main task of defining metrics for deployment area evaluation and prioritization, plays an integral role in understanding the potential context of sensor utilization. This contextual understanding subsequently shapes participants' perspectives on critical considerations for deployment location evaluation.

Each participant initially pondered over this question independently, followed by intra-group discussions and finally a collective discourse. The process was carefully documented by individual group moderators, and their notes are made available as supplementary material to this document.

Post-workshop, we compiled the collective insights into a comprehensive document, categorizing the various proposed uses and associating them with relevant stakeholders. It's important to clarify that the consolidation process was anonymized and did not attribute specific responses to individual participants. The classification of uses and their corresponding stakeholders was based on our analytical interpretation.

Following is a table detailing the array of sensor usage scenarios derived from our workshop. These findings hold significant implications on multiple fronts: It offers insights into stakeholder-specific requirements in the realm of sensor development, data collection, and distribution. It provides a procedural framework for local government bodies aiming to conduct their stakeholder elicitation using our methodology. It also sparks fresh thinking around potential uses and stakeholder engagement, which can be pivotal for researchers involved in flood-monitoring sensor development. Moreover, these findings can pave the way for synergistic collaborations among diverse stakeholders, thereby fostering a more integrated and effective use of sensor technologies.

STAKEHOLDER	SCOPE		EXAMPLES
LOCAL, REGIONAL AND FEDERAL AGENCIES PROVIDING PUBLIC SERVICES	Regular services not directly related to floods		• Provide information on road conditions for public services, such as street garbage collection and snow plows
	Flood protection		• Monitor and automate flood control systems, such as pumps or flood gates and other protection systems • Signal when catch basins need to be cleaned
	Emergency management (during and post event)	Emergency operations	• Sending flood alerts to residents and visitors • Coordinating evacuation • Raising flood-risk awareness • Guiding resource allocation (before, during or after an event) • Receiving aids to withstand the emergency (e.g. food supplies) • Guiding post-event recovery activities
		Protection of emergency facilities	• Monitoring area around hospitals (e.g. avoid receiving incoming patients, or avoid flooded routes to the hospital) • Monitoring fire stations
LOCAL COMMUNITIES	Community engagement		• Communicating flood hazards to residents
	Infrastructure investments pre-event		• Provide evidence to receive public funds for protection and mitigation infrastructure • Provide evidence to receive aid for building upgrades
	Flood emergency		• Receiving flood alerts
	Post storm recovery		• Provide evidence to support applications for post-storm financial assistance
INSURANCE AND REAL ESTATE AGENTS	Risk evaluation		• Identifying insurance gaps for flood protection (e.g. identifying neighborhoods at risk without flood insurance, or where the flood risk is underestimated) • Updating risk models to estimate industry losses • Trigger for parametric insurance
	Property value assessment		• Informing buyers and renters about potential impacts of floods on the property
INFRASTRUCTURE OWNERS	Monitoring and updating public infrastructure	Drainage	• Detect poor conditions/failure in stormwater and/or combined stormwater-sewage drainage systems
		Mitigation and protection	• Monitoring the effectiveness of flood mitigation projects (e.g. green infrastructure) • Planning and designing of new flood mitigation and protection projects
		Critical	• Monitoring the flooding of critical infrastructure during and after an event (energy, waste water, etc.)
		General	• Identifying flooded areas to assess potentially damaged public infrastructure after an event
	Monitoring, managing and updating transportation infrastructure		• Monitoring street entrances to subway transportation networks during an event • Rerouting private and public transportation based on flooded areas
	Monitoring private buildings		• Monitoring flood level near basement dwellings and areas of low topographic elevation (for both tenants and building owners)
	Monitoring land development		• Monitoring the impact of new development on flooding

RESEARCHERS AND ENGINEERS	Hydrologic and Hydraulic (H&H) modeling / weather forecasting	• Developing and validating flood models coupled with weather and/or tide events (e.g., capturing data to better understand the relationship between rainfall and local flood) • Research to improve flood forecasting based on tide/weather data • Developing time-varying flood maps for recorded events • Keeping records of tides • Evaluate changing trends in floods due to changing climate
	Disaster Risk Analysis	• Mapping and measuring the spatial and temporal impact of a storm across multiple interdependent infrastructure systems (transportation, housing, power) and multiple communities
	Infrastructure modeling	• Improving the forecasting of floods' impacts to cities

Table 3: Possible uses of the flood-monitoring sensor

5.1.2 Stakeholders' needs metrics

In the proceeding section, we're primarily focusing on the responses garnered from the second workshop question: what elements should we weigh when deciding upon potential sensor locations? Our ultimate aim is to extract key metrics from the answers to this query and a subsequent one, which will steer our course when it comes to ranking areas for sensor deployment.

Preceding the group discussion, we introduced some hypothetical responses inspired by our previous research conversations, including prioritizing areas with high population density or significant transit routes. To set the stage for future discussions, we also emphasized that we would be juxtaposing each suggested metric with existing flood maps—be it from the City, FEMA, or the Stormwater Flood Maps. This meant that if the population was a suggested metric, we would isolate the flood-prone population using these maps. Thus, the potential for flooding was already a given in their suggestions.

The participants were then given time to reflect individually and in groups. Each group presented their discussion points to the entire workshop, and our research team member visually captured these on a whiteboard. Occasionally, a suggestion would ignite a new thread of discussion and bring to the forefront insights that were not previously considered. These responses were kept on display for further reference during the subsequent voting segment, described in detail in the following chapter. For completeness, we have attached images of the whiteboard and the notes taken by each group moderator.

Once the workshop concluded, we synthesized the visual and textual data. We embarked on post-processing the responses, categorizing them into broad groups, much like our approach for the first question. For instance, any mention of transportation networks was compiled into one category.

These resulting metrics were put to a vote, and the eight deemed most pertinent were processed through the Analytical Hierarchy Process (AHP) for ranking. These chosen metrics then played a key role in informing our process for prioritizing sensor deployment across New York City. In the subsequent table, we've included all the metrics considered during the workshop. These will hopefully provide a starting point for other institutions or governments seeking to undertake a similar sensor prioritization process. We anticipate this list will be expanded upon in future stakeholder consultations, taking into account an ever-widening range of perspectives.

WHERE TO PLACE SENSORS	POSSIBLE METRICS
In areas where the probability of flooding is higher due to historical evidence or natural susceptibility (e.g. insurance claims, 311 service requests, predicted locations of historical waterways, wetlands and marshlands, etc.)	• Within flood maps • Emergency Response Incidents • 311 flood complaint data • Transportation routes that suffered interruptions during past flooding events • Applications for post-storm assistance • Flood insurance claims • Areas where there is anecdotal evidence of flooding • City inspected flood complaints • Damages to the public infrastructure • Community Flood Watch reports • NOAA/NWS impact catalogs • Predicted locations of historical waterways, wetlands, and marshlands • In low-lying areas
Where there is higher concentration of residents and workers	• High population density (residents) • High population density (workers and visitors)
Where buildings and infrastructure are more vulnerable to flooding	• Old buildings (building code before 1961 didn't include requirements for flood protection) • Buildings that are within flood maps but don’t have flood insurance • Basement dwellings • Road underpasses • Subway stations with potential to be impacted by surface flooding • Land use type

	• Areas with pollution hazards (e.g. toxic releases from polluted sewers)
In the proximity of critical and socially important services	• Presence of critical infrastructure that is susceptible to flood damage/interference (energy, communications, wastewater facilities) • Presence of emergency response facilities (hospitals, evacuation centers, fire stations) • Socially relevant services (supermarkets, schools, community centers)
In the proximity of drainage infrastructure nodes	• Presence of combined sewers • Major catch basins and sewer collectors • Presence of wastewater facilities
Close to relevant transportation networks	• Major transportation routes (private and public) for vehicles and foot traffic • Bus and train stations • Emergency and evacuation routes
Where the new infrastructure investments are planned	• Areas where mitigation measures (e.g. green infrastructure) have been recently completed or planned • Areas with new or planned infrastructure
Where there is possibility for model validation	• Areas where models have higher uncertainties (Validation spots for flood models, mismatch between flooding reports and modeled flooding)
In locations that maximize information and avoid redundancy	• Places where sensors would provide an optimal spatial coverage • Places where sensors would provide an optimal coverage of the sewer network
In areas where there is greater potential of	• Places where large investments (infrastructure, housing) are planned

economic losses due to flooding	• Places with greater property value at risk

Table 4: Metrics representing the stakeholders' needs

5.1.3 Equity Metrics

In this segment of the report, we present the deliberations that followed the third question at the workshop: What attributes of a community could be pivotal for embedding equity within the sensor deployment prioritization strategy?

Engaging the participants with this question necessitated a clear context to facilitate thoughtful responses. The central intention behind this query was to elucidate community characteristics that might not directly contribute to flooding yet might play a vital role in shaping an equitable deployment strategy. Previous studies have highlighted communities whose socio-economic conditions impede their resilience to disasters. However, that is merely one aspect of considering equity in the context of flood sensor placement. To guide this exploration, we considered the question: How could a community significantly benefit from this flood data?

For example, we could infer that communities with less developed transportation networks could be better served with flood sensors. This additional monitoring could improve their transit infrastructure management, particularly during adverse weather conditions. Likewise, communities that are more isolated or have less frequent interactions with government entities might see their needs better met with the inclusion of flood-monitoring sensors in their locality.

An interesting aspect that emerged was the issue of underrepresentation, especially in conventional elicitation processes. This suggests a need for more intentional, direct relationships with communities hosting the sensors, thus facilitating a two-way communication channel.

The discussion initiated by this question contributed to a broader discourse on the incorporation of equity considerations in flood management strategies, specifically in relation to flood sensor deployment.

Following is a table that includes the metrics concerning equity that were identified during the workshop. Notably, there might be overlaps or correlations among some metrics. For instance, the Social Vulnerability Index, discussed during the workshop, includes elements such as the percentage of elderly people, also mentioned as a separate metric. A potential correlation might also exist between literacy rates and median income. Hence, a comprehensive review of these potential correlations would be an important consideration in future stages of analysis.

The identified metrics can form a starting point for other agencies or local governments looking to incorporate equity in their sensor deployment decision-making process. With continuous research and broader stakeholder engagement, this list can be expanded to ensure that a wide range of perspectives and needs are taken into account in the decision-making process.

EQUITY CATEGORY	EQUITY METRIC
Social vulnerability	• Belonging to Environmental Justice Areas • Belonging to high displacement risk areas • High Social Vulnerability Index (SVI) • High percentage of non-documented households (not eligible for city and federal funding) • Belonging to marginalized communities • Communities with lower income • Belonging to Redlined Areas • High number of people with disability issues, medically fragile groups • Communities with lower wealth/savings • High percentage of children and elderly (people over 60) • Presence of Senior housing and Naturally Occurring Retirement Communities • High occurrence of overcrowded buildings • High percentage of unhoused population • Communities with low literacy rate • Less advocacy groups • English-as-a-Second Language communities • Communities that make heavy use of food stamps • High percentage of single-person households • Presence of shelters for homeless people (formal and informal - nonprofits, churches, etc.) • Higher percentages of small businesses over chains and established companies • High levels of segregation (economic, racial)
Excessive economic burden	• High flood insurance premium • High percentage of insurance claims that were denied • High ratio of housing costs over income

Lack of public services, infrastructure, and social cohesion	• Limited access or lacking of emergency response facilities • Longer time to emergency response (e.g. longer response time after an emergency call has been placed) • Limited access to private and public transportation • Lack of redundant evacuation routes, low connectedness • Low accessible transit entrance points • Historically low investments in mitigation infrastructure (e.g. green spaces) • Lack of essential public services (schools, markets, evacuation centers) • Social isolation/lack of civil capacity (lack of senior or community centers) • Dearth of stewardship • Areas of public disinvestment
Data scarcity	• Locations at high risk of flooding but low rates of community reports (e.g. 311 calls) • Poor voter turnout • Absence of Community-based flood monitoring groups (e.g. Flood Watch in NYC)
Compound hazards	• Presence of brownfields and superfunds • Locations of compound risk (e.g. flooding and heat waves)

Table 5: Metrics representing equity

5.1.4 Selected Metrics and AHP Results

The subsequent tables feature the pair of metric groups chosen during the workshop by way of the voting procedure, along with their corresponding importance factors, derived from the execution of the Analytical Hierarchical Process. Each metric has two associated importance factors. The first one originates from a pairwise comparison conducted among all the metrics, while the second is a compensatory adjustment implemented due to the exclusion of certain metrics from the analysis because of data unavailability.

	Metric	AHP	Adj.
M1	Presence of electricity substations	0.172	0.211
M2	Presence of buildings built or ultimately renovated before 1961	0.171	0.210
M3	Annual Average Daily Traffic for vehicular traffic	0.170	0.208
M4	Higher uncertainties in the flood model	0.118	-
M5	Subway stations annual ridership	0.108	0.133
M6	Presence and size of public green infrastructure projects under completion	0.104	0.127
M7	Presence of Environmental Remediation Sites	0.091	0.111
M8	Higher number of flood insurance claims		-

Table 6: AHP factors for the Stakeholders metrics

	Metric	AHP	Adj.
E1	Centers for Disease Control and Prevention (CDC) Social Vulnerability Index	0.195	0.299
E2	Lack of Schools	0.169	0.259
E3	Locations suffering of compound risk (e.g. heat waves)	0.150	-
E4	Lack of Community centers	0.126	0.194
E5	Environmental Protection Agency Environmental (EPA) Justice Index	0.102	0.156
E6	Locations at high risk of flooding without reports	0.101	-
E7	Higher presence of non-documented households	0.096	-
E8	Percentage of residents whose housing costs exceed 30% of their income	0.060	0.092

Table 7: AHP factors for the Equity metrics

5.2 Data Analysis

5.2.1 Prioritized Deployment Areas

Upon assigning each Census Tract a final consolidated metric, we successfully ranked the NYC Census Tracts to discern which should be prioritized for flood-monitoring sensor deployment. The subsequent map showcases the top ten locations as determined by our method. The number of Census Tracts employed can be adjusted based on the quantity of sensors intended for deployment.

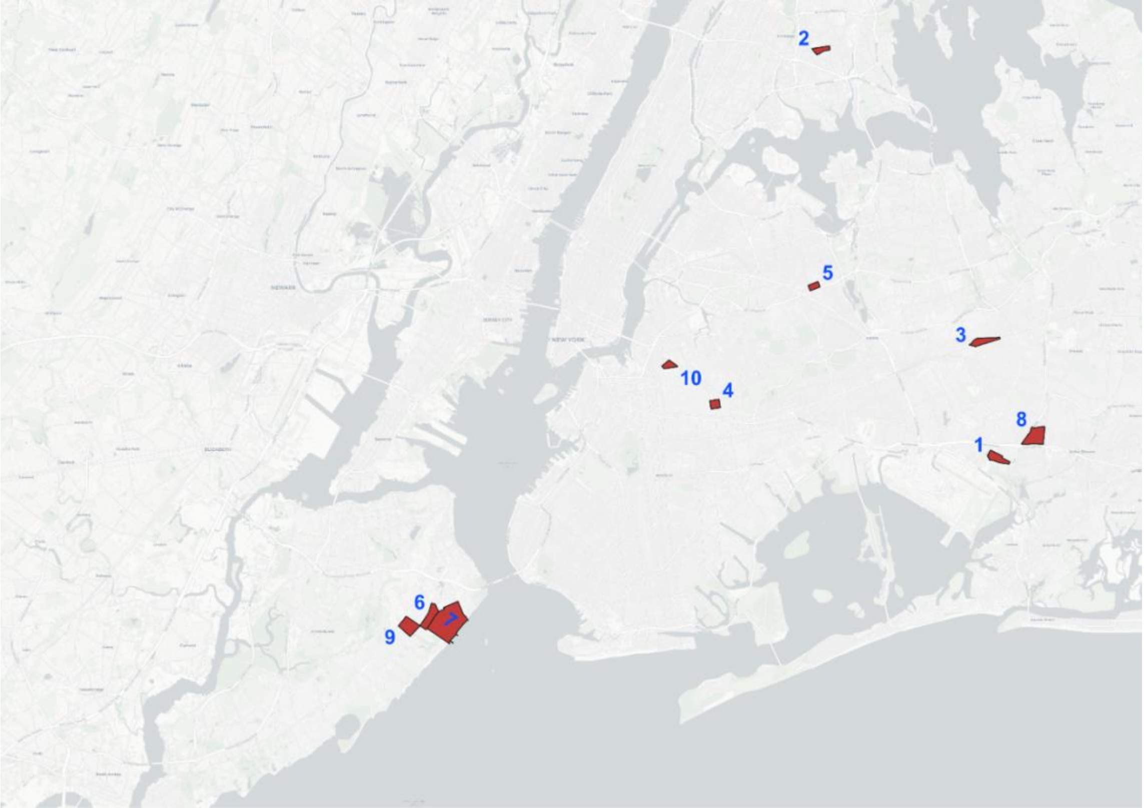
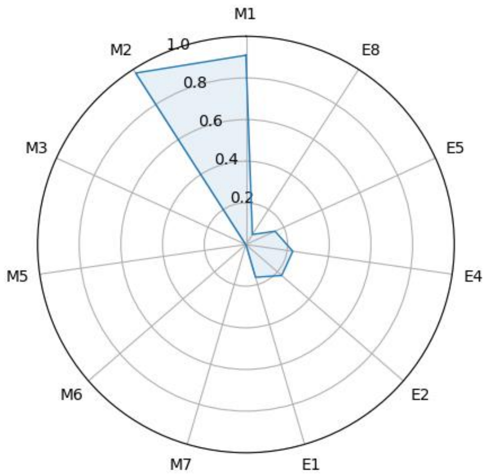
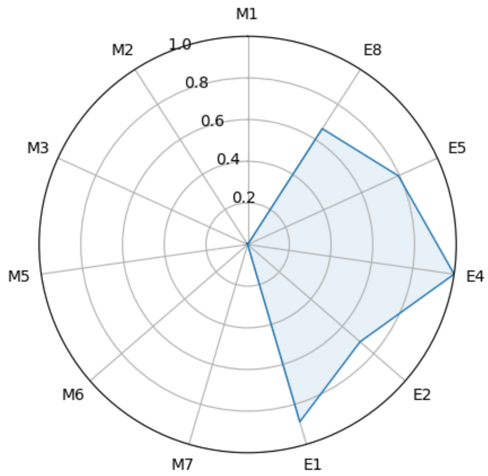


Figure 6 Map showing the Top 10 Census Tracts according to our prioritization method

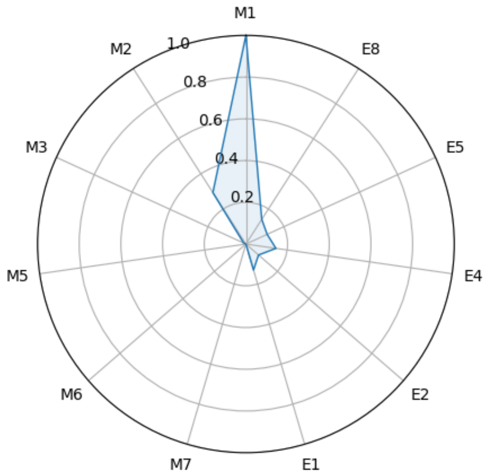
In the subsequent radar charts, which correspond to the top 10 Census Tracts as identified by our method, we examine the influence of each metric within the final consolidated metric. This analysis plays a crucial role in discerning the elements that guide the prioritization process. Furthermore, it empowers those deploying the sensors with the ability to fine-tune the importance factors attributed to each metric.



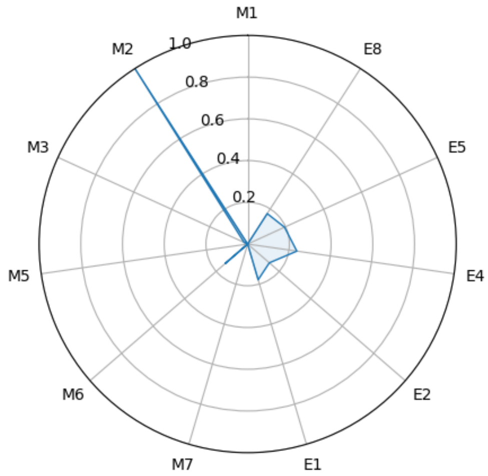
Census Tract 1



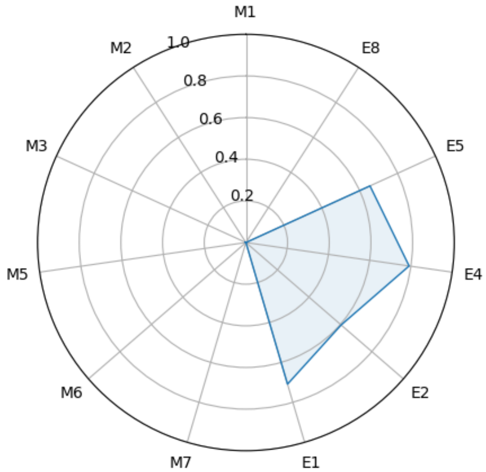
Census Tract 2



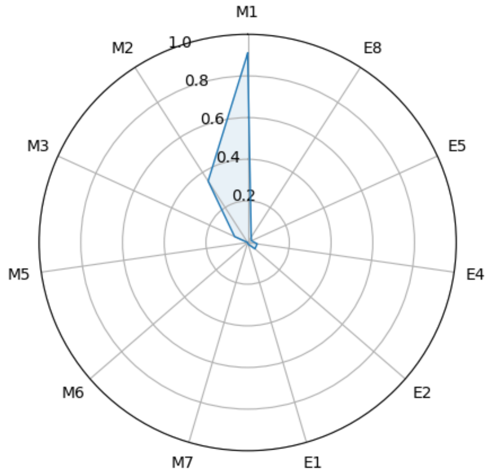
Census Tract 3



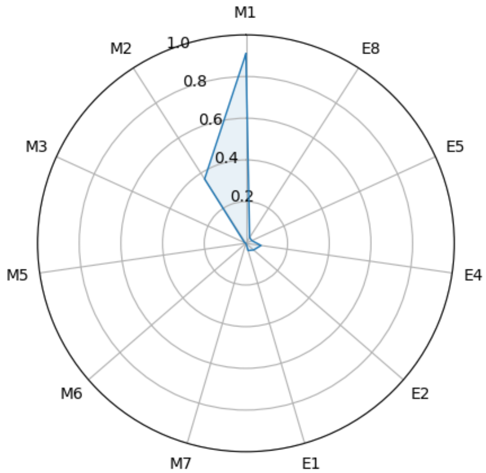
Census Tract 4



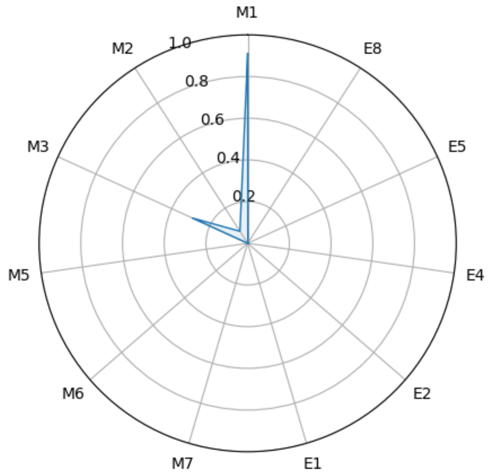
Census Tract 5



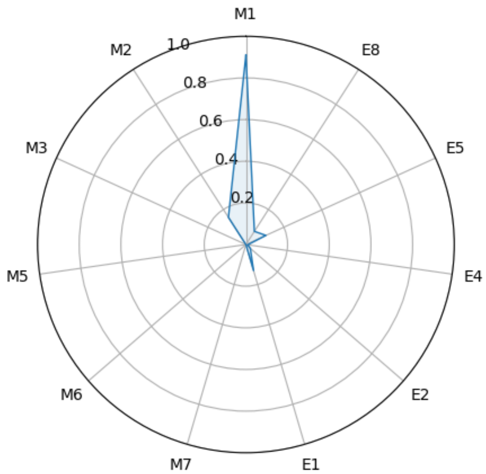
Census Tract 6



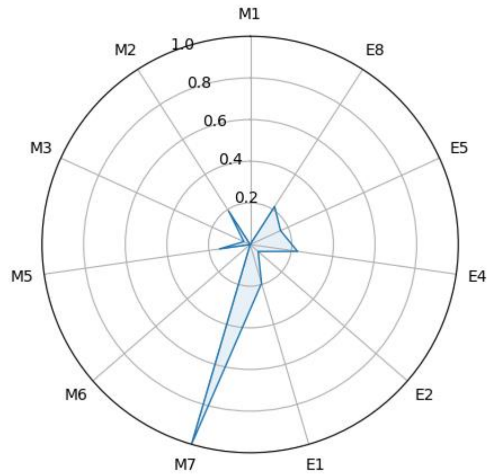
Census Tract 7



Census Tract 8



Census Tract 9



Census Tract 10

Interestingly, despite the equal weighting of both stakeholders' and equity metrics in our combination, the stakeholders' metrics evidently play a more substantial role in the prioritization process. In fact, eight out of the top ten Census Tracts are primarily driven by one of the stakeholders' metrics. Furthermore, among the stakeholders' metrics, M1, corresponding to the presence of electricity substations, is the most dominant. This observation aligns with the Analytical Hierarchical Process, in which M1 was assigned the highest importance.

5.3 Use of 311 Data to Address Flood Model Uncertainties and Flood Reporting Biases

In this chapter, we present the findings of our comparison exercise, where we juxtaposed 311 service requests data against the Stormwater flood maps. Our primary objective was to shed light on potential inaccuracies inherent in the flood modeling and to pinpoint equity issues concerning the utilization of the 311-reporting system.

5.3.1 Comparison Between Data

Below is a scatter plot illustrating a comparison between flood intensity as per 311 service requests and the flood model employed for the Stormwater flood maps. Every data point signifies a distinct Census Tract within NYC. The horizontal axis quantifies the annual flood-related service requests, while the vertical axis denotes the number of structures inundated as per the flood model. Notably, both metrics have been normalized by the total number of buildings present within each respective Census Tract.

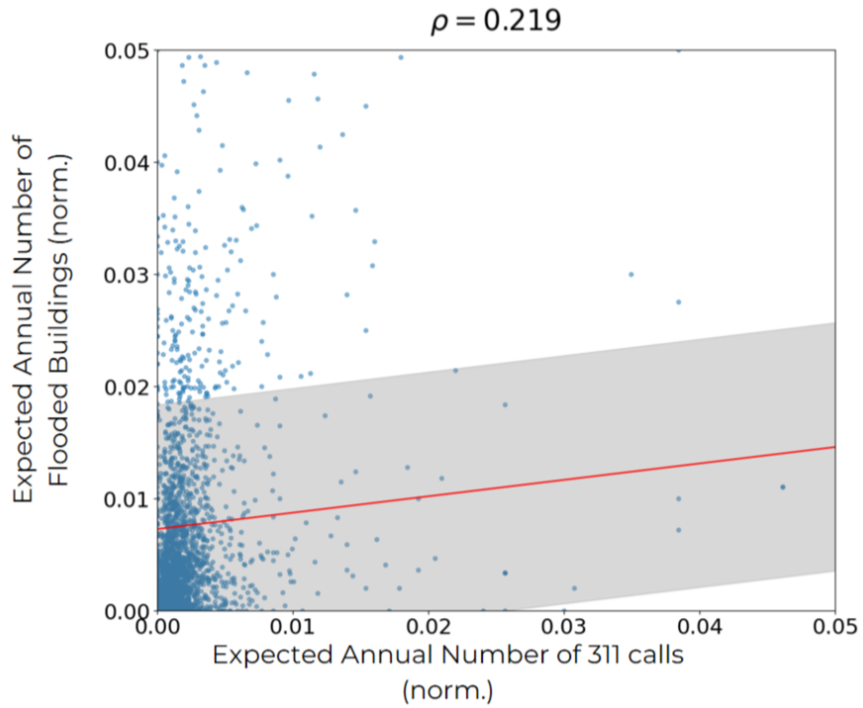


Figure 7 Scatter plot representing the correlation between flood-related 311 calls and the prediction of the flood model at Census Tract level

5.3.2 Field Visits

Upon identifying the Census Tracts deviating most significantly from the regression line, we initiated field visits to four such locations. Two of these locations exhibited a high volume of 311 calls, yet lacked predicted flooding according to the Stormwater flood map. Conversely, the remaining two indicated considerable predicted flood areas, yet registered no 311 calls.

In one scenario, the geographical feature of a steep street slope resulted in water funneling and subsequent flooding into basement units at the slope's end. This dynamic event failed to be captured by the model. In another contrasting case, despite significant flooding predictions on the Stormwater flood map, none of the interviewed local residents or business owners recollected instances of flooding.

Additionally, in a separate case, although residents affirmed regular flooding incidents, they expressed difficulties in utilizing the reporting system due to language barriers, with the dominant language in the area being Cantonese.

The insights gained from these field visits underscore the significance of juxtaposing 311 data with flood model predictions. This comparison not only assists in identifying inaccuracies in the model's predictions but also highlights potential equity issues related to the underutilization of the 311-reporting system.

Section 6 Conclusions

6.1 Including/Excluding Metrics

Our study introduces a novel framework for sensor location prioritization, supported by a case study emanating from a workshop we conducted. The metrics employed in this case study were derived from that workshop. However, it's crucial to note that the FloodNet team, the City of New York, and any other parties interested in implementing our method, can adapt it to suit their specific needs. This could involve expanding or narrowing the set of metrics used, or assigning them different weights, depending on the relevance of various sensor uses. As illustrated by the two examples that follow, the employment of different metrics results in notably varied prioritizations.

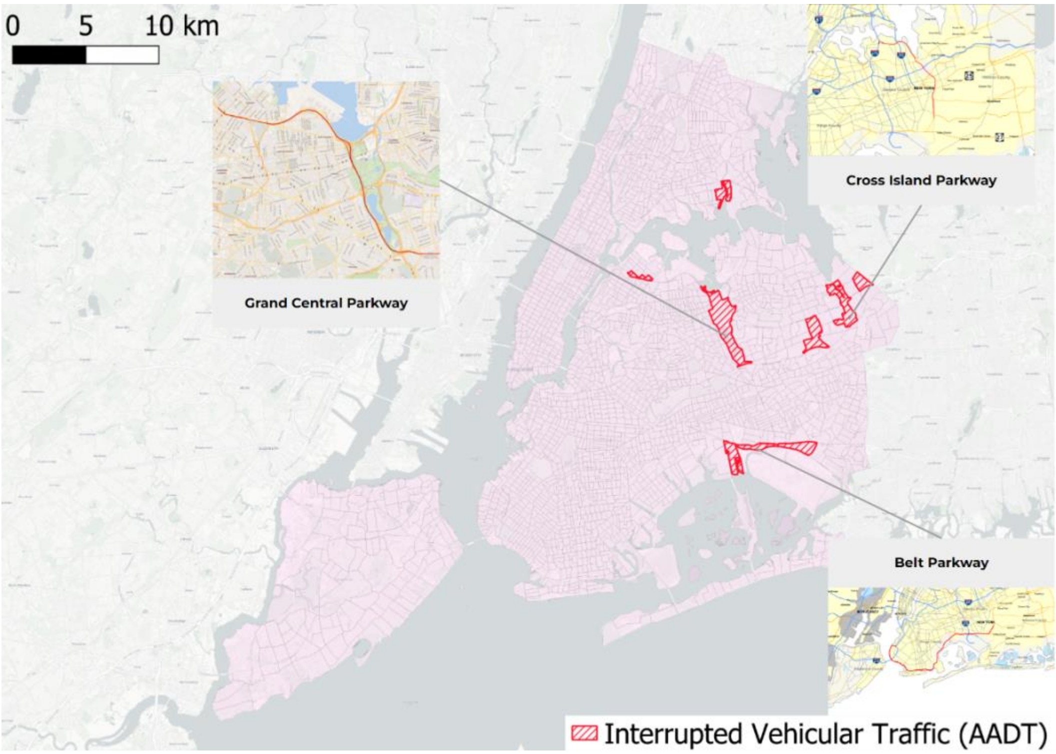


Figure 8 Top 5 Census Tracts identified using the metric "Annual Average Daily Traffic for vehicular traffic"

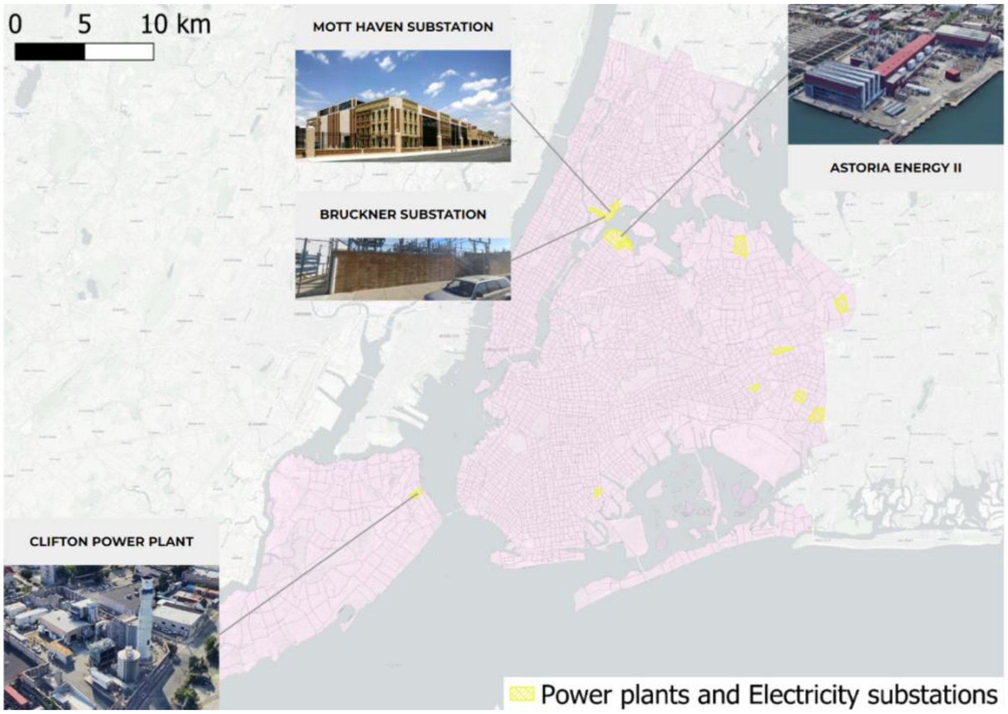


Figure 9 Top 5 Census Tracts identified using the metric "Presence of electricity substations"

Furthermore, utilizing different return periods can yield distinct outcomes, underscoring the significance of statistically merging the results derived from various return periods.

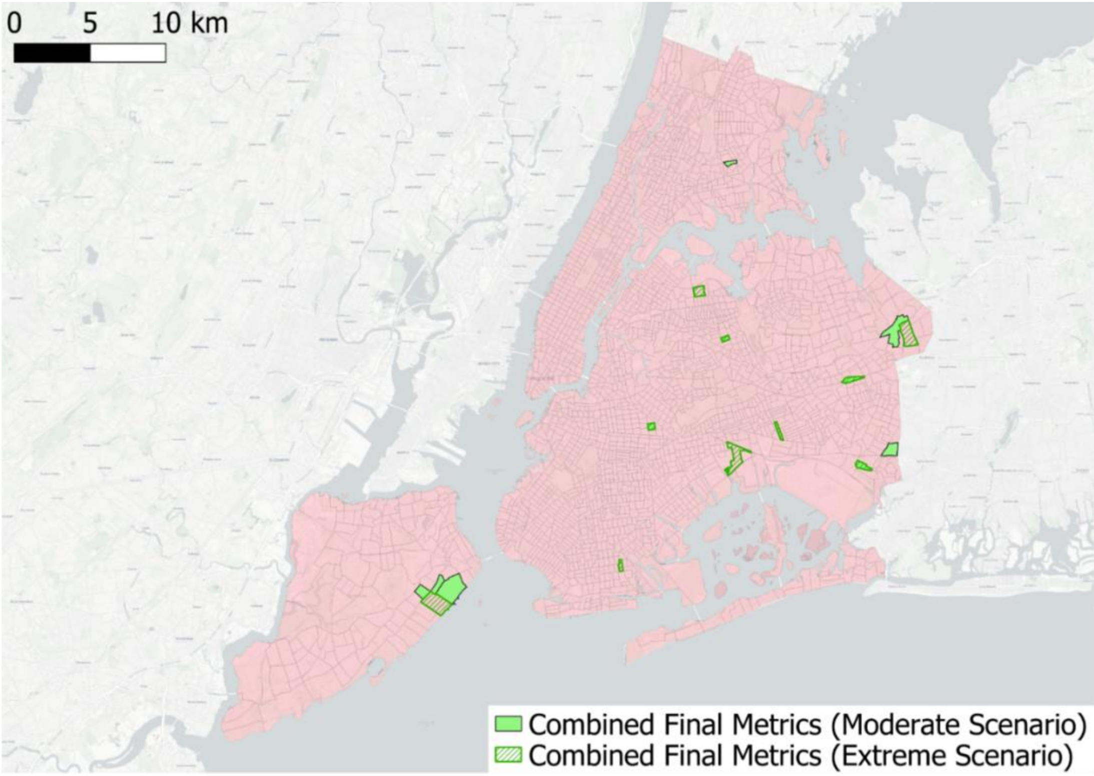


Figure 10 Comparison between the top 5 locations identified using the Stormwater flood map corresponding to a 10 year return period and those corresponding to a 10 years return period

6.2 Flood Maps

In our case study, we concentrated on pluvial flooding, leveraging the available Stormwater Flood Maps published by the NYC Department of Environmental Protection (DEP). It is important to note, however, that our method is adaptable to various types of flood maps and can accommodate different types of flooding scenarios.

6.3 Relative Importance Between Stakeholders and Equity Metrics

As previously outlined, in our approach, we assigned equal weight to both the resulting stakeholders' metrics and the final equity metrics. However, in implementing our methodology, it might be advisable to consider the possibility of weighting these two components differently. The weights could be adjusted and decided upon directly by the agency responsible for the sensor deployment, based on their specific requirements and priorities.

6.4 Comparison Between 311 Data and the Stormwater Flood Maps

The comparison of 311 call data with the Stormwater flood maps serves two primary purposes: it aids in refining the flood models and aids in identifying potential equity issues. Instances where the model and the 311 data differ provide valuable opportunities for using sensor data to understand and address these discrepancies. The utility of this approach lies in its potential to fine-tune flood prediction models and, equally importantly, shed light on underreported areas due to potential social, economic, or linguistic barriers.

Section 7 Research Outputs and Tech Transfer

As an outcome of this research project, three main research outputs were produced along with dissemination. The following table summarizes those results.

Type of research output	Notes	Title	Status
Conference paper	International conference ICASP14, held in Dublin between July 9th and July 13th 2923	Investigating the Use of Citizen-Science Data as a Proxy for Flood Risk Assessment in New York City	Submitted
Conference presentation	International conference ICASP14, held in Dublin between July 9th and July 13th 2923	N/A	Delivered
Journal paper	Scientific Journal for publication not selected yet	Prioritizing Flood-Monitoring Sensor Locations in Urban Areas: A Stakeholder-Based and Equity-Driven Approach	In progress

Table 8: Research outputs

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