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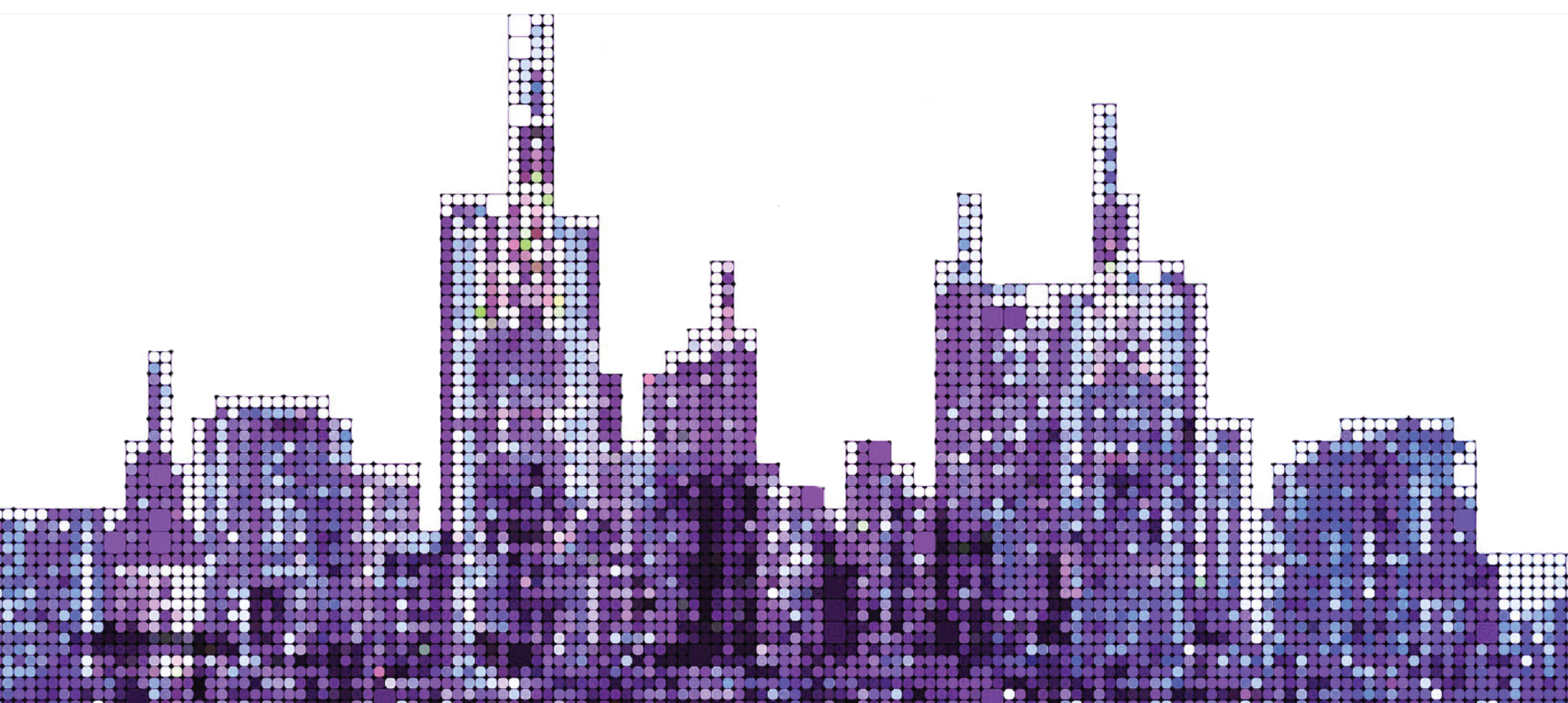
Deployment and Tech Transfer of a Street-level Flooding Platform: Sensing and Data Sharing for Urban Accessibility and Resilience

December 2022



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16. Abstract

Of the many impacts that are predicted to accompany climate change, flooding is expected to have an outsized influence on public health, infrastructure, and mobility in urban areas. However, very little data exist on the frequency and extent of urban surface flooding, and there is an unmet need for hyperlocal information on the presence and depth of street-level floodwater. Therefore, previous work funded in 2020-2021 was focused on the design and assessment of robust, low-cost sensors deployed in diverse urban environments to track street-level flood occurrence and depth. Given the success and lessons learned from our previous research program, the goal of the work funded in 2021-2022 was to expand sensor deployment and transfer data to our stakeholders through the following objectives: (1) expand the flood sensor network (2) develop a public-facing data dashboard to transfer flood data to a range of stakeholders, and (3) evaluate feasibility of new flood sensor modalities. During this time, we have designed, tested and built two new ultrasonic prototypes, designed and implemented plans for Design for Manufacturing, deployed 23 prototypes across all five boroughs in New York City, and collected a total of 744 days of data, logging multiple flood events and their profiles, including the highly impactful floods accompanying the storms Henri and Ida in August 2021. We have maintained collaborations with research partners at CUNY and city agency partners at DEP, DOT, NYC MOR and NYC MOCTO, furthering the goals of the FloodNet.NYC consortium founded during our prior funding cycle. We collectively applied for additional funding and secured a commitment for $7M in funding from the City of New York's Department of Environmental Protection to deploy an additional 500 sensors over the next 5 years, as well as $250K from the Alfred P. Sloan Foundation to prototype methods for public engagement around flood data.

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Deployment and Tech Transfer of a Street-level Flooding Platform: Sensing and Data Sharing for Urban Accessibility and Resilience

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Disclaimer

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We would like to acknowledge the Marron Institute, who funded a seed project to study the impact of flooding on urban surfaces, which sparked the question of flood sensing. We would also like to acknowledge the Pinkerton Foundation, who funded work in the Silverman lab, and the Center for Urban Science and Progress (CUSP) at NYU Tandon which provided the sensor lab in which the prototypes described here we developed. We would like to acknowledge the Integrated Design and Media program and the Civil and Urban Engineering department at NYU who both funded Master's students who worked on this project. We would also like to acknowledge all of our community partners for their consistent support, time and resources invested, and enthusiasm.

Executive Summary

Of the many impacts that are predicted to accompany climate change, flooding is expected to have an outsized influence on public health, infrastructure, and mobility in urban areas. However, very little data exist on the frequency and extent of urban surface flooding, and there is an unmet need for hyperlocal information on the presence and depth of street-level floodwater. Therefore, our previous work funded on 2020-2021 was focused on the design and assessment of robust, low-cost sensors deployed in diverse urban environments to track street-level flood occurrence and depth. Given the success and lessons learned from our previous research program, the goal of the work funded in 2021-2022 was to expand sensor deployment and transfer data to our stakeholders through the following objectives: (1) expand the flood sensor network (2) develop a public-facing data dashboard to transfer flood data to a range of stakeholders, and (3) evaluate feasibility of new flood sensor modalities.

During this time, we have designed, tested and built two new ultrasonic prototypes, designed and implemented plans for Design for Manufacturing, deployed 23 prototypes across all five boroughs in New York City, and collected a total of 744 days of data, logging multiple flood events and their profiles, including the highly impactful floods accompanying the storms Henri and Ida in August 2021. We have maintained collaborations with research partners at CUNY and city agency partners at DEP, DOT, NYC MOR and NYC MOCTO, furthering the goals of the FloodNet.NYC consortium founded during our prior funding cycle. We collectively applied for additional funding and secured a commitment for $7M in funding from the City of New York's Department of Environmental Protection to deploy an additional 500 sensors over the next 5 years, as well as $250K from the Alfred P. Sloan Foundation to prototype methods for public engagement around flood data.

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1. Introduction

Literature Review

Of the myriad impacts that are predicted to accompany climate change, flooding is expected to have an outsized influence on public health, infrastructure, and mobility in urban areas. In New York City, for example, sea level rise and an increase in the occurrence of high intensity rain storms (which convey large volumes of water to drains, leading to backups and overflows) have led to a dramatic increase in flood risk, particularly in low-lying and coastal neighborhoods.[1] The physical presence of standing water on streets and sidewalks can impede mobility and restrict access to transportation.[2] Additionally, urban flood water contains a diverse array of contaminants, including industrial and household chemicals, fuels, and sewage.[3, 4] Access to real-time information on flooding can improve resiliency and efficiency by allowing residents to identify navigable transportation routes and make informed decisions to avoid exposure to floodwater contaminants. However, very little data exist on the frequency and extent of urban surface flooding, and there is an unmet need for hyperlocal information on the presence and depth of street-level floodwater. This unmet need for data from urban floods motivated the development of the FloodSense project in early 2020, with the objective of**: developing a platform to provide real-time, street-level flood information - including the presence, frequency, and severity of local surface flood events - to a range of stakeholders, including policy makers, government agencies, citizens, emergency response teams, community advocacy groups, and researchers.**

[1] Talke, S. A., Orton, P. & Jay, D. A. Increasing storm tides in New York Harbor, 1844–2013. *Geophysical Research Letters* **41**, 3149–3155 (2014).
[2] Christie, N., Griffin, L., Chan, N., Twigg, J. and Titheridge, H. Private needs, public responses: vulnerable people's flood-disrupted mobility. *Disaster Prevention and Management* **25**, 244-260 (2016).
[3] Makepeace, D. K., Smith, D. W. & Stanley, S. J. Urban stormwater quality: Summary of contaminant data. *Critical Reviews in Environmental Science and Technology* **25**, 93–139 (1995).
[4] NYC Office of Emergency Management. *NYC's Risk Landscape: A Guide to Hazard Mitigation* (2014).

Background Research

The FloodSense project began in 2020-2021 with funding from the C2SMART Transportation Research Center, with overarching goals to (1) design, build, deploy, and assess robust, low-cost sensors in diverse urban environments to track street-level flood occurrence and depth, and ultimately, (2) to implement an interface to communicate the data to a range of stakeholders. Specific tasks were the following:

- Task 1- Sensor solution discovery and evaluation (including evaluation of sensor, power, connectivity, and data storage and delivery solutions)
- Task 2 - Prototype deployment, assessment, and initial data collection
- Task 3 - Development of an online interface for data communication

During this time, we designed, tested and built over 7 iterative prototypes, deployed three final prototypes in the field, and collected over 200 days of data, logging two flood events and their profiles. We forged collaborations with research partners at CUNY and city agency partners at DEP, DOT, NYC MOR and NYC MOCTO, founding the FloodNet.NYC consortium and collectively applied to additional funding from five state- and federally-funded sources. We secured an additional 90K in funding from the Empire State Development Fund to continue work started under this grant.

Based on our experience conducting the work described above, and conversations with various stakeholders, we identified three objectives required for larger scale deployment of a flood sensor network that provides actionable data for improved mobility and resiliency across stakeholder categories, which we have been working on in the context of the 2021-2022 C2SMART funding:

Objective 1 - Expand the ultrasonic flood sensor network

Given our successful pilot sensor deployment, we plan to expand the number of ultrasonic flood sensors in the network. The deployment locations will be decided in consultation with NYC agencies and community partners, in an effort to fulfill a range of data needs.

Objective 2 - Develop public-facing data dashboard to transfer flood data to a range of stakeholders

The outcome of this objective will be an easily accessible, public-facing online portal that provides flood sensor data in a manner that meets the needs of various stakeholders, and incorporates additional data streams such as community reported flood events, rainfall levels, 311 flooding complaints, and social media feeds.

Objective 3 - Evaluate feasibility of new flood sensor modalities

The current sensor configuration involves mounting the unit on a U-post, which limits flood detection to water levels that rise over the curb cut and onto the sidewalk (i.e., floods must be greater than approximately 7 inches in depth). This is because the ultrasonic sensor can only measure water level directly underneath the sensor, and U-posts are always installed on sidewalks. While this remains important information, additional sensor modalities are required to measure floods that are confined to roadways. We plan to evaluate the feasibility of additional sensor types that can either utilize different urban infrastructure for sensor deployment (e.g., sewer grates in the roadway), or alternate sensor technologies (e.g., cameras employing edge computer-vision) to measure flood extent more remotely.

2. Methods

Objective 1 - Sensor network expansion

WIth the success of the pilot deployments in the project's previous phase, a number of sensor deployment requests were received from city agencies, and community groups. To reduce the inperson site scouting required to evaluate a potential deployment location, our student workers created a detailed spreadsheet containing: flood model data of the area, possible mount points, elevation data, distance to nearest gateway, and other useful information. The prioritization of these deployment locations is still a work in progress but will be driven by an equitable approach that determines the risk flooding presents at each location.

The sensor network expanded by 23 sensors to cover all five boroughs in flood prone neighborhoods, including: Red Hook - Brooklyn; Foxhurst - Bronx; Harlem - Manhattan; South Jamaica - Queens; Far Rockaway - Queens; and various locations on Staten Island. The expansion to Far Rockaway on Beach 84 with its tidally influenced flood issue was a particularly useful set of additional data as flooding there occurs regularly and at high depths.

To aid in large scale future deployments, a design for manufacture (DFM) process was carried out to create a new sensor that will be assembled by a contract manufacturer at a scale of 500. These devices are ruggedized and incorporate a number of new features to enable long term operation and ease of upgrade and maintenance in the field including: remote firmware update, reed switch power cycling for on-the-ground bringup, high gain antenna, larger battery capacity, advanced solar charge circuit, and ultra low power operation.

Objective 2 - Development of public facing dashboard

To meet our objective of developing an easily accessible, public-facing online flood data portal, FloodNet contracted with FieldKit, a software development company focused on environmental sensing. After a year of iterative platform development, which incorporated feedback from two rounds of user sessions, we released the 1.0 version of this site (dataviz.floodnet.nyc) to the public. The dashboard includes a map of all operational FloodNet sensors, a list of sensors sorted by flood depth, dataview pages with interactive sensor timelines, and info pages that provide sensor metadata. Users can also view multiple sensor data streams, as well as relevant precipitation or tide data streams, on the dataview page for a given sensor.

Objective 3 - Evaluate feasibility of new flood sensor modalities

A study was conducted into the feasibility of using Light Detection and Ranging (LiDaR) sensing for flood depth detection which produced results that suggest that this sensor modality isnt adept at dealing with water surfaces due to the diffraction of the sensor's light beams. In light of this, a capstone group was formed to investigate the use of cameras for computer vision (CV) based flood detection. A partnership was formed with team members from the NYC DOT traffic management center who provided a list of 46 known flood prone roadways with existing traffic cameras mounted. These cameras are publicly accessible and provide an image every 1s of the roadway. A script was written that scraped these 46 feeds and stored an image per camera every ~6s. This process began in January of 2022 and has resulted in over 10TB of images collected to date. The student capstone team took a subset of these images, labeled them and using an active learning approach, expanded this dataset, resulting in a dataset of 3500 flood images. The resultant trained CV model used a ResNet based classifier and was showing accuracies of 92% with unseen test data taken from the 46 traffic cameras. This is a promising first result with a high level of interest from the DOT who sponsor the capstone project and the MTA. A second capstone application has been submitted to continue this work in 2023.

3. Description of Data Produced and/or Used/Software Generated

3.1 Data produced: flood level data across 744 days, for 33 sensors

Data can be viewed interactively at dataviz.floodnet.nyc as well as the zenodo repository (https://zenodo.org/record/7245376#.Y5EfeOzMJqs)

3.2 Data produced: flood prone traffic camera image data

Daily compressed files of traffic camera images taken every ~6s from 46 flood prone locations totalling 10TB in size. Dataset is currently stored on CUSP servers but will be made publicly available with all access code open sourced in Spring 2023.

3.3 Software generated: dashboard

See Objective 2 Methods section above.

3.4 Feedback from community workshops

During the data dashboard development process, FloodNet and FieldKit worked together to schedule two rounds of user workshops. FloodNet invited community partners, researchers, and government agencies to share feedback, which we then converted into action items for data dashboard improvement. These attendees represented all 5 boroughs of New York, and included members of the Gowanus Canal Conservancy, Bronx River Alliance, New Hamilton Beach Civic Association, and other community groups. We also gathered feedback from NYC DEP, the Mayor's Office of Climate Resiliency, NYC DOT, and NYC Emergency Management.

User feedback was crucial in helping us tailor the dashboard to various use cases. Community members emphasized that the data should be easy to understand and share in real time. Researchers highlighted their need for a flexible data download interface. NYC Emergency Management requested a list of sensors that sorts by where flooding is the worst, to help them determine where to send resources.

Much of the user feedback we collected has already been incorporated into the dashboard, but we have kept records of all user suggestions. We plan to incorporate as much of this input as possible into future dashboard iterations.

4. Discussion

Outputs

Publications:

Andrea I. Silverman, Tega Brain, Brett Branco, Praneeth sai venkat Challagonda, Petra Choi, Rebecca Fischman, Kathryn Graziano, Elizabeth Hénaff, Charlie Mydlarz, Paul Rothman, Ricardo Toledo-Crow, "Making waves: Uses of real-time, hyperlocal flood sensor data for emergency management, resiliency planning, and flood impact mitigation" Water Research, Volume 220, 2022, https://doi.org/10.1016/j.watres.2022.118648.

Dashboard:
https://dataviz.floodnet.nyc/

Code:
https://github.com/floodnet-nyc/flood-sensor

Outcomes

Community Engagement:

- In total, 9 researchers, 14 community members, and 16 city agency representatives attended our two rounds of community workshops to develop the data dashboard.

Informal partnership conversations:

- Franco Montalto (Drexel)
- Marouane Temimi (Stevens Institute)
- Westchester County
- River Keeper
- Battery Park City Authority
- Emails with community members in New Orleans and Charleston, SC

Collaborations within NYU

- Collaboration with Luis Ceferino (NYU CUE/CUSP) - C2SMART funded proposal "Developing a Framework to Optimize FloodNet Sensor Deployments Around NYC for Equitable and Impact-based Hyper-local Street-level Flood Monitoring and Data Collection"
- Collaboration with Chen Feng (NYU CUE/MAE) to lead CUSP capstone project on computer vision for camera-based flood detection

Formal partnerships:

- CUNY ASRC: collaborative research on sensor development
- Science and Resiliency Institute at Jamaica Bay: collaborative research on sensor development
- Data visualization team at Pratt Institute for report design and map development
- Collaboration with Maddalena Romano (NYC DOT asset management and special projects) to help lead CUSP capstone project on computer vision for camera-based flood detection
- GuyCarpenter, Wharton and CNYCN: research collaboration and sensor deployment
- NYC Mayor's Office of Climate Resiliency (MOCR): research support and collaboration
- NYC Mayor's Office CTO (MOCTO): research support and collaboration; help with design and deployment of flood sensor signage and the www.floodnet.nyc website
- Voltaic: in-kind contribution of solar hardware
- The Things Network: in-kind contribution of hardware for sensor connectivity
- New York State Empire State Development: funding for data backend and frontend
- New York City Department of Transportation: permission to mount sensors on any of the signpost U-poles in the City

Grant Funding received

- City of New York: $7M for 2022-2027
- Alfred P. Sloan Foundation: $250K for 2022-2023
- C2SMART: $90K for 2022-2023

Impacts

We now have a live, public-facing dashboard the displays real-time flood data at the sensor locations. Members of impacted communities can use this platform to decide to move their parked car, choose an alternative route, or an alternative form of transportation.

5. Outreach

Invited Talks

1. Silverman, A. I., Mydlarz, C., Hénaff, E., Brain, T., Challagonda, P. Research and Practice: Implementing a Flood Sensor Network for a Resilient NYC. Invited panel discussion at NYU C2SMART Transportation Research Center. 24 May 2022. https://www.youtube.com/watch?v=6MYIWE450P0
2. Silverman, A. I. FloodNet: low-cost, real-time sensors for hyperlocal, street-level flood monitoring in New York City. Invited seminar (departmental colloquium) at George Washington University, Department of Civil and Environmental Engineering. 4 March 2022.
3. Silverman, A. I. It Will Rain Again: Data Needs and Opportunities in a Post-Ida New York City. Panelist; NYC Open Data Week. 8 March 2022. Link. https://www.youtube.com/watch?v=tcFW9BYtiqs
4. Silverman, A. I. FloodNet: low-cost sensors for real-time measurement of hyperlocal, street-level floods. Presentation to NYC Comptroller Brad Lander. 6 October 2021.
5. Silverman, A. I., Mydlarz, C. How Sensors are Making Better Urban Environments. Seminar for IEEE Spectrum. 22 October 2021. Link.
6. Silverman, A. I., FloodNet: low-cost sensors for real-time measurement of hyperlocal, street-level floods. Presentation for Community Based Organizations in Red Hook, Brooklyn (Red Hook Initiative, Resilient Red Hook, and Pioneerworks Community Sensor Lab). 25 October 2021.
7. Silverman, A. I. FloodNet: low-cost sensors for real-time measurement of hyperlocal, street-level floods. Invited seminar for NYC Department of Environmental Protection. 17 September 2021.
8. Silverman, A. I. FloodNet: low-cost sensors for real-time measurement of hyperlocal, street-level floods. Invited seminar for the NYC Department of Transportation GIS working group. 24 September 2021.

9. Silverman, A. I. FloodNet: low-cost sensors for real-time measurement of hyperlocal, street-level floods. Invited seminar at NY/NJ Harbor Estuary Program Water Quality Work Group. 11 May 2021.
10. Silverman, A. I. Living with Water: Using Qualitative and Quantitative Data on Flooding to Engage with Communities and Agencies. NYC Interagency Flood Working Group. April 2021.
11. Silverman, A. I., Hénaff, E. FloodNet: low-cost sensors for real-time measurement of hyperlocal, street-level floods. Seminar for the Gowanus Canal Conservancy. 19 March 2021.
12. Silverman, A. I., Hénaff, E., Brain, T. FloodNet: Longitudinal Remote Urban Flood Monitoring. Invited seminar at NYU Marron Institute. 26 March 2021.
13. Silverman, A. I. Living with Water: Using Qualitative and Quantitative Data on Flooding to Engage with Communities and Agencies. Panelist; NYC Open Data Week. 12 March 2021.
14. Silverman, A. I., Mydlarz, C., Hénaff, E., Brain, T. FloodSense: Longitudinal Remote Urban Flood Monitoring. Invited seminar (departmental colloquium) at NYU Center for Urban Science and Progress. 4 December 2020.

Students Mentored

- High School (Through NYU ARISE program)
    - Nikki Chang (2021)
    - Nazifa Rahaman (2021)
    - Celeste Badillo (2022)
    - Krittika Chowdhury (2022)
- UNDERGRAD
    - Nidhi Desu, Computer Science, NYU (2022)
    - Sadhvi Surendhran, Applied Mathematics, NYU (2022)
- MS
    - Jatin Palchuri, Computer Science, NYU (2022)
    - Jeremy Rucker, Urban Science, NYU (2022)
    - Heng Quan, Urban Science, NYU (2022)
    - Gwen Wu, Urban Science, NYU (2022)
    - Jianlin Huang, Urban Science, NYU (2022)
    - Swarangi Kulkarni, Urban Science, NYU (2022)

6. Press

9/2/2022	Brooklyn Daily Eagle	Staff	New online tool helps agencies know where flood waters are rising
9/1/2022	CBS New York	Natalie Duddridge	1 year after Ida, New York City to build 2,000 new rain gardens, install flood sensors citywide
4/4/2022	Spectrum NY1	Ari Ephraim	Flood sensor project will offer city real-time data as storms intensify
9/2/2022	Archinect News	Josh Niland	One year after Hurricane Ida, NYC updates its water infrastructure in the hopes of preventing another tragedy
9/2/2022	Phys.org	NYU Tandon	New data dashboard reporting street-level flooding in NYC gives real-time information on rising waters
2/24/2021	Government Technology	Elias Gbadamosi	Data Project May Drive Policy for Hyperlocal Flooding in NYC
11/3/2021	IEEE Spectrum	Dexter Johnson	Sensor Networks Help Fight Floods and Noise Pollution
9/1/2022	City of New York	Press Release	Mayor Adams, DEP Honor First Anniversary of Hurricane Ida, Announce Suite of Stormwater Infrastructure Initiatives to Make NYC More Resilient to Intense Rainfall
9/1/2022	NYU Tandon	Press Release	New data dashboard reporting street-level flooding in NYC gives government, responders, the public, and researchers real-time information on rising waters
9/7/2022	GCN	Susan Miller	Dashboard, sensors report real-time data on city flooding
9/9/2022	Spectrum NY1	Ari Ephraim	Dashboard showing real-time street flooding data is now live
Fall 2021	Brooklyn College Magazine	Jamilah Simmons	Fighting the Tide
9/16/2022	News 12 The Bronx	News 12 Staff	New technology could improve NYC response, preparedness for future floods
9/28/2022	engadget	A. Tarantola	NYU is building an ultrasonic flood sensor network in New York's Gowanus neighborhood
10/21/2022	NYTimes	Ronda Kaysen	A Decade After Hurricane Sandy, New Yorkers Still Fear the Rain

7. Conclusion

The goal for this funding was to expand sensor deployment and transfer data to our stakeholders through the following objectives: (1) expand the flood sensor network (2) develop a public-facing data dashboard to transfer flood data to a range of stakeholders, and (3) evaluate feasibility of new flood sensor modalities.

We successfully expanded the sensor network to 33 sensors, with new and improved design and functionality, and secured additional funding from the NYC DEP to deploy up to 500 sensors over the next five years. A public-facing data portal is now available at dataviz.floodnet.nyc, which was developed according to stakeholder consultations with researchers, city agencies and community members, and have secured further funding from the Sloan foundation to develop design prototypes to further develop the functionality of the data portal and integrate our quantitative data with the qualitative data collected through our partner project FloodWatch. We advised a capstone project through CUSP to assess the feasibility of image-based flood detection and concluded that the sensor-based modality we have implemented is the best for our current goals.

In conclusion, we have met our three goals for this funding, and secured further funding for pursuing two of the three aims.

In addition, one of the major takeaways of this research was that determining the placement of sensors for the expanded senscity-wide network is key with respect to equity and environmental justice, as well as the success of this project from a data collection perspective. As such, we have successfully secured a third year of funding from C2SMART, led by CUSP faculty Luis Ceferino, to develop risk models to inform sensor placement.

The team expressed its gratitude to C2SMART for its continued support for this project, and acknowledge that the funding that it has provided to seed this work has enabled it to grow to the multidisciplinary, multi-million project it has become.

References

1. Talke, S. A., Orton, P. & Jay, D. A. Increasing storm tides in New York Harbor, 1844–2013. Geophysical Research Letters 41, 3149–3155 (2014).
2. Christie, N., Griffin, L., Chan, N., Twigg, J. and Titheridge, H. Private needs, public responses: vulnerable people's flood-disrupted mobility. Disaster Prevention and Management 25, 244-260 (2016).
3. Makepeace, D. K., Smith, D. W. & Stanley, S. J. Urban stormwater quality: Summary of contaminant data. Critical Reviews in Environmental Science and Technology 25, 93–139 (1995).
4. NYC Office of Emergency Management. NYC's Risk Landscape: A Guide to Hazard Mitigation (2014).

Appendix

Build Instructions for Sensor

https://github.com/floodnet-nyc/flood-sensor