Nuisance Flooding in Coastal Communities: Real-time Modeling and Decision Support to Improve Transportation Infrastructure Resilience

University of Virginia
UVA ENGINEERING
LINK LAB

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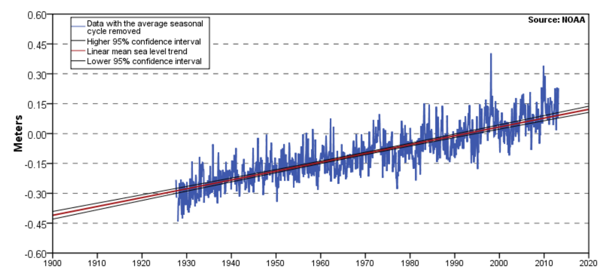
THE CITY OF NORFOLK
NSF

Problem Statement

- **Increased frequency and severity of nuisance (or recurrent) flooding due to climate change and sea level rise**
- **Flooding of roadways has cascading impacts to other infrastructure systems**
- **Lack of decision support for interdependent systems to guide investments**


Sea level at Sewell's Point


Flooded underpass in Norfolk

Approach: Cyber-Physical Systems

Adaptive and citizen science crowdsourced sensor networks

Sense

Predict

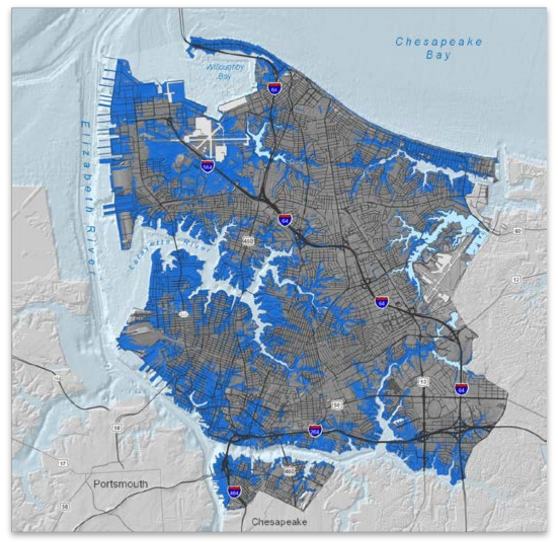
Physically-based and data-driven prediction models

Smart real-time control of interdependent infrastructure systems

Control

Testbed: the City of Norfolk, Virginia

- **Low-lying topography surrounded by major water bodies**
- **Major center for industry, military, and shipping**
- **Flooding impacts average annual daily traffic volumes up to 34,000 vehicles**


FEMA flood hazard zone

SENSE

Agency Data

NOAA
- Tidal Level
- Rainfall

HRSD
- Rainfall
- Groundwater Level

the heartbeat of Hampton Roads TPO Transportation Planning Organization
- Road Geometry

VTRC Virginia Transportation Research Council
- Traffic counts

THE CITY OF NORFOLK
- Stormwater Pipelines
- Flood Reports
- Topographical Data

- **Enhancing the communication network for the city using The Things Network (TTN) and LoRaWan**


LoRa Module

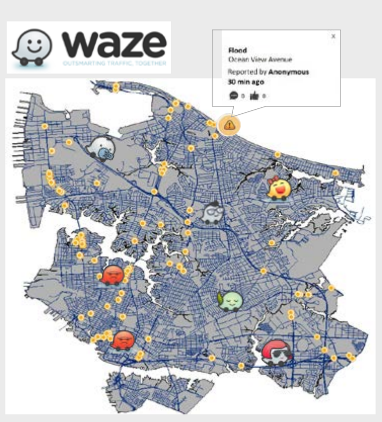
THE THINGS NETWORK
The Things Network

Crowdsourced Data

WEATHER UNDERGROUND


Rainfall data from citizen owned personal weather stations

waze


Flood reports data from Google Waze users

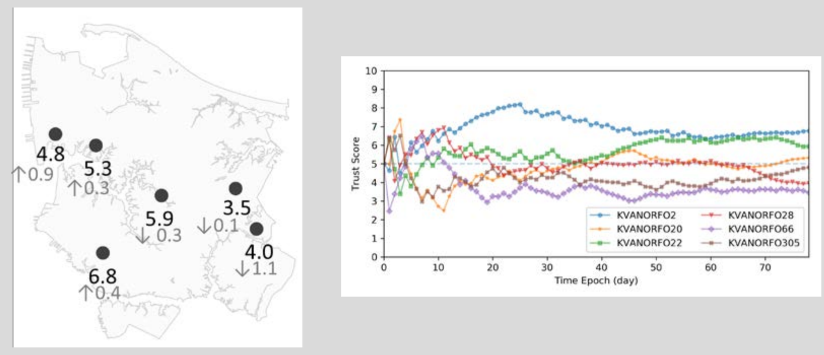
STREETLIGHTDATA


Traffic data from location-based services (LBS) enabled devices collected by StreetlightData

Data Trustworthiness

- **Reputation system for ensuring data trustworthiness of crowdsourced weather stations** [1]

Assigning real-time trust score on crowdsourced personal weather station to ensure trustworthy and useful data

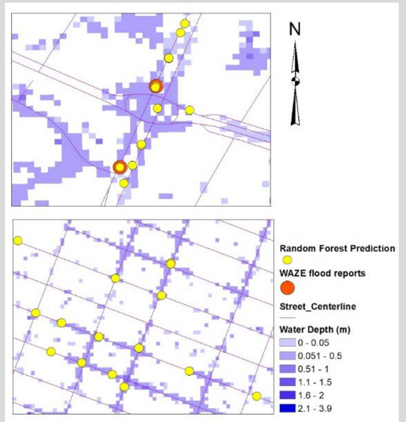

Personal weather station trust score assessment

PREDICT

Street-Scale Flooding Prediction

- **Predicting Urban Coastal Street Flooding at Hourly Time Scale Using Random Forest And Google WAZE** [2]

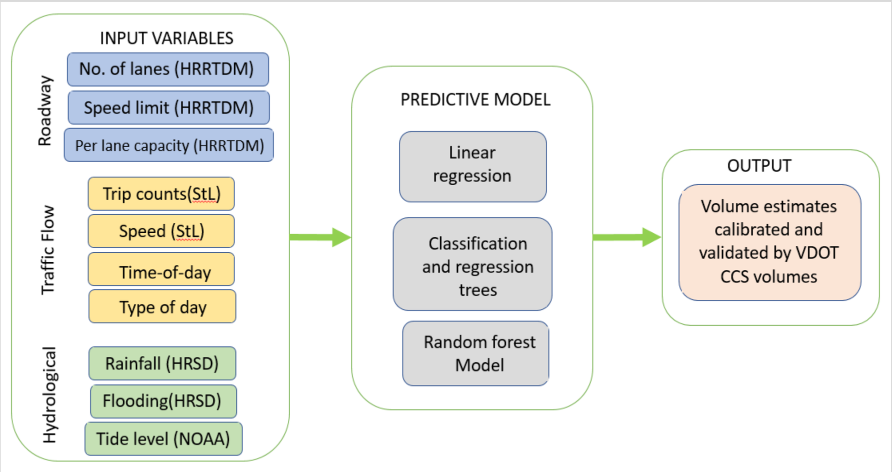
Using environmental and topographic data coupled with crowdsourced Google Waze flood reports to predict locations of flooded street


Street-scale flooding prediction

Travel Impacts of Flooding

- **Use of crowdsourced data to study economic impacts of nuisance flooding** [3]

Analyzing travel pattern and economic impacts on flooded and non-flooded days for major roadways

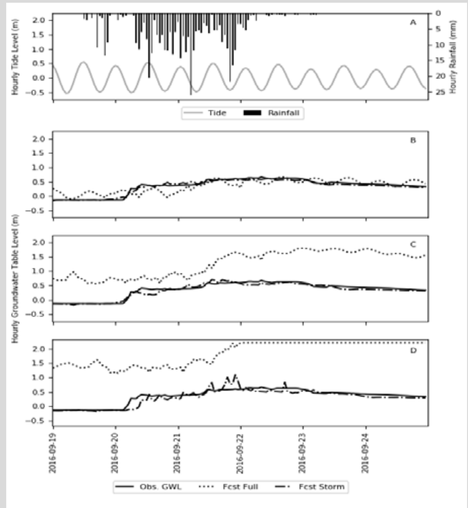


Roadway traffic condition prediction

Real-time Groundwater Predictions

- **Forecasting Groundwater Table in Flood Prone Coastal Cities Using Long Short-term Memory and Recurrent Neural Networks** [4]

Establishing groundwater table forecasting models to increase accuracy of real time flood prediction in coastal areas

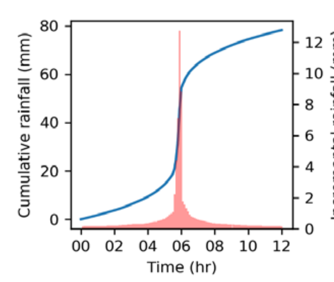

Shallow groundwater level prediction

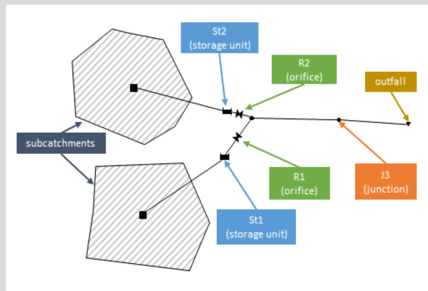
CONTROL

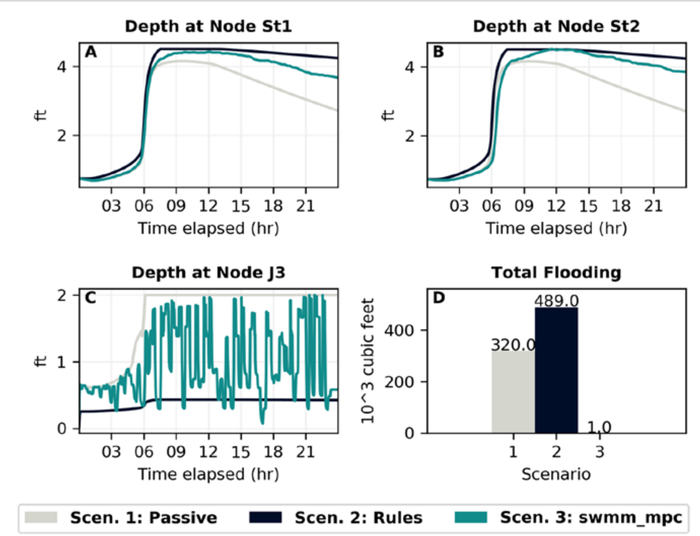
Stormwater Model Predictive Control (MPC)

- **Assessing Current and Future Utility of Predictive Active Stormwater Controls for Reducing Flooding in Coastal Cities** [5]

Developing an open-source software written in Python to produce control strategies that minimized flooding and maintained water levels at a target level


Demonstration storm event


Demonstration model schema

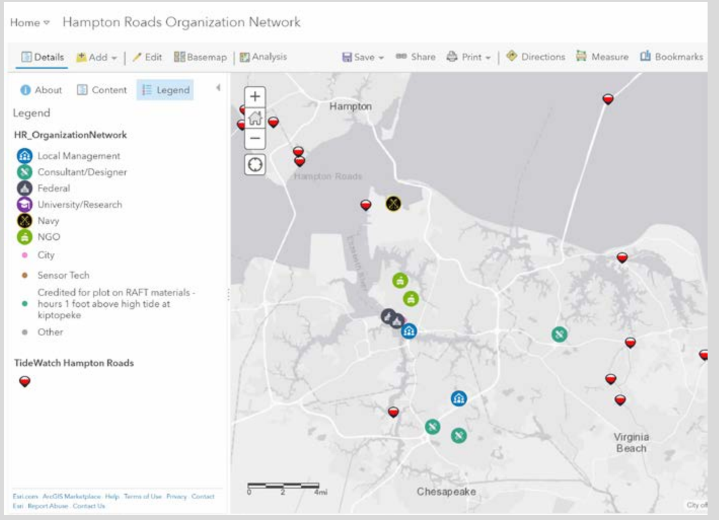


Demonstration model results

Collaborative Decision-Making

- **Collaboration among apparently incommensurable expertises: Case study of combining expertises and perspectives to manage climate change in coastal Virginia** [6]

Developing a web application to visually represent relationships between stakeholders including type of interaction and strength


Online GIS network map of the stakeholders to promote collaboration

For more details, please see …

[1] Chen, A.B., Behl, M. and Goodall, J.L., 2018, November. Trust me, my neighbors say it's raining outside: ensuring data trustworthiness for crowdsourced weather stations. In *Proceedings of the 5th Conference on Systems for Built Environments* (pp. 25-28). ACM. **(Best Poster Award Winner)**

[2] Zahura, F., Sadler, J.M., Goodall, J.L., 2018, December. Predicting Urban Coastal Street Flooding at Hourly Time Scale Using Random Forest and Google WAZE. in *AGU Fall Meeting Abstracts.*

[3] Praharaj, S., Chen, T. D., and Behl, M., 2019, Data predictive approach to estimate nuisance flooding impacts on roadway networks: a Norfolk, Virginia case study. *World Conference for Transportation Research*.

[4] Bowes, B.D., Sadler, J.M., Morsy, M.M., Behl, M., Goodall, J.L., 2019. Forecasting Groundwater Table in a Flood Prone Coastal City with Long Short-term Memory and Recurrent Neural Networks. Water 11, 1098. https://doi.org/10.3390/w11051098

[5] Sadler, J.M., Goodall, J.L., Behl, M., Bowes, B.D., Morsy, M.M., 2020. Exploring real-time control of stormwater systems for mitigating flood risk due to sea level rise. Journal of Hydrology. 583, 124571. https://doi.org/10.1016/j.jhydrol.2020.124571

[6] Gorman, M.E., Bowes, B.D., Fauss, K. and Z. Zhang, Collaboration Among Apparently Incommensurable Expertises: A Case Study of Combining Expertises and Perspectives to Manage Climate Change in Coastal Virginia. To appear in Caudill, Conley & Gorman (Eds) The *Third Wave in Science and Technology Studies - Future Research Directions on Expertise and Experience*. Springer, Cham.

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