# Small Stream Hydrologic Monitoring Using Outdoor IoT Technologies: A Pilot Project at Clemson University

Christopher J. Post, Vishwas Powar, Kaushik Tilve,
Elena A. Mikhailova

Dr. Michael Cope, Kelly Kruzner, Chuck Cook, Paul Minerva

CLEMSON UNIVERSITY

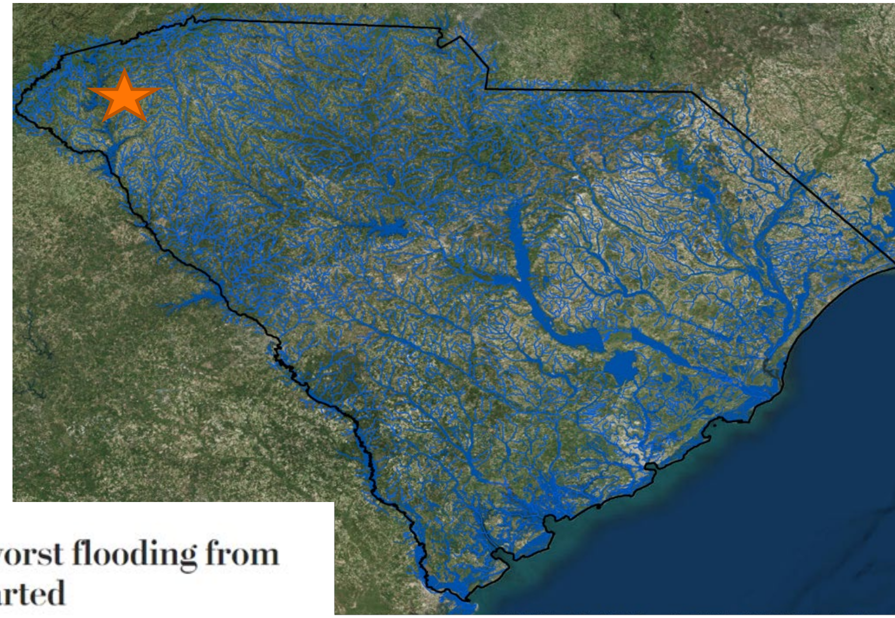
Intelligent River®

# Outline

- Motivation and Focus
  - Accurate, low-cost, resilient, near real-time water quantity and quality monitoring systems
- Sensor Network Components
  - Anatomy of sensor network
- Remote Sensing
  - Non-contact water level sensing
- Clemson University Hunnicutt Creek Test Bed
  - Comparison of three level sensing technologies
  - Level data throughout a rain event

# Intelligent River®

# Motivation



Capital Weather Gang

## South Carolina is enduring some of its worst flooding from Florence, more than a week after it departed

Kayaks are paddled up Long Avenue past flooded sections of the Sherwood Drive community of Conway, S.C., on Sept. 23. (Jason Lee/Sun News/AP)

By **Jason Samenow**
September 24, 2018

Under calm, blue skies, eight days after Florence's final drops rained down, parts of northeast South Carolina and southeast North Carolina are experiencing devastating flooding from the long-departed hurricane. Entire communities are underwater as some rivers continue to rise.

Carolinas Precipitation Patterns & Probabilities An Atlas of Hydroclimate Extremes

## 1998-2002 Drought

- Introduction
- Agriculture
- Forestry
- Water Supply & Quality
- Notes

Beginning in 1998, many areas in the Carolinas experienced several years of below-normal precipitation: precipitation deficits over the next four years were among the largest ever recorded. The meterological drought quickly became an agricultural one: farmers and foresters were particularly affected. The prolonged duration of the drought had severe hydrological effects, with the cumulative shortfall of precipitation resulting in record lows for streamflows, groundwater levels, and reservoir storage.

[L]ow water levels on Lake Wylie forced organizers to cancel a fishing tournament that had been planned for later this month. That will mean the loss of an estimated $200,000 in motel reservations and banquet events, a York County tourism official said."

— *Bruce Smith, AP, "Heavy Rains Help, But Drought Persists," September 4, 2002*

# Anatomy of a Sensor Network

Water Questions

Data Driven Answers

| SENSORS | EMBEDDED PLATFORMS | DEPLOYMENT SYSTEMS | NETWORKS | DATA STORAGE AND ANALYTICS |
| --- | --- | --- | --- | --- |
| Non-contact sensing when possible. High accuracy, low cost, low power. | Low power, networked embedded computing platforms | Enclosure/ Battery/Power systems are key to long-term, low cost deployments | LPWAN LoRaWAN/ Sigfox CAT-NB1/ CAT-M1 | Location-aware sensor data storage linked to detailed metadata about sensor and deployment systems |

**PEOPLE**

# Level Sensors

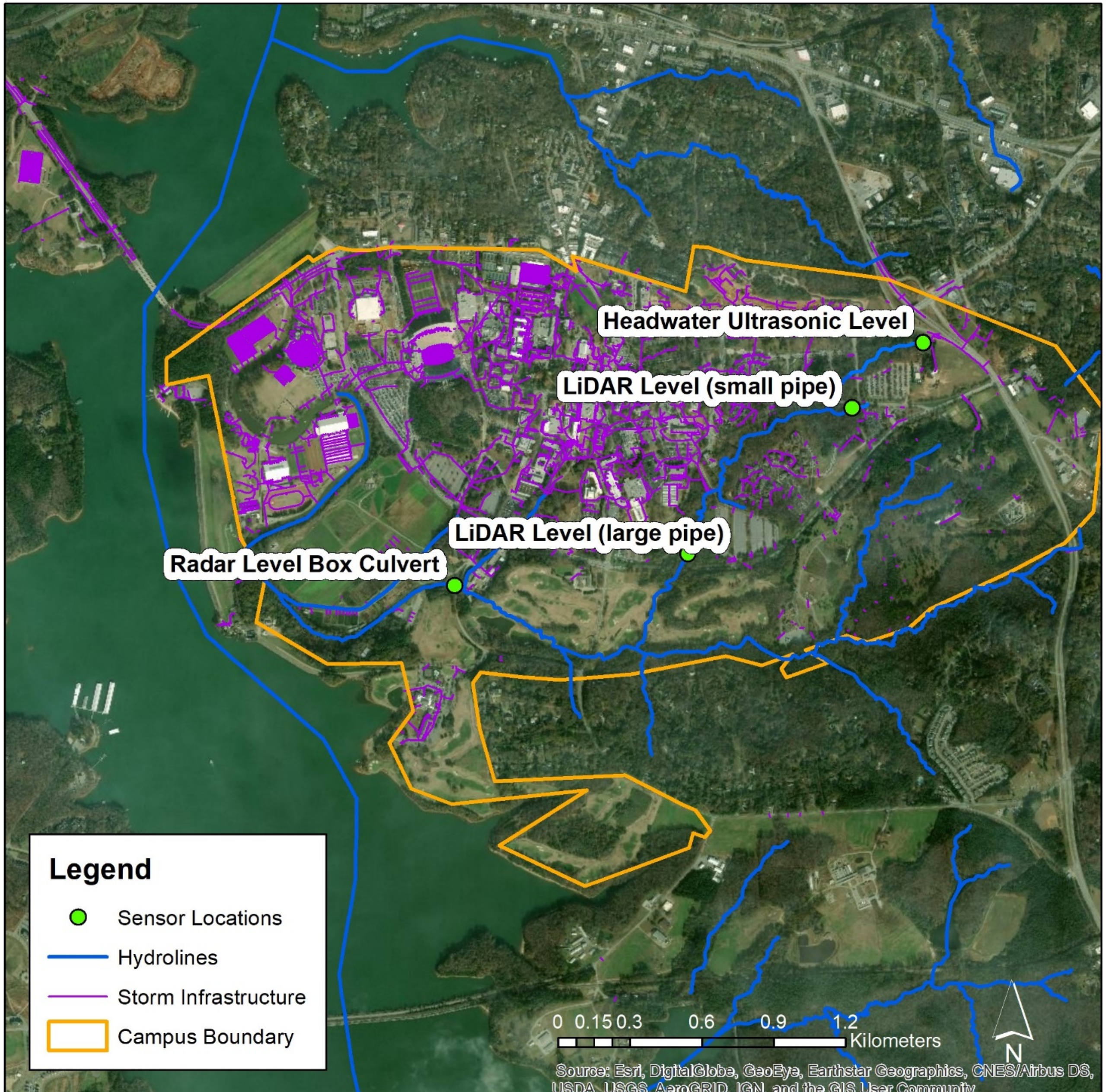
Remote sensing of water level has distinct advantages over direct, contact sensing. Sensors placed above water bodies should be able to last for years without human intervention. New sensor advances in distance sensing are lowering the cost of accurate water level measurement.

Sonar
Level Sensor

LiDAR
Level Sensor

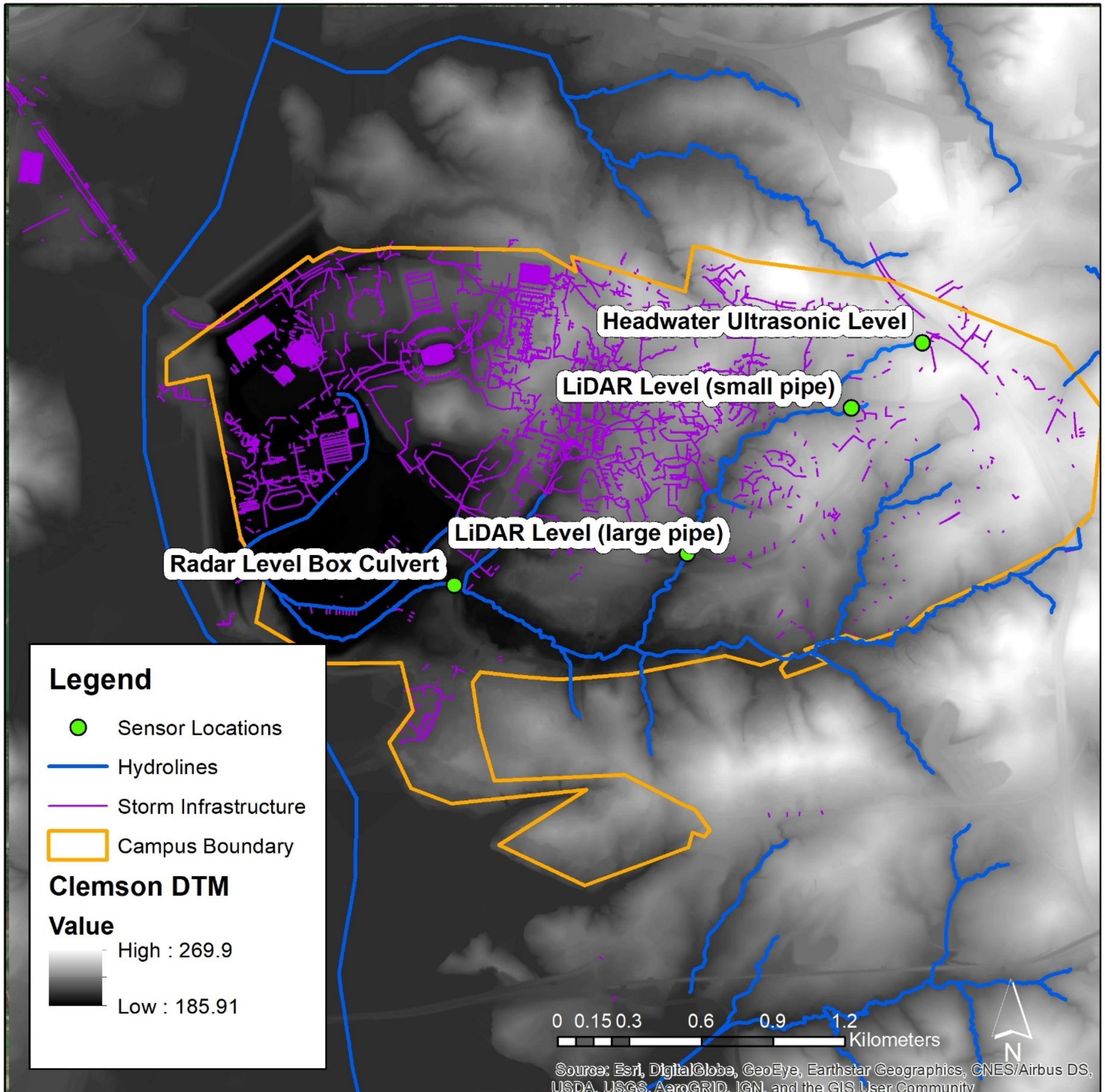
Radar level
Sensor

# Study Area



Headwater Ultrasonic Level
LiDAR Level (small pipe)
LiDAR Level (large pipe)
Radar Level Box Culvert
Legend
Sensor Locations
Hydrolines
Storm Infrastructure
Campus Boundary
0 0.15 0.3 0.6 0.9 1.2
Kilometers
N
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

# Study Area



Headwater Ultrasonic Level
LiDAR Level (small pipe)
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Sensor Locations
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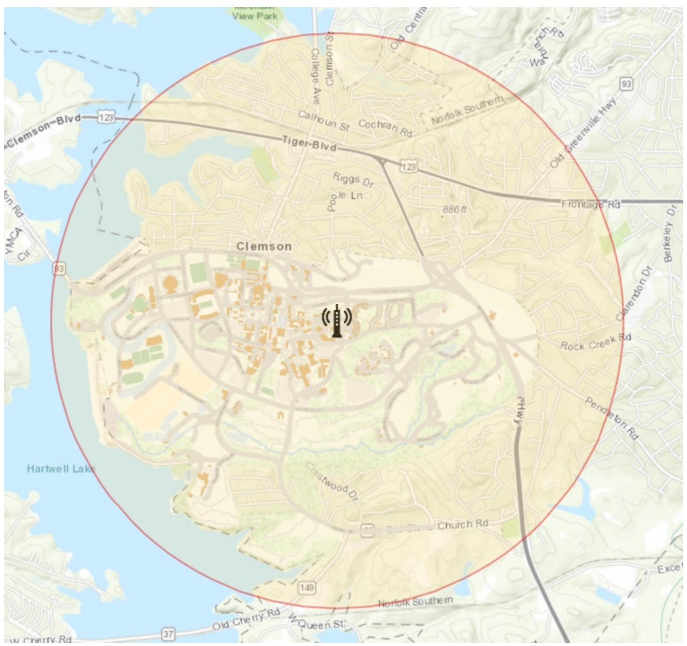
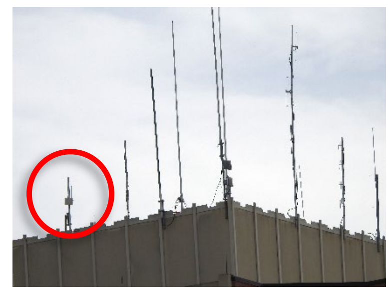
Storm Infrastructure
Campus Boundary
Clemson DTM
Value
High : 269.9
Low : 185.91
0 0.15 0.3 0.6 0.9 1.2
Kilometers
N
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

# LoRaWAN Network

A commercial LoRaWAN gateway has been deployed to serve the campus sensing community. Redundant gateways are planned.

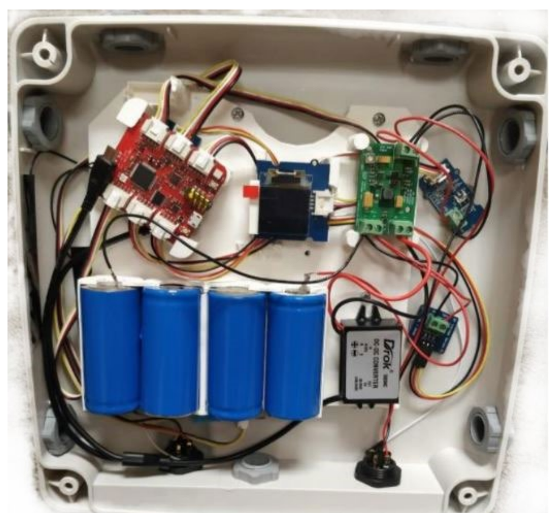


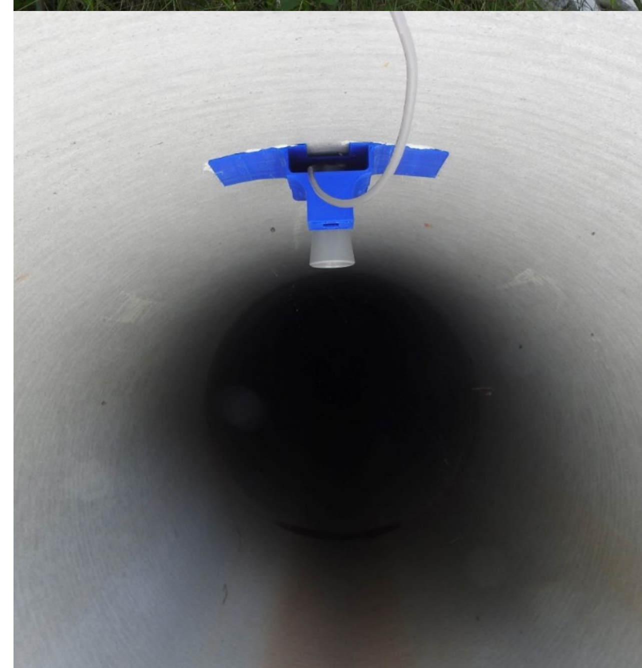

Approximate LoRaWAN network coverage live at Clemson.



LoRaWAN Gateway

# Headwaters Ultrasonic Ranging Sensor



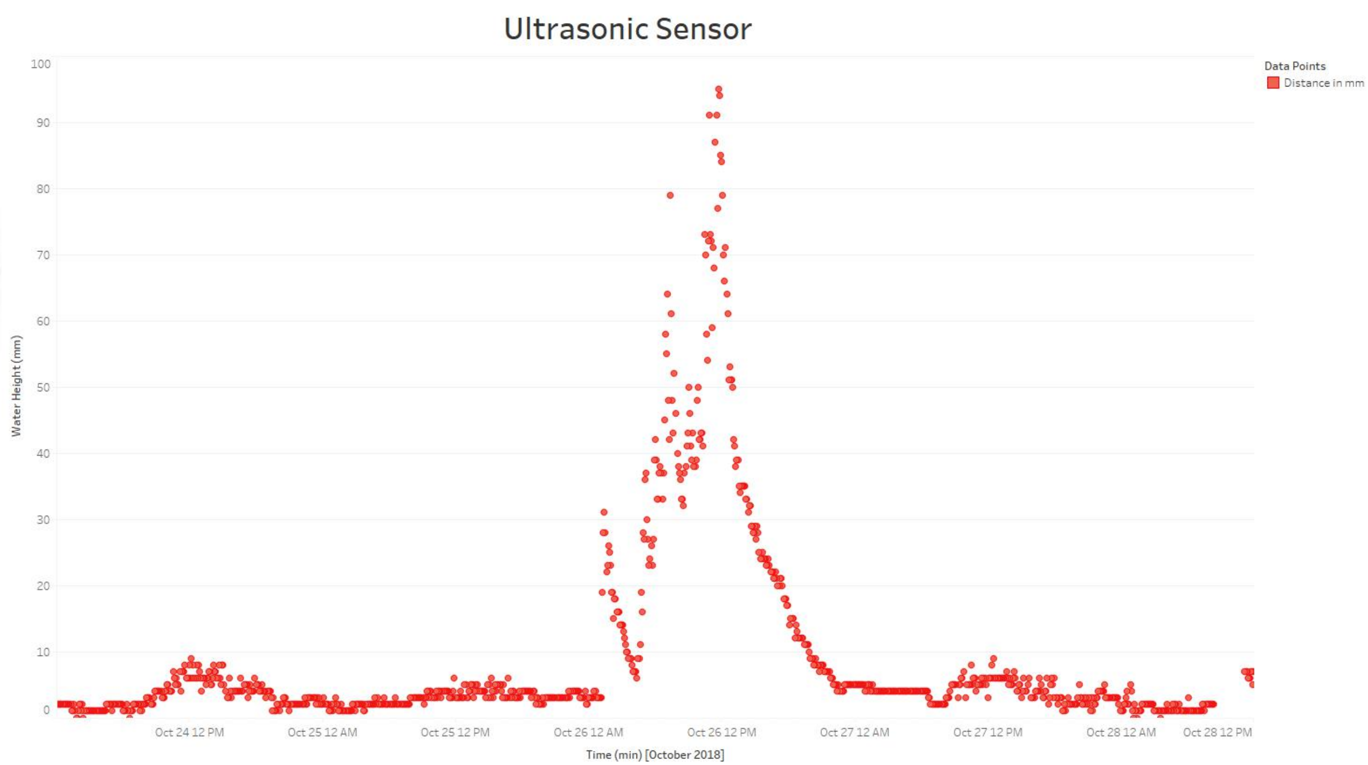


MaxBotix Ultrasonic Level Sensor

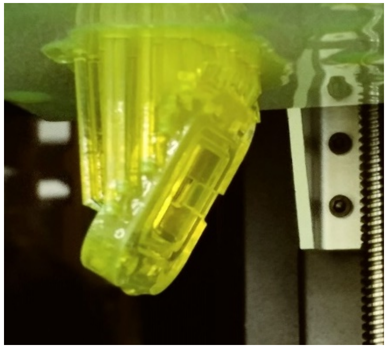
# Headwaters Ultrasonic Ranging Sensor

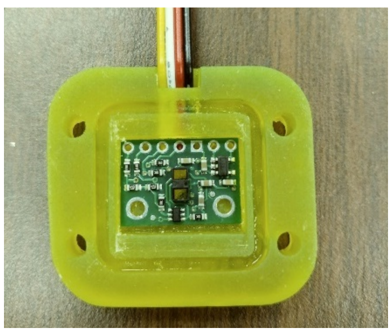
| Ultrasonic Level Sensor Example | |
|---|---|
| Range | ~5 – 10m |
| Reported Accuracy | ± 2-5mm |
| Observed Accuracy | ± 5mm |
| Cost | $140 |
| Potential Issues | Temp Stability |

MaxBotix Ultrasonic Level Sensor



# LiDAR Level Deployments



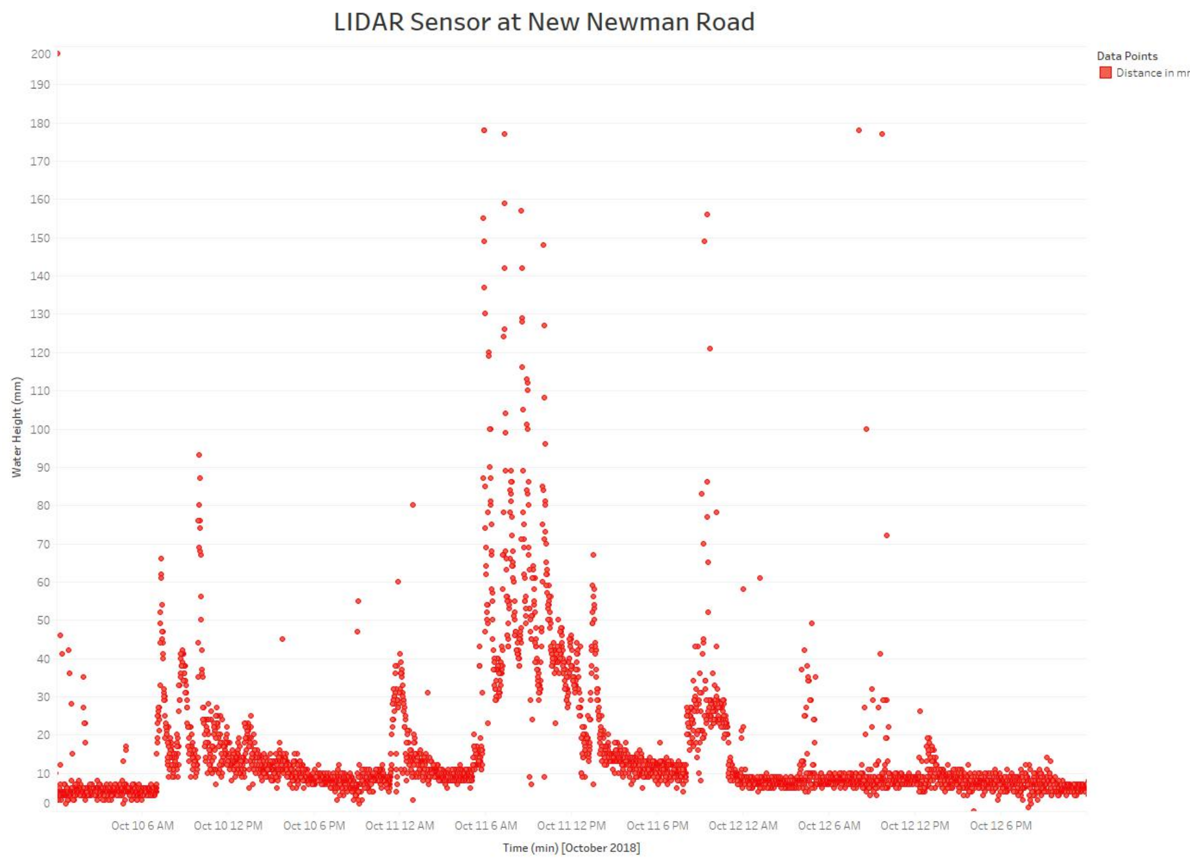


LiDAR
Level Sensor

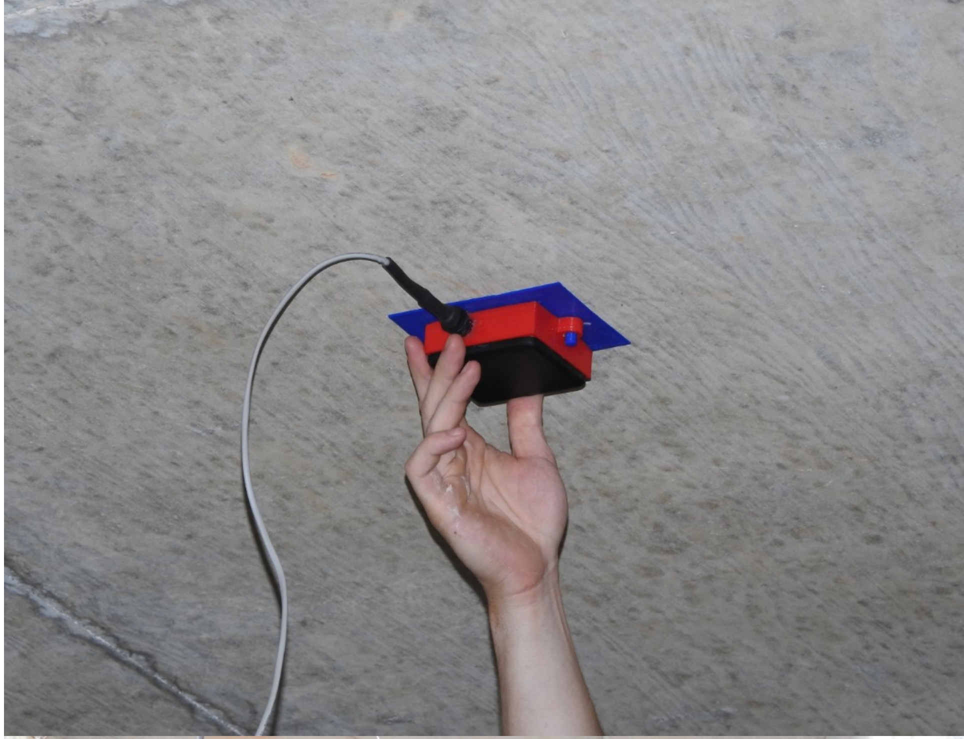
# *LiDAR Level Deployments*

| LiDAR Level Sensor Example | |
|---|---|
| Range | ~4m |
| Reported Accuracy | $\pm$ 2.5mm |
| Observed Accuracy | $\pm$ 2.5mm - $\pm$ 10mm |
| Cost (with case) | $20 |
| Potential Issues | Light Interference |

LiDAR
Level Sensor



# *Radar Deployment*

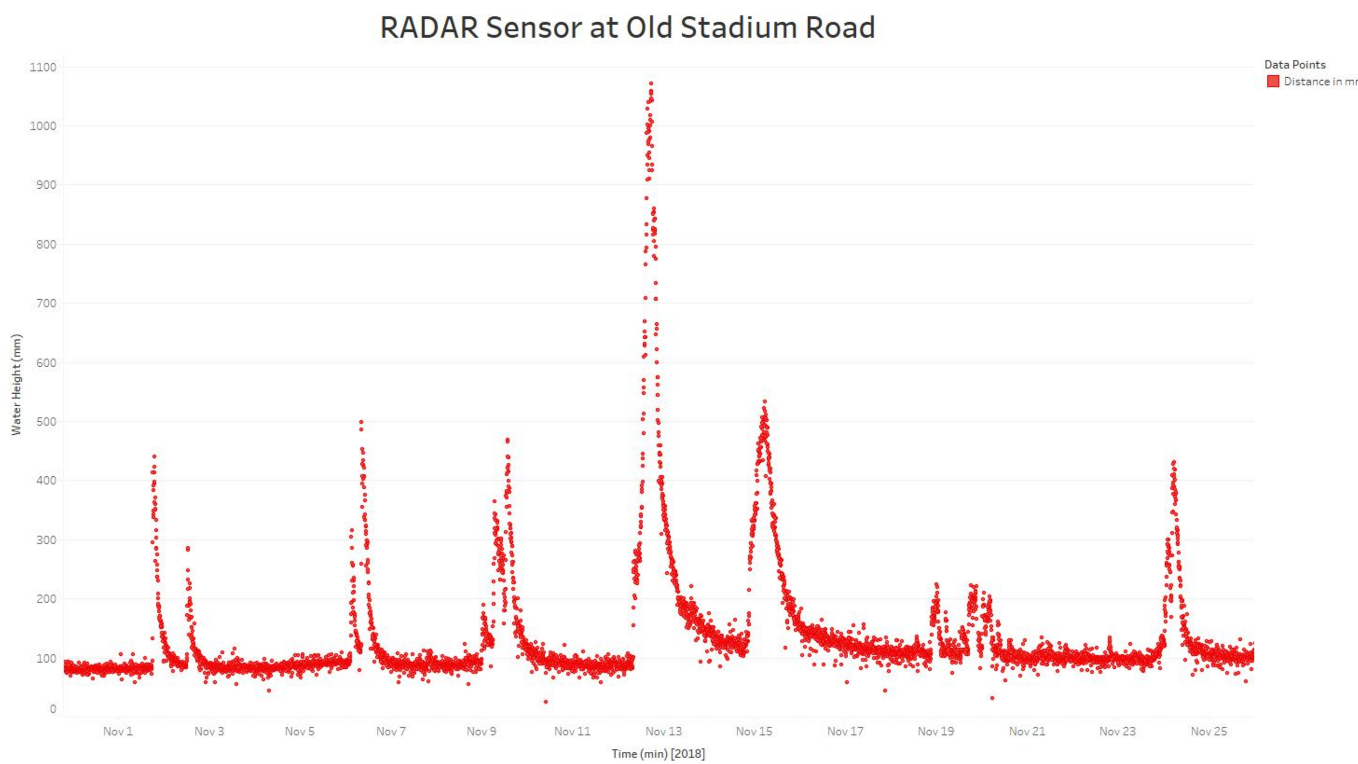


77 Ghz Radar
Level Sensor

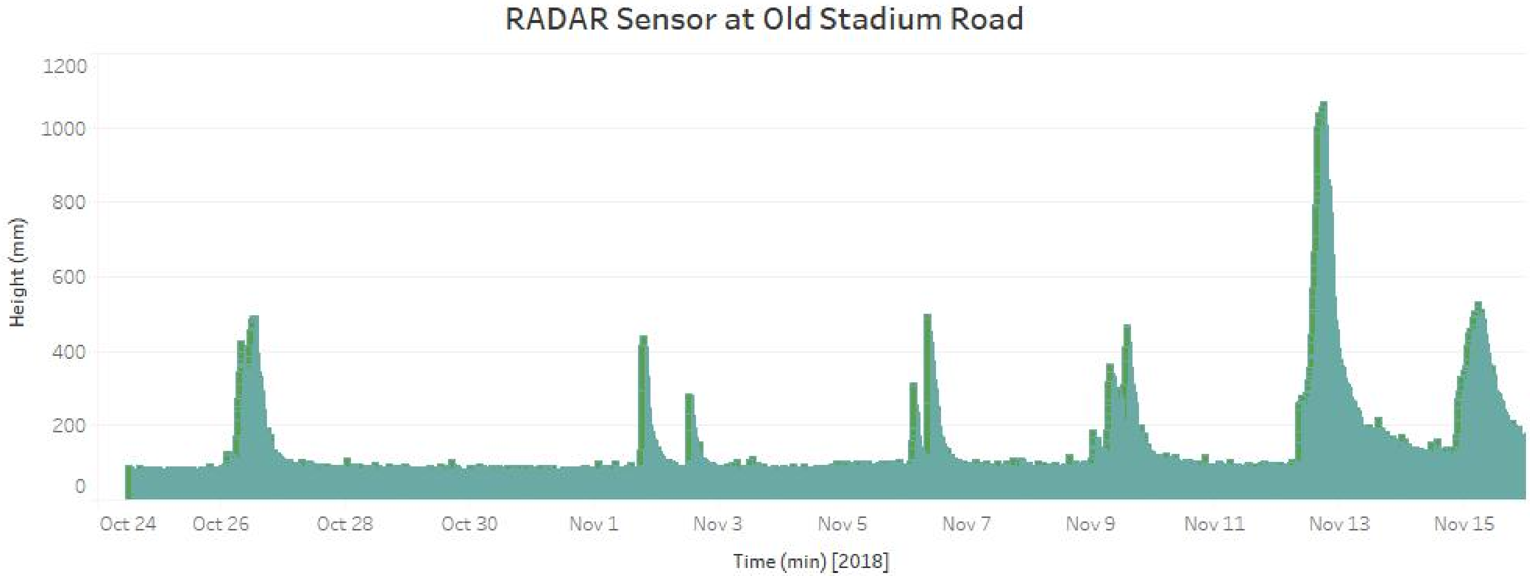
# Radar Deployment

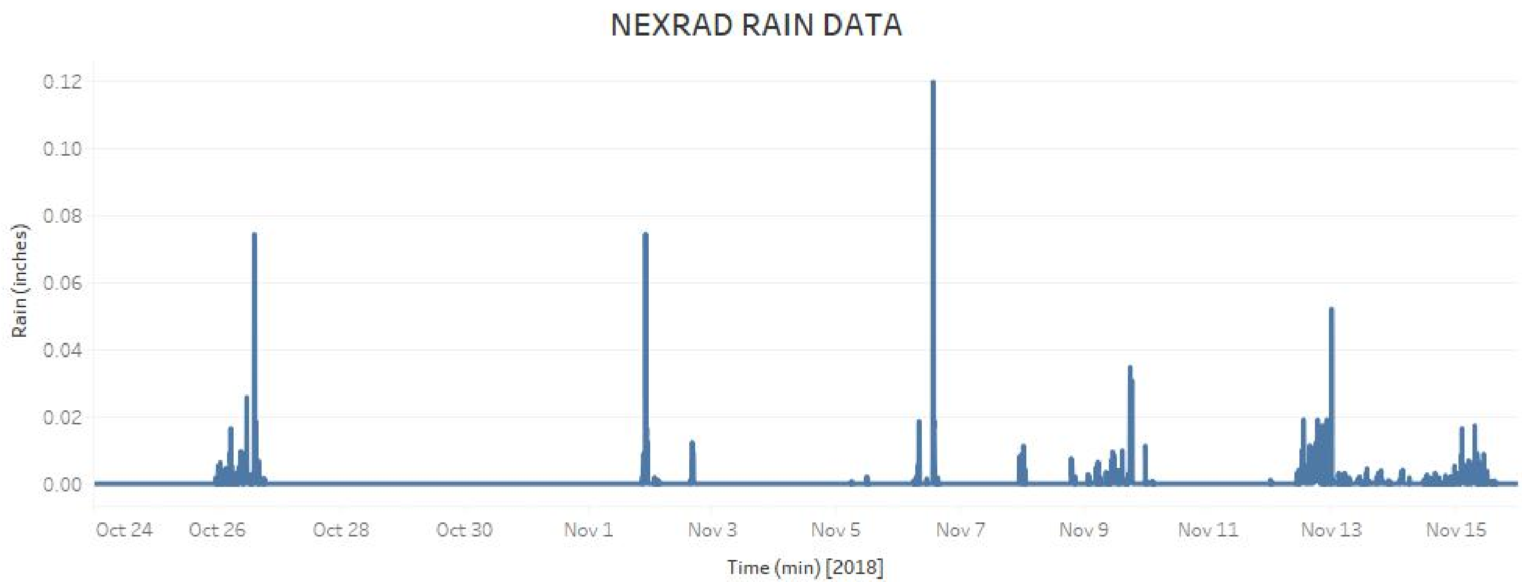
| Radar Level Sensor Example | |
|---|---|
| Range | ~10m |
| Reported Accuracy | ± 3mm |
| Observed Accuracy | ~ ± 5mm |
| Cost | ~$300 |

77 Ghz Radar Level Sensor



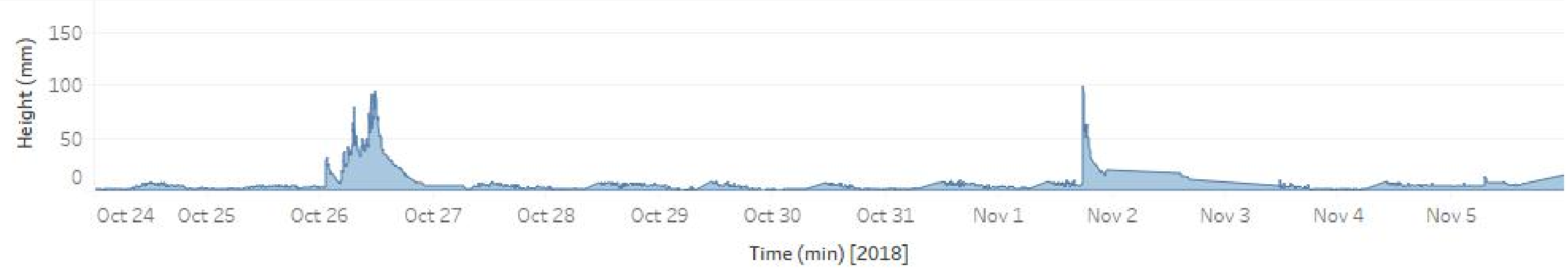
# Radar Data with Rainfall



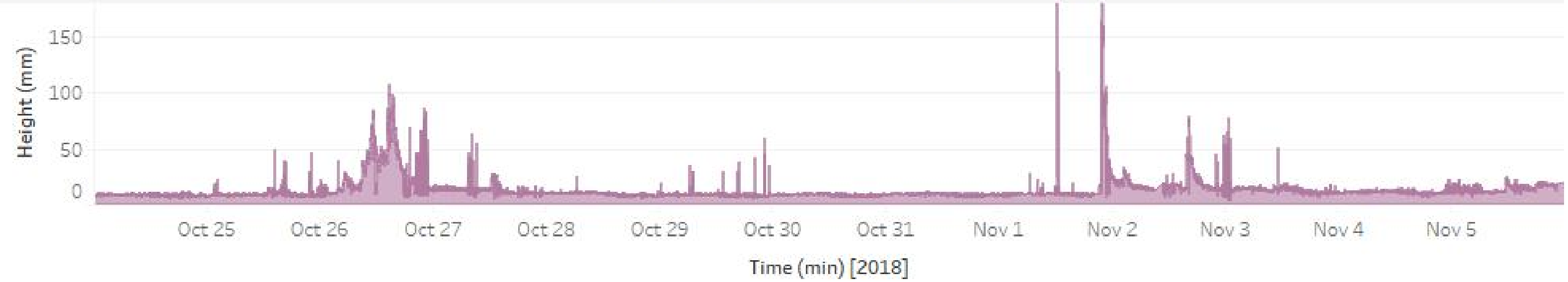



# Stacked Sensor Readings

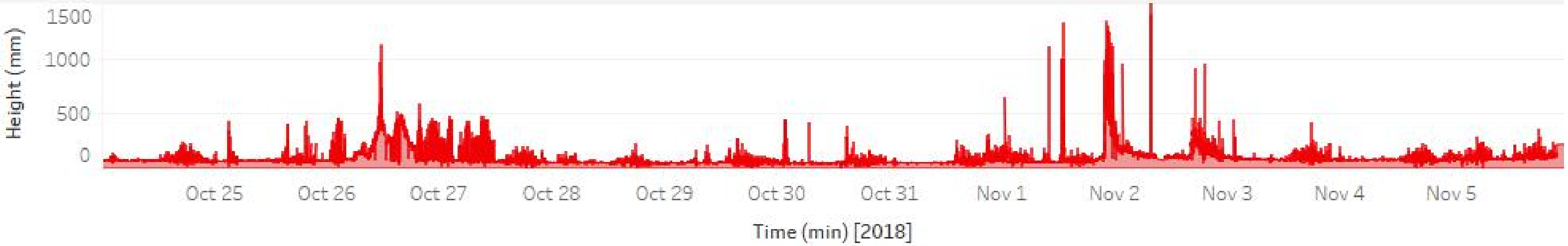
## Ultrasonic Sensor



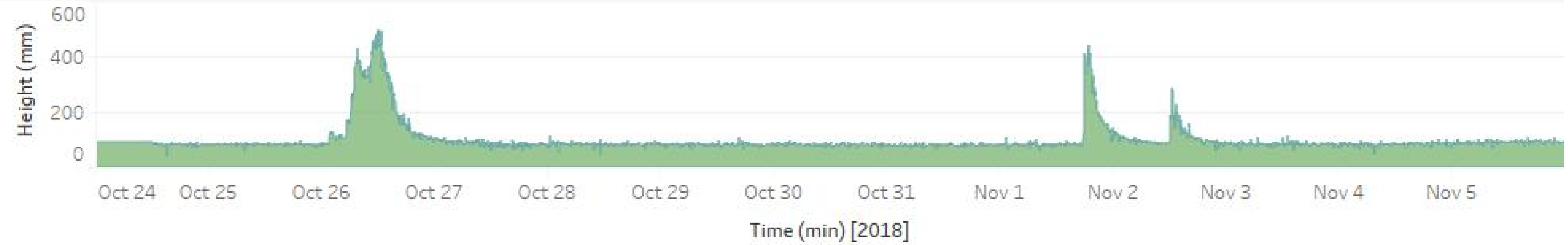

## LIDAR Sensor at New Newman Road



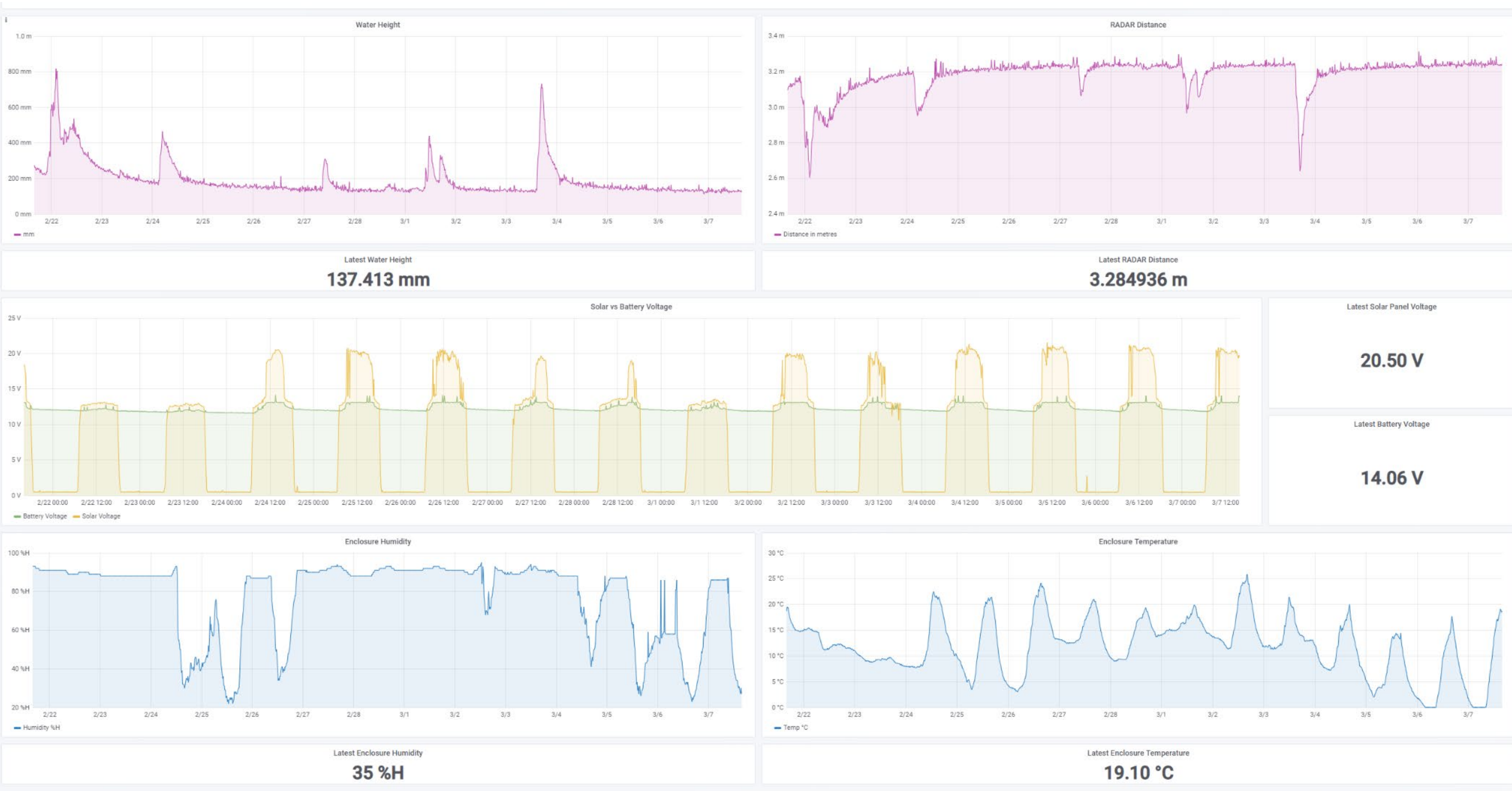

## LIDAR Sensor at Perimeter Road



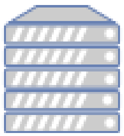

## RADAR Sensor at Old Stadium Road



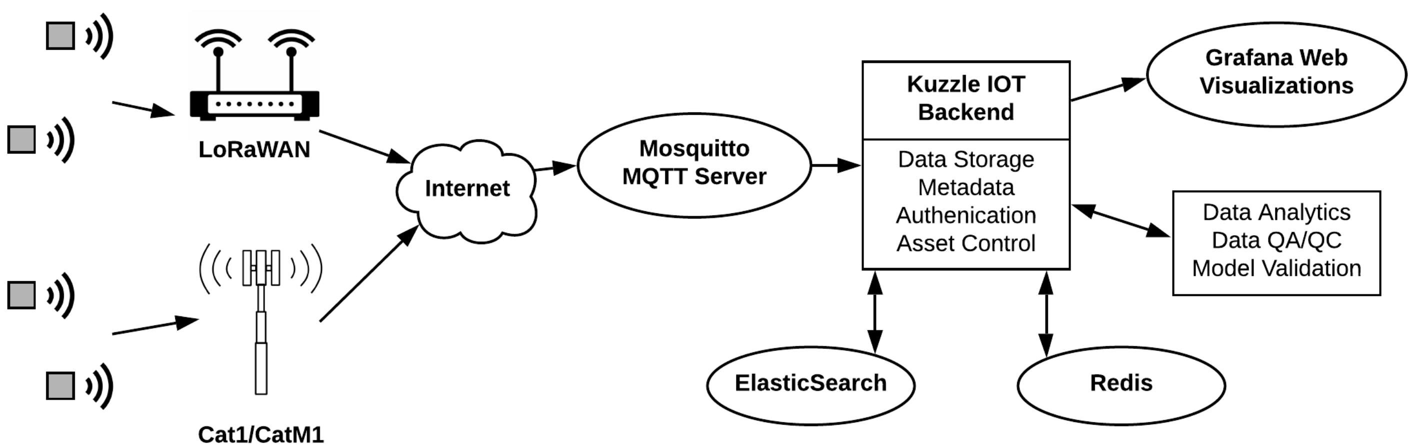

# System Dashboard

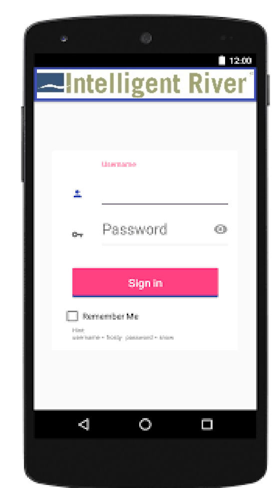


# What about the data?



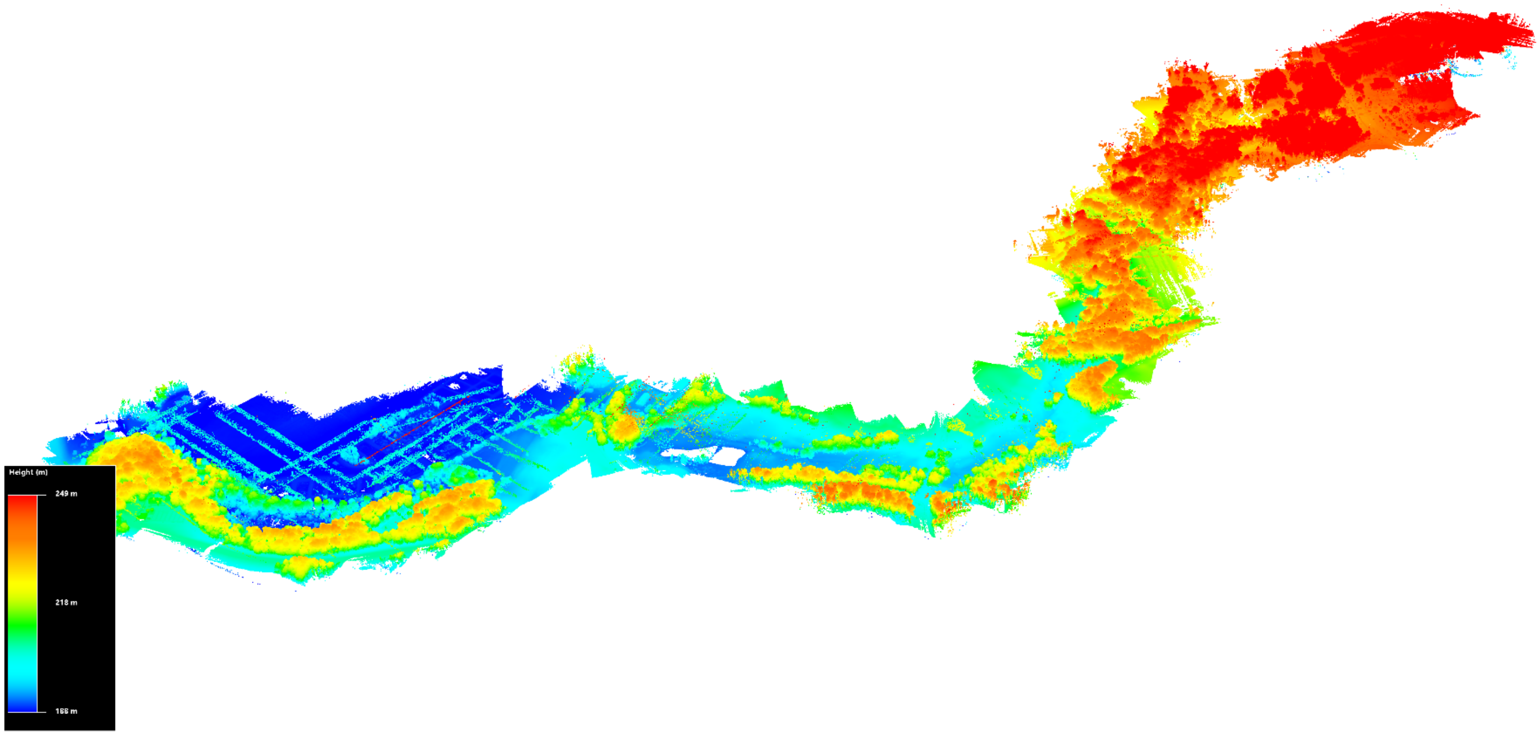
Location-aware data storage and analytics with extensive Metadata that describes all aspects of the sensors and deployment Systems.



# Current Efforts

- Developing rating curves and modeling water flows with PCSWMM
- Testing radar-flow based methods to automate rating curves
- Deploying 25 additional water level sensor nodes and water quality sensors in the testbed
- Determining packet loss and optimal sampling frequency
- Validating accuracy with pressure transducer loggers
- Using LiDAR UAV based terrain models to visualize surface hydrology



# Questions ?