TEXAS
The University of Texas at Austin

WHAT STARTS HERE CHANGES THE WORLD

Water Networks and Infrastructure

2024 DoD SERDP NICE Project Workshop

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Urban water infrastructure

Water treatment

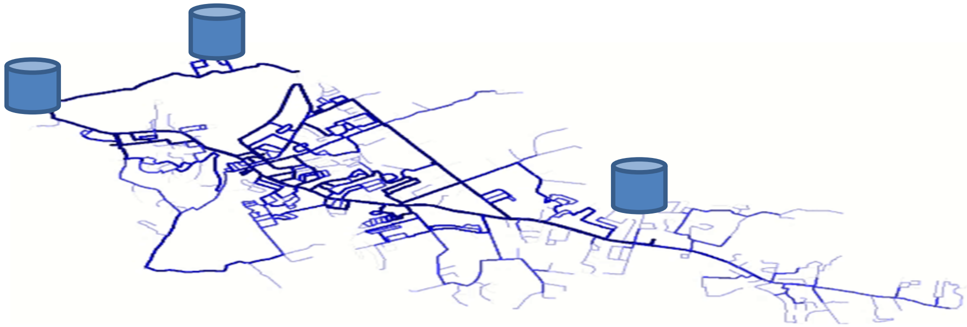
Pumping

Distribution

End-users

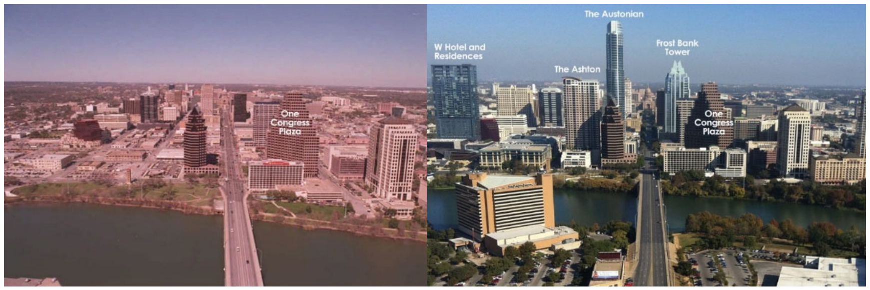
Operate & manage:

- ✓ Water loss
- ✓ Water quality
- ✓ Energy requirements
- ✓ Infrastructure failures
- ✓ Supply interruptions



Urban water infrastructure

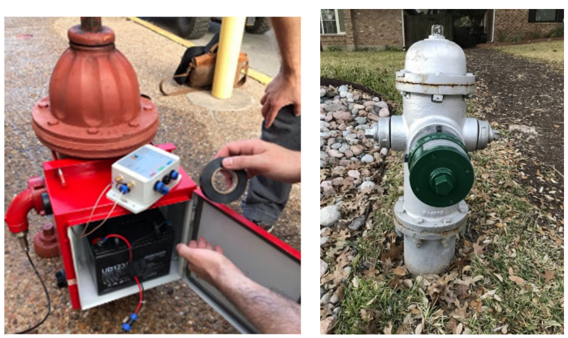
Challenges



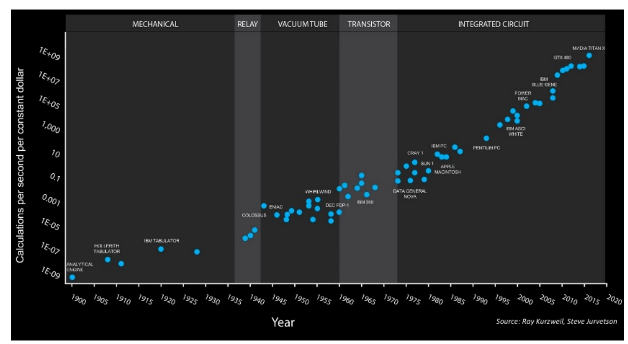
Urbanization

Aging infrastructure

Opportunities



Sensing

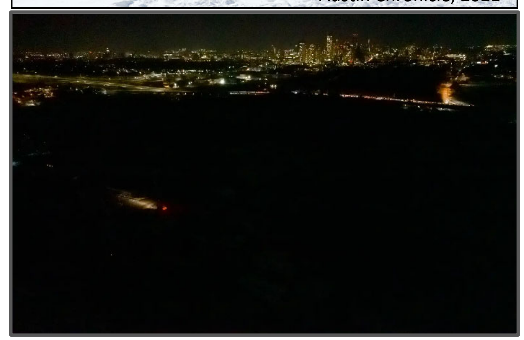


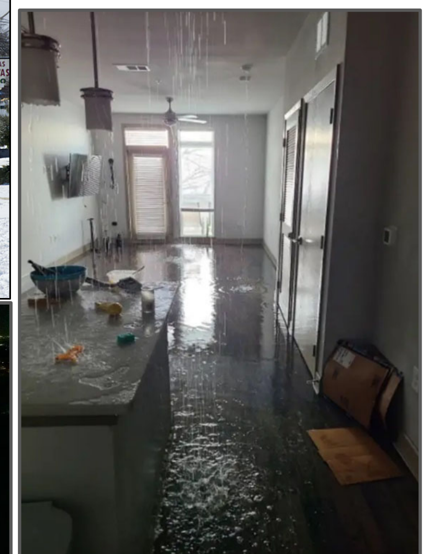
High performance computing

Winter Storm Uri

- February 2021
- Heavy ice, snow, and over five days of subfreezing temperatures
- Cascading failures in energy system led to water system failures (Busby et al. 2021, Glazer et al. 2021)
- 49% of surveyed residents experienced water outages (Watson et al. 2021)
- 40% of community water systems issued boil water notices (TCEQ 2021)

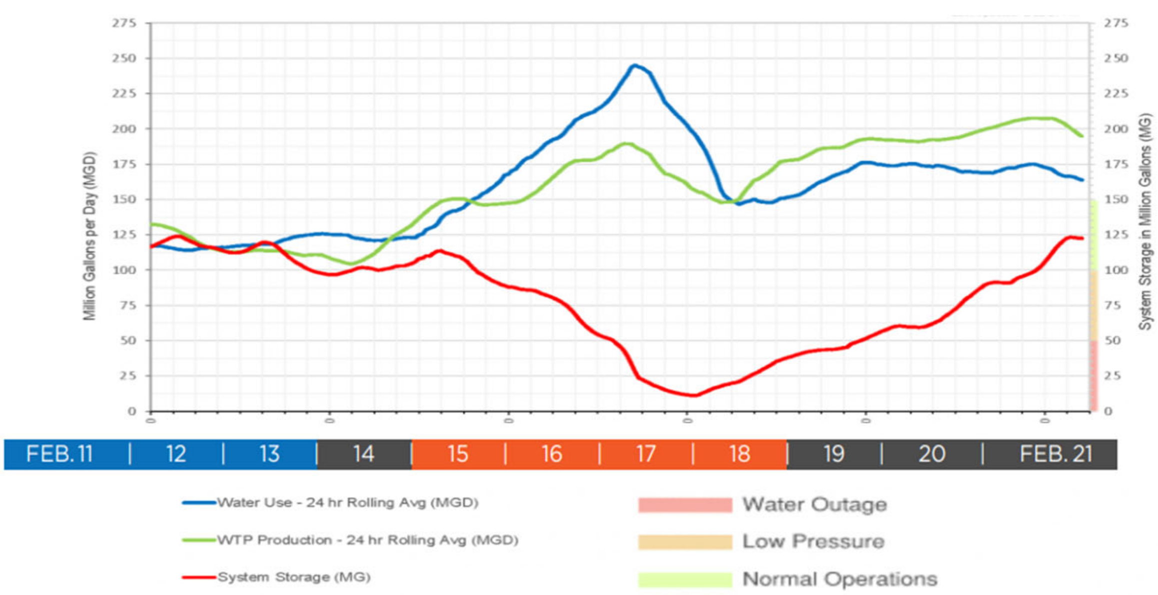
Austin Chronicle, 2021





What matters for water system resilience during extreme events?

Water Use, Production, & Active Capacity



Investigate water system resilience during Winter Strom Uri

Pipe failure models

- ✓ Many models, historical data, provide useful information
- ✗ Limited practical information for performance indicators

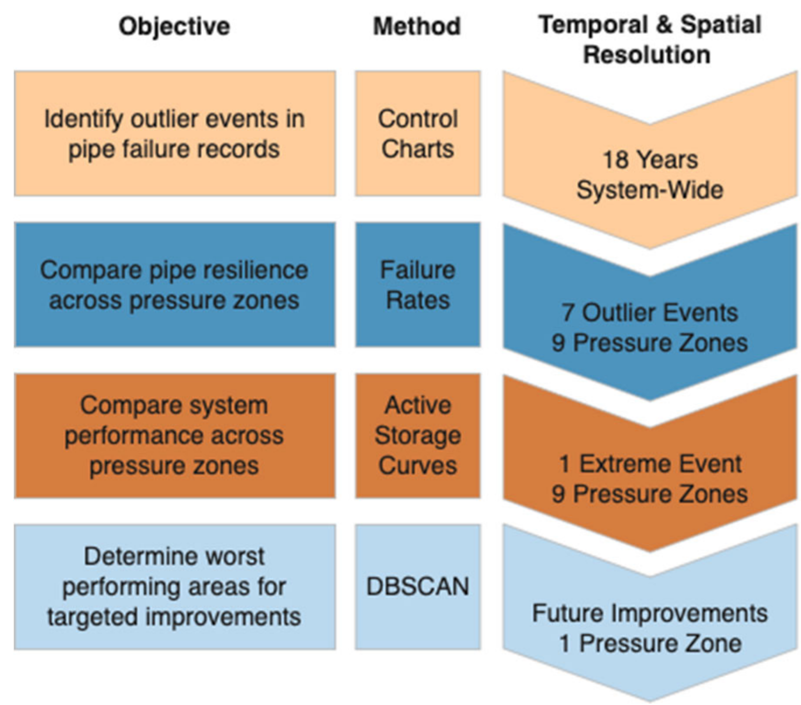
Resilience models

- ✓ Many models, disaster scenarios, performance indicators
- ✗ Synthetic data, simulated system performance

Objectives

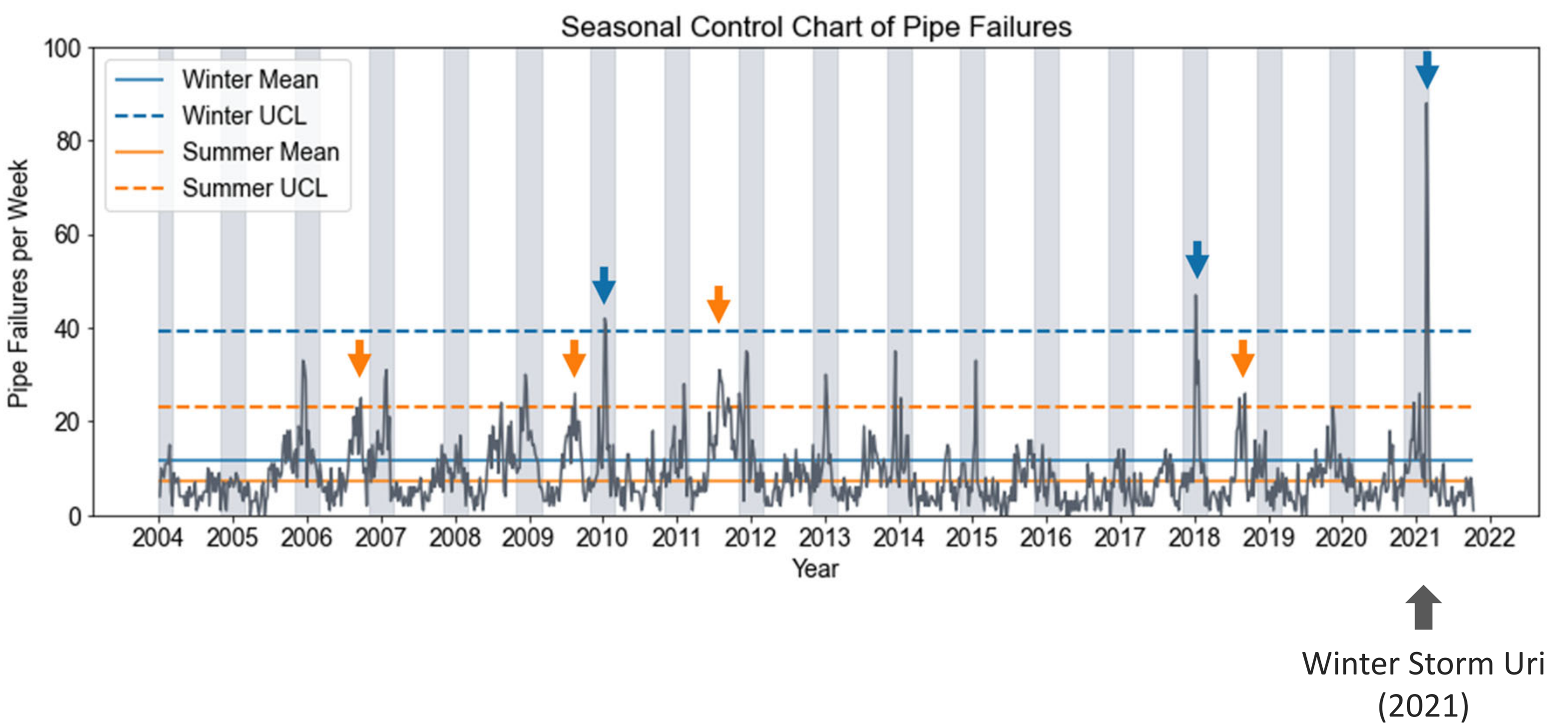
- Is pipe resilience the main driver for system performance during extreme events?

- Can we learn from non-emergency performance to prepare for extreme events?



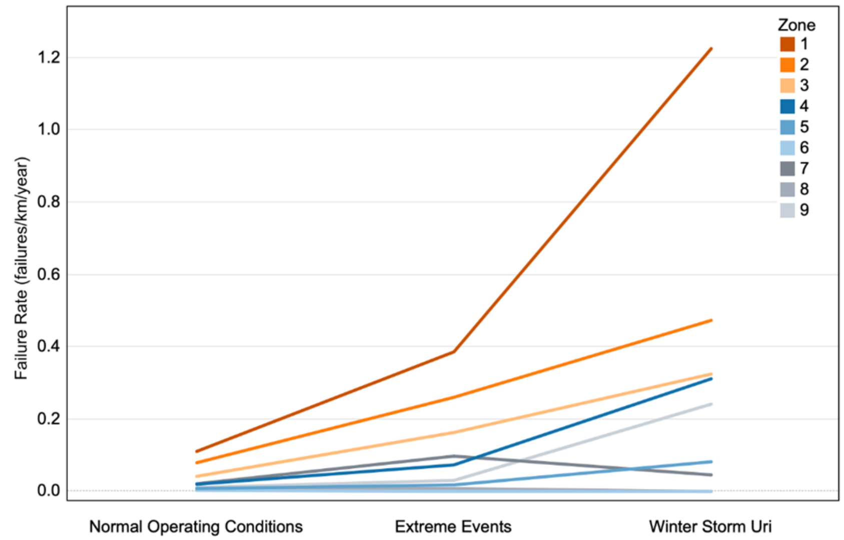
Identifying extreme events in pipe failures

- Using control charts with winter and summer upper control limits
- Identified 4 summer and 3 winter extreme events



Comparing failure rates during normal and extremes

- Failure rates **increase** during extreme events, and further during Uri
- The rankings of rates remain **consistent across pressure zones** (with exception of zone 7)

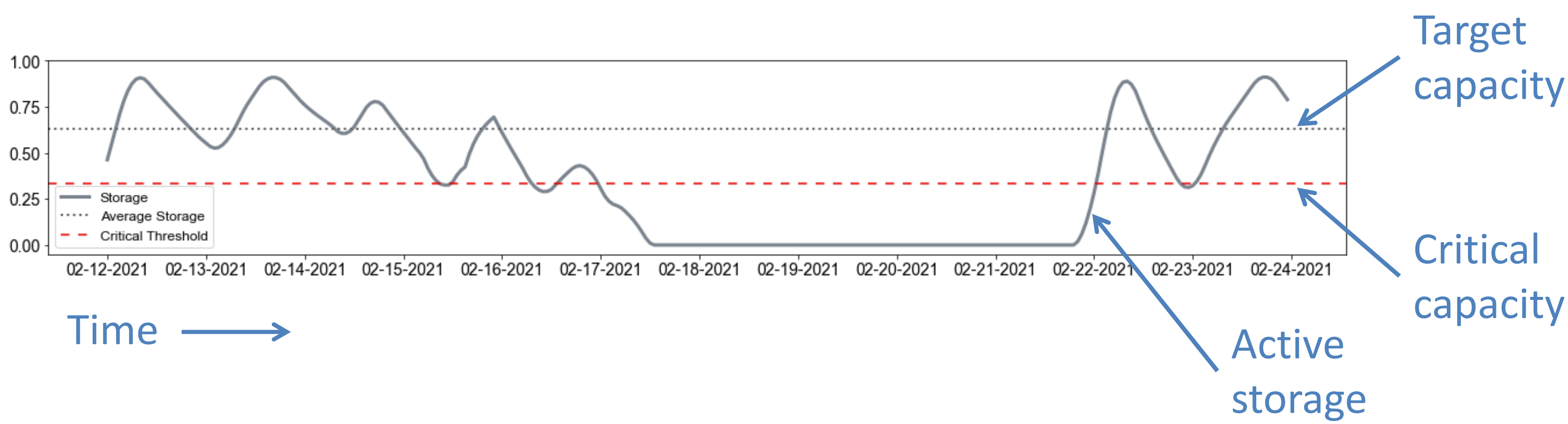


$$\text{Failure Rate} = \frac{\text{\# of failures}}{\text{total length of pipe}}$$

- $\textbf{Pipe Performance Index (PPI)} =$ $1 - \text{normalized failure rate}$

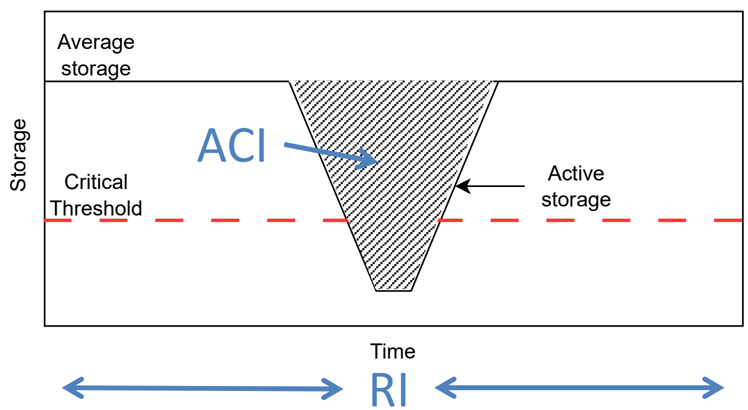
Evaluating system performance

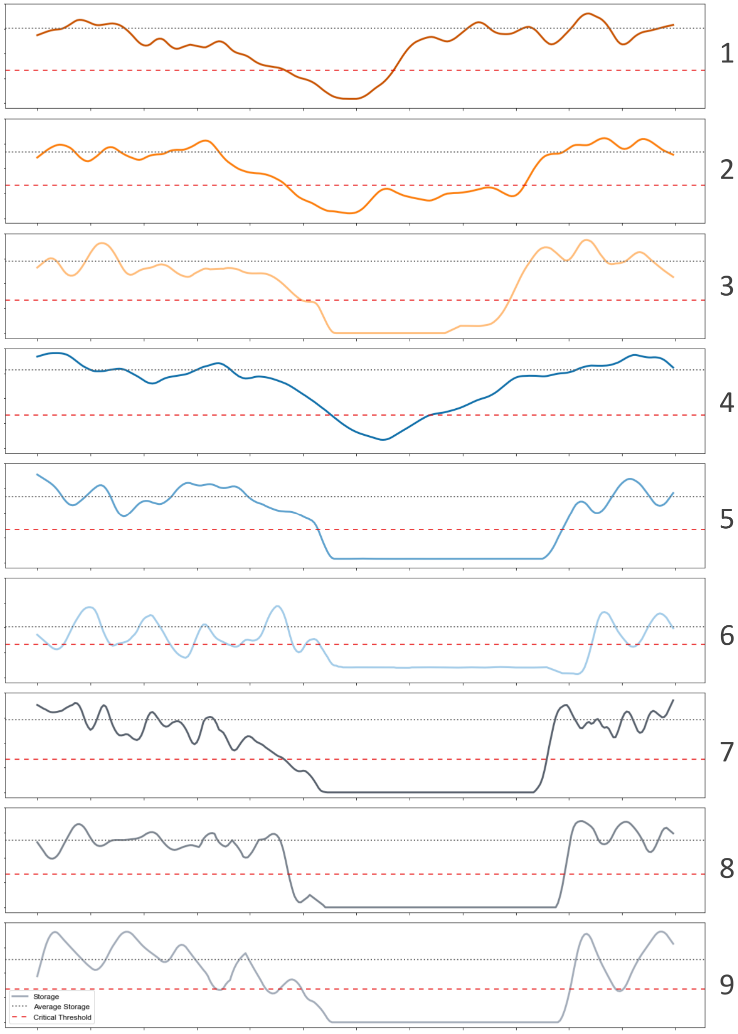
- **Active storage** by pressure zone: a measure of available water for consumers and ability of system to absorb shocks or disruptions



Active storage curves for pressure zones

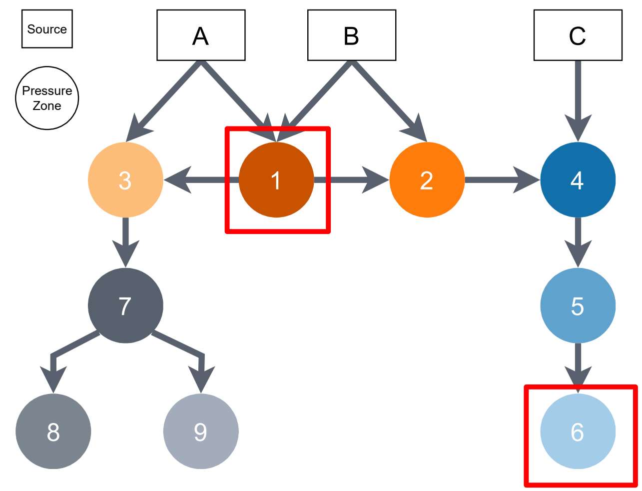
- **Resilience Index (RI)** = fraction of **time** the available storage is greater than the critical level
- **Absorptive Capacity Index (ACI)** = 1 – ratio between the actual and potential **magnitude** of disruption





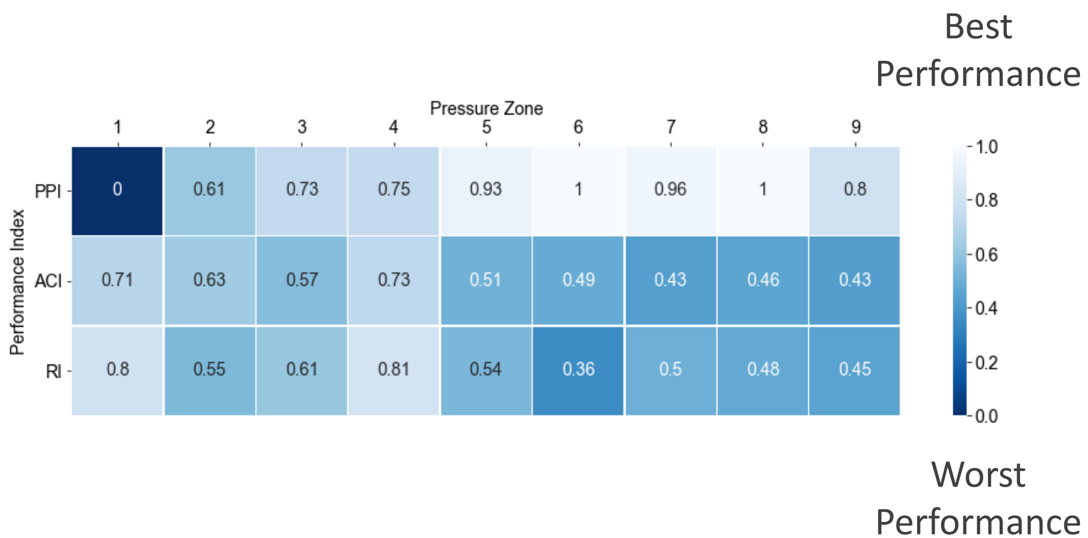
(Francis & Bekera, 2014; Kwasinski, 2016, Poulin & Kane, 2021)

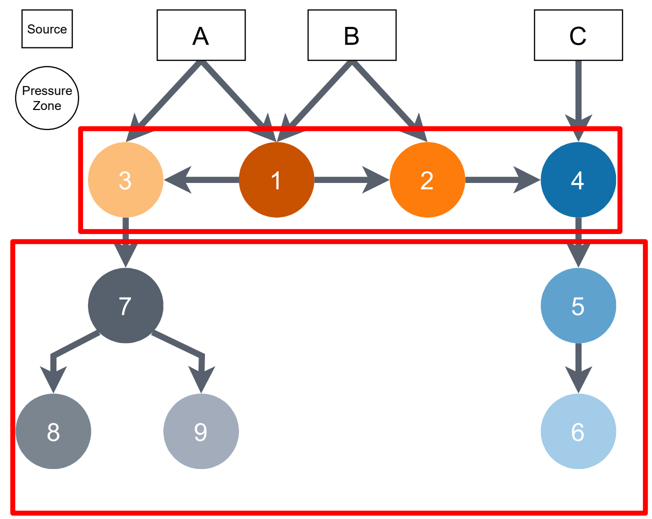
Comparing pipe and system performance



- Zones 1-4 with **worse pipe** performance, but **better system** performance
- Zones 5-9 with **better pipe** performance, but **worse system** performance

Comparing pipe and system performance





- Zones 1-4 with **worse pipe** performance, but **better system** performance
- Zones 5-9 with **better pipe** performance, but **worse system** performance

Learning from past events

Approach

- Spatial density based clustering to find high failure rates regions during non-extreme events
- Test if non-extreme clusters are good predictors of extreme event clusters

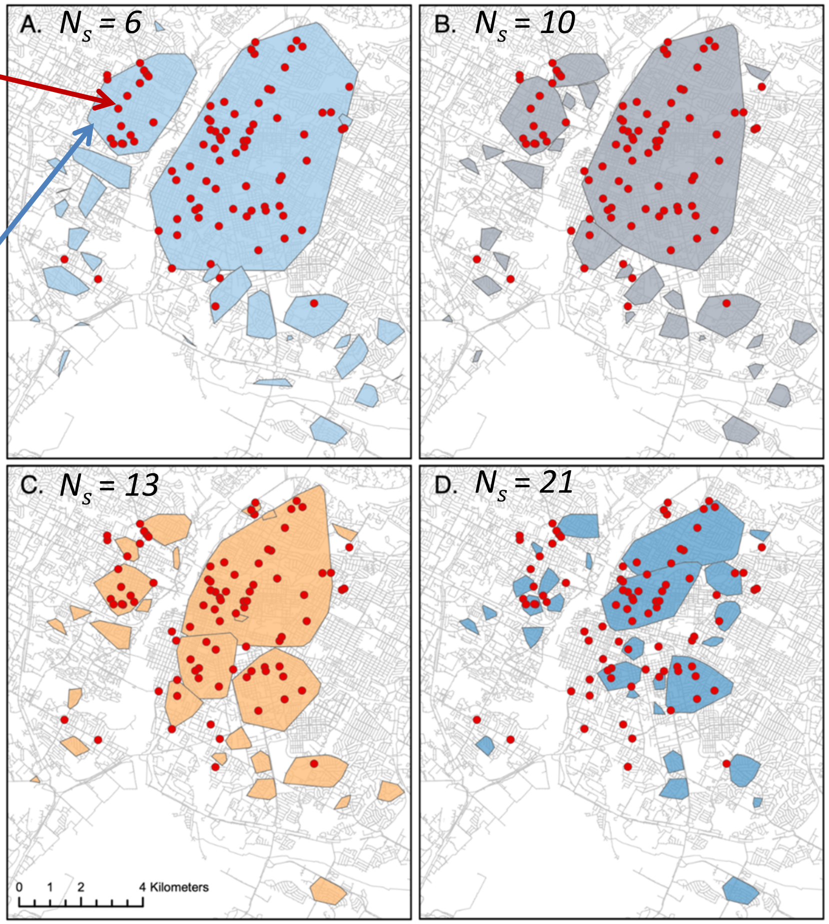
Method

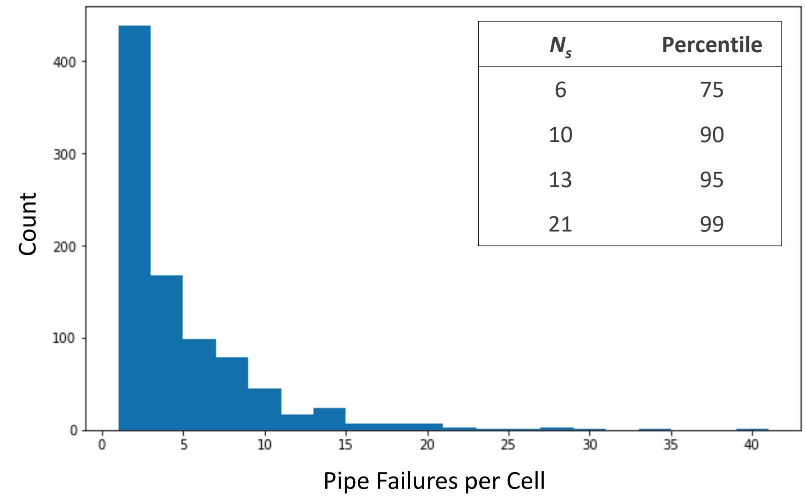
- Density based spatial clustering of applications with noise (DBSCAN)
- Data:
  - Training set = Non-Uri failures
  - Test set = Uri failures
- Parameter selection
  - ε = radial distance 300m (~two city blocks)
  - N_s = minimum number of points within radial distance for cluster formation

Learning from past events

Uri failure

Non-Uri failure cluster





- Location of failures during non-extreme events is a good predictor for failures during Winter Storm Uri

Learning from past events

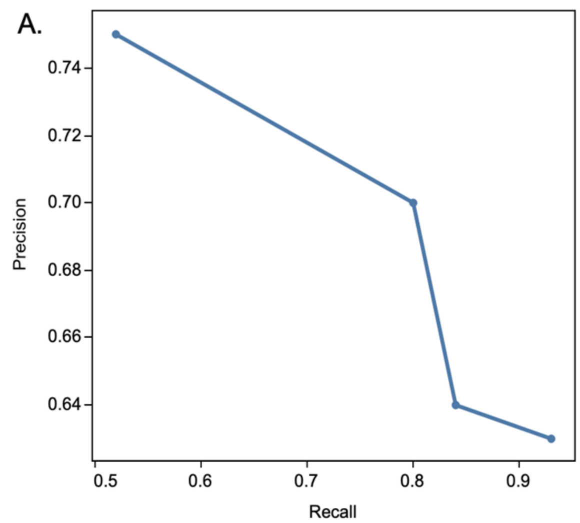
$$\text{Precision} = \frac{\text{True Positive}}{\text{False Positive} + \text{True Positive}}$$

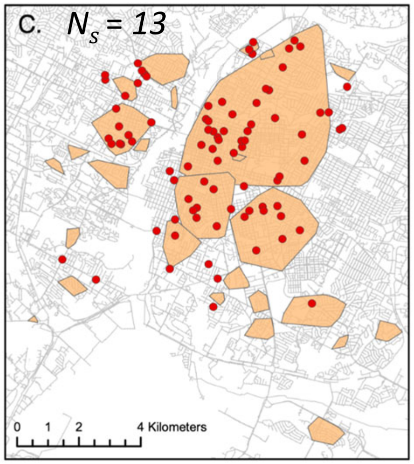
$$\text{Recall} = \frac{\text{True positive}}{\text{False Negative} + \text{True Positive}}$$

TP = Uri failure in cluster

FP = Cluster with no Uri failures

FN = Uri failure not in cluster





Key takeaways

- Control charts applied to pipe failure dataset to identify outlier events
- Pipe performance does not drive system performance locally but impacts entire system
- Network structure allowed negative impacts to cascade to outer regions of system
- Spatial and temporal agreement between normal and extreme events
- Analysis used commonly available data and could be repeated for other systems

Looking ahead

- Modeling and technical resources **overlook** the data requirements and processing needs
- Extensive **data requirements**, lack of standardized and/or centralized data management
- Need for **multiple software**, no single software has all the capabilities
- Need for **trained staff** in different modeling skills
- **Institutional knowledge** is a critical resource of information

Issues Facing the Water Industry in 2020

2020 RANKING	CHALLENGE
1	Renewal and replacement of aging water and wastewater infrastructure
2	Financing for capital improvements
3	Long-term water supply availability
4	Public understanding of the value of water systems and services
5	Watershed/source water protection
6	Public understanding of the value of water resources
7	Aging workforce/anticipated retirements
8	Emergency preparedness
9	Compliance with current regulations
10	Groundwater management and overuse
11	Compliance with future regulations
12	Cost recovery (pricing water to accurately reflect the cost of service)
13	Governing board acceptance of future W/WW rate increase
14	Public acceptance of future water and wastewater rate increases
15	Talent attraction and retention
16	Cybersecurity issues
17	Water conservation/water use efficiency
18	Asset management
19	Improving customer, constituent, and community relationships
19	Data management
20	Drought or periodic water shortages

American Water Works Association

Acknowledgements

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- Austin Water
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H. Tiedmann, K. Faust, and L. Sela. “Looking beyond individual failures: A system-wide assessment of water infrastructure resilience to extreme events”. *Reliability Engineering & System Safety,* 244, 109910, pp. 1 – 13, April 2024. https://doi.org/10.1016/j.ress.2023.109910