Resilience Analysis Using the Water Network Tool for Resilience

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Background

- Recent natural disasters and environmental emergencies have highlighted the vulnerability of water infrastructure:
  - Hurricane Maria / Puerto Rico
  - Hurricane Harvey / Texas
  - Elk River Spill / Charleston, West Virginia
  - Lead contamination / Flint, Michigan
- General guidance on preparedness and resilience is available
- Quantitative site-specific analysis is needed to justify capital investments in building resilience

How to Model Resilience

Potential Hazards

Natural Disasters

- *Drought*
- *Earthquakes*
- *Floods*
- *Hurricanes*
- *Tornados*
- *Tsunamis*
- *Wildfires*
- *Winter Storms*

Terrorist Attacks

Cyber Attacks

Transportation / Industrial Accidents and Spills

Consequences

Human Health

Pipe Breaks

Other Infrastructure Damage

Power Outage

Service Disruption (source treatment, distribution, storage)

Loss of Access to Facilities / Supplies

Loss of Pressure/Leaks

Change in Water Quality

Environmental / Financial /Social

Response Actions

Public Health Advisories

Repairing Pipe Breaks

Fixing Infrastructure Damage

Restoring Power

Treating Water

Repairing Roads/Access

Fighting fires

Communication with Customers

Conservation

Mitigation Strategies

Back up Power / Fuel Storage

Earthquake resistant pipes

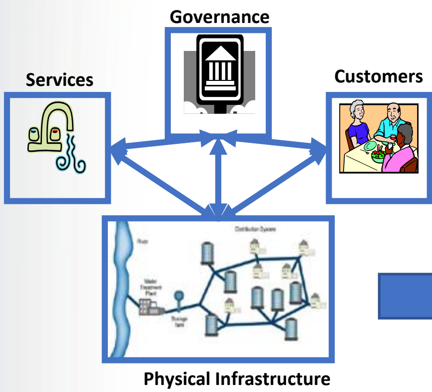
Securing facilities/assets

Water Quality Monitoring

Increased Redundancy

Practiced Emergency Response Plans

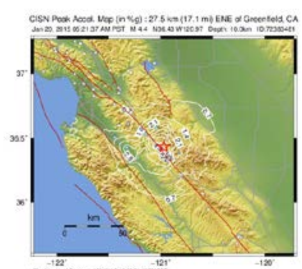
Water Network Tool for Resilience

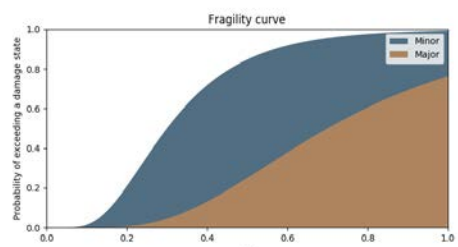


Water System Model

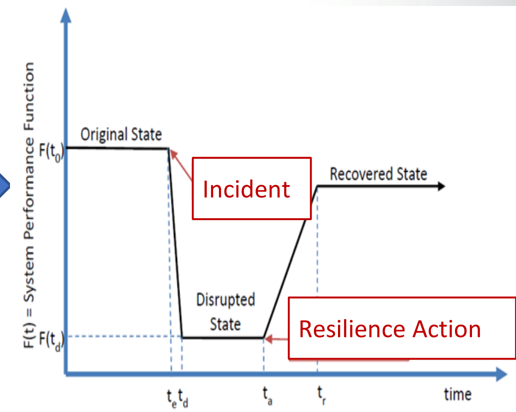
WNTR Simulation Engine
EPANET
Disaster Models
Response Models
Mitigation Models
Resilience Indicators

S1 S2 S3 … SN





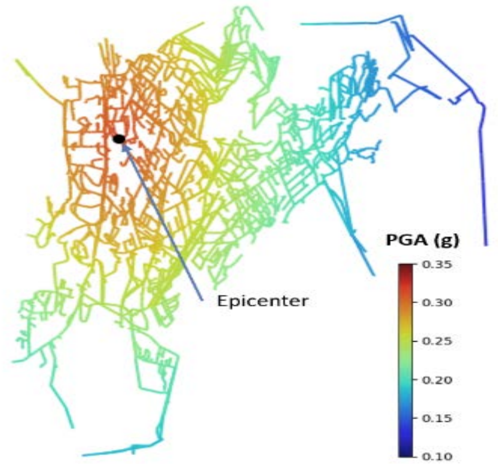
Disaster Models & Data

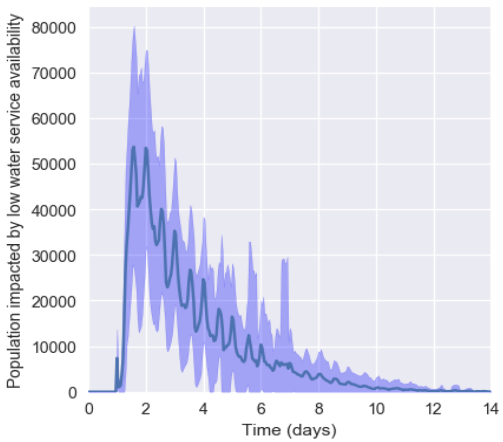


WNTR Plots & Data

WNTR Functionality

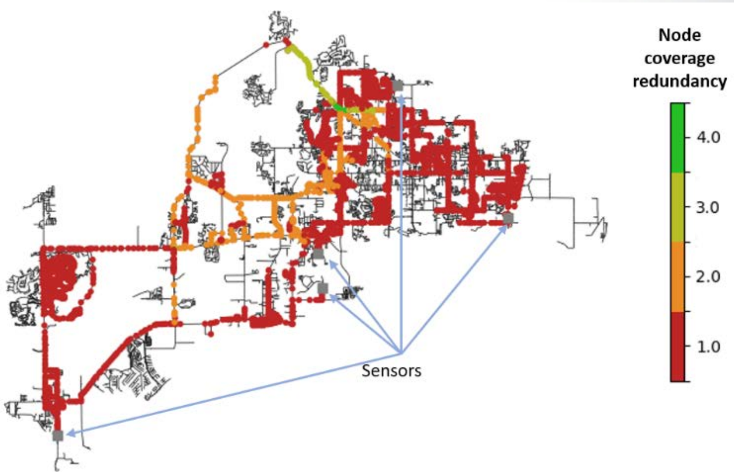
- **WNTR functionality includes**
  - **Model specific disaster/recovery incidents or run stochastic analysis of future scenarios**
  - **Simulate hydraulics using demand driven or pressure dependent demand**
  - **Compute resilience using hydraulic, topographic, water quality, and cost metrics**
  - **Generate network graphics, time series plots, and animations**
  - **Stop and restart simulations, change operations and network structure**

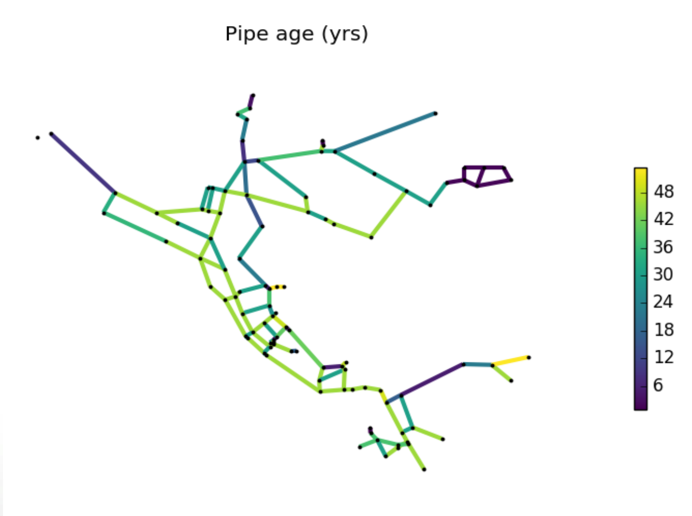




WNTR Framework

- WNTR was designed to integrate analysis with efficient open source software tools
  - Numpy and Scipy
  - Pandas
  - NetworkX
  - Matplotlib and Plotly
- WNTR is EPANET compatible
  - Generate network models from EPANET INP files
  - Complete unit converter and read/write functionality

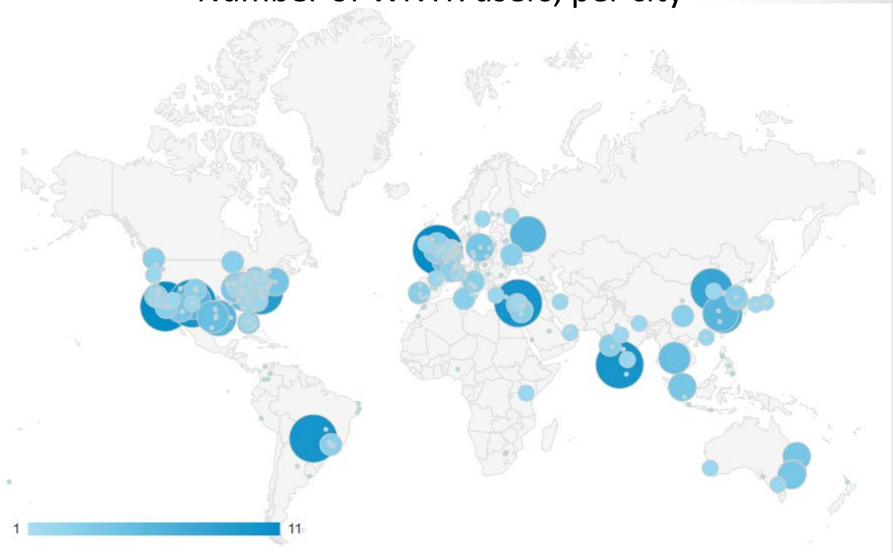




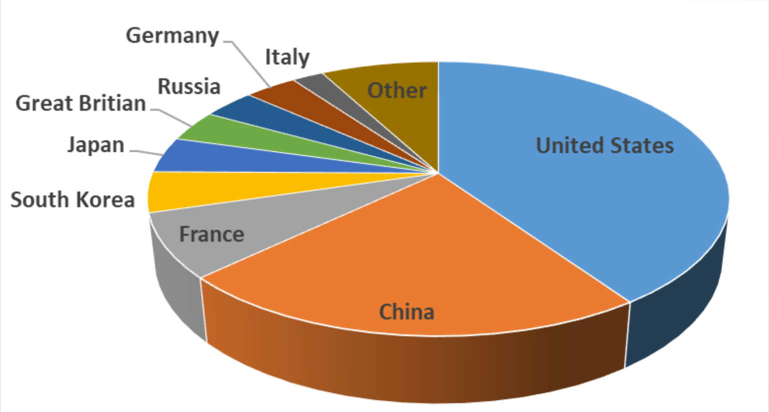
WNTR Use and Availability

- **WNTR Users**
  - **UCLA**
  - **University of South Florida**
  - **NIST**
  - **Arcadis**
- **Over 7000 downloads from pypi**
- **170 clones and 39 forks on GitHub**
- **WNTR can be installed through the EPA GitHub Site: https://github.com/USEPA/WNTR**
- **Online software tests, issue and feature reporting, documentation, and contributor guidelines**

Number of WNTR users, per city



Downloads, per country



Resilience Analysis Options

1. Hydraulic connectivity during normal and abnormal times of service

   Which tank supplies water to each critical asset in the network?

   Which part of the network is pressurized by a particular pump?

2. Component criticality analysis (rank the impact of individual component failures)

   How does the network operate when a single pipe, pump, or tank fails?

   How does the network operate when fire conditions are implemented at a single node?

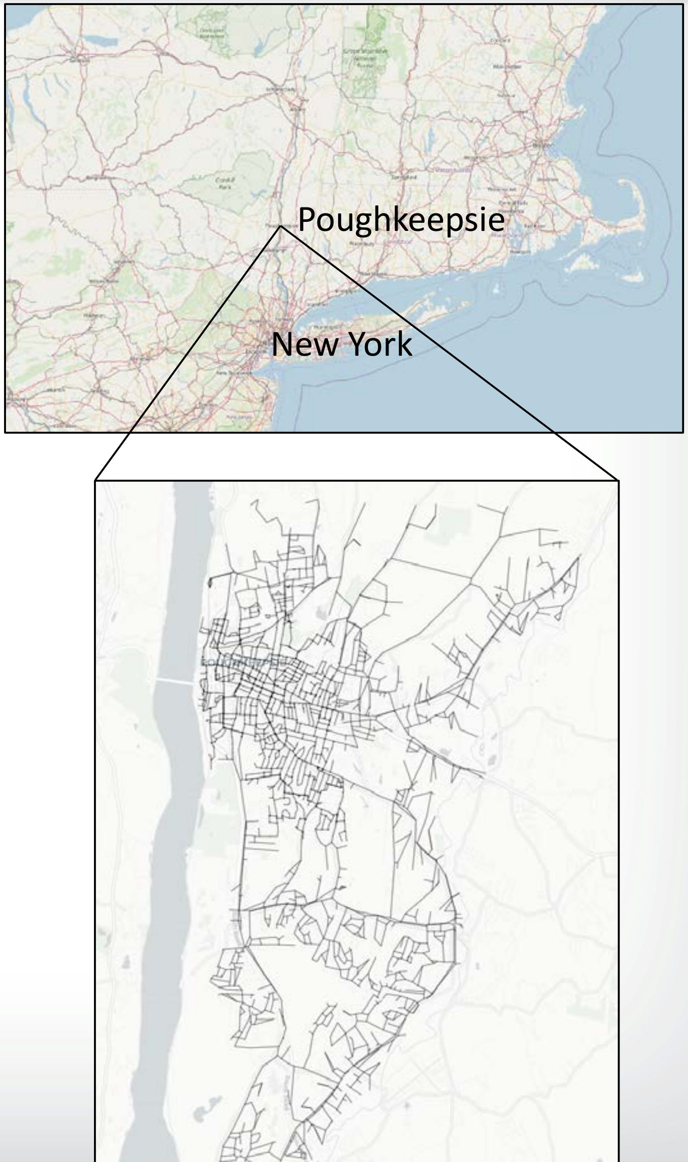
3. System resilience analysis (system wide damage and recovery actions)

   After a magnitude 7 earthquake, which network components might be damaged and how should crews prioritize repair?

   If the water treatment plant is offline for 5 days, which populations are most impacted? How much does water conservation help?

Water Utility Case Study

- Poughkeepsie, New York
  - Hudson River Source
  - 80,000 population
  - 10 MGD water treated
  - 23 MG system storage
  - 4628 junctions, 5204 pipes, 2 tanks
- Resilience scenarios of concern
  - Loss of source water due to contamination of river, frozen intake, or pump failure
  - Large scale pipe break
- WNTR Resilience analysis
  - Hydraulic connectivity
  - Pipe criticality analysis
  - Compromised source water analysis

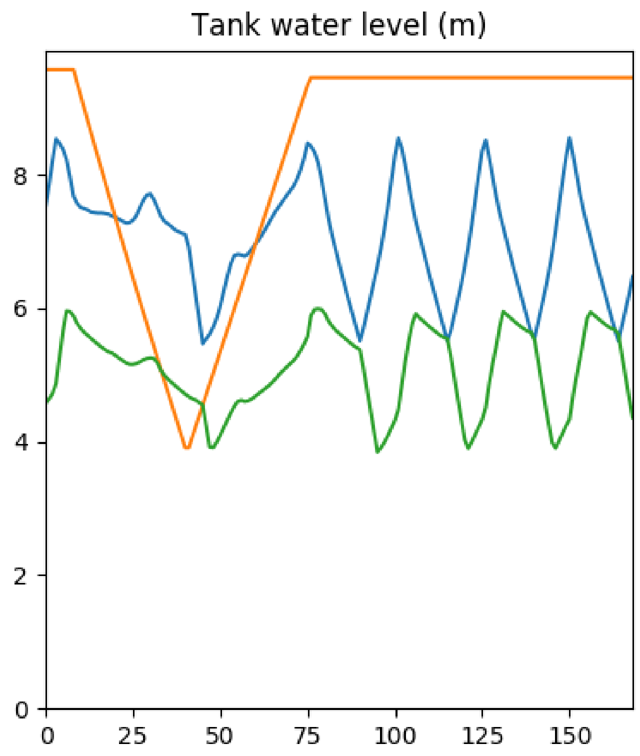


Loss of Source Water Analysis

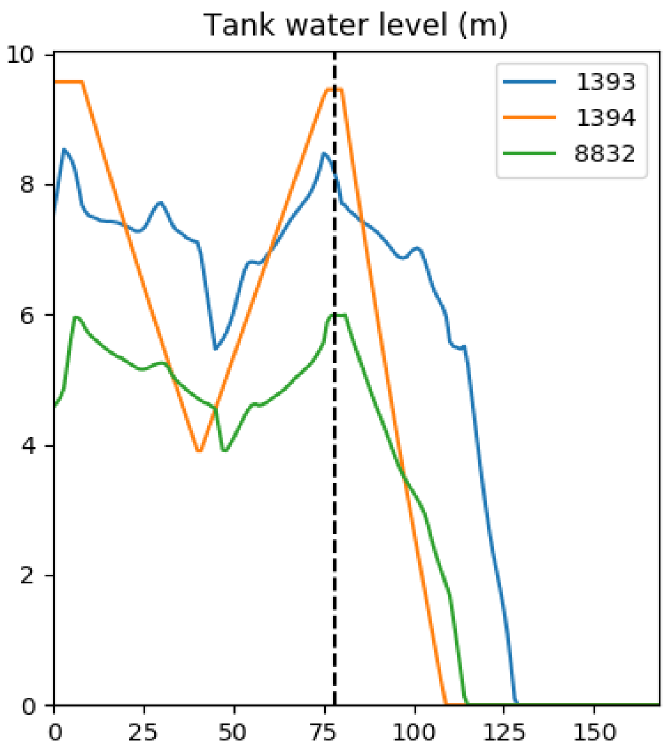
- Loss of source due to river contamination, treatment plant failure, winter storm freezing intake, or power outage.
- How long can the system maintain service if water is not supplied from the treatment plant?
  - Run PDD simulation under the following conditions and extract pressure and water service availability over time. Shut off water supply from the treatment plant
    - Shut down the main pump station that delivers water to the surrounding town
    - Allow tanks to drain completely
    - Discontinue water service to large industrial users
  - What mitigation strategies can be effective?

Tanks Draining After Shutdown

Tank levels during normal operations

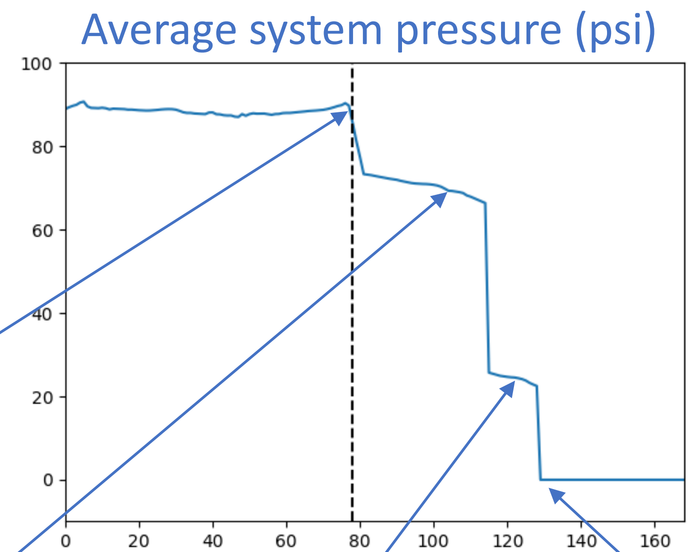


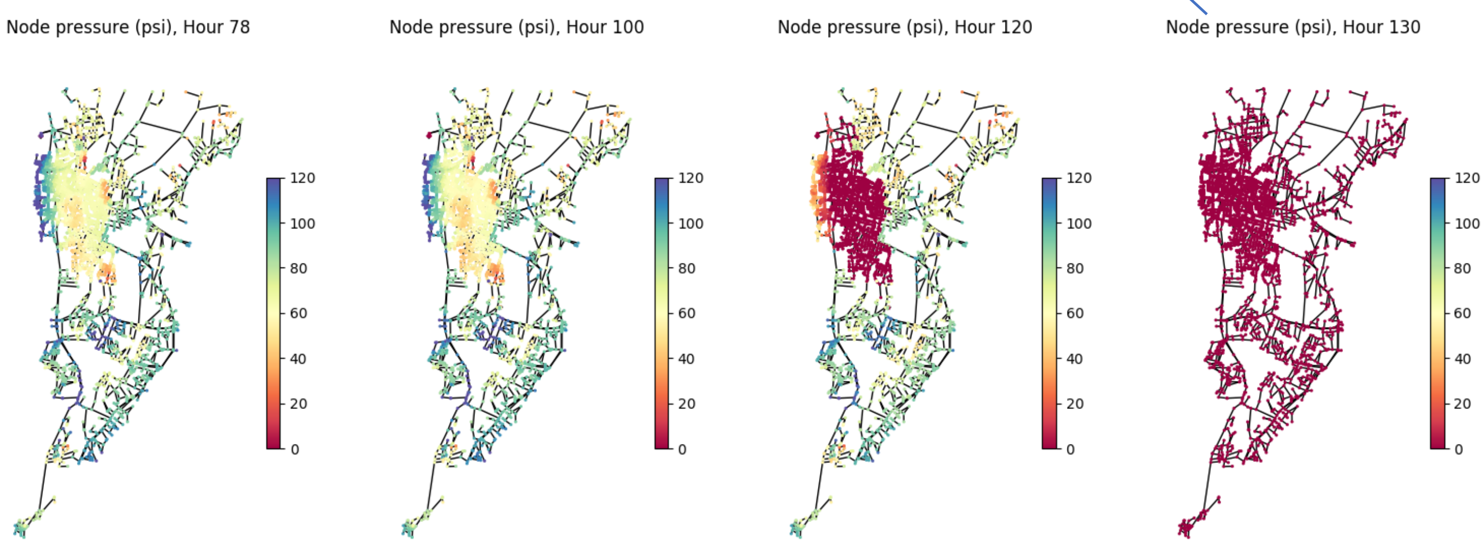
Tank levels after water supply is shut off at hour 78



Pressure Loss After Shutdown

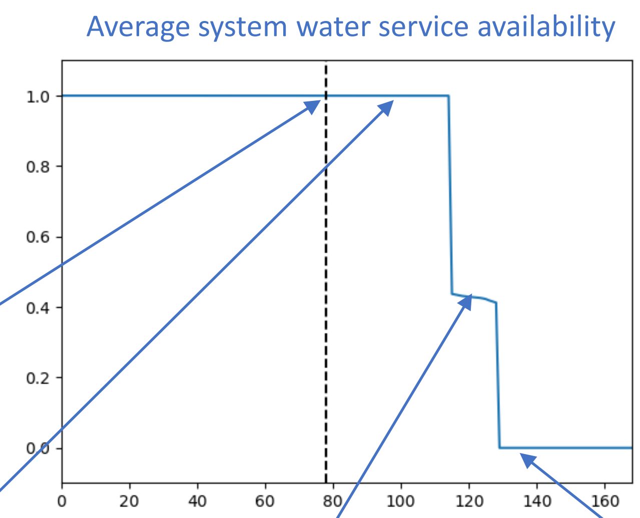
System wide average pressure shows steep decline as tanks empty

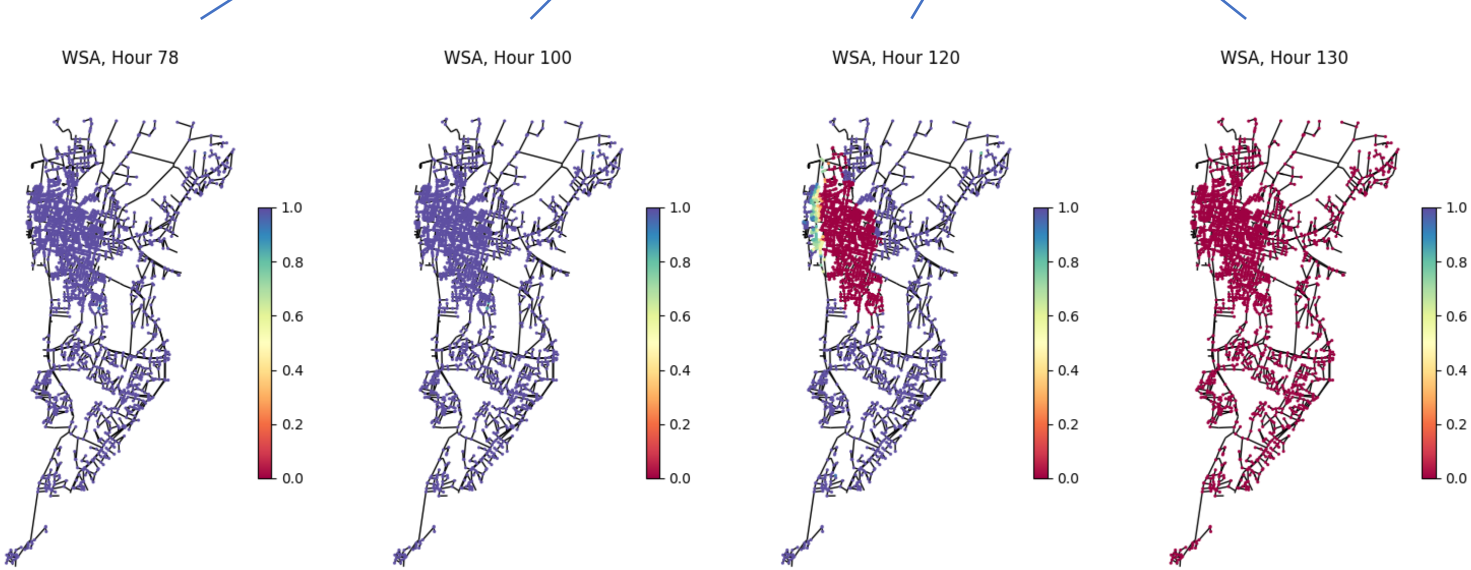




Water Service Availability After Shutdown

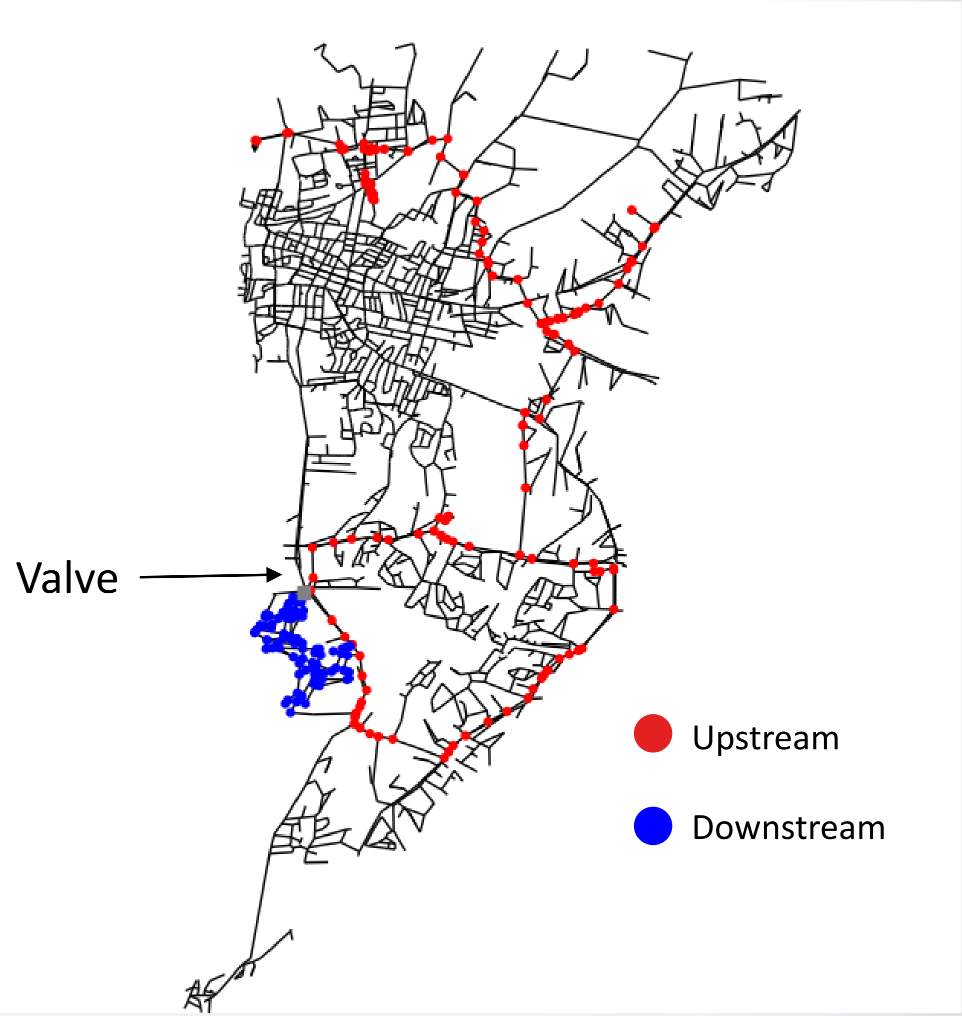
Full water service availability is maintained for 32 hours after shutdown, then service declines until it shuts off 51 hours after shutdown.





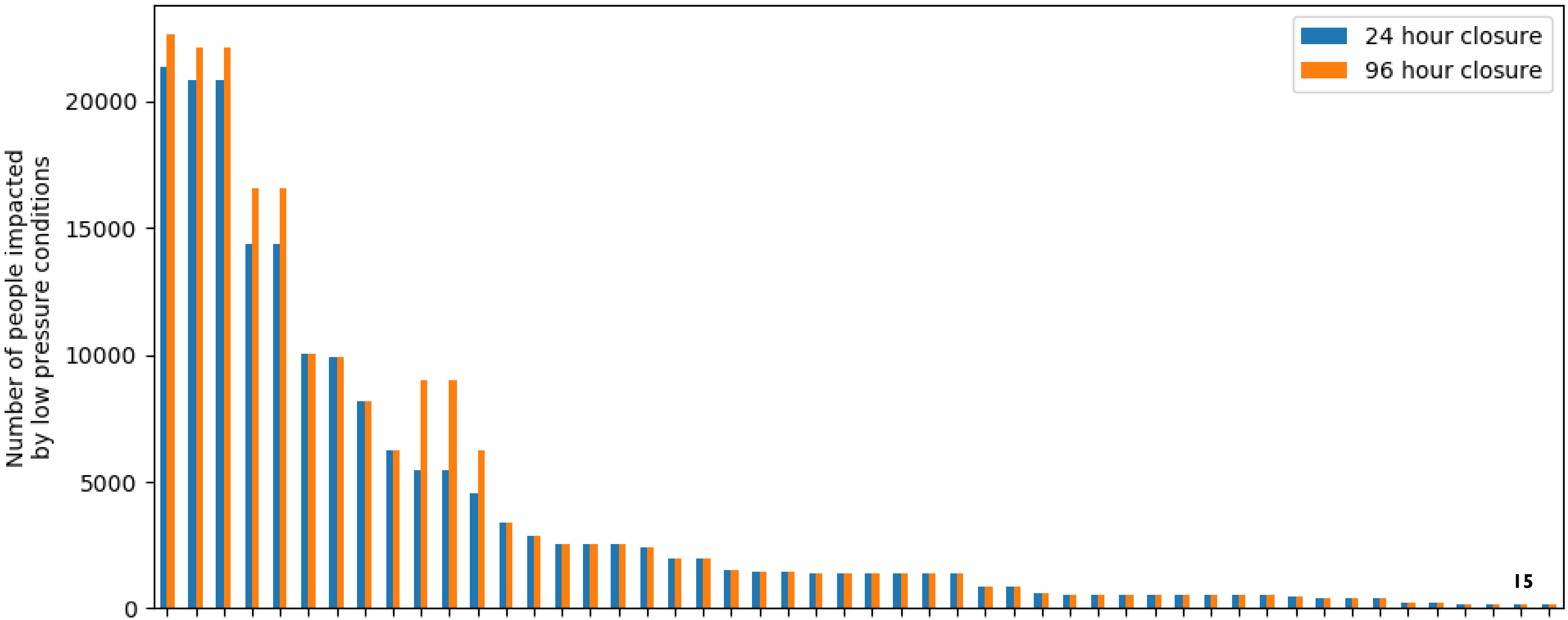
Hydraulic Conductivity Analysis

- **Hydraulic connectivity: understand critical hydraulic pathways in the network in order to better understand what customers would be affected by shutdown over time**
  - **Run trace simulations to track the percent of flow originating from each node in the network**
  - **Gather upstream and downstream nodes from each node**

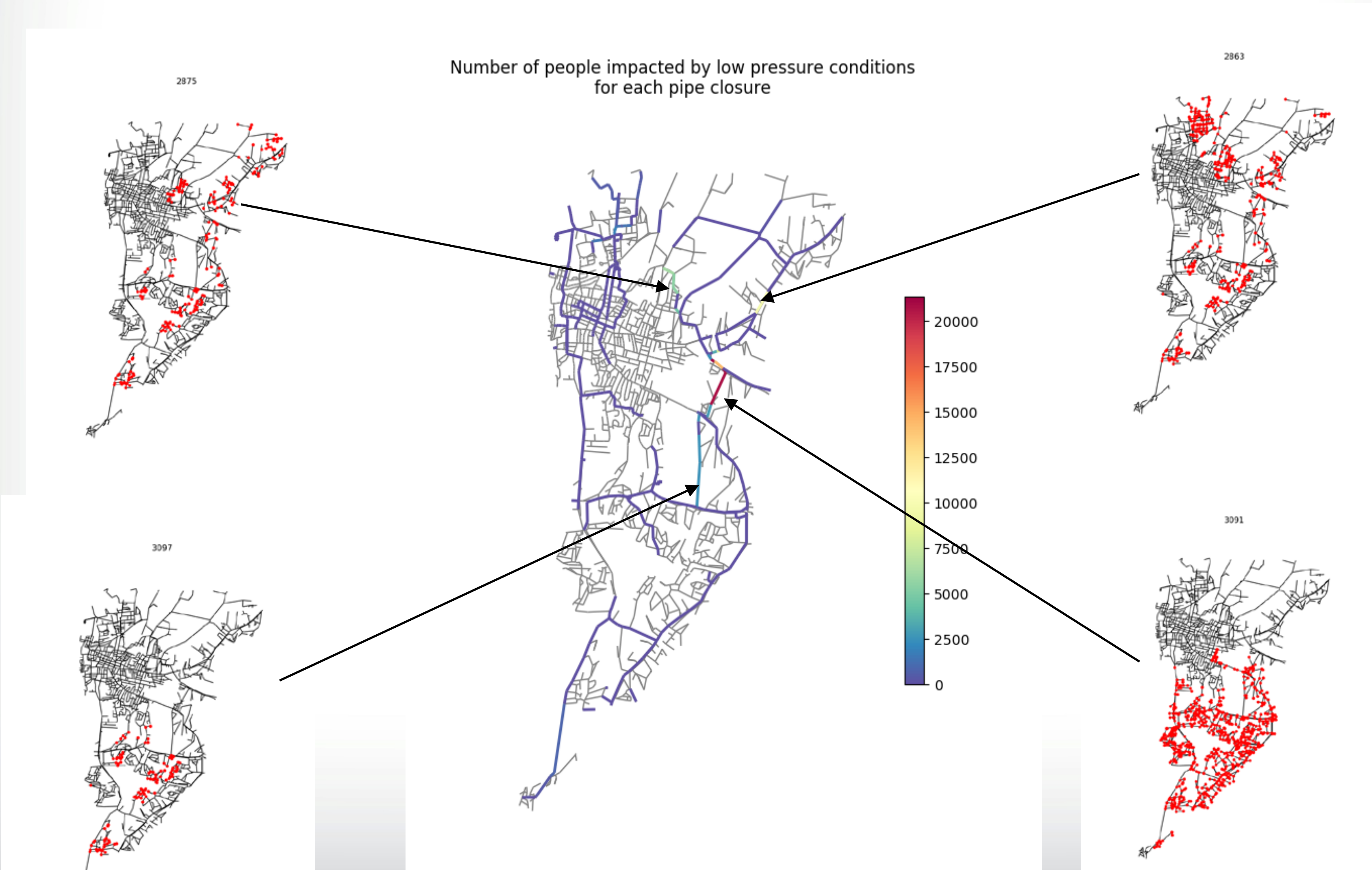


Pipe Criticality Analysis

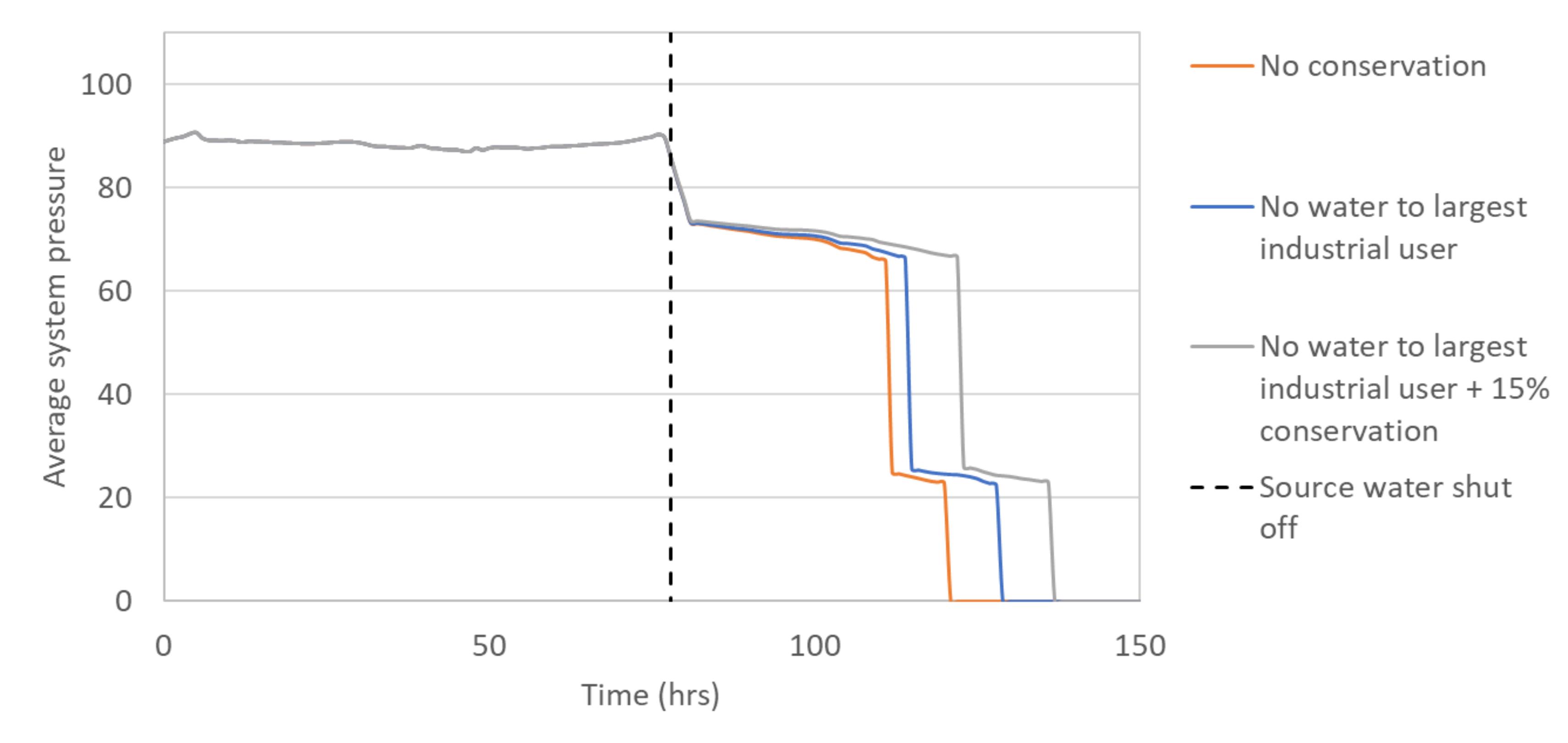
- Pipe criticality analysis: identify the number of people experiencing low pressure conditions following individual pipes closures
  - For each pipe >= 12 inches, run a PDD hydraulic simulation where the pipe is closed for 24 or 96 hours
    - Extract number of people impacted by pressure < 20 psi



Large Scale Pipe Break Analysis



Mitigation Strategies

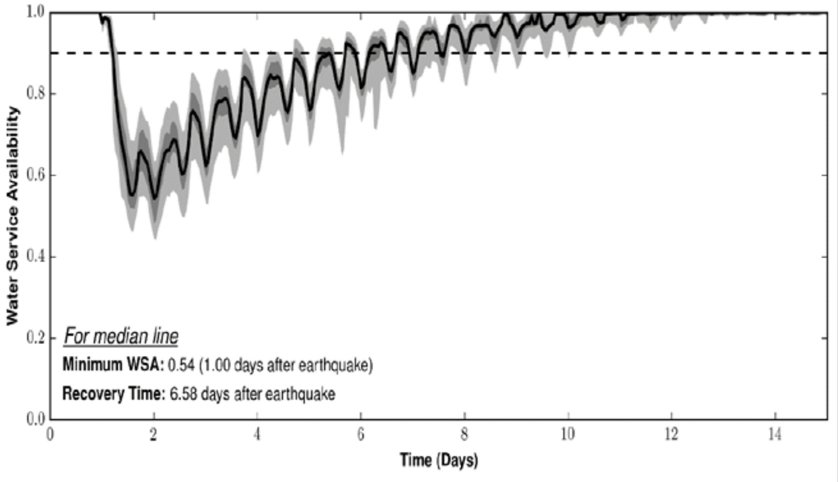


Long Term Power Outage

- Black Sky Event (>1 month)
- 14 Day Army Water & Energy Directive
- Consequences
  - Reduction in water service availability over time
  - Reduction in quality of water provided
- Response
  - Identify bare minimum levels of emergency service (scale back on quantity and quality)
  - Direct/isolate flow only to critical customers
  - Public health orders / conservation
- Mitigation
  - Additional back up power, local generation
  - Interconnections and agreements

Haywired Earthquake Scenario

- Magnitude 7 earthquake on Hayward Fault in San Francisco Bay Region
- Consequences
  - Reduction in water service availability over time
  - Reduction in pressure
- Response
  - Firefighting
  - Infrastructure repair
  - Public health orders / conservation
- Mitigation
  - Earthquake resistant pipes
  - Interconnections and agreements



Conclusions

- WNTR is a powerful tool for quantifying the resilience of water distribution systems to a variety of disaster scenarios
- WNTR extends the capabilities of basic hydraulic modeling to be more robust to failure scenarios
- By quantifying resilience, the benefits of different utility response strategies and long-term mitigation strategies can be compared
- WNTR is available at:

  https://github.com/USEPA/WNTR

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