United States Environmental Protection Agency

EPA Tools and Resources Webinar: Water Network Tool for Resilience

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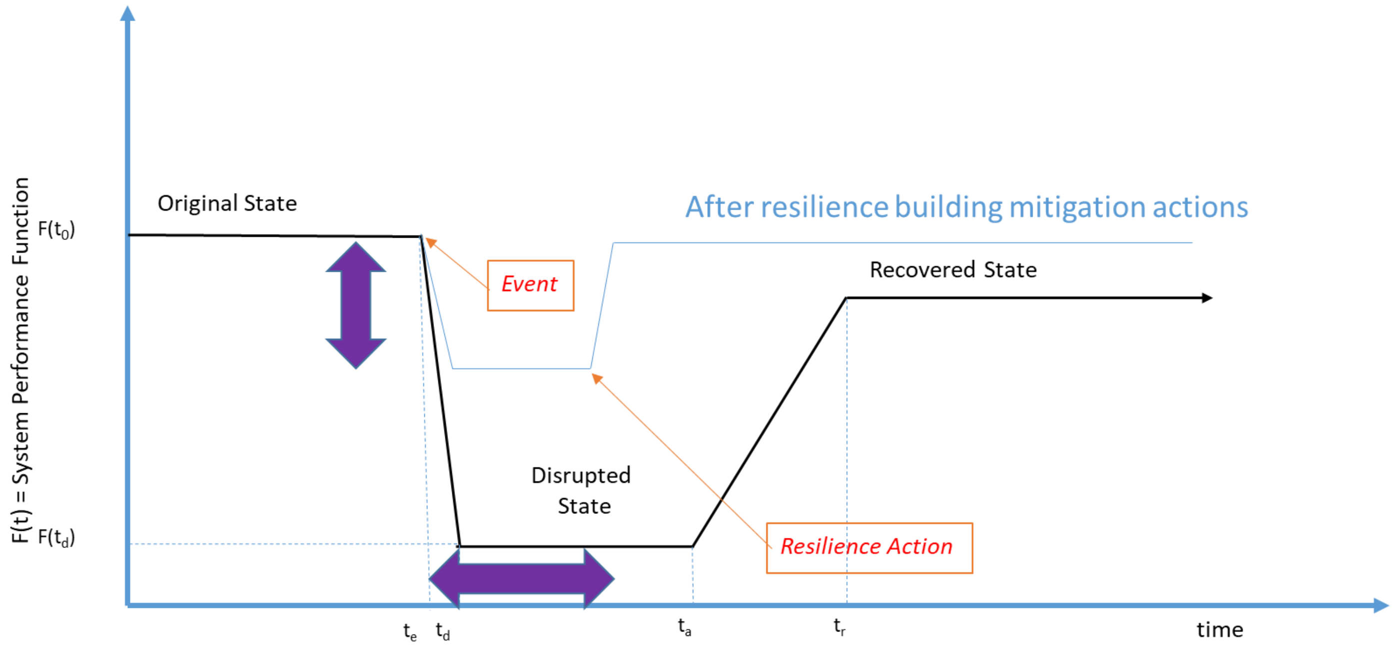
Motivation and Background

- More than 50,000 community water systems around the US supply high quality drinking water to customers
- Drinking water distribution systems face a variety of challenges
  - Solving water quality problems
  - Replacing aging infrastructure
  - Optimizing operations
  - Managing emergencies
  - Planning for the future

Potential Hazards	Potential Impacts
Natural disasters - Drought - Earthquake - Floods - Hurricanes - Tornados - Tsunamis - Wildfires - Winter storms Terrorist attacks Cyber attacks Hazardous material release Climate change	Infrastructure damage - Pipe breaks - Pump failure - Tank damage Service disruption Loss of access to facilities/supplies Loss of pressure or change in water quality Environmental impacts Financial impacts Social impacts

Building Resilience to Disasters

- Goal of a resilient system is to minimize the magnitude and duration of disruption
- Resilience of drinking water systems is influenced by
  - Design
  - Maintenance
  - Operations
  - Dependence with other critical infrastructure



Water Sector Resilience Guidance

[Access the EPA's Office of Water Hazard Resilience Guides]

Infrastructure Resilience Policy

- Installation Energy and Water Security Policy (Army Directive 2017-07)
  - Establish energy and water infrastructure requirements that ensure continuous availability, reliability and quality
  - Preparation for extended outages, providing necessary energy and water for a minimum of 14 days
- America's Water Infrastructure Act (AWIA, 2018)
  - Requires drinking water systems serving more than 3,300 people to develop
    - Comprehensive water system risk and resilience assessment
    - Emergency response plans that address physical and cybersecurity threats

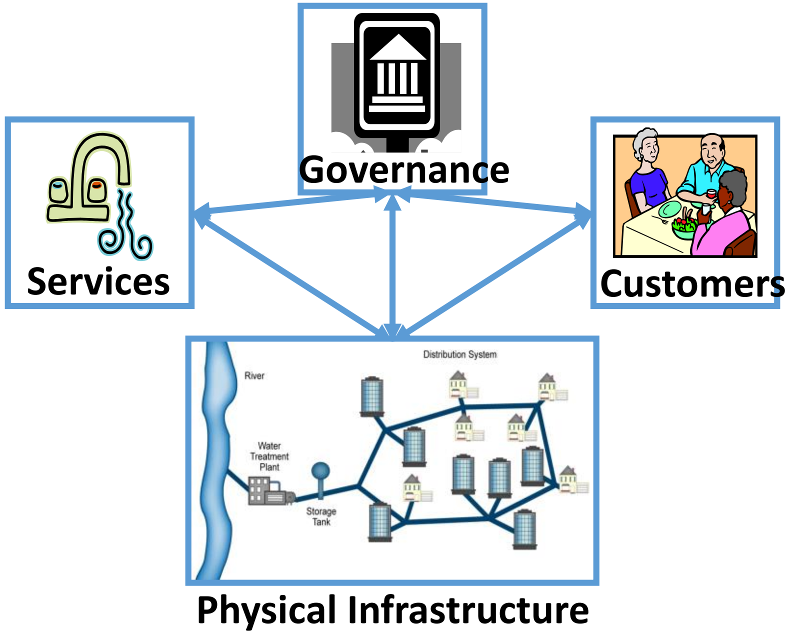
Utility Questions

- What type of infrastructure damage could be caused by the disaster?
- How long can the system continue to provide water to customers?
- How many people will be impacted?
- What is the best response in the immediate aftermath?
- Which components should be hardened to minimize future disruptions?

Credit: KTLA

Hydraulic Modeling

- Water distribution modeling tools can help
  - Quantify consequences for different disasters
  - Evaluate and prioritize resilience-enhancing actions
  - Justify capital investments in building resilience

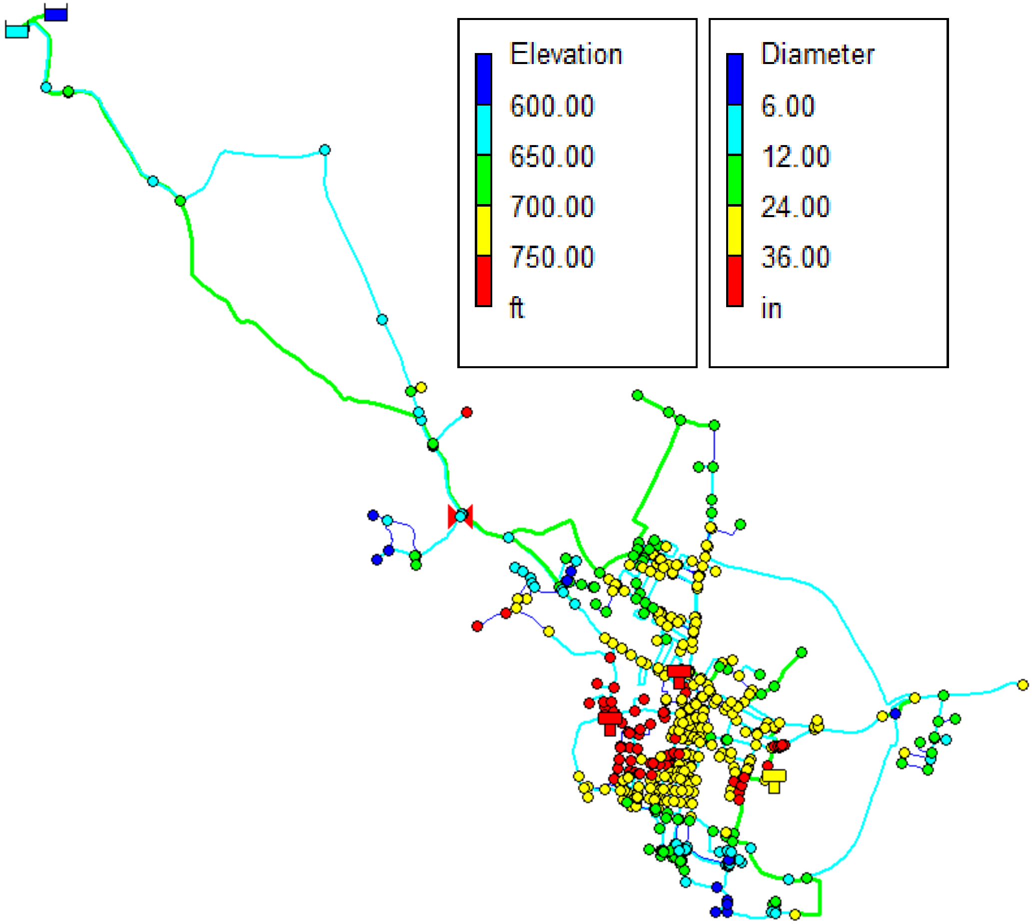


Hydraulic modeling is a systems-based approach to solving problems

Modeling and simulation tools (e.g., EPANET) simulate flow, pressure and water quality in distribution system

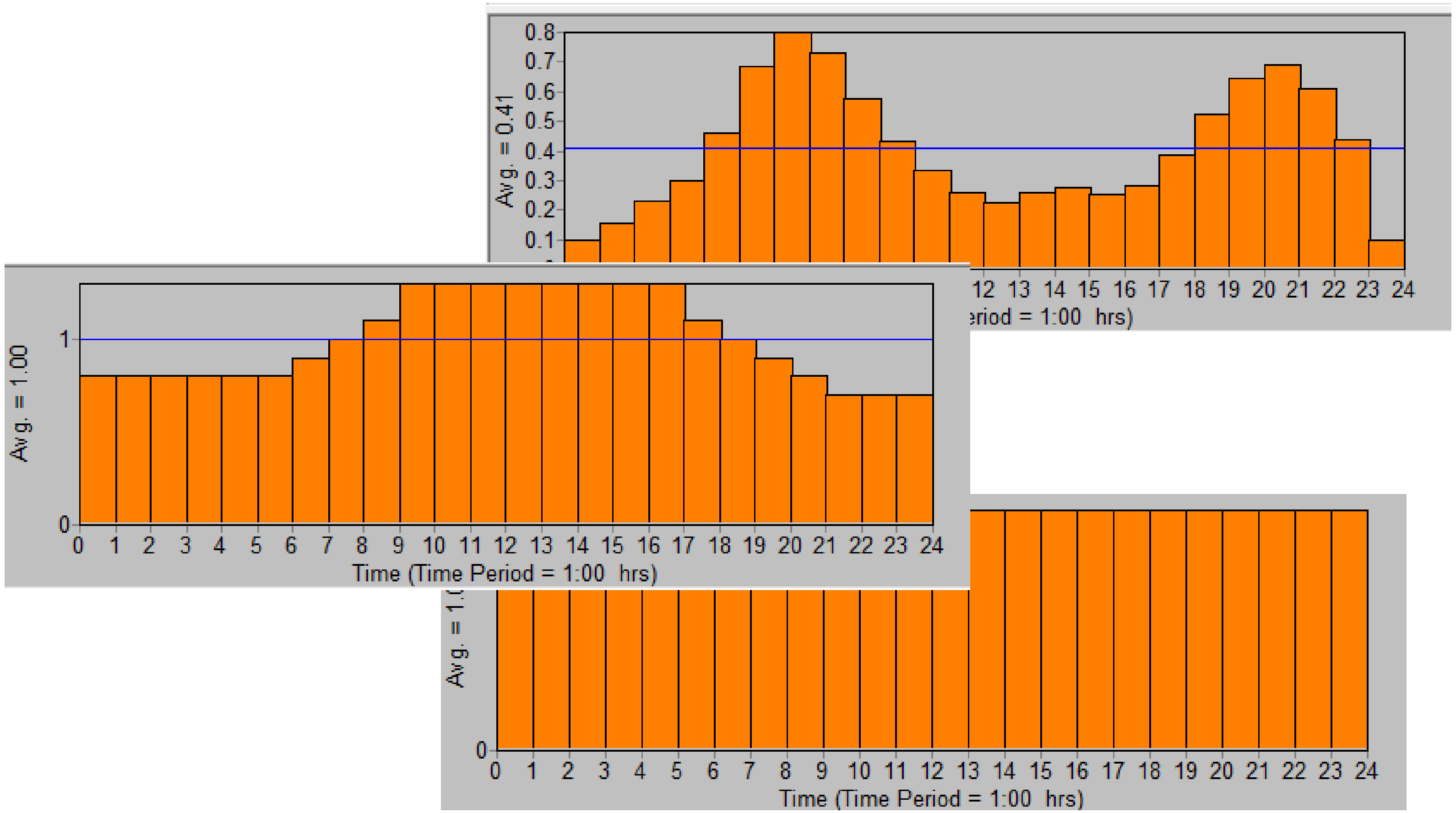
Represents Infrastructure

- 1.5 million gallons per day (MGD)
- 3,000 customers
- 2 reservoir sources
- 2 pumps
- 2 tanks
- 60 miles of pipe
- 645 pipes
- 545 junctions



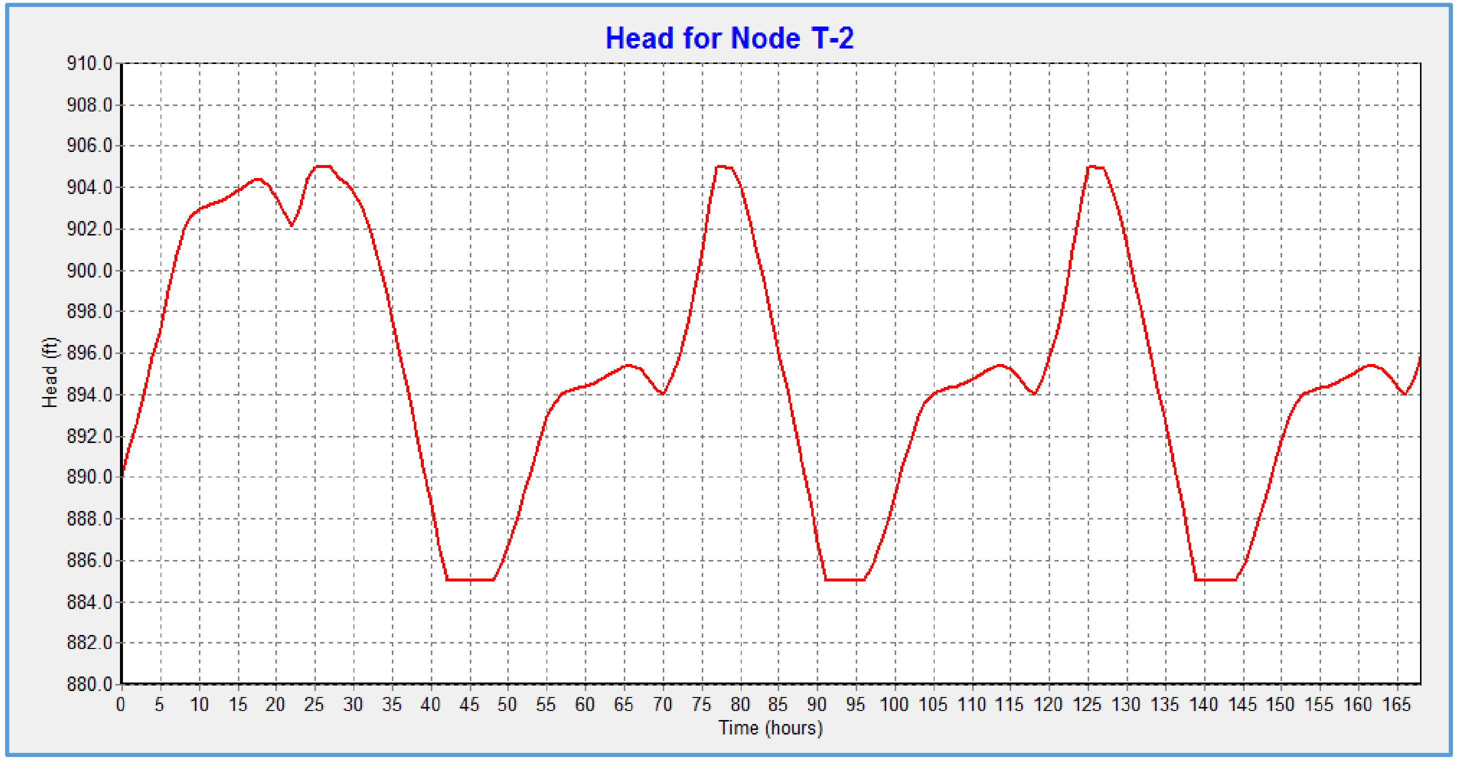
Represents Customer Usage

- 3,000 customers
- 60% residential use
- 25% commercial use
- 15% unaccounted for water

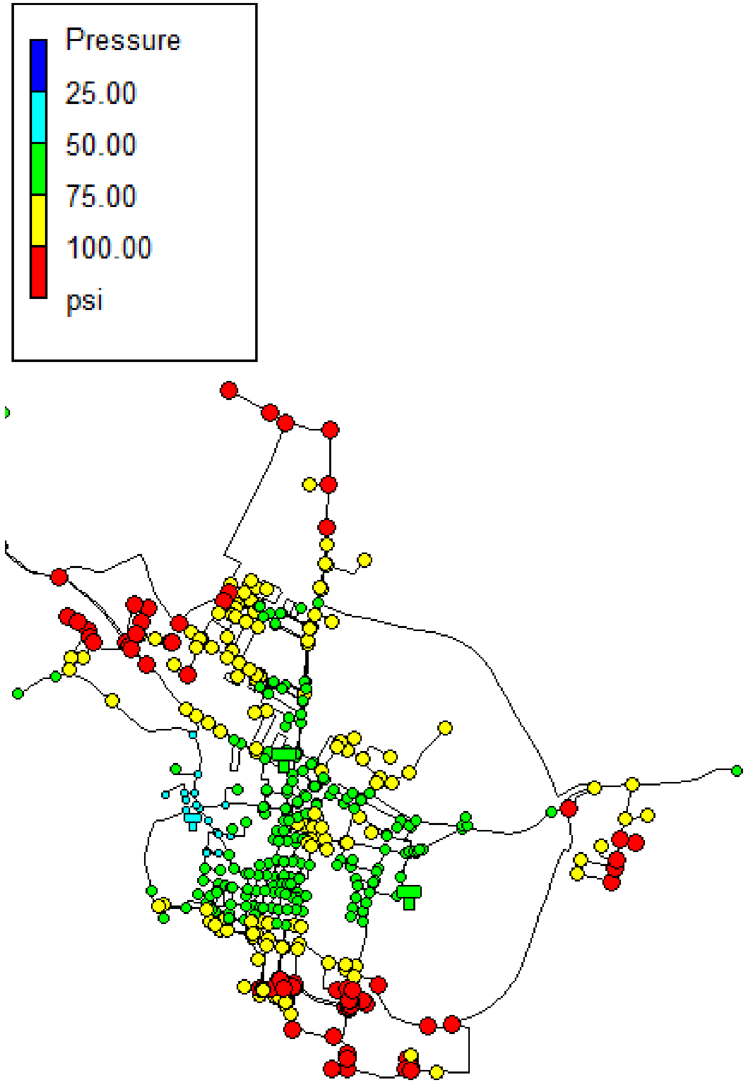


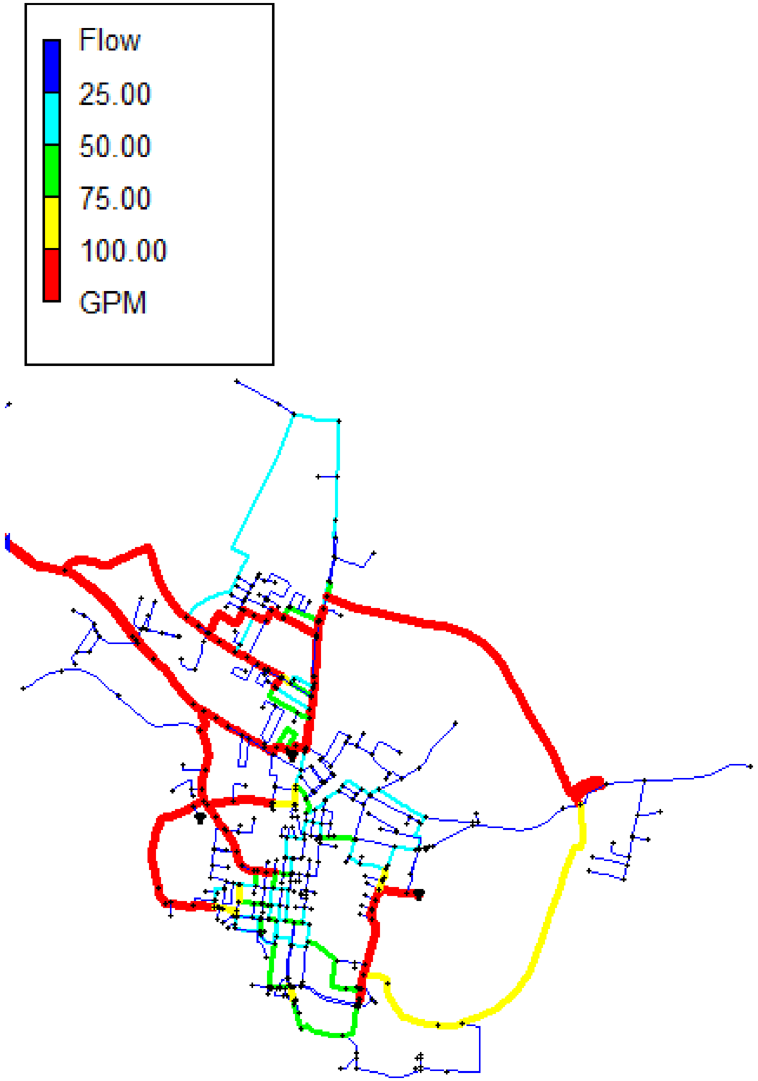
Represents Operations

- Pump is On if Tank is below 5 ft (888 ft)
- Pump is Off if Tank is above 19 ft (904 ft)



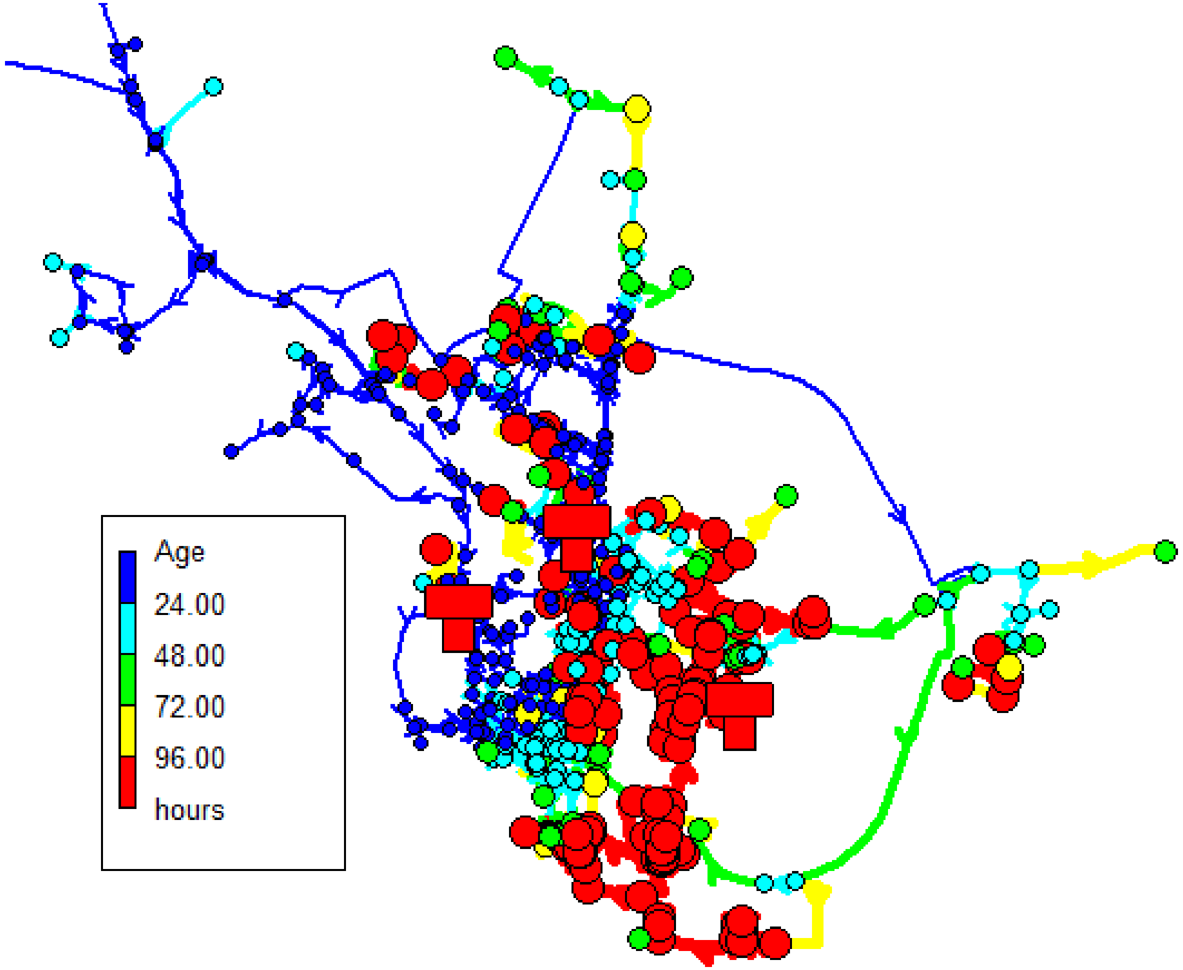
Predicts Pressure and Flow





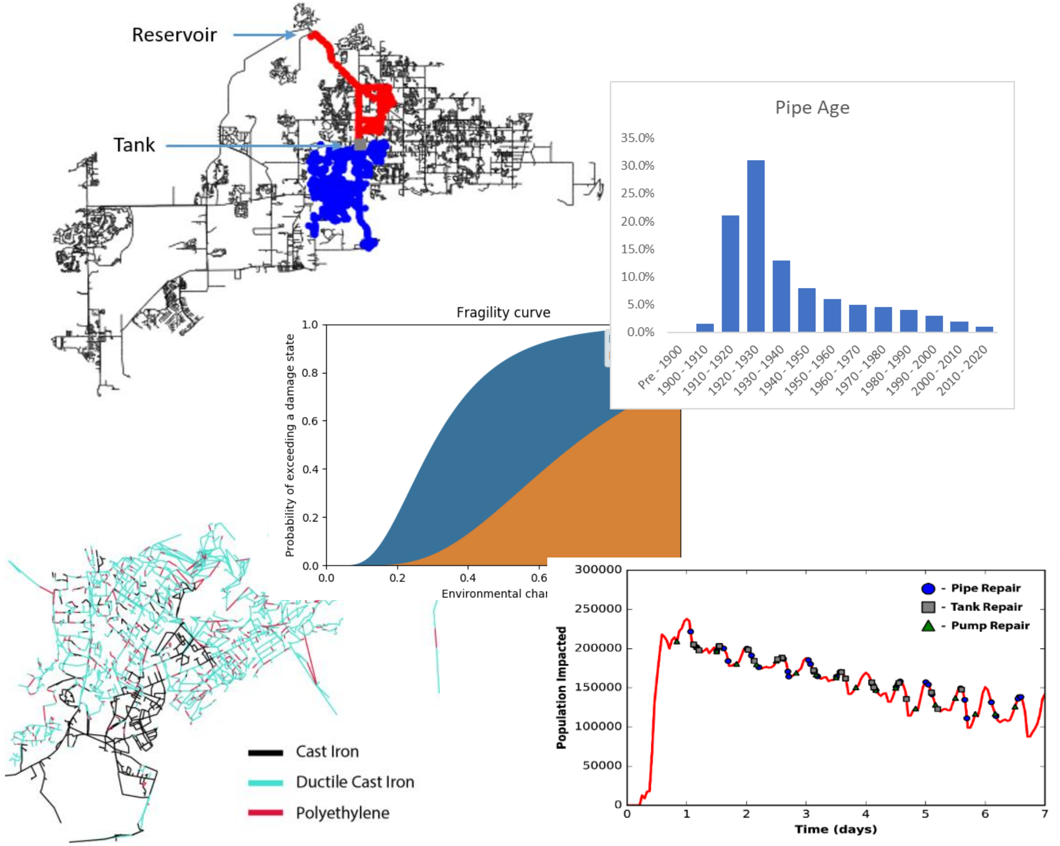
Predicts Water Quality

- Water age can be a surrogate for declining water quality



Water Network Tool for Resilience (WNTR)

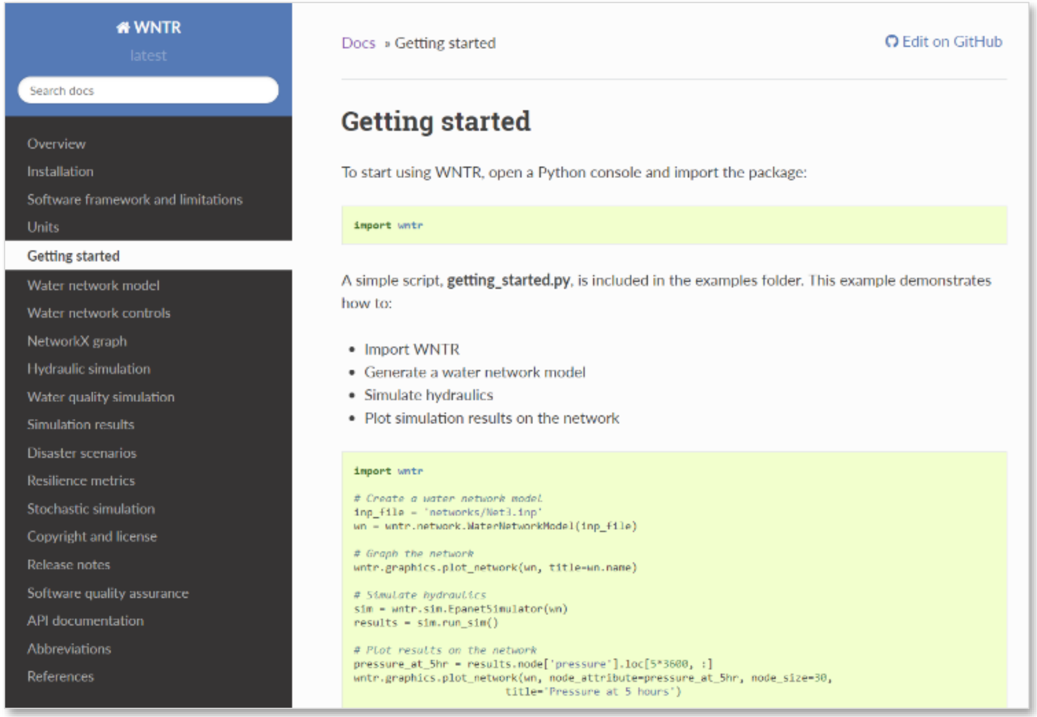
- Designed to analyze water distribution system failure and recovery

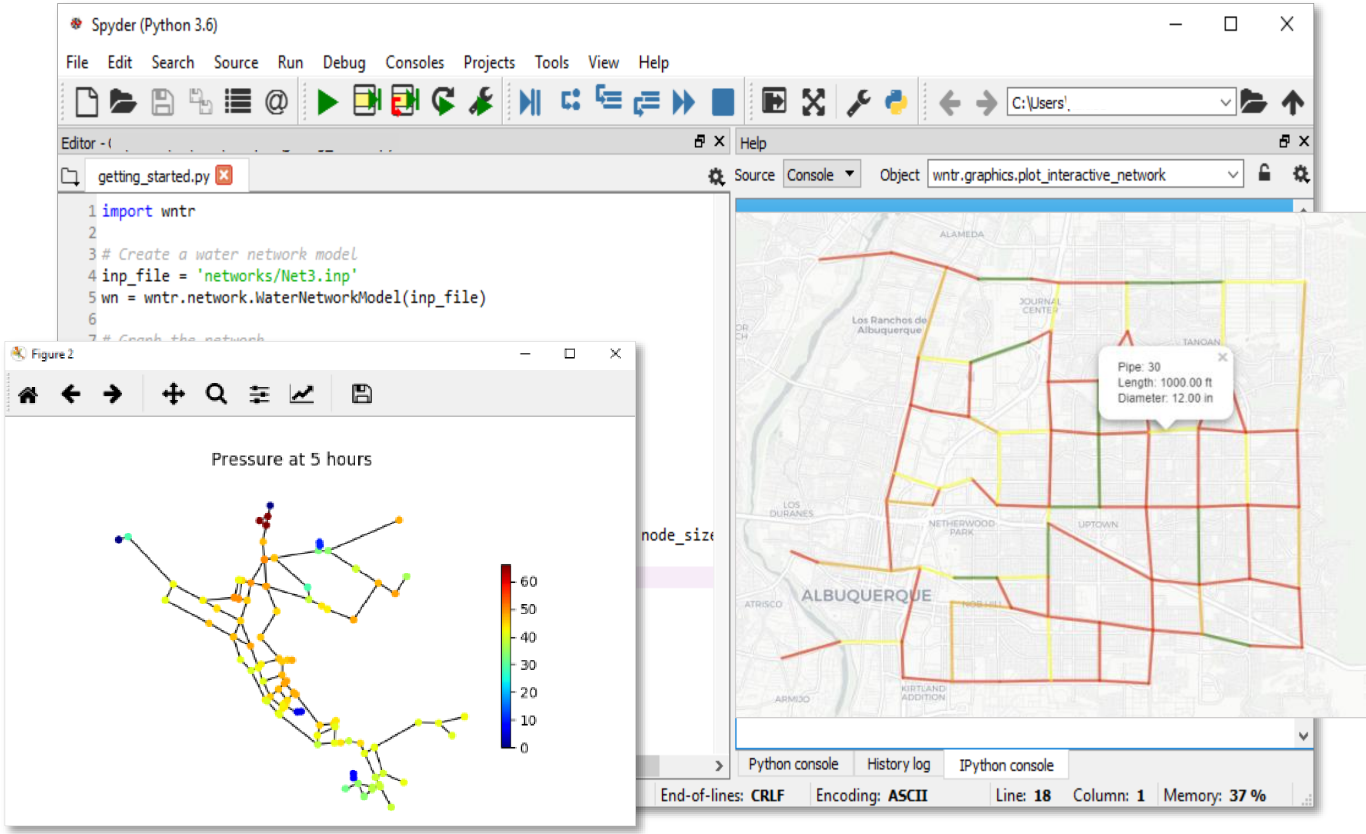


[Access the Water Network Tool for Resilience (on GitHub)]

WNTR Framework

- Open source Python package
- Integrates commonly used and efficient Python packages
- Git repository, extensive online testing and documentation





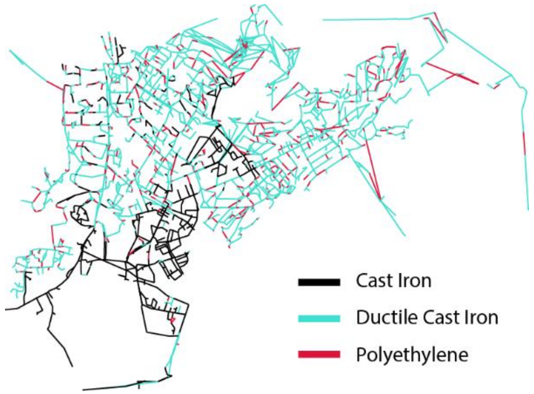
WNTR Water Network Model

- Generate network model from EPANET INP file or from scratch
- Model contains physical layout and system operations
- Add/remove/modify components
- Query node/link attributes
- Skeletonize network models
- Assign and plot network attributes
- Analyze network structure

Original network

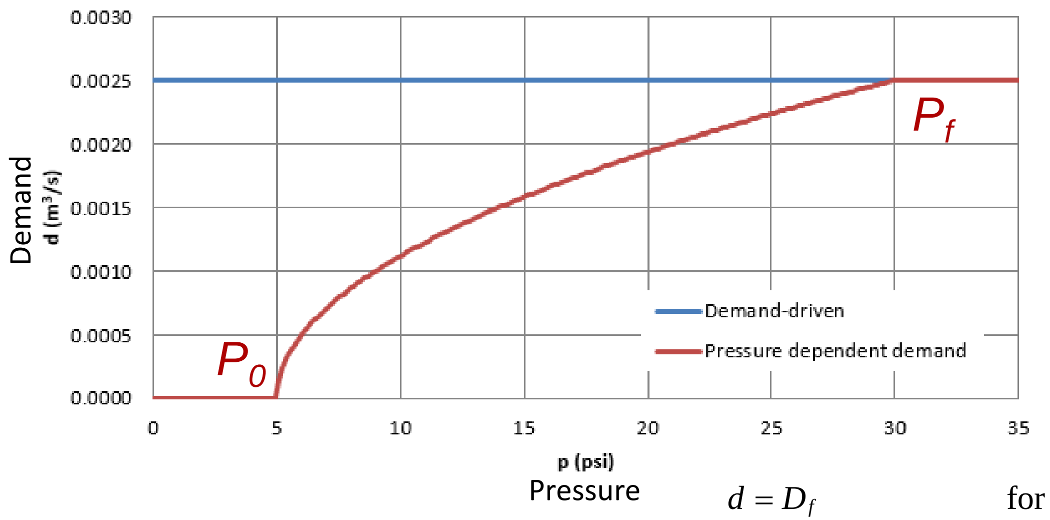
Skeletonized network

Pipe Material



Hydraulic and Water Quality Simulation

- Demand-driven hydraulic simulation
- Pressure dependent demand hydraulic simulation
  - Demand at node depends on pressure available at node
- Water quality simulations to compute water age or contaminant concentration
- Simulation start/stop capabilities
- Feedback loops, cascading failure
- Monte Carlo simulation for sensitivity analysis
- Parallelization – multiple simulations performed at once



$$d = D_f \qquad \text{for } p \geq P_f$$

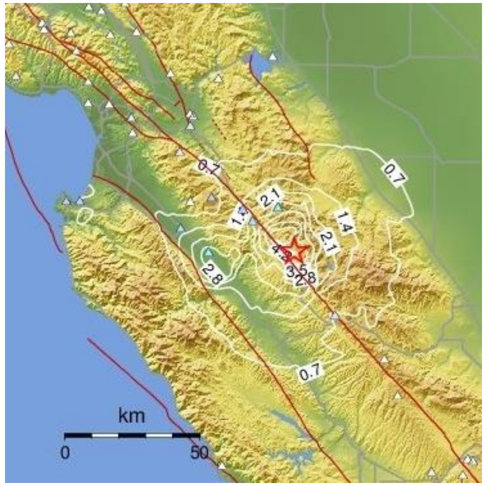
$$d = D_f \left(\frac{p - P_o}{P_f - P_o} \right)^{1/e} \qquad \text{for } P_o < p < P_f$$

$$d = 0 \qquad \text{for } p \leq P_o$$

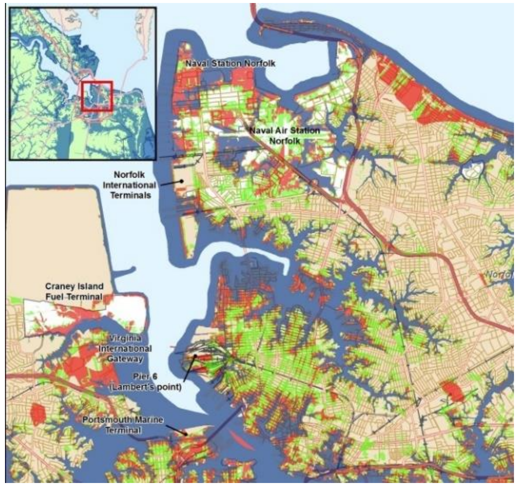
Modeling Disruptive Incidents

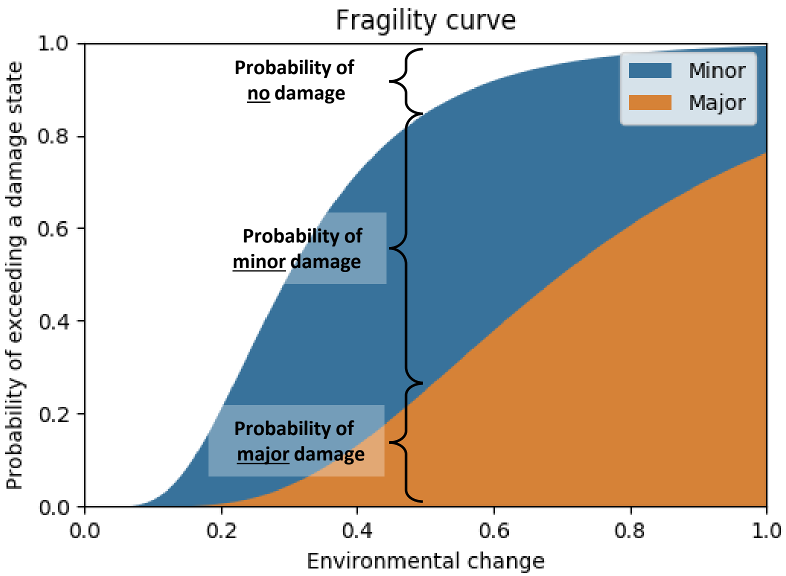
- Define disruptive incident
  - Informed by data or a model
- Define probability of damage
  - Fragility and survival curves
- Modify the model
  - Controls, demands, components, attributes to match each scenario

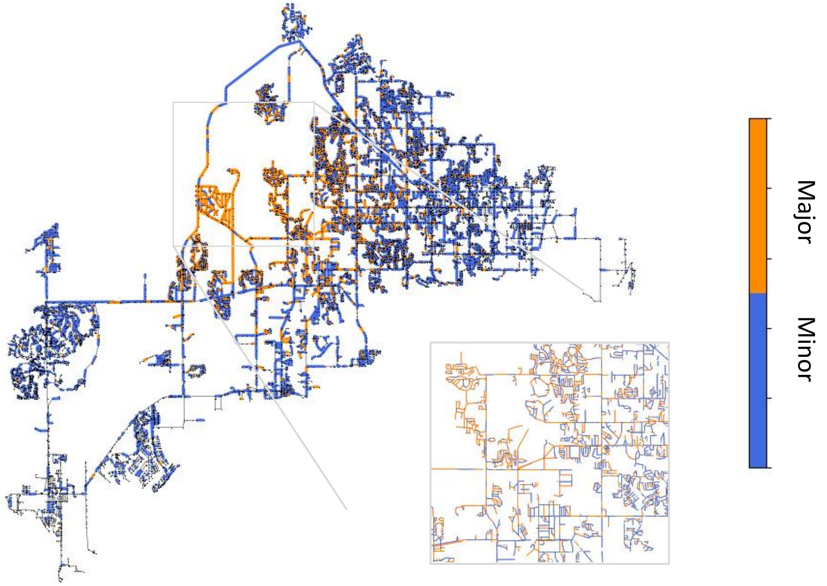
PGA after an earthquake in California (USGS)



100-yr flood stage with sea level rise in Virginia (100RC)



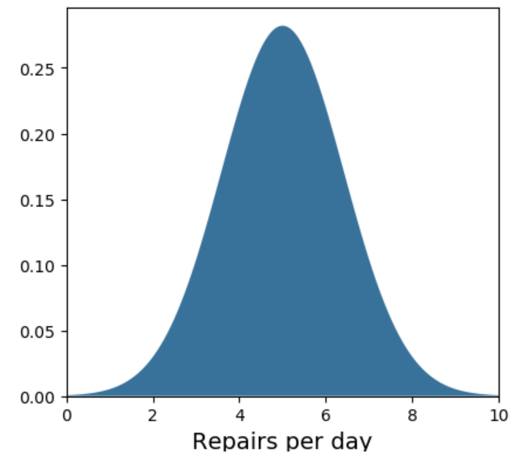




Modeling Restoration Actions

- Define the restoration action
  - Type of repair actions
  - Number of crews
  - Time to repair
  - Supply chain
- Define priorities
  - Distance from the reservoir or maintenance yard
  - Magnitude of leak
  - Number of people affected
- Modify the model
  - Controls, demands, components, attributes to match each scenario

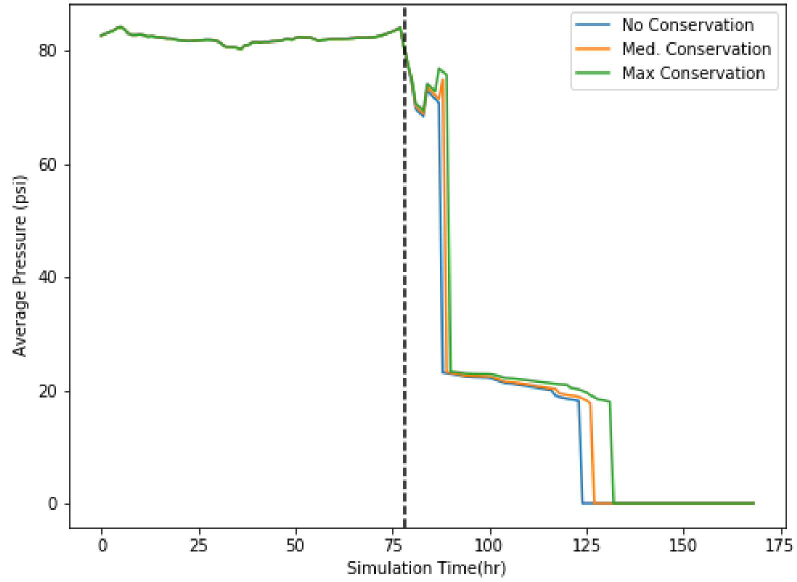
Repair Strategy Following 2014 Napa Valley Earthquake
Number of repair crews – 5
Repairs per day – 5 *(120 breaks fixed in 5 days)*
Repairs started 24 hours after earthquake
Separate team repaired tank
Prioritized repairs by proximity to limit travel time
Production maximized to feed leaks
Boil water order for affected regions

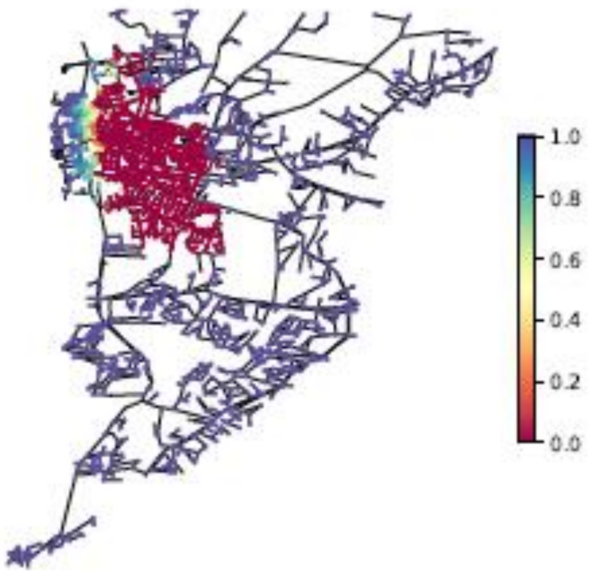


Quantifying Resilience

- Numerous metrics have been suggested to quantify reliability, robustness, redundancy, and security for water distribution networks
  - Topographic metrics
  - Hydraulic metrics
  - Water quality metrics
  - Economic metrics

- Commonly used metrics include
  - Water service availability
  - Population impacted by service disruption or low-pressure conditions
  - Water age and chlorine residual
  - Cost associated with repair and lost service

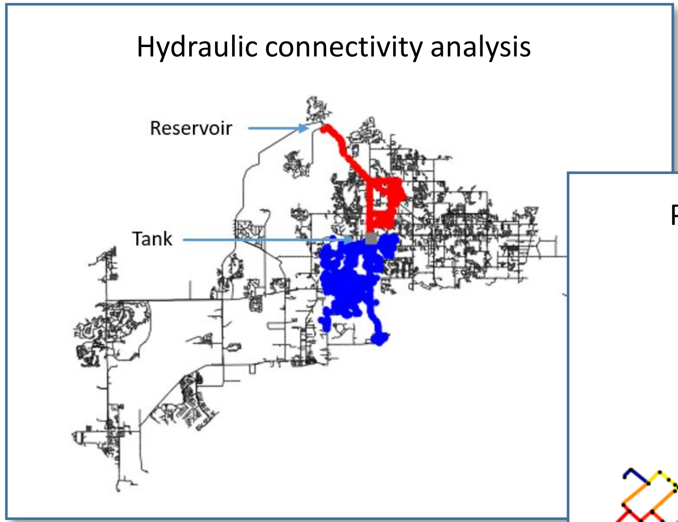


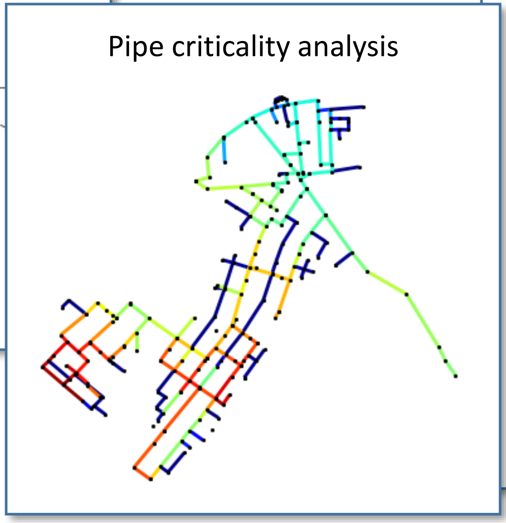


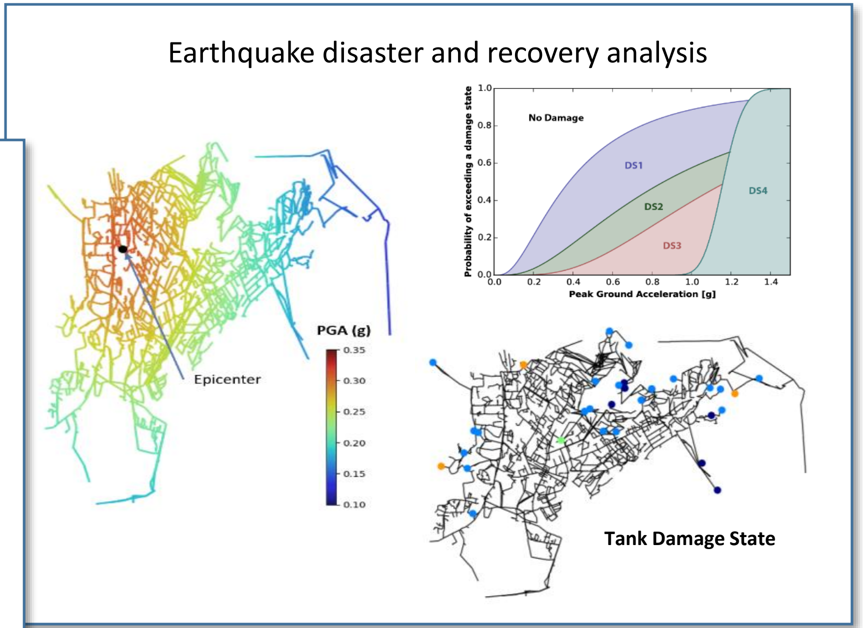
Water service availability at hour 88

Resilience Analysis Options

- Hydraulic connectivity during normal and abnormal times of service
- Component criticality analysis (rank individual component failures)
- System resilience analysis (system wide damage and recovery actions)

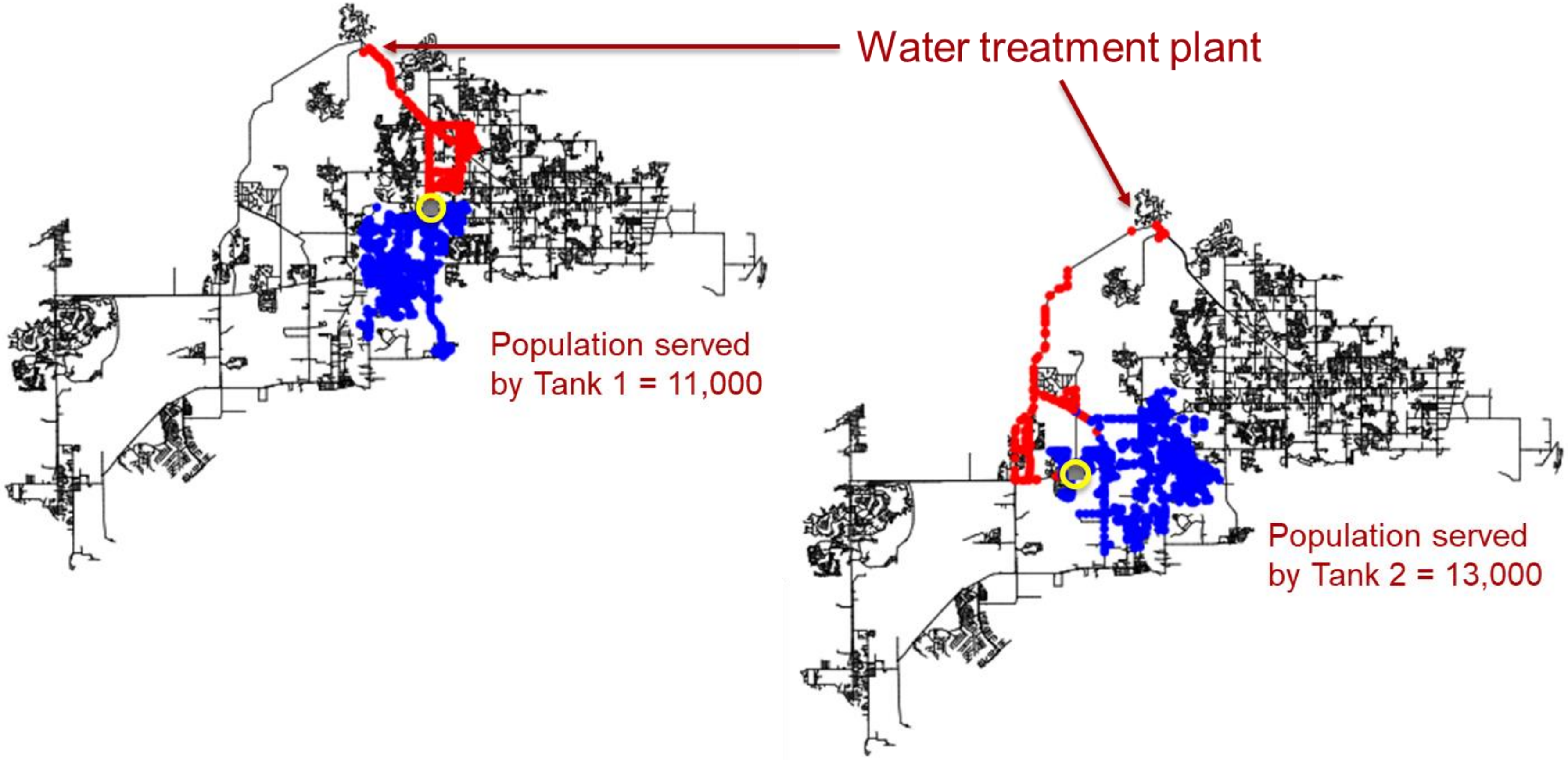






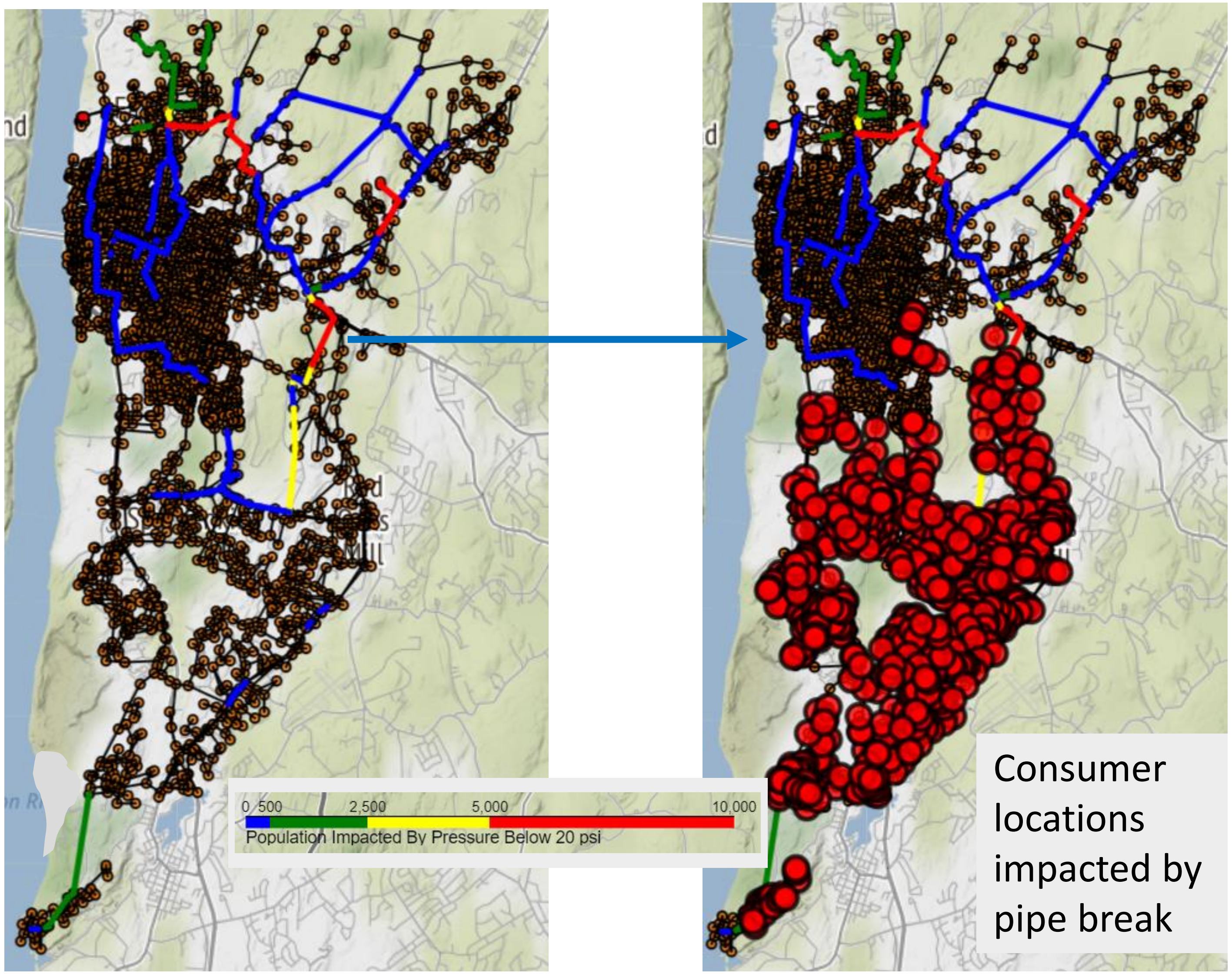
Hydraulic Connectivity Analysis

- Evaluate critical paths between water treatment plant and customers
- Compute upstream and downstream nodes from tanks, valves, pumps



Pipe Criticality Analysis

- Identify population impacted by low pressure conditions caused by individual pipe breaks
- Extend analysis to include valve segments
- Results help prioritize capital expenditures



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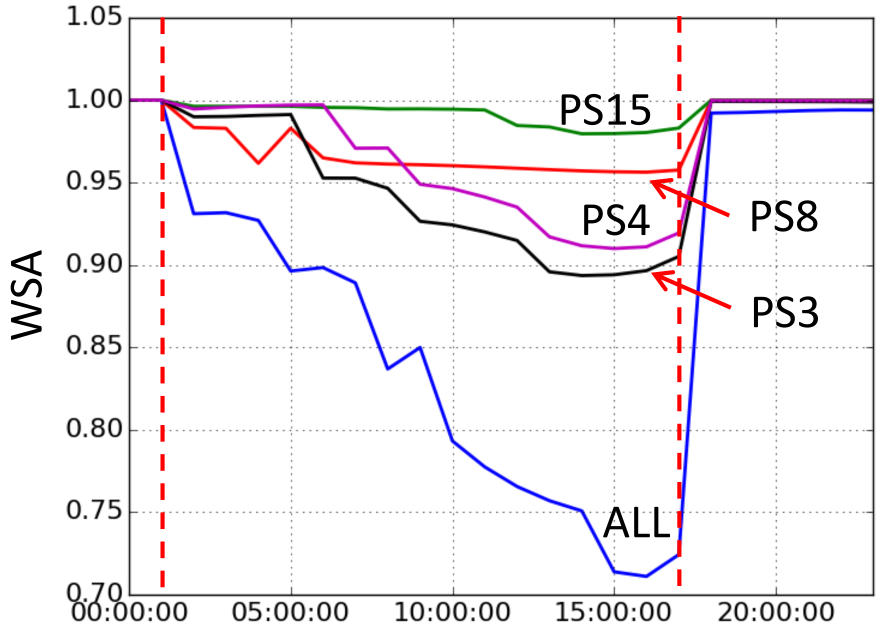
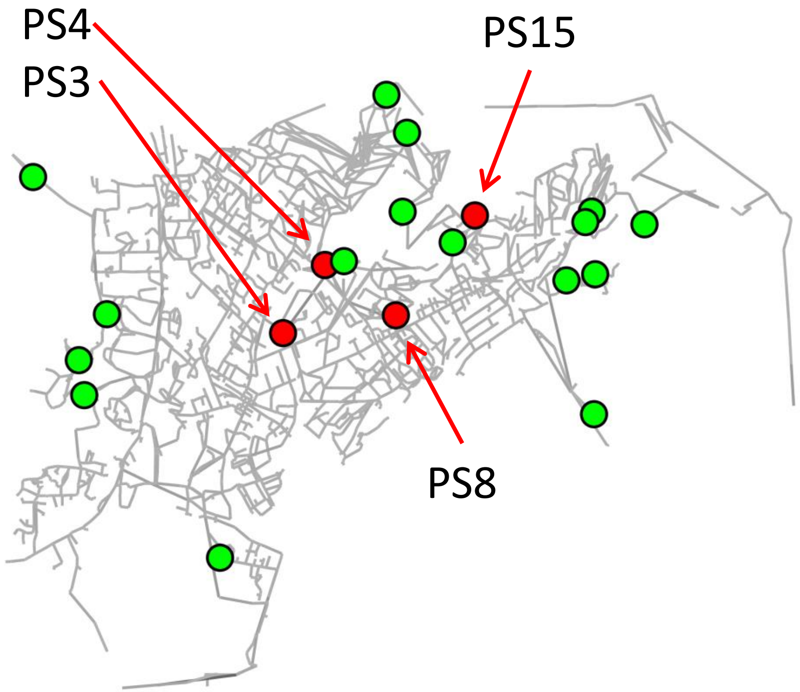
Power Outage Analysis

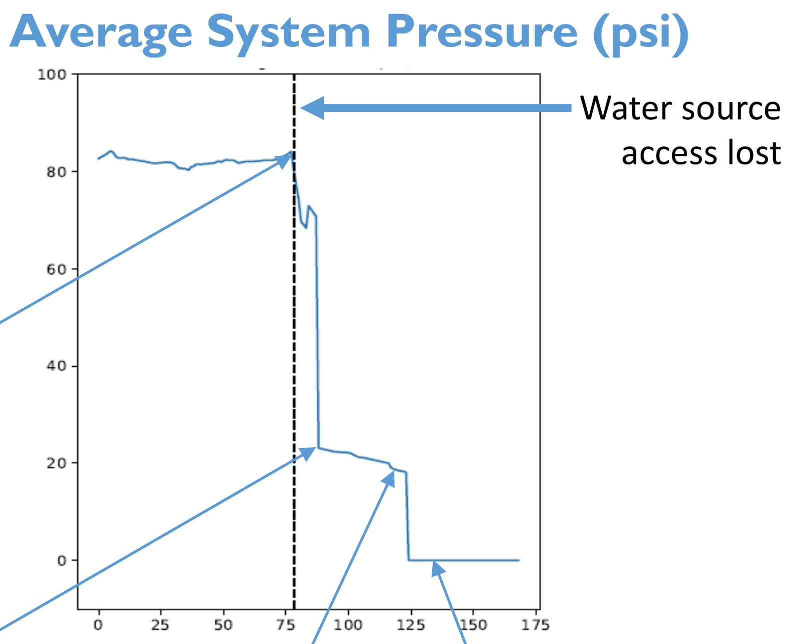
- Water Service Availability (WSA) decreases when the power outage begins
- WSA increases again when the power is restored after 15 hours
- Results for single pump outages and simultaneous failure at all four pumps (red circles) shown

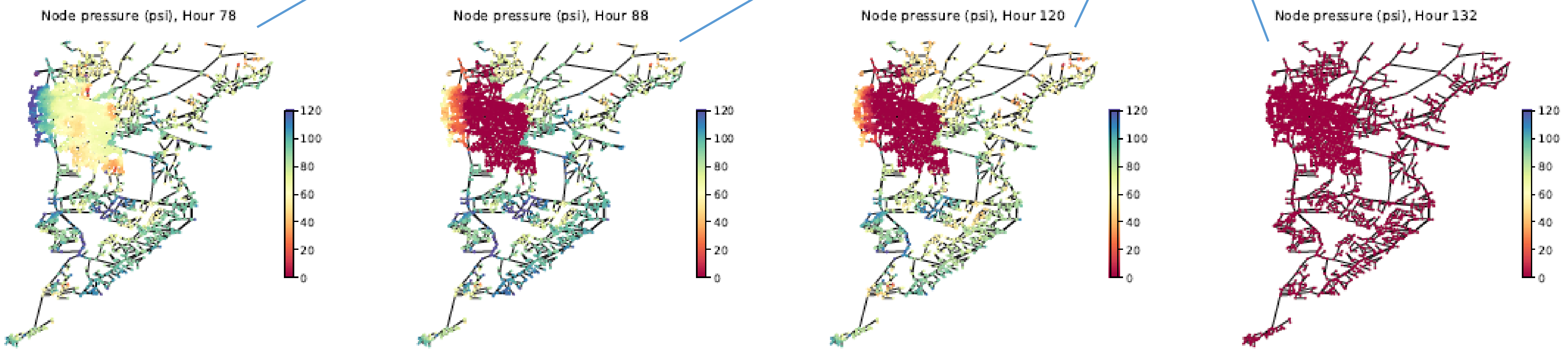




Compromised Source Water Analysis

- Loss of source water due to river contamination, treatment plant failure, winter storm freezing water intake, or power outage
- Track water pressure and water service availability over time
- Test and evaluate mitigation strategies





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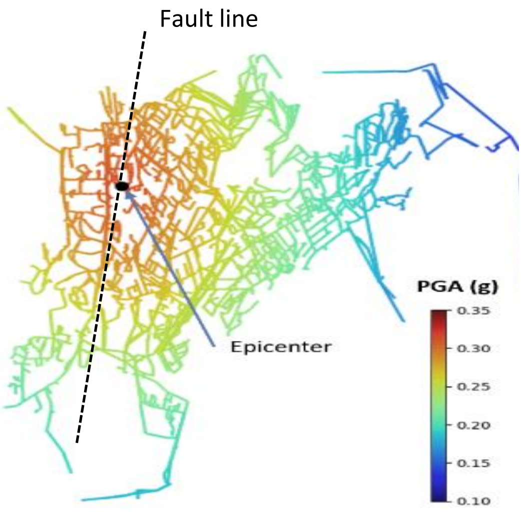
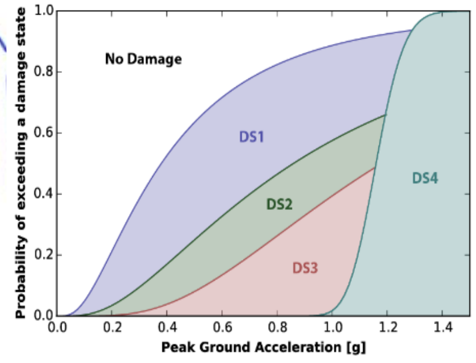
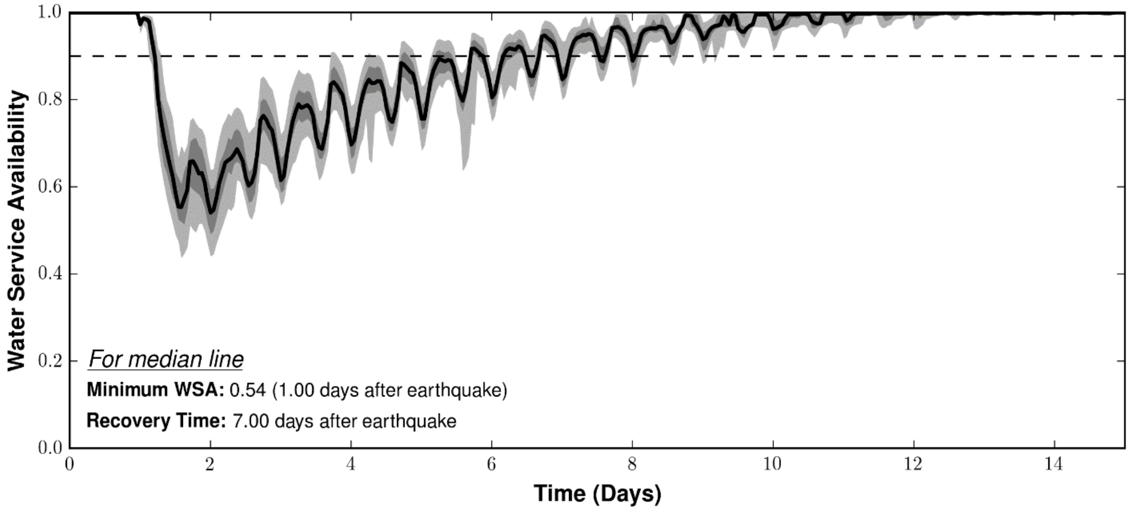
Earthquake Analysis

- Based on 2014 Napa Valley Earthquake
- Assess water service availability and fire fighting capacity following earthquake along fault that bisects water utility
- Damage a function of soil type, pipe material, and peak ground acceleration using fragility curves
- Repair strategy
  - Set number of pipe, tank, and pump repair crews
  - Prioritization for largest leak and pumps closest to reservoir





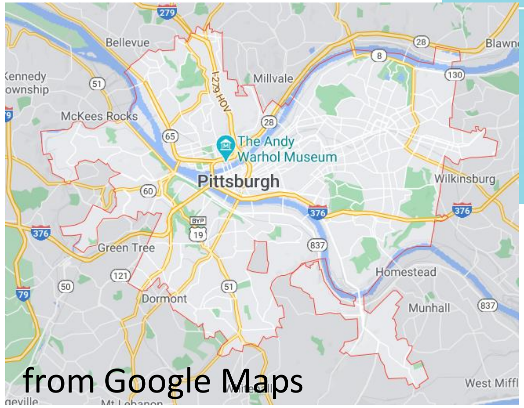
Central epicenter, 6.5 magnitude earthquake



Klise, K.A., Bynum, M., Moriarty, D. and Murray, R., 2017. A software framework for assessing the resilience of drinking water systems to disasters with an example earthquake case study. *Environmental Modelling & Software*, *95*, pp.420-431.

Ongoing Case Study Applications

- Fort Campbell Army Base – Fort Campbell, Kentucky
    - General resilience, pipe criticality
    - 14-day water and energy security directive
- Pittsburgh Water and Sewer Authority (PWSA) – Pittsburgh, Pennsylvania
    - General resilience, pipe criticality
    - Landslides
- Water and Power Authority (WAPA) – St. Croix & St. Thomas/St. John, US Virgin Islands
    - General resilience, pipe criticality
    - Fire-fighting capability
    - Hurricanes
    - Earthquakes



Case Study Analysis Results

- Inform capital and operational investments
  - Additional storage
  - Backup repair supplies
  - Additional repair crews
  - Backup power supply/generators
- Assist in training exercises for emergencies
  - Quantify consequences
  - Compare response and mitigation strategies

WNTR Future Directions

- Incorporate optimization algorithms to help prioritize response and mitigation actions
  - Los Angeles Department of Water and Power – identify installation order for earthquake resistant pipes

- Expand capabilities to simulate additional disaster and response scenarios
  - Long-term power outages (Black Sky Event >1 month)
- Develop example disaster scenario scripts to increase WNTR usability
- Engage with additional case study partners

Summary

- Wide range of capabilities to help water utilities do “deeper dive” into understanding the resilience of their drinking water system
- Integrating hydraulic models and resilience metrics helps water utilities quantify benefit of response actions and long-term mitigation strategies
- Open-source software makes these methods available to wide audience
- Water utilities, research groups, and government organizations are invited to work with us on case studies

Contact

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[Access the Water Network Tool for Resilience (WNTR)]

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