Using Hydraulic Modeling to Assess Resilience of Drinking Water Systems to Natural Disasters and Other Hazards

Regan Murray

USEPA Office of Research & Development

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Presentation Outline

- Motivation & background
- Systems modeling
- Modeling resilience
- Water Network Tool for Resilience (WNTR)
- Case studies

Motivation

- What kind of damage should *we* expect in *our* drinking water system from:
  - A magnitude 7 earthquake (e.g., Napa Valley, CA)?
  - A hurricane (e.g., Irene in VT)?
  - A regional power outage (e.g., Northeast Blackout)?
  - A contamination incident (e.g., Elk River Spill in WV)?
  - A tornado (e.g., Joplin, MO)
- How long can *we* continue to provide water to customers?
- How many people will be affected?
- How can *we* best respond in the immediate aftermath?
- How can *we* harden our system against future such disasters?

Building Resilience to Disasters

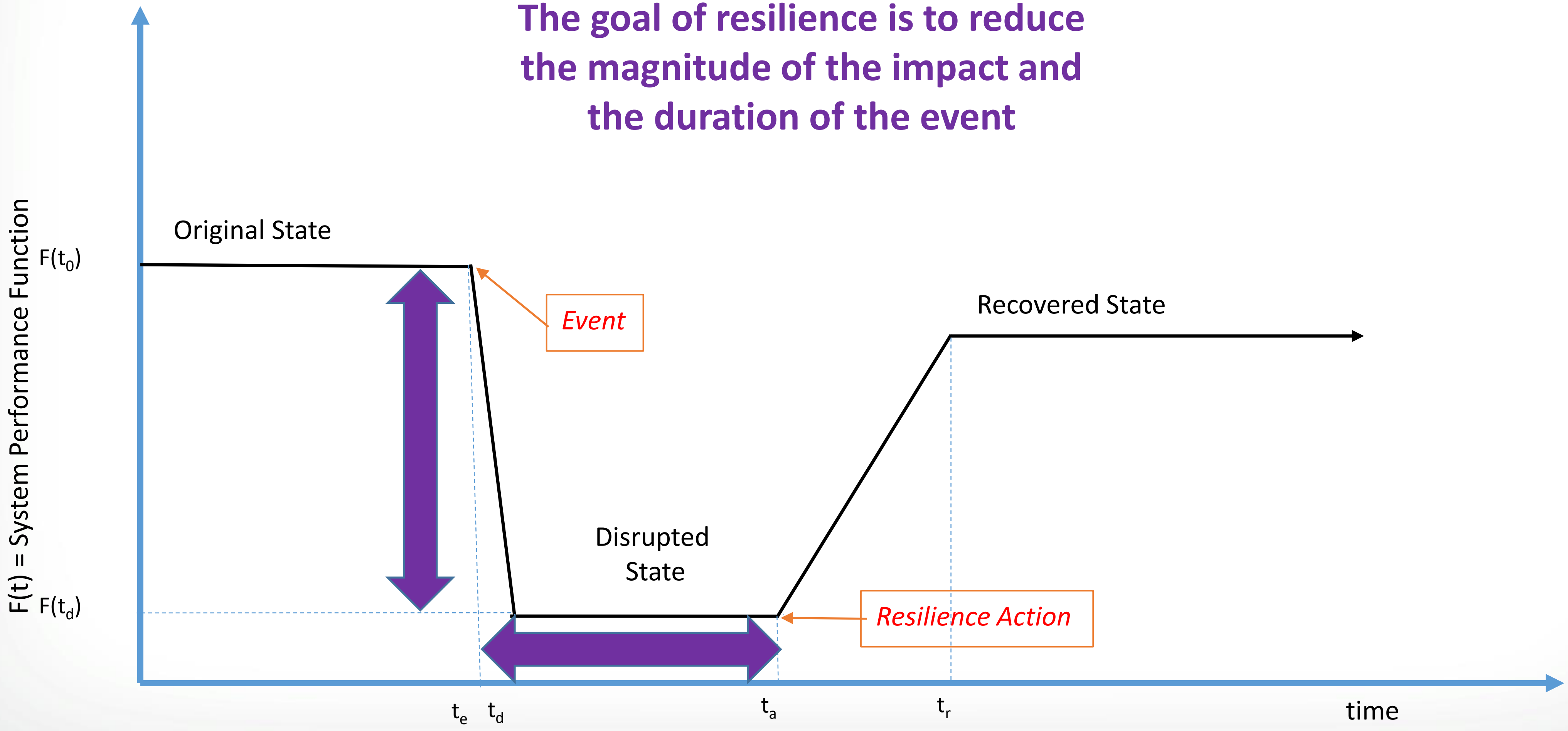
- Disaster resilience is the ability of a human system to prepare and plan for, manage during, recover from, and successfully adapt to adverse events

- Resilient systems are:
  - Robust
  - Redundant
  - Resourceful
  - Adaptable
  - Able to recover rapidly

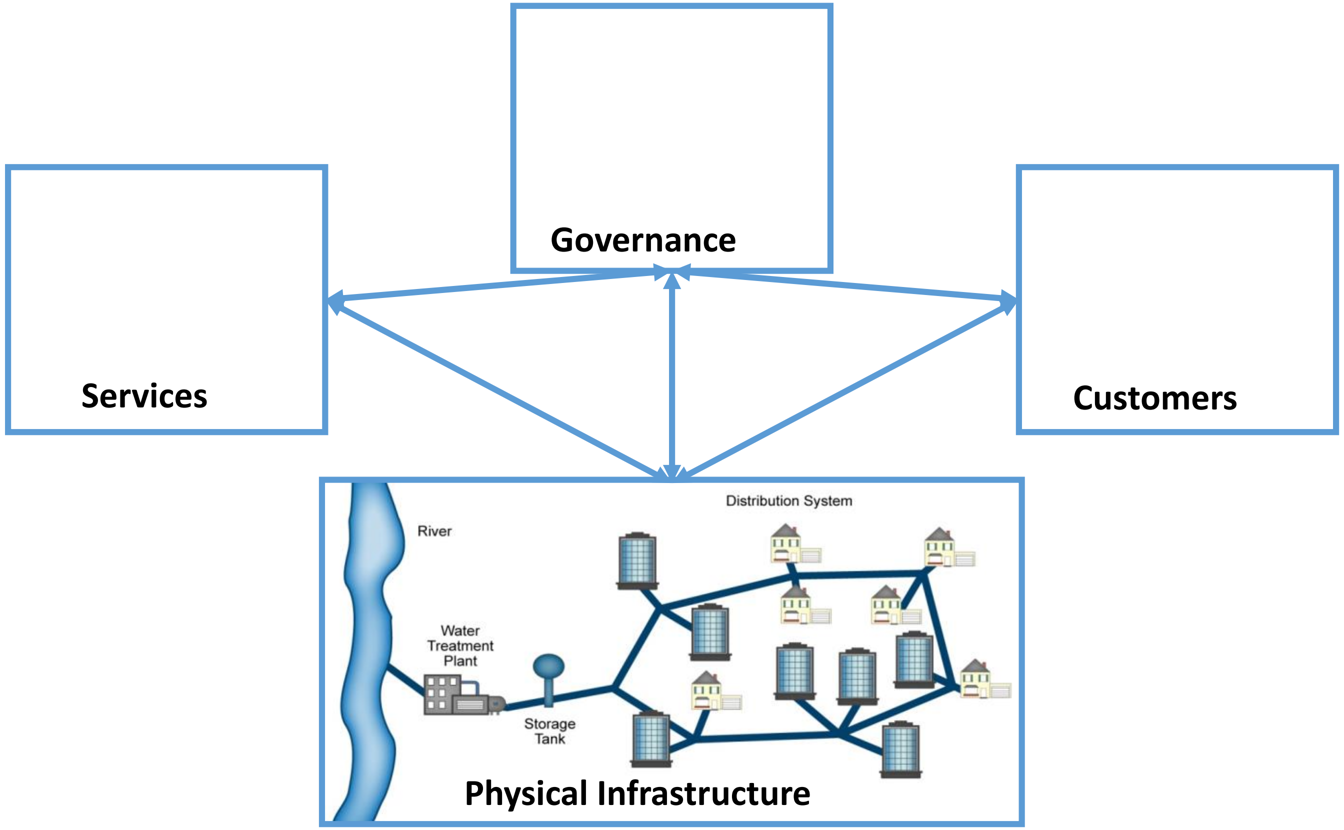
Cycle of Building Resilience

Resilience Function

The goal of resilience is to reduce the magnitude of the impact and the duration of the event



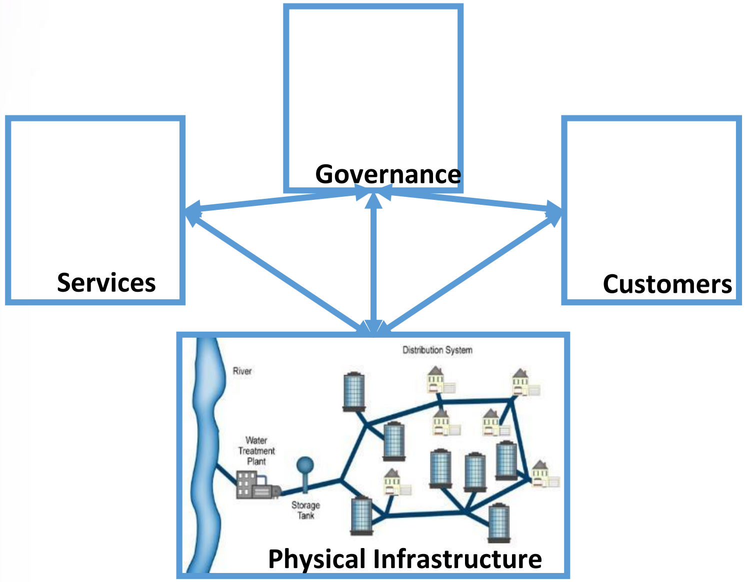
Water Infrastructure Systems



Drinking Water System

A hydraulic model of a drinking water system incorporates all of these components

What is Hydraulic Modeling?

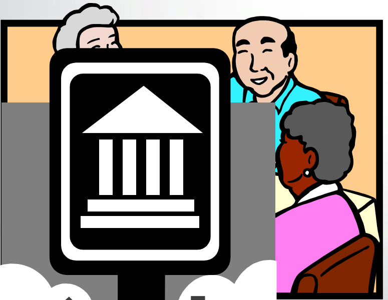


Input data

EPANET or other software: first principles physics-based equations for flow, pressure and water quality

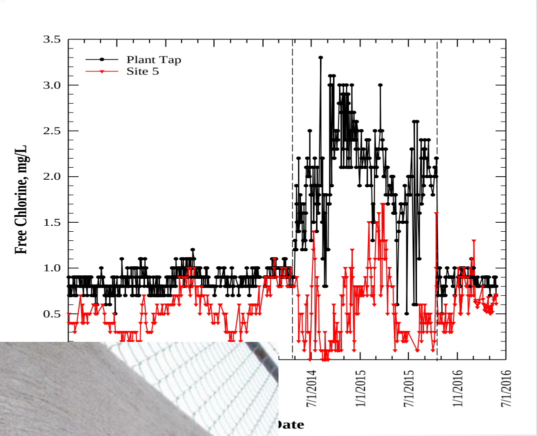
Pressure
Head
Flow
Tank Levels

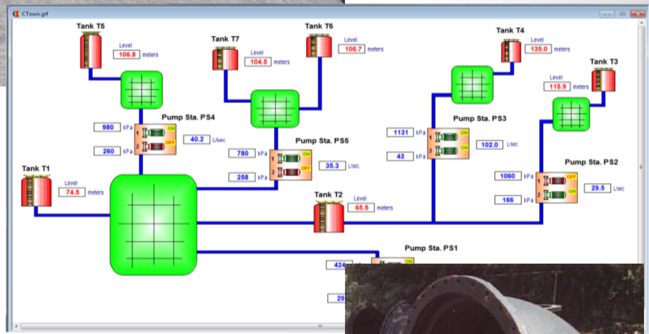
Output data



Problems Modeling Can Address

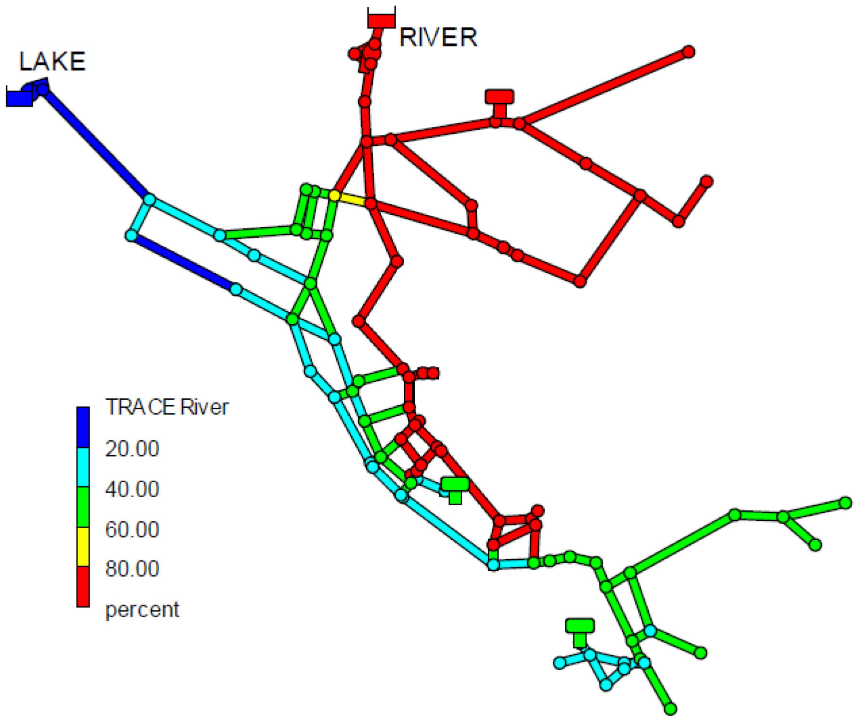
- Replacing Aging Infrastructure
  - Main breaks, damaged hydrants and valves, water loss
- Optimizing Operations
  - Pump schedules, tank cycling, pressure management, chlorine dosing, energy reduction
- Planning
  - Future demands, sizing new pipes & facilities, evaluating supplies, growth and decline
- Solving Water Quality Problems
  - Violations, customer complaints, low disinfectant residuals, disinfection byproducts





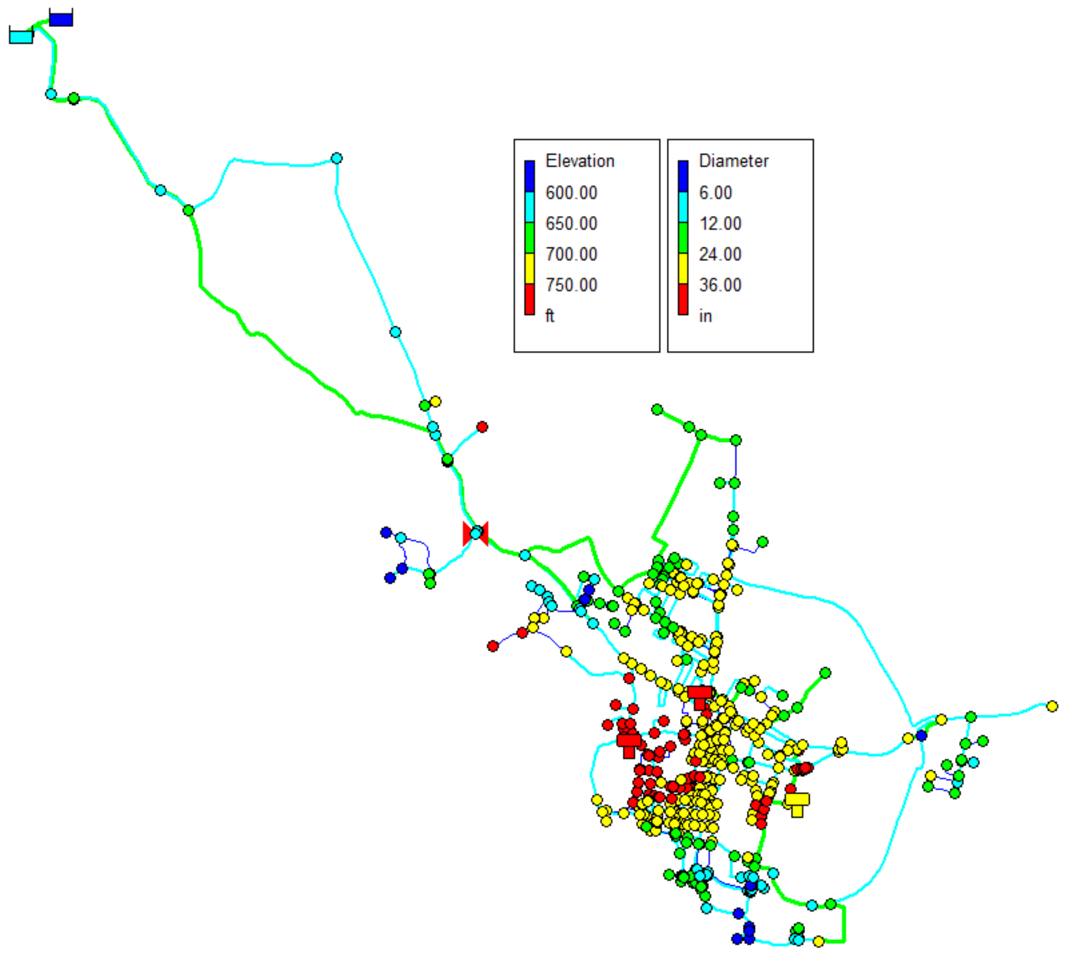
EPANET Software

- Models and simulates hydraulics within water distribution network
- Models and simulates simple decay/growth of a single substance
- Available for free on EPA's website
- Developed in 1990
- Provides basis for multiple commercial software packages



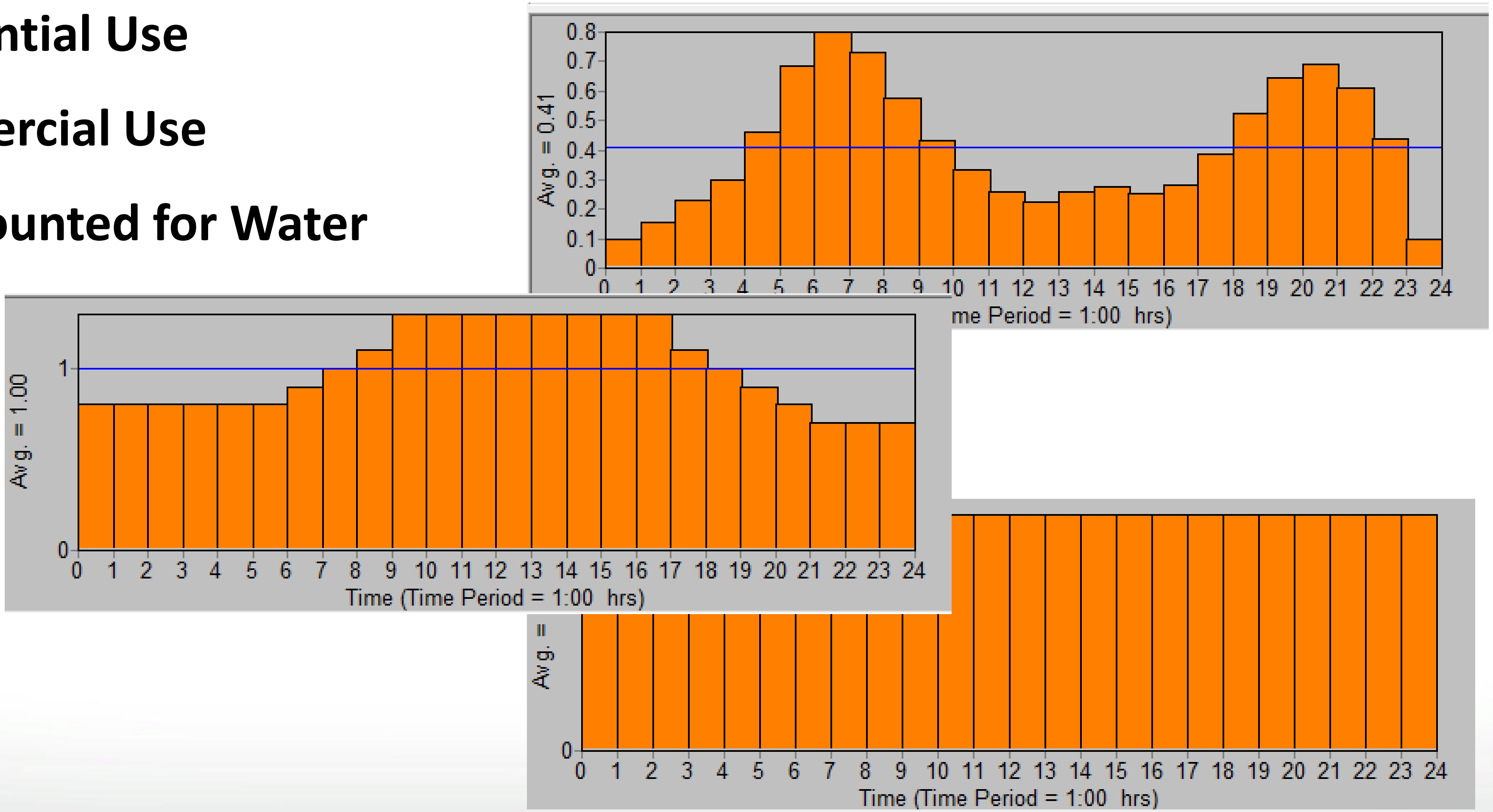
Represents the Infrastructure

- 1.5 MGD
- 3,000 customers
- 2 reservoir sources
- 2 pumps
- 3 tanks
- 60 miles of pipe
- 645 pipes
- 545 junctions



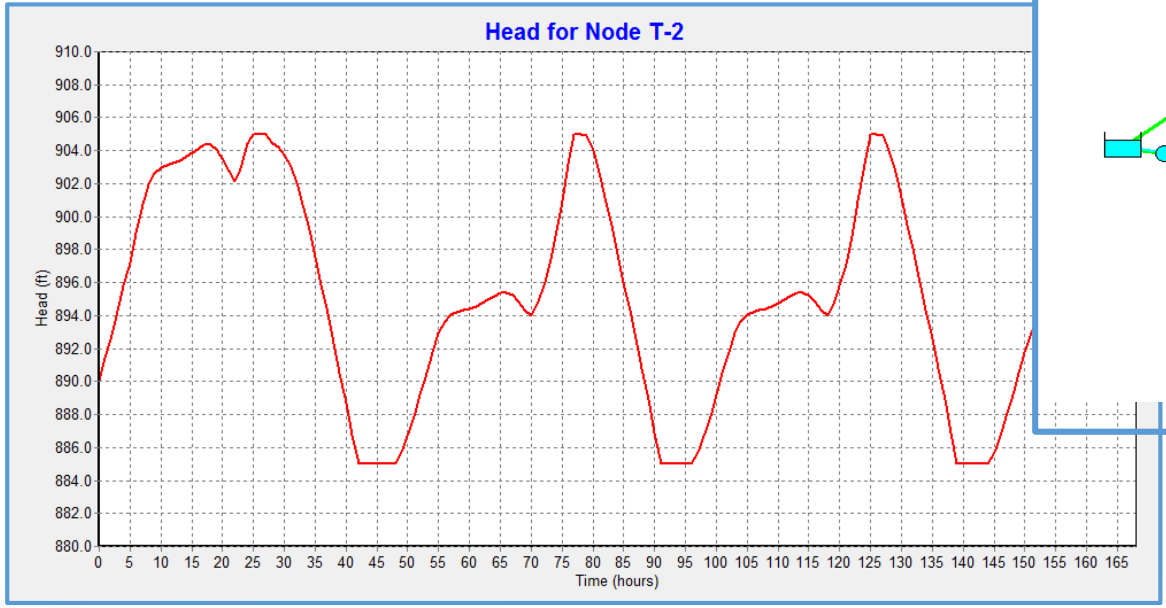
Represents Customer Usage

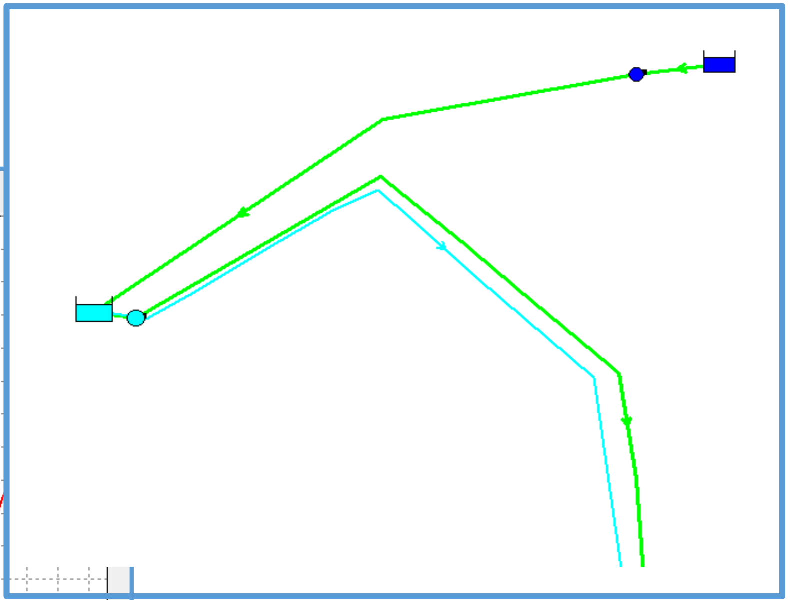
- 3,000 customers
- 60% Residential Use
- 25% Commercial Use
- 15% Unaccounted for Water



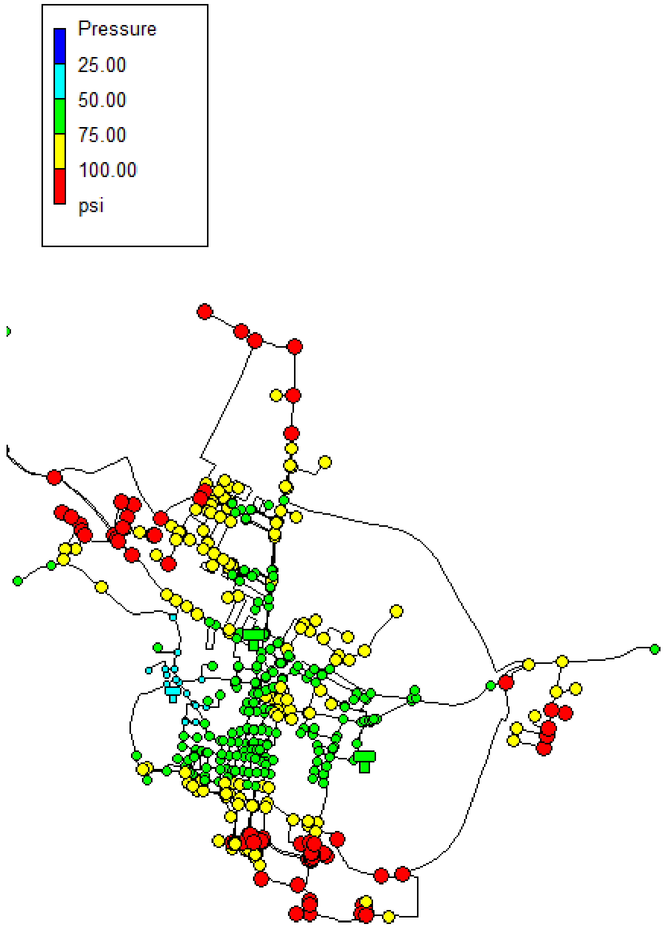
Represents Operations

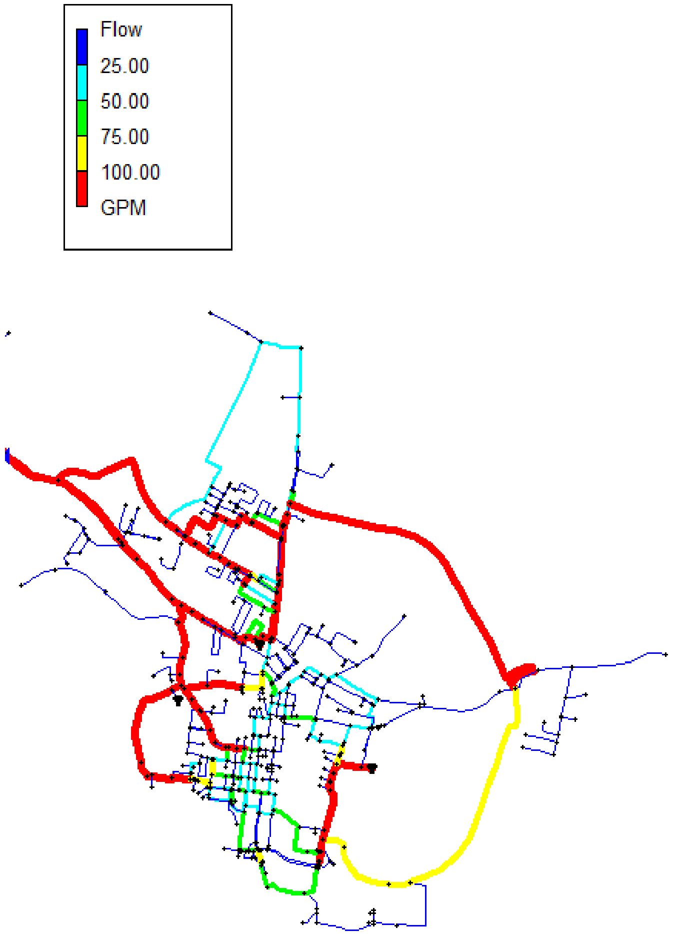
- PUMP Open If TANK Below 5 ft (888)
- PUMP Closed If TANK Above 19 ft (904 ft)



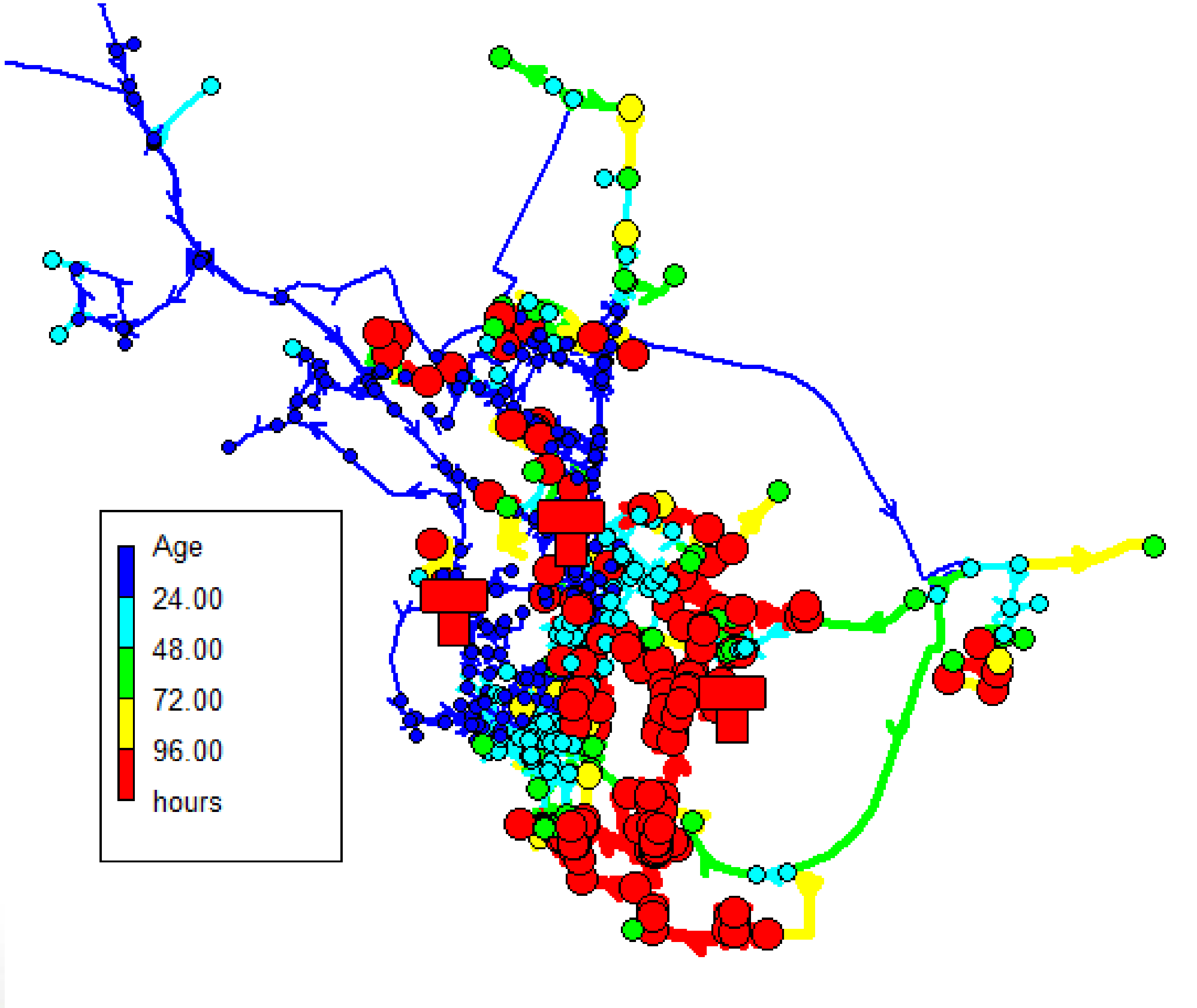


Predicts Pressure and Flow





Predicts Water Quality



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

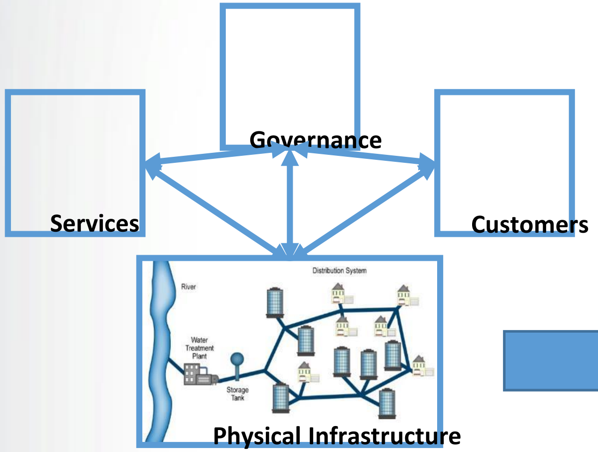
Securing facilities/assets

Water Quality Monitoring

Increased Redundancy

Practiced Emergency Response Plans

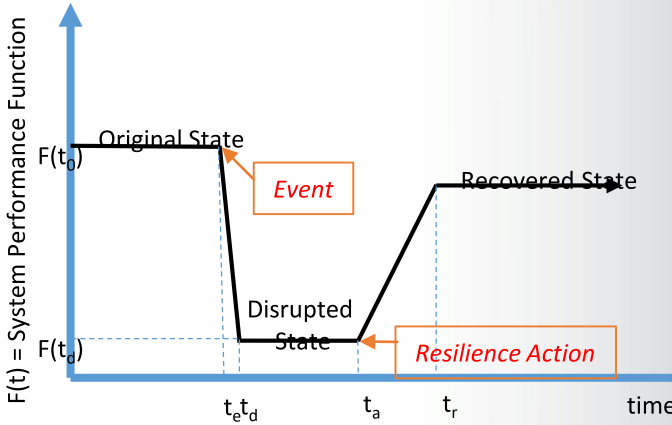
Water Network Tool for Resilience



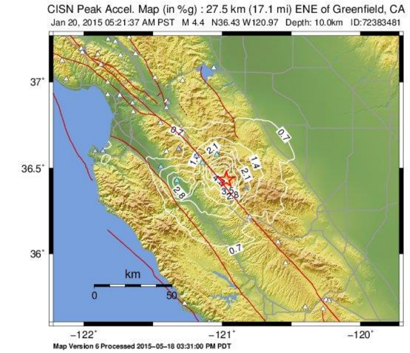
Water System Model

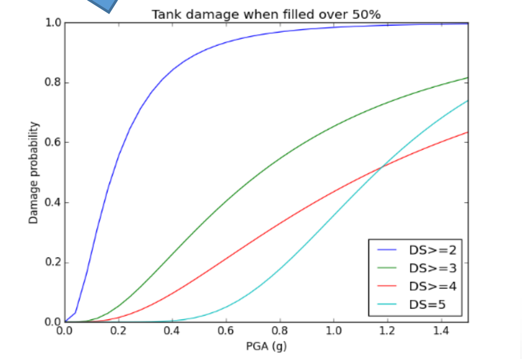
WNTR Simulation Engine
EPANET

S1 S2 S3 … SN



WNTR Plots & Data

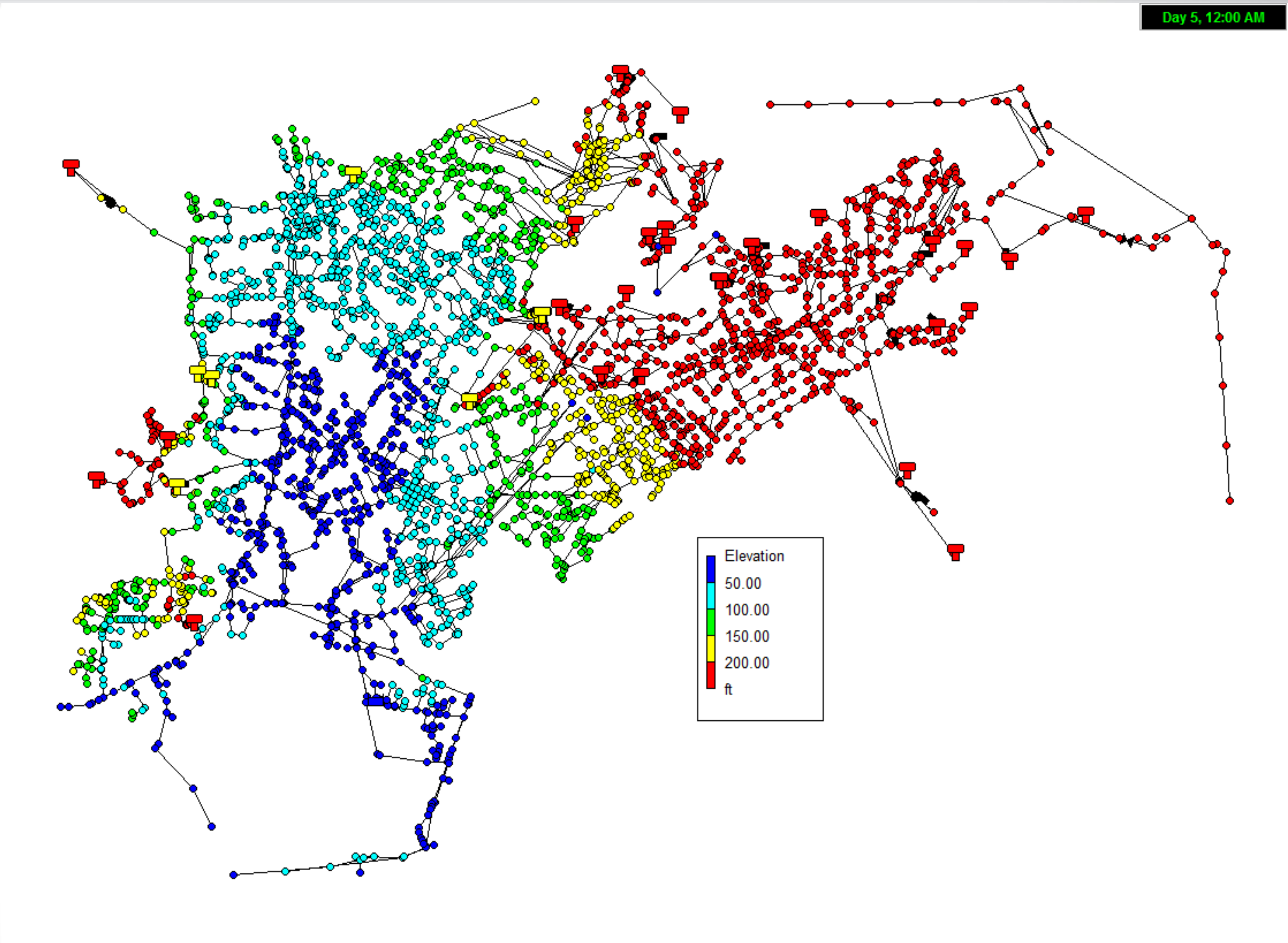




Disaster Models & Data

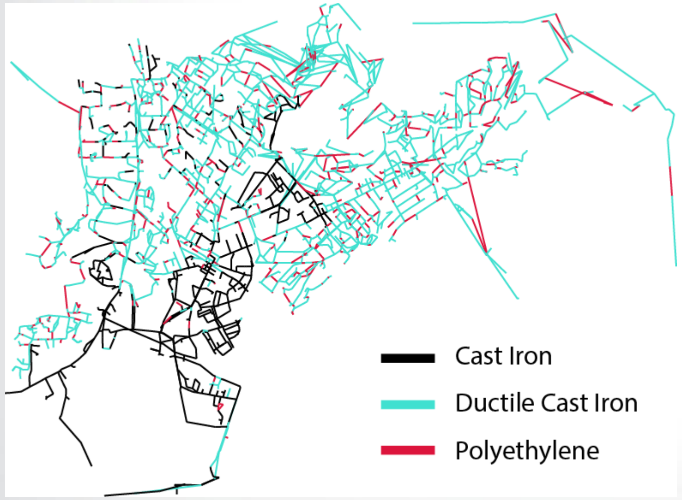
Case Study Water System

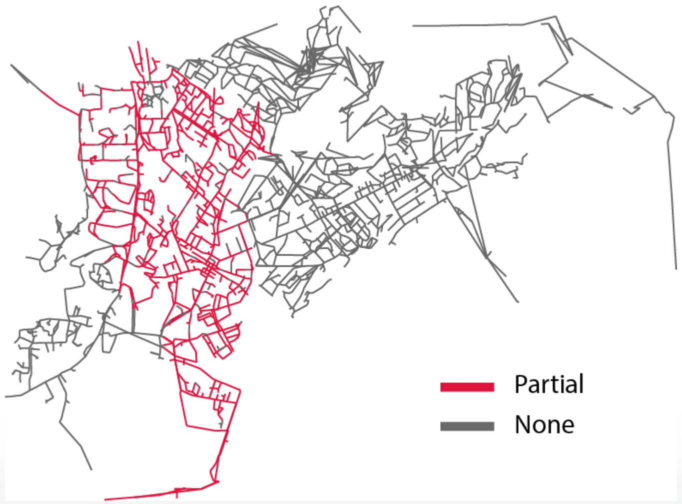
- System characteristics
  - 152,000 customers
  - 1 reservoir
  - 34 tanks
  - 61 pumps
  - 400 miles of pipes
    - 4 – 48 inch pipes
    - 50% 8 inch pipes
    - 30% 12 inch pipes
  - Operations
    - Water pumped from reservoir to higher locations in the network

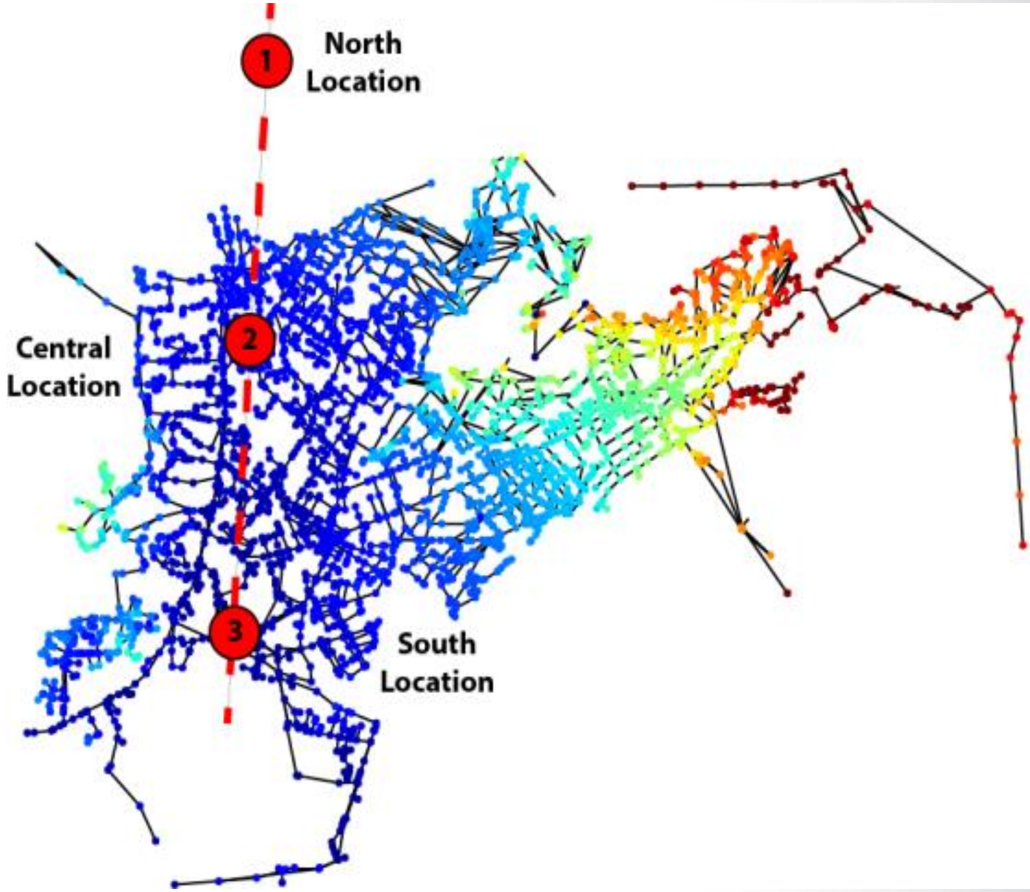


Earthquake Scenario

- Earthquake scenario
  - 6 AM along NS fault
  - Magnitude 6, 6.5, or 7
  - Damage a function of soil type, pipe material and diameter, distance from epicenter

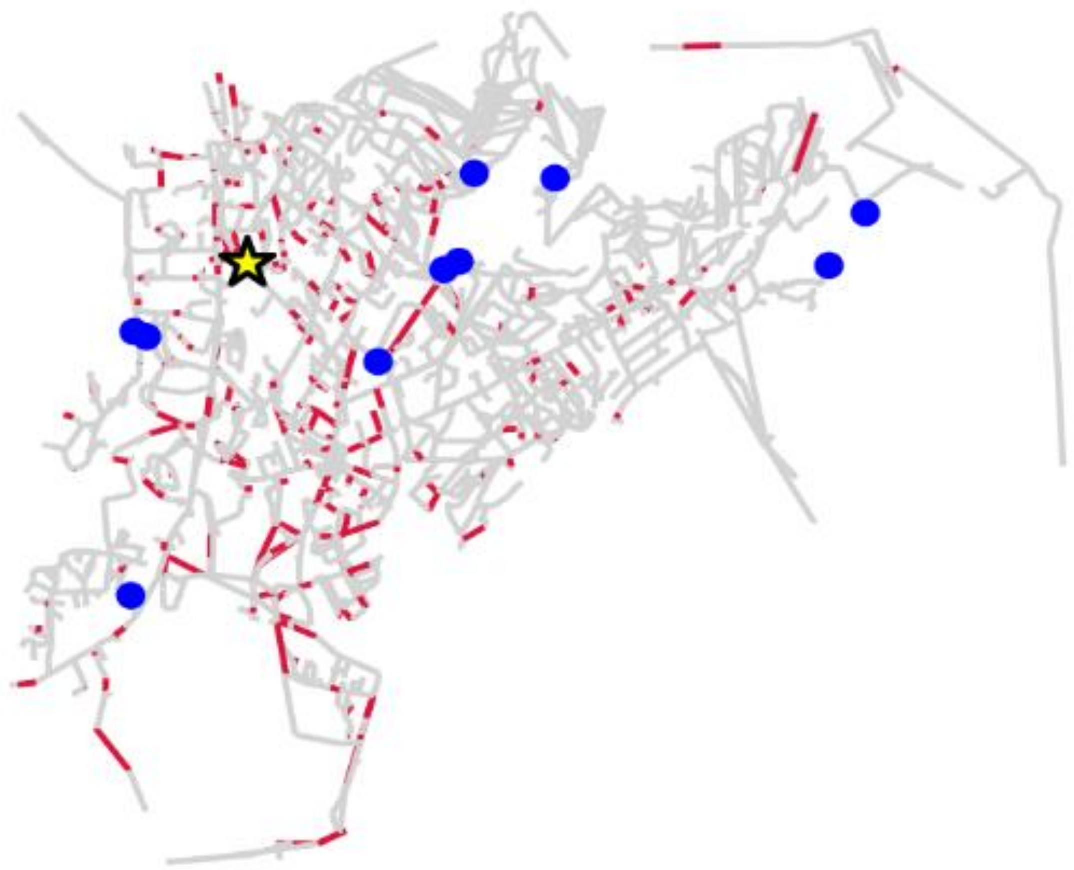






Earthquake Damage

- Magnitude 6.5, central location
- 239 pipes damaged (red)
- 10 tanks damaged (blue)
- 14 pumps lost power
- 28 fires

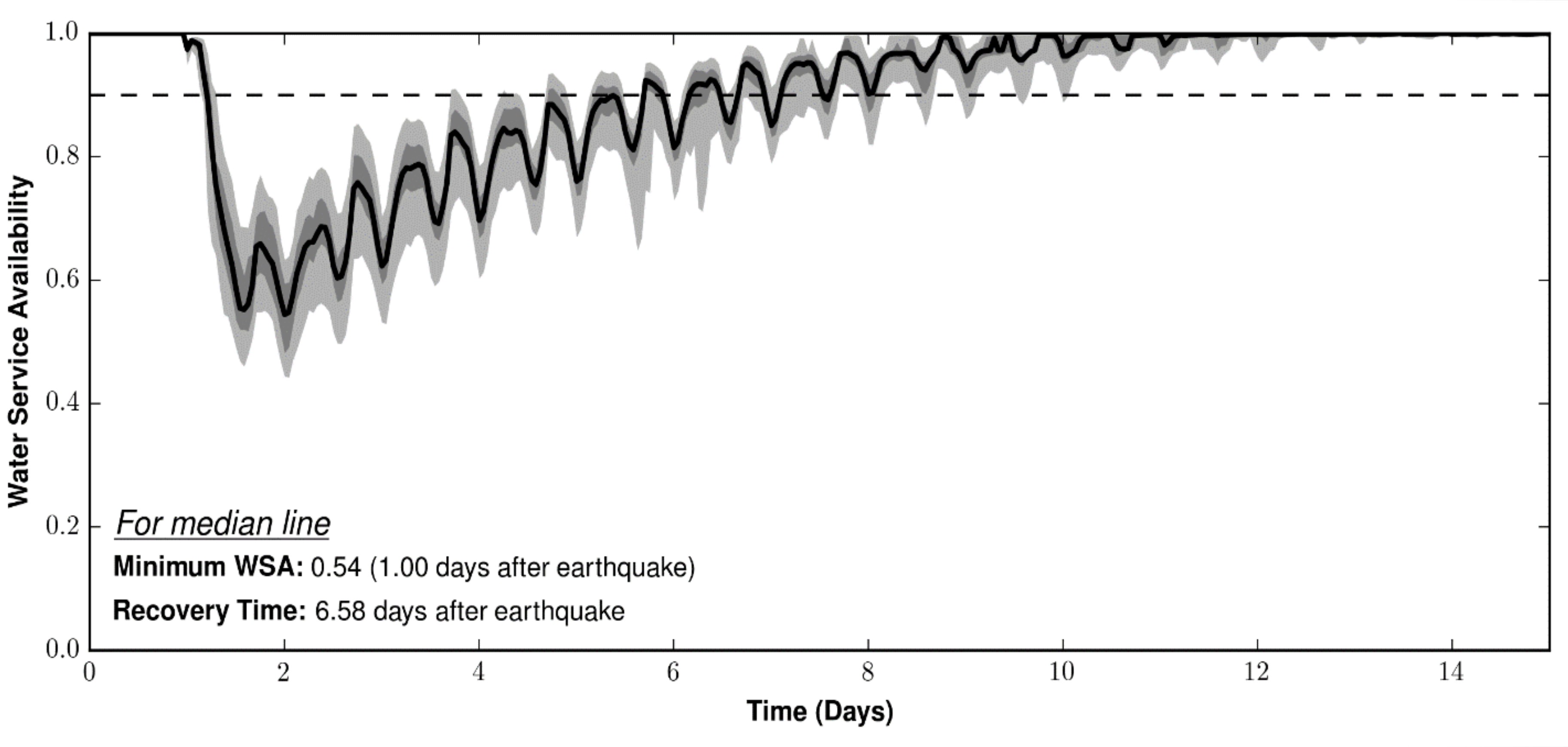


Repair Strategy

- Five pipe repair crews
  - Fixed one leak every 12 hours
  - Leaks isolated then repaired then returned to service
  - Prioritized based on largest leak volume
- Two tank repair crews
  - Fixed one tank every 12 hours
  - Prioritized largest leaks
- One pump repair crew
  - Fixed one pump every 8 hours
  - Prioritized pumps nearest reservoir
- One fire fighting crew
  - Fought one fire every 12 hours for 2-4 hours
  - Random order

Water Service Availability

Water service availability is the water volume *received* divided by the water volume *requested* by customers



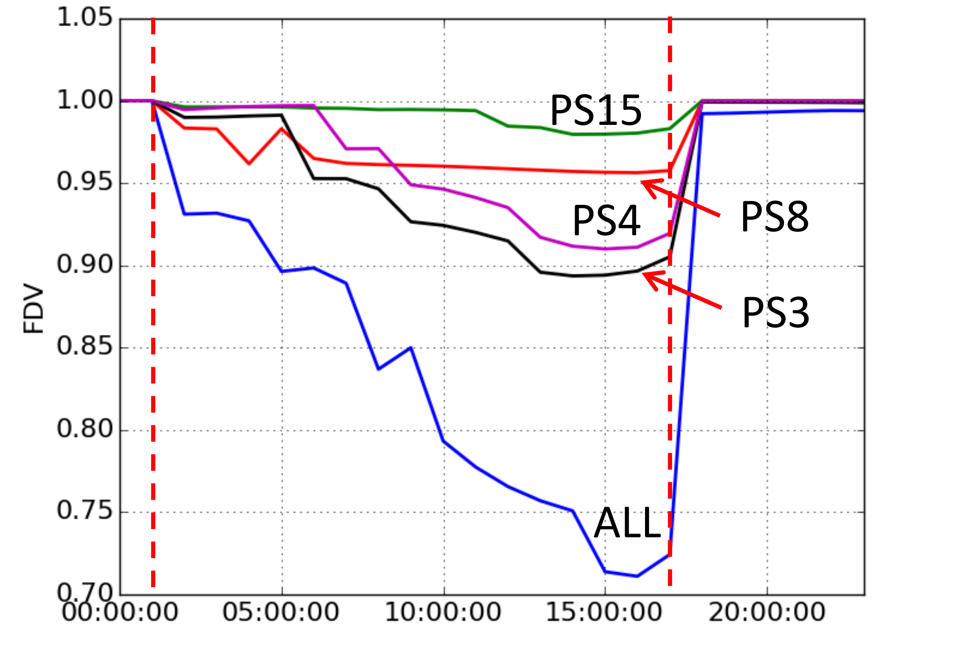
Comparison with Mitigation Strategy

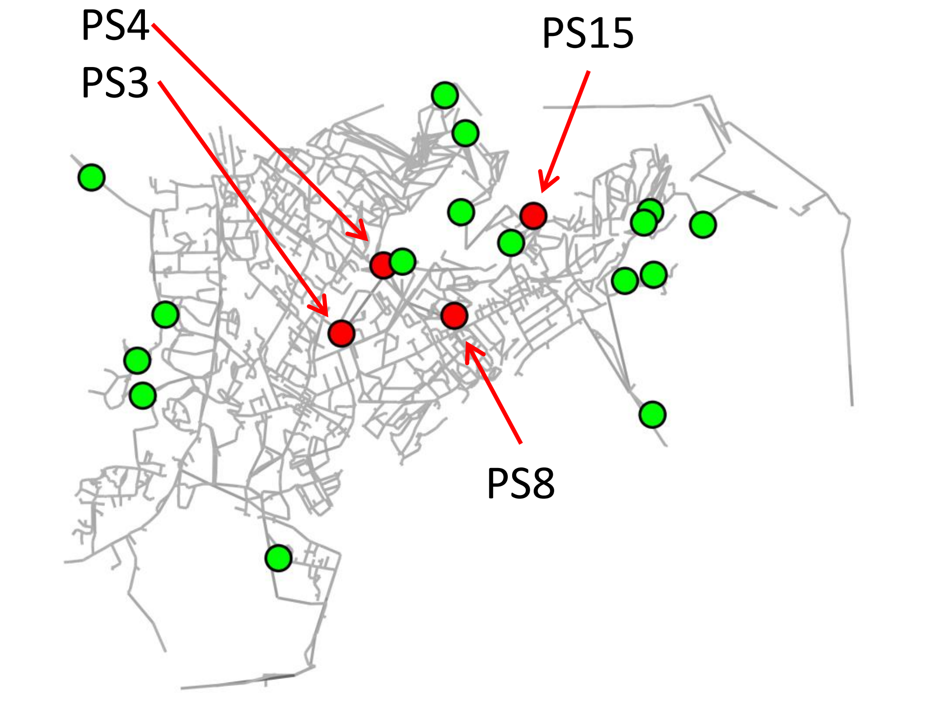
- Repair strategy 1 – pipe, tank, pump repair and fire fighting
- Repair strategy 2 – RS 1 and 40% water conservation
- Repair strategy 3 – RS 1 with seismic resistant pipes in the fault zone

Repair Strategy	Minimum WSA	Recovery Time in Days	Max Pop. Impacted
RS 1 (Pipe, tank, pump repair & fire fighting)	0.54	6.58	89,912
RS 2 (RS1 with 40% water conservation)	0.66	4.00	56,770
RS 3 (RS1 with seismic resistant pipes)	0.85	1.08	27,054

Power Outage Scenario

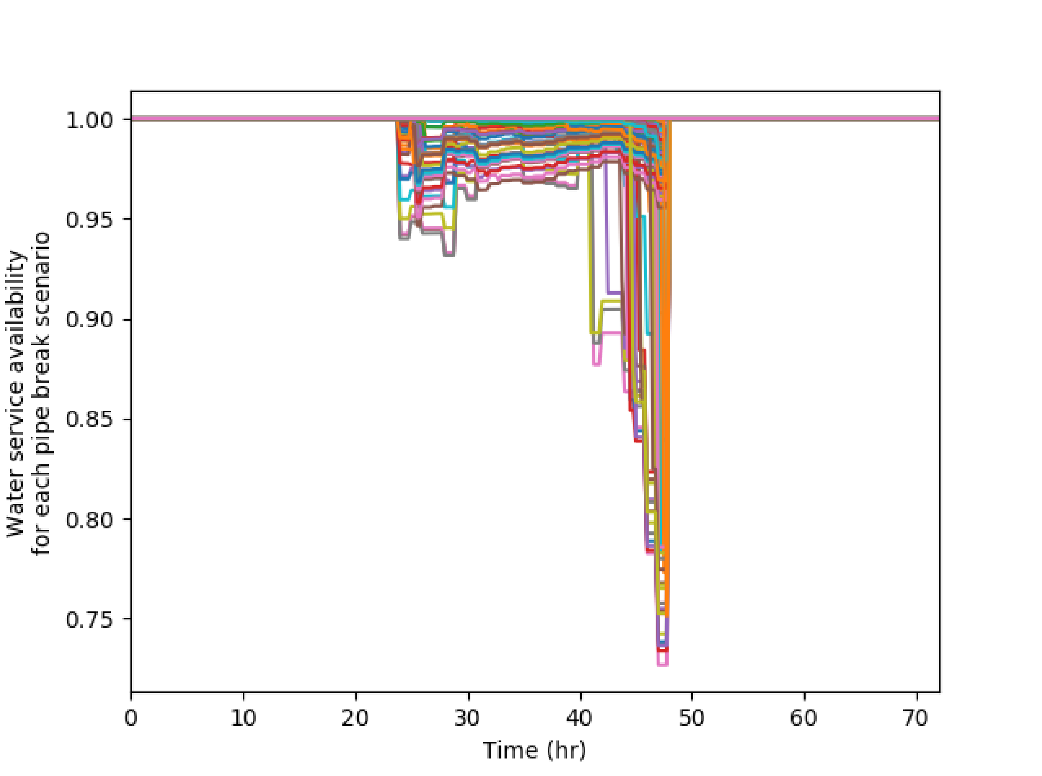
- Water Service Availability decreases when the power outage begins.
- WSA increases again when the power is restored after 15 hours.
- Results for single pump outages and simultaneous failure at all four pumps (red circles) shown

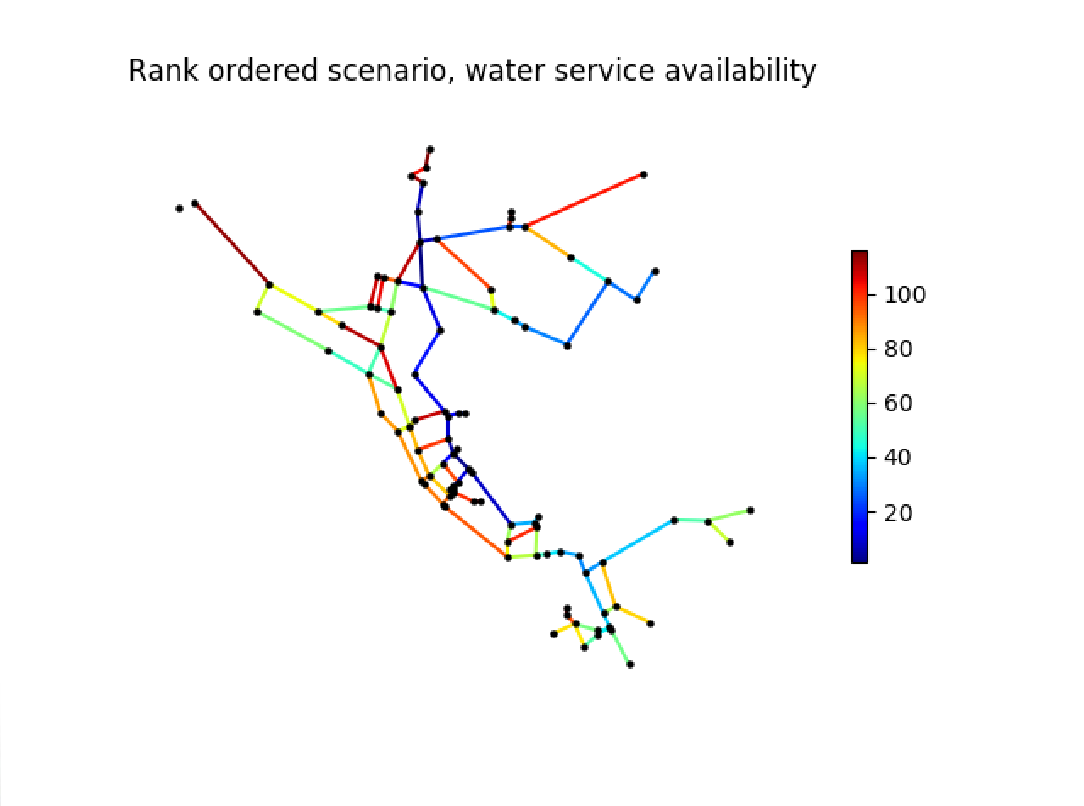




Pipe Criticality Analysis

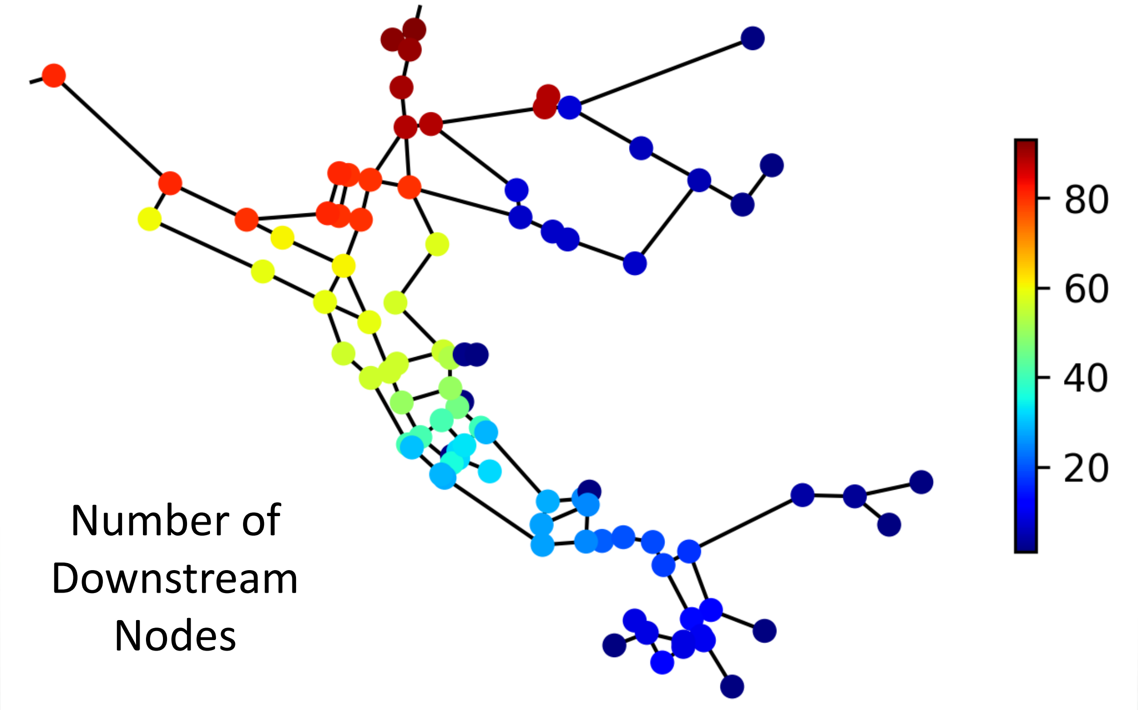
- Breaks at each pipe are simulated one at a time
- Water service availability is shown for each pipe break
- Pipe criticality ranking plotted on figure

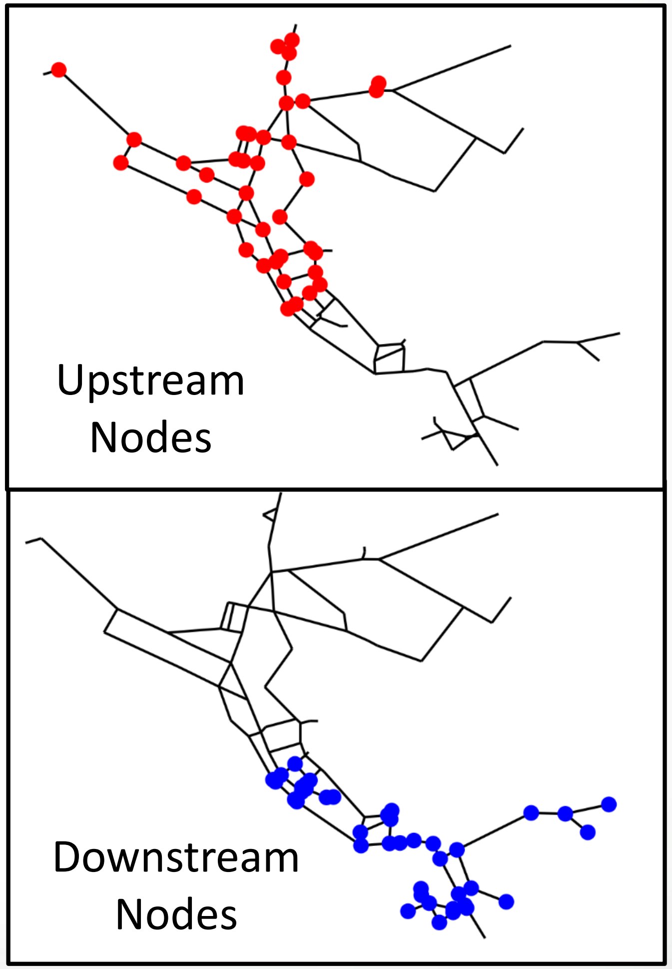




Sampling Location Analysis

- Number & location of all upstream and downstream nodes is calculated in WNTR
- Evaluates "coverage" of sampling locations





Summary and Conclusions

- Hydraulic modeling is a powerful tool for addressing water quality problems, replacing aging infrastructure, optimizing operations, and planning for the future
- WNTR extends the capabilities of basic hydraulic modeling to help water utilities do a "deeper dive" into understanding the resilience of their drinking water system to disasters
- By quantifying resilience, the benefits of different utility response strategies and long-term mitigation strategies can be compared
- A prototype of WNTR will be available soon, but water utilities are invited to work with USEPA researchers now on case studies