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WNTR Water Network Tool for Resilience

An open-source Python package for modeling disturbances to water distribution systems

Innovative Science for a Sustainable Future

WATER INFRASTRUCTURE RESILIENCE EVALUATION USING WNTR

Background

Drinking water utilities face multiple challenges, including aging infrastructure, water quality concerns, uncertainty in supply and demand, natural disasters, and intentional attacks. All of these have the potential to disrupt a large portion of a water distribution system for extended periods of time. Increasing resilience to these types of hazards is essential to improving water system security. The Water Network Tool for Resilience (WNTR) is a simulation and analysis tool that can help water utilities predict how their system will respond to expected, and unexpected, incidents and help inform decisions to make water distribution systems more resilient over time (Klise et al., 2023). It was developed by the United States Environmental Protection Agency and Sandia National Laboratories.

Software Capabilities

WNTR is an open-source Python package designed to simulate and analyze resilience of water distribution systems. It builds site-specific resilience analysis for water utilities, quantifies the economic and social impact of disruptions, and helps prioritize response action plans by integrating these critical aspects into a single framework.

The software includes capabilities to:

- Create and modify water network models
- Simulate hydraulics and water quality
- Analyze results and generate graphics
- Assign fragility and survival curves to network model components
- Model disruptive events such as power outages, earthquakes, and contamination incidents
- Model response and repair strategies
- Evaluate resilience using a wide range of metrics
- Integrate dependency with other critical infrastructure and supply chains
- Integrate socioeconomic geospatial data
- Export results into geograpic information system (GIS) formats

Using WNTR for Decision-making

WNTR provides a flexible platform for modeling a wide range of disruptive incidents and repair strategies that drinking water utilities might be interested in examining. WNTR can be used to estimate infrastructure damage, evaluate preparedness strategies and identify worst case scenarios and best practices for maintenance and operations. WNTR analysis can help authorities prioritize responses to disruptive events based on which actions are found to have the greatest impact in restoring access to water for the most users. A variety of resilience metrics are available in WNTR. Commonly used metrics include population impacted and water service availability (WSA), which is the fraction of expected water volume customers receive.

Usage Statistics

- Over 200,000 downloads
- Cited in 180+ publications
- Users include universities, national laboratories, engineering consultants, and water utilities

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Case Study Applications

Earthquakes can cause damage to pipes, tanks, pumps, and other infrastructure as well as power outages and fires. WNTR includes methods to add leaks to pipes and tanks, shut off power to pumps, and change demands for fire conditions. When simulating the effects of an earthquake, fragility curves are commonly used to define the probability that a component is damaged with respect to peak ground acceleration, peak ground velocity, or repair rate. The tool can be used to compute peak ground acceleration, peak ground velocity, and repair rate based on the earthquake location and magnitude.

An earthquake case study, using WNTR, demonstrated that infrastructure damage was associated with network integrity and earthquake magnitude, as well as the resources and repair strategies used to resume delivery of water to the community (Klise et al., 2017). Figure 1 shows the potentially damaged infrastructure components from an earthquake. This information could be used to priortize which pipes could be replaced with more earthquake resistant pipes.

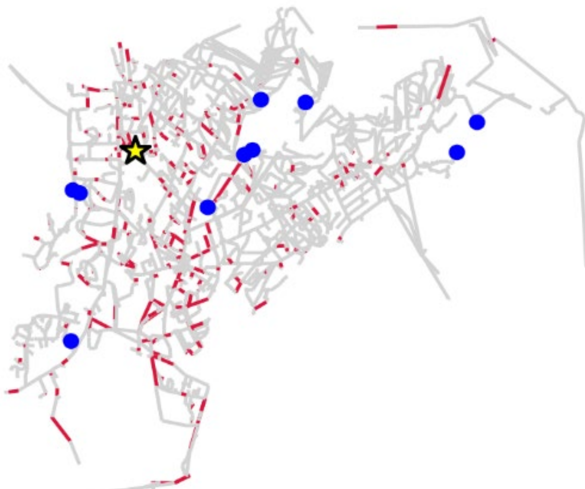

Figure 1. Water network model showing damaged pipes (red lines) and tanks (blue circles) for a 6.5 magnitude earthquake at the epicenter location (yellow star) [taken from Klise et al., 2017].

Figure 2 shows the predicted change in WSA over time as repairs are implemented for the earthquake case study.

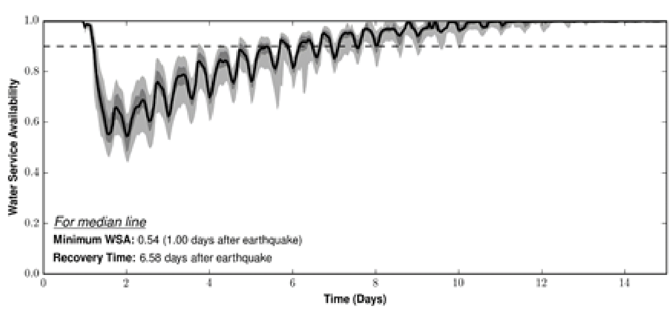

Figure 2. Statistical prediction of WSA over 14 days for 6.5 magnitude earthquake. Shading is the 5th-95th percentiles, with the dark line as median [taken from Klise et al., 2017].

Power outages can cause pump stations to shut down and result in reduced water pressure, which could lead to water shortages in some areas. WNTR can be used to simulate power outages by changing the pump status and defining the duration of the outage.

The US Virgin Islands water utility is susceptible to the effects of powerful hurricanes, which include power outages and infrastructure damage. WNTR was used to evaluate the resilience of the water systems of St. Croix and the combined system of St. Thomas/St. John to four-week power outages in different regions of the islands (Klise et al., 2022). The analysis quantified differences in the water delivery, quality, and quantity during and after the disruption. Figure 3 shows the water network model for St. Thomas/St. John and two of the resilience metric results for the system-wide outage scenario. WSA was able to return to baseline soon after the outage ended, while the tank in the West region required more than 30 days to return to baseline capacity. The analysis highlighted the reliance on power for water service in different regions of the island. These results could help provide justification for resilience planning and preparedness to future storms.

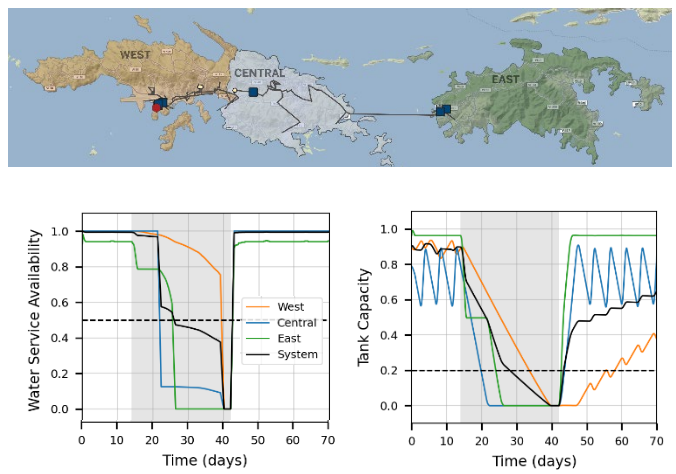

Figure 3. St. Thomas/St. John water network model and the water service availability and tank capacity results for the system-wide outage averaged over the East, Central, and West regions, and entire system. The duration of the power outage is marked by the light shaded area [modified from Klise et al., 2022].

Contaminants can enter the distribution system through source water intakes, reservoirs, tanks, and at other access points during disasters. WNTR simulates the contaminant injection as well as the fate and transport of contaminants in the distribution network model. In addition, WNTR supports the evaluation of different response actions to minimize the effects of contamination on operations.

Poughkeepsie, New York has a water source threatened by contamination due to saltwater intrusions caused by sea level rise and accidental releases of chemicals in the river. WNTR was used to assess the effect of source water loss on water service availability (Chu-Ketterer et al., 2023a). The results illustrated that conservation efforts extended water service for an additional 20 hours (Figure 4).

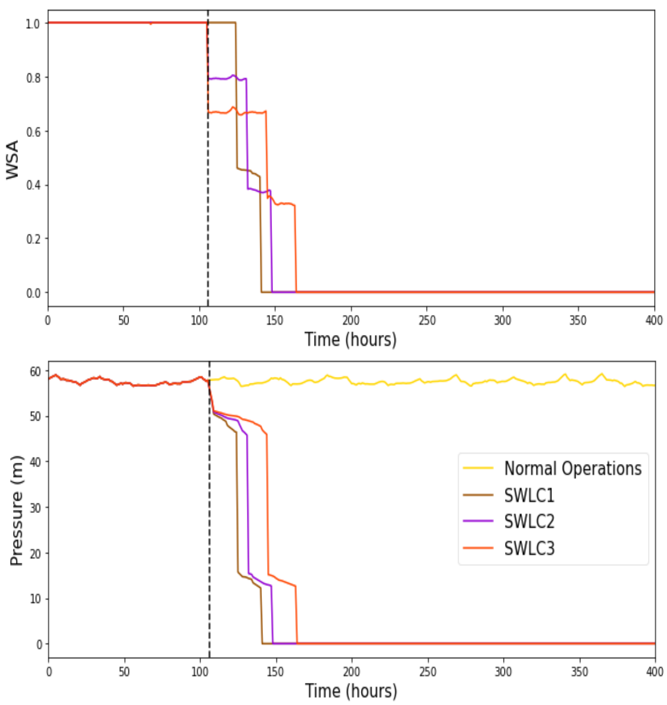

Figure 2. WSA and pressure over time for the loss of source water scenarios. SWLC1 is the loss of source water scenario with zero conservation efforts. SWLC2 is the loss of source water scenario with conservation efforts of 25% water reduction. SWLC3 is the loss of source water scenario with conservation efforts of 40% water reduction and stopped service to the three highest consumers [modified from Chu-Ketterer et al., 2023a].

Fires can cause damage to system components and/or increase water usage at specific locations due to fighting fires. WNTR simulates firefighting conditions by specifying the demand, time, and duration of firefighting. Figure 5 shows the population impacted with pressures below 20 psi by increased demands from firefighting at specific locations in the Poughkeepsie network model. More details of this case study can be found in Chu-Ketterer et al. (2023a).

Other disasters like floods, droughts, tornadoes, extreme winter storms, and wind events can also cause damage to drinking water systems. WNTR can be used to simulate effects of these disasters like power outages and pipe breaks.

Figure 3. Poughkeepsie water network model with nodes highlighted with population impacted by reduction in water pressure due to increased demands from firefighting [modified from Chu-Ketterer et al., 2023a].

Environmental justice conerns can be incorporated within the WNTR analysis to identify additional vulnerable areas and ensure equitable resilience within the water distribution system.WNTR can be used to prioritize pipes based on user-specified criteria. In a Pennsylvania water system, a pipe criticality analysis was combined with socioeconomic and environmental census tract data to show how weighting based on factors like blood lead levels, women and children counts, historical pipe breaks, and income changes the priority areas compared to weighting all factors equally (Chu-Ketterer et al., 2023b). Figure 6 shows more areas in the water network model are prioritized areas when using the proportional weight approach.

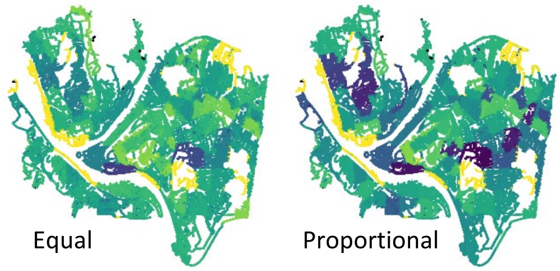

Figure 4. Pennsylvania water network model showing priority areas based on socioeconomic and environmental factors for equal and proportional weight approaches [modified from Chu-Ketterer et al., 2023b].

Resilience analysis can be used to compare emergency response actions before any disruptions, which helps minimize water service interruptions and prevent unintended consequences. These case studies highlight how WNTR helps water utilities quantify the resilience of their systems, by enabling them to:

- Evaluate the effects of disruptions on water pressure and water service availability over time
- Test and assess response and mitigation strategies to help restore service
- Inform capital and operational investments such as additional storage, backup power supply/generator, backup repair supplies, and additional repair crews
- Assist in training exercises for emergencies

Download and Installation Information

WNTR can be installed through the United States Environmental Protection Agency GitHub site at https://github.com/USEPA/WNTR. Documentation is available at https://usepa.github.io/WNTR/.

DISCLAIMER

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REFERENCES

L-J. Chu-Ketterer, R. Murray, P. Hassett, J. Kogan, K. Klise, T. Haxton (2023a) "Performance and resilience analysis of a New York drinking water system to localized and system-wide emergencies" *Journal of Water Resources Planning and Management* 149(1).

K. Klise, R. Moglen, J. Hogge, D. Eisenberg, T. Haxton (2022) "Resilience analysis of potable water service after power outages in the U.S. Virgin Islands" *Journal of Water Resources Planning and Management* 148(12).

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

K.A. Klise, D.B. Hart, M. Bynum, J. Hogge, R. Murray, J. Burkhardt, T. Haxton (2023). Water Network Tool for Resilience (WNTR) User Manual: Version 1.0, U.S. Environmental Protection Agency Technical Report, EPA/600/R-23/098.

L-J. Chu-Ketterer, W. Platten III, S. Bolenbaugh, T. Haxton (2023b) "Resilience analysis and emergency response evaluation for drinking water systems" *Journal of AWWA* June 2023.