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Water Distribution Systems (WDS) Analysis Using Water Network Tool for Resilience (WNTR)

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ABSTRACT

Water sustains life. Water utility companies provide ease of access to potable water through water distribution networks. The security, reliability and availability of these networks can be marred by increasing demands, pressure surges, pipe bursts, and natural disasters. Thus, there is a need for the networks to be robust and resilient against the aforementioned events. To achieve this, water utility companies use water network simulation packages to model the hydraulic dynamics of water. The EPANET package, the de facto industry tool, is a package used for modelling water distribution systems. However, it is not capable of modelling energy utilisation, disruptive events and running probabilistic simulations. Thus, Water Network Tool for Resilience (WNTR) was created to extend the capabilities of EPANET by addressing the foregoing limitations. This project explored the capabilities of WNTR in water network modelling. A WNTR-based web application named Water Network Analyser was developed and deployed on Amazon Elastic Compute Cloud (Amazon EC2) instance. The app can simulate disruptive events and carry out network analyses. This can help water utilities to better plan for these disruptive events and consequently reduce downtime and water network management costs.

Key words: WNTR – WDS – Simulation

1 INTRODUCTION

Water Distribution Systems (WDS) face numerous disruptions due to earthquakes, leakages, bursts, fires etc. (WNTR, 2019). These events can adversely affect lives by threatening water security, availability, reliability and quality. Modern advancements in computing make it easier to plan, study, and evaluate WDSs through hydraulic and water quality simulations. Water utilities can use simulation and analytic tools to better understand how their systems might react to a variety of disruptive situations and to improve long-term planning to make systems more resilient.

There are various types of packages, both commercial and open-source, that can be used to make the WDS more resilient. EPANET is the de facto industry standard package that can be used for modelling WDS. However, its limitation in terms of energy modelling makes it unsustainable (Gómez et al., 2016). Thus, Water Network Tool for Resilience (WNTR, pronounced winter) was created to extend the capabilities of EPANET with emphasis on improving distribution systems' resilience.

This project is a proof of concept that aims at evaluating whether WNTR is a viable alternative to EPANET. WNTR is a python package designed to simulate and analyze resilience of water distribution networks. The following paper includes a description of WNTR capabilities and applications to help users understand whether WNTR is a viable alternative to EPANET. WNTR is used as a simulation and analysis tool that can help water utilities better understand their system's design, operations and maintenance dynamics.

WNTR is a python-based package which is compatible with EPANET, pandas, Numpy, SciPy and NetworkX .Various classes exist in WNTR to model network elements. The interactions between water and a WDS are modelled by the two WNTR simulator classes; EpanetSimulator and WNTRSimulator (WNTR, 2019).

In this project, the team explored the open-source WNTR package capabilities to develop and simulate the hydraulic dynamics of WDS. WNTR's sub-packages and classes were then used to build and deploy a near real-time monitoring tool (Water Network Analyser). This tool is used for conducting water network analysis and simulating various disaster scenarios (Berglund et al., 2020).

WNTR package includes the capabilities to (1) generate and modify water network structure and operations, (2) simulate disaster scenarios, (3) model response and repair strategies, (4) simulate pressure-dependent demand and demand-driven hydraulics, (5) simulate water quality, (6) calculate resilience metrics, and (7) visualize simulation results. A data pipeline was developed to bridge the near-real-time network monitoring tool with the WNTR application. The tool is designed to help evaluate disruptive events and plan mitigation steps against negative impacts e.g., system downtime.

2 METHODOLOGY

Exploratory steps were taken to accomplish the prevalent project goal. Primarily done through trial and error, these steps delved around the development of water network models and related modifications, running hydraulic simulations (e.g., sensor placement optimisation and disaster scenarios), quantifying resilience metrics, creating a data pipeline architecture, building the Water Network Analyser with StreamLit, and subsequent app deployment on AWS EC2 instance.

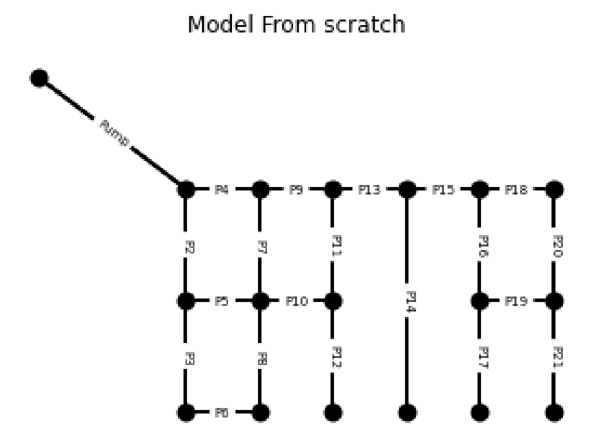

Figure 1. Water Network Model Generated from Scratch

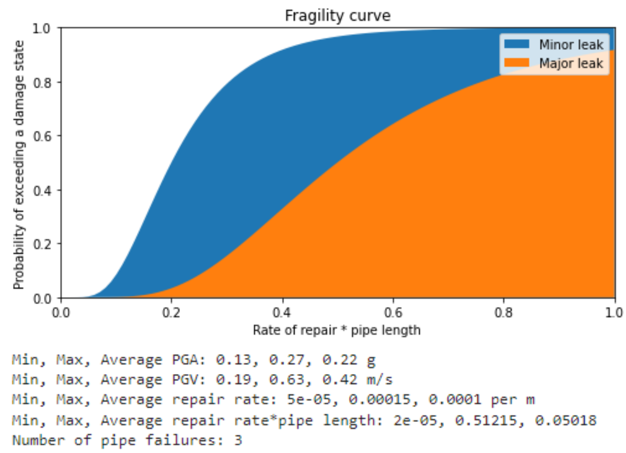

Figure 3. Generation of earthquake scenario

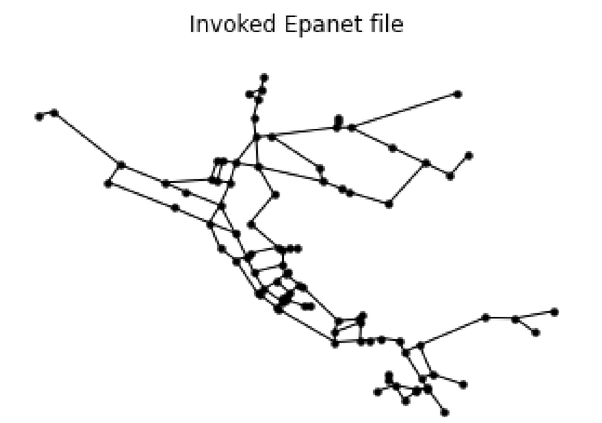

Figure 2. Water Network Model Generated from EPANET's .inp File

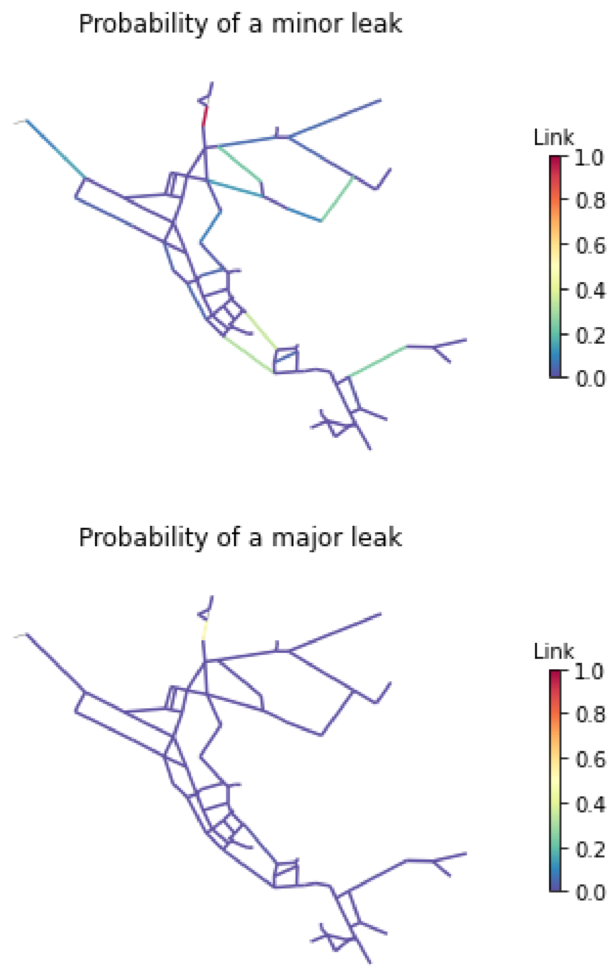

Figure 4. Plots of probability of leaks and damage state

3 WNTR CAPABILITIES

3.1 Building Water Network Models and Modifications

In this project, two networks were modelled: one from scratch and the other from EPANET's .inp file (Net3.inp - available in the WNTR documentation).see Figure 2. To build a network from scratch (Figure 1), an empty model was instantiated using wntr.network.WaterNetworkModel() class and various network elements were added by adjusting the parameters of their corresponding methods.

To build a network from the EPANET's Net3.inp file (Figure 2), the file was simply passed as an argument to the wntr.network.WaterNetworkModel() class.

3.2 Hydraulic simulations

Disaster events like leakage, fire and earthquake were simulated using the WNTRSimulator and EpanetSimulator. Disruptive events like pipe closure were evaluated by visualising the number of nodes and consequently the population that can be impacted by the closure. This is shown in figure 3 and Figure 4 which demonstrate the damage and the probability of the damage respectively

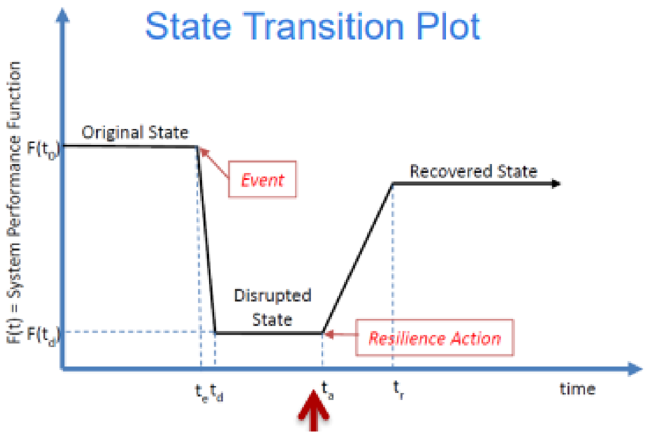

Figure 5. Plot of transition state.

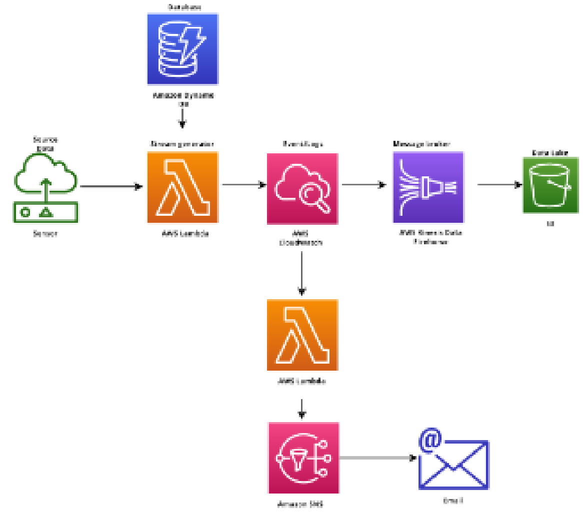

Figure 6. High level architectural diagram of the data pipeline.

3.3 Quantifying Resilience

Resilience metrics are indices used to assess a water network and better plan for the network restoration after failure. In order to measure the security, redundancy, resilience, and dependability of water distribution networks, a number of metrics have been proposed like:topographic metrics, hydraulic metrics, water quality metrics, water security metrics, and economic metrics.

In this project, the team have explored and used various metrics to ensure the resilience of the network. This includes pressure, demand, water age, Todini index etc. These can be used to improve the availability of the network amongst other things.(Figure 5)

3.4 Data Pipeline Architecture

The data streaming process was done using AWS services and python programming. A python script was used to simulate generation of hydraulic network data being fetched from hydraulic network APIs. AWS CloudWatch services are used to configure a trigger for lambda which will run it on a periodic basis. For pipeline observability a second lambda script is used to send an AWS SNS notification to one or more email addresses whenever the configured lambda based script stops functioning correctly. To transfer the data to the downstream storage destination, s3, AWS Kinesis Data Firehorse was used.(Figure 6)

3.5 Building Water Network Analyser with Streamlit

The monitoring tool is built in Streamlit. The tool which we named Water Analyser has tabs from home, network graphs, analysis, metrics to simulation each with quantifying metrics to help water utilities to monitor the network. The app was deployed in EC2 instance(Figure 7). The app has the potential of making water network management more economical while conserving a critical natural resource.

Figure 7. Near real-time monitoring App developed in Streamlit.

4 CONCLUSION

Resilience can be improved by being able to anticipate how water distribution systems will operate during disruptive situations and by knowing how to absorb, recover from, and adapt to such incidents.From our findings, the WNTR Python package designed to meet this need.The software can be used to assess the resilience of the water distribution system in the face of a variety of disruptive events, such as earthquakes, power outages, water quality issues, supply and demand uncertainty, and cyber attacks.The software offers the water distribution systems analysis community with a rich set of simulation and analysis tools.

5 RECOMMENDATIONS

Wireless sensor networks consideration for near real-time monitoring Using a machine learning model for predicting a disruptive event. Real-world data to test the capability of WNTR.

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