AquaSCALE: Exploring Resilience of Community Water Systems

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Motivation

Water is a critical resource and a lifeline service to communities worldwide. The failure of water network often causes disruptions ranging from temporary interruptions in services to extended loss of business and relocation of residents. Southern California experiences the drought crisis over the year where one of the manifestations is “sinking lands” or subsidence because of excessive groundwater pumping. NASA suggests that the resulting subsidence can have a significant impact on surface infrastructure causing broken pipes and damage to other infrastructure such as large aqueducts or open conduits. In addition, based on the report from the Los Angeles Department of Water and Power (LADWP), Los Angeles (LA) has been experiencing an unusual increase in pipe breaks and leaks, mainly in old pipes that are susceptible to corrosion problems and pipe joint displacements caused by surface deformations. About one-fifth of the city’s water pipes were installed before 1931 and nearly all will reach the end of their useful lives in the next 15 years. The drought has taken its toll on water distribution pipes --- intermittent use as a result of water conservation programs has caused atypical stresses on these older pipes.

Southern California is also currently experiencing the worst El Nino effects in decades. On one side, extensive rainfall will help to replenish fallen water tables and fill existing reservoirs. On the other side, excessive rainfall could also result in significant damage to the region in the form of flooded infrastructure, damage to residential and commercial buildings, and damage to underground pipes that may experience excessive movement in surrounding soils because of rapid re-saturation from pounding rains. Compaction of soils (as a result of water extraction) and then re-saturation (as a result of El Nino) in relatively short periods of time could stress already weakened pipes to the point of causing significant increases in leak rates and thus major pipe breaks of failures.

In this project, we aim to design a middleware framework, AquaSCALE, to identify the most vulnerable spots in community water infrastructures, and determine regions where more instrumentation and management are required for sustainable and resilient operation of the entire system. This platform will allow us to model, simulate and explore water systems at two layers, a higher service layer and a lower built infrastructure layer, by executing a logical observe-analyze-adapt loop at its core. Input to the service layer is derived from observations gather from sensors and human reports, and stored in the data management module. Analytics modules that subsume models developed by domain experts operate on the near real-time data to generate higher level awareness for specific application tasks, such as pipe leak detection, flood prediction (due to pipe burst), and evacuation planning. The awareness then triggers corresponding logical adaptations to explore solutions in cyberspace before instantiating them into a physical infrastructure.

Research Tasks

To truly understand the behaviors of water pipelines and improve the resilience of water networks, a middleware based approach is required to integrate existing functional modules and improve information integration. The middleware can embed a variety of loosely coupled pre-existing simulators based on structural reflection and metamodel concepts to study the joint effect and cascading of multiple phenomena. The proposed integrated treatment consists of three interrelated thrusts.

IoT/Sensor Data Acquisition

In this task, we will explore mechanisms for gathering hydraulic and hydrometeorological data using a variety of sensors/instrumentation to understand the cost/utility of various observation modalities. It enables gathering and managing of real-time field information, identifying effects of new information on an analysis begun already, and projecting effects of new information, with updates from the field on simulation outcomes.

Hydrometeorogical data (i.e. precipitation, surface temperature and humidity) can be collected by satellite remote sensing, weather radars and point observation. G-WADI GeoServe, a cloud classification system developed at UCI, can support observing, monitoring and analyzing extreme weather events in near real time at high resolution (0.04degree ~ 4km) globally (60^{o}N ~ 60^{o}S). It allows users to access global precipitation estimation as far back as 72 hours in real time. Wireless sensors considered in water infrastructures include those whose function is similar to those in SCADA base systems --- these include commercially available sensors pressure, moisture, humidity, acoustic and chemical sensing devices. Human sensing platform enables human participations to help identify e.g. weather events and water pipe leak events via crowdsourcing. We are currently collecting water-related data including weather, pipe break, flood etc. from twitter via tweet-acquisition platform developed at UCI. In the near future, we will explore mechanisms for collecting hydraulic data (e.g. pressure, flow rate, water quality) by studying dynamic sensor selection and intelligent sensor placement. Seismic monitor system will be integrated since earthquake hazards often cause damage to water supply system.

Exploring Resilience to Infrastructure Disruptions
The key objectives are to understand how the system performs under real-time events (e.g. disasters) and study the propagation and cascading effects of the damage. The outcome is to identify regions/points of higher vulnerability in the network model and quantify the potential extent of damage and impact.

We are currently working on the leakage detection since pipe breakage is one of the most frequent types of failure of water networks. Leakage can be detected by correlating changes in pipeline pressure and/or flow characteristics to changes in a hydraulic model for a given water network. This correlation is achieved by updating a hydraulic model numerous times to find a scenario whose outcomes best match the monitored data obtained from the sensors. To ensure that our design is executable in real-world settings, we consider a canonical water distribution network without assumptions on its characteristics. Due to the dynamics of water systems, no single mathematical equation or neural network can effectively monitor the behavior of the entire system. We, therefore, build an integration platform to allow the system simulation modeling to be updated with actual post-event observations. When a discrepancy is observed, the platform triggers the hydraulic model updated to iterate to a solution that is the best match with the observations. It then helps to identify the potential leakage location.

Scaling AquaSCALE to Address Large-System Problems and Needs
We will work with the Los Angeles Department of Water and Power (LADWP) to extend the methodology to a large water utility. The water system has been through several large earthquakes in the past 50 years, including the 1971 San Fernando earthquake and the 1994 Northridge earthquake. Recent studies indicate that the water systems that supply Los Angeles with 88 percent of its water all cross the San Andreas Fault: “The Los Angeles Aqueduct, Colorado River Aqueduct, and California Aqueduct cross the San Andreas Fault zone a total of 32 times and will likely be simultaneously damaged in a single earthquake event, resulting in the inability to import water to Los Angeles for many months”.

We will also work with the Washington Suburban Sanitary Commission (WSSC) to study the impacts on the water distribution network due to extreme weather (e.g. snowstorm). According to WSSC, the extremely cold temperatures in February 2015 resulted in over 400 water main breaks. The water demand increased from an average of 150 million gallons per day to 188 million gallons per day because of the water lost through these leaks.