Implementation of new water quality model into EPANET in hopes of reducing Arizona Public Drinking Water System’s Vulnerability to Contamination

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Arizona’s current water distribution network is a complex grid of pipes, pumping stations, treatment plants, and storage tanks covering thousands of square miles within large cities such as Tucson and Phoenix. These entry points into the water grid provide countless opportunities for chemical, biological, and/or radiological contaminants to pollute the public drinking water supply. Using current water quality prediction models, there is a limited capacity to detect and trace pollutants. So any disruptions to the network such as a pipe break could mean that a fire department cannot fight a fire, sewage would leak into the drinking water, or that crops would be ruined.

In most metropolitan cities, water planners use computer models or similar commercial packages to plan for the distribution of the water throughout the city. All of these computer programs are based on a modeling software called EPANET whose water quality model hasn’t been updated in over 10 years. In the past, there wasn’t any need for detailed analyses of water quality. However, now in the post 911 era, having a fast and reliable system for the detection and tracking of foreign substances in the water supply is essential.

The current EPANET water quality simulator uses a LaGrangian time-based approach to track the fate of biological agents and chemicals as it moves along pipes and mix together at junctions. Species mixing at intersections is calculated as instantaneous and perfect.

However, a series of experiments and detailed computational fluid dynamics studies conducted at Sandia National Laboratories and at the Water Village of the University of Arizona are suggesting otherwise. Real world mixing at an intersection is not completely uniform. The concentrations at the two outlets are not 50% and 50% each, but the split is probably closer to 85% and 15% and can vary widely based on the Reynolds’ numbers of the incoming and outgoing pipes. Therefore, the current mixing model can lead first-responders and engineers to quarantine wrong sections of the city, cleanup wrong portions of the water supply network, and then unsuspecting citizens end up drinking contaminated water.

The approach to improving EPANET’s water quality model is to fix the species mixing problem at the pipe intersections. Through simulations using computational fluid dynamic (CFD) models and also conducting real life experiments, we can determine what is actually happening at the pipe cross junctions. Then the proper set of equations and code can be implemented into EPANET for further research and verification on the large scale.

So far CFD models have shown that the mixing at the pipe intersections is highly correlated with the incoming and outgoing Reynolds’ Numbers. By using the Navier-Stokes Equations, the k-e Turbulent Model, and mass balance of species transport, the water quality of the outgoing pipes can be predicted using the incoming concentrations and each of the respective Reynolds’ Numbers. The experimental data using salt as the pollutant also confirm the results of the CFD models. Although the experiments do not exactly match CFD models, both results show that the current EPANET water quality model is wrong. (See Graphs)

For the implementation into EPANET, a set of programming codes were developed to accommodate the changes. Since the new water quality model is more complex than just complete and instantaneous mixing, a new set of parameters were created. The new model only works for common cases where species mixing only occurs at a cross junction and does not account for T cross sections or bends. In addition, each cross junction has a total of 4 pipes where two pipes are inflows and the other two are outflows.

According to the CFD models, the most important part for determining the results of pipe junction mixing is the dependence on the Reynolds Ratios, the incoming and outgoing. For
purposes of simplification, they were named $\text{Re}_{S/W} = \frac{\text{Re}_S}{\text{Re}_W}$ and $\text{Re}_{E/N} = \frac{\text{Re}_E}{\text{Re}_N}$, where the S/W is the incoming flows and the E/N are the outgoing flows. Then there are the four different scenarios that can occur based on the respective Reynolds’ Numbers of each pipe.

Scenario I: Equal Inflows and Outflows ($\text{Re}_S = \text{Re}_W = \text{Re}_N = \text{Re}_E$)

Scenario II: Equal Outflows, varying Inflows ($\text{Re}_S \neq \text{Re}_W$, $\text{Re}_N = \text{Re}_E$)

Scenario III: Equal Inflows, varying Outflows ($\text{Re}_S = \text{Re}_W$, $\text{Re}_N \neq \text{Re}_E$)

Scenario IV: All four flows are different ($\text{Re}_S \neq \text{Re}_W \neq \text{Re}_N \neq \text{Re}_E$)

Each of these scenarios has its own set of mixing patterns. So the result is a matrix of mixing data that outputs a dimensionless concentration multiplier, $C^* = \frac{C - C_W}{C_S - C_W}$, based on the Reynolds Ratios. This $C^*$ value is used to calculate the two outflow concentrations and thus correcting water quality model in EPANET.

Since EPANET 2.0 is actually one program written in several different programming languages, it has been a challenge to implement the new set of water quality equations. EPANET’s windows graphical user interface is written in Delphi/Pascal code. The water quality model and other water analysis code such as the hydraulic model is written in C/C++ in the form of a .dll file which is called by the Delphi/Pascal part.

The trial setup network was a simple 5 by 4 network. (See network below) The setup is on the ground level with no changes in elevation. The pump is a 1-point curve with a flow of 300 GPM (1135.6 L/min) and a head of 40ft (12.2 m). The pump provides pure water ($C = 0$ mg/L). The injection point injects a constant amount each hour: 100 mg/L of salt at 1 GPM (3.78 L/min). Subdivisions A, B, and C are demand points, each with a demand of 100 GPM (378.5 L/min). Each section of the pipe has a diameter of 12 in (30.48 cm), a roughness of 100 (HW), and a length of 500ft (152.4 m).

After the network was created in EPANET, the C/C++ code was modified so that each pipe displayed its corresponding Reynolds numbers. CFD simulations were carried out based on these Reynolds numbers. The dimensionless concentration splits were calculated and entered into the EPANET code. For each of the instances where a junction had 2 inlets and 2 outlets, CFD produced the corrected splits for each outlet, and the results were added to the existing water quality model in the original EPANET code on a node-by-node basis.

When the modified EPANET code was used, concentrations at Demand Points A, B, and C all displayed sizeable changes. (See Table below) For Demand Point A, for example, the salt concentration was drastically reduced by almost 9 times. For Demand Point B, the salt concentration was slightly elevated. For Demand Point C, the salt concentration was increased by nearly twice its original amount. Similarly, the mass rates changed significantly.

The changes can be seen better when the concentration contours are shown for the 5 x 4 system. The concentration was evenly spread throughout the neighborhood using the original EPANET water quality model. Demand points A and C received a low amount, while the point B received a moderate concentration level. However, after the modified EPANET code was implemented using C/C++, the majority of the salt concentrations traveled to the Eastern part of the network. Demand point A barely received any salt, while demand points B and C had large increases in the amounts of salt. These results demonstrate that there are a lot of implications if the modified EPANET is used for solute transport for real world applications.
Communities in Arizona are using an outdated water quality system that is inadequate in determining what areas will be affected. There are ways to protect people from disruptions on the most basic and necessary of public services such as our drinking water. The revised EPANET water quality model will drastically improve the city’s effectiveness in monitoring the water supply and ensure that the citizens of Arizona have access to the cleanest water in the world.

The modification in EPANET was for a specifically built network. More work still needs to be completed before a more generalized version of the mixing code can be implemented. The tracing of biological/chemical species in real-time is still in the early stages. Also axial dispersion is an area that needs further research and funding.

Additional Information:

Scenario III: Equal Inflows, varying Outflows ($Re_S = Re_W$, $Re_N < Re_E$)
CFD outcomes, $Sc = 0.7$ (default)
Experimental Outcomes, $D = \frac{3}{4}”$ (1.905 cm), and EPANET
Scenario building and corresponding EPANET setup; (a) typical mid-town water distribution network and (b) a simplified water distribution network for a EPANET example case.
References


