Raising the bar on disinfectant residuals

Using a digital twin of a water distribution system can help utilities manage disinfectant residual concentrations and comply with water quality regulations. **Tom Walski** of Bentley Systems, Inc. explains.

Maintaining a disinfectant residual – whether using chlorine, chloramine, or other chemicals – is an important part of providing protection against microbial contamination of water systems. However, there are wide-ranging opinions on what disinfectant residual concentration is needed and the best approaches to meet those requirements.

Providing disinfection at the source does not necessarily mean the residual will be maintained throughout the system. Disinfectants are active chemicals that react with other constituents in the bulk fluid or along pipe walls, resulting in a decrease to the extent that residuals may not be detectable at the far extents of the system.

The US Environmental Protection Agency (EPA) regulations (40 CFR 141.72) require that some measurable level of disinfectant be maintained in systems that are fed by surface water or by groundwater under the influence of surface water. However, some states have established regulations requiring higher concentrations, such as 0.1 or 0.2 milligrams per liter (mg/L).

Understanding the problem

Disinfectant residual concentrations are not steady or uniform. They vary over time and location. In some locations, it is easy to maintain an acceptable residual value, while in others it may be virtually impossible without considerable expense. Sampling in the system provides only a partial picture of what is occurring in the pipes. The concentration may be different a half-mile away or an hour later.

One approach to obtaining a more complete picture of what is occurring is to run a calibrated hydraulic/water quality model of the system. A hydraulic model can be viewed as a digital twin of the real system. A digital twin behaves like the real system, but can also fill in values where samples aren't available and can predict what will happen in the future or with a different operation. A combination of modeling and sampling can identify locations and times when maintaining an adequate residual will be problematic.

With the model, a system operator can determine residual concentrations for the existing system with different demands and reaction rates. For all but the smallest systems, the model usually shows that there are locations that will struggle to meet any regulatory standard. Some additional measures must usually be taken to remain in compliance.

A color-coded map created with WaterGEMS of a large distribution system with its source in the north. Green areas show high disinfectant values while red and magenta show low values, revealing potential problems at locations that are far from the source.

Potential solutions

Numerous measures can be taken to increase disinfectant residuals – each with its own advantages and disadvantages: Some are summarized below:

Increase disinfectant dose at the source: This requires no capital investment but increases chemical costs. However, increasing disinfectant dose raises issues with disinfectant byproduct formation as well as taste and odor complaints.

Install booster disinfectant feeds: Because only a portion of the system is likely to experience shortfalls, booster disinfection feeds can be installed. This effectively gets the disinfectants where they are needed with a minimum dose compared to feeding only at the source. This incurs a significant capital investment as well as a modest cost for additional chemicals and labor.

According to the WaterGEMS plot, booster disinfection stations can bring residual values into a range where they meet regulatory requirements. The impact of booster chlorination is shown where the magenta line indicates low concentration while the green line shows the improvement due to a booster chlorine station.

Modify pump and tank operation: The longer water remains in tanks, the further the residual will drop. When that water finally leaves the tank, it may be devoid of disinfectant. If excessive tank storage proves to be the problem, then more frequent turnover of the tank may be an inexpensive solution.

Manual flushing: Water with low residuals can be flushed from the system and fresher water will move in to take its place. This is a labor-intensive measure that requires no capital investment and can pinpoint problem areas. However, flushing increases nonrevenue water and can stir up sediment if not done properly.

Automated flushers: Installation of automatic flushing hydrants that can automatically flush the portions of the system has very low labor costs but involves a substantial capital investment. Since these hydrants cannot readily be moved around, the selection of their location is important. Alternative locations can be tested in the digital twin with no expense. In cold climates, flushing hydrants need to be protected from freezing.

Flowing blowoffs: Instead of flushing at intermittent times, a blowoff can be opened that will continuously flow to eliminate water with low residuals. This involves minimal capital and labor investment but has the most adverse effect on nonrevenue water and can be difficult to control.

Switching disinfectants: Chloramines tend to have slower decay rates than chlorine. Switching disinfectants may be a solution. However, switching simply to meet a residual target may not be worthwhile because chloramines have their own issues such as nitrification and more difficult dosing at booster feed locations.

Decreasing decay rate: Disinfectant decay rates depend on water quality and pipe condition. Improving treatment – for example, by adding a membrane process – will produce water with a slower decay rate, but the extra cost is usually not justifiable. Cleaning pipes to remove biofilms and sediment with flushing, pigging, or lining can reduce decay rates but extensive cleaning may not be economically justifiable. A digital twin can calculate the effect of reducing decay rates.

Increase demands: For small rural

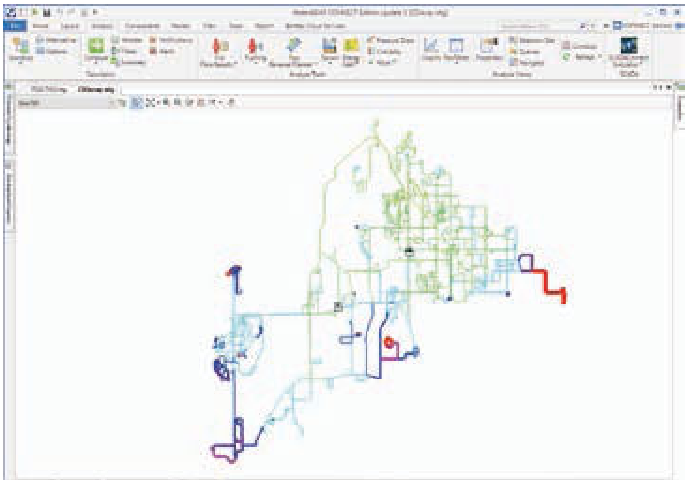

Figure 1. Green areas show high disinfectant values while red and magenta show low values. Courtesy of Bentley Systems

systems with small pipes, it may be possible to give an inexpensive detection kit to a customer at the end of the system and have them analyze the residual value each day. If the concentration is low, the customer can run a faucet until the value improves and get a credit for the water used.

Selection of monitoring points and times: Some operators may only sample for residuals at locations and times when the values are known to be good. This skirts the letter of the regulation, but more importantly, it violates the intent of the regulations, which are to protect human health.

Selecting a solution

It is clear, there is no one-size-fits-all solution for low residuals. The best alternative will depend on local conditions, such as decay rate, size of the system, extent of the problem, and the water system's preference for incurring additional capital, labor, treatment, or chemical costs.

Rather than basing the decision on an arbitrary selection, it is best to quantify the effectiveness of each solution method. The hydraulic/water quality model able to point out the extent of the problem can also be used to simulate the alternative solutions. For each of the solutions, the model can simulate various effects.

For example, the model can reveal the effects of increasing disinfectant feed at the source using the model and to see how the change shows up in the distribution system. It is very easy to change the disinfectant concentration in a model. In certain cases with multiple sources, it may only be useful to change dosing at one source. If disinfectant by products are also an issue, their formation can also be simulated.

The model can also reveal the effect of installing booster disinfection stations. They can be placed in different locations and use different set points in the digital twin to maximize their effectiveness. As well as, the effect of increasing or decreasing tank turnover to determine if changing pump set points can significantly improve residual values.

The model can predict how different manual flushing approaches identify when and where flushing is needed and how much water should be flushed to bring disinfectant residuals up to their desired values. A model run can show how high-quality water moves to the flushed hydrant and how long it will take to arrive.

The location, frequency of flushing, and volume needed for flushing to maximize the effectiveness of automated flushers and minimize cost of operation by moving them around the system to identify the best locations can also be simulated by the model.

Using the digital twin, identification of the best blowoff location to maximize effectiveness and minimize the water used can minimize the impact on nonrevenue water. It can also identify the impact that changing disinfectants has on the distribution system, as well as the effect of modifying water quality on the persistence of disinfectants by changing their reaction rates in the digital twin.

Additionally, the model can assess the value of increasing demand to maintain disinfectant residuals, while revealing what the residual concentration is likely to be at monitoring points before taking any samples.

Ancillary issues

Several complicating factors increase the need and value of a digital twin model.

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Disinfectant residual values are not constant but vary weekly and seasonally. Within a day, values can differ depending on whether a location in the system is receiving water directly from the source or from water that has spent several days resting in a tank. Some industrial areas may not use water on the weekend, which means that the water may age and lose residual value by Monday. Aging may be good for wine, but not for water.

A beach resort town may provide fresh water in the summer when water use is at a maximum but have problems with old, stale water during the off-season. The opposite may be true for ski resort towns in the mountains. Weather can also impact dis-infectant residuals. In systems where extensive lawn irrigation is practiced, rain can dramatically reduce water use, which increases water age and decreases residual values. Decay rates are also temperature-dependent.

Another complexity is found in land development projects that may take several years to "build out." A 400-millimeter (16-inch) pipe may be needed to meet fire-flow demands in a new industrial park. Yet, in its early years the industrial park may only have one warehouse located 400 meters (quarter mile) from the nearest neighboring water customer and only requires water for two restrooms. Providing adequate disinfectant would be virtually impossible without heroic measures.

Systems that receive a mix of chlorinated and chloraminated water may have trouble along the front where the two waters mix and concentrations near breakpoint. Models can help identify where that front is located and where and when it moves.

Future considerations

As disinfectant residual concentration regulations evolve, it may become more difficult to comply with new standards. There are numerous steps that can be taken to address this issue and the use of a hydraulic/water quality model – a digital twin – can be very effective in comparing alternatives in order to determine what option would be the most effective for the system under study.

Author's Note

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