From Plant to Tap
Optimize Quality

The characteristics of water a treatment plant produces can affect what changes may occur in a distribution system. With the next round of regulations focusing on distribution systems, utilities are turning their attention to quality of water delivered. **BY DAVID R. WILKES**

WITHIN A distribution system, pipe materials, storage tank characteristics, and variable demand patterns affect the quality of water that reaches customers. A distribution system can also be vulnerable to vandalism or terrorism. That's why utilities are focusing more on distribution system water quality, system configuration and operations, and overall performance improvements.

REGULATORY FRAMEWORK

Distribution systems have been regulated primarily for controlling bacteria and by-products resulting from disinfection and corrosion. During the last several years, the US Environmental Protection Agency (USEPA) worked with AWWA and distribution system experts to compile information on potential health risks associated with distribution systems to prepare a series of Total Coliform Rule (TCR) issue papers. The documentation contributed to proposed 2010 TCR revisions (see www.epa.gov/safewater/disinfection/tcr).

To help USEPA prioritize these issues, the National Academy of Sciences (NAS) developed a distribution system water quality study. The first report, Assessing and Reducing Risks, released in 2006 by the Committee on Public Water Supply Distribution Systems, indicates USEPA should consider several high priorities in developing new regulations, including cross-connections and backflow, new or repaired water mains, and finished water storage facilities. The new rules will likely include elements that address security risks and system vulnerability. Based on this proposed regulatory framework, utilities should assess their systems and determine how best to optimize distribution system design, operations, and maintenance.

WATER QUALITY

"Unintended consequences" is a catchphrase concerning distribution system water quality. Many water quality problems that develop in pipe networks and storage tanks result from treatment method choices. For example,

- reducing organics to low levels produces lower disinfection by-products (DBPs) but may enhance copper pinhole corrosion.
- increasing pH to improve corrosion control may increase trihalomethane formation.
- changing coagulants may improve organic carbon removal but could change the water's chemical makeup and increase lead corrosion.
- adding new filtration techniques may improve microbiological quality but might allow soluble inorganic compounds (e.g., manganese) to pass into the distribution system where residual disinfectant oxidizes them, causing precipitation and particle formation and resulting undesirable aesthetics.

These examples indicate the need for comprehensive analysis and review of water system components, as well as how changing those components affects distribution system water quality. Biological stability and biofilm, corrosion and corrosion control, DBPs, and aesthetic quality are primary issues to consider.

Biological Stability and Biofilms. Biologically stable water is less likely to support growth of microbiological contaminants that may have escaped treatment or were introduced through a pipe network. Biologically stable water is required in many

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Ted Hejka, City of Ann Arbor (Mich.) Water Utilities, uses a coring device to collect granular activated carbon (GAC) samples at different depths. Biological filtration, comprising granular media such as GAC, sand, or anthracite, can improve water quality in a distribution system and reduce the growth of opportunistic organisms.

PHOTOGRAPH: CITY OF ANN ARBOR (MICH.) WATER UTILITIES

David R. Wilkes is water practice leader for Jacobs (www.jacobs.com), Norcross, Ga.

European countries that don't maintain a distribution system disinfectant residual. In those countries, stability is measured with assimilable organic carbon (AOC), which analyzes the quantity of carbon in the water that's readily available as food for bacteria. Although US treatment facilities are required to maintain a disinfectant residual, incorporating methods of reducing AOC enhances biological stability and improves overall water quality.

Biofilms are diverse communities of organisms that coat pipe walls, commonly forming in large quantities in unlined iron pipe where there's a steady source of humic carbon, even in the presence of high chlorine concentrations. Biofilm prevalence and vitality relate to many factors, including

- type of carbon and its concentration.
- disinfectant type and concentration.
- type of pipe materials.
- corrosion-control methods.

Optimizing water quality to increase biological stability and reduce biofilm formation is akin to biological treatment at a plant. Many plants that have introduced ozone as a disinfectant for *Cryptosporidium* control have added biological filters to remove ozonation by-products, such as aldehydes. Biological filters provide a biofilm on the filter media. Granular activated carbon is usually used for filter media because it provides more surface area and better growth sites. Water produced by these filters has low organic levels and tends to meet the low AOC levels found in European waters that are considered stable. Utilities should consider biological filtration as one element of the treatment process that could potentially improve overall biological water quality in the distribution system and reduce the growth of opportunistic organisms.

Corrosion and Corrosion Control. Interior corrosion of iron pipe and leaching of lead and copper have been the primary focus of distribution system corrosion-control efforts. Past events indicate the complexity and difficulty in controlling corrosion. For example, in Washington, D.C., a firestorm of controversy resulted when a switch from free chlorine to chloramines as a final disinfectant caused a dramatic increase in distribution system lead levels. In Durham, N.C., lead levels increased when coagulants were changed to improve natural organic matter (NOM) removal. The change appeared to alter the ratio of chlorides to sulfates. These scenarios indicate a need to take a broader view of distribution system corrosion and develop more data on complex interactions to ensure safety from inorganics and maintain aesthetic water quality.

For optimum corrosion control, a system's water must be studied for its unique characteristics. For lead leaching, research regarding the interaction of chloramines and lead and copper is under way, but no definitive cause-and-effect relationships have yet been established. Other concerns being considered are the production of higher levels of N-nitrosodimethylamine (NDMA) in chloramine systems, production of more potent unregulated iodinated DBPs, and nitrification. Therefore, utilities should carefully consider all implications before switching to chloramines for DBP control. In addition, copper-pitting corrosion research revealed several key factors related to pitting development:

- Low NOM concentrations
- Aluminum residuals greater than 50 ppb as Al
- Free chlorine residuals greater than 2.5 mg/L
- pH levels greater than 8.2
- Chloride levels less than 30 mg/L
- Frequent flow through the pipe, continuous flow being the worst case

Because most utilities keep NOM low to reduce DBPs and control biofilm development, the other factors above should be evaluated to control copper-pitting corrosion. Aluminum, pH, and free chlorine definitely can be controlled by optimizing their use at the treatment plant and avoiding threshold values.

From an aesthetic perspective, a key element of corrosion control is to aggressively replace or rehabilitate old iron pipes. Red water and other color issues in a distribution system are directly attributable to interior pipe corrosion. Use of phosphate-type inhibitors can help control release of these compounds, but the best approach is to replace the pipes. Optimizing phosphate

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Corrosion control entails assessing pipe conditions and studying a system's water for its unique characteristics.

PHOTOGRAPH: HDR

inhibitors is another approach to lead and copper corrosion control and biofilm reduction. In addition, research indicates that orthophosphates generally are better for lead and copper control, and polyphosphates are better for red water control.

Disinfection By-products. One of the most-researched distribution system water quality issues is DBP control. The Stage 2 Disinfectant and Disinfection Byproduct Rule (Stage 2 DBP rule) changed the compliance approach, and many utilities have made significant treatment and distribution system changes to meet the new requirements. Also, new, more potent DBPs demonstrate that reducing NOM to low levels before adding oxidants is an important optimization step to consider.

Utilities also have other options to improve DBP levels following the treatment plant:

Implementing Flushing Programs. Many utilities have found that implementing a systematic flushing program can improve distribution system water quality by reducing stale water in dead-end lines and creating higher flows to decrease water age.

Improving Storage Tanks. Hydraulic configuration and lack of turnover of tank contents during normal operations may contribute to excessive DBP levels. In evaluating DBP reduction, it's important to monitor tanks for potential problems. Modifying a tank's inlet–outlet and inducing greater turnover can reduce DBPs.

Distribution system storage tanks dampen peak-hour requirements and provide fire protection storage. Tanks are designed to accommodate moving a quantity of water into and out of a tank as easily as possible. That's why most tanks have a common inlet–outlet pipe—and resulting dead spaces and stagnation that lead to higher DBPs, potential chlorine residual loss, and deteriorated water quality. A system that completely mixes tank contents reduces detention time, eliminates dead spaces, and improves water quality. Utilities should consider retrofitting tanks with mixing systems and installing such systems in new tanks.

Reducing Water Age. A major contributor to continued distribution system DBP production is excessive contact time caused by pipe configurations and areas of reduced demand. Although many utilities may consider piping modifications to be an expensive DBP control method, eliminating dead ends through looping and other modifications may be preferable to expensive alternative disinfectants or precursor removal options. These system modifications can be evaluated relatively inexpensively with computer modeling, using various "what-if" scenarios to compare potential control strategies.

Aesthetic Quality. Water color, taste, and odor are important factors in maintaining consumers' confidence in the quality of their tap water. Major problems eliciting consumer complaints result from iron and manganese and are related to high levels of soluble metals and precipitated compounds. Other issues relate to sloughing of corrosion products on pipe surfaces, leading to red water complaints. Problems also include odors caused by high doses of chlorine; misapplication of ammonia in the formation of chloramines, producing odorous dichloramines or trichloramines; or cat-urine odors associated with chlorine dioxide.

Optimum metals control uses effective corrosion-control chemicals and effective soluble iron and manganese removal in a treatment plant. If manganese, in particular, is allowed to pass through a plant, it will precipitate in the distribution system because of slow reaction kinetics at neutral pH with free-chlorine oxidation. Many utilities intermittently experience pepper water production, caused by sediments lying dormant at the bottom of pipes until a hydraulic transient stirs them up and produces major complaints. These soluble metals must not be permitted to enter the distribution system. The key to controlling corrosion products is aggressive pipe replacement. Use of phosphate inhibitors may help, but removing the red water source is preferable.

To control tastes and odors related to disinfection practices, treatment facilities should optimally monitor and control disinfectant use. Such optimization involves using only the amount of chlorine necessary to achieve disinfection at the plant and to maintain a residual in the

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Many water quality problems that develop in pipe networks and storage tanks result from treatment method choices.

distribution system. For chloramines, strict adherence to best practices for chlorine to ammonia ratios and effective mixing at the point of addition will avoid odors associated with dichloramine and trichloramine formation. Finally, with chlorine dioxide, the best approach for controlling potential cat-urine odors is use of a ferrous compound to remove chlorite, because reformation and volatilization of chlorine dioxide in the distribution system requires the presence of sufficient amounts of chlorite reacting with chlorine.

Online instrumentation provides input to the water quality baseline.

PHOTOGRAPH: HACH

OPTIMIZATION TOOLS

Although several approaches ultimately will be combined to provide effective management, the primary tools are real-time water quality monitoring and computer hydraulic modeling.

Real-Time Monitoring. The most credible threat to water quality is intentional cross-connection contamination through use of biological or chemical agents. For this reason, utilities should consider strategically locating several continuous water quality monitoring stations throughout their distribution systems. The stations should minimally monitor chlorine residual and pH. Although new technologies for measuring other parameters are being developed, current systems can monitor these two parameters, as well as turbidity and conductivity.

Many biological agents that terrorists might use are susceptible to chlorination. A well-planned attack on a water system with one of these agents would most likely be preceded by adding a dechlorinating agent to ensure maximum effect. With continuous monitoring and alarm capabilities, early warning of a possible attack would be provided. In addition, such a threat would require toxic chemicals to be delivered in concentrated form. These concentrated forms typically would be acidic or basic and would affect distributed water pH significantly when introduced in large quantities of continuously fed water.

Monitoring station locations should take into account the potential ability of a terrorist organization to lease space large enough to set up necessary equipment and store large quantities of agent. Also, monitoring facility locations downstream of major tanks or concentrated populations is prudent. Specific locations should also take into account the vulnerability of units targeted for destruction by a terrorist operation. Connecting these stations to the main water system control facilities through a supervisory control and data acquisition system is also required.

In general, water quality protection can't be completely assured against colorless, inorganic, odorless, and tasteless agents. However, the monitoring methods suggested here provide valuable operational information.

Hydraulic Modeling. Computer hydraulic modeling is a tool that will ultimately be used for distribution system water quality management. Such modeling has been used by many utilities to comply with the Initial Distribution System Evaluation requirements of the Stage 2 DBP rule. By using a well-calibrated model, distribution system water age can be determined and effective options for age reduction can be modeled. With computer modeling, future pipeline and storage tank projects may be analyzed for hydraulic feasibility, as well as the influence of water age and quality.

Utilities can use computer models to analyze and compare alternatives to optimize hydraulic performance and water quality. In addition, linking computer models and geographic information systems will provide more effective operation and control of distribution systems to ensure the highest-quality water.

CONSIDER THE OPTIONS

Utilities may approach optimal distribution system water quality from several directions, but the following options provide the best opportunities for major improvements:

- Aggressively replace or rehabilitate unlined iron pipes.
- Remove as much NOM as possible before oxidant addition or release to the distribution system.
- Produce biologically stable water.
- Control all types of corrosion.
- Remove insoluble metals, particularly manganese, in the treatment plant.
- Use water quality monitoring and computer hydraulic modeling as optimization tools.

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