# Tech Brief

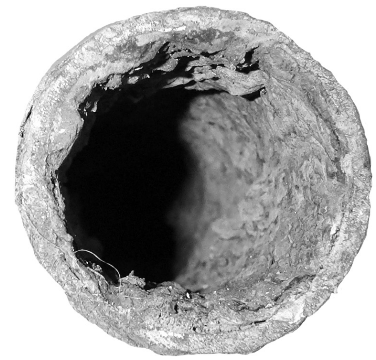
A NATIONAL DRINKING WATER CLEARINGHOUSE FACT SHEET

## Water Quality in Distribution Systems

by **Z. Michael Lahlou, Ph.D.**, Technical Assistance Consultant

**Summary**

A drinking water system's water quality may be acceptable when the water leaves a treatment plant. However, a variety of physical, chemical, and biological transformations can happen once the water enters and travels through a distribution system. Water producers need to understand the sources of water quality degradation during the distribution process because, in addition to taste and odor problems that can occur, research also suggests that degraded water quality increases the risk of gastrointestinal illnesses.



### Water Quality Deterioration Factors

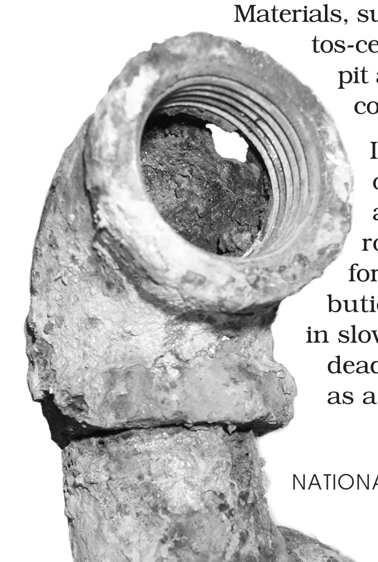
A distribution system's pipes and storage facilities constitute a complex network of uncontrolled physical, chemical, and biological reactors that can produce significant variations in water quality. The principal factors that affect water degradation during distribution are the system's structure, its operation, and a number of water quality factors.

### Structural Factors

Drinking water distribution systems are typically thought of as the underground network of interconnecting mains or pipes. They also can include storage facilities, valves, fire hydrants, service connections, and pumping stations.

Historically, water system designers tended to create oversized pipelines and storage facilities. While system designers may be considering an area's future drinking water needs, oversized facilities result in long detention times, loss of chlorine residual, taste and odor concerns, and other water quality problems.

Furthermore, some of the materials designers choose to install in distribution systems create suitable environments for microorganism growth. Materials, such as cast or ductile iron, asbestos-cement, or pressurized concrete, can pit and make way for microorganisms to colonize.



In addition, oxidant-resistant microorganisms settle on pipe surfaces and produce a complex microenvironment known as biofilm. Biofilms form when organisms enter the distribution system and become entrapped in slow-flow areas, line obstructions, or dead-end sections. They usually appear as a patchy mass in pipe sections or as a uniform layer along the inner walls of a storage tank.

While not all biofilm is bad, researchers are currently unsure of its exact effect. Coliform bacteria may colonize in it, and biofilm may interfere with coliform detection. It may also cause taste and odor problems.

Designers now theorize that the material manufacturers use in pipes, as well as the condition of pipes, valves, and storage facilities, may exert a high-chlorine demand.

Pipe materials can cause water quality to deteriorate in other ways. Iron pipes can corrode, and lead and copper from pipe walls can dissolve. For example, unlined or exposed ferrous materials in pipelines can corrode and cause red or rusty-colored water. To avoid corrosion problems, systems are turning to plastic materials, such as polyethylene and polyvinyl chloride (PVC).

Finally, contamination via cross-connection, leaky pipe joints, or pipe breaks may influence water quality. Pathogens, such as *Cryptosporidium* and *Giardia lamblia*, may enter the system through contaminated raw water, in-line reservoirs, or breaks in pipelines. System personnel need to carefully and thoroughly perform flushing and disinfection procedures following repairs.

### Operational Factors

From an operations standpoint, network operating conditions—such as slow water velocities, supply sources going on and off-line, and the amount of time that systems store water—greatly affect water quality. Any of these factors can cause chlorine residual to fade, and, thus, allow microbial growth in the network. Further, hydraulic conditions can cause sediment to deposit, accumulate, and serve as both habitat and protection from disinfectants for microbial growth.

What's more, many storage facilities are kept full so that the system can be better prepared for emergency conditions. However, the long detention times result in degraded water quality.

### Water Quality Factors

Some of the factors that provide optimal conditions for microorganisms to multiply include long water-detention times in tanks and pipes, adequate nutrient levels, and warm temperatures.

In addition, research has shown that the level of biodegradable organic matter in the distribution system strongly affects bacterial re-growth and harbors opportunistic pathogens. An opportunistic pathogen can be any disease-causing organism, bacterium, virus, helminth, or protozoan that slips through the treatment processes or enters the distribution system during pressure loss and finds the opportunity or favorable circumstances to lodge or reproduce in organic material, bacterial slime, or other material that it finds attractive.

A number of other conditions also can affect water quality. For example, disinfectants may react with organic and inorganic compounds and cause taste and odor problems or form disinfection by-products. Also, particulate re-suspension may cause increased turbidity.

### Contamination Prevention and Control

Drinking water systems can improve water quality or prevent its deterioration in the distribution system. They can modify system operations and maintenance alternatives, make changes in treatment practices, and improve water quality monitoring and modeling. Generally, systems need to find an optimal combination of these actions, which can involve trade-offs between cost, water supply needs, and water quality considerations.

### Modifications to System Operation

Systems can use five primary operation procedures to maintain water quality:

1. minimize bulk water detention time,
2. maintain positive pressure,
3. control the direction and velocity of the bulk water (see Figure 1 on page 3),
4. maintain a disinfectant residual in the distribution system (Disinfectant residual, usually chlorine, provides a relatively effective barrier to the growth of microorganisms in bulk water and biofilm.), and
5. prevent cross-connections and backflow.

Utilities should minimize bulk water detention time because the interactions between the pipe walls and the bulk water result in water quality deterioration. Furthermore, stored finished water should be turned over frequently because the stored water's age contributes to the overall water age in the distribution system.

To reduce possible pathogen intrusions, drinking water utilities should maintain minimal water pressure in the distribution network, particularly if cross-connections are present. Further, the utilities should maintain a positive pressure throughout the distribution system to minimize the potential for back siphonage or backflow of contaminants to occur. However, excessive water pressure may cause pipe leaks or even breaks.

Utilities should minimize rapid or extreme fluctuations in flow velocities and should minimize the frequency of reversals. Activities that may affect flow velocities include rapidly opening or closing a valve, a power loss, and hydrant flushing. Changes in flow velocity can scour sediments, tubercles, and deposits from interior pipe surfaces and degrade water quality.

### Maintenance Alternatives

Distribution system flushing is an important tool to keep the water system clean and free of sediment, remove stagnant water, and remove unwanted contaminants that may have inadvertently entered the system. (See summer 2002 *On Tap* "How to Flush a Distribution System.")

Drinking water systems can use a variety of pipeline cleaning techniques. These techniques include mechanical scraping, pigging, swabbing, chemical cleaning, and flow jetting. Utility maintenance also includes emergency pipe repairs with sanitary precautions in place. Utilities should:

- try to keep contaminated water out of the trench and pipe;
- flush the line in the vicinity of the break;
- apply disinfectant to potentially contaminated components;
- disinfect new mains;
- disinfect storage tanks after construction, inspection, or maintenance; and
- conduct bacteriological testing to confirm the absence of contaminates.

Other maintenance activities that utilities can use to minimize water quality degradation:

- prevent and eliminate cross-connections;
- cover and vent storage tanks;
- maintain an adequate separation from sewers; and
- enforce applicable building plumbing codes.

### Changes in Treatment Practices

## Corrosion Properties of Different Materials Used in Distribution Systems

| Distribution Material | Corrosion Resistance | Potential Contaminants |
|---|---|---|
| Copper | Resists corrosion well, but is subject to corrosive attack from high velocities, soft water, chlorine, dissolved oxygen, and low pH. | Copper |
| Lead | Corrodes in soft water with low pH | Lead, arsenic, and cadmium |
| Mild steel | Subject to uniform corrosion, particularly sensitive to high dissolved oxygen levels | Iron, resulting in turbidity and red-water complaints |
| Cast or ductile iron | Aggressive waters can cause surface erosion | Iron, resulting in turbidity and red-water complaints |
| Galvanized iron | Aggressive waters can cause galvanic corrosion of zinc | Zinc and iron |
| Asbestos-cement | Good corrosion resistance; aggressive waters can leach calcium from cement | Asbestos fibers |
| Plastic | Resistant to corrosion | |

Source: Larry Mays, 1999

**Figure 1**

Disinfection means using chemicals to inactivate harmful microorganisms that might be present in water. This practice protects distributed water from pathogen re-growth or recontamination. Water systems treating surface water supplies maintain a level of residual chemical disinfectant throughout the distribution system. They also usually use some kind of booster disinfection or a more stable secondary disinfecting chemical, such as chloramines.

On the other hand, excessive chlorine levels will produce taste and odor problems, may accelerate pipe corrosion, may enhance formation of harmful disinfection by-products, or produce health concerns for the system's customers.

Pipes can and do corrode internally, reacting with the water and deteriorating. Internal corrosion can cause toxic metals, such as lead and copper, to leach into water, impart a metallic taste to water, stain plumbing fixtures, harbor nuisance and pathogenic microorganisms, reduce a pipe's hydraulic carrying capacity, and ultimately result in leaks and clogs.

Numerous physical, chemical, and biological factors can increase corrosion's rate and occurrence. Some individual factors can either promote or inhibit corrosion, depending upon other conditions. The most significant factors include temperature, pH, alkalinity, dissolved oxygen, total dissolved solids, hardness, and bacteria.

**Three approaches to control corrosion:**

1. Modify the water quality to make the water less corrosive, such as adjusting the pH.
2. Lay down a protective lining between the water and the pipe, such as using chemical inhibitors.
3. Switch to plastic pipe, which is less prone to corrosion.

Attempts to control biofilm in the distribution system have taken several directions. To avoid releases of biofilm, utilities can manipulate their water chemistry, such as adjusting pH, alkalinity, or the Langlier Index (an indicator of corrosiveness). They also can apply corrosion inhibitors not only to protect pipe materials but also to firm up the coating of the sediments that harbor microbial communities.

### Water Quality Monitoring and Modeling

Utilities should develop a sampling plan to address monitoring and modeling issues, such as selecting sampling sites, establishing test parameters and monitoring frequencies, establishing field-monitoring protocols, and addressing laboratory considerations. The most commonly monitored test parameters to determine general distribution system water quality include coliform bacteria, heterotrophic plate count (HPC) bacteria, disinfectant residual, temperature, turbidity, pH, and color.

Utilities may find that it is difficult to use monitoring data alone to understand all the possible interactions among the multiple parameters that affect water quality between the treatment plant and the user's tap. The flow pathways and travel times of water through these systems are highly variable because of the looped layout of the pipe network and the continuous changes in water usage over space and time. In addition, utilities commonly use storage facilities that are not part of the distribution system, making matters even more variable.

For these reasons, water utility managers are turning to hydraulic and water quality models as attractive monitoring supplements. They can use these models to perform a variety of water quality-related studies. Systems can:

- use chemical tracers to calibrate and test hydraulic models of the system,
- locate and size storage facilities,
- modify system operations to reduce the age of the water,
- modify the design and operation of the system to provide a desired blend of waters from different sources,
- find the best combination of pipe replacement, pipe relining, pipe cleaning, reduction in storage holding time, and location and injection rate at booster stations to maintain desired disinfectant levels throughout the system,
- assess and minimize the risk of consumer exposure to disinfectant by-products, and
- assess the system's vulnerability to incidents of external contamination.

Furthermore, as water utilities make more use of such tools as geographic information systems (GIS) and supervisory control and acquisition (SCADA) technologies, they can achieve a degree of data integration that enables more reliable network analysis and management.

**Where Can I Find More Information?**

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**Z. Michael Lahlou** holds a doctorate in environmental and natural resource economics, a masters in civil and environmental engineering, and an MBA. Formerly the technical assistance coordinator for the National Drinking Water Clearinghouse, Lahlou now resides in Huntington Beach, CA.