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Mark W. LeChevallier is principal of Dr. Water Consulting (www.drwaterconsulting.com), Morrison, Colo. Hunter Adams is water source and purification superintendent and Mark Southard is utilities operations manager with the City of Wichita Falls (www.wichitafallstx.gov), Texas. Steve Ash is training manager with Texas A&M Engineering Extension Service (www.teex.org), College Station, Texas.

Operators Need to Know Water Treatment as Public Health

Understanding how water treatment affects public health can help operators realize the importance of their daily work.

BY MARK W. LECHEVALLIER, HUNTER ADAMS, STEVE ASH, AND MARK SOUTHARD

THE WATER operator's role is important, affecting the public health and safety of everyone in a community. A bad doctor, nurse, or dentist only affects the patients they serve, but a water operator impacts everyone. So, it's important that operators are on top of their game 24/7 for 365 days of the year. It's critical for operators to be regularly reminded about the seriousness of their role in the water industry. This article continues the "Operators Need to Know" series to discuss how water treatment affects public health, starting in source water, moving through treatment and the distribution system, and ending in customers' plumbing.

THE IMPORTANCE OF OPERATORS

One of the first *Cryptosporidium* outbreaks in the United States was in 1987 in Carrollton, Ga. The mixing arms for the flocculation system had broken and were being repaired. It's something that could easily happen to almost any water system, but the coagulation impairment allowed *Cryptosporidium* oocysts to penetrate through the filters and cause an outbreak in the community. Operators reported that their kids came home from school crying because the other kids said that their dad had made their family sick. This kind of situation is a powerful reminder of the important job operators do.

Similarly, in the Walkerton, Ont., outbreak in 2000, two operators (who were brothers) were on suicide watch after being responsible for more than 2,300 illnesses and at least 7 deaths. Although one of the chlorinators for the groundwater system was broken, the disinfection logs continued to report a chlorine residual because "that's what the number was supposed to be." Heavy rains washed manure from a nearby cattle farm into an adjacent well. A subsequent inquiry found that the operators had limited training and were uninformed about drinking water safety.

These and other tragedies are tragic reminders that water treatment is more than "ticking boxes" on a report or filling in numbers on a log sheet; it's fundamentally about protecting the public health of entire communities! So, operators need to know, and remind one another daily, of the tremendous importance of the job they do and to be mindful of even the smallest deviation in operations and treatment.

MULTIPLE BARRIER CONCEPT

The *multiple barrier* concept is a useful tool for thinking about the overall water treatment process and its effect on public health. Multiple barriers are important, as no single treatment barrier is 100% effective against all contaminants, and the combined effect of multiple barriers significantly enhances contaminant removal and system resilience. Table 1 lists common contaminant types related to public health with which operators should be familiar. For full lists see the US Environmental Protection Agency (EPA) National Primary Drinking Water Standards.

In the Walkerton case, the following cascade of failures resulted in the outbreak:

- manure too close to the drinking water wells
- heavy rains that washed the manure into the well water
- loss of a disinfectant residual
- delay in responding to the water quality test results
- failure to promptly notify the public

Actions to avoid or correct even one or two of the failed barriers could have prevented, or at least mitigated, the impact of the outbreak. Fundamentally, the lack of knowledge and training of the operators was the root problem. Table 2 lists critical elements of a multiple barrier concept that operators should be aware of as well as their purpose to help prevent or reduce the effects of waterborne public health concerns.

SOURCE WATER PROTECTION AND MANAGEMENT

Regardless of whether source water comes from a surface supply (like a river or lake), groundwater, desalination, or even nonpotable reclaimed water, source water protection is a critical first step in protecting public health. Operators should be aware of potential source water contamination sources.

Operators play a vital role in protecting public health through every stage of water treatment and delivery.

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The details of conducting a source water assessment can vary by state, but there are three principal elements:

- **Delineate the source water protection area.** For groundwater supplies, this means determining the *area of influence*, which is the land surface directly above the cone of depression where groundwater is pulled toward

Table 1. Example Health-Related Contaminant Types and Problems Caused

Familiarity with key contaminant categories reinforces an operator's ability to safeguard public health.

Contaminant Type	Example	Problem Caused
Bacteria	Total coliforms (including *Escherichia coli*)	Naturally occurring; indicator organisms
	Legionella	Naturally occurring; can cause Legionnaires' disease
Protozoans	*Giardia lamblia* and *Cryptosporidium*	Gastrointestinal illness (such as diarrhea, vomiting, and cramps)
Viruses	Enteric viruses	Gastrointestinal illness (such as diarrhea, vomiting, and cramps)
Inorganics	Arsenic	Skin damage or problems with circulatory systems, and possible increased risk of getting cancer
	Copper	Gastrointestinal distress; liver or kidney damage
	Fluoride	Bone disease; mottled teeth
	Lead	Kidney problems; high blood pressure
	Nitrate and nitrite	Blue-baby syndrome
Disinfection Byproducts	Trihalomethanes	Liver, kidney, or central nervous system problems; increased risk of cancer
	Haloacetic acids and bromate	Increased risk of cancer
	Chlorite	Anemia
Organics	Pesticides and herbicides	Liver, kidney, nervous system, and reproductive system damage
	Industrial chemicals	Liver, kidney, or immune system problems; increased risk of cancer
	Per- and polyfluoroalkyl substances (PFOA and PFOS)	Cardiovascular, immune, and liver effects; increased incidence of certain types of cancers, including kidney and testicular
Radionuclides	Alpha and beta particles, radium 226 and 228, uranium	Increased risk of cancer

Table 2. Summary of Critical Elements in the Multiple Barrier Concept

Core treatment barriers highlight areas where operator knowledge and training are essential to preventing or reducing the effects of waterborne public health concerns.

Critical Treatment Barrier	Purpose
Source water protection	Identifying and protecting the best available water sources from contamination at the watershed level
Source water management	Identifying and reducing contamination sources in watersheds and protecting wells and collection systems
Water treatment: pretreatment, coagulation, flocculation, sedimentation, filtration	Managing the process to remove particulate, inorganic, organic, and other contaminant material during treatment
Water treatment: disinfection	Inactivation of pathogenic microbes
Treatment system operation and maintenance	Ensuring facilities are well-designed, constructed, and properly operated and maintained by trained and certified operators
Distribution system integrity	Managing infrastructure to minimize leaks and maintain adequate water pressure and disinfectant residuals, preventing recontamination in the distribution network
Monitoring and compliance	Regular monitoring of water quality at various points (source, treatment, pipe network) to quickly detect and fix problems
Emergency response and contingency planning	Developing plans and redundancies to respond to emergencies and unexpected events
Public information	Providing customers with actionable information on water quality and health effects

a well. For surface water supplies, the area of influence is land in the watershed upstream of a water system's intake; the segment closest to the intake (typically determined by time of flow) has the highest priority.

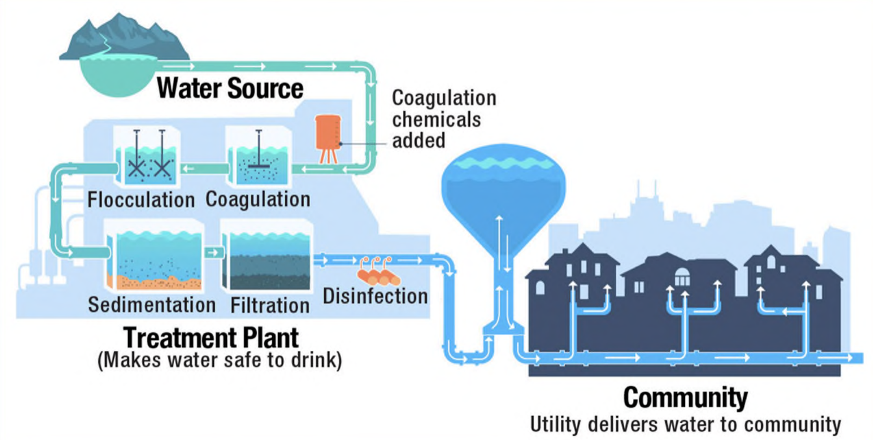
- **Conduct an inventory of potential contamination sources.** This step identifies potential sources of pollutants that could contaminate the water supply, including underground or aboveground storage tanks, sources of human or animal fecal material, residential areas or golf courses, and sources of pesticides or fertilizers from farms or other industrial activities. Roads or railways should also be considered where accidents could spill fuel, oils, and other materials into the watershed.
- **Determine the susceptibility or vulnerability of the water supply to contamination.** This step prioritizes the approaches for protecting the drinking water supply based on the contaminant's nature and severity. This information is incorporated into a source water assessment report that develops plans for addressing potential threats to a water supply and prioritizing activities for protecting the water from contamination. AWWA and EPA have extensive resources to help water utilities develop source water protection plans. For more information, see "Operators Need to Know Source Water Basics," which appeared in *Opflow*'s November 2022 issue.

DRINKING WATER TREATMENT

Virtually all community drinking water sources require some level of treatment. From simple pH and corrosion control to advanced oxidation and membrane treatment, the treatment plant is at the heart of public health protection for drinking water supplies. Therefore, it's important

Figure 1. Drinking Water Treatment From Source to Tap

Because every source and system is different, operators must understand why each treatment step exists and how these processes work together to safeguard public health.



Every day water operators should remind each other, "Hey! Let's protect public health today!"

for treatment plant operators to know the treatment processes in their facility, understand the reasons why those processes exist, and appreciate the public health protection they provide (figure 1). When it comes to drinking water treatment, there's no one-size-fits-all solution. Treatment plant operators need to know why their specific treatment process was designed to treat their unique water source. It's amazing how often operators are told to just operate the plant because "this is the way we've always done it!"

Providing a detailed description of all water treatment processes is beyond the scope of this article, but there are many good reference books, such as AWWA's *Water Quality & Treatment*, which provide more details. Figure 1 gives a useful overview of the steps in drinking water treatment. For more information, see "Operators Need to Know Conventional Treatment Processes," and "Operators Need to Know Advanced Treatment Processes," which appeared in *Opflow*'s March and April 2022 issues, respectively.

Pretreatment. Typically, at or near the water intake, oxidants such as chlorine, chlorine dioxide, or permanganate, or adsorbents such as powdered activated carbon (PAC), are added to initiate treatment to remove source water contaminants. Oxidants can be used to treat dissolved iron or manganese and condition organic material for better removal in subsequent treatment. PAC can adsorb pesticides and herbicides as well as other organic contaminants, some of which can cause objectionable tastes or odors. Some treatment trains may use a roughing filter or a presedimentation basin to remove silt and sediment. Aeration can be used in groundwater supplies to remove dissolved gases such as hydrogen sulfide, methane, carbon dioxide, or radon; increase the oxygen content of anoxic groundwater; and oxidize minerals like iron and manganese. Failure of any of the pretreatment processes will put additional stress on the remaining treatment steps and could be detrimental to their effectiveness.

Coagulation. In this step, chemicals like aluminum sulfate (alum) or ferric chloride are added to the water to neutralize the electrical charge on suspended particles, allowing them to clump together to be removed by sedimentation and filtration. Once the particles lose their negative charges, they're able to stick to each other and begin to form larger, heavier clumps called *floc*. The coagulation process is influenced by the water's pH, coagulant dosage, and rapid mixing to ensure even distribution of the coagulant and promote rapid floc formation. Failure of the coagulation step would likely result in higher turbidity, particles, and microbes like *Giardia* cysts and *Cryptosporidium* oocysts in the finished drinking water. Also, the choice of coagulant and pH can affect the amount of organic carbon removal, which can affect subsequent disinfectant byproduct levels and biological growth in the distribution system.

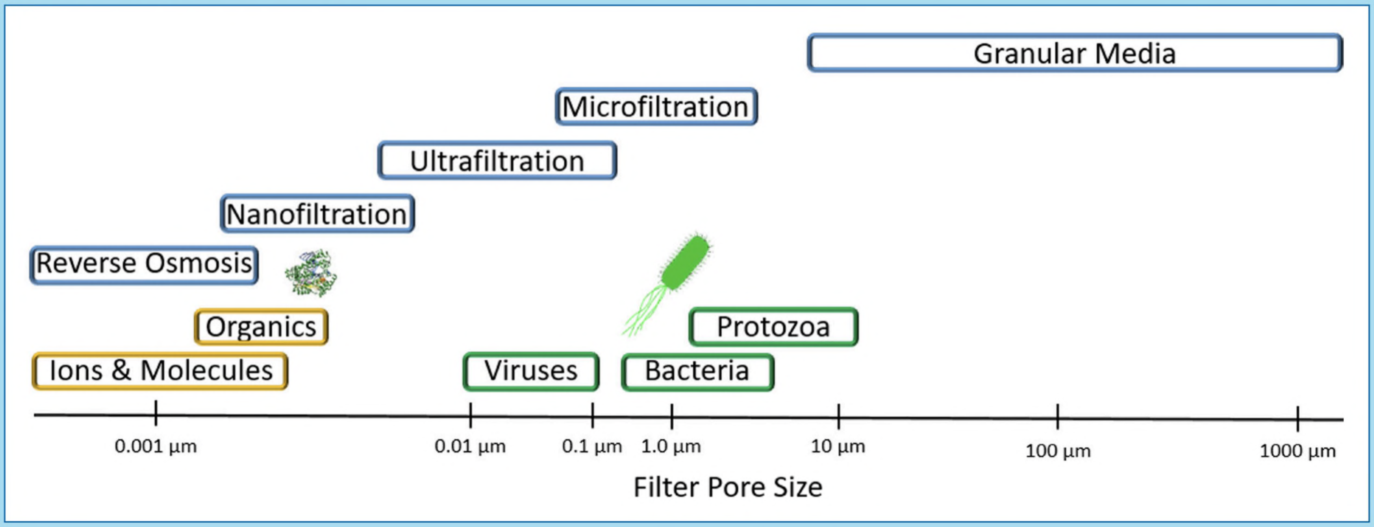
Flocculation and Sedimentation. During flocculation, the water is slowly mixed, causing the coagulated particles to clump together, forming larger, heavier floc. The objective of slow mixing is to promote particle collision without breaking up the fragile floc. Adding polymeric coagulant aids can be used to help stabilize the floc. During sedimentation, heavier floc is allowed to settle to the bottom of the tank as sludge, which is then removed. Some treatment processes use high-rate processes that can accelerate sedimentation using plates, tubes, sludge blankets, or clay or fine sand (called *ballasted flocculation*). The failure to achieve effective flocculation and sedimentation will result in excessive particles being carried on to the filters, resulting in short filter runs and the potential for particle and microbial breakthrough, with the potential of causing a waterborne outbreak.

Filtration. The clarified settled water is then passed through beds of sand, gravel, garnet, coal (anthracite), or activated carbon to filter out small particles, microbial cysts/oocysts, and other remaining contaminants. After the filters accumulate this debris, they need to be backwashed with clean water, typically based on differential pressure (called *head loss*) or filter run time. Failure to properly clean the filter media will result in "mud balls" (clumps of sediment) and channeling in the media that can short-circuit filtration. Some groundwater systems can use specialized filters called *greensand*, in which the media includes manganese dioxide that acts as a catalyst to remove iron and manganese. Advanced membrane filtration can include microfiltration, ultrafiltration, nanofiltration, or reverse osmosis filters that, depending on pore size, can remove submicron-sized particles, minerals, and organic compounds (figure 2). It's important for operators to thoroughly understand the filtration systems they control; their performance mechanics; and associated indicators such as turbidity, particle counts, pressure loss, etc. Monitoring these parameters can provide an early indication that the filters may not be operating at their highest level of performance.

Disinfection. Disinfection is a critical step in protecting drinking water public health, as it inactivates pathogenic bacteria, viruses, and other microorganisms that might pass through the filters. Disinfection doesn't result in sterile water but is targeted to inactivate microbes that pose a public health threat, so even a short interruption in disinfection can result in a waterborne outbreak. Disinfection of public water systems is most often achieved using chlorine, chloramines, chloride dioxide, ozone, or ultraviolet light (table 3). Concentrated forms of these chemicals may be harmful, and their handling requires specialized training and equipment. Combinations of different disinfectants may be used to optimize their effectiveness while minimizing any weaknesses.

Figure 2. Contaminants and Filter Pore Size

By understanding how pore size affects removal capabilities and closely monitoring performance indicators, operators can detect early signs of declining filter efficiency.



Disinfection can be thought of as a balance between inactivating pathogenic microbes while avoiding the production of unacceptable levels of potentially harmful disinfection byproducts (table 4). The efficacy of disinfection is often influenced by the disinfectant's concentration, contact time, temperature, pH, turbidity, natural organic matter, and some minerals that can react with the disinfectant (e.g., iron, manganese, ammonia, hydrogen sulfide). Operators should be aware of these "demand-causing" compounds, particularly how rainfall and seasonal patterns can increase these chemicals in the source water. Disinfectants can also be used to oxidize chemical compounds in the water, including some minerals, pharmaceuticals and other man-made chemicals, and some organic compounds that cause objectionable tastes and odors. Given the importance of disinfection in producing safe drinking water, operators should thoroughly understand the specifics of their treatment process.

Other Treatment Processes. Depending on the water source, additional treatment may be performed, such as softening, alkalinity and pH adjustment, radon removal, or adding chemicals to boost fluoride concentration or control the water's corrosivity. These processes are targeted at specific public health threats and may require special training for operators using such systems.

DISTRIBUTION SYSTEMS

A drinking water distribution system is a complex network of pipes, pumps, valves, storage tanks, reservoirs, meters, fittings, fire hydrants, and other appurtenances that delivers clean water from treatment

Table 3. Disinfectant Effectiveness Against Pathogens

Operator familiarity with disinfectant performance, along with proper chemical handling and monitoring, supports consistent inactivation of disease-causing microorganisms.

Pathogen	Disinfectant				
	Chlorine Dioxide	Free Chlorine	Chloramines	Ozone	Ultraviolet
Bacteria	Excellent	Excellent	Good	Excellent	Good
Protozoans	Fair	Poor	Poor	Excellent	Excellent
Viruses	Excellent	Good	Fair	Excellent	Fair

There are numerous critical processes that operators must professionally manage, and failure to do so could put an entire community at risk.

plants or wells to consumers' taps. Its purpose is to ensure a safe, continuous, and pressurized supply for residential, commercial, and firefighting needs. Spanning almost 1 million miles in the United States, distribution systems make up most of the nation's water supply infrastructure and can present significant operational and public health challenges.

Protection from public health risks in the distribution system falls into three key areas:

Physical Integrity. This is the ability to maintain a continuous, impermeable barrier between the treated water inside distribution lines and the external environment, preventing contamination from entering the pipes. Given that main breaks occur almost daily in some systems, maintaining physical integrity means conducting main repairs and new pipe installations in a manner that protects drinking water quality. Several studies have shown that low-pressure events caused by main breaks (and scheduled maintenance) were related to increased cases of gastrointestinal illnesses in customers that lived downstream of the break—particularly in chloraminated systems (chloramines are a slow-acting disinfectant). So, it's important to properly clean and disinfect mains after repair, particularly when the pipelines are depressurized. Maintaining physical integrity also means routine inspections of storage tanks to correct any sanitary defects. Several large pathogen outbreaks have been attributed to cracks or holes in storage tanks where birds or other small animals were able to contaminate the drinking water.

Hydraulic Integrity. This refers to a system's ability to provide adequate and reliable water pressure, meet water demands (including fire protection), and maintain acceptable water flow and water age throughout the network to safeguard public health and deliver uninterrupted service. Adequate water pressure prevents any contaminants from entering the distribution system, and monitoring and controlling hydraulic transients prevents even momentary low-pressure events that could result in contaminant intrusion. Numerous outbreaks have occurred when low distribution system pressures have allowed chemical or microbial contaminants to enter drinking water supplies. Having an effective cross-control program is essential to prevent backpressure or backsiphonage of water from building plumbing back into the distribution system.

Water Quality Integrity. This means maintaining the safety and quality of treated water as it travels from the treatment plant to the tap, preventing contamination and degradation from internal factors like biofilms, corrosion, and leaks. Maintaining an effective disinfectant residual is an important element in sustaining water quality integrity, and a rapid loss of a disinfectant residual can indicate a problem in the system. Water stagnation, corrosive metallic pipes, nitrification, biofilm and sediment accumulation, and intrusion of contaminated water are only some of the problems that can result in a loss of a disinfectant residual. Operators should be ready to respond and investigate any loss of a disinfectant residual because of the potential negative effect on public health.

Effective corrosion control also affects water quality integrity and episodes of colored or discolored water, black water, or objectionable tastes or odors occurring in the distribution system. Such concerns should be investigated immediately.

Routine monitoring of the distribution system is more than just a regulatory requirement to show compliance with state or federal mandates; it's the "eyes and ears" of the operator to ensure the safety of the drinking water is maintained all the way to the customer. It's important to have protocols to quickly respond to unusual test results. In addition to the periodic "grab sample" for microbial, disinfectant byproduct, or corrosion control compliance, it's useful to have fixed, continuous sensors to monitor water quality (e.g., chlorine, pH, conductivity) and pressure at critical locations in the network to quickly indicate any disruptions in distribution system integrity. For more information, see "Operators Need to Know Basics of Distribution System Water Quality," and "Operators Need to Know Key Elements of Distribution System Integrity," which appeared in *Opflow*'s May 2022 and April 2026 issues, respectively.

Table 4. Disinfection Byproducts and EPA Maximum Contaminant Levels (MCLs)

Disinfectants react with natural organic matter, minerals, and other compounds in source water, making it vital for operators to anticipate these reactions and manage byproduct formation effectively.

Chlorine Dioxide	Free Chlorine	Chloramines	Ozone
Chlorite; MCL 1.0 mg/L	Trihalomethanes; MCL 0.080 mg/L	Cyanogen chloride; No MCL	Bromate; MCL 0.010 mg/L
Chlorate; No MCL	Haloacetic acids; MCL 0.060 mg/L		Aldehydes; No MCL
			Ketones; No MCL

EPA—US Environmental Protection Agency

Public Health

In addition, it's important to respond to any customer complaints about water quality, particularly any complaints about colored water, tastes, or odors that might indicate chemical or waste contamination. In this manner, the operator is always attentive to any changes that might indicate a serious public health problem. For more information, see "Operators Need to Know How Customers Complaints Can Improve Water Quality," which appeared in *Opflow*'s May 2023 issue.

EMERGENCY RESPONSE, CONTINGENCY PLANNING, AND COMMUNICATIONS

Because operators must be vigilant about water quality 24 hours a day, 7 days a week, 365 days a year, it's inevitable that emergency situations will arise that might affect either operations continuity or the multiple barriers protecting public health. Contingency planning is critical in being prepared for such emergency situations, including developing a risk assessment to identify potential hazards, creating a response plan with defined roles and procedures, establishing backup water supplies, and conducting regular training and exercises to ensure the plan's effectiveness. EPA and AWWA have additional guidance and templates for developing an emergency response plan (see AWWA Manual of Water Supply Practice M19, *Emergency Planning for Water and Wastewater Utilities*; ANSI/AWWA Standard J100-21, *Risk and Resilience Management of Water and Wastewater Systems*; and ANSI/AWWA Standard G440-22, *Emergency Preparedness Practices*).

A critical component in the emergency response plan is timely communication with customers. Should the water system lose confidence in the safety or reliability of the water supply, then issuing public notification to "do not use" the water or to "boil the water" before use is the final act to protect public health. Too often, water systems see such notices as an admission of failure rather than the public health tools that they are.

BUILDING PLUMBING

Although not under the control of the public water system operator, degradation of water, particularly in large buildings, is the leading cause of drinking water pathogen outbreaks. The US Centers for Disease Control and Prevention (CDC) recently reported that Legionnaires' disease, which primarily occurs in building plumbing systems, was responsible for 160 (92%) outbreaks, 666 (60%) cases, 462 (97%) hospitalizations, and 68 (97%) deaths related to community and noncommunity water systems from 2015 to 2020.

Developing a water management plan is the single most effective action building owners can take to reduce the public health risk of plumbing-related illnesses. CDC and the American Society of Heating, Refrigerating, and Air-Conditioning Engineers have programs to help building managers develop water management plans. Public water system operators should be aware of these resources and be ready to help building managers with any drinking water quality information they might need. For more information, see "Operators Need to Know How to Support Building Water Systems," which appeared in *Opflow*'s April 2025 issue, and "Operators Need to Know *Legionella pneumophila* and Its Control," which will appear in the July/August 2026 issue.

OPERATORS PROTECT PUBLIC HEALTH

An iconic line from *Hill Street Blues*, a 1980s television show, was at the end of the morning briefing when the sergeant would remind everyone, "Hey! Let's be careful out there." Similarly, every day water operators should remind each other, "Hey! Let's protect public health today!" While admittedly not as catchy, it's still true. From source water to building plumbing, there are numerous critical processes that operators must professionally manage, and failure to do so could put an entire community at risk. It's an important job and critical to public health.

ADDITIONAL RESOURCES

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