Evolution of Water Treatment in the Greater Boston Area

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Abstract

For generations, Massachusetts Water Resources Authority (MWRA) and its predecessor agencies have strived to produce safe and better tasting drinking water. It takes more than a good raw water source to ensure safe and potable drinking water. Water treatment practices are key. This article will discuss what treatment processes MWRA, and its predecessors have used, and currently use, to meet and stay ahead of evolving water treatment requirements and will discuss potential next challenges on the horizon, as science allows us to detect ever smaller quantities of substances in water, and climate change alters natural reservoir and watershed processes.

Keywords: water treatment, drinking water, watershed protection, ozone, ultraviolet, disinfection, chloramination

1. Evolving Water Treatment

From Boston's early beginnings, there was a thirst for water. From the 1600s and into the 1800s, more and more water was needed to support the growing population, and the search for a water source pushed further and further out from the city. With superior foresight and planning, in the late 1800s and through the early 1900s, critical water supplies were developed with the creation of the Wachusett and Quabbin Reservoirs. MWRA's predecessors understood the benefits of establishing water sources upstream and away from the dense urban areas they served, providing protection from industries, large populations, and street runoff. Pristine upstream sources located at higher elevations also allowed the use of gravity to get the water to the coastal metropolitan area. The Wachusett and Quabbin Reservoirs continue to serve the needs of more than a third of the Massachusetts population today, providing clean, plentiful, and safe drinking water.

1.1 Surface Water Treatment Rule and MWRA's Waiver from Filtration

When the U.S. Environmental Protection Agency (EPA) Surface Water Treatment Rule (SWTR) came into effect in 1989, many surface water supply systems were required to provide filtration to address contamination concerns in drinking water. Under a narrow set of criteria, very well-protected sources like MWRA's Wachusett and Quabbin Reservoirs could receive a "waiver" of the filtration requirement. Wachusett Reservoir did not initially meet the filtration avoidance criteria. The MWRA in partnership with the then Metropolitan District Commission (MDC), began developing a Watershed Protection Plan to ensure the high-quality reservoirs would continue to provide clean safe water. While the watershed protection plan was developed, an initial decision was made in 1991 to build a filtration plant. In June 1993, MWRA entered a dual track scheduling Administrative Consent Order with the Massachusetts Department of Environmental Protection (MassDEP). The Consent Order required the siting and design of a filtration plant but allowed MWRA and DCR until 1998 to demonstrate compliance with all criteria and request a waiver of filtration just prior to construction.

The Watershed Protection Plan included the establishment of a Watershed Land Acquisition Program. This Program focuses on the protection of source waters by purchase of land or watershed preservation restrictions (WPR) within the Quabbin Reservoir, Wachusett Reservoir, and the Ware River watersheds. Since it was developed, it has protected 28,175 acres of watershed area (Table 1).

As noted, the Wachusett Reservoir did not initially meet the source filtration waiver criterion, specifically for fecal coliform bacteria levels. It was determined that the elevated bacteria levels were primarily due to flocks of gulls roosting on the reservoir. The Watershed Protection Plan included employing various actions to reduce the attractiveness of the region by better management of local landfills, discouraging the gulls roosting on the reservoirs, and incorporating shoreline management practices to minimize nesting and feeding areas. These efforts, including the Watershed Land Acquisition Program, which protected by ownership or easement 29% of the Wachusett Reservoir Watershed, were highly successful in reducing bacteria levels in the source water. By 1993, the Wachusett Reservoir was brought into compliance with the criteria of the filtration wavier (Figure 1). The Watershed Land Acquisition Program continues to be a significant factor in MWRA's ability to maintain our filtration waiver.

1.2. Treatment Decision

After an extensive research and decision-making process, the MWRA Board of Directors voted in October 1998 to request a waiver of the filtration requirements from MassDEP and to build a new water treatment facility using ozone for primary disinfection and chloramines for residual disinfection to treat the water from

Table 1. DCR Watershed Management Land Acquisitions 1985 compared to 2022.

Watershed	Total Watershed Area (Land Acres Only)	Acres Owned 1985	Percent Owned 1985	DWSP Fee 2022*	DWSP WPR 2022*	Total DWSP Controlled 2022*	Percent DWSP Controlled 2022*
Wachusett Reservoir	70,876	5,608	7.9%	17,868	2,716	20,584	29.0%
Ware River	61,671	19,300	31.3%	23,803	1,404	25,207	40.9%
Quabbin Reservoir	95,364	51,792	54.3%	54,280	4,804	59,084	62.0%
TOTAL	**227,911**	**76,700**	**33.7%**	**95,951**	**8,924**	**104,875**	**46.0%**

* Ownership numbers are through FY2022 (6/30/2022)

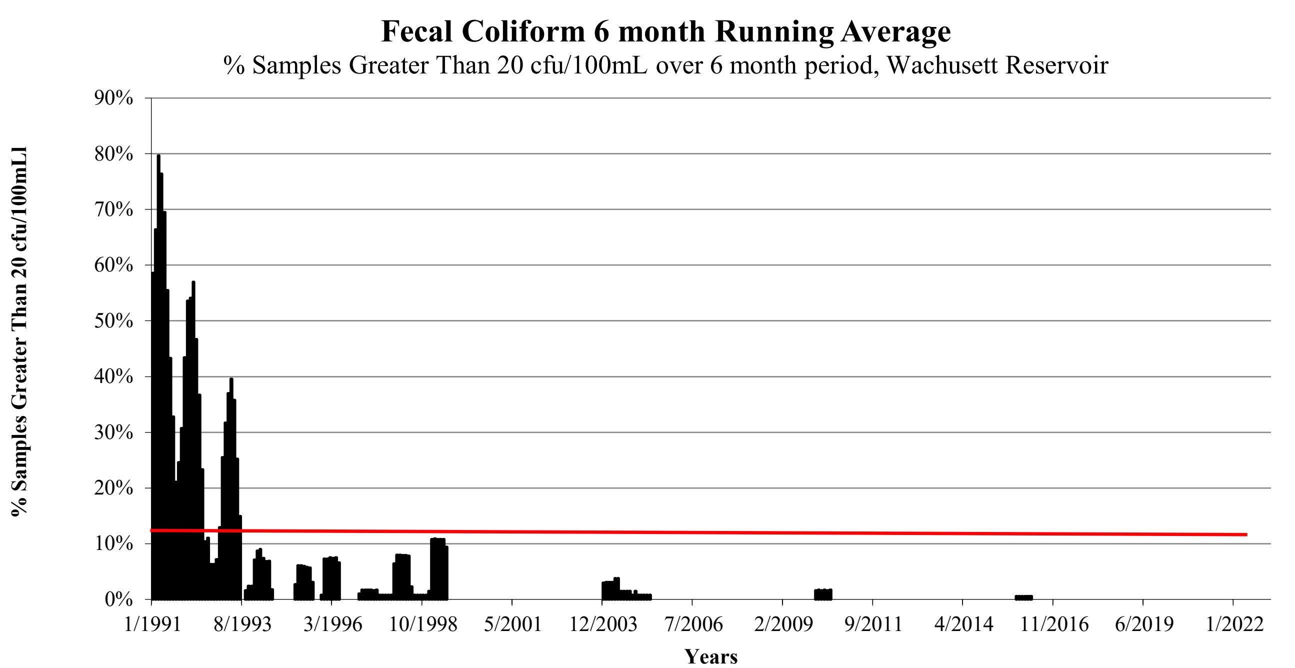

Figure 1. Presents compliance data under the SWTR; No more than 10% of fecal coliform results can exceed a count of 20 CFU/100mL in samples collected at least 5 times per week from the raw water source.

Wachusett Reservoir. To accomplish its overall water quality and water system goals, MWRA established a 10-year, $1.7 billion Integrated Water Supply Improvement Program. The Improvement Program was developed to improve the reliability and quality of the water supply and meet the stringent requirements of the SWTR. Key components of the Improvement Plan included watershed protection, construction of water treatment facilities, construction of a water transmission tunnel, removal the existing open reservoirs from service, construction of covered water storage facilities and distribution pipelines improvements. In December of 1998, MassDEP agreed with the MWRA approach and determined that filtration was not required for the MWRA system. This decision was challenged in court by the EPA, but Federal District Court Richard G. Judge Stearns ultimately found that EPA failed to show that filtration of MWRA water was required either as a matter of cost-benefit or scientific necessity.

1.3 Effective Disinfection

Chlorination of drinking water first began in the United States (US) in the early 1900s and was critical to improving the public safety of water and reducing the transmission of disease. In 1930, the Metropolitan District Commission (MDC), the governing public water supply agency at the time, began using continuous chlorination of all potable water delivered to the water distribution system (DeMarini, 2020). By 1932, the treatment process of water evolved to chloramination. Chloramination is the process of adding chloramine to drinking water to disinfect it and kill germs. It is sometimes used as an alternative to chlorination. Chloramines are a group of chemical compounds that contain chlorine and ammonia (CDC, 2020). MWRA's water distribution system was the first large water distribution system in the US to employ chloramination as its method of disinfection. The combination of effective disinfection practices and the use of pristine water sources are attributed to some of the reasons why the Metropolitan Boston Region experienced lower levels of waterborne disease than the rest of the country, during the 1930s (Kempe, 2006).

The Total Coliform Rule (TCR) was implemented by the EPA in 1989. As data was collected throughout MWRA's and community distribution systems under this new rule; it was apparent that maintaining chlorine residuals through the large distribution system continued to be a challenge. During the 1990s, MWRA member communities experienced elevated total coliform positives and depressed system chlorine residuals within the water. At the time, disinfection with chloramines was performed at the Norumbega Open Reservoir (in addition to chlorination at the other open reservoirs, until they were removed from service) but, there was no free chlorine contact time as chlorine and ammonia were added simultaneously. To better optimize the chlorine to ammonia ratio, MWRA decided to separate the chlorine and ammonia addition points at Norumbega Reservoir, the modification was completed in August of 1997. Following this change, the chlorine to ammonia ratio within the distribution system was adjusted from 11:1 to about 4.5:1 to 5:1. Dramatically improved distribution chlorine residuals were observed after the separation (Figure 3).

1.4 Implementing Corrosion Control

Prior to the promulgation of the EPA's Lead and Copper Rule (LCR) in 1990, lead was regulated at 50 µg/L at a free running tap. The MDC had experimented with full-scale zinc orthophosphate treatment within the distribution system in an effort to reduce lead corrosion in 1976, but discontinued this treatment method when

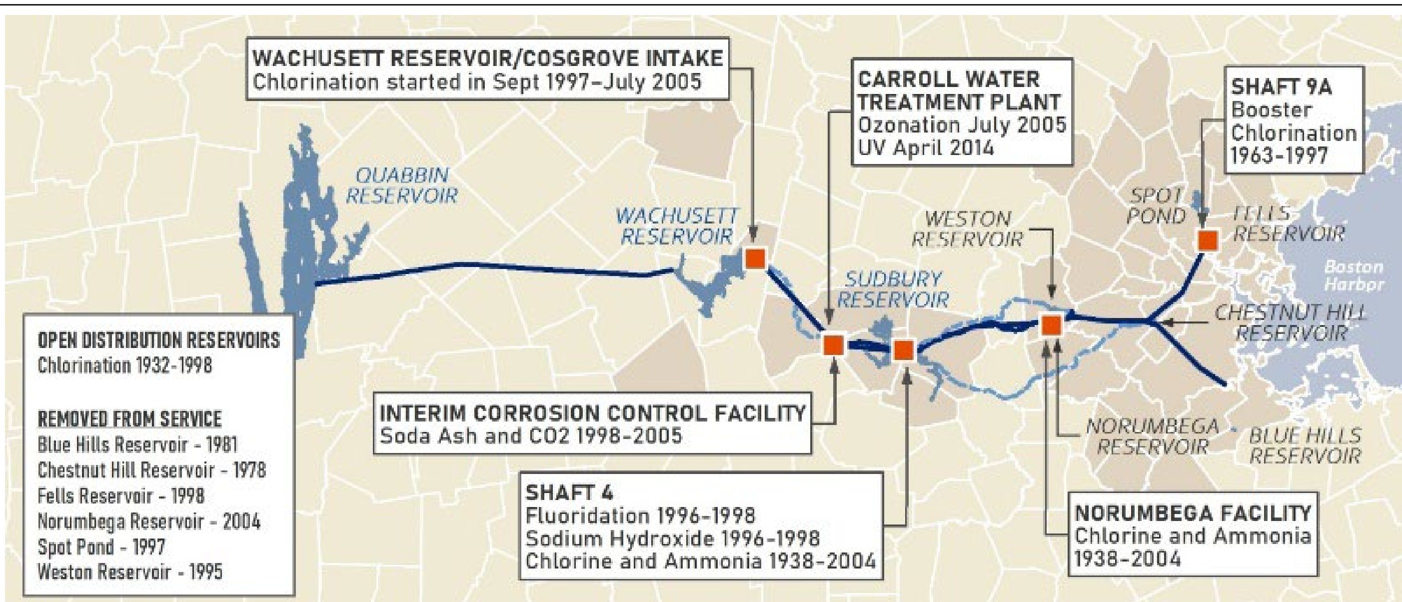

Figure 2. Map of Key locations at Wachusett Reservoir and Downstream Distribution System.

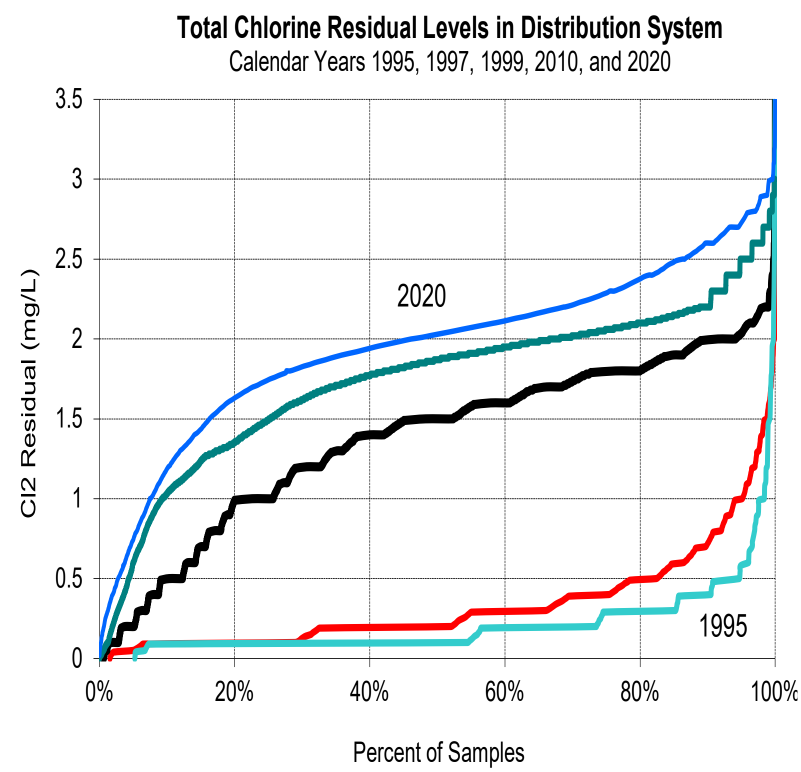

Figure 3. Improved distribution of chlorine residuals recorded following treatment improvements Norumbega Open Reservoir (1997).

lead sampling indicated no improvement and algae blooms occurred in downstream open reservoirs. Starting in 1978 and continuing to 1996, the MDC, and later the MWRA, raised the pH of the water by the addition of sodium hydroxide with a target entering the system of pH around 9 at Shaft 4 (located on Figure 2). However, pH levels varied significantly were frequently in the mid-7 range in the distribution system because Wachusett Reservoir water has little buffering capacity. The LCR established a more stringent Action Level of 15 μg/l in water. To meet the requirements of the new rule, the Interim Corrosion Control Facility (located on Figure 2) was constructed at the beginning of the distribution system, to adjust both pH and alkalinity by feeding soda ash and carbon dioxide into the water. The Interim Corrosion Control Facility was placed on-line in June 1996. Initial targets for water sampling were pH 7.5-7.8 and alkalinity 30 mg/L and were ramped up gradually to avoid scale disruption. In July 1998 the pH was adjusted upward to 9.0, while alkalinity remained at 30 mg/L. In March 2002, alkalinity was adjusted to 35 mg/L. In February 2004 alkalinity was adjusted to 40 mg/L. Current targets are pH 9.3-9.5 and alkalinity 40 mg/L. These small adjustments were made in an effort to reduce lead corrosion and bring water in the overall system into compliance with the lead Action Level. Lead levels have dropped significantly over the period, although individual communities periodically exceed the lead Action Level (Figure 4).

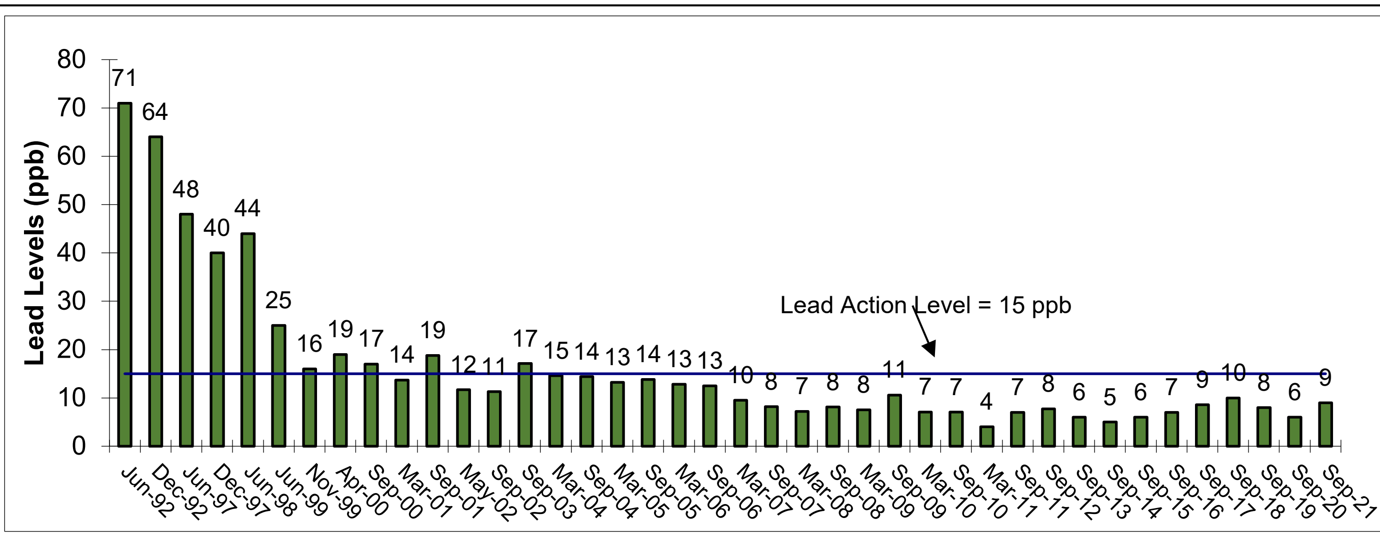

Figure 4. Significant drop in the lead levels after corrosion control processes were established.

1.5 Pivoting from Open Reservoirs to Covered Water Storage

While the Watershed Protection Plan concentrated on source water protection to help meet filtration waiver goals, MWRA formulated a plan to remove its remaining open reservoirs from service. After the Blue Hills Reservoir was removed from service in 1981, MWRA still maintained four open reservoirs in active distribution throughout the 1980s and 1990s. Several of these reservoirs required booster chlorination water downstream, and multiple downstream communities also practiced phosphate addition and additional booster chlorination. Pivoting to covered water storage would lessen the risk of contamination to the potable water and stabilize water quality. Between the years 1995-1998, MWRA retired the Weston, Spot Pond, and Fells Reservoirs, removing them from service. In March 2004, MWRA's 115-million-gallon Norumbega Covered Storage Facility was put on-line and the Norumbega Reservoir, the remaining open reservoir, was removed from service. For the first time, water from the Wachusett Reservoir did not see the light of day from when it left the Reservoir until it reached customers taps.

In subsequent years, two more covered water storage projects were completed replacing two off-line reservoirs; two 10-million-gallon covered storage tanks were completed at Blue Hills Reservoir in 2009, replacing the off-line Blue Hills Reservoir and the Spot Pond Storage Facility completed in 2015 consists of two 10-million-gallon covered storage tanks, replaced the off-line Spot Pond Reservoir

1.6 The John J. Carroll Water Treatment Plant

The Carroll Plant (location shown in Figure 2) was completed in July 2005. This facility allowed for the consolidation of all water treatment − disinfection, and corrosion control − within a single facility, and included water storage at the end of the treatment process, resulting in a more stable treatment process and improved water quality.

Treatment at the Carroll Plant includes ozonation for primary disinfection, chloramines for residual disinfection, fluoridation for dental health, and soda ash and carbon dioxide for corrosion control. The Carroll Plant is designed to treat up to 405 million gallons of water per day.

1.7 Strengthening Primary Disinfection

The SWTR required that distribution water from unfiltered systems achieve 3-log *Giardia* and 4-log virus inactivation. The Carroll Plant uses ozonation (Figure 5) to inactivate *Giardia* and viruses within the water. This process reduces disinfection by-products and enhances taste and odor of the water. The ozonation process at the Carroll Plant was also designed to voluntarily achieve 2-log inactivation of *Cryptosporidium,* even though this was not required by regulation at that time.

When the Long Term 2 Enhanced SWTR was issued in 2006 it required that unfiltered water systems have two primary disinfectants, one of which was required to inactivate *Cryptosporidium.* The Carroll Plant modified their water treatment process to include ultraviolet (UV) disinfection (Figure 6) as a second primary disinfectant to inactivate *Cryptosporidium* in 2014.

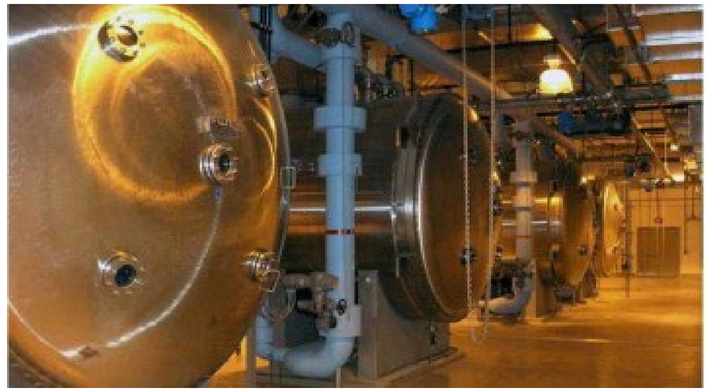

Figure 5. Ozone generators at Carroll Plant.

Figure 6. Ultraviolet disinfection units at Carroll Plant.

Using ozone since 2005 and UV light since 2014, the Carroll Plant has exceeded regulatory requirements for inactivation of 99.9% of Giardia, 99% of *Cryptosporidium* and 99.99% of viruses that may be in our source water. These disinfectants perform without creating the regulated disinfection by-products (total trihalomethanes, and halo acetic acids) that were created by the previous 'chlorine-only' treatment. The levels of disinfection by-products dropped dramatically since the Carroll Plant went on-line (Figure 7). Most noticeably to MWRA customers, ozone reduces apparent water color and neutralizes taste and odor compounds that previously affected the system, particularly during summer when algae grow in Wachusett Reservoir.

Chlorine and ammonia are combined at the Carroll Plant to form monochloramine, a stable and long-lasting residual disinfectant, which carries deep into MWRA's community distribution systems inhibiting microbiological re-growth. Presently, over two thousand bacteriological samples are collected from community distribution systems each month and bacterial counts are continuously very low and chlorine residuals have been very good without a residual chlorine taste and odor complaints.

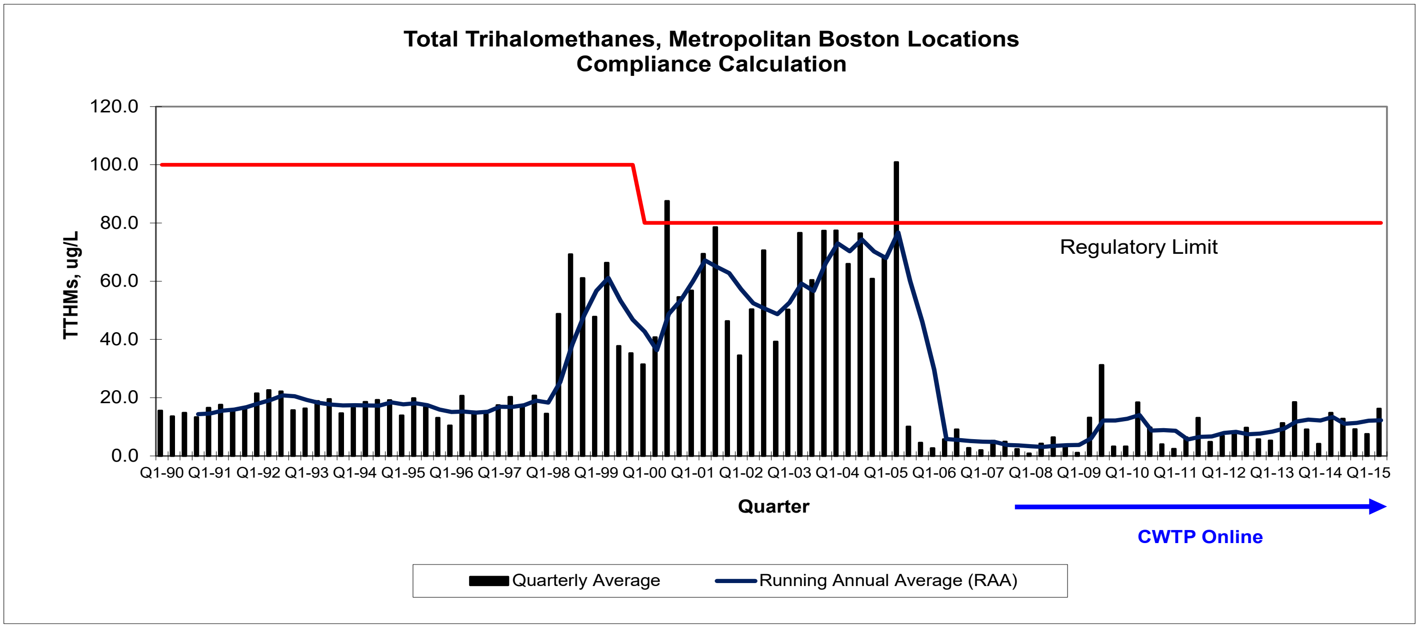

Figure 7. Levels of disinfection by-products dropped dramatically after the Carroll Plant went online.

MWRA's drinking water has achieved several accolades including receiving the New England Waterworks Association (NEWWA) the "Best of New England" taste award multiple times and first and second place ranking in the "Best of the Best" Water Taste Test at the American Waterworks Association's National Conference (AWWA) in 2014 (for Boston and MWRA entries). Most recently, MWRA won first place in AWWA's 16^{th} "Best of the Best" Water Taste Test in 2021. In addition to industry drinking water awards received, the plant water operations and quality assurance staff have also received the MassDEP's Public Water System Award, and the Annual Water Fluoridation Quality Award from both the US Centers for Disease Control (CDC) and Massachusetts Department of Public Health.

2. Future Challenges

2.1 Revisions to the Lead and Copper Rule

To continue to provide excellent drinking water and improve upon the current treatment technology; MWRA will soon initiate a study to evaluate further optimization of corrosion control treatment. This study is in response to the LCR Revisions of 2021. The original LCR, discussed above, included an Action Level of 15 µg/l lead within distribution water. Revisions to the original LCR included a 10 µg/l "Trigger Level" level that will require water systems to provide further water treatment, monitoring and public notification actions when the threshold level is exceeded. When more than 10 percent of samples collected during a monitoring period exceed the action level; the water distribution system must implement additional corrosion control treatment within 48 months of the sampling event. Regional sampling of MWRA distribution system has historically tracked below 10 µg/l. However, since some of MWRA's community member systems water sampling has exceeded 10 µg/l; MWRA has proactively initiated a corrosion control study, in advance of regulatory requirements. As part of the study, MWRA collected excavated lead service lines from community members and assembled six sets of four pipes to support the evaluation of alternative corrosion control strategies (Figure 8). MWRA convened an outside panel of experts in corrosion control treatment to optimize the strategies explored and assist in development of the experimental plan. MWRA plans to commence the study once acclimation is complete in August 2023.

2.2 Emerging Concerns

New challenges are ever present in the drinking water industry. Fortunately, with well-protected water sources and watersheds, MWRA water quality and quantity continues to be excellent. Looking forward, MWRA anticipates experiencing both more intense rain events, and more periods of drought due to changing weather patterns brought on by climate change. The full impacts of the changing weather patterns is not fully understood. MWRA is already observing greater variability in organic levels in samples from source water supply, as measured by UV254. Higher levels of organics have multiple impacts including higher chlorine demand and higher rate of chloramine decay, which makes it harder to maintain chlorine residuals throughout community distribution systems. The changing weather patterns may also favor the growth of cyanobacteria in the water. These developing trends actively threaten water quantity and reliability of other water systems, outside of MWRA's drinking water service area. MWRA's water conservation efforts have resulted in a water

Figure 8. Corrosion control study - lead pipe rigs.

distribution system that has the capacity to aide other communities in the region.

Throughout the Northeastern US, chloride concentrations have been increasing in freshwater bodies, streams, and groundwater. The increased chlorides have been attributed to road salt application and they have the potential to increase the corrosivity in the water distribution system. Increased corrosivity may then have a cascading effect on the water distribution system including, impacting lead levels, and aquatic life in reservoirs. MWRA and DCR staff are monitoring rising chloride levels in the Wachusett and Quabbin Reservoirs. MWRA has funded training for local Department of Public Works (DPW) staff and is funding new de-icing equipment to reduce road salt applications throughout the MWRA – DCR watershed area.

While Per- and polyfluoroalkyl substances (PFAS compounds) − a family of chemicals used since the 1940s to manufacture stain-resistant, water-resistant, and non-stick products − are adversely impacting many water supplies throughout the country, they have only been detected at trace levels in the MWRA system. MWRA continues to routinely tests samples for PFAS compounds as well as for another contaminant of emerging concern, Harmful Algal Blooms (HABs) and cyanotoxins, which have only been detected at very low levels.

MWRA's water distribution system has been instrumental in meeting the water needs of Massachusetts residents and industries. The foresight and dedication of our predecessors have resulted in a remarkable water system that is designed to cater to future generations. MWRA is committed to an ongoing mission of enhancing water quality, striving to deliver reliable, cost-effective, and high-quality water that prioritizes public health, environmental conservation, customer confidence, and a thriving economy. This is achieved through sustained efforts in watershed protection, innovative water treatment methods, and effective communication with member communities.

MWRA remains vigilant in tracking proposed state and federal drinking water regulations to ensure compliance and safety. When appropriate, MWRA provides comments on proposed regulations and collaborates with member communities to discuss their potential impact. This proactive approach helps preserve MWRA's water system for the benefit of future Massachusetts residents, ensuring a sustainable and secure water supply for generations to come.

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