Report

Milwaukee Water Works Corrosion Control Best Practices Evaluation

Prepared for

City of Milwaukee Office of the Comptroller and Milwaukee Water Works

Prepared by

JACOBS

March 2020

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Submitted to:

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and

Milwaukee
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Executive Summary

In preparation for anticipated revisions to the federal Lead and Copper Rule (LCR) and in response the City of Milwaukee Resolution number 170525 to perform an outside review of the Milwaukee Water Works' additives and corrosion control products, the Milwaukee Water Works (MWW) undertook the Corrosion Control Practices Evaluation (Evaluation). Jacobs Engineering Group Inc. (Jacobs) was hired to perform the Evaluation.

The objectives of the Evaluation were as follows:

- Review the current practices used by MWW for lead and copper corrosion control.
- Review MWW's history of compliance with the LCR, including sampling protocols, test results, water quality parameters, and reporting.
- Research best practices nationally for comparison with MWW current practices.
- Identify opportunities for enhancement and make recommendations for potential improvements.

Background

Since 1996, MWW has been not only complying with, but exceeding, the requirements of the LCR. MWW has successfully maintained lead levels at customers' taps to less than half the regulated action level (AL) of 15 micrograms per liter (µg/L). Likewise, the LCR set an AL for copper at customers' taps at 1,300 µg/L in the 90^{th} percentile. MWW has 90^{th} percentile copper levels less than 100 µg/L. MWW achieves excellent results in minimizing lead and copper levels in drinking water through corrosion control treatment, water quality monitoring, and through distribution system operations and maintenance practices that reduce the potential for corrosion. MWW's integrated efforts to maintain distribution system water quality, demonstrate operating efficiency, and maximize distribution system assets' life cycle were recently recognized by the drinking water industry's national Partnership for Safe Water (PSW) Program.

Current Practices

MWW's current operating and maintenance approaches and techniques for effectively minimizing customers' exposure to lead and copper in drinking water are organized in six key best practice areas:

Optimize Corrosion Control Treatment - Produce drinking water with water quality characteristics that minimize the lead and copper concentrations at users' taps and support simultaneous compliance with all national drinking water regulations.

Manage Water Age - Operate the water system to minimize the time it takes for water to travel from the water treatment plants to consumers .

Monitor Water Quality and Response - Analyze water quality throughout the distribution system to detect and mitigate conditions that can increase the potential for corrosion.

Clean the Distribution System - Routinely and systematically clean storage facilities and flush water mains and to remove any sediments and introduce fresh water in areas of low water use.

Reduce Sources of Lead - Remove lead service lines and lead-containing materials.

Public Education and Outreach - Provide accurate and readily understandable information about the risks associated with lead in water and actions consumers can take to minimize their exposure.

Current Practices Evaluation

Jacobs assessed MWW's current practices and techniques for lead and copper corrosion control to understand improvement opportunities and to determine its ability to respond to pending revisions to the LCR. A best practice is defined as a procedure that has been shown by research and experience to produce optimal results and that has been established as suitable for widespread adoption. A single repository or standard toolbox of corrosion control best practices for community water systems does not exist due to the site-specific nature of corrosion control. Consequently, the Evaluation was conducted by comparing MWW's procedures, work approaches, and results with industry best practices outlined in several widely accepted guidance documents and those techniques practiced by similar utilities.

Recommendations Summary

The following mechanisms for limiting lead in water at customers' taps were addressed in the Evaluation:[1]

- Control water chemistry to maintain stability and limit the solubility of lead in water.
- Remove sources of lead.
- Minimize water age and remove sediment from the distribution system via flushing.
- Provide point-of-use lead removal filters when lead lines are disturbed or replaced.

MWW has demonstrated proficiency in several corrosion control practices and techniques used to achieve the above mechanisms. The recommendations summarized in Table ES-1 are prioritized, highest to lowest, for MWW consideration as it continues to implement and continuously improve its corrosion control practices. Several of the recommendations, denoted with an asterisk (*), are related or identical to opportunities included in the PSW self-assessment improvement plan.

The recommendations may take years to achieve and are dependent on available resources and other utility priorities.

Table ES-1. Corrosion Control Best Practices Recommendations Summary

	*	Accelerate development of privately owned service line material inventory.
		Establish long-term lead service line replacement (LSLR) rate goals and financial plan.
		Establish strategic partnerships to increase privately-owned LSLRs.
	*	Reduce effective water age in storage facilities.
		Enhance distribution system operations with process control charts.
		Develop a better understanding of corrosion with a library of pipe corrosion samples from entire system.
	*	Enhance distribution system hydraulic model to better understand system performance and aid in system operation and maintenance.
	*	Use distribution system model to aid design of a customized flushing program.
		Provide greater website information transparency.
		Update Communication Plan.
		Conduct research to explore how biomechanisms in MWW system may affect lead release.
		Consider future use of advanced automation to track water quality events.
		Study ways to reduce aluminum phosphate precipitation (an unintended consequence of corrosion control treatment) that do not adversely impact corrosion control. Study impacts of other water quality changes on corrosion through continued pipe loop testing.
		Plan for meeting future proposed LCR sampling requirements in partnership with City of Milwaukee Health Department.

[1] Water Research Foundation Project # 4409 Controlling Lead in Water

Acronyms and Abbreviations

μg/L	micrograms per liter
AL	Action Level
CCT	corrosion control treatment
GIS	geographic information system
EPA	Environmental Protection Agency
Evaluation	Corrosion Control Best Practices Evaluation
Jacobs	Jacobs Engineering Group
LCR	Lead and Copper Rule
LSL	lead service line
LSLR	lead service line replacement
mg/L	milligram per liter
MHD	Milwaukee Health Department
MWW	Milwaukee Water Works
OCCT	optimized corrosion control treatment
PSW	Partnership for Safe Water
PO_4	orthophosphate
SDWA	Safe Drinking Water Act
UDF	unidirectional flushing
U.S.	United States
WDNR	Wisconsin Department of Natural Resources
WTP	Water Treatment Plant

Objectives and Approach

In preparation for anticipated revisions to the Lead and Copper Rule, Milwaukee Water Works (MWW) is undertaking the Corrosion Control Practices Evaluation (Evaluation) to review its current practices and techniques for lead and copper corrosion control, compare current practices to best practices nationally, identify opportunities for enhancement, and make recommendations for potential improvement. This Evaluation is also being conducted under the direction of the City of Milwaukee Comptroller's Office to satisfy the requirements of Common Council Resolution number 170525. Jacobs Engineer Group Inc. (Jacobs) was hired to perform the Evaluation.

Background

The presence of lead in drinking water results from the contact of water with lead-containing pipes and fixtures within the distribution system or inside customer houses/buildings (premise plumbing). In addition, lead-containing scales that have accumulated inside piping can serve as a source of lead. Total lead levels have been regulated in United States (U.S.) public drinking water systems since the Lead and Copper Rule (LCR) was promulgated by the U.S. Environmental Protection Agency (EPA) in 1991. Under the LCR, if over 10 percent of the samples tested contain lead concentrations above the Action Level (AL) of 0.015 milligrams per liter (mg/L) (15 micrograms per liter [µg/L]), then the water system must increase water quality monitoring, undertake additional corrosion control efforts, and implement training and public education for customers.

Since 1996, MWW has been not only complying with, but exceeding, the requirements of the LCR. MWW has successfully maintained lead levels at customers' taps to less than half the AL of 15 µg/L. Likewise, the LCR set an AL for copper at customers' taps at 1,300 µg/L in the 90^{th} percentile. MWW has 90^{th} percentile copper levels less than 100 µg/L. MWW achieves excellent results in minimizing lead and copper levels in drinking water through corrosion control treatment (CCT), water quality monitoring, and through distribution system operations and maintenance practices that reduce the potential for corrosion. MWW's integrated efforts to maintain distribution system water quality, demonstrate operating efficiency, and maximize distribution system assets' life cycles were recently recognized by the drinking water industry's national Partnership for Safe Water (PSW) Program.

The PSW Program is sponsored by six industry-leading organizations working together to optimize water systems: The American Water Works Association, Association of Metropolitan Water Agencies, Association of State Drinking Water Administrators, EPA, National Association of Water Companies, and the Water Research Foundation. PSW offers self-assessment and optimization programs so that operations, managers, and administrators have the tools to improve above and beyond even proposed regulatory levels.[2] Many of the best practices established in the PSW Program complement the practices supportive of minimizing lead and copper concentrations to the lowest practical levels. In 2018, MWW invested in the PSW self-assessment process and earned the PSW 2019 Directors Award for Distribution System Operations. This national recognition is bestowed on utilities that demonstrate commitment to delivering superior-quality drinking water and exceed regulatory requirements. MWW is acknowledged as a utility that works to continuously optimize water distribution operations and performance.

[2] https://www.awwa.org/Resources-Tools/Programs/Partnership-for-Safe-Water (January 2020)

Current Practices

MWW's current operating and maintenance approaches and techniques for minimizing lead and copper levels in drinking water are organized in six key best practice areas:

- Optimize Corrosion Control Treatment
- Manage Water Age
- Monitor Water Quality and Response
- Clean the Distribution System
- Reduce Sources of Lead
- Public Education and Outreach

Optimize Corrosion Control Treatment

To meet and exceed LCR requirements, MWW adds phosphoric acid (a source of orthophosphate, which is a corrosion inhibitor) to drinking water for CCT. The optimum water quality parameters for lead and copper corrosion control were previously identified by the Wisconsin Department of Natural Resources (WDNR) as follows:[3]

Linnwood Water Treatment Plant (WTP)

- Safe Drinking Water Act (SDWA) Operating Range at Entry Point = 1.59 – 2.65 mg/L as orthophosphate (PO_4)
- SDWA pH Range at Entry Point = 7.21 – 7.81

Howard WTP

- SDWA Operating Range at Entry Point = 1.49 – 2.48 mg/L as PO_4
- SDWA pH Range at Entry Point = 7.30 – 7.90

MWW CCT has been previously optimized in past water quality studies.[4] Additional efforts to further demonstrate optimized corrosion control treatment (OCCT) and validate previously established water quality parameters include MWW's 2020 – 2021 planned pipe loop study. The pipe loop study is a year-long demonstration test to evaluate CCT techniques using lead service lines (LSLs) harvested from the water distribution system.

Manage Water Age

Water age is the time it takes water to travel from treatment plants to customers. Overall, MWW does not have systematic water quality issues related to excessive water age based on water quality measurements across the distribution system. However, MWW is aware of potential areas where water age is potentially high—at dead end mains/air vents. These areas are flushed at least annually and monitored for turbidity and chlorine residual.

MWW performs extensive water quality monitoring in the distribution system. MWW's LCR compliance data collected since 1993, water quality measurements reported monthly to WDNR over the past five years, and supplemental water quality data MWW collects beyond regulatory requirements demonstrate that water quality in the distribution system is stable and consistent. That is, areas of the system with relatively longer water age have water quality similar to lower water age areas. In addition, MWW has distribution system operational procedures for lowering and refilling water storage tanks to turn over stored volume and minimize water age.

[3] Wisconsin Department of Natural Resources (WDNR). 2002. Letter to Milwaukee Water Utility on Optimum Water Quality Parameter Ranges and Lead and Copper Monitoring. December 18.
[4] CH2M HILL. 1994. *Lead and Copper Corrosion Control Report for Milwaukee Water Works*.

MWW has a full-pipe, steady-state distribution system hydraulic model that is partially calibrated and used for master planning, evaluating water main sizing, and wholesale customer water supply modeling. MWW plans to enhance and calibrate the model so that it can be used to simulate extended periods of water distribution performance and be used to estimate water age in the system.

Monitor for Water Quality Problems and Response

MWW uses chloramines (chlorine plus ammonia) for distribution system disinfection. MWW meets performance goals of at least 0.5 mg/L chloramine concentration for 95 percent of its distribution system residual samples, which is a recommended best practice per the PSW. Chloramine residual samples are collected from sites throughout the system. MWW currently uses three continuous online water quality analyzers capable of measuring seven parameters, and is in the process of purchasing three additional online water quality analyzers for installation in other locations in the system. MWW's water quality monitoring procedures and response actions to water quality data support efforts to minimize potential lead and copper corrosion. Specifically monitoring chloramine residual, orthophosphate, and water quality parameters indicative of conditions for nitrification—pH, nitrite, nitrate, ammonia—enables MWW to adjust treatment and distribution system operation to mitigate corrosion.

MWW has established a chloramine residual AL of 0.6 mg/L and response procedures. In the event that distribution system chloramine residuals begin to approach the AL, at the direction of the Water Quality Manager, areas of concern will be flushed or the water plants will increase the target plant effluent chloramine residual leaving the plants (for example, increase chloramine from 1.50 to 1.75 mg/L). Changes in setpoint chloramine residuals entering the distribution system typically coincide with changes in water temperature.

Distribution system chloramine residuals are widely reviewed and discussed by key MWW staff. For example, chloramine residuals are summarized weekly and shared via email with managers and staff from all MWW departments, including: Plants, Water Quality, Distribution, Engineering, and Administration. The email also includes summaries of the trends for the past weeks and highlights the locations with the lowest chloramine residuals. Those areas with the chloramine residuals that do not meet the goal are investigated to determine the reasons for the low residuals. In addition, the MWW Administration Manager conducts a monthly meeting titled "Water Quality in the Distribution System," which includes reviewing and discussing the chloramine residual trends. Any problem areas of low chloramine residuals are investigated until resolved. Low residual conditions are remedied with flushing and/or confirming valves' positions to identify normally open valves that may have been inadvertently left closed. Follow-up chloramine residual sampling is conducted to confirm situation resolution. Managing chloramine residuals is important for public health and corrosion control, by minimizing the potential for corrosion caused by microbial activity.

Clean the System

Conventional water distribution system flushing is primarily undertaken through routine hydrant exercising and in response to customer concern calls. MWW exercises about 10,000 hydrants annually, or about 50 percent of the system. Hydrants are also flushed in response to customer concern calls or water quality monitoring data. Further, all hydrants located on dead-ends are flushed annually. Eight automatic flushers have been located on dead end mains in three areas of the system.

The estimated average flushing hydrant rate is about 1,800 gallons per minute. Because flow to a hydrant is supplied from two directions, the flush flow in each pipeline is estimated to be about 900 gallons per minute. Flushing is terminated when flushed water turbidity is less than or equal to 5 nephelometric turbidity units, and total chlorine residual is greater than or equal to 0.5 mg/L.

Per WDNR requirements, WTP clearwell storage facilities are wet inspected every five years and dry inspected every 10 years. Distribution system storage facilities inspections are scheduled with a similar frequency. Storage facilities are cleaned during dry inspections every ten years. Historically, when storage facilities are removed from service for routine cleaning, minimal sediments accumulation has been observed.

Reduce Sources of Lead in the System

MWW has an estimated 75,223 utility-owned and privately owned LSLs that compose about 45 percent of the total system service lines.[5] MWW has a verified utility-owned service line material inventory. While records of privately owned services are incomplete and gathering information of private property is challenging, MWW continues to develop a verified privately owned LSL material inventory. Privately owned service line information is gathered by visual observation when MWW staff make service calls that involve entering the property. Evidence of previous service line replacement (concrete floor or foundation patch) is also noted.

MWW records indicate the presence of a wide variety of service line materials and potential sources of lead and copper:

- LSLs, copper service lines, combination lead and copper service lines
- Copper pipe with lead/tin solder
- Brass fittings installed prior to 2014 that are not lead-free
- Unknown service line material

These materials, along with galvanized steel, may also be found in premise plumbing.

MWW committed to full lead service line replacement (LSLR) program in 2017, and since then has implemented over 2,550 full LSLRs. As LSLs are removed, MWW prepares quarterly updates to the LSL inventory that is publicly available on MWW's website.

MWW's LSLR program is based on prioritized LSLRs consistent with *AWWA 810-17 Replacement and Flushing of Lead Service Lines* (AWWA 2017). MWW has made LSLRs mandatory in the event of a service line leak or failure, when the supply main is replaced and at licensed childcare facilities and schools. MWW also replaces the utility-owned portion of the LSL if the privately owned portion of the LSL is replaced for any reason (i.e., owner-initiated).

With LSLRs, MWW provides a voucher for an NSF 53 certified lead removal water pitcher filter with instructions for 30 days post-LSLR use, instructions to flush premise plumbing, and remove and clean faucet aerators. MWW also offers LSLR program participants free water testing using a three-bottle test kit.

Public Education and Outreach

Since 1991 when the LCR was published, MWW has complied with the public notice and public education and outreach requirements. MWW has gone beyond regulatory requirements with the development of an extensive public education and information program related to lead and copper in drinking water and health risks. The program is proactive; targets the general public and at-risk populations; provides reliable, accurate, and current information; and integrates helpful resources from the local community, state and federal regulatory agencies, and national organizations.

[5] MWW Operating Data, October 2019.

Educational materials are developed in multiple formats (for example, print media, graphic images, videos) and in English, Spanish, Braille, and Large Print to meet a wide-ranging audience. Information made available via the MWW Lead and Water webpage aligns with content recommendations published in *Communicating About Lead Service Lines: A Guide for Water Systems Addressing Service Line Repair and Replacement* (AWWA, 2014), including, but not limited to, the following:

- Frequently asked questions and fact sheets about sources of lead, what MWW is doing to minimize lead in water, and what customers can do to reduce risks
- MWW's LSLR program priorities, requirements, and easy-to-understand participation guidance
- Certified lead-removing water filters and customer access to free filters
- Certified laboratories to perform third-party lead sample analysis

Further, in collaboration with the City of Milwaukee Health Department (MHD), MWW champions a "Lead-Safe Milwaukee, Safe Paint – Safe Water – Safe Kids" public education campaign that includes a second portal for customers to access information about lead in water. MWW also partners with MHD and other stakeholders as part of the Inter-Agency Clean Water Advisory Council established in 1993 to communicate and manage water quality issues in the community. The multi-agency team meets regularly to discuss a range of water quality and public health and safety issues.

In addition to web-based resources, MWW communicates about lead to customers through bill inserts, door hangers, annual Consumer Confidence Reports, materials posted in public buildings, and through presentations given in community meetings. In all its communication, MWW provides information on how to contact the utility by toll free telephone for further information.

Current Practices Evaluation

Jacobs assessed MWW's current practices and techniques for lead and copper corrosion control to understand where improvements can be made and to determine its ability to respond to pending revisions to the LCR. Unlike the extensive nationally vetted best practices and numerical key performance indicators that compose the PSW distribution system operations program, there is no standard toolbox of corrosion control best practices for community water systems because corrosion control is very site specific.

> *A best practice is defined as a procedure that has been shown by research and experience to produce optimal results and that has been established or proposed as a standard suitable for widespread adoption.*
> Merriam-Webster Collegiate Dictionary

Because a single repository of national standard guidance does not exist, the Evaluation was conducted by comparing MWW's procedures, work approaches, and results with industry best practices outlined in various guidance documents (see References) and those practiced by similar utilities.

The Evaluation is also based on the assumption that the suite of highly effective MWW practices and procedures in place to minimize customers exposure to lead in water—including OCCT, distribution system water quality monitoring, distribution system maintenance, LSLR program, and public education and outreach—continue to function and are periodically refined to incorporate lessons learned. The Evaluation results in identifying potential opportunities for improvement and recommendations for future consideration and possible implementation.

Opportunities for Improvement and Recommendations

Through its documented assessments, utility capital plans, water quality monitoring program, standard operating procedures, and response actions, MWW demonstrates its abilities to exceed minimum requirements, embrace established best management practices, and efficiently meet simultaneous compliance objectives. Like other quality management efforts, this focused review of corrosion control practices illustrates MWW's commitment to providing safe drinking water and reliable, affordable water service through continuous improvement.

The following are potential opportunities for MWW improvement within the six key best corrosion control practice areas:

Optimize Corrosion Control Treatment

For over 20 years, MWW has implemented CCT and conducted studies to evaluate and optimize CCT. MWW LCR compliance samples, along with extensive additional water quality data, provide evidence that customers' exposure to lead is controlled to low levels of about 5 µg/L. In California, achieving 5 µg/L is considered optimized and low as can be reliably maintained from system samples at customers taps.

Opportunity: Develop a better understanding of corrosion with a system-wide pipe corrosion library.
Recommendation → Develop a library of pipeline corrosion samples from throughout the distribution system and from various types of pipe. Some utilities save pipeline segment samples; others use digital photographs linked to geographic information systems (GIS) to preserve and provide ready access to the information.

Opportunity: Study impacts on corrosion control from other potential treatment process changes.
Recommendation → Following the year-long pipe loop test MWW is undertaking to demonstrate the effectiveness of its current phosphate-based CCT techniques, set up a permanent pipe loop test arrangement within the distribution system to use in the evaluation of other process changes or simulations of varied distribution system water quality conditions.

Opportunity: Study ways to reduce aluminum phosphate precipitation (an unintended consequence of CCT) that do not adversely impact corrosion control. Study impacts of other water quality changes on corrosion through continued pipe loop testing.
Recommendation → While MWW is doing an excellent job with CCT it could investigate ways to minimize aluminum phosphate precipitation in the distribution system. Aluminum phosphate forms when aluminum from the coagulation treatment process reacts with phosphate from the CCT process. This precipitate deposits on pipes and tanks in the distribution system, potentially increasing the energy to pump water and causing cloudy particles in the water. Actions to consider include the following:

- Start analyzing accumulated settled solids in storage reservoir as part of routine cleaning to provide potential insights on aluminum phosphate precipitation.
- Collect and analyze precipitates inside pipe walls encountered during water main work, flushing, and/or distribution system sampling.
- Based on the outcome of the aluminum phosphate precipitate monitoring, evaluate ways to maintain the desired orthophosphate concentration entering the distribution system while minimizing aluminum phosphate particle formation.
- Consider means of reducing aluminum levels in treated water, which may include adjusting the pH of coagulation, alternative coagulants, and/or modifying phosphate addition location (injection at rapid mix to precipitate aluminum within the treatment process and supplement in finished water to reach target orthophosphate dose). Any change in the treatment process requires a study to thoroughly consider the risks, benefits, and costs.

Manage Water Age

Excessive water age can contribute to water quality conditions that can increase the potential for lead corrosion. Based on extensive water quality data collected from throughout the distribution system, MWW is managing the system to mitigate excessive water age. MWW proactively uses system water quality characteristics to inform operating and maintenance decisions. For example, when water quality changes, e.g., chloramine residual concentration declines, MWW pre-emptively flushes water mains before a problem develops. In locations where water quality data shows greater potential for water age issues (low water use on dead end mains), MWW conducts routine scheduled flushing to avoid conditions that increase corrosion potential.

Opportunity: Reduce effective water age in storage facilities.

Recommendation → Following planned installation of new water quality monitors at its storage facilities, consider adding mixers to storage reservoirs to reduce hydraulic short circuiting which increases the potential for "pockets of old water." Evaluate mixing effectiveness with installed monitors capable of measuring total chlorine, conductivity, pH, fluoride, oxidation reduction potential, temperature, and turbidity.

Opportunity: Enhance distribution system hydraulic model to better understand system performance and aid in system operation and maintenance.

Recommendation → Enhance MWW steady-state water distribution system hydraulic model so it can be used in extended period simulations for system performance to estimate available flows, pressures, and water age under different operation conditions; to optimize MWW's conventional and automatic flushing operations; and to prevent potential water quality issues that can contribute to corrosion. Once calibrated, the model can also be used to estimate water quality changes in the distribution system.

Monitor for Water Quality Problems and Response

In many ways, MWW has a benchmark water distribution system water quality monitoring program. Monitoring program data reveals that system water quality exceeds the compliance requirements of the LCR, the Disinfectant/Disinfection Byproduct Rule, and the Total Coliform Rule. The following are examples of how MWW is not simply collecting data required by regulations, but using the information in day-to-day operations and maintenance decisions and long-range planning:

- MWW has a practice of reviewing and discussing water quality data across utility departments weekly. These conversations lead to proactive measures such as follow-up sampling, flushing, or operational changes.
- MWW has established a formal chloramine residual AL of 0.6 mg/L in the distribution system. Chloramine residual is closely monitored, and actions are taken before the AL is triggered to prevent issues.
- MWW uses water quality and flushing water volume information to refine its conventional and automatic flushing operations.
- MWW voluntarily conducted sequential sampling designed to capture all stagnant water in a customer service line and premise plumbing (and correspondingly highest potential lead levels) in advance of revised LCR requirements to inform its long-range compliance planning efforts.

Opportunity: Enhance distribution system operations with water quality process control charts.

Recommendation → Leverage existing practices into development of process control charts for select water quality parameters to assist in distribution system operations and maintenance to provide early warning of water quality issues and avoid conditions that increase potential for corrosion.

Opportunity: Consider future use of advanced automation to track water quality events.

Recommendation → In the future, evaluate application of automated algorithms and artificial intelligence, in conjunction with existing monitoring and control systems, to rapidly identify patterns and relations among water quality parameters that could more reliably predict an anomaly, rather than action thresholders of individual parameters.

Opportunity: Conduct research to explore how biomechanisms in MWW system may affect lead release.

Recommendation → Develop microbial protocols to evaluate the impact of different water conditions on biofilms and help better predict when conditions exist that can increase the potential for corrosion, including lowering the AL for nitrite to 0.1 mg/L as NO_2-N.

Opportunity: Plan for meeting proposed LCR sampling requirements in partnership with City of Milwaukee Health Department.

Recommendation → Continue preliminary planning efforts to coordinate with MHD for implementation of additional lead sampling at schools and childcare facilities as defined in the proposed revision to LCR.[6]

Clean the System

In addition to LCR samples that confirm low lead levels at customers' taps, comprehensive distribution system water quality data indicate stable water quality, and the system is cleaned to maintain conditions that minimize lead release.

Opportunity: Use distribution system model to aid design of a customized flushing program.

Recommendation → Use the MWW distribution system hydraulic model as a design tool to develop a customized flushing program that encompasses various flushing techniques for MWW system constraints that may prevent achievement of desired flushing velocities. The program would result in recommendations for flushing using a combination of conventional flushing, automatic flushers, and unidirectional flushing (UDF). To the extent it is practical to implement, the general UDF principle of flushing from a cleaned area out toward an area to be cleaned is recommended. UDF has been proven to be highly effective, but requires extensive upfront planning. Based on initial experiences, use of UDF principles may need to be implemented in tandem with MWW's valve exercise/replacement program.

In addition to helping MWW quickly evaluate what flushing techniques are optimum in different areas of the system, use of the model can help improve the flushing effectiveness and efficiency, where "effectiveness" is cleaning the system to maintain target water quality objectives while minimizing disruption to individual customers and the service area, and "efficiency" is minimizing the measured volumes of non-revenue water required to achieve water quality targets.

Reduce Sources of Lead in the System

For over 20 years, MWW has been reducing the sources of lead in the water system by removing utility-owned LSLs and passing various regulations and rules prohibiting the use of lead pipe. Historically, replacing utility-owned LSLs was considered best practice. After industry research confirmed that partial LSLs can result in lead spikes at customers' taps, MWW changed its practices. In 2017, MWW enacted polices to make mandatory full LSLRs (both utility- and privately owned portions) and implemented an LSLR program to provide financial incentives and other resources to private property owners to help minimize their exposure to lead in water. In the past three years, MWW LSLR efforts have achieved the following results:

- Progressively increased the number of full LSLRs each year, toward a replacement rate of over 1.3 percent of the estimated total number of LSLs in 2019 and planned 1.5 percent LSLR in 2020.

[6] National Primary Drinking Water Regulations: Proposed Lead and Copper Rule Revisions

- Invested an estimated $25,500,000 in lead-reducing efforts, including full LSLRs at a cost of about $10,600[7] each.
- Prioritized LSLRs for customers with highest exposure risks, including licensed and certified childcare facilities, customers with service line leaks, and customers impacted by water main disturbances and replacement projects.

Removing LSLs is difficult and costly. There is currently no established ideal LSL replacement rate, in part because compliance with the LCR is not the only issue facing water utilities and competing for limited resources, and in part because community water systems and local needs vary greatly. For example, Denver Water is undertaking a 15-year program to replace an estimated 64,000 – 84,000 LSLs[8] and rely on achieving setpoint pH levels for CCT instead of adding a phosphate corrosion inhibitor. This strategy is being implemented because phosphate addition adversely impacts wastewater system operations and impairs receiving waters in ways unacceptable to local stakeholders.

Opportunity: Accelerate development of privately-owned service line material inventory.
Recommendation → MWW has a reliable inventory of utility-owned service line material. Efforts to confirm private service line material data have had limited success. To address unknown material in the system inventory, collaborate data-collection techniques with partners who can gather that information incidental to other work being conducted on private property. Collaborative partners could potentially include MWW meter or cross connection control technicians, private home inspection service providers, City of Milwaukee home inspectors, and professional plumbers. MWW or the City of Milwaukee could provide a GIS interface to organize and archive collected data that is accessible to select City departments.

Opportunity: Establish long-term LSLR rate goals and financial plan.
Recommendation → MWW has committed to programmatic replacement of LSLs with a general goal of maximizing LSLRs; however, MWW has not defined a numerical LSLR rate target over time with a supporting financial plan. To be successful, removing sources of lead must be planned and achievable within technical, managerial, and fiscal means of MWW as established with input from rate payers, property owners, community leaders, and regulatory agencies. Setting numerical goals with a financial plan can help MWW balance competing needs across the utility; maintain equitable rates; and set service expectations among customers, regulators, and community leaders. Establishing a target annual LSL rate must factor in physical replacement costs and administrative costs incurred by collaborating with customers and other City departments.

Jacobs recommends that MWW's continuing efforts to investigate funding sources to offset private property owner LSLR costs consider funding through approved water rates under Wisconsin Act 137 and programs under the Water Infrastructure Finance and Innovation Act, Water Infrastructure Improvements for the Nation Act Grant Programs, and Department of Housing and Urban Development. Federal and state programs and program appropriations change periodically; local elected officials can play a role in providing input to program funding.

Opportunity: Establish strategic partnerships to increase privately-owned LSLRs.
Recommendation → Further reductions in lead in water are a responsibility shared by the MWW, the City of Milwaukee, and property owners. Obtaining private property owner participation in MWW's LSLR program can be challenging and resource intensive. Despite risk communication, LSLR program communication, and financial incentives, some property owners refuse to replace their service lines.

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[7] MWW LSLR program data, February 13, 2019 and July 7, 2019.
[8] *Denver Post* December 20, 2019.

To help increase rate and efficiency of private LSLRs, MWW could explore with Department of Neighborhood Services new outreach techniques to improve program effectiveness. Neighborhood associations or community-based groups could be engaged in promoting MWW's lead reduction efforts. LSLR program incentives and responsibilities could possibly be integrated in the landlord training that is provided by the City of Milwaukee and in professional plumbing certification programs. Further, the City of Milwaukee and MWW could engage landlords through rental real estate organization(s) to determine if LSLR program changes could result in more private LSLRs. In addition, the City of Milwaukee may want to explore with legal advisors, community leaders, and other stakeholders the regulatory mechanisms needed to require private LSLRs with property sale transactions. Policy changes at the local and state level are needed to facilitate full LSLRs and make progress toward eliminating lead exposure.

Public Education and Outreach

MWW developed and maintained a suite of highly informative resources to help customers understand health risks associated with lead in water, ways to minimize those risks, and opportunities to remove their LSL. In addition to making available strong, audience-targeted educational materials, MWW conducts lead awareness outreach through meetings within the community.

Opportunity: Provide greater website information transparency.

Recommendation → If customers do not know MWW's accomplishments, they might assume not enough is being done. Consider sharing more LSLR program performance statistics, including costs and private property owner participation; MWW communication effectiveness (number and percent survey respondents, number of hits to websites or Tweets received, etc.); and general statistics on customer concern calls or calls about lead. Streamline information to provide the best information to the public.

Opportunity: Update Communication Plan

The communication plan used by MWW and MHD needs to be updated. For MWW, exceeding the lead AL and associated public notice is unlikely; however, having a useful communication plan with established personnel roles and responsibilities during a water quality event, defined channels of communication, and pre-scripted messages for target audiences is a water utility best practice. For lead exposure risk communication, messages should be gauged to avoid undue public panic with appropriate explanations of risk associated with chronic exposure to lead versus risk associated with acute exposure to pathogens.

Recommendations Summary

The following mechanisms for limiting lead in water at customers' taps are addressed in the Evaluation:[9]

- Control the chemistry of water to maintain stability and limit the solubility of lead in contact with water.
- Remove sources of lead.
- Minimize water age and remove sediment from the distribution system via flushing.
- Provide point-of-use filters for lead removal when lead lines are disturbed or replaced.

MWW has demonstrated proficiency in several corrosion control practices and techniques used to achieve the above mechanisms. The recommendations summarized in Table 1 are prioritized, highest to lowest, for MWW consideration as it implements continuous improvements. Several of the recommendations, denoted with an asterisk (*), are related or identical to performance issues included in the PSW self-assessment improvement plan. These recommendations may take years to achieve and will be dependent on available resources and other utility priorities.

[9] Water Research Foundation Project # 4409 Controlling Lead in Water

Table 1. Corrosion Control Best Practices Recommendations Summary

	*	Accelerate development of privately owned service line material inventory.
		Establish long-term lead service line replacement (LSLR) rate goals and financial plan.
		Establish strategic partnerships to increase privately-owned LSLRs.
	*	Reduce effective water age in storage facilities.
		Enhance distribution system operations with process control charts.
		Develop a better understanding of corrosion with a library of pipe corrosion samples from entire system.
	*	Enhance distribution system hydraulic model to better understand system performance and aid in system operation and maintenance.
	*	Use distribution system model to aid design of a customized flushing program.
		Provide greater website information transparency.
		Update Communication Plan.
		Conduct research to explore how biomechanisms in MWW system may affect lead release.
		Consider future use of advanced automation to track water quality events.
		Study ways to reduce aluminum phosphate precipitation (an unintended consequence of CCT that do not adversely impact corrosion control. Study impacts of other water quality changes on corrosion through continued pipe loop testing.
		Plan for meeting future proposed LCR sampling requirements in partnership with City of Milwaukee Health Department.

References

American Water Works Association (AWWA). 2014. *Communication About Lead Service Lines: A Guide for Water Systems Addressing Service Line Repair and Replacement*.

American Water Works Association (AWWA). 2017. *AWWA Standard C810-17 Replacement and Flushing of Lead Service Lines*.

American Water Works Association (AWWA). 2017. *AWWA Manual of Water Supply Practice M58 – Internal Corrosion Control in Water Systems*.

CH2M HILL. 1994. *Lead and Copper Corrosion Control Report for Milwaukee Water Works.*

Lead and Copper Rule Working Group. 2015. *Report of the lead and copper rule working Group to the National Drinking Water Advisory Council*.

Milwaukee Water Works. 2018. *Phase III Distribution System Self-Assessment Report for Milwaukee Water Works Water Distribution System, Partnership for Safe Water*.

U.S. Environmental Protection Agency (EPA). 2016. *Optimal Corrosion Control Treatment Evaluation Technical Recommendations for Primacy Agencies and Public Water Systems*.

U.S. Environmental Protection Agency (EPA). 2018. *3Ts for Reducing Lead in Drinking Water in Schools and Child Care Facilities, Revised Manual*.

U.S. Environmental Protection Agency (EPA). 2019. *National Primary Drinking Water Regulations: Proposed Lead and Copper rule Revisions, Docket No. EPA-HQ-OW-2017-0300*.

Water Research Foundation (WRF). 2015. *Project #4409 Controlling Lead in Drinking Water*.

Water Research Foundation (WRF). 2015. *Project #4569 Evaluation of Lead Sampling Strategies*.

Water Research Foundation (WRF). 2013. *Project #4349 Impact of Galvanic Corrosion on Lead Release Following Partial Lead Service Line Replacement*.

Water Research Foundation (WRF). 2017. *Project #4586 Optimization of Phosphorous-Based Corrosion Control Chemicals and Flushing for Lead and Copper Control*.

Water Research Foundation (WRF). 2018. *Project #4584 Evaluation of Flushing to Reduce Lead Levels*.

Wisconsin Department of Natural Resources (WDNR). 2002. Letter to Milwaukee Water Utility on Optimum Water Quality Parameter Ranges and Lead and Copper Monitoring. December 18.