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SEWRPC Staff Memorandum

LEAD IN DRINKING WATER IN SOUTHEASTERN WISCONSIN

April 19, 2019

INTRODUCTION

Lead is a toxic metal that can cause major health impacts in both children and adults. One potential route of human exposure to lead is through its release into drinking water supplies. This can happen when lead-containing water service lines and other plumbing materials corrode.

The experience of the City of Flint, Michigan provides an example of the potential risks posed by lead contamination of drinking water. In April 2014, the City of Flint switched its source of water supply from water purchased from the City of Detroit that was withdrawn from Lake Huron to water withdrawn from the Flint River. Despite the change in water source to one with softer and more acidic water, the City of Flint did not implement treatment to control corrosion. In October 2015, Flint switched its source of water supply back to Lake Huron water provided by the City of Detroit. During the period that Flint was using water withdrawn from the Flint River, water mains, water service lines, and plumbing within buildings sustained major corrosion, which released lead into water flowing to customers' taps. A research team from Virginia Polytechnic Institute and State University found high levels of lead in municipal water sampled at taps within Flint residences. In addition, a study by a local medical clinic found that the percentage of children under the age of six with elevated blood levels of lead increased following the change in the source of water supply to the Flint River.

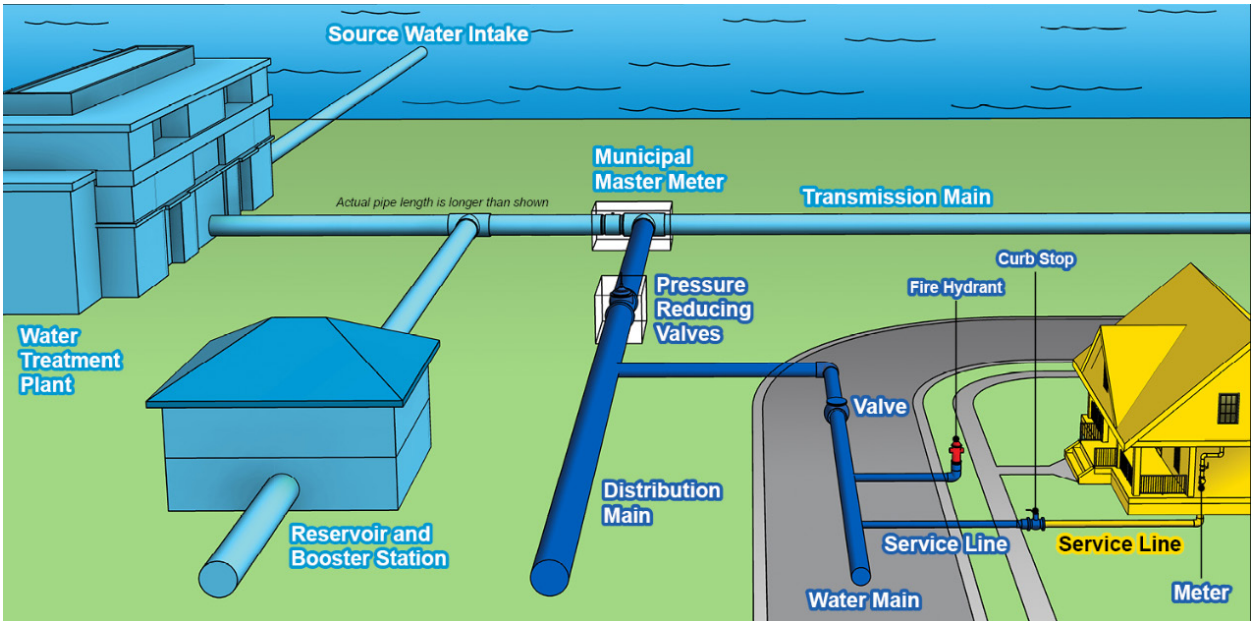
This paper summarizes information regarding lead in drinking water in Southeastern Wisconsin. It briefly describes a number of issues including background topics, such as the elements of municipal water distribution systems and Federal rules regarding lead in water supply systems, and topics regarding lead in drinking water, such as the health effects of lead, sources of lead, how lead is released from plumbing materials, and ways of addressing lead in drinking water.

BACKGROUND

Water Supply Distribution Systems

While there are differences among public water supply systems, they all perform a common set of functions. The basic design of a public water system is shown in Figure 1. First, raw water is taken from a source. In the Southeastern Wisconsin Region, this is done by withdrawing water from either groundwater through wells or Lake Michigan through intake pipes. The water is then treated to remove or inactivate impurities. The types of treatment the raw water receives depend on the source of the water and its chemical composition. Commonly used treatment techniques include sedimentation to remove particles, filtration to remove particles and some chemicals, aeration to remove some chemicals, chemical treatment to improve the performance of sedimentation and/or filtration, and disinfection to kill or inactivate disease-causing organisms such as bacteria and viruses. The techniques are chosen so that the treated water complies with Federal and State standards for drinking water. Concentrations of lead and copper in treated water are low.

Figure 1
Layout of a Public Water Supply System



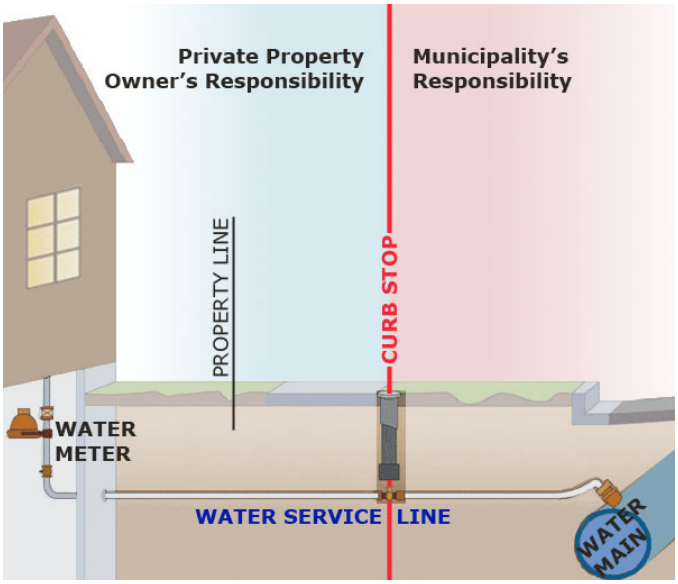
Source: Great Lakes Water Commission

The treated water may then be pumped into reservoirs and/or tanks for storage until it is needed. As it is needed, treated water flows by gravity or is pumped into transmission and distribution systems. Transmission mains provide treated water to other public water supply systems that purchase water from the system that withdraws and treats the water. Distribution mains transport the water to individual customers. These mains form a network of pipes through a community and are usually located below the community's streets.

Individual buildings are connected to the distribution mains by water service lines. This is illustrated in Figure 2. Typically the service line includes three parts:

- A pipe that runs from the water main to the curb stop
- The curb stop, a control valve for the water supply to a building
- A pipe that runs from the curb stop into the building

Figure 2
A Water Service Line Connection



Source: Wisconsin Department of Natural Resources

The curb stop is usually located between the sidewalk and curb. According to the Wisconsin Department of Natural Resources (WDNR), service lines that were installed before 1951 were often made of lead.[1] This includes the pipes on both sides of the curb stop.

[1] *The City of Milwaukee banned the use of lead service lines in 1962.*

In Wisconsin, responsibility for the service line is shared between the property owner and the municipality or utility. The property owner is responsible for the portion of the service line that extends from the curb stop into the building. The municipality is responsible for the portion that extends from the curb stop to the water main.

With the exception of the water meter, the property owner is responsible for the plumbing inside the building.

Federal Rules Regarding Lead in Water Supply Systems

Two Federal rules affect the use of lead in plumbing materials and management of lead concentrations in water provided by public water supply systems: the Reduction of Lead in Drinking Water Act and the Lead and Copper Rule. The State of Wisconsin implements these rules through its building codes and drinking water quality standards.

Reduction of Lead in Drinking Water Act

The Federal Reduction of Lead in Drinking Water Act[2] regulates the use of lead in plumbing materials. This law has two major provisions. First, it defines lead-free plumbing materials. Under this Act, pipes, pipe fittings, and plumbing fixtures that contain less than 0.25 percent lead, and solders and fluxes that contain less than 0.2 percent lead, are considered to be lead free. Prior to 2011, pipes, pipe fittings, and plumbing fixtures that contained less than 8 percent lead were considered lead-free. Second, as of June 1986, this Act prohibits the use of any pipe, plumbing fixture or fitting, solder, or flux that is not lead-free in the installation or repair of any public water system or plumbing in a residential or nonresidential facility providing water for human consumption. The Act has exemptions for pipes, fittings, and devices that are used exclusively for providing water for uses other than human consumption or cooking.

Lead and Copper Rule

The Federal Lead and Copper Rule[3] regulates concentrations of drinking water at customers' taps in order to protect public water system consumers from exposure to lead and copper in drinking water. It was adopted in 1991 and revised in 2000, 2004, and 2006. This rule has several provisions that apply to public water supply systems.

The rule requires operators of public water supply systems to monitor concentrations of lead and copper in drinking water at the taps of customers who have lead service lines or lead-based solder in their plumbing systems. The number of sites at which the system operator is required to collect samples, the frequency of sampling, and requirements to sample other water quality parameters are based on the number of customers served by the water system and the system's history of exceeding drinking water quality standards.

The rule also sets action levels for concentrations in the sampled water of 0.015 milligrams per liter (mg/l) for lead and 1.3 mg/l for copper. These action levels are screening tools that can trigger other requirements of the rule. When 10 percent or more of the samples taken exceed an action level, the water supply system is required to do additional work. Such work may include:

- Monitoring other drinking water quality parameters that can affect the corrosivity of water
- Implementing programs to educate consumers about the sources and health effects of lead and steps that they can take to minimize their exposure
- Monitoring the system's source water to determine the contribution of source water to lead and copper levels at the tap
- Implementing treatment of source water, if lead or copper concentrations in source water exceed the maximum permitted levels set by the State
- Installing and optimizing of corrosion control treatment
- Replacing lead service lines

[2] *Section 1417 of the Federal Safe Drinking Water Act as revised in 2011.*

[3] *40* Code of Federal Regulations *Part 141, Subpart I.*

The type of action that is triggered depends upon the size of the system and the actions it has previously taken. All water systems serving more than 50,000 people were required to install corrosion control treatment soon after the Lead and Copper Rule went into effect. Systems serving fewer than 50,000 people that exceed the action level and have not installed corrosion control technology must begin working with their state to monitor water quality parameters and install, optimize, and maintain corrosion control. Any system that exceeds the lead action level must conduct public education. Any system with lead service lines that exceeds the lead action level after installing and optimizing corrosion control technology must begin replacing lead service lines that they own. When a water system replaces their portion of a service line, the rule requires that they offer the building owner the opportunity to replace the privately owned portion of the service line at the same time. The rule does not require the water system to pay for replacement of the privately owned section of the service line.[4]

HEALTH EFFECTS OF LEAD

Exposure to lead can cause a number of adverse health effects. The most sensitive tissues are the nervous system, blood and the cardiovascular system, and the kidneys. Developing nervous systems are especially susceptible to lead toxicity because exposure to lead during development can interfere with the formation, maintenance, and regulation of connections between nerve cells in the brain.

Relatively low levels of exposure to lead can affect neurobehavioral development. This can result in cognitive deficits that may also be associated with distractibility, inability to inhibit inappropriate responses, and preservation of behaviors that are no longer appropriate. Somewhat higher levels of exposure can cause anemia due to the inhibitory effect of lead on the synthesis of heme, a component of hemoglobin, and shortening of the lifespan of red blood cells. These levels of lead exposure can also result in peripheral nerve dysfunction, resulting in weakness and loss of coordination in wrists, hands, feet, and ankles. Even higher levels of exposure can lead to colic, kidney damage, muscle weakness, brain damage, paralysis, and death.

Children are more vulnerable to lead poisoning than adults. Young children are more likely than adults to be exposed to lead through inhaling or swallowing lead in dirt, dust, or sand while playing on the floor or ground. Children absorb lead into their bodies more efficiently than do adults. A greater fraction of the lead absorbed remains in the bloodstream and soft tissue in children's bodies than in adult bodies. Finally, because their nervous systems are still developing, children tend to be more sensitive to the neurological health effects of lead.

The U.S. Centers for Disease Control and Prevention considers a lead blood concentration of 5 micrograms per deciliter (µg/dl) or more as indicative of lead poisoning. Based on data from local health departments, the Wisconsin Department of Health Services reported that from 2011 through 2016, an annual average of 3,616 children under six years of age out of an annual average of 47,747 tested in the seven-county Southeastern Wisconsin Region were found to have blood stream lead concentrations greater than 5 µg/dl. The highest numbers of children with blood stream lead concentrations exceeding this level were reported by the health departments serving the City of Milwaukee, City of Racine, Kenosha County, and Waukesha County. The highest percentages of children tested found to have blood stream lead concentrations greater than 5 µg/dl were reported by the health departments serving the City of Milwaukee, City of Racine, Kenosha County, and the City of West Allis.

Over the last 40 years, there have been major reductions in childhood exposure to lead in the United States. The median blood lead level found in children between the ages of one and five has decreased from 15 µg/dl during the period 1976 through 1980 to 1 µg/dl in recent years.

SOURCES OF LEAD

Humans can be exposed to lead from a variety of sources. This section summarizes some of the most typical sources of human exposure: lead in drinking water and lead in buildings and the environment from the use of leaded gasoline and paint.

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[4] *As described in more detail below, utilities need approval from the Wisconsin Public Service Commission to use ratepayer dollars to provide financial assistance to customers for replacing privately-owned portions of lead service lines.*

Figure 3
Potential Sources of Lead in Household Plumbing

Source: U.S. Environmental Protection Agency

Water Mains, Service Lines, and Plumbing Fixtures

Plumbing systems in older buildings may include several types of components that contain lead. Examples of these components are shown in Figure 3.

Historically, water service lines made from lead were widely used. Homes and commercial buildings built before 1951 were likely constructed with lead service lines. Beginning in the 1930s, service lines made from galvanized iron or copper began to be used in place of lead service lines. The transition from the use of service lines made of lead to those made from other materials depended partly on the local community. The City of Milwaukee, for example, required the use of lead service lines until 1948. The City banned the use of lead service lines in 1962. Nationally, the use of lead service lines was banned in 1986. The WDNR estimated that there are at least 121,500 lead water service lines in the seven-county Southeastern Wisconsin Region. This includes an estimated 70,000-75,000 lead service lines in the City of Milwaukee. Other communities reporting large numbers of lead service lines include the Cities of Racine (12,900 lines), Kenosha (9,080 lines), Wauwatosa (8,660 lines), and West Allis (6,690 lines). In their 2017 annual reports to the Wisconsin Public Service Commission, several water utilities in Southeastern Wisconsin indicated that they are currently assessing the numbers of lead service lines, if any, that are connected to their distribution systems.

Other plumbing materials installed prior to 1986 may also contain lead. These materials include the pipes such as goose necks and pigtails that are used to connect water service lines to water mains, solder used to connect pipes to one another, plumbing fixtures such as faucets, and interior plumbing lines. Since June 1986, pipes, plumbing fixtures and fittings, solder, and flux used in plumbing in residential or nonresidential facilities providing water for human consumption are required to be lead free.

Finally, lead in water can be deposited and accumulate in scale on the inside of household plumbing pipes. While this lead can be relatively inert, disturbance of these pipes or changes in the chemistry of the water flowing through these pipes can cause this lead to be released.

Other Sources of Lead in Buildings and the Environment

People can be exposed to lead from sources other than drinking water. The greatest potential for human exposure to lead is linked to two of its former uses, as an additive to gasoline and a pigment in paint. The use of lead as an additive to gasoline resulted in its widespread dispersal throughout the environment. The Federal government phased out the use of leaded gasoline beginning in 1976, and its use was completely banned in 1996. While lead additives are no longer used in gasoline, lead from gasoline use is still present in soil. Decaying, peeling, or flaking interior and exterior paint can also introduce lead into household dust and soil. Buildings constructed before 1978 may contain lead-based paints. Lead was added to paint and other coatings, such as varnish, in high concentrations up until 1950. In 1978, the Federal government banned the use of lead in residential paint and other coatings.

Exposure to lead may also result from other less common sources. Powders used in some cultural ceremonial practices and makeups such as kohl or kajal contain lead. Lead has also been found in ceramic dishes, jewelry, beads, toys, clothing, hair accessories, spices, candies, and children's products. Prior to World War II, lead-arsenic compounds were used as pesticides, especially in orchards.

Some of these other sources of lead may be responsible for a greater portion of exposures to lead than drinking water. The U.S. Environmental Protection Agency estimated that drinking water accounts for about 20 percent of exposure to lead. They noted that in some instances, infants who consume mostly formula mixed from tap water can receive 40 to 60 percent of their exposure to lead from drinking water.

HOW LEAD IS RELEASED FROM LEAD-CONTAINING PLUMBING

Corrosion of Pipes and Other Plumbing Fixtures

Corrosion of lead service lines and lead-containing plumbing fixtures and fittings constitutes a major source of lead in drinking water. Corrosion consists of an electrochemical dissolution that can convert some of the lead in plumbing materials from metallic form to a form soluble in water. This allows the leaching of lead from a metal surface such as a pipe or tank into the adjacent water.

Corrosion occurs by means of the flow of electrons in a process similar to what happens in a battery. When water contacts metal piping, the pipe surface provides microscopic sites that act as anodes and cathodes. Electrons flow through the metal between the anodic and cathodic sites. Portions of the solid metal that have lost electrons are transferred to the adjacent water as positive ions. The water can supply negative ions, consisting of materials such as oxygen and carbonate. This method forms a new compound that is initially dissolved in the water. If this new compound has high solubility, the dissolved lead concentration in the water increases and metal loss from the plumbing material continues. If the new compound has low solubility, it may be deposited as scale along the metal surfaces on the plumbing material.

Several factors can influence corrosion and metal release from plumbing. These include:

- The acidity or alkalinity of the water are major factors influencing corrosion. Water with high acidity (low pH) can promote corrosion. By contrast, water with high alkalinity (high pH) may help form chemical scales within pipes that can, under some circumstances, protect against corrosion.

- Excessively high rates of water flow can cause physical erosion of scale and pipe walls, promoting corrosion and metal release.

- High water temperatures increase the rates at which chemical reactions and biological activities occur, promoting corrosion.

- The presence of dissolved solids or dissolved gases such as oxygen, carbon dioxide, or chlorine can make the water more electrically conductive, promoting corrosion.

- The presence of suspended solids in water can cause physical erosion of scale and pipe walls, promoting corrosion and metal release.

- Presence of certain types of microorganisms in water can promote corrosion. Several aspects of microbiological growth can contribute to the corrosion of metal surfaces. Some microorganisms can secrete acidic enzymes that attach to metal surfaces. Others produce acidic waste products. Still others use electrons from metals as an energy source. Nitrifying bacteria produce nitrate that can form highly soluble compounds with metals such as lead and copper. Each of these microbiological activities can result in corrosion of metal in water systems. In addition, some microorganisms can form biofilms on surfaces that can intensify the impacts of some microbial activities on pipe walls.

- Free chlorine resulting from the use of chlorine gas or hypochlorite for disinfection is a strong oxidant and can contribute to corrosion.

- Improper matching of pipes, fixtures, or fittings made from different metals can promote corrosion.

- Water that is in contact with pipes for longer periods of time will tend to have higher concentrations of metal due to greater opportunity for leaching of metals.

Disturbance of Pipes

Lead can also be released into a building's water through disturbance of its water service line. Disturbance of these lines can cause accumulated scale to detach from the interior surface of the pipes and be carried as particles in the flow of the water. When the compounds making up the scale include insoluble lead compounds, this can carry lead through the tap. Detachment of the scale can also expose previously covered pipe surfaces to water, leading to additional corrosion of the pipe.

Types of disturbances to water service lines that can cause the release of lead into water include road construction and construction and maintenance of underground infrastructure. Partial replacement of lead service lines can constitute a major disturbance. Removal and replacement of a portion of the service line can cause lead-containing scale in the remaining portion to detach from pipe walls and enter the water. Data indicate that partial service line replacements can lead to short-term increases in the concentration of lead in the water provided. The available data suggest that the elevated concentrations of lead gradually stabilize, in some instances at levels below and in other instances at levels similar to those observed prior to the partial service line replacement. The U.S. Centers for Disease Control and Prevention have also found a correlation between partial service line replacement and elevated blood lead levels in children. These results indicate that it would be a best practice to replace both the publicly owned and privately owned sections of water service lines at the same time.

ADDRESSING LEAD IN DRINKING WATER

Distribution System Treatment Methods

There are two general strategies that utilities can adopt to reduce leaching of lead from lead service lines and other lead-containing plumbing fixtures and fittings: installing and optimizing corrosion control treatment and removing sources of lead. Neither of these strategies are easy solutions to implement.

There are a variety of corrosion control treatment approaches available for reducing leaching of lead from service lines and other plumbing fixtures and fittings. In some instances, the acidity (pH) of water in the distribution system can be managed in such a way as to encourage the formation and deposition of carbonate scales on the inside of the pipes. Corrosion inhibitors consisting of phosphate or silicate compounds can be added to the water during treatment. Such inhibitors form relatively insoluble compounds that can be deposited on pipe walls. In both of these cases, formation of such scales can prevent corrosion. Finally, reducing the availability of nutrients such as organic carbon, nitrate, and phosphate to microorganisms in the distribution system can reduce the growth of microorganisms and the development of biofilms that can contribute to corrosion.

Optimizing corrosion control treatment in a municipal water distribution system can be a complex and challenging task. Such optimization requires that treatment minimize the concentrations of lead and copper

in water at users' taps while ensuring that the treatment does not cause the water system to violate any national primary drinking water standard. It can be difficult to create conditions throughout a municipal water system that reduce the corrosivity of the water, while simultaneously maintaining disinfection and optimal levels of fluoride and reducing levels of other materials such as iron, manganese, and radium. In addition, it can be difficult to determine optimized treatment levels, especially at different locations within a distribution system.

About two-thirds of the municipal water utilities in the Southeastern Wisconsin Region have implemented treatment for corrosion control. Most use inhibitors consisting of phosphate compounds. A few utilities use silicate compounds. One utility adjusts the acidity (pH) of its water during treatment.

Removing sources of lead involves replacing lead service lines and other lead-containing plumbing fixtures and fittings with lead-free lines, fixtures, and fittings.

Removing lead sources from municipal water systems can also be challenging. It can involve locating and replacing buried infrastructure. Many communities have substantial numbers of lead service lines that can take a long time to replace. Responsibility for addressing a lead service line is shared between the water utility and the private property owner, with the utility being responsible for the portion of the service line between the water main and curb stop and the property owner being responsible for the portion between the curb stop and the building. Since the best practice is to replace both portions of the service line at the same time, this shared responsibility can complicate replacement. Funding is limited and replacing service lines can be expensive. In May 2018, the WDNR estimated the average cost of replacing the privately owned portion of a water service line to be between $2,000 and $7,000. Finally, if a building's interior plumbing includes pipes, fixtures, and/or fittings containing lead, replacing a lead service line may not be sufficient to reduce lead concentrations at the tap below the lead action level of 0.015 mg/l.

The WDNR established a two-year program for fiscal years 2017 and 2018 to assist disadvantaged municipalities in replacing lead service lines on private property for projects that result in full lead service line replacements. This program provided about $13.5 million in each year to fund replacements in about 38 communities, including the Cities of Milwaukee, Racine, St. Francis, and West Allis and the Village of West Milwaukee.

Utilities need approval from the Wisconsin Public Service Commission to use ratepayer dollars to provide financial assistance to customers for replacing privately owned portions of lead service lines. To receive such approval, the utility must meet requirements established under the *Wisconsin Statutes*. These include the requirement that the municipal government in which the utility provides financial assistance enact an ordinance that permits the utility to provide financial assistance to private property owners and that requires utility customers to replace their service lines that contain lead. Currently, one community in the State has received approval from the Public Service Commission to provide such assistance. The City of Kenosha received approval from the Commission in September 2018 and is currently developing its program.

Addressing Lead in Water Within Residences and Other Buildings

There are several actions that can be taken within residences and other buildings that have lead water service lines to reduce the risk of exposure to lead in drinking water. Flushing plumbing by running the cold water for three minutes or longer prior to using tap water for drinking, cooking, or preparing infant formula will replace water in the building's plumbing and service line with water from the water main. Since longer residence of water in lead-containing plumbing can result in higher lead concentrations, such flushing can reduce the amount of exposure. Because the solubility of lead increases with water temperature, using only water from the cold water tap for cooking and drinking will reduce the risk of exposure. Periodically removing the screen and aerator from faucets, rinsing out any debris that they contain, and reattaching them to the faucet will reduce the accumulation of small lead-containing particles at the faucet. Lead can also be removed from water for cooking and drinking through the use of a home filtration system. A variety of systems are available, including pour-through pitcher systems and systems that are connected to water taps. Such filters should be certified by the National Sanitation Foundation/American National Standards Institute (NSF/ANSI) under Standard 53 for removal of lead. In addition, the filters in these systems may require periodic replacement.

In 2016, the City of Milwaukee distributed over 1,700 free filtration devices to low-income residents living in homes with lead service lines. In addition, the City of Milwaukee Health Department, the United Way of Greater Milwaukee and Waukesha County, and A. O. Smith Corporation have partnered to provide residents of the Milwaukee area with drinking water filters at a discounted cost.