DEPARTMENT OF HEALTH

Lead in Minnesota Water

ASSESSMENT OF ELIMINATING LEAD IN MINNESOTA DRINKING WATER

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Minnesota Department of Health
Environmental Health Division
PO Box 64975
St. Paul, MN 55164-0975
651-201-4700
health.drinkingwater@state.mn.us
www.health.state.mn.us

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Contents

Executive Summary

The 2017 Minnesota Legislature directed the Minnesota Department of Health (MDH) to “conduct an analysis to determine the scope of the lead problem in Minnesota's water and the cost to eliminate lead exposure in drinking water.” In this report, MDH assesses the scope of the lead problem by examining the extent of lead already in water systems as well as factors that allow lead to get in drinking water. However, because drinking water systems across the state are diverse and have varying requirements and resource needs, broad estimates are used to gauge costs.

Addressing lead in drinking water has both costs and benefits. This report estimates costs for removing the two most significant sources of lead to be between $1.52 billion and $4.12 billion over 20 years. Estimated benefits associated with removing lead from water include improvements in population mental acuity and IQ (and resulting increases in lifetime productivity, earnings and taxes paid). The projected range of benefits is $4.24 billion to $8.47 billion over 20 years, although there are a number of reasons to believe these benefits may be underestimated. Therefore, resources allocated to reducing lead in drinking water would be expected to yield a return on investment of at least twofold.

According to the Centers for Disease Control and Prevention (CDC), no safe level of lead exposure has been found. Consequently, preventing exposure at any level is now considered the best protective measure. While anyone may face health impacts when exposed to lead at elevated levels, children are the most vulnerable due to their developing brains and behaviors. For infants and children, exposure to lead can cause significant damage to the brain, nervous system, red blood cells, and kidneys.

Lead exposure can happen in several ways, including household exposure to lead-based paint. While those other potential pathways to exposure merit strong consideration, this report focuses exclusively on lead exposure via drinking water. Minnesota’s drinking water is provided by private wells and public water systems (PWSs). Water from PWSs is regulated by the Lead and Copper Rule of the federal Safe Drinking Water Act as well as other state and federal laws.

The most significant contributor of lead to drinking water is leaching from plumbing. Lead is almost never found in groundwater or surface water. However, the chemical composition of the water can influence whether lead leaches from plumbing into drinking water. For example, water with lower pH levels (more acidic) will be more likely to leach lead out of plumbing. Well and treatment facilities are not significant contributors of lead to drinking water.

The two most significant sources of lead in Minnesota drinking water are lead service lines, which generally are controlled by cities, and plumbing fixtures, which generally are controlled by property owners. There are estimated to be 100,000 lead service lines remaining in Minnesota. Pipes and solder installed before 1986 could also have high levels of lead. The report concludes with a set of recommendations for mitigation, ranging from low-cost to high-cost interventions.

Introduction

This report characterizes potential lead exposure from drinking water and costs of removing lead from drinking water at each stage of the water delivery system. The 2017/18 Minnesota Legislature, as part of Clean Water Fund appropriations (Laws 2017, chapter 91, article 2, section 8), required the Minnesota Department of Health (MDH) to "conduct an analysis to determine the scope of the lead problem in Minnesota's water and the cost to eliminate lead exposure in drinking water." The following report fulfills this reporting requirement.

After an overview of health issues related to lead and the general nature of drinking water systems, this report presents an analysis organized to mirror the general process of delivering drinking water from source to a tap. We focused on drinking water at residences, and not at schools, daycare locations or workplaces. While children do drink water at schools, we do not have sufficient information regarding the relative exposure compared to that of the home. Additionally, since lead exposure at young ages is the most damaging, and children typically do not start school until the age of 5, it is likely that overall potential harm from exposure to lead from drinking water at school is substantially less than that from the residence. Likewise, workplace exposures will be substantially less than those at residences. Finally, costs associated with lead in drinking water are assessed.

Given that lead can still be found commonly in the environment, it is important to recognize at the outset that goals to "eliminate" lead have to be aspirational. In 2000, the federal government released a coordinated federal strategy to eliminate childhood lead poisoning by 2010 (PTF, 2000). While significant progress was made, elimination was not achieved. More recently, the U.S. Environmental

Protection Agency (EPA) is developing a federal strategy to reduce childhood lead exposure and eliminate associated health impacts (EPA, 2018c). There is optimism for the ability to remove lead from drinking water in Minnesota based on past successful public health interventions to exclude lead from gasoline and residential paint and significant progress by other states – but progress is likely to be slow.

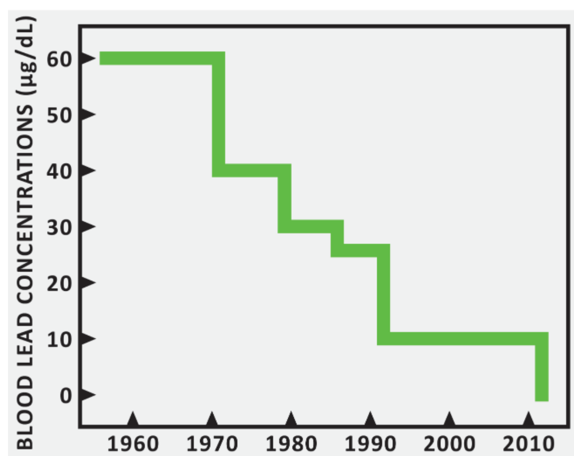
Health Issues

Health concerns over lead in water date back to Roman times, where lead was used as an inexpensive and reliable piping for the network of plumbing that kept Rome supplied with water. In fact, the word "plumbing" comes from the Latin word for lead, *plumbum*. The lead pipes that were the arteries of ancient Rome were forged by smithies whose god, Vulcan, exhibited several of the symptoms of advanced lead poisoning: lameness, pallor, and wizened expression (Lewis, 1985).

More recently, events in Flint, Mich., revealed the potential for catastrophic public health impacts from lead. In that case, the community suffered from widespread exposure to elevated levels of lead after the public water system failed to maintain appropriate corrosion control. Specifically, a change in source water altered the water chemistry, resulting in an increase in corrosivity of the water and leaching of lead into drinking water. In 2015, a series of 32 samples were collected in Flint from kitchen cold water taps and analyzed for lead. All 32 samples were above the EPA "action level" of 15 parts per billion (ppb) for public water systems (PWSs). The minimum concentration found in the samples was 217 ppb, and four samples were above EPA's hazardous waste threshold of 5,000 ppb (Pieper, et. al., 2017).

Historically there was a level of lead exposure presumed to be "safe." Over the years, however, the level considered safe was lowered based on new research (Figure 1), until in 2012 the Centers for Disease Control and Prevention (CDC) dramatically changed the way lead toxicity is assessed (ACCLPP, 2012). Instead of setting a safe level, the new approach acknowledges no known safe level of lead exposure, and instead recommends a primary prevention approach (e.g., preventing exposure problems before they occur) to reducing risk.

Figure 1: Blood Lead Concentrations Considered Harmful by CDC



Children are more susceptible to lead because their bodies absorb metals at higher rates than the average adult. Children younger than 6 years old are most at risk due to their rapid rate of growth and ongoing brain development. Exposure to lead can damage the brain, nervous system, red blood cells, and kidneys. Lead also has the potential to cause lower IQs, hearing impairments, reduced attention span, hyperactivity, developmental delays and poor classroom performance. The damage from lead exposure in children is permanent. Fortunately, the negative consequences of lead exposure can be minimized with good nutrition, a stimulating education and a supportive environment (CDC, 2012).

High blood lead levels in adults have been linked to increased blood pressure, poor muscle coordination, nerve damage, decreased fertility, and hearing and vision impairment. Pregnant women and their fetuses are especially vulnerable to lead exposure since lead can significantly harm the fetus, causing lower birth weight and slowing mental and physical development. For more information on the health impacts of lead, please see the MDH webpage on Lead (http://www.health.state.mn.us/topics/lead).

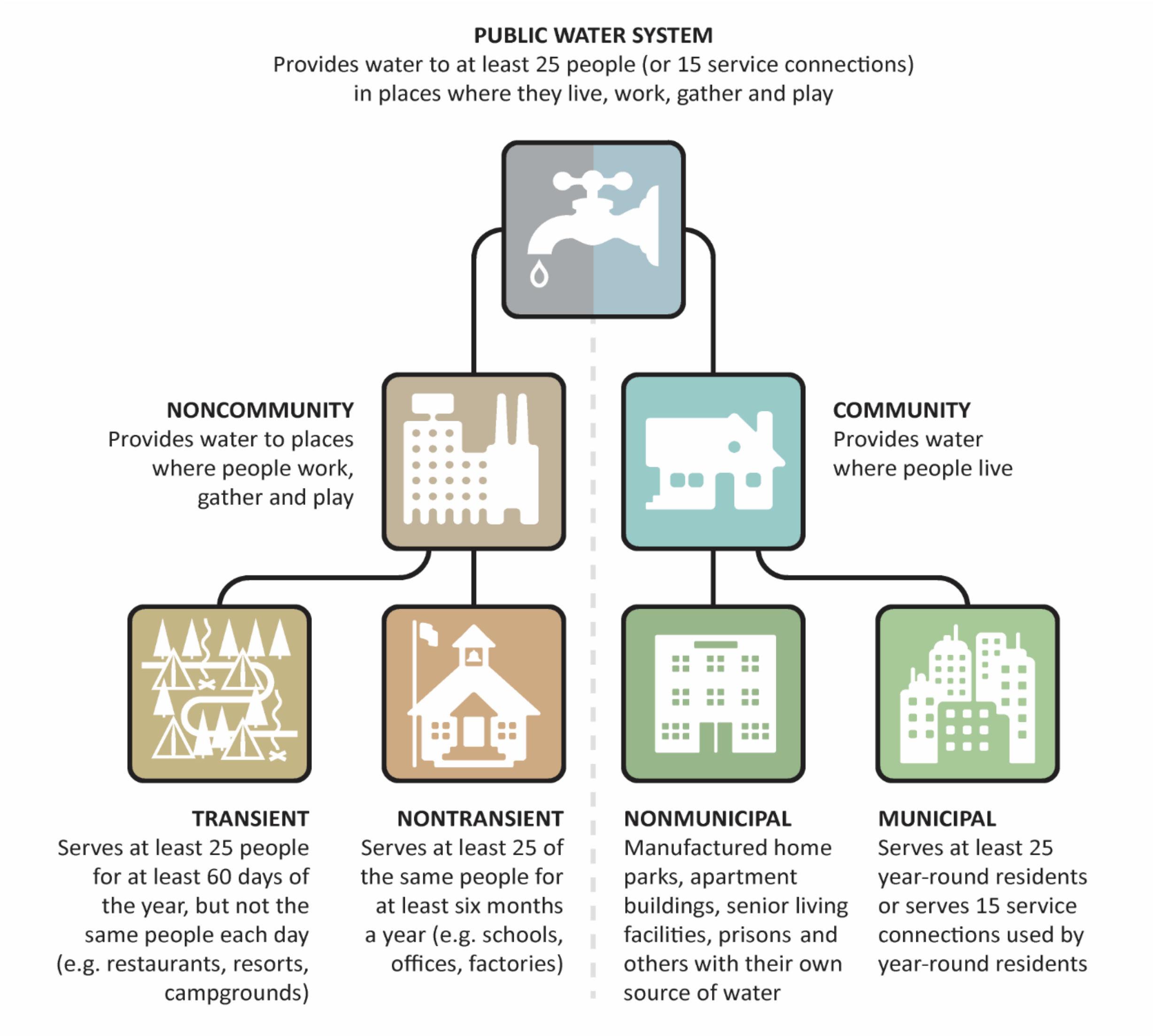
Minnesota children are regularly tested for blood lead levels. When elevated blood lead results are found, lead exposure routes in individual homes are assessed and managed by an established system for marshalling medical and environmental health resources. Specifics are outlined in Minnesota Statute (144.9501 – 9512). While lead in drinking water is proportionally becoming a bigger contributing factor in cases of elevated blood lead levels, lead-based paint dust was found to be a primary contributing factor for about 75 percent of children with elevated blood lead levels over 15 micrograms of lead per deciliter of blood (mcg/dL) in 2007. Other sources of lead identified included soil, contaminated spices, contaminated cultural or religious items such as sindoor powder, swallowed lead-containing metallic objects, and take-home occupational lead contamination from an adult household member (for example, lead dust brought home on a parent’s work clothes).

Drinking Water

If a water system in Minnesota has 15 service connections, or serves 25 or more people for at least 60 days a year, it is considered a public water system under the Safe Drinking Water Act (SDWA; 40 CFR 141.2). The EPA has granted MDH primary authority for implementing and enforcing the SDWA in Minnesota using federal statutes/rules, state statutes (Minnesota Statutes, sections 144.381 to 144.387), and state rules (Minnesota Rules 4720). There are various types of PWSs (Figure 2).

Minnesota has 967 community water systems serving water to people where they live; 731 of these are municipal water systems (owned by a city/town). Other community water systems include manufactured home parks, housing developments, nursing homes, and prisons. Minnesota also has nearly 6,000 noncommunity water systems, which serve water in places that are not long-term residences. These can be schools, resorts, restaurants, highway rest stops, or state parks.

Figure 2: Types of Public Water Systems as Defined by the Safe Drinking Water Act



Drinking water that does not come from a PWS is usually delivered as part of a private well system using groundwater accessed through a well with a pump. Unfortunately, well water can contain contaminants that adversely affect health. These may occur naturally, as in the case of arsenic, or as the result of human activities such as chemical spills, improper waste disposal, improper agricultural practices, or failing septic systems. Wells that are old, shallow, in disrepair, or improperly located and constructed are more likely to have unsafe water.

Drinking water, whether delivered from a PWS or a private well, has the highest quality right out of the well or just leaving the treatment plant. If drinking water stagnates or takes a long time to get from the source to the tap, water quality and stability degrade and there is a greater potential to change chemistry, absorb contaminants like lead, and have increased growth of microorganisms. In some areas, source contaminants must be managed or removed to ensure high-quality drinking water, but this almost never involves lead.

Corrosion control is essential to assessing lead levels in drinking water. Corrosion is a chemical reaction causing the dissolution of a material into its environment. It can cause lead and copper concentrations to increase by dissolving the metals from pipes and solder into the water within those pipes. Corrosion control treatment can include the addition of chemicals (e.g., orthophosphates) to create a barrier between the pipes and the drinking water (protective scaling) or the modification of drinking water chemistry (pH and hardness) to inhibit the potential for corrosion (AWWA, 2014).

There are a number of legal requirements and guidance materials applicable to reducing lead in drinking water (see below). They represent a range of laws, rules (enforceable), and guidance (not enforceable) developed in the past 30 years. Much has been learned over that time regarding lead health impacts, requiring an ongoing evolution in the way we address lead hazards. These legal requirements are used to guide efforts to eliminate lead from drinking water in Minnesota.

Regulations and Guidance Governing Lead in Drinking Water

STATE STATUTORY REQUIREMENT

Minnesota Statute (121A.335)
Effective Date: 2018
Applies to: All public and charter schools in Minnesota

Lead Poisoning Prevention Act (MS 144.9501 – 9512)
Effective Date: 1995
Applies to: Children with elevated blood lead

STATE RULES AND CODES

Lead Prohibition in Potable Water-Supply Wells (MR 4725.4750)
Effective Date: 2008
Applies to: Any potable water supply well

State Plumbing Code (MR 4714)
Effective Date: 2015
Applies to: All new plumbing installations performed anywhere in the state

FEDERAL LAWS AND RULES

Lead and Copper Rule (SDWA)
Effective Date: 1991/2007
Applies to: All public water systems

Lead Contamination Control Act
Effective Date: 1988
Applies to: All schools

Reduction of Lead in Drinking Water Act (SDWA)
Effective Date: 2014
Applies to: All public water systems or facilities providing drinking water

FEDERAL GUIDANCE

3Ts for Schools
1994, 2006: **T**raining, **T**esting, **T**elling
2018: **T**raining, **T**esting, **T**aking Action
Effective Date: 1994/2006/2018
Applies to: All schools

The Lead and Copper Rule (LCR) of the federal Safe Drinking Water Act has had the greatest impact on overall lead exposure in drinking water across the state. It was first passed in 1991, updated in 2007, and applies to PWSs (see EPA, 2018 for additional information). Compliance with the LCR currently is based on the 90th percentile concentration value being below a threshold of 15 ppb from samples collected after the water reaches consumers' taps. Testing under the LCR is based on a tier system, with the highest priority being individual residences served by pipes and/or piping material containing lead. Options to reduce lead in the whole system include installing chemical treatment to reduce water corrosivity or lead leaching, or physically removing/replacing lead pipes and/or lead service lines. Because the LCR emphasizes a system-wide treatment approach, it does not apply to individual taps.

Compliance with the LCR in Minnesota is managed by public water supplies with technical assistance from MDH. Efforts to address drinking water hazards proactively are supported by federal funds from EPA and state funds from the service connection fee and Clean Water Fund. When results from an individual sampling point within a system are 15 ppb or above, the PWS must provide notice to the resident within 24 hours. If monitoring rounds indicate increasing trends or if an exceedance occurs, MDH works with the system to determine the causes of the problem and provide technical assistance. Water chemistry is closely monitored and adjusted as needed, but due to the complex nature of water chemistry in the distribution system, it may take time for changes to stabilize and lead levels to drop. MDH collaborates with operators and city officials to discuss methods to reduce lead and minimize increases during source water or treatment changes.

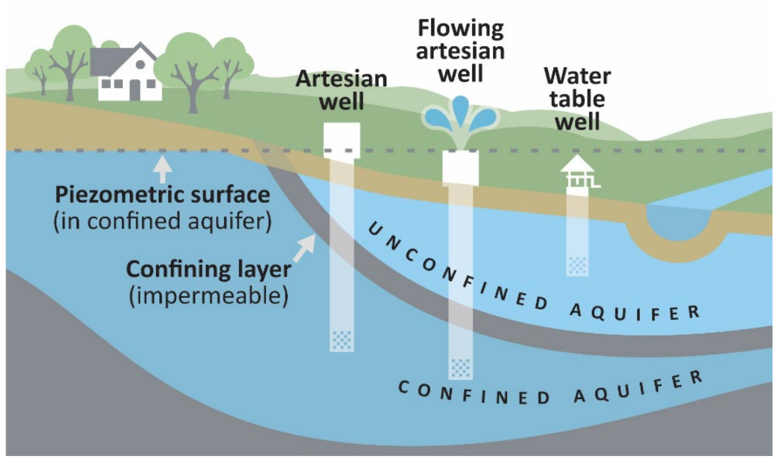
Lead in Sources of Water

This section addresses lead issues related to sources of drinking water, including the geology (type of ground), geography (shape of the ground), hydrology (water flowing over or through ground), land use, and pumping/removal method right up to the point where the water is leaving the natural environment and entering the water treatment/distribution system.

Groundwater

Groundwater underlies the Earth's surface almost everywhere and may occur close to the land surface, as in a marsh, or lie many hundreds of feet below the surface. Groundwater is stored in, and moves through, moderately to highly permeable rocks called aquifers (Figure 3). The word aquifer comes from the two Latin words *aqua*, or water, and *ferre*, to bear or carry. Aquifers literally carry water underground. An aquifer may be a layer of gravel or sand, a layer of sandstone or cavernous limestone, or even a large body of massive rock, such as fractured granite, that has sizable openings. Groundwater is the largest single supply of fresh water available for use by humans (USGS, 2018).

Figure 3: Aquifers and Wells



While lead is a naturally occurring contaminant, it is not very soluble in water, is nearly immobile in soil, and is rarely found in appreciable levels in groundwater in Minnesota. A 1999 investigation of 954 wells across Minnesota found nine wells above 15 ppb, with a median concentration in groundwater of 0.22 ppb. Lead concentrations were highest in the groundwater of the St. Lawrence (median = 2.7 ppb) and Prairie du Chien (median = 0.50 ppb) aquifers (MPCA, 1999). These aquifers are in southeastern Minnesota.

Rather than as a direct source, the biggest impact groundwater is likely to have on lead levels in drinking water comes indirectly from its chemistry, which affects lead in other areas of the system. For example, water with lower pH levels will be more likely to leach lead out of plumbing.

Surface Water

Minnesota has 12,000 lakes, more than 104,000 miles of streams, and approximately 9.3 million acres of wetlands. Those lakes, streams, and wetlands are organized into 81 major watersheds, which define the area of land where all the water that falls in it and drains off it goes to a common outlet (MPCA, 2018).

Of the known aquatic releases of lead to surface water across the country, the largest ones are from the steel and iron industries and lead production and processing operations (EPA 1982a). Urban runoff and atmospheric deposition can be significant indirect sources of lead found in the aquatic environment.

Lead reaching surface waters is usually absorbed by suspended solids and sediments (EPA 1982a), and therefore not readily available to be in drinking water.

Like groundwater, surface water is very unlikely to be a significant direct source of lead into drinking water in Minnesota. Also like groundwater, its primary impact on lead levels will be indirectly through its chemistry, increasing the likelihood of leaching from other areas of the system.

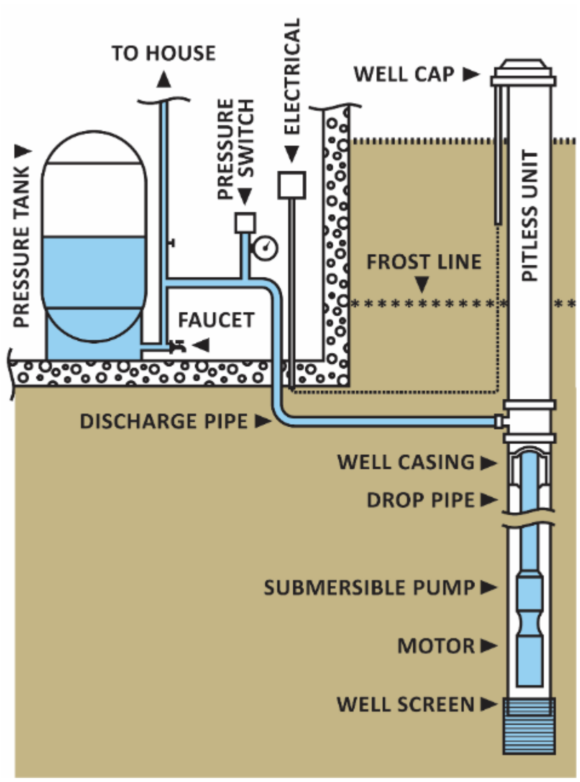
Well Components

A well is the most common way to obtain groundwater for household use. A well is essentially a hole in the ground, held open by a pipe (or casing) that extends to an aquifer. A pump draws water from the aquifer for distribution through the plumbing system (Figure 4). The depth to which wells are constructed is determined by factors such as 1) depth to groundwater, 2) groundwater quality, and 3) geologic conditions at the well site. Wells in Minnesota range in depth from 15 feet to more than 1,000 feet.

Minnesota's laws and rules governing well construction, which were first adopted in July 1974, establish minimum standards for the location, construction, repair, and ultimate sealing (closure) of wells and borings in Minnesota to protect public health and the state's invaluable groundwater. These laws and rules are known collectively as the "well code."

Rules specific to lead (4725.4750) became effective in 2008 and state that materials used in construction of a potable water-supply well that contact water must not exceed 8 percent lead (weighted average) for pipes, pipe fitting, plumbing fitting, and fixtures and 0.2 percent lead for solder and flux. Because federal law has a standard of 0.25 percent lead for pipes, fittings, and fixtures, all components should meet this standard. By reducing the amount of lead in well components, the likelihood of lead entering drinking water from that source is reduced.

Figure 4: Basic Components of a Private Well



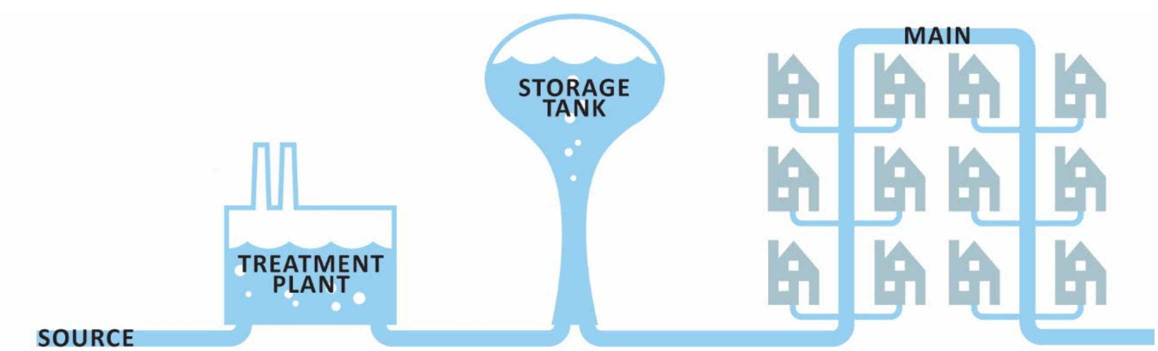
Because private well owners are not required to submit sample results to MDH for any sampling done after the construction of a well, there are no statewide data regarding the occurrence of lead in private well systems. However, a study in 2017 (Wells and Increased Infant Sensitivity and Exposure Study) in Dakota County examined the potential exposure of residents on private wells to manganese and other metals. Lead was detected in 144 of 273 outside spigot water samples above the laboratory detection limit of 0.5 micrograms per liter (µg/L) (53 percent). The maximum concentration found was 111 µg/L, with five results exceeding the EPA action level of 15 µg/L (Dakota County, 2017).

It is reasonable to assume there are some private well systems with older plumbing fixtures contributing a small amount of lead to drinking water. The situations most likely to contribute lead involve areas where water will stagnate for many hours in contact with lead-containing materials (e.g., brass) or with very "aggressive" water chemistry (e.g., extreme pH, high dissolved gasses or solids, different metals in direct contact).

Lead in Distribution Systems

This section addresses lead issues related to drinking water from the point where it leaves the source or water treatment plant and enters the distribution system through delivery to a service line to a customer. The distribution system includes an interconnected series of pipes, storage facilities, and components that convey drinking water (Figure 5) and are designed to meet fire protection needs for an area. Spanning almost 1 million miles in the United States, drinking water distribution systems represent the vast majority of physical infrastructure for drinking water supplies, and thus constitute a primary management challenge from both an operational and public health standpoint (EPA, 2010)

Figure 5: Water Supply Distribution System



Water Treatment Plants

Depending on the size of the community being served, water treatment plants can process anywhere from thousands to millions of gallons of water per day. Unless a specific area of a plant is being serviced or there is a catastrophic failure of the whole system, water in a treatment plant virtually never stops moving long enough to accumulate significant levels of lead. Areas in a plant that are serviced or not in use are flushed thoroughly before being put back online. Therefore, water treatment plants are very unlikely to contribute lead to drinking water. However, treatment processes may change water chemistry and in some cases contribute to corrosion downstream in the distribution system.

Water Mains

A water main is any pipe or tube designed to transport drinking water to consumers. The varieties of water pipes include large-diameter main pipes, which supply entire towns and smaller branch lines that supply a street or group of buildings. Water mains can range in size from one-inch pipes used to feed individual buildings up to 12 feet in diameter. Materials commonly used include polyvinyl chloride (PVC), cast iron, copper, steel, and in older systems concrete or fired clay. Joining individual water pipe lengths to make up extended runs is possible with flange, nipple, compression, or soldered joints (SSWM, 2018). No literature could be found documenting potential lead exposure from primary water mains. However, with the exception of old soldered joints, lead is not likely to be added to drinking water from water mains due to protective scaling and rapidly moving water.

Water Meters

The risks of lead from water meters is very similar to what occurs in private wells. The older the meter the more likely it is to have components containing significant levels of lead and, therefore, more likely to add lead to drinking water. The risk is diminished by the fact that water flows through the meter regularly, reducing the contact time for the water. While a water meter may add a small amount of lead in some circumstances (EPA, 2008), it is unlikely to be a significant, consistent source of lead in drinking water because older meters with potentially higher levels of lead content have likely developed protective scaling and newer versions must meet lower lead content requirements. Additional study is needed to better characterize the contribution of water mains and meters to lead in drinking water.

Other Non-Premise Plumbing

The term “non-premise plumbing” refers to any fixture, valve, pump, or other conveyance used to transport drinking water that is not part of the final delivery point (e.g., house). There are a wide variety of uses and materials involved in non-premise plumbing. Therefore, specific contributions of lead in an individual situation needs to be assessed on a case-by-case basis. Older fixtures are relatively more likely to have higher levels of lead available. Older areas of a distribution system with reduced demand are more likely to contribute lead due to reductions in flow rate and volume. Demand is related to land use patterns, types of commercial-industrial activity present in a community, the weather (i.e., lawn watering), and water use habits of the community (i.e., conservation practices, reuse practices) (EPA, 2002).

Due to the large number of variables, it is not possible to reasonably estimate the average contribution of non-premise plumbing to lead levels in drinking water statewide. Individual, older, declining systems have a higher risk that must be assessed on a case-by-case basis. Unless certain specific site conditions exist (e.g., high levels of lead present and corrosive water conditions), however, non-premise plumbing is not likely to be a major source of lead in drinking water.

Lead in Service Lines

This section addresses lead issues related to drinking water from the point where it leaves the distribution system (typically from a water main) and is delivered to the premise (typically a house or building). While this is a relatively short and simple path compared to other areas of a drinking water system, it can be of critical importance because some service lines were made from lead. The terms "service line," "service connection," and "street service" are equivalent. When discussing service lines made of lead the term lead service line (LSL) will be used, while other general connections between the water main and an individual property will be referred to as service connections. A service connection can be defined as "the point of connection between the customer's piping or constructed conveyance and the water system's meter, service pipe, or constructed conveyance."

Historically, lead was used in service connections because it was less expensive than iron, could more easily be bent around existing structures without leaking, and allowed more durable connections to stiffer pipes that expand/contract with temperature. By 1900 more than 70 percent of cities with populations greater than 30,000 used lead water lines (Rabin, 2008). In Chicago, for example, LSLs were not only used, but were required until 1986. The current LCR requires a PWS that has a lead exceedance to replace 7 percent of their existing lead service lines per year.

A number of field studies have demonstrated that a lead service line contributes about 50 percent of the total mass of lead measured at the tap (Table 1). Because LSLs contribute so significantly to lead in drinking water, there is a national effort to find and remove them. Due to the nature of water jurisdictions, however, hazard reduction actions will have to be driven at the state or local level. Madison, Wis., and Framingham, Mass., have completed removal of LSLs within their jurisdictions. Twelve states currently have policies that support LSL replacement through a range of requirements and incentives paid for by rates, grants, state funding, and property owner contributions (EDF, 2018). Madison, Wis., removed 8,000 LSLs for $15.5 million, Washington, D.C., removed 35,000 LSLs for $400 million, and Boston removed 5,000 LSLs for $15 million.

In addition to LSLs, service lines made of galvanized steel sometimes had a lead "gooseneck" installed to compensate for expansion/contraction during changing temperatures. The gooseneck is a short piece of flexible lead pipe between the two stiffer steel lines that reduces breakage during heat expansion/contraction. These goosenecks can contribute lead to drinking water and should be addressed as part of LSL removal approaches.

Table 1. Average Lead Contributions from Lead Service Lines (EPA, 2008)

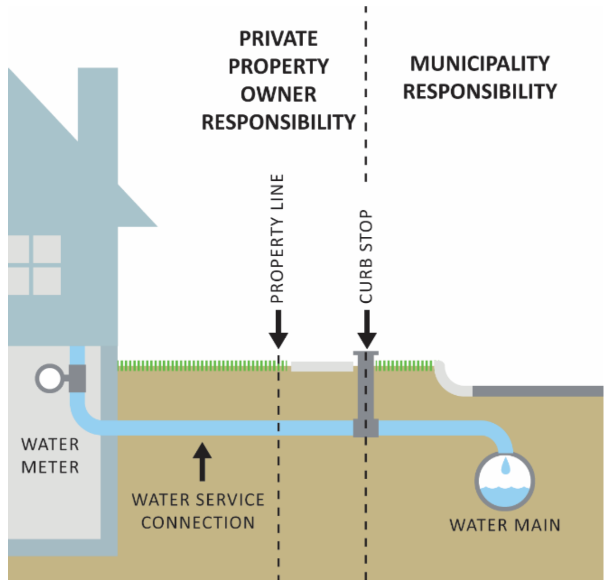
Field Study	Average Pb mass from LSL (ug)	Average % contribution of LSL	Number of LSLs replaced	Cost of project
Madison	139	49 %	8,000	$15.5 million
DCWASA	55	57 %	35,000	$400 million
BWSC	31	48 %	5,000	$15 million
Toronto	44	48 %	35,000	N/A
Framingham	110	51 %	N/A	N/A

Note: DCWASA is the District of Columbia Water and Sewer Authority and BWSC is the Boston Water and Sewer Commission.

Publicly Owned

One of the biggest challenges in addressing LSL removal is that frequently two separate entities are responsible for the line (Figure 6). Public utilities and government agencies generally have jurisdiction up to the curb stop, which allows them to more easily access and remove LSLs. However, the precise separation between who owns what is determined at the local level by the PWS and municipality. Some form of eminent domain is commonly used to access areas on private property.

Figure 6: Water Service Line Ownership



In the City of St. Paul, ownership of the service line, whether it be an LSL or other material, is consistent with Figure 6. Most lead services were installed in homes built prior to 1927. A small percentage of homes built between 1942 and 1947 have lead service lines. The city has a program whereby a homeowner can have the costs of LSL replacement work on private property assessed over several years and collected through property taxes. In some communities, however, residents may have to pay the cost upfront unexpectedly and may be assessed other costs such as sidewalk repair/installation. This can add up quickly for low-income or fixed-income residents and have a big impact on their lives.

The exact number of LSLs in Minnesota is not available because, while individual PWSs were required to develop LSL inventories by the LCR, the results have not been systematically collected and tracked. One way of roughly estimating the number is by looking at the number of homes built during a specified period. There are 400,000 homes in Minnesota built before 1940 (U.S. Census). As more was learned about lead toxicity, most cities moved away from using LSLs by the 1920s (Rabin, 2008). Anecdotal information gathered by MDH indicates that most LSLs are located in the Twin Cities and Duluth areas. Therefore, estimating that half of the homes built in Minnesota were in the Twin Cities/Duluth area, and half of the homes built before 1940 still contain LSL, it can be estimated that there are 100,000 LSLs remaining in Minnesota.

A second method for estimating the number of LSLs in Minnesota is by adding up individual estimates from high-risk cities. For example, public information estimates that Duluth has 5,000 (NewsTribune, 2016), St. Paul has 28,000 (SPRWS, 2017), and Minneapolis has around 49,000 (MDH, 2018a). The total of 82,000 does not include LSLs in any other cities in Minnesota or other remaining potentially hazardous components in service lines such as lead goosenecks or pigtails (short lengths of lead pipe used to connect other, stiffer lines). Therefore, the estimate of 100,000 LSLs in Minnesota, while created based on fairly crude assumptions, is sufficiently accurate for broad estimates of potential costs.

A 2016 study estimated the number of LSLs nationwide and regionally (Cornwell, et. al, 2016). The national estimate is 6.1 million LSLs, with more than half that amount in the north-central portion of the country. Because estimates provided for individual states are generated using regional assumptions, the authors warn, "state-specific estimates are presented only to provide relative information on state variability." Therefore, the Cornwell estimate of 260,000 LSLs in Minnesota is not used in this assessment.

Privately Owned

Replacing LSLs on the private portion of the system has traditionally been the responsibility of the homeowner. In Minneapolis, for example, the property owner is responsible for all costs related to the maintenance of service lines, including LSLs, from the home all the way to the water main. If an LSL breaks in Minneapolis, city ordinance requires that it be replaced and not fixed. Resolving ownership and related issues (e.g. using public funds for private property improvements) will be the most complex aspect of LSL removal.

When considering full LSL removal versus partial LSL removal (e.g., just the public or private portion), it is crucial to include the potential public health consequences of disturbing the LSL. In September 2011, the EPA's Science Advisory Board found that the available data indicate partial lead service line replacement "may pose a risk to the population, due to the short-term elevations in drinking water lead concentrations." Both CDC's Advisory Committee on Childhood Lead Poisoning Prevention and EPA's Children's Health Protection Advisory committees have subsequently expressed similar concerns about elevated lead concentrations in drinking water from partial LSL replacements. Therefore, partial LSL removal should be avoided whenever possible.

Lead in Premises

The highest concentrations of lead in drinking water typically are found in the water nearest to the tap. Lead may be present in various materials in the plumbing system such as lead solder, brass fixtures, valves, and lead pipes (Figure 7). Corrosion of these materials allows lead to dissolve into the water passing through the plumbing system. The amount of corrosion depends on the type of plumbing materials, water quality characteristics, electrical currents, and how water is used. The longer water remains in contact with lead materials, the greater the chance lead can get into the water.

Lead in premise plumbing (e.g., indoor) can be present in either dissolved or particulate form. The dissolved form of lead comes from stagnant water being exposed to plumbing materials containing lead. Concentration changes tend to be gradual and are related to the length of time water is allowed to sit still. Particulate lead comes from physical disruption of plumbing materials and protective scaling from corrosion control efforts and can result in dramatic concentration changes depending on the number and size of particles liberated. The form of lead present in an individual system will significantly influence the hazard reduction steps necessary to reduce lead levels in both public and private systems (Pieper, et. al, 2016)

The agencies responsible for tracking lead in buildings are the Minnesota Department of Labor and Industry (for plan review and inspection of new construction) and the Minnesota Department of Commerce (for retail sale of plumbing products). Compliance is regulated by the Minnesota Plumbing Code, which is based on the 2012 Uniform Plumbing Code and found in Minnesota Rules 4714.

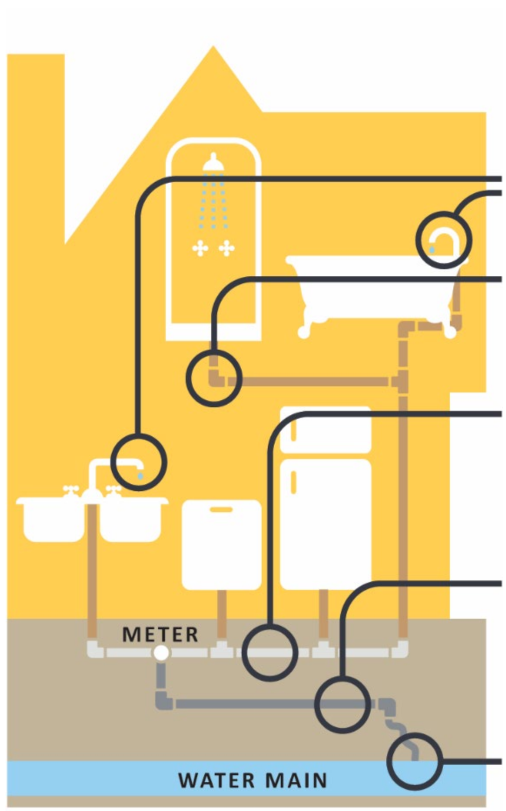


Figure 7: Sources of Lead in Home Plumbing

Faucets: Fixtures inside your home may contain lead.

Copper Pipe with Lead Solder: Solder made or installed before 1986 contained high lead levels

Galvanized Pipe: Lead particles attached to the surface can enter drinking water, causing elevated lead levels.

Lead Service Line: Running from the water main to internal plumbing is a major source of lead contamination.

Lead Goose Necks and Pigtails: Short pipes connect to the water main.

Pipes

In 1986, Congress amended the SDWA to prohibit the use of pipes, solder, or flux that are not “lead free” in public water systems or plumbing in facilities providing water for human consumption. At the time, lead free was defined as pipes with no more than 8.0 percent lead. In 1996, Congress further amended the SDWA to prohibit the use of pipe and plumbing fittings and fixtures that are not lead free in the installation and repair of any public water system or plumbing in a facility providing water for human consumption (Federal Register, 2017). In 2011, Section 1417 of the SDWA established the definition for lead free as “a weighted average of 0.25% lead calculated across the wetted surfaces of a pipe, pipe fitting, plumbing fitting, and fixture.”

Therefore, pipes installed prior to 1986 could have significant levels of lead, those installed between 1986 and 2011 may have up to 8 percent lead, and those installed after 2011 will have very low (< 0.25 percent) levels of lead. The contribution of pipes to lead in drinking water will be highly dependent on the age of the system and the chemistry of the water.

Solder

Since the Safe Drinking Water Act Amendments of 1986, the use of lead-containing solders in potable water systems has effectively been banned nationwide. The major impact of the act has been on solder containing 50 percent tin and 50 percent lead (50-50), until then the most widely used solder for drinking water systems. Lead-base solders have been replaced by tin-antimony and tin-silver solders containing no more than 0.2 percent lead. Like pipes, the contribution of solder to lead in drinking water will be highly dependent on the age of the system and the chemistry of the water.

Fixtures

Lead levels in the water within fixtures can vary greatly from tap to tap. Plumbing materials and usage patterns influence the amount of lead in drinking water due to the variety of materials in the system (e.g., lead or copper pipes, lead solder, and brass fixtures). The amount of time the water is in contact with various materials in the plumbing system may have a significant effect on the concentrations found as well. An "on-again, off-again" water use pattern can contribute to elevated lead levels in drinking water. Water that remains stagnant in plumbing overnight, over a weekend, or during a vacation has longer contact with plumbing materials and therefore may contain higher levels of lead.

Aerators at the end of taps can trap particulate lead that is dislodged from plumbing and increase lead concentrations in drinking water. Exposure can be reduced by routinely cleaning out the aerator or allowing the water to run prior to drinking. However, one study demonstrated that removing and cleaning the aerator actually increased lead levels and that replacing fixtures did not always result in lower lead levels (EDF, 2018a).

There are eight American National Standards Institute accredited third-party certification bodies that provide product certification to the SDWA lead-free requirement for manufacturers of drinking water system and plumbing products (EPA, 2015).

Cost Summary

The cost of removing lead from drinking water in Minnesota is followed by an estimate of the benefits that would accrue from that action and possible sources of funding to support lead hazard reduction efforts. A detailed description of the uncertainty related to the data used in this report is included in Appendix A.

Costs and benefits are estimated for a 20-year implementation period. Federal regulations (40 CFR 141.84) and New Jersey (NJDEP, 2017) use a 15-year timeframe for LSL removal, while Madison, Wis., targeted a 10-year window for LSL replacement in their jurisdiction. However, using a 20-year project window allows for a more measured approach and facilitates cost and planning efficiencies (e.g., combining LSL removal with street/utility maintenance).

Cost estimates are based on removing lead from the two main sources: LSLs and premise plumbing. In addition to costs, however, there are benefits from removing lead. Generally, benefits were estimated based on the cost avoidance of any reduction in IQ due to lead in drinking water in the absence of a 20-year lead removal program; in other words, the expected value of the IQ gain due to the investment in removing lead from drinking water. Details on how the benefits were calculated are in Appendix B.

When evaluating the best approach for protecting against lead exposure in drinking water, it is important to balance a number of factors:

- Current research has not identified a safe level of exposure to lead.
- Lead is present in many areas of the environment, making it difficult to eliminate all exposure.
- The risks of developing irreparable damage from lead in water increase with higher concentrations of lead and longer exposure times.
- The source and nature of lead hazards from water across the state are very different, which impacts the likelihood of lead exposure.
- Local jurisdictions and PWSs have the best understanding of their communities and how they function; they can work with parents, water operators, and local officials to come up with the best approach for their specific situation.

An effective response to lead in water must consider all of the factors listed above. In addition, it is critical to understand that health risks from lead do not abruptly change at varying concentrations of lead. As lead concentrations, the duration of exposure, or the number of taps impacted (i.e., distribution) steadily increases, the risk posed to people steadily increases. Response options should consider vulnerability of those exposed, concentration of lead, duration of exposures, and current practices to reduce lead, among other things. The most accurate relationship between lead risk and appropriate responses follow a smooth path as concentration increases. Therefore, a result of 19 ppb is not appreciably safer than a result of 21 ppb. Both the risk present and response options needed for lead exposure should be evaluated as a continuum and not be driven by specific numbers.

In summary, there are significant uncertainties associated with the information required to assess lead in drinking water systems. Given that lead can still be commonly found in the environment, it is critical to maintain perspective on the scope of the problem and realize that goals that “eliminate” lead must be aspirational.

Cost of Lead Removal

The primary costs for permanently removing lead from drinking water are linked to 1) replacing plumbing fixtures, pipes, and lead solder; 2) replacing LSLs and goosenecks; and 3) technical assistance. As mentioned in the introduction, we only analyze the cost of removal of lead in the home, not at schools. While schools are a potential source of contamination, they would only be so for school-age children, who are less vulnerable than younger children. In addition, due to the wide range of school buildings, variable lead concentrations, and uncertain exposure, a reasonable estimate of the cost to remove lead from schools is beyond the scope of this assessment. Therefore, the benefits calculation was limited to children up to age 6, who would only have had completed kindergarten.

Absent permanent removal, the three methods for addressing elevated lead in water, either temporarily or long term, are 1) water treatment, i.e., implementing a Corrosion Control Program and optimizing corrosion control treatment; 2) flushing; and 3) ongoing public education on reducing lead in drinking water. Additionally, technical assistance is needed to ensure efforts are targeted, effective, and sustainable. To meet the goal of eliminating lead from drinking water we focus on the costs of replacing lead in supply lines (LSLs and goosenecks) and plumbing. We therefore presume that the costs of treatment, corrosion control, public education, and technical assistance will be costs irrespective of this program. However, they are discussed below.

Replacement costs are assumed to be phased in over the 20-year period (at 34,000 homes per year – see below). However, costs in the future are not the same as costs in the present. Present value, also called "discounted value," is the current worth of a future sum of money. Future money is discounted at a discount rate. The higher the discount rate, the lower the present value of the future money. Determining the appropriate discount rate is the key to properly valuing future money (Investopedia, 2018). In this assessment, total costs are accumulated over 20 years using a discount of 3 percent, with a 2 percent inflation rate. We discount back to the present value in 2018.

Fixtures and Solder

A 1,500 square-foot, two-bathroom home will require between $2,000 and $6,000 to replace exposed plumbing (Houselogic, 2018). There were 1.35 million homes built in Minnesota before 1980 (Census, 2010). The lead limit in plumbing was reduced from 8 percent to 0.25 percent in SDWA amendments in 1986, so complete removal of lead from premise plumbing would need to replace fixtures in homes built before 1986. Using the aforementioned discount and inflation rate and assuming that half of the homes built before 1980 need to have lead fixtures/solder removed (e.g., 675,000 homes), the cost range would be between $1.23 billion and $3.70 billion to replace indoor lead fixtures. To address half the homes built before 1980 within a 20-year project window would require doing 34,000 locations per year, which would require an unprecedented level of commitment. In addition, a recent study of childcare centers (EDF, 2018a) found it difficult to access homes to replace fixtures, even when everything was funded and installed.

Lead Service Lines

Estimated costs for removal of lead service lines range from $2,500 to more than $8,000 per line, with 6.5 to 10 million LSLs existing nationwide (EPA, 2016). Using the aforementioned discount and inflation rate and using a total of 100,000 LSLs in Minnesota (see page 15) yields a cost for full replacement of between $228 million and $365 million. Costs to agencies, homeowners, and building owners could be reduced significantly if removal were coordinated with other street construction/excavation. To remove LSL in Minnesota within a 20-year project window would require addressing 5,000 locations per year.

Technical Assistance

Technical assistance includes both staff to advise residents on best practices for lead hazard reduction and sampling to characterize lead in water and document effective removal. Determining how much lead is in a home would require an average of three water samples ($30 each) per home in each of the 675,000 homes estimated to have lead fixtures. In addition, to manage questions, collect samples, and promote best practices, three full-time employees are needed (total cost $100,000 per person annually for salary and benefits). Additional aspects of providing technical assistance would include preparing communication to residents and other interested stakeholders on status and progress of ongoing work and assisting PWSs with inventorying LSLs. Therefore, the total would be $61 million for a 20-year project.

Additional Considerations

Some costs are not included in the final estimate because they must occur regardless of lead elimination efforts (corrosion control) or are not large enough to significantly change the final total (flushing, point of use, point of entry). They are presented here to provide a complete picture of potential activities.

Corrosion Control

Corrosion control is routinely done at PWSs across the state to negate the negative impacts of corrosion on their system and water quality. The need for corrosion control will not be eliminated by removing lead, as corrosion control is also needed for any copper present in the water or system. Corrosion control prolongs the life of the water system and contributes to managing water quality and stability.

Minneapolis spends about $350,000 annually for ortho-polyphosphate and sodium hydroxide to meet corrosion control needs. St. Paul spends about $250,000 annually for sodium hydroxide to meet corrosion control needs. Medium-sized PWSs (10,000 to 100,000 served) will spend between $15,000 and $75,000 annually on corrosion control. Small-sized PWSs (less than 10,000 served) will spend $2,000 to $15,000 annually. There are 86 medium-sized PWSs in Minnesota and 878 small-sized PWSs. Carrying those costs out over a 20-year project period results in a range between $67 million and $369 million for corrosion control.

Costs cited above do not include routine tests to ensure that water quality is constant throughout the distribution system or corrosion control studies that may be needed when/if a PWS makes treatment or source changes for other needs (e.g., system growth/demand, treatment for other contaminates). Costs could also come from needing to address possible impacts to waste water phosphates/chloride.

Flushing

Flushing drinking water taps (letting the water run for a set amount of time on a regular basis) can effectively reduce lead concentrations in drinking water in both homes and commercial buildings. A flushing program works to reduce lead concentrations by clearing water that has been in contact with components that may contain lead. While flushing can work to reduce lead, it requires effort, diligence, and commitment to ensure effectiveness. Essential to any flushing program is monitoring after flushing to verify effectiveness. Guidelines on flushing in PWSs have been presented in a webinar hosted by the American Water Works Association (AWWA, 2016).

There are two primary types of flushing programs: Individual Tap Flushing and Main Pipe Flushing.

Individual Tap Flushing Program

- May be implemented if lead concentrations are found to be high at certain taps.
- Flush individual taps that have been tested and found to have high lead levels.
- Frequency and duration of flushing should be reasonably documented.

Main Pipe Flushing Program

- May be implemented if lead concentrations are found to be high throughout the entire system or confined to a certain area of the system.
- Flushed samples should be periodically collected and analyzed for lead to confirm the effectiveness of flushing programs.
- Review the results upon receipt and continue to optimize the procedure to reduce lead.

Flushing a home or building is a very low-cost approach to reducing lead levels because no additional materials are required to implement. However, it can be very difficult to identify precise locations for flushing and consistently perform the flush. Therefore, while flushing is a valuable tool for short-term lead reduction, it should only be used in circumstances where effectiveness can be assured. The corrosivity of the water is a key factor, as research in New Jersey showed that lead levels in school drinking water fountains returned to initial morning levels by lunch (Murphy, 1993).

Point-of-Use Building and Residential Treatment Device

A point-of-use (POU) water treatment device may be installed at taps where lead has been detected. It is strongly encouraged that the POU device is installed, operated, and maintained in accordance with the manufacturer's recommendations. POU treatment systems may be subject to Minnesota Department of Labor and Industry or local administrative authority plan review and approval prior to installation.

The City of St. Paul currently provides pitchers with replacement filters for homes when they do LSL replacement to attempt to combat the temporary lead release caused by disruption of LSL. They also do free lead in drinking water tests for residents with LSL using a two-liter sample protocol (to reach the lead from LSL). Unfortunately, depending on the amount of disturbance and the condition of the LSL, lead levels in drinking water may remain elevated for a potentially lengthy period of time (LSLRC, 2018a).

Point of Entry Building and Residential Chemical Treatment

Adjusting the water chemistry as it enters a premise may reduce the amount of lead absorbed by the water. Typical methods of chemical treatment include addition of a phosphate-based or silica-based corrosion inhibitor or an adjustment to the water's pH or hardness. All chemical treatment systems installed in public water systems are subject to MDH plan review and approval prior to installation. In addition, installing a point-of-entry corrosion control treatment may result in the facility becoming a public water system that is required to meet the regulatory requirements of the SDWA and have a certified water operator.

Benefits of Lead Removal

Lead is a neurotoxin that can cause severe cognitive damage at high levels, particularly to exposed children. Even at lower levels, lead can result in impairment, leading to reduced IQ and increased likelihood of behavioral symptoms and loss of economic opportunity. Because higher IQs are correlated with increased productivity, one economic benefit of removing lead comes from increased lifetime productivity in children with lower exposure to lead due to improved IQs. This exposure/damage method, dealing exclusively with the cognitive impacts on children, has been widely used when assessing lead in drinking water.

It is important to note that this type of benefits assessment likely underestimates actual values. Lost productivity is only one type of personal cost of lead poisoning. Children exposed to lead have a higher chance of committing crime (Nevin, 2007). A study conducted in France estimated that lead poisoning caused 0.3 percent of the total cost of crime, an amount equivalent to more than $70 million per year (Pichery et al., 2011). Additional values such as quality of life can be estimated with willingness to pay analyses, but these would require comprehensive and expensive surveys, which would have to be developed, administered, and analyzed with the appropriate expertise to ensure valid results. A form of willingness to pay, however, can be estimated through home values, which are discussed below. For this report, the lost productivity method will be used, keeping in mind that it is not holistic even when only IQ is considered. This is especially true considering that focusing on children and IQ ignores other possible health damage effects to children and adults.

For children exposed to lead, maintaining the status quo has implications. Removing lead exposure would remove the associated negative outcomes and result in significant benefit for Minnesota. A 2014 report from MDH (MDH, 2014) estimated the overall lifetime cost of lead exposure to a single birth cohort (e.g., just those children born in 2007) to be $1.94 billion. We have built on that study, focusing on the most sensitive children (up to 6 years old) and assuming a 3 percent discount rate. We used a more relevant relationship between lead concentrations and IQ at lower blood lead levels (0.513 IQ points per µg/dL; Lanphear et al 2005; Gould, 2009) for low blood concentrations. From EPA (EPA, 2018a), we presume that water consumption on average contributes up to 20 percent of a child's total lead intake. The same source estimates that for infants fed formula, 40 to 60 percent of their lead exposure comes from drinking water. However, we have not included the formula-fed infants in our calculations.

We kept the gender-based differences in expected lifetime earnings even though there should be an expectation of convergence between males and females over the next 20 years. However, we have added value from household work as lifetime earnings include both wages and value from housekeeping, childcare, etc. The literature on the lead-IQ-earnings relationship supports including household work, but varies a bit on the best way to account for it, depending on the research. Salkever

(1995) uses 50 percent of the high estimate for household work. Attina & Trasande (2013) use the low estimate. We used the market values estimated by Grosse, Kreger, & Mvundura (2009), but unlike in MDH (2014), we also use their household values, derived via the low estimate.

Finally, we use the same coefficients from MDH (2014) for the relationship between IQ reductions and salary changes (based on Salkever, 1995) even though 1) this is likely to be sensitive to socio-economic circumstances and may well have increased as the economy has become more high tech, and 2) women likely have a stronger relationship between IQ and lifetime earnings (Salkever, 1995).

On this basis we have made three estimates of productivity losses due to lead exposure: total productivity (wages and housework), workplace productivity (wages), and avoided tax losses (using 30 percent taxation rate), as shown in Table 2. Low and high estimates represent the range produced from using either 0.1 or 0.2 for the fraction of lead poisoning due to drinking water. See Appendix A for methods and parameters.

Table 2: Benefits from IQ/Productivity Analysis (in millions of dollars)

Benefits		
Lost TOTAL Productivity	$4,235	$8,471
Lost MARKET Productivity	$2,972	$5,945
Lost TAXES	$892	$1,783

Benefits of Removing LSLs

As stated previously, LSLs contribute around 50 percent of the lead found in water. Therefore, removing the estimated 100,000 LSLs in Minnesota could be estimated to result in 50 percent of the benefits shown in Table 2.

Benefits of Removing Pipes, Solder, and Lead Fixtures

If LSLs contribute 50 percent of the lead found in water, and premise plumbing is the only other significant contributor to lead burden in water, then it can be assumed that premise plumbing contributes 50 percent of the lead in water. Therefore, a similar benefit to IQ for each birth cohort from removing LSL could be realized by replacing premise plumbing – 50 percent of the benefits shown in Table 2.

Increased Home Value

Removing lead increases the value of homes resulting from the lower health hazard. It has been shown that money invested in lead hazard reduction results in a return of $2.60 for every $1 spent (Billings and Schnepel, 2017). While the total renovation costs in Billings and Schnepel (2017) ranged from $3,283 to $9,630 per home, which is roughly the same as the costs discussed here ($2,000 to $6,000 per home), the paper focused on lead paint remediation, not drinking water. Drinking water contributes about 20 percent of lead in blood, whereas lead paint contributes a higher percentage (President’s Task Force, 2000). These differences may make the results of Billings and Schnepel less applicable for the purpose of this report on plumbing and drinking water. However, if we apply their results, we calculate a benefit of 2.6 times the costs of fittings and pipe replacement, which is between $4.1 and $11.7 billion. These estimates reveal something about willingness to pay for better water as embodied in house prices. Willingness to pay (WTP) should not be considered as additional to the productivity estimates in Table 3. Rather WTP analyses are a different approach to estimating these benefits. Interestingly, the range of $4.1 to $11.7 billion in WTP is as much, if not greater than the benefits calculated from the productivity analysis.

Improved Health Equity

Addressing lead hazards in water improves equity in high-risk communities. While that benefit is difficult to quantify financially, a number of steps were outlined by the Lead Service Line Replacement Collaborative (LSLRC, 2018b) to ensure that LSL replacement programs are equitable, including:

- Recognizing that minority and low-income residents are more likely to be exposed to other sources of lead (lead-based paint), and that reducing further harm is a priority.
- Ensuring planning, implementation, and oversight includes affected low-income and minority consumers and gives serious consideration to their concerns.
- Taking steps to protect people with low incomes or limited access to capital so they do not opt out of LSL replacement.
- Making replacing LSLs serving rental property a priority because landlords may not otherwise see the value of the investment and tenants are often, depending on the area in question, more likely to be low income or minority.

Existing Funding Sources

The Drinking Water State Revolving Fund (DWSRF) loan program is the largest source of financing for drinking water infrastructure projects throughout Minnesota. The DWSRF is jointly administered by the Minnesota Department of Health (MDH) and the Minnesota Public Facilities Authority (PFA) and is supported by a combination of federal funds, state funds, and loan repayments. The DWSRF is a potential funding source for private lead service line replacement (LSLR), but additional work is needed to determine how it would be incorporated into the DWSRF program and implemented by local governments. MDH and PFA are exploring options and determining what statute and rule changes may be needed. Once potential LSLR funding options are clarified, they will be presented to a stakeholders' group for input.

The Lead Service Line Replacement Collaborative (LSLRC) reviewed results from a number of states that have set up approaches to support the removal of LSL (LSLRC, 2018c; Table 3). In addition to direct appropriations, a common approach is to adjust utility rates to generate funds to be used for lead hazard reduction. Unfortunately, adjusting utility rates can often be hindered by legal complications and barriers related to using public funds to improve private property. The issues related to Minnesota were summarized in a 2017 report by the University of North Carolina and are presented in Appendix C (UNC, 2017).

In St. Paul, the water utility urges customers to replace their section of pipe at the same time the city replaces its line to the street. Unfortunately, fewer than half of residents choose to pay the $3,000 - $4,000 required to address their half of the work (MPR, 2016). Homeowners can fund their portion of LSL replacement by having the cost assessed to their property taxes.

The proposed FY 2019 budget for the US EPA includes $2.3 billion for the State Revolving Funds (SRF), which supports efforts across the country to eradicate lead pipes that may leach into the drinking water supply (EPA, 2018b). Schools may use long-term facilities maintenance funds for lead in water testing/remediation. However, the demand is generally much greater than the amount available. In Minnesota in 2018, the Project Priority List, which is used to fund work through the SRF, had more than $600 million in requests (MDH, 2018b).

Table 3: Recent State Approaches to Funding LSL Replacement

Date	Source	Amount	Goal
June 2016	Wisconsin Department of Natural Resources	$27.8 million	Grants to disadvantaged communities for full LSL replacement
October 2016	Washington State Department of Health	State revolving fund	Modified eligibility so systems with LSLs get higher funding priority
March 2017	Pennsylvania Public Utilities Commission	Water rates	Allowed rate increase to fund full LSL replacement
March 2017	Vermont Department of Environmental Conservation	$125,000	Individual grants to fund LSL inventory, educate the public, and develop replacement plans
March 2017	Virginia Department of Health	$5,000 per service line	Full LSL removal through utility rebates for sensitive populations
April 2017	New York State	$20 million	LSL replacement grant program prioritized by lead risks
2017	New Jersey Department of Environmental Protection	$30 million	State revolving loan funds for LSL replacement with 90% principle forgiveness & 10% interest-free loans.

Conclusions

Given the common occurrence of lead in the environment and its continued presence in portions of drinking water systems, the goal of total elimination should be considered aspirational. However, there is reason for optimism based on past successful public health interventions to get lead out of gasoline and residential paint.

Ultimately, assessing the cost to eliminate lead in drinking water in Minnesota requires balancing the risks posed by any single exposure route versus the resources required to mitigate exposure. In addition, the urgency to complete the effort will directly impact annual costs, with shorter time frames requiring higher levels of investment. Finally, removing LSLs and plumbing fixtures containing lead will require a major intrusion into private property and residences, which will dramatically limit capacity to implement plans on a large scale and increase the need for clear communication and coordination between hazard reduction efforts and residents.

Risk Characterization

Despite significant progress in reducing exposures over the past 20 years, lead remains a potent neurotoxin that is still widely distributed in the environment. While lead in water is increasing in relative importance, dust from leaded paint in homes built before 1978 remains the primary source for elevated blood lead cases in children between 9 and 72 months old.

For children less than 9 months old, being fed formula prepared with water from a home with lead in the plumbing water can be the primary route of lead exposure. Children less than 9 months old have not traditionally been tested for blood lead levels as part of standard care. Therefore, additional efforts are needed to raise awareness in parents and caregivers to ensure that risk factors are recognized and mitigated. While a blood lead test can provide useful information, the first step in assessing the home of an infant will always be to test the water and remove lead sources.

The primary public health risks from lead in drinking water result from leaching from premise plumbing, including fixtures and solder in pipes, and leaching from LSLs. The amount of leaching can be minimized by corrosion control in water treatment, but protective layers can be decreased by chemical changes in water or physical disruptions from construction/renovations. Therefore, removing lead is the best, permanent solution.

Partial replacement of LSLs can dislodge lead particles, create adverse electrochemical conditions that liberate lead, and reduce protective layers leading to increase exposure to lead. A number of national organizations have advised against partial LSL replacement and they should be avoided whenever possible.

Cost/Benefit Summary

One of the goals of this report was to assess the cost to eliminate lead from drinking water in Minnesota. To eliminate lead will require implementing permanent solutions. Therefore, the costs and benefits for permanent solutions are summarized in Table 4. An implementation time of 20 years is assumed.

A range of results is presented to capture uncertainty in the estimates. Costs are considerable ($1.5 to $4.1 billion), but gains in total and wage productivity are even more ($3.0 to $8.5 billion); and these would go along with considerable returns to public revenues from the increase in income and sales taxes due to wage growth ($0.9 to $1.8 billion). Moreover, there are a number of reasons, already documented, for believing that the benefits are underestimated.

Table 4: Cost/Benefit Comparison of Permanent Lead Removal Activities (in $ millions) Benefits represent total productivity

Costs	Low $	High $	Benefits	Low $	High $
Fixtures/Solder	1,232	3,697	IQ/earning gain - fixtures	2,118	4,235
LSL Replacement	228	365	IQ/earning gain – LSL removal	2,118	4,235
Technical Assistance	61	61			
Total	1,521	4,123	TOTAL	4,236	8,470

Resources required could be reduced by taking a longer time to complete lead removal or by focusing on high-risk areas or populations. However, the longer lead remains in the environment, the longer children exposed to lead will continue to have degraded IQ levels, and resulting losses in earnings and potential.

Recommendations

These potential strategies have a range of costs, but all would be projected to have a positive return on investment in the form of reduced health impacts and associated public expenditures. MDH can provide more details about specific staffing and financial resources required to implement all or a portion of the recommendations as requested.

Lead Service Lines

Lead service lines contribute about 50 percent of the lead measured at the tap. Yet the cost of removing them is only 10 percent of the total estimated cost of removing all sources of lead from drinking water in Minnesota. Also, the estimated benefit of removing lead service lines is 10 times greater than the estimated cost. Specific recommendations include:

- **Highest priority:** Conduct a statewide inventory of lead service lines. This would improve our estimate of the number and location of lead service lines and improve cost estimates for removal. This is a key first step in reducing lead in drinking water.
  - **Cost:** Medium
  - **Staff:** Project Manager
- **High priority:** Remove lead service lines at a measured pace. This would remove a major source of lead
  - **Cost:** $228 million to $365 million over 20 years (about $15 million/year)
  - **Staff:** Engineer

Public Awareness Campaigns

While direct interventions such as removing lead service lines offer the greatest risk reduction, it is also important to make sure Minnesotans have greater awareness of low-cost actions they can take on their own to protect themselves and their families. Raising awareness of lead hazards can encourage people to take action (testing water or flushing stagnant water, for example) to prevent or reduce exposure. The best approach to raising public awareness is one that is sustained over time to ensure maximum audience message penetration and integration of protective actions. MDH data can be used to target efforts to high-risk or vulnerable communities. Specific recommendations include:

- **Medium priority:** Increase awareness of the dangers of lead exposure, with a focus on dangers to formula-fed infants younger than 9 months old.
  - **Cost:** Low
  - **Staff:** Communicator/Planner
- **Low priority**: Create general public information campaign. Homeowners and renters will not take action unless they know they have a lead service line.
  - **Cost:** Low, but complex, time-consuming process
  - **Staff:** Communicator/Planner

Technical Assistance and Partnerships

Addressing lead is a complex task for local communities. Technical assistance to community water systems is needed to help them begin or maintain effective corrosion control programs, which limit lead in water from indoor plumbing. Partnerships between water systems and lead poisoning prevention programs increase efficiency and enhance efforts.

- **Medium priority:** Conduct corrosion control studies and implement optimized corrosion control.
  - **Cost:** Primarily borne by community water systems, and MDH staff time
  - **Staff**: MDH Engineer
- **Low priority:** Create partnerships and coordinate efforts between MDH, community water systems, and lead poisoning prevention programs that traditionally focus on paint-based hazards.
  - **Cost:** Low
  - **Staff**: Communicator/Planner

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Appendix A: Data Quality Issues

Blood Lead Data

MDH collects results of all blood lead tests on Minnesota residents to track trends, ensure services are provided, and target primary prevention efforts to the highest-risk populations. Because results are not generated randomly (only those who get a test are reported), the data are not statistically representative of all of Minnesota. However, a large enough number of samples are received to provide reasonable estimates of population characteristics for children under 6 years old. In addition, because a blood lead test represents all exposure to an individual, it can be difficult to attribute a specific source (e.g., water versus lead paint dust) to a result. While environmental results collected as part of a risk assessment for an elevated blood level investigation can provide insight into the magnitude of exposure routes, cases that are investigated have, by definition, unusual levels of exposure to lead. Therefore, sources identified by MDH assessments may not be representative of overall exposure to children statewide.

Operation of Drinking Water System

To generate an estimate of statewide costs to operate a drinking water system under various scenarios, it is necessary to use average values. Actual costs incurred by an individual PWS to meet all regulatory requirements for water and consistently deliver water that is acceptable to their customers will be highly variable.

One example of an operating cost is corrosion control. Corrosion in water systems is defined as the electrochemical interaction between a metal surface such as pipe wall or solder and water. During this interaction, metal is oxidized and transferred to the water or to another location on the surface as a metal ion. If lead is present in plumbing materials, corrosion can get it into the drinking water.

LCR Compliance Statistics

To assess lead hazards from drinking water most accurately, it is necessary to estimate both the quantity and quality of water being consumed. While the quantity can be obtained from risk assessment literature, the quality of water (and therefore the potential for lead leaching) is highly variable across the state. In addition, because the LCR is designed to statistically assess drinking water distribution system conditions in primarily residential situations, the data collected do not readily translate into population exposure estimates. LCR data does not include exposure risks for drinking water from non-residential facilities served by community PWSs such as schools and workplaces. The LCR compliance samples target high exposure risk sites and are collected under the highest risk conditions (after at least six hours of stagnation).

LSL Replacement

The actual cost of removing an individual LSL is highly dependent on location, length, available excavation methods, the number of replacements being done, and funding source. If the excavation and replacement can be performed in conjunction with other efforts, such as road repair, costs to a utility can be significantly reduced. A logistical issue related to LSL replacement relates to ownership of the line and the capacity for public agencies to do work on private property. Using public funding to improve private property will involve legal hurdles at the state and local level. Requiring property owners to pay will greatly reduce the number of full LSL replacements done and may have environmental and social justice implications for low- or fixed-income residents.

Finally, the actual number of LSLs must be estimated because statewide surveys have not been able to generate numbers that are more accurate. Future revisions of the LCR may require water systems to collect information that is more detailed on plumbing materials and service lines and for state primacy agencies to review that information.

Water Sampling

While testing for lead in water is relatively straightforward from an analytical perspective, it is very difficult to collect a single sample that is representative of long-term exposure. If the lead element is near the tap, the highest concentration of lead will come out very quickly. A smaller sample of water can be collected in this situation (typically 250 mL) rather than the 1 L sample size used for LCR compliance testing, which attempts to reach lead from the service line. However, if the lead element is further away (e.g., LSL), then the tap would need to be flushed for a period of time to reach the highest lead concentration or sequential samples maybe collected to create a profile of lead in the premise plumbing. In addition, the length of time water is in contact with lead elements will also significantly influence lead concentrations. Analytical variability will make it difficult to document sustained lead reductions from hazard interventions.

There are a number of accredited labs around the state that can analyze water for lead. Prior to collecting a sample, the lab will typically send instructions for sampling, sample bottles, and a chain-of-custody form to document time and date collected, collector name, and sample location. Costs vary from lab to lab but are usually between $20 and $50 per sample. A listing of accredited labs can be found at Environmental Laboratory Data-Online (www.health.state.mn.us/labsearch).

Appendix B: Lost Productivity

We estimated the expected value of the reduction in IQ due to lead in drinking water, were the 20 year program not to occur; in other words, the expected value of the IQ gain due to the project. We include the 20 years of the program, 2018 through 2037, plus the years 2013 through 2017. The years prior to 2018 are included because children born in those years could still receive a benefit from the program, as they would not have reached 6 years old by the program start. For a child born in a given year, $y \epsilon \{2013, 2014 \ldots 2037\}$, the expected value of the reduction, R_y is:

$$E[R_y] = \begin{cases} \rho \cdot M_y & y = 2013 \\ E[R_{y-1}] + \rho \cdot M_y & 2014 \leq y \leq 2032 \\ \rho\left((y-2018)M_y + \sum_{y}^{2037} M_{y-20}\right) & 2033 \leq y \leq 2037 \end{cases} \quad \text{[A1]}$$

where ρ is the probability a home is chosen in a given year; we assume $\rho = 0.05$. The later cohorts ($2033 \leq y \leq 2037$) have a different, approximated $E[R_y]$as those children have fewer than 6 years in the program. M_y is the maximum possible reduction a child born in year y could have:

$$M_y = \begin{cases} 1 - \left(\frac{2018-y}{6}\right) & 2013 \leq y \leq 2017 \\ 1 & 2018 \leq y \leq 2037 \end{cases} \quad \text{[A2]}$$

For each birth cohort, we assume the same benefit is acquired regardless of when during the year the retrofitting is completed. We also assume there is a linear relationship between benefit of lead removal and age in years (i.e. up to six years old, IQ loss over time occurs at a fixed rate). The fraction of lost productivity reduced by the project for a child born in year y is L_y, given by:

$$L_y = E[R_y] \cdot D \quad \text{[A3]}$$

where D is equal to the fraction of lifetime earnings lost due to lead in drinking water:

$$D = \beta\sigma I\omega \quad \text{[A4]}$$

where β is the mean peak blood lead level, σ is the IQ points lost due to lead poisoning, I is the fraction of lifetime earnings lost due to IQ loss, and ω is the fraction of lead poisoning due to lead in drinking water. See Table A1 for parameter values. The total gained productivity due to the project, G, is then:

$$G = \sum_{s}\sum_{y} L_y n_s \tau_s \quad \text{[A5]}$$

where s is the gender of the child, either male or female (we do not account for nonbinary identifying people). n_s is the size of the 2004 birth year cohort. We have not accounted for increasing number of births per year. While not every child in Minnesota would be affected by this program, the children who are affected would have a higher blood lead level. We account for these issues by using the mean blood level and the total number of children. τ_s is the average lifetime productivity for a child born in 2007, adjusted for inflation to 2018 dollars. τ_s does not vary by year as for future cohorts we assume an inflation rate of 2% and a yearly productivity rate increase of 1%. Since we used a 3% discount rate, each cohort's total productivity is the same. The total productivity of each cohort, τ_s, includes both wages earned and household productivity. The total earned wages, which excludes household productivity, W, is:

$$W = \sum_s \sum_y L_y n_s w_s \qquad [A6]$$

where w_s is the average wages earned for a child born in 2007, adjusted for inflation to 2018 dollars. Like τ_s, w_s does not vary by year as for future cohorts we assume an inflation rate of 2% and a yearly productivity rate increase of 1%. Since we used a 3% discount rate, each cohort's total earned wages is the same. The portion of W paid in taxes, T, is:

$$T = Wt \qquad [A7]$$

where t is the tax rate.

Table A1: Parameters

Parameter	Definition	Units	Value
β[1]	Mean peak blood lead level	µg/dL	2.54
σ[2]	IQ points lost due to lead poisoning	IQ points $(\mu g/dL)^{-1}$	0.513
I[1]	Fraction of lifetime earnings lost due to IQ loss	IQ point lost^{-1}	0.0239
ω[1]	Fraction of lead poisoning due to drinking water	--	0.1 to 0.2
n_{girl}[1]	Number of girls born in MN in 2007	--	34,626
n_{boy}[1]	Number of boys born in MN in 2007	--	35,988
τ_{girl}[3]	Average lifetime productivity of girls	$	1,353,531.22
τ_{boy}[3]	Average lifetime productivity of boys	$	1,632,849.43
w_{girl}[3]	Average lifetime wages of girls	$	775,140.72
w_{boy}[3]	Average lifetime wages of boys	$	1,314,044.24
t[4]	Tax rate	--	0.3

[1] MDH, 2014 [2] Lanphear et al., 2005; Gould, 2009 [3] Lifetime productivity and wage data (3% discount rate) are from Grosse, Kreger, & Mvundura, 2009, inflated by a factor of 1.24 (from the Consumer Price Index Inflation Calculator). [4] Estimated by authors.

Appendix C: Legal Issues For Setting Water Rates

Note: This is an excerpt from a larger report, "Navigating Legal Pathways to Rate-Funded Customer Assistance Programs: A Guide for Water and Wastewater Utilities." (https://efc.sog.unc.edu/pathways-to-rate-funded-customer-assistance)

Minnesota is one of only six[1] states in which private water and wastewater companies are not regulated by a state utility commission. Rather, municipal water and wastewater utilities are regulated by the local government within which they operate.

Under Minn. Const. art. XII, § 4, local governments in Minnesota may adopt home rule charters. According to Minn. Stat. § 456.37, a home rule charter city "may charge a reasonable fee for supplying water." A second type of city in Minnesota, a "statutory city," operates under Minn. Stat. § 412.321.[2] For both types of cities, as well as for counties, Minn. Stat. § 444.075(3), provides that rates should be "just and equitable." Additionally, under the same statutory provision, "charges made for service rendered shall be as nearly as possible proportionate to the cost of furnishing the service."[3]

In Daryani v. Rich Prairie Sewer & Water Dist.,[4] a case addressing water and wastewater rates charged to an apartment complex, the Minnesota Court of Appeals acknowledged the difficulties in rate setting. Specifically, the court made reference to "perfect equality in establishing a rate system" not being "expected, nor can quality be measured with mathematical precision."[5] Instead, the court went on, the goal should only be a practical basis when establishing a rate system, "and apportionment of utility rates among different classes of users may only be roughly equal."[6] As for the rate challenged in the Daryani case, the court stated that it would "uphold an established rate system unless it is shown by clear and convincing evidence to be in excess of statutory authority or results in unjust, unreasonable, or inequitable rates."[7]

Thus, the biggest statutory challenge for utilities in Minnesota seeking to implement low-income customer assistance programs (CAPs) funded by rate revenues would be the requirement that rates be "proportionate to the cost of furnishing the service."[8]

[1] The others are Georgia, Michigan, North Dakota, South Dakota, and the District of Columbia

[2] Of the 853 cities in Minnesota, 747 are statutory cities

[3] Minn. Stat. § 444.075(3). The statute includes an exception for specific rate restrictions found in individual charters

[4] Daryani v. Rich Prairie Sewer & Water Dist., No. A05-1200, 2006 WL 619058, at *2 (Minn. Ct. App. Mar. 14, 2006) (unpublished opinion).

[5] Daryani, 2006 WL 619058, at *4.

[6] Id

[7] Id. at *2.

[8] Minn. Stat. § 444.075(3)

State Population (2016): 5,519,952

Median Annual Household Income (2015): $61,492

Poverty Rate (2015): 11.3%

Typical Annual Household Water and Wastewater Expenditures (2015): $487

Minnesota has 967 community water systems (CWS), of which 230 are privately owned and 878 serve populations of 10,000 or fewer people.

Minnesota has 171 publicly owned treatment works facilities (POTWs), of which 141 treat 1 MGD or less.

43,681 people are served by privately owned CWS; 4,321,274 are served by government-owned CWS; and 3,318,877 are served by POTWs.

Estimated Long-Term Water and Wastewater Infrastructure Needs: $9.7 billion

Sources: U.S. Census Bureau, 2016 Population Estimate & 2011–2015 American Community Survey 5-Year Estimates; 2016 EFC Rates Survey; U.S. Environmental Protection Agency, 2016 Safe Drinking Water Information System, 2011 Drinking Water Infrastructure Needs Survey, and 2012 Clean Watersheds Needs Survey. See Appendix C for more details.