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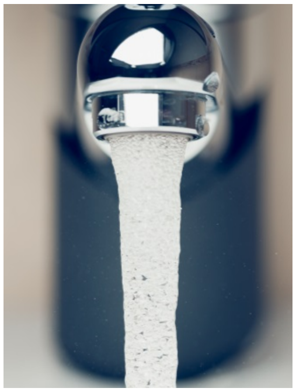
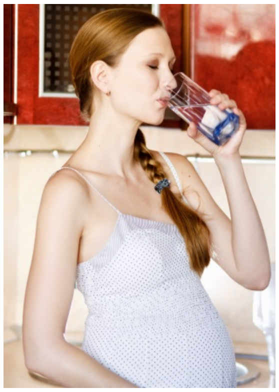


# Lead in Water

## *Public Health Recommendations for Private Residences*

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# Acronyms

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|---|---|
| **BLL:** | Blood lead level |
| **CDC:** | Centers for Disease Control and Prevention |
| **CI:** | Confidence interval |
| **DHS:** | Wisconsin Department of Health Services |
| **DNR:** | Wisconsin Department of Natural Resources |
| **DSPS:** | Wisconsin Department of Safety and Professional Services |
| **EBLL:** | Elevated blood lead level[a] |
| **EPA:** | U.S. Environmental Protection Agency |
| **IEUBK:** | Integrated exposure uptake biokinetic |
| **GM:** | Geometric mean |
| **LCCA:** | Lead Contamination Control Act |
| **LCR:** | Lead and Copper Rule |
| **LHD:** | Local health department |
| **LSL:** | Lead service line |
| **OR:** | Odds ratio |
| **RLDWA:** | Reduction of Lead in Drinking Water Act |
| **SDWA:** | Safe Drinking Water Act |
| **SHEDS:** | Stochastic Human Exposure and Dose Simulation |
| **THC** | Tribal health center |
| **WLL** | Water lead level |

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[a] In this document, elevated blood lead level (EBLL) is defined in accordance with the CDC's definition and refers to lead level in blood at or above 5 micrograms per deciliter (µg/dL). This level is referred to as "lead poisoning" or "lead exposure" in Wis. Stat. § 254.11(9).
It is important to note that this definition differs from the definition of elevated blood lead level in Wisconsin Statute, which defines elevated blood lead level as a level of lead in blood that is 20 µg/dL or higher, as confirmed by one venous blood test, or 15 µg/dL or higher, as confirmed by two venous blood tests that are performed at least 90 days apart, Wis. Stat. § 254.11(5m).
The CDC's definition is used because it is consistent with how elevated blood lead level is defined in the literature referenced in this document.

## Introduction

This document reviews the risks posed by lead in drinking water and outlines a recommended framework to guide individuals and public health practitioners through the assessment of lead exposures from water consumption and implementation of strategies to reduce or interrupt those exposures. **The information presented here will be used to inform the development of outreach materials for the general public and guidance documents for local health departments and tribal health centers on strategies to address lead in drinking water concerns.**

Characterizing the risk of lead poisoning from ingestion of contaminated drinking water depends on many complex and interrelated factors. The hazard posed varies considerably depending on the lead source and water chemistry. Exposure is dependent on magnitude and duration of water consumption as well as the characteristics of the population of concern.

This document includes a discussion of the main sources of lead in water, key regulations governing use of lead-containing plumbing materials, and a review of the current evidence on the contribution of contaminated water to the overall burden of EBLLs in the population. This document concludes with a discussion of strategies for homeowners to assess lead exposures from drinking water and take appropriate actions to reduce or interrupt exposures.

**This document focuses on single family owner-occupied residences.** Schools, child care facilities, and multi-unit residences are beyond the scope of this review.

### Highlights

- Ingestion of contaminated water can represent a substantial fraction of the total lead exposure among young children.
- Basic water sampling procedures do not reliably identify peak lead levels, which makes it difficult to evaluate the potential for lead exposure from these approaches.
- DHS recommends a stepwise approach to minimizing the potential for lead exposure from drinking water. In this approach, all residents are encouraged to follow a set of baseline actions, and high-risk populations are encouraged to take additional actions to minimize risk.

# Background

## Health Effects of Lead Exposure

Lead is a naturally occurring heavy metal that has a large presence in the environment due to its widespread use during the 19th and 20th centuries in paint, gasoline, and plumbing.[1] Lead-based paint was banned in 1978 for use in homes, while leaded gasoline was phased out in the mid-1970s and completely banned in 1996.[2] The environmental persistence of lead places both children and adults at risk of exposure and poisoning. Children are at elevated risk compared to adults because of the increased vulnerability of the nervous system during early development, differences in exposure pathways, and differences in toxicokinetics.[3] While risks are usually lower for adults, certain occupations and hobbies place some individuals at increased risk.[4] Lead poisoning in pregnancy is of particular concern given the increased vulnerability of the fetus during critical developmental stages.[5]

Lead exposure can have long-lasting effects in children, particularly when exposure occurs during early development.[6] There is no known safe level of lead, and research continues to reveal adverse health effects at low levels.[7] Blood lead levels (BLLs) less than 5 micrograms per deciliter (µg/dL) are associated with a variety of adverse neurodevelopmental outcomes including decreased cognitive performance, increased incidence of problem behaviors, and increased diagnosis of attention-related behavioral disorders.[7]

In children, BLLs less than 10 µg/dL are associated with delayed puberty and reduced postnatal growth. In teens, BLLs less than 10 µg/dL may be associated with decreased kidney function in and elevated serum immunoglobulin E. In adults, BLLs less than 10 µg/dL are associated with decreased renal function, hypertension and essential tremor, and limited evidence of increased cardiovascular mortality.[8] In pregnant women, BLLs less than 10 µg/dL are associated with reduced fetal growth and limited evidence of increased spontaneous abortion and preterm birth.[5] Higher BLLs (e.g., greater than 80 µg/dL) are associated with acute and sometimes life-threatening health effects including profound anemia and encephalopathy.[3]

Given the large body of evidence demonstrating health effects at even low levels of lead exposure, public health authorities have dedicated considerable resources to identifying and mitigating lead exposures, particularly for young children.

## Economic Impacts

The health effects caused by low level lead exposure, particularly reductions in IQ and increased risk of attention-related behavioral disorders, result in significant costs to society. These effects are associated with reduced education attainment and earnings, as well as increased criminal behavior and rates of incarceration.[9-11] A number of studies have attempted to quantify the economic impact of lead exposure along with expected savings from targeted interventions. Direct medical costs from lead exposure are estimated to be \$5.9 million annually in the U.S., with an additional \$50.9 billion in lost economic productivity.[12] Net economic benefits from improvement in high school graduation rates and reductions in crime by reducing BLLs to less than 1 µg/dL have been estimated at \$50,000 per child annually with overall savings of \$1.2 trillion in the U.S.[9] Analyses comparing the costs of lead hazard control with expected economic benefits estimate that each dollar invested in control measures produces a return on investment of \$17–\$221.[13] Although there is considerable variation between studies, the economic impact of lead exposure reduction is consistently predicted to yield substantial and positive rates of return.

## Lead Sources and Exposure Pathways

Given the ubiquity of lead within the environment, people can be exposed through a variety of routes, including ingestion of contaminated food, dust, water, and soil, as well as inhalation of contaminated air and airborne particulate matter.[14] Exposure among adults in the U.S. is often related to occupation, with workers in battery manufacturing, smelting, and construction industries at highest risk.[15] Non-occupational exposures in adults typically occur through hobbies, incidental ingestion, and home renovation activities.[16]

In young children, hand-to-mouth behaviors increase risks of exposure to lead in dust, paint, and soil found in the child's environment.[7] Additionally, children absorb more lead per exposure than adults because their metabolic rates are higher relative to their body size, and they have a larger ratio of surface area to body mass. Due to the susceptibility of children, the remainder of this section will focus on lead sources and exposures relevant for this age group.

### Leaded gasoline

Historically, combustion of leaded gasoline was a major driver of elevated blood lead levels (EBLL) in children. Emissions resulted in lead contamination of the air as well as deposition of lead-containing particulate matter in the environment. As leaded gasoline was phased out, BLLs declined in parallel.[14] This strong correlation has been observed in multiple studies across several countries.[17] Despite the continued decline in BLLs among children in the U.S. in the decades after the phase-out, evidence of the harmful effects of low-level lead exposure prompted continued study into identifying other major sources of lead exposure among children.

### Lead-based paint

Ingestion of lead-containing dust within the home is known to be a major source of lead exposure.[18,19] Multiple studies have demonstrated that BLLs rise dramatically with increases in floor dust lead loadings, and up to 70% of EBLLs in children are linked to lead paint or contaminated dust and soil.[11,20] Lead-based paint is incorporated into house dust as it degrades and poses a risk factor for hand-to-mouth exposure in young children.[20] Lead-based paint also poses an inhalation risk during renovation activities that involve sanding, grinding, or blasting with power tools and equipment not furnished with a shroud and high-efficiency particulate air (HEPA) vacuum attachments to remove old paint layers.[14] Degradation of exterior lead-based paint may result in contamination of soil, creating another route for exposure. These findings resulted in a ban on residential lead paint in 1978 and the beginning of many public health initiatives to identify and abate homes with lead-based paint hazards.

### Other sources

A wide range of nonpaint sources of lead continue to provide potential exposure to individuals of all ages, especially young children. These sources can include, but are not limited to, cosmetics; religious powders; certain Ayurvedic products[b]; leaded crystal; handmade pottery and cultural cookware; imported candies, teas, and spices; porcelain or enamel glazed bathtubs; candle wicks; leaded aviation fuel; “take-home” lead in the home from occupationally-exposed workers, and wild game harvested with lead ammunition.

Current regulations limit the amount of lead allowed in children’s furniture, toys, and many food products (except spices). However, many of these items continue to be imported as suppliers find ways around regulations. Additionally, many cultural items are brought with families when they enter the country, or are mailed to families by relatives.

While removing lead from gasoline was significant in reducing lead contamination from auto emissions, leaded aviation fuel still contributes to air emissions of lead.[22] Current research under the Piston Aviation Fuels Initiative (PAFI) aims to find a safe unleaded fuel for aviation use to further reduce lead in our environment from combustion engine emissions.[23]

A single bullet of lead ammunition for hunting wild game can generate more than a hundred lead fragments that are too small to be seen or felt and remain in the meat. Because of this, many health care providers advise against young children and pregnant women consuming wild game harvested with lead bullets or shot.

### Drinking water

Despite success in eliminating the use of lead in gasoline and residential paint, which has resulted in a decline in childhood BLLs in the U.S., lead is still used in thousands of applications.[14] Continued progress toward reducing the burden of lead in the population

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[b] Ayurveda is a system of medicine with historical roots in the Indian subcontinent.[21]

requires investigation into other environmental sources that contribute significant risk. Indeed, children at lower BLLs (e.g., 5–10 µg/dL) are more likely to have exposure to multiple sources compared to children at higher BLLs who are more likely to have exposure to known risk factors such as older housing.[24] This has important implications for public health: as the threshold for what constitutes an EBLL is lowered, more children may be identified who have been exposed to multiple, unknown sources. Improved source characterization and attribution is needed to allocate funds toward effective hazard mitigation strategies.

Ingestion of lead in drinking water is estimated by the EPA to be as high as 20% or more of a person's total lead exposure, and as high as 60% for infants.[25] Despite efforts by the Safe Drinking Water Act (SDWA) and the Lead and Copper Rule (LCR) to reduce lead in drinking water, the total exposure to lead from this source is not well understood. Consequently, increased attention toward less studied exposure routes, such as ingestion of contaminated water, is warranted. The sources of lead in drinking water and associated potential health risks are discussed in more detail below.

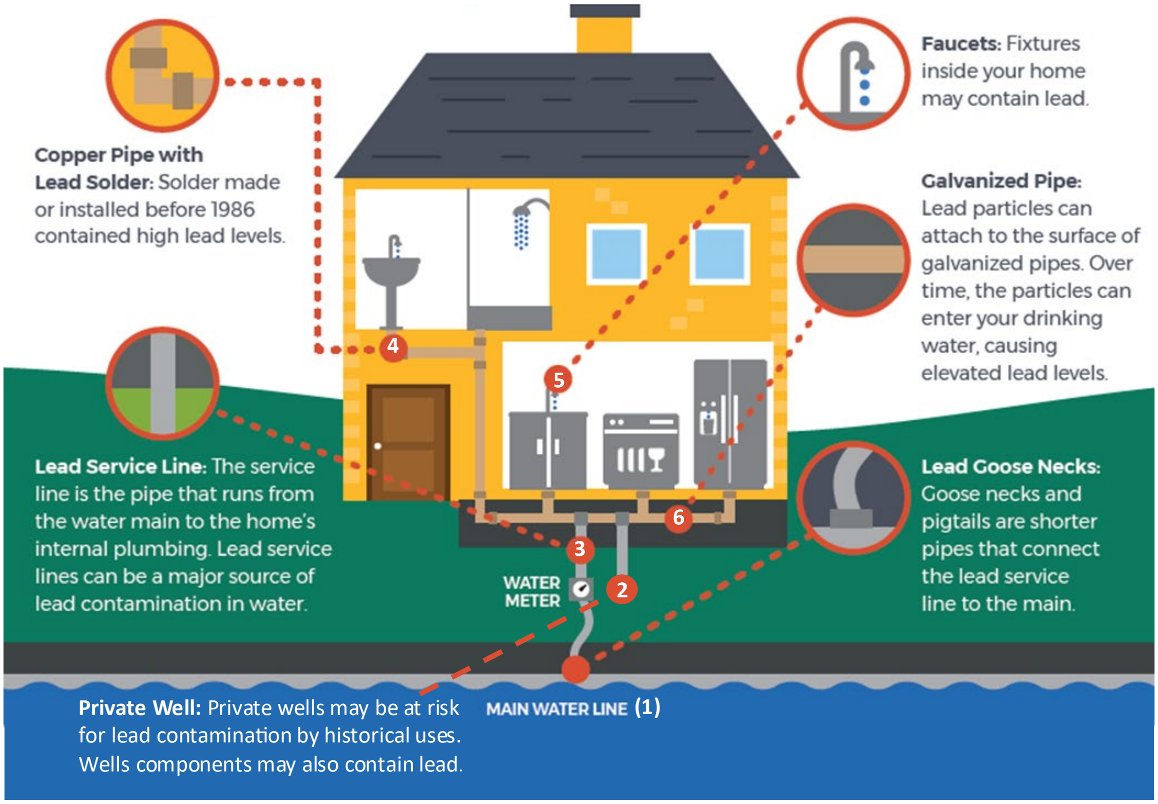
### Lead exposure from breastfeeding

Postnatal exposure of infants to lead through consumption of breast milk is of potential concern in scenarios with marked elevations in maternal blood lead levels. The ratio of breast milk lead to maternal blood lead is approximately 3% or less.[26-29] For example, maternal BLLs of 10 and 20 µg/dL results in milk lead levels of 3 and 6 µg/L, respectively. Based on reported relationships between milk lead and infant BLLs[30], the CDC estimates that the predicted contribution of breast milk lead to infant blood lead at 1 month of age is 2.5 µg/dL at a maternal BLL of 20 µg/dL and 0.25–0.5 µg/dL at maternal BLLs of 2–4 µg/dL.[5] Consequently, CDC recommends that breastfeeding only be temporarily interrupted when infant BLLs are 5 µg/dL or higher, maternal BLLs are higher than 20 µg/dL, and no other lead source can be identified.[5]

## Sources of Lead in Drinking Water

Lead in drinking water is rarely attributable to source water (i.e., the groundwater or surface water used for drinking). Rather, it is typically the interaction of water with metallic infrastructure found in water delivery systems that contributes lead to drinking water. Multiple components of the water delivery system can be sources of lead in drinking water (Figure 1). Delivery system components that can contribute to lead in drinking water include lead service lines, lead goosenecks, copper plumbing with lead-based solder, brass or bronze fixtures, lead pipes, and galvanized pipes. Lead service lines are typically responsible for the majority of contamination, where present. Source water, either from the utility or groundwater from a private well, can also contain lead, but plumbing components are the predominant source. Each potential source is discussed below.

*Figure 1: Potential Lead Sources in Drinking Water Include the Main Water Line (1), Private Well Water (2), Lead Service Line (3), Lead Solder (4), Brass Fixtures (5), and Seeding of Non-Lead Plumbing Components (6)*



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

**Faucets:** Fixtures inside your home may contain lead.

**Galvanized Pipe:** Lead particles can attach to the surface of galvanized pipes. Over time, the particles can enter your drinking water, causing elevated lead levels.

**Lead Service Line:** The service line is the pipe that runs from the water main to the home's internal plumbing. Lead service lines can be a major source of lead contamination in water.

**Lead Goose Necks:** Goose necks and pigtails are shorter pipes that connect the lead service line to the main.

**Private Well:** Private wells may be at risk for lead contamination by historical uses. Wells components may also contain lead.

Adapted from [EPA's Sources of Lead in Drinking Water Infographic]

## Utility Water and Main Water Line (1)

Water provided by utilities, sourced from either surface water or groundwater, generally contributes little to the overall amount of lead measured at consumer taps.[14] Water mains rarely contain lead, and water flowing through distribution systems rarely makes contact with any lead-containing materials. A study of surface water samples obtained from 50,000 water stations in the U.S. found water lead levels (WLLs) to be relatively low, with a mean of 3.9 micrograms per liter (µg/L), based on 39,490 occurrences.[31] Further study by the Environmental Protection Agency (EPA) of 1,000 randomly selected groundwater supplies found very few that were positive for lead when tested at the entry to the distribution system. The EPA estimated that, nationally, approximately 600 groundwater suppliers and 215 surface water suppliers have WLLs higher than 5 µg/L (a previously proposed maximum contaminant level for source water) in water leaving the plant. Collectively, these suppliers account for less than 1% of public water systems in the U.S.[32]

## Groundwater and Private Wells (2)

Although occurrences of significantly elevated WLLs in public utility wells (i.e., source water wells) are infrequent, private wells may be at risk. Wells drilled in the former lead-zinc mining region of extreme southwest Wisconsin may be vulnerable to natural sources of contamination.[33] Anthropogenic sources from historical use of lead arsenate pesticides may also place wells at risk.[34] Lead isotopic analyses have shown that contamination can be caused by a combination of naturally occurring lead deposits in aquifers as well as site-specific lead contamination due to human activities.[35] Although Wisconsin does not maintain a complete database of private well testing results, an analysis of nearly 4,000 results showed that 1.8% of private wells had WLLs in excess of 15 µg/L (Wisconsin's public health groundwater enforcement standard for lead).[36] The well itself, rather than the groundwater, may also be a source of contamination. Some well components (e.g., screens, packing collars, and old submersible pumps) contain lead. Additionally, some well owners have used lead shot or lead wool to prevent sand infiltration into wells, despite these practices never being recommended.[33]

## Lead Service Lines (3)

Lead service lines (LSLs) likely contribute the greatest amount of particulate and dissolved lead to the drinking water of water consumers. LSLs carry water from utility mains to residences and other buildings. Although cities and towns began restricting the use of lead pipes in the 1920s, usage was common until the 1950s, and not banned until 1986.[37,38] The number of homes and other buildings with LSLs nationwide is unknown; estimates of residential homes range from 6.5 million to more than 10 million.[39] One study estimates that there are approximately 240,000 LSLs in Wisconsin.[40]

The risk of lead release from LSLs depends on many factors, including water chemistry, physical disturbance to the line, and low water usage. Over time, most LSLs develop a scale (build up) consisting of a variety of compounds that can serve as a barrier against the leaching of lead into water. In the absence of corrosion inhibitors, scales are dominated by divalent lead compounds [Pb (II)], such as hydrocerussite and cerussite.[41] Under oxidative conditions, tetravalent lead compounds [Pb(IV)], such as lead oxide, can predominate. Conditions that favor formation of insoluble and adherent scale will result in a lower rate of release. Changes in water chemistry, however, can disrupt scale and cause release of lead, as observed in Washington, D.C. during 2000–2004 and Flint, Michigan, during 2014–2015.[42,43] A variety of water chemistry parameters, such as alkalinity, pH, dissolved oxygen, and hardness, can affect the rate of corrosion of lead-containing materials.[41] As part of the Lead and Copper Rule, public water systems are required to control corrosivity of the water served to customers to limit lead and copper exposure at the tap.[32] Corrosion inhibitors (particularly orthophosphate) tend to be more effective in reducing lead levels, especially from lead pipes, than pH/alkalinity adjustment. However, a study by del Toral et al. found that even well-operated water systems with high-quality source water and using corrosion inhibitor, can have elevated lead levels in water that stagnates in an LSL.[38]

Partial LSL replacements are the most commonly documented instance of physical disturbance of LSLs,[44] but other events like street work and construction can also trigger release of lead from LSLs.[45-47] In most Wisconsin communities, the LSLs are owned partially by the public water system (i.e., the portion of the service line connected to the water main), and partially by the private property owner (i.e., the portion of the service line connected to the water meter); typically, these two services are joined together by a valve called a curb stop. When repairing or replacing water mains, public water systems may replace only the system-owned portion and join new pipe with the lead-containing segment service line owned by the property owner. If the replacement occurs during routine maintenance, the owner and residents of the property may not know that the line was partially replaced. The resulting disruption can result in prolonged release of lead-containing particulate that may last days, weeks, or months.[44,48-50] If copper pipe is joined directly with the remaining portion of the LSL, the potential for galvanic corrosion also exists. To help address this issue, the American Water Works Association (AWWA) recently published a standard for LSL replacement that includes "no water use" during LSL removal work so that the dislodged scale and sediment with high lead levels are not worked into the home plumbing during the replacement.

In summary, LSLs are an important source of lead in drinking water. Although estimates vary and depend on a multitude of factors, LSLs may contribute 50-75% of the total lead measured in tap water within homes.[45,51]

## Premise Piping and Plumbing Fixtures (4-6)

Premise piping and plumbing fixtures consist of interior piping, typically copper and/or galvanized pipe, solder used to join pipe sections, and faucets and fittings used to dispense water. All of these components can contribute to a significant proportion of total lead found in water, as discussed below.

**Lead solder (4):** The primary type of solder used in the U.S. to join copper piping was 50-50% tin-lead solder until regulatory changes in 1986.[14] This type of solder is common in older homes. A liquefied 50-50 tin-lead formulation leaches greater amounts of lead compared to other formulations.[52] Although, where present, LSLs likely contribute the greatest amount of lead to tap water, leaded solder can contribute to the total through galvanic corrosion.[53-55] Tin-lead solder can be a source of lead exposure depending on quality of the soldering and amount of solder in contact with the water.[56] Lead release depends on a variety of factors, including the age of the solder and volume of water exposed to soldered joints. Release is highest when solder is newly applied,[45] but declines over time.[57]

**Brass fixtures and components (5):** Brass faucets (including chrome-plated brass fixtures) can be a source of lead contamination of drinking water, particularly when water has remained stagnant.[58,59] Investigations have revealed that even modern buildings with brass components can have more than 100 µg/L of lead in flushed water when the brass contains high lead content, the water is moderately corrosive to the metal, and there is low water demand.[60] Although brass fixtures may be a major contributor of lead in first draw samples,[61] studies estimate that more than 95% of lead is released in the first 200–250 mL of water from the faucet.[62] As a proportion of total dissolved lead, faucets contribute a small fraction, even in residences without LSLs (Table 1). A report from the American Water Works Association suggests that replacement of faucets and fittings may or may not improve lead levels at the tap.[45] In 2014, the Reduction of Lead in Drinking Water Act went into effect, making it illegal to sell plumbing products that contain 0.25% lead (by weighted average), thereby reducing the potential for lead exposure from these materials.[63]

**"Seeding" of non-lead plumbing components (6):** In addition to potential release of lead from LSLs, solder, and fixtures, lead can also accumulate in the interior plumbing of homes and other buildings downstream from an LSL. Galvanized iron pipes appear more likely to be "seeded" by dissolved and particulate lead, making the entire plumbing system a potential source for lead. [45,64,65] Changes in flow rate, water chemistry, or water quality can also result in release of particulate.

*Table 1. Relative Contribution from Sources as Percentage of Total Lead Mass*

| Utility | Faucet | Premise | Service | Main* |
|---|---|---|---|---|
| Madison, WI | 1% | 37% | 49% | 16% |
| DCWASA | 1% | 37% | 57% | 10% |
| BWSC | 3% | 38% | 48% | 12% |
| Toronto, CA | 2% | 29% | 57% | 17% |
| Framingham, MA | 0.7% | 21% | 76% | 7% |
| MDC** | 12% | 55% | 16%† | 16% |

Summary of relative % lead contribution from various lead sources as a percentage of total mass measured during sequential sampling. DCWASA: District of Columbia Water and Sewer Authority. BWSC: Boston Water and Sewer Commission. MDC: Metropolitan District Commission, Hartford, Connecticut. *Lead in samples representing main likely due to mixing of lead from other service and premise sources. **Entire service was copper. †Copper service, but service line samples had lead reported at the detection level (1.0 mcg/L), which was used in analysis. Adapted from Table 3.8 of AWWA Research Foundation's *Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues*.[45]
This information was adapted from Table 3.8 in Sandvig et al., 2009.[45]

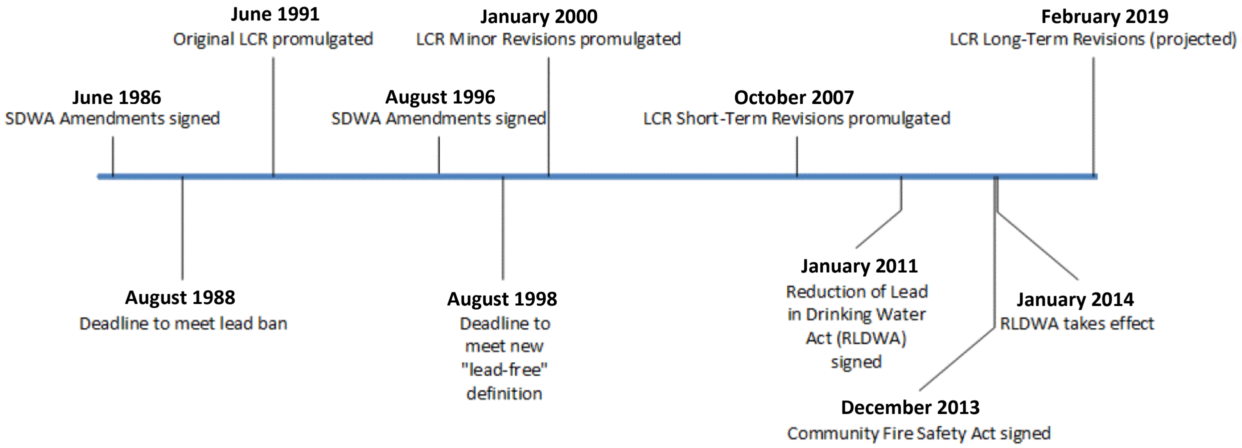
# Regulations to Reduce Lead Exposure from Drinking Water

Federal, state, and local governments have implemented regulations over the past four decades to reduce exposure to lead in drinking water by limiting use of lead-containing materials in plumbing components and requiring public water systems to monitor drinking water supplies for contamination. The following briefly outlines the current regulatory framework.

## Federal Regulations

The Safe Drinking Water Act of 1974 (SDWA) requires EPA to determine the level of contaminants in drinking water at which no adverse health effects are likely to occur. The maximum contaminant level goal (a non-enforceable standard) for lead is zero. Under authority conferred by the SDWA, EPA published the Lead and Copper Rule (LCR) to control lead and copper in drinking water. More details about the LCR can be found below.

*Figure 2. EPA's Timeline of Regulatory Actions Related to the Lead and Copper Rule*[41,66]



The Safe Drinking Water Act Lead Ban of 1986 revised the SDWA to require the use of “lead free” plumbing components for pipes, solder, and flux when installing or repairing public water systems or residential and nonresidential facilities that provide water for consumption.[67] Solder and flux were considered lead free if they contained less than 0.2% lead. Pipes and fittings were considered lead free if they contained less than 8% lead. Plumbing fixtures not meeting this requirement were banned from sale after August 1998.[68]

The Lead Contamination Control Act of 1988 (LCCA) was promulgated to reduce lead exposure in drinking water at school and day care centers. This statute created monitoring and reporting requirements and required the replacement of water fixtures that contained higher amounts of lead. However, states were not required to establish testing programs after a successful challenge to the Fifth Circuit Court of Appeals in 1996. Nonetheless, states are permitted to voluntarily enforce the provisions of the Act (or alternate provisions) through their own authority.[69]

The Lead and Copper Rule of 1991 (LCR) requires public water utilities to monitor for lead in drinking water and institute treatment for corrosive water if lead or copper are found to exceed contaminant-specific action levels in more than 10% of compliance samples collected from high-risk customer taps. High-risk customer taps are homes containing lead service lines, interior lead pipes, and leaded solder. The LCR established a lead action level of 15 µg/L. Revisions to the LCR are under consideration as of February 2018.[39,70]

The Safe Drinking Water Act was amended in 1996 to require plumbing fittings and fixtures to comply with lead leaching standards and to prevent the sale of components that are not "lead free" as defined in the SDWA.[71]

The EPA revised the Lead and Copper Rule (LCR) in 2007 to improve monitoring by clarifying the number of samples that are required, and to prevent systems that are out of compliance from remaining on a reduced monitoring schedule. Water systems must also receive approval for changes in treatment or source water that could increase the corrosion of lead.[72]

The Reduction of Lead in Drinking Water Act of 2011 (RLDWA) amended the SDWA to define "lead free" as 0.25% of lead across wetted surfaces of pipes, fitting, and fixture and 0.2% for lead solder and flux. The statute also prohibited the sale of any new plumbing components that are not "lead free" unless for manufacturing or industrial purposes. Implementing this regulation has been proposed and public comment ended in May 2017.[73]

## State Regulations

In Wisconsin, the Department of Safety and Professional Services (DSPS) is the state agency with authority over the plumbing code (Wis. Admin. Code chs. SPS 381 to 387), which includes rules regarding the material composition allowed in plumbing products. Over the last 40 years, revisions of the plumbing code by DSPS and its predecessor agency, the Wisconsin Department of Commerce, banned the use of lead and/or reduced allowable lead content in specific water supply system components (Table 2).

*Table 2. Sunset Dates of Lead Use and Lead Content in Wisconsin Water Supply Systems.*

| Water System Component | Date | Details of Plumbing Code Revision |
|---|---|---|
| Water service | July 1976 | Reference to lead removed.<br>Lead did not appear in any of the new tables. |
| Water distribution | July 1976 | Reference to lead removed.<br>Lead did not appear in any of the new tables. |
| Solder | September 1984 | 50/50 (50% tin/50% lead) no longer allowed.<br>The maximum lead content of solder was reduced to 0.2% solder (95/5). |
| Pipes<br>Pipe fittings | January 2014 | Revised definition of "lead free" to apply to solders and flux, pipes, pipe fittings, and fixtures. For pipes, pipe |

| | |
|---|---|
| Plumbing fittings<br>Plumbing fixtures | fittings, and fixates, the definition includes a maximum total lead content and maximum weighted average for wetted surfaces. |

This information was provided by the Wisconsin Department of Safety and Professional Services (DSPS) and compiled via the DSPS online code archive and hard copies of former code editions.[74]

## Local Ordinances

A number of Wisconsin municipalities have passed ordinances related to lead in drinking water. While there is some variation among the different ordinances adopted by Wisconsin municipalities, they mostly focus on the replacement of the privately owned portion of LSLs through the creation of LSL replacement programs. Typically this is done in combination with removal of the system-owned lead service line in order to prevent or avoid partial lead service line replacement. To facilitate the replacement of LSLs, some municipalities have been able to leverage funding, such as funds received through the Wisconsin Department of Natural Resources (DNR) Private LSL Replacement Funding Program, to reimburse some of the costs borne by property owners.

# Lead Exposures Attributable to Contaminated Drinking Water

Despite widespread use of lead in most plumbing components and the resulting contamination of drinking water, some studies show that other sources of lead exposure often confer equal or greater risk for EBLLs. The following section reviews epidemiologic and modelling studies that estimate the risk attributable to consumption of lead-contaminated water in relation to common lead sources such as dust and paint.

## Epidemiology Studies

We conducted a literature review was conducted to examine the findings from epidemiology studies evaluating the risks of lead poisoning from consumption of drinking water (Appendix A). We reviewed 19 studies reviewed and they are summarized in Table A1. Of these, there are four studies that found a significant association between WLLs and BLLs while also controlling for lead present in other environmental media.[75-78] Levallois et al.accounted for lead in dust and paint (controlling for age, ethnicity, season, parental education, day care use, chronic disease, second-hand smoke, and parental occupational exposure to lead) and found a strong association between BLLs 1.78 µg/dL and higher, the upper quartile in the study population, and WLLs higher than 3.27 µg/L (odds ratio or OR=4.7, confidence interval or CI: 2.1-10.2).[75] Etchevers found that WLLs higher than 5 µg/L were associated with BLLs after adjustment for dust, soil, paint, as well as other factors, including second-hand smoke, presence of traditional ceramic cookware or cosmetics, and parental occupational exposure.[76] In two studies, Lanphear et al.found associations with BLLs at higher WLLs (higher than 5 µg/L), while adjusting for lead in dust, paint, iron intake, residence at rental vs. owner-occupied property, and race.[77,78]

Other epidemiology studies also show an association between WLLs and BLLs but do not control for lead in other environmental media. Pocock evaluated BLLs among adult men and showed a significant association both on the individual and the ecological (town of residence) level.[79] The association appeared to be linear at lower WLLs. This linear trend did not hold true at higher WLLs. Lacey studied mother-infant pairs and showed that among formula-fed infants, there was a significant association of WLL and BLL.[80] Watt found a significant association between WLL and maternal BLL, while Fillion reported a similar significant association among Inuit children living in Canada (other media were evaluated but not controlled for in the analysis).[81,82]

Two studies can be considered “intervention” studies. The first asked women to flush (run) the water before use and/or consume only bottled water as opposed to drinking tap water. This study found that WLL was associated with BLL and that the intervention resulted in decreases in BLL.[83] The other study examined BLLs among residents in a community where LSLs were removed and found that BLLs were lower after removal, but did not provide numerical results.[84]

Four studies found no association between WLL and BLL; two of these provided no numerical results.[85,86] Of the two studies that provided numerical results, one showed a nonsignificant association between increased WLL and EBLL children when compared with non-EBLL children (mean WLLs of 5.3 and 3.6, respectively) and the other did not find associations with any media studied (water, soil, and dust).[87,88]

## Modeling Studies

Given the challenges in designing epidemiology studies to assess and apportion the risk of lead exposure from various environmental sources, researchers have used mathematical modeling to isolate the potential effects of consuming lead-contaminated water. The EPA’s Integrated Exposure Uptake Biokinetic (IEUBK) Model for Lead in Children is a widely utilized tool that incorporates multiple sources of exposure and models lead intake and movement through the body. The IEUBK Model provides outputs predicting a plausible range of BLLs for an individual or group of individuals with the same exposure. The tool can also provide the predicted BLL geometric mean for a population along with the proportion of the population expected to exceed a specified threshold under a set of pre-specified conditions. A literature review was conducted to examine the findings from modeling studies evaluating the risks of lead poisoning from consumption of drinking water (Appendix A). Four studies were reviewed and are summarized in Table A2.

Three studies assessed the relative contributions of environmental sources of lead by incorporating home measurements of WLLs into the IEUBK Model. Hogan et al., compared IEUBK Model predictions with epidemiologic data for children aged 6 to 84 months and used first draw water lead measurements from three communities for model inputs.[89] However, the majority of WLLs were below the limit of detection and results describing contribution of water lead were not presented. Nonetheless, there was close approximation between predicted and measured BLLs (observed and predicted geometric mean BLLs were within 0.7 µg/dL), suggesting that unmeasured water lead sources were unlikely contributors. Goodrum et al. also utilized the IEUBK Model and did not compare predicted to measured BLLs. Instead, the model was used to predict lead exposures and BLLs among children aged 2–3 years. Model inputs for lead concentration in drinking water were higher at 26 µg/L based on pilot sampling data obtained from Syracuse, New York.[90] The authors estimated that for children with BLLs below 10 µg/dL, approximately 60% of total lead intake was from interior dust with less than 20% of total lead intake coming from soil and water. At BLLs higher than 25 µg/dL, the author estimated that lead from paint chips were the predominant source. Deshommes et al. used extensive water sampling data from residences in Montreal, Canada to predict lead exposures in children 0–7 years of age.[91] Sampling was conducted throughout the year to measure changes in WLLs with temperature. Background levels of lead in soil and dust were also integrated into the IEUBK Model and held constant over time. The model predicted that the percentage of children with BLLs higher than 5 µg/dL varied seasonally with WLLs and the highest percentage was predicted in older buildings with LSLs.

Two studies examined the contribution of lead from drinking water in schools. Sathyanarayana et al. utilized the IEUBK Model to predict BLLs in children aged 5–6 years in Seattle, Washington. First draw and 30-second flush sample results were used from 71 elementary schools.[92] Modelling assumed that 25% of water consumed came from the first draw sample and the remaining 75% from flushed water under worst case (90th percentile of WLLs) and typical (median WLLs) scenarios. Fifty percent of daily water intake was assumed to be from homes with estimated WLLs of 10 µg/L. Model inputs for soil, dust, and air were obtained from background levels for Washington state. Under worst case scenarios, predicted geometric mean BLLs at each school ranged from 1.7–5.0 µg/dL, with typical scenario means ranging from 1.6–2.8 µg/dL. Triantafyllidou used similar methods to predict BLLs before and after remediation (e.g., addition of water filters, removal of lead plumbing, periodic flushing) at schools in Seattle and Los Angeles, California. Under baseline scenarios with WLLs assumed to be zero, 2.8% of children were predicted to have BLLs higher than5 µg/dL. When school and home water lead exposures were incorporated into the model, this proportion increased to 11% before remediation and approximately 5% after remediation for the typical school.[93]

Pizzol et al. used an alternative model based on a biokinetic approach developed by Pounds and Leggett to assess risks of lead exposure among Danish children 0–6 years of age.[94] WLLs were assumed to be 4.3 µg/L based on environmental sampling. The model predicted that water ingestion contributed the most daily lead intake for children younger than 6 months and food sources contributed the most daily lead intake for children aged 6 months to 6 years.

The EPA's Science Advisory Board utilized the IEUBK Model to assess the risks of lead exposure from water under a variety of scenarios for children aged 0–12 months (Table 3).[44] Model input parameters for other lead sources were assumed to be zero. Assuming a worst case scenario with a WLL of 30 μg/L and daily water consumption of 1.5 liters per day (L/d), the model estimated that the mean BLL would be 8.2 μg/dL. Under this worst-case scenario, they predicted that approximately 86% of young children would exceed a BLL of 5 μg/dL without consideration of other sources of exposure.

*Table 3. Predicted geometric mean BLL (μg/dL) for Children Aged 0–12 Months*

| | **Water Consumption** | | | | | |
|---|---|---|---|---|---|---|
| | **0.5 L/d** | | | **1.5 L/d** | | |
| **Water Pb (μg/L)** | Blood Pb (μg/dL) | % above 5 μg/dL | % above 10 μg/dL | Blood Pb (μg/dL) | % above 5 μg/dL | % above 10 μg/dL |
| **10** | 1.2 | 0.0 | 0.0 | 3.3 | 18.7 | 0.9 |
| **15** | 1.7 | 1.2 | 0.0 | 4.7 | 44.7 | 5.4 |
| **20** | 2.3 | 4.7 | 0.1 | 6.0 | 64.8 | 13.7 |
| **30** | 3.3 | 18.7 | 0.9 | 8.2 | 85.6 | 34.1 |

Adapted from the EPA Science Advisory Board's Evaluation of the Effectiveness of Partial Lead Service Line Replacements[44]

A recent peer-reviewed publication by Zartarian et al. used the IEUBK Model coupled with the Stochastic Human Exposure and Dose Simulation (SHEDS) Multimedia Model to quantify relative contributions of water, soil, dust, food, and air to children's lead exposure.[95] The SHEDS Model can simulate aggregate or cumulative exposures over time for dietary and residential routes. When combined with the IEUBK Model, this approach allows for simulation of variability in lead exposures and doses for different pathways and different age groups. For children aged 0–6 months at the 90th to 100th BLL percentiles (2.15–8.50 μg/dL), soil and/or dust and water accounted for approximately 52% and 39% of the BLL, respectively. For children 12–23 months of age, ingestion of soil and dust was the predominant exposure source. Above the 90th BLL percentile for this age group, water is estimated to account for 7% of the BLL.[95]

## Summary and Implications for Public Health

The widespread use of lead in distribution system infrastructure and other plumbing components has presented a significant challenge. Although LSLs are the largest contributor to WLLs where present, lead in premise plumbing may also be a significant contributor to water contamination. Evidence of water contamination, in and of itself, is not sufficient to conclude that water is a significant contributor to EBLLs without also considering the magnitude of exposure, the characteristics of the population that is exposed, and relative contribution of other lead sources in the environment. Epidemiologic analyses provide evidence for an association between WLLs and BLLs and indicate that young children, particularly infants, are at increased risk. However, the epidemiologic literature is limited by both the small number of studies and the substantial variability in environmental sampling methods, analytic approaches, and target populations. These limitations make quantifying the relationship between BLLs and WLLs difficult for some populations of interest. Modelling approaches allow BLL predictions that closely approximate measured BLLs, provided model inputs accurately reflect the environmental conditions of the studied population. As with the epidemiologic literature, modelling studies are difficult to compare because they use a variety of different input assumptions and examine age groups with varying exposure risks.

Despite these limitations, these studies consistently indicate that ingestion of contaminated water can represent a significant fraction of the total lead exposure among young children. Formula-fed Infants less than 12 months of age appear to be at the greatest risk[80,83,96,97]; other environmental sources, particularly household dust, are more important contributors to exposure among older children. Given the increased vulnerability of young children to the toxic effects of lead, interventions to reduce exposure to contaminated water in this age group are likely to have the greatest public health impact. Studies assessing the contribution of water to adults' total exposure are fewer, and findings are less robust.

Adult exposures differ significantly from young children and typically occur through work, hobbies and recreational activities; use of alternative healing remedies; use of lead-glazed pottery; pica; and home renovation.[7] Exposures among pregnant women are similar, but the susceptibility of the developing fetus to transplacental movement of lead makes pregnant women a vulnerable group.[5] Consequently, reducing prenatal lead exposure by limiting exposure to contaminated water among pregnant women is a public health priority. Given that maternal ingestion of water lead alone is unlikely to result in BLLs high enough to significantly impact breast milk and infant BLLs, routine steps to reduce maternal exposure to contaminated water are likely to be sufficiently protective.

# Testing Water for Lead

## Lead and Copper Rule Compliance

Traditionally, testing household water for lead has been the recommended approach for understanding WLLs and informing whether action should be taken by the public water system to mitigate lead exposures. The sampling protocol required by the Lead and Copper Rule involves collection of a first draw sample (i.e., the first liter of water after a multi-hour stagnation period) from a household tap used for obtaining water for drinking and preparing food, such as a kitchen tap. This information is intended to characterize WLLs at the point of use at high-risk sampling locations in order that the public water system can take actions to reduce exposure to the community as a whole. Therefore, compliance testing is useful for understanding system-wide water quality conditions that may impact the risk of lead in drinking water.

## Evaluating Residential Water Consumers' Risk to Lead from Drinking Water

While the importance of compliance testing for lead in water should not be underestimated, many factors (e.g., materials present at various points in the water system, water and ambient temperatures, water use, and disturbances of the water system) affect WLLs. As a result, WLLs can fluctuate in an unpredictable manner, making it difficult to identify peak WLLs.[11,38,45,55,98-103] These factors make it difficult to use water testing to evaluate the potential risk from lead in drinking water on an individual household basis. Careful consideration is needed when interpreting and communicating the significance of data collected at the household level. The risk of falsely concluding that a household has low WLLs based on a single water test is a significant concern.

A handful of studies have evaluated sampling approaches to measure WLLs (Table 4), including some methods that could provide more accurate assessments of WLLs, either through profiling greater lengths of the premise plumbing or targeting specific major lead sources (e.g., an LSL).[38,45,98,104,105] Due to the variability in premise plumbing configuration among properties and/or the number of samples required, these procedures can be expensive, complex, and of questionable reliability for the characterization of peak WLLs.[38,98,104] For example, a study evaluating multiple lead sampling strategies found that conducting a full profile for each sampling event could identify potential peak WLLs. However, none of the other methods were found to be similarly proficient at finding peak WLLs.[98] Because of this, it is anticipated that the general public may find these methods unfeasible for characterizing their own household's risk for lead in water.

*Table 4. Examples of sampling strategies for lead in water*

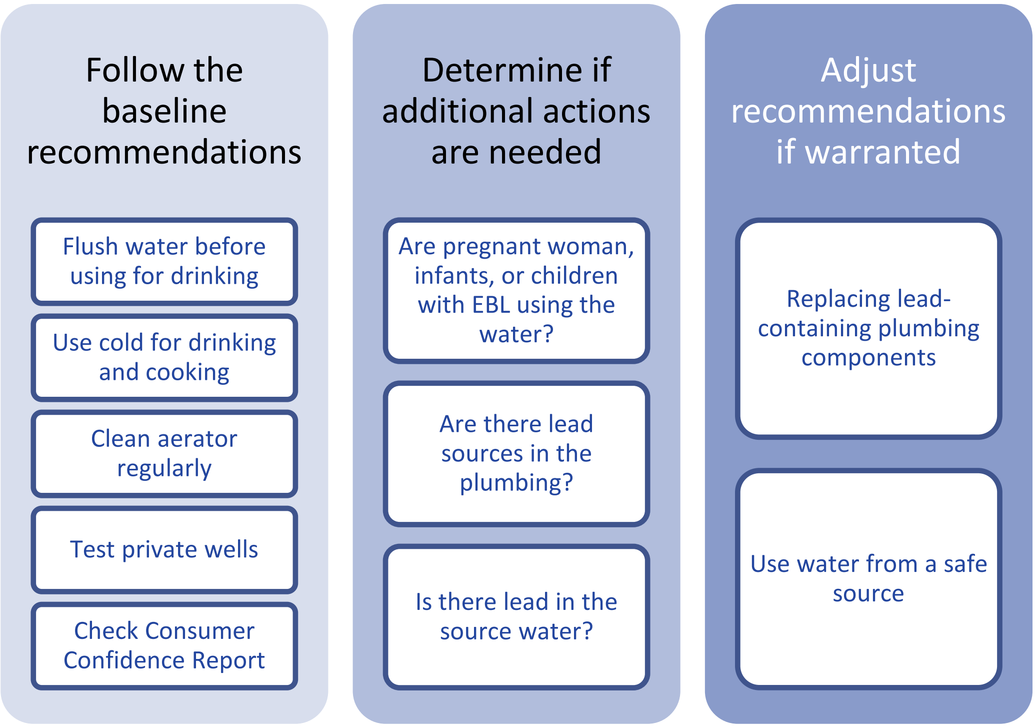
| Sampling Strategy | Goal | Limitations |
|---|---|---|
| Composite sampling | Collect a single large sample or multiple samples to average WLL over a greater sample volume. | This strategy averages results, making detection of peak WLLs less likely. |
| First draw sample | Collect a single sample of the first water to come out of the fixture after a designated stagnation time. | • This strategy may not identify peak WLLs if lead-containing components are upstream of sampling point.<br>• WLLs depend on how long the water has been in contact with the LSL during the stagnation time. |
| Random daytime sampling | Collect samples from the residence without further stagnation or flushing to gauge average exposure. | • This approach does not seek to identify peak WLLs.<br>• A large number of samples is required to characterize average exposure. |
| Sequential sampling | Create a profile of the plumbing system by collecting discrete volumes of water along a greater length of pipe. | • The expense is high (~$30/sample multiplied by ~10 samples).<br>• Organization and care are required to ensure that samples are not misordered.<br>• The number and volume of samples required depends on the specific premise plumbing configuration at the property. |
| Targeted LSL sampling | Collect water from the service line by using knowledge of premise plumbing configuration at the property to estimate when service line water is passing through the fixture. | Knowledge of the specific premise plumbing configuration and other parameters (e.g., pipe diameter) is required. |
| Temperature-based LSL sampling | Collect water from service line using the assumption that the temperature drops when service line water is passing through the fixture. | This approach is potentially subjective depending on how temperature is measured (e.g., gauging temperature by touch). |
| Time-based flushed sampling | Sample at multiple points in the premise plumbing by collecting water at different time points while running water from the main drinking water outlet. | This approach does not allow for reliable sampling from the same locations within premise plumbing at different properties due to variability in plumbing configurations. |

# Recommendations for Residential Water Consumers

The limitations associated with the interpretation of data from water testing raises questions about residential water consumers conducting water testing as the primary approach for assessing risks of elevated WLLs at individual properties. Thus, in developing the following recommendations, DHS considered approaches that, in combination, provide useful and actionable information for residents seeking to understand whether they should be concerned about lead in their drinking water and what steps they can take to address it.

DHS recommends a stepwise approach to minimizing the potential for lead exposure from drinking water (Figure 3). In this approach, DHS highly recommends that all residents follow a set of baseline actions, and take additional actions if property-specific information indicates they are warranted. In developing this approach, DHS considered information from the scientific literature, federal recommendations, and current state procedures.

*Figure 3. DHS's Stepwise Approach for Addressing Lead in Drinking Water*



## Baseline Recommendations

**DHS highly recommends that all residents follow, at a minimum, the baseline recommendations** as they are broadly beneficial. These recommendations include:

- Flushing the drinking tap when water has been sitting for more than two hours for at least 2–3 minutes.[c] Lead has been shown to rebound quickly after flushing, depending on factors such as water quality and the composition of plumbing materials.[83,107-110]
  - Cleaning aerators regularly and whenever the flow rate of the faucet is low or construction or plumbing work has been done in the area.
  - Using only cold water tap for drinking or food preparation including infant formula.
  - Testing private wells for lead at least every five years, and testing before it will be used by a pregnant woman or to feed an infant (under 24 months).
  - Checking the Consumer Confidence Report annually to see if elevated lead levels have been found in the community water system.

By implementing these baseline recommendations, residents can protect themselves from lead and a wide range of potential concerns associated with ingesting lead. Following the recommendations helps residents avoid consumption of water that has been in contact with plumbing materials for extended periods of time and may contain elevated levels of particulate matter or dissolved metals.

## Evaluating the Need for Additional Recommendations

While the baseline actions help all residents reduce lead exposure, there are situations in which additional actions may be needed. To determine if additional actions are needed, three pieces of information are evaluated: who is using the water, whether or not there are lead sources in the premise plumbing, and whether or not there is lead in the source water.

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[c] To evaluate potential flushing times, DHS used the following assumptions:

- Flushing the tap involves fully opening the faucet.
- Maximum faucet flow rate can vary from 1.26 gallons per minute (gpm) to 3.02 gpm, based on a survey of flow rates from 21 faucets.[106. Welter G. Typical Kitchen Faucet-Use Flow Rates: Implications for Lead Concentration Sampling. *Journal - American Water Works Association.* 2016;108:E374-E380.]
- Premise plumbing pipes are generally either 5/8” or 3/4” in diameter.

Based on these assumptions, a two-minute flush is anticipated to clear water from 157 to 377 feet of 5/8” pipe, or 110 to 263 feet of 3/4” pipe. An American Water Works Association report describes survey data from 90 water utilities in which maximum reported length of service lines (i.e., main to residence) were 83 feet (for urban areas) and 110 feet (for suburban areas). (45. Sandvig A, Kwan P, Kirmeyer G, et al. Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues. In: Awwa Research Foundation; 2008.) This suggests a two- to three-minute flush would likely be sufficient in that the faucet would be dispensing water from the main.

## Who is using the Water?

Additional protective measures are recommended if pregnant women, infants (under 24 months), or children with elevated blood lead levels are using the water, as these groups are more susceptible to the negative health effects caused by lead.

## Are there Sources of Lead in the Plumbing?

The available literature on sampling methods for water lead analysis highlights the inability of basic sampling procedures to reliably identify peak WLLs as well as the expense and complexity associated with water sampling methods that can comprehensively evaluate WLLs in a home. Given this, DHS concludes that basic sampling procedures (e.g., first-draw sampling) do not generally provide enough reliable information about WLLs to be of value to public water supply users conducting their own water lead assessments. Rather, DHS recommends the collection of information through other methods to inform the decision making of public water supply users.

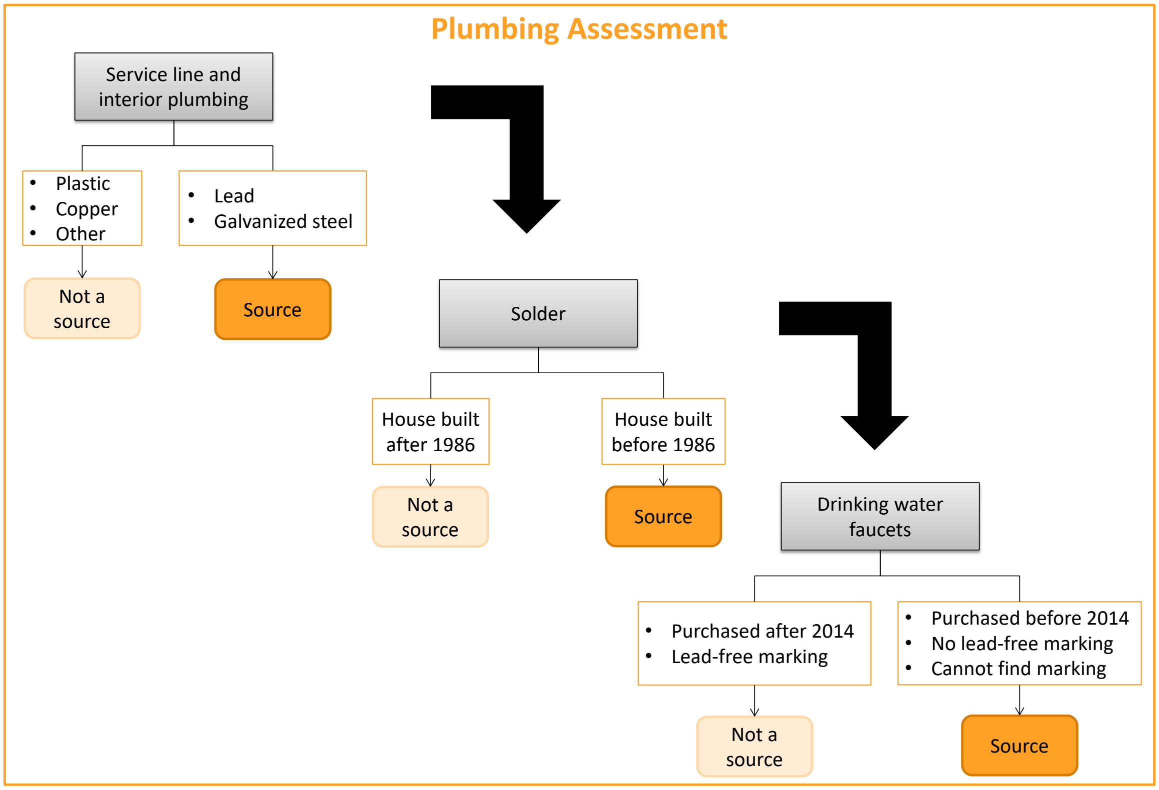
A plumbing assessment can provide important information about the potential for elevated WLLs in a home. DHS recommends that all residents conduct a plumbing assessment of their home to better understand the materials in their premise plumbing. This assessment involves collecting information about the components present in the property's plumbing system. Specifically, residents determine what type of service line, interior pipes, and fixtures are present in their home and whether lead solder is present (Figure 4).

***Service lines and interior pipes;*** Several online tools can be used to determine what type of pipes (service line, interior pipes) are in the home.[111,112] Service lines and pipes made from lead and galvanized steel are sources of lead. In general, residential private service lines made of plastic and copper are not considered a source of lead. For more specific information about their home, residents can reach out to the water utility to see if there is a record of homes that have lead service lines on the public side.

***Solder.*** Before 1986, tin-lead solder was used in many homes. Homes built before 1986 that have not undergone major plumbing repairs are assumed to have solder as a source of lead.

***Leaded brass.*** Brass in fixtures or components (including the water meter) purchased or installed before 2014, without a "lead free" marking or where a marking cannot be found, are considered sources of lead.[63]

*Figure 4. Components of the Plumbing Assessment*



## Is There Lead in the Source Water?

***Public water source.*** The water system's lead test results from LCR compliance sampling provide general information about lead levels in the system's water prior to contributions from premise plumbing in individual homes (i.e., the source water). However, given the wide potential variation in premise plumbing materials and configurations at individual properties, the LCR data is incapable of describing WLLs that might be found at any unmonitored location.

***Private water source.*** Lead contamination of water can come from both natural and built environment sources. Private wells are not subject to the same monitoring requirements that apply to public water systems. Thus, unlike properties served by a public water system, it is the responsibility of private well owners to use water testing to understand their water quality. Data collected using basic water sampling procedures can be used to characterize groundwater quality.

For properties that rely on private water supplies, DHS recommends that samples be collected from the cold water kitchen tap after flushing for at least five minutes to evaluate whether the groundwater or well components are a source of lead. If the sample has lead 15 µg/L or higher[d], additional sampling may be needed to determine the source of the lead.

## Adjust Recommended Actions as Appropriate

Given the range of actions available to protect against lead exposures and their differences in cost, effectiveness, and ease of implementation, DHS considered the information collected about water user, plumbing sources, and source water to help residents select which options will be sufficiently protective in their particular situation.

When vulnerable populations (infants under 24 months, pregnant women, children with EBLL) are present, extra precautions may be warranted to reduce the potential for lead poisoning. While infants and young children are the most susceptible to lead poisoning, lead is hazardous to everyone and all residents should take steps to reduce lead exposure as much as possible. If there are known lead sources in the service line, premise plumbing, or source water, removing these sources are the surest way to reduce exposure.

The list below outlines additional actions that residents can take to further reduce exposure to lead in drinking water.

- Consider replacing as many lead sources in the plumbing system with as many "lead free" components as feasible.[63]
    - Replace lead and galvanized steel service lines (highest priority).
    - Replace any interior pipes made from lead or galvanized steel.
    - Replace brass fixtures purchased before 2014 (lowest priority).
- Use water from a known safe source for drinking and food preparation including infant formula.
    - Use bottled water.
    - Use a water-filtered water pitcher or other point-of-use filter with an NSF certification[e] to remove lead.[113]

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[d] For this assessment, 15 µg/L is used as an indication that additional action should be taken to reduce lead exposure. This value is Wisconsin's public health enforcement standard for the protection of groundwater for lead and is the value used as the action level by SWDA to trigger additional actions by public water systems.

[e] Filters and treatment devices should be certified to meet NSF 42 and NSF 53 standards. As an additional measure, NSF 42 Particulate (Class 1 / 0.5-1 um) certification often co-occurs with NSF 53 for lead (but less commonly so with pitcher filters than faucet mount or separate-tap/under sink POUs). The specific certification for particulate helps protect against particulate lead.

  - Install a water treatment device certified by the Wisconsin Department of Safety and Professional Services (DSPS) to remove lead. [114]
  - Drill a new well (private wells with lead in source water).

## Scenarios Illustrating Conditions for Additional Action

DHS created a summary of possible scenarios illustrating when residential water consumers should take additional actions to reduce exposure to lead in drinking water. **In general, extra precautions are recommended when vulnerable populations are present and there are lead sources in the home.** In cases where vulnerable populations are not present, but lead sources are found in the home, DHS recommends that homeowners address these sources as feasible.

| Scenario | Are vulnerable populations using the water? | Are there lead sources in the premise plumbing? | What is the water source and does it have lead? | Additional Actions Recommended |
|---|---|---|---|---|
| 1 | Yes | Yes | Public - No | • Consider replacing lead plumbing components.<br>• Use water from safe source. |
| 2 | No | Yes | Public – No | Consider replacing lead plumbing components. |
| 3 | Yes | Yes | Private – No | • Consider replacing lead plumbing components.<br>• Use water from safe source. |
| 4 | No | Yes | Private – No | Consider replacing lead plumbing components. |
| 5 | Yes | Yes | Private – Yes | • Consider replacing lead plumbing components.<br>• Use water from safe source or drill a new well. |
| 6 | No | Yes | Private – Yes | Consider replacing lead plumbing components. |
| Vulnerable populations include pregnant women, infants (under 24 months), and children with EBLL<br>For each of these scenarios, renters should contact the landlord or homeowner and let them know that the plumbing poses a risk to their family. | | | | |

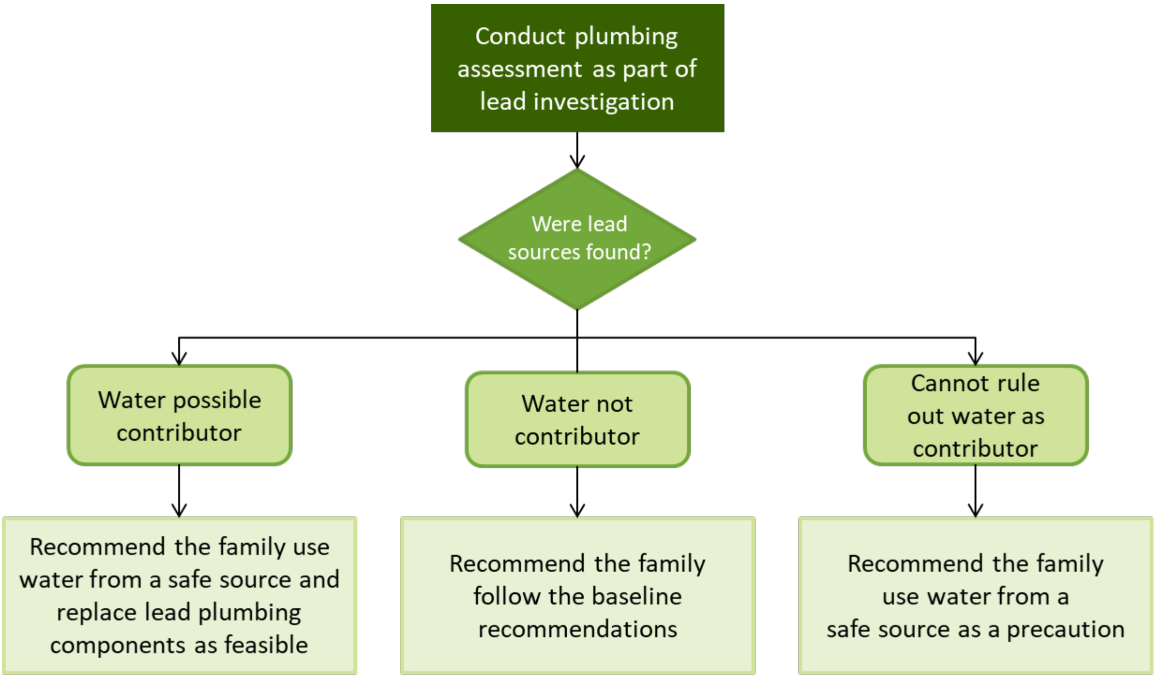
*Table 5. Scenarios Where Additional Actions are Recommended to Reduce Lead Exposure*

# Recommendations for Public Health Professionals

In Wisconsin, local health departments (LHDs) are required to conduct investigations for children under 6 years of age that have one of the following: a level of lead in blood that is 20 µg/dL or higher, as confirmed by one venous blood test, or 15 µg/dL or higher, as confirmed by two venous blood tests performed at least 90 days apart. DHS highly recommends that LHD staff routinely conduct a plumbing assessment (as described in Figure 4) as part of this investigation. The results of this assessment can be used to determine if the family should take additional actions to reduce exposure to lead in drinking water (Figure 5).

- If lead sources are found during the plumbing assessment, DHS recommends that the family use water from a known safe source for drinking and food preparation, and replace lead-containing plumbing components as feasible.
- If lead sources are not found during the plumbing assessment, DHS recommends that the family continue to follow the baseline recommendations.
- If a plumbing assessment cannot be completed (e.g., staff cannot find the private-side service line or indoor piping), DHS recommends that the family use water from a known safe source for drinking and food preparation, including infant formula, as a precaution.

*Figure 5. Process for Determining if Additional Actions are Needed to Reduce Lead Exposure from Drinking Water as Part of an EBLL Investigation*



In many cases, a plumbing assessment may provide sufficient information such that measuring WLLs is not needed to inform lead remediation actions. However, there are some situations in which water testing may be warranted to evaluate the potential for lead exposure. For instance, as described above, water testing is recommended in homes with private wells. For these cases, DHS recommends that a water sample be taken at the pressure tank to determine if the groundwater or well may be a source of lead. Another scenario in which water testing may be warranted, is after a lead service line disturbance has occurred or when no other lead sources can be found in and outside the home. In these cases, LHDs should consult with DHS to determine whether water testing is appropriate. DHS will determine what protocol should be used in these cases based on available information.; The protocol will likely involve collecting a profile of lead in the drinking water and considering WLL variability over time. Through its basic agreement with the Wisconsin State Laboratory of Hygiene, DHS has the ability to support fee-exempt lead analysis of water samples collected by LHDs.

## Conclusions

Lead is a pervasive contaminant and exposure occurs through a variety of media. Although interventions targeting the most prominent lead sources (e.g., leaded gasoline and paint) have resulted in substantial reductions in BLLs, continued efforts to eliminate other lead sources are needed as adverse health effects are observed at very low levels of lead exposure. Lead-contaminated water has received increased attention as an underappreciated source of lead exposure given the historical use of lead-containing plumbing components. While epidemiology and modelling studies are unable to precisely apportion the risk attributable to ingestion of contaminated water, the balance of evidence indicates that water is an important source of lead exposure, particularly among young children. Current and proposed federal, state, and local regulations will continue to reduce the risk of exposure, but lead plumbing components remain in widespread use and will continue to present a hazard for the foreseeable future. Comprehensive recommendations for homeowners and guidance for local health departments are needed to address this risk in the context of broader lead mitigation efforts.

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# Appendix A: Summary of Epidemiological Studies

**Table A1. Epidemiological Studies on Risk of Lead in Drinking Water**

| Citation | Place | Medium/Media examined | Water testing protocol | Population | Main results/findings |
|---|---|---|---|---|---|
| Brown et al., 2010 | Washington, DC | Presence of LSL at residence, partial/full LSL replacement; disinfection with chlorine, chloramine, and chloramine+orthophosphate | N/A – presence of LSL determined by water suppliers | 63,854 children <6 years with a BLL reported to Washington DC Department of Health during 1998-2006 | Presence of LSL independent risk factor for BLL ≥10 and 5 µg/L. OR of BLL >10 was 3.3, comparing partial LSL replacement vs. no LSL |
| Levallois et al., 2014 | Montreal, QC | Drinking water, house dust, paint | 5 one-liter samples of cold kitchen tap water; first sample followed a 5 min. flush at typical flow (5 to 7 L/min);after a 30-min stagnation period, 4 consecutive liters sampled | 306 children aged 1–5 years currently drinking tap water and residing in certain Montreal boroughs | Geometric mean (GM) of samples ranged from 0.9 to 1.9 µg/L (overall GM was 1.6)<br>WLL associated with BLL (OR for BLL ≥75th percentile = 4.7 when WLL>3.3 µg/L) |
| Edwards et al., 2009 | Washington, DC | Water, presence of LSL | 1 L sample after 6h holding time (EPA protocol), plus “flushed” sample | 28,000 records from Children’s National Medical Center, children aged ≤30 months | No correlation between BLL and WLL over entire dataset; Comparing “high” to “low” risk zip codes showed statistically significant difference (test unknown) |

**Table A1. Epidemiological Studies on Risk of Lead in Drinking Water**

| Citation | Place | Medium/Media examined | Water testing protocol | Population | Main results/findings |
|---|---|---|---|---|---|
| Etchevers et al., 2014 | France, French West Indies, Reunion Island | Presence of LSL at residence | N/A– presence of LSL determined by water suppliers | 3,831 children aged 6 months–6 years, recruited at hospital pediatric departments, without "severe disease" or chelation indicated | Drinking LSL water (vs. bottled water) was the factor most strongly associated with BLL (GM: +51% for tap water only and GM: +66%for both tap and bottled water); in the absence of LSL, drinking only tap water (vs. bottled water) resulted in a BLL (GM) +12% |
| Etchevers et al., 2015 | France | Water, soil, dust, paint, cosmetics, traditional cookware | 2 L sample collected after 30-minute stagnation | 484 children aged 6 months-6 years, recruited at hospital pediatric departments, without 'severe disease' or chelation indicated | WLL ranged from <1 to 74 µg/L, with a median of <1<br>Household dust and tap water were biggest contributors to GM and 90th quantile of BLLs (WLL: +44% in GM with a range of 1 to 14 µg/L); WLL >5 µg/L positively correlated with the GM, 75th and 90th quantiles of BLLs in children drinking tap water |
| Fertmann et al., 2004 | Hamburg, Germany | Water | By participant: stagnant water in morning, water taken after 3 minutes of flushing, water at lunchtime "intended for cooking" | Non-smoking women aged 20-30 years living at residence for at least one year (no pregnant or breastfeeding women)<br>248 in cross-sectional study, 52 in intervention program (flushing/bottled water) | WLL generally higher for stagnant water sample (mean 24 µg/L) compared with flushed water sample (mean 6 µg/L) or "lunchtime" (mean 16 µg/L) samples<br>WLL strongly associated with BLL (Spearman rho=0.43); the intervention decreased BLL significantly (21-37%) but was deemed non-sustainable |

**Table A1. Epidemiological Studies on Risk of Lead in Drinking Water**

| Citation | Place | Medium/Media examined | Water testing protocol | Population | Main results/findings |
|---|---|---|---|---|---|
| Lacey et al., 1985 | Glasgow, Scotland | Water and diet (milk/formula) | By participant: "kettle" water samples per normal use habits, first draw (1L) after overnight stagnation, random daytime sample (1L) taken at other point during the day | 131 mother-infant pairs followed prenatal to ~13 weeks postnatal | First draw>Kettle>Daytime WLLs<br>Formula-fed infants had significant association of WLL and BLL |
| Lanphear et al., 2002 | Rochester, NY | Dust, paint, soil water – sampled at baseline (6 months), 12, 18, and 24 months | By participant: 0.25L collected after 1 minute of flushing from kitchen tap | 276 children, 90% followed from 6-24 months participating in a separate dust control RCT | 65/181 (44%) samples had WLL >LOD of 5 ppb<br>WLL >5ppb significantly associated with BLL in multivariate analyses (estimated increase of 1.02 µg/dL) |
| Lanphear et al., 1998 | Rochester, NY | Dust, paint, soil water | By participant: 0.25L collected after 1 minute of flushing from kitchen tap | 183 children aged 12-31 months participating in a separate dust control RCT | WLL nearly significantly associated with BLL in multivariate analyses (slope=0.07, p=0.06)<br>Increase from background (0.0005 mg/L) to 0.015 mg/L estimated to increase BLL by 1.6 µg/dL |
| Ouholte et al., 2011 | France | Dust, paint, soil, water | 2 L sample collected after 30-minute stagnation | 125 children aged 6 months–6 years with BLL≥2.5 µg/dL, recruited at hospital pediatric departments, without "severe disease" or chelation indicated | "The geometric mean of B-Pb was 30 µg/L in case of dust as a single contamination source, 36 µg/L for paint, 70 µg/L for water, 38 µg/L for soil, and 38 µg/L for unusual sources" |

**Table A1. Epidemiological Studies on Risk of Lead in Drinking Water**

| Citation | Place | Medium/Media examined | Water testing protocol | Population | Main results/findings |
|---|---|---|---|---|---|
| Pocock et al., 1983 | UK | Water | By participant: 1L first draw water<br>By researcher: 1L random daytime, 1L after flushing (10 pipe volumes of water) | 910 men aged 40-59 years | Order of WLLs: First draw>Daytime>Flushed; WLL was negatively associated with hardness of water<br>BLL and WLL were significantly associated at all levels, but differs according to WLL (~linear up to 100 µg/L, less steep afterward)<br>"…we have estimated that as first-draw water lead increases from 0 to 100 µg/L, mean blood lead increases from 0.7 to 1.0 µmol/L. The chance of an individual having blood lead >1.7 µmol/L increases from under 1% to over 5%" (p.6) |
| Rabinowitz et al., 1984 | Boston, MA | Water, indoor air | Kitchen tap, cold water collected after 4L flush at 1 and 6 months of age | 232 infants followed from birth to ~6 months | No correlation between BLL and WLL |
| Schlenker et al., 1989 | Milwaukee, WI | Water | By sanitarian: first draw, and after 2- to 3-minute flush | 37 pregnant women+9 women of childbearing age | No numeric results; authors state that no significant correlation was found between WLL and BLL |

**Table A1. Epidemiological Studies on Risk of Lead in Drinking Water**

| Citation | Place | Medium/Media examined | Water testing protocol | Population | Main results/findings |
|---|---|---|---|---|---|
| Thomas et al., 1979 | UK | Water – sampled 3 times at 2- week intervals | By participant: first draw<br>By researcher: first draw during visit ('daytime') and after flushing for 5 minutes. | 55 adult women and 39 children in "lead estate"<br>60 adult women and 20 children in "copper estate" | Lower BLLs observed following LSL removal<br>Curvilinear relationship between WLL and BLL observed (see fig 1 in the paper), but no numeric results were presented |
| Watt et al., 1996 | Glasgow, Scotland | Water | By researcher: "repeat kettle water sample," 1L daytime sample | 342 mother-infant pairs | Significant association observed between WLL and BLL (Spearman rho=0.4)<br>"The estimated proportions of cases of maternal blood lead concentrations above 5 and 10 μg/dL, which were attributable to a tap water lead concentration above 2 μg/L, were 62% and 76% respectively." (page 980) |
| Fillion et al., 2014 | Canada | Water, soil, dust, paint, food | From tap most often used for drinking water; "water was allowed to flow rapidly until the pressure pump was initiated. The tap was closed for 30 min and the first liter of tap water was collected" | 34 participants— Nunavat adults with elevated BLLs participating in the Inuit Health Survey, as well as children (<10 years old) and pregnant women from their households; 18 adults and 16 children participated in total | Significant association observed between WLL and BLL (Spearman rho 0.63); both WLL and BLL were elevated for 3 adults<br>Lead isotopic composition in water samples was not similar to that found in blood samples |

**Table A1. Epidemiological Studies on Risk of Lead in Drinking Water**

| Citation | Place | Medium/Media examined | Water testing protocol | Population | Main results/findings |
|---|---|---|---|---|---|
| Gulson et al., 2013 | Australia | Water, soil, dust, paint | "A tap water sample was collected if the residents had not collected an early morning sample as requested at the previous visit." | 30 children aged 1-4 years participating in a national survey of BLL | WLL and BLL were not significantly associated but median value was somewhat lower in those with non-EBLL (defined as <15 µg/dL) - medians of 3.6 and 5.3, respectively |
| Hinwood et al., 2013 | Australia | Water, soil, dust | By participant: 0.5L from 'most common source in home' for drinking water | 173 non-smoking women participating in the Australian Maternal Exposure to Toxic Substances (AMETS) study | "The concentrations of lead were low and no factors were identified that influenced biological concentrations." (p121)<br>Note that all WLL were <10 µg/L, median was 0.4 µg/L |

### A2. Modeling Studies on Risk of Lead in Drinking Water

| Citation | Place | Medium/Media examined | Water Testing Protocol | Population | Main results/findings |
|---|---|---|---|---|---|
| Deshommes et al., 2013 | Montreal, QC | WLL | See Table 1— varied by data source (4 separate studies); Note: Total Pb in tap water was considered as soluble Pb and 50% bioavailable | Children aged <8 years | Differences in WLL by: season (warmer>cooler); water temperature (warmer>cooler); type of dwelling (single home>multi-unit); presence of LSL<br>Highly dependent upon sampling season and protocol |
| Gulson et al., 1997 | Australia | Drinking water, default IEUBK model values for outdoor/indoor air, indoor dust, diet, and outdoor soil | First draw: 100 µg/L<br>Daily average: 46 µg/L | Children aged 0.5-7 years consuming all water at home<br>Considered four exposure scenarios:<br>• 46 µg/L at 50% consumption of first-draw water<br>• 46 µg/L at 100% consumption first-draw water<br>• 100 µg/L at 50% consumption of first-draw water<br>• 100 µg/L at 100% consumption of first-draw water | BLL would exceed 10 µg/dL if 100% of consumed water contained 100 µg/L. BLLs could possibly exceed 10 µg/dL if >0.5 L first-flush water was consumed by a formula-fed infant or a pregnant woman |
| Sathyanarayana et al., 2006 | Seattle, WA | Drinking water, default IEUBK model values for outdoor/indoor air, indoor dust, diet | First draw: 1-1600 µg/L<br>Second draw: 1–370 µg/L<br>Home levels fixed at 10.3 µg/L<br>Soil levels fixed at 24 µg/g | Children aged 5–6 years consuming half their water at one of 71 schools, and half at home;<br>Considered 50th and 90th percentiles of WLL in schools | No instances of BLL exceeding 10 µg/dL were modeled |

## A2. Modeling Studies on Risk of Lead in Drinking Water

| Citation | Place | Medium/Media examined | Water Testing Protocol | Population | Main results/findings |
|---|---|---|---|---|---|
| Triantafyllidou et al., 2014 | Some data from Gulson and Sathyanarayana publications | SCENARIO 1: 1- to 2-year-old child drinking tap water, background exposures from other lead sources set to IEUBK default values<br>SCENARIO 2: Formula-fed, average consumption; dietary exposure set to 0, background exposures from other lead sources set to IEUBK default values<br>SCENARIO 3: Formula-fed infant, high consumption; background exposures from other lead sources set to 0 | SCENARIO 1: 500 mL/day water consumption, Geometric Standard Deviation (GSD) 1.6 µg/dL (IEUBK default)<br>SCENARIO 2: 800 mL/day water consumption, GSD 1.45 µg/dL<br>SCENARIO 3: 1,200 mL/day water consumption, GSD 1.6 µg/dL (IEUBK default) | Young children (hypothetical) | Predicted WLL for 50% of children to exceed 5 µg/dL was 18 µg/L (scenario 2),<br>20 µg/L (scenario 3), or 24 µg/L (scenario 1); other results can be found in Table 3 of the paper, indicating that even low WLLs can affect sensitive populations |