A Critical Opportunity: Lead in Drinking Water at Child Care Facilities

By

Elizabeth Stanbrough

A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
May 1, 2021

Keywords: lead, drinking water, child care facilities, lead mitigation, LCR revision

Approved by

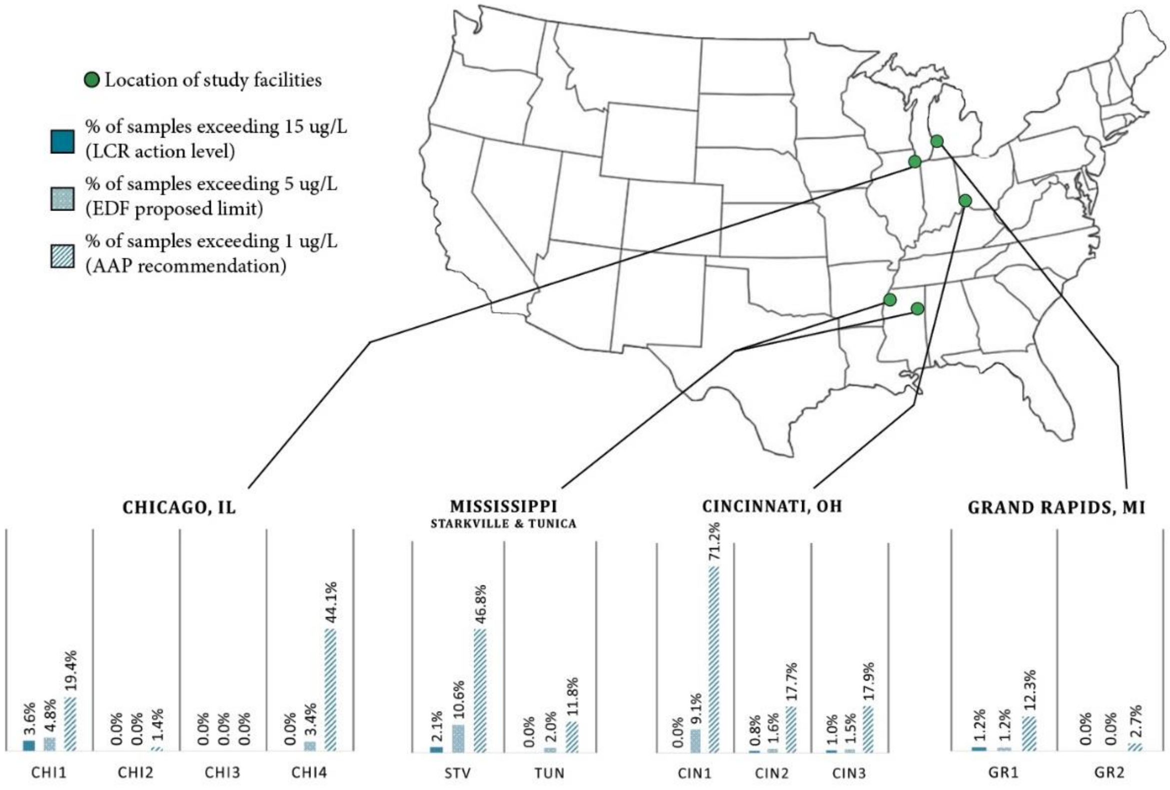
Mark Barnett, Chair, Professor of Civil Engineering
Dongye Zhao, Professor of Civil Engineering
Natalie Capiro, Professor of Civil Engineering

Abstract

There is no safe level of lead exposure. As exposure from point sources like lead paint have been reduced through legislation, non-point sources such as drinking water have become a greater proportional source of total lead exposure. Even at low levels, lead exposure is shown to harm children, contributing to impaired development as well as learning and behavioral issues. This paper summarizes the key results of an Environmental Defense Fund (EDF) pilot study conducted at 11 child care facilities in 4 US states to evaluate approaches to testing and remediating lead in water at child care facilities.

Ten of 11 child care facilities produced at least one sample above 1 μg/L, the action level recommended by the American Academy of Pediatrics. Fixture flushing, aerator cleaning, and fixture replacement were evaluated as remediation strategies. The LCR revision approved December 2020 was found to be inadequate in prompting mitigation at locations where lead was widespread in this facility sample set.

Graphical Abstract



Pb levels at study locations exceeding referenced Pb-in-water recommendations. Lead in drinking water is a particular threat to children. Even in locations where a majority of all samples contained lead above the AAP-recommended level, comprehensive testing and a lower action level are needed to ensure detection of persistent lead.

Acknowledgements

I thank my advisor, Dr. Mark Barnett, for his encouragement to pursue a thesis amid a global pandemic and his support in coordinating the study partners.

Funding for this study was provided to Environmental Defense Fund by the W.K. Kellogg Foundation. Local partners recruited child care facilities into the study and oversaw sample collection at each site: Elevate Energy (Chicago), Greater Cincinnati Water Works (Cincinnati), Healthy Homes Coalition of West Michigan (Grand Rapids), Mississippi State University Extension (Starkville and Tunica), and People Working Cooperatively (Cincinnati).

Table of Contents

List of Tables

List of Figures

1.0 Introduction

1.1 Problem Statement

Lead is a neurotoxin that has threatened human health throughout history. Some of its damaging effects have long been recognized, though more subtle, long-term effects have only been documented relatively recently, in light of centuries of exposure. In the US, lead paint and leaded gasoline were recognized as major sources of lead exposure in the 1970s. These sources were strictly regulated and lead has been entirely removed from gasoline and new paint, though already-applied lead paint is still a hazard as it ages. Lead reductions in paint and gasoline led to a decline of children aged 1 to 5 with mean blood lead levels (BLLs) greater than 10 μg/L from 80% in 1980 to 0.8% in 2010 (CDC, 2013). As these exposure sources have decreased, sources like water and dust have become the focus of eliminating environmental lead. Recent studies suggest that non-paint exposure sources have been underestimated (Cartier et al., 2012) and exposure from lead in water is particularly high for infants 0-6 months of age due to consumption of formula reconstituted with water (Zartarian et al., 2017).

Lifelong negative outcomes from persistent low levels of lead exposure have been documented and children under the age of six are most vulnerable to the effects of environmental lead exposure (EPA, 2012). Lead in tap water as low as 3.27 μg/L has been shown to impact children's BLLs, cognitive development, and lifetime achievement (Triantafyllidou et al., 2014a). Excess lead in drinking water is highly localized, even to the level of specific zip codes and neighborhoods (Edwards et al., 2008); (HHS, 2020). Lead exposure follows the trend of many environmental risk factors: people in lower socioeconomic areas bear the highest risk (Marshall et al., 2020); (Triantafyllidou et al., 2014a).

Lead enters public drinking water by leaching from pipes, solder, and fixtures on the way to the tap (Elfland et al., 2010). Lead service lines (LSLs), where present, can contribute up to 75% of lead in water (Sandvig et al., 2008), and current best practice is removal of LSLs where found. Even where LSLs are not present, lead-alloyed fixtures and pipes can leach lead into water (Deshommes et al., 2010) and previous study suggests that fittings may contribute more total lead than non-lead pipes (Pieper et al., 2015).

1.2 Objectives

Child care facilities present a unique opportunity to mitigate lead exposure for clusters of the most vulnerable age and socioeconomic groups. In 2016, over 8 million children under the age of six were cared for by center- or home-based child care facilities (Digest of Education Statistics, Table 202.30). The Environmental Protection Agency (EPA) published recommended testing, sampling, and mitigation guidelines for schools in "3Ts [Training, Testing, and Taking Action] for Reducing Lead in Drinking Water" with an original action level of 20 μg/L. The American Academy of Pediatrics recommends 1 μg/L as the most appropriate health-based action level, based on widespread testing capabilities.

The Lead and Copper Rule (LCR) sets lead-in-water testing and treatment requirements for public water utilities and did not include testing of child care facilities or elementary schools until almost 2021. The LCR contains an action level of 15 μg/L, with the stated reasoning that it is based on corrosion control feasibility in public water distribution systems (HHS, 2020). The World Health Organization (WHO) recommends a limit of 10 μg/L Pb, also based on technical feasibility (SCHER, 2011).

Environmental Defense Fund (EDF) conducted sampling and mitigation loosely based on the EPAs' 3Ts guidance. In collaboration with local partners, 2 LSLs were replaced, and samples were collected at 11 child care facilities. Recommendations in the 3Ts and other public guidelines include flushing, aerator cleaning, and fixture replacement as the most effective and accessible mitigation methods for public citizens. These techniques were implemented, and samples were collected before and after each mitigation method. The study was undertaken as an intervention and proof-of-concept at the involved facilities, to determine how effective the guidelines would be for any facility director who voluntarily addressed lead in water.

The resulting data illuminated two distinct problems related to the national regulations and guidelines regarding lead in drinking water: (1) action levels are not health-based and are much too high to be useful for triggering mitigation where lead is found in water (2) if action levels are lowered to be more proactive in protecting health, recommended mitigation methods may not be reliable, efficient, and affordable. This thesis analyzes the results to determine whether the LCR revision approved December 2020 would be likely to prompt mitigation at locations in this sample set, and whether common mitigation techniques as recommended by public health guidelines show statistical benefit. The results may be a useful addition to the literature as the most exact assessment of published guidelines that has thus far been conducted.

1.3 Organization

The organization of this report follows the guidelines for a publication-style thesis. This thesis includes four chapters. Chapter one identifies the problem and key objectives of the study. Chapter two contains a review of foundational literature and related studies. The materials, methods, results, and discussion from the drinking water study are presented in chapter three. This chapter is formatted as a draft manuscript, which will be submitted for publication. Chapter four contains original analysis of the EDF study, as well as recommendations for future work.

2.0 Literature Review

2.1 Effects of Lead on Children

Very high levels of lead exposure can cause significant and obvious symptoms including abdominal pain and vomiting, encephalopathy, and even death (Hauptman et al., 2017). The United States phased out major sources of lead, leaded paint and gasoline, beginning in the 1970s and the prevalence of elevated blood levels in children has since fallen drastically (CDC, 2017). As those primary sources have been eliminated, other environmental sources of lead such as household dust, soil, and drinking water have emerged as the next targets to further reduce lead exposure.

At lower levels, lead poisoning manifests as more benign symptoms such as headaches, abdominal pain, skin sensitivity, etc. In 2012 the CDC lowered the reference value for blood lead in children from 10 ug/dL to 5 ug/dL, based on the 97.5th percentile of a survey of blood lead in children. Though children are more protected from routine exposure to significant lead, there is enough lead in their environment to put the most sensitive children at significant risk (Triantafyllidou et al., 2014a). Effects of lead up to 5 ug/dL include decreases in IQ, cognitive achievement, increased attention-related and problem behaviors (Hauptman et al., 2017). Effects of lead up to 10 ug/dL, include decreased auditory function, reduced postnatal growth, and delayed puberty as well as effects from lower levels (Hauptman et al., 2017).

Edwards et al conducted extensive study of widespread elevated lead events in

Washington, DC (Edwards et al., 2008) and Flint, Michigan (NRDH). In both events, testing for lead in water was found to be difficult to reproduce and widely variable among homes and neighborhoods. A later study of lead exposure risk assessment methods determined that existing regulations established to protect the "average" child are misguided. Lead prevalence is highly correlated with zip codes, therefore considering all children to determine baseline limits, including children living largely free of lead exposure, sanctions exposure for children most at risk of detrimental effects of continued exposure (Triantafyllidou et al., 2014a).

Marshall et al found strong negative associations between high-lead-risk census tracts and low-income cognitive scores in children when assessing cortical surface area, a proxy for cognitive development. They identified a need for higher spatial resolution in lead risk maps, ie census tract or block rather than existing zip code resolution, to pinpoint the most at-risk populations and provide a means of targeting remediation for the potential worst cases. Housing age and poverty rates were found to significantly contribute to lead-risk scores (Marshall et al., 2020).

Multiple studies have found that children's BLLs can reach the CDC's reference value without any lead exposure through drinking water. Gleason et al found that discrepancies between race were increased in high poverty areas (Gleason et al., 2019). A multivariate logistic regression showed increasing white and Hispanic populations inversely associated with increased risk of elevated blood lead (EBL) while poverty and housing age were directly associated. Seasonal variations were found with BLLs highest during summer and lowest during winter. Gleason et al found that increased neighborhood segregation was associated with EBLs even after controlling for socioeconomic and housing factors.

Childhood lead exposure requires extra medical and special education costs to mitigate the effects of exposure. Medical and educational costs associated with childhood lead exposure has been estimated to equal $5600 per child exposed. Hauptman et al recommend targeted prevention in high-risk communities as the most reliable and cost-effective strategy to reduce childhood exposure to lead and the subsequent consequences (Hauptman et al., 2017).

2.2 Presence of Lead in environment

Historically, EBLs in children have been caused by leaded paint and gasoline, leading the US to regulate and reduce exposures to these sources (CDC, 2017). Decades of improvement have resulted in success: 30% of children with elevated EBLs do not have an immediate identifiable lead paint exposure (Levin et al., 2008). However, other environmental sources such as drinking water and home dust have not been as strictly regulated and are more difficult to quantify.

In a study of the effects of environmental lead on children, Zartarian et al found that water can contribute to 40% of blood lead in infants up to 6 months who are primarily fed water-mixed formula. The target BLL is exceeded with standard exposure to lead in soil and dust, even before the contribution of water is considered. Uncertainties resulting from LCR collection guidelines limits the ability to accurately predict drinking water lead exposure (Zartarian et al., 2017).

Triantafyllidou et al assessed risk of EBL in students rather than geometric mean. They found significant risk posed by school water lead, distinct from exposure to dust, soil, and home water, indicating that if lead in water in schools can be reduced, total lead exposures can be markedly improved (Triantafyllidou et al., 2014b). In a study of risk before and after remediations including fixture replacements, flushing regimens, and filters, risk was found to decrease up to 25%, from 31% in high risk locations and 11% in typical risk locations to approximately 5%. Where full sampling is not feasible, they recommended targeted sampling and remediation of outlets used for consumption.

2.3 Sources of Lead in Water

The Safe Drinking Water Act (SDWA) enacted in 1986 banned the use of LSLs but allowed plumbing components to contain up to 8% lead by weight. This “lead-free” designation was lowered to 5% in 2014, and NSF 61 standard was revised in 2020 to allow leaching of no more than 5 ug Pb per approximately 20 L, a marked regulatory improvement.

In a study of non-point sources of lead exposure such as indoor dust, outdoor dust, and paint, tap water and home dust were found to significantly contribute to EBLs in children (Levallois et al., 2014). Drinking water was found to be a significant source of persistent low-level lead exposure with concentrations as low as 3.27 ug/L found to have a significant effect on BLLs of children living in the homes. In this study, a seasonal relationship emerged, with lead exposure increasing in warmer seasons.

Sandvig et al determined that while 50-75% of lead concentration is a result of LSLs, up to 35% can be due to premise plumbing. Partial LSL replacements resulted in marginal improvements in total lead even two months after the replacement. Sandvig et al recommended that replacing end-use fixtures may be appropriate at sites without LSLs that experience elevated lead in drinking water (Sandvig et al., 2008).

2.3.1 Lead Service Lines

In 2016, a survey of lead service lines (LSLs) in the United States estimated that 6.1 million LSLs were still in use, down from 10.2 million estimated in 1991. In the United States, an estimated 15-22 million people, conservatively 4.5% of the total population, are served by full or partial LSLs. Most of these are located in the Midwest and Northeast (Cornwell et al., 2016).

Partial service line replacements have been found to have minor impacts on lead concentrations in water (Cartier et al., 2012); (Sandvig et al., 2008); (Wang et al., 2013). Wang et al theorized that galvanic effects between lead, copper, and brass might promote lead release from the remaining lead components, as most partial replacements do not show decreased lead for months. Wang et al found that particulate lead increased after partial replacement, indicating interaction with lead-containing passivated scale.

Especially in the case of partial replacement of either of the main connection line or the service line, where copper and lead pipes occur in series, medium or high flow can release significantly more lead, due to disturbance of corrosion during replacement and resulting galvanic effects. Most testing protocols specify to collect samples at a "pencil-thin flow", or exceptionally low flow, and can therefore underestimate the lead exposure encountered during normal use of the tested tap (Cartier et al., 2012).

2.3.2 Lead-Alloy Components

While LSLs are believed to contribute the most lead to drinking water sources, contributions from "lead-free" plumbing components such as fixtures and fittings, and lead-alloyed solder, are less well understood (Levin et al., 2008).

In addition, though corrosion control treatments increase passivation within pipes and can prevent leaching from the pipe material, the precipitated scale can release lead under the right conditions. High lead was found to be correlated with other metals in water, a strong indicator of leaching from metal-alloy components (Pieper et al., 2015). Trueman et al found a correlation between colloidal iron and lead in drinking water. Iron corrosion was found to be significant where high concentrations of lead were present, especially in cast iron plumbing (vs ductile iron) (Trueman et al., 2017).

Lead solder, brass fittings, and fixtures can contribute significant amounts of lead compared to LSLs (Deshommes et al., 2016). In addition, the benefits of 30-second flushing were short-lived, returning to pre-flush distribution after 30 minutes of stagnation. Thus, flushing as a mitigation technique should be reexamined. In addition, flushing requires every user to remember and flush for the requisite time for any water meant to be consumed. Any mitigation that depends on perfect adherence to a method by every and all users cannot be considered best practice.

In addition to lead solder and brass fittings, aerators can contribute to particulate lead in water (Deshommes et al., 2010). The EPA testing method may not entirely dissolve particulate lead, leading to underestimates of total lead in samples. Studies have speculated that lead leached from pipes can perhaps precipitate on the aerator screen and be released later in high flow or disturbance of the aerator, but this is not supported through study from Deshommes et al.

Pieper et al provided further confirmation that brass fittings may contribute more lead than interior piping material, even LSLs (Pieper et al., 2015). Of all households in the study, 2% experienced increased lead after 5 minutes of flushing, suggesting presence of lead-bearing components upstream of the fixture piping.

Elfland et al addressed lead leaching from inline devices where LSL was not present. NSF standards regulate lead in component plumbing and is assumed to ensure insignificant lead leaching but is largely untested. In this study, NSF certified fixtures sampled above 15 ug/L. Samples with high concentrations contained mostly particulate lead. After profile sampling at fixtures with high concentrations, inline ball valves were determined to leach the most lead. Inline devices generally have less stringent NSF standards and were not required to be adhered to by most state codes at the time of the study. Based on the profile sampling required to find the true source of lead leaching, Elfland et al concluded that the first liter sample usually required by testing protocols is not adequate to capture true worst-case lead levels (Elfland et al., 2010).

Kim et al found that particulate lead contributed to the majority of total lead in flowing systems, while soluble lead contributes the majority of total lead in stagnant systems (Kim et al., 2011). In stagnant systems, particulate lead becomes significant at high pH values. In addition, total lead was found to be up to two orders of magnitude higher at pH of 6 than pH of 8. They recommend that lead control strategies should account for patterns and rate of water consumption.

2.4 Regulations for Lead in Water

2.4.1 Nationwide Requirements

Perhaps the greatest shortcoming of US regulations of lead in water is that the action level is not based on achieving lead levels safest for human health. The World Health

Organization recommends a lead action level of 10 μg/L based on twenty-first century corrosion control technology, which many European nations adhere to, yet the US maintains a general action level of 15 μg/L. The EPA's maximum contaminant level goal (MCLG) for lead is 0 μg/L. MCLGs differ from maximum contaminant levels (MCLs) in that they are recommended health-based levels, yet not legally enforceable.

The LCR revision approved December 2020 updates required testing at elementary schools and licensed child care facilities. At child care facilities, samples should be collected at one drinking fountain and one sink used for consumption, or at two sinks if a fountain is not present. The variability within and among fixtures in a building creates a high probability that limited sampling may allow lead in water to go undetected. Including locations in sampling where mitigation can have maximum impact is a step forward, though not a complete solution.

Redmon et al concluded that an action level nearer to the MCLG is advisable (Redmon et al., 2018). The quantification limit of ICP-MS testing, the gold standard in lead measurements, is 0.1 μg/L, meaning a lower limit is possible from a testing perspective as well. Study after study shows that the majority of samples tested for lead in water, 60%-80%, contain lead below 1 μg/L. Though fixtures associated with high lead appear to be present in most buildings, if the fixtures could be identified, major remaining sources of lead could be eliminated. However, efficiently and dependably identifying offending fixtures remains a major challenge.

2.4.2 Voluntary Guidelines

EPA published the original voluntary guidelines for child care facilities – "3Ts for Training, Testing, and Telling' – in 2006. This document contained steps for assessing potential sources of lead in a facility, sampling all fixtures used for water consumption, and implementing mitigation where needed. The 2006 version included an action level of 20 μg/L, 5 μg/L higher than the LCR's action level. In 2014 the 3Ts were revised, eliminating the 20 μg/L action level without establishing a new one. Instead, facility directors are advised to begin mitigation if "excessive lead" is found.

In an investigation of the effect on lead concentrations of various sampling protocols, Cartier et al found 5 minutes of flushing to be sufficient as a universal standard to clear stagnated lead from most systems in the UK. First and second liters were found to be most indicative of high potential lead, indicating that expanding sampling protocols to capture up to the first 2 liters out of the tap may improve detection. Length of LSLs were found to be significant where present, and temperature was found to increase lead in water by 5% for every increase of 1 degree Celsius (Cartier et al., 2011).

Del Toral et al drew 45-s, 3-min, 5-min, and 7-min samples from fixtures drawing from LSLs in water systems in line with LCR requirements. The flushed profiles were found to contain up to four times the maximum lead detected in first draw samples. Overall, first draw testing was found to significantly underestimate peak lead, yet no time ‘t’ was determined to be representative of lead across locations. High variability was found within and between sampled buildings, and maximum lead largely dependent on individual plumbing (Del Toral et al., 2013).

Triantafyllidou et al outlined three types deficiencies which can inhibit lead detection in samples: inadequate sampling procedures, poor mixing after preservation, and incomplete detection of particulate and soluble lead. Particulate lead was identified as the main culprit of undetected lead as tendencies to settle causes problems with any transfer between bottles or inadequate digestion. EPA protocol required samples to be digested in collection bottles, so the issue is particularly of concern in situations where EPA requirements are not mandatory, such as in voluntary testing by child care facilities (Triantafyllidou et al., 2013).

Masters et al found that flow rate does indeed affect mobilization of particulate lead: sampling at low flow can cause significant underestimates of total lead release. Low flow decreases variability of sampling, along with accurate quantification of lead in water and associated health risks at normal flow. Using power analysis and Kirmeyer tests, the group determined that between 600 and 1600 samples are needed to accurately characterize mean lead under LCR protocols. In reality, the LCR only requires 50 to 100 samples for an entire service area. While accurate lead quantification may not be critical to identifying a lead problem, this indicates that the LCR requirements allow lead in water to go undetected because of inadequate sampling. This works illuminates the inherent issues associated with one-time sampling of a tap (Masters et al., 2016).

2.5 Related Studies

A similar study by Redmon et al surveyed lead in drinking water at North Carolina child care centers, also using "citizen scientist" sample collection (Redmon et al., 2020). This study collected 1266 samples in total, 77% with detectable lead, 63% over 1 ug/L; compare this to 80% with detectable lead in the EDF study. Only 1.74% of samples were found to exceed the LCR action level. Facility type and fixture type were found to be associated with elevated lead (Redmon et al., 2020).

Miller-Schulze et al outlined three distinct patterns found in lead sampling. (1) High first draw lead, then lower subsequent concentrations, (2) low first draw, an elevated sample, then return to low levels, and (3) persistent high concentrations of lead. The first case is theorized to indicate leaching from the end-point fixture and immediate associated plumbing which the second indicates leaching from an inline device, such as the ball valve detected by Elfland et al. This study also concludes that limiting sampling to first draws may allow worst cases to go undetected (Miller-Schulze et al., 2019). This study in particular outlined the need for identifying characteristic types of high lead in order to choose the best mitigation techniques, an undertaking that proves to be elusive.

Burlingame et al summarized lessons learned from past studies on lead in US schools. In Chicago, a full-building flush was performed to increase mobility of water at all taps and improve quality by circulation, encouraging continued use and improved long-term circulation (Burlingame et al., 2018). A unique aspect of this report was the emphasis on regular use of all fixtures and implementation of flushing to maintain water quality by reducing overall stagnation. Burlingame further identified school sample collection and utility-facilitated testing as the most effective strategy in building a partnership to detect and remediation lead in school drinking water.

A recent assessment of school remediation efforts in North Carolina confirmed the correlation between lead concentration and building age (Carter et al., 2020). High variation and spikes were found among samples. Analysis showed that buildings constructed before the LSL ban and those whose water lacks corrosion control treatment should be prioritized for lead sampling. Carter notes that even with full replacement of LSLs, Lead-containing infrastructure will remain, presenting a possible source of lead in water. Thus, corrosion control treatment should be implemented as primary prevention. In addition, specific minimum detection limits are identified as a shortcoming of testing.

To achieve total elimination of lead in water, accurate testing is required. Studies have been conducted with a ICP-MS minimum detection limit of 1 ug/L to 3 ug/L though the technique can be accurate down to 0.1 ug/L. For any goal under 3 ug/L, the lowest possible detection limit is necessary for accurate analysis and development of mitigation methods.

3.0 A Critical Opportunity: Preventing Lead in Drinking Water at Child Care Facilities

3.1 Introduction

Lifelong negative outcomes from persistent low levels of lead exposure have been documented (HHS, 2012), with children under the age of six being the most vulnerable to the effects of environmental lead exposure (EPA, 2012). Environmental lead sources such as drinking water and home dust correlate with elevated blood lead levels (EBLs) in children (Levallois et al., 2014). Lead in tap water as low as 3.27 μg/L has been shown to impact children's blood lead levels (BLLs), cognitive development, and lifetime achievement (Triantafyllidou et al., 2014a).

As the US has set goals to eliminate children's exposure to lead, sources like lead paint and leaded gasoline have been regulated and significantly reduced. This has led to a decline of children aged 1 to 5 with mean BLLs greater than 10 μg/L from 80% in 1980 to 0.8% in 2010 (CDC, 2013). The proportional exposure from sources like drinking water has increased as lead paint and gasoline sources have decreased. Recent studies suggest that non-paint exposure sources have been underestimated (Cartier et al., 2012) and exposure from lead in water is particularly high for infants 0-6 months of age due to consumption of formula reconstituted with water (Zartarian et al., 2017).

In 2003, children between the ages of 1 and 5 living in the 10 largest US cities accounted for 46% of EBLs reported to the CDC (Levin et al., 2008); these children make up 7% of the associated population. Excess lead in drinking water is highly localized, even to the level of specific zip codes and neighborhoods (Edwards et al., 2008); (HHS, 2020). Lead exposure follows the trend of many environmental risk factors: people in lower socioeconomic areas bear the highest risk (Marshall et al., 2020); (Triantafyllidou et al., 2014a).

3.1.1 A Critical Opportunity

Field study has shown that testing protocols systematically miss high lead levels, underestimating human exposure (Del Toral et al., 2013) and failing to flag public health crises such as occurred in Flint, Michigan in 2014 (NRDC); (Katner et al., 2016). Child care facilities present a unique opportunity to mitigate lead exposure for clusters of the most vulnerable age and socioeconomic groups. In 2016, over 8 million children under the age of six were cared for by center- or home-based child care facilities (National Center for Education Statistics, 2018).

Despite the elevated risks for young children, there has historically been no national mandate for lead in water testing at child care facilities; before the LCR revision in late 2020, only eleven states required lead-in-water testing at licensed child care facilities (Figure 1). The Environmental Protection Agency (EPA) published recommended testing, sampling, and mitigation guidelines for schools in "3Ts [Training, Testing, and Taking Action] for Reducing Lead in Drinking Water" in 2006 and published a revision in 2018. Remediation measures recommended in the 3Ts Toolkit focus on routine flushing, installing and maintaining filters, as well as aerator cleaning and replacement of lead-containing plumbing components. The 2006 version contained an action level of 20 μg/L, which was removed in the 2018 update but was not replaced with a definitive number, but rather instruction to implement remediation measures if samples show “elevated levels of lead.” Adherence to 3Ts guidance is entirely voluntary.

This paper summarizes the key results of an Environmental Defense Fund (EDF) pilot study conducted to evaluate sampling and remediation of lead in water at child care facilities, expanding on 3Ts guidance (McCormick et al., 2018). In collaboration with local partners, potential sources of lead in drinking water such as lead service lines (LSLs) and brass fixtures were identified and assessed for lead leaching and LSLs detected were replaced before sampling. Flushing, aerator cleaning, and fixture replacement were conducted at each facility with samples taken before and after each mitigation method. This study was conducted primarily to mitigate lead at the partner facilities and assess the immediate impact of mitigation performed by a provider. Approximately 1,500

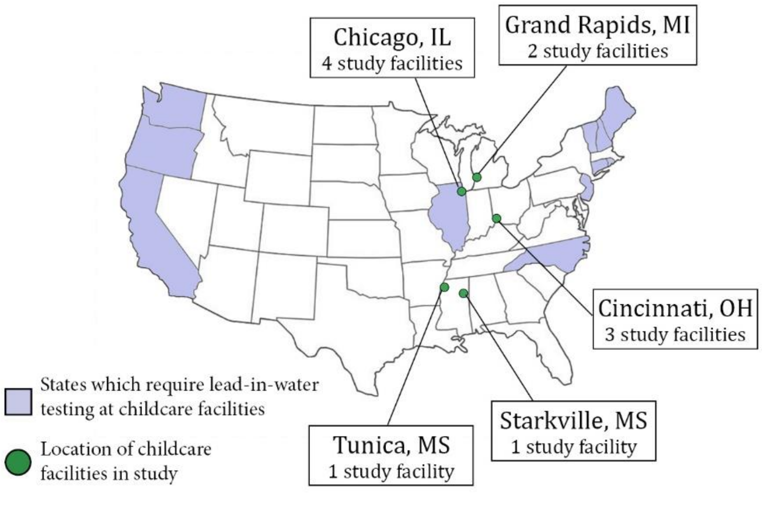


Figure 1: Sampling was performed at 11 child care facilities in 4 states. Only the Chicago facilities had requirements for Pb concentrations in drinking water. The state of Illinois limits Pb in water to 2 g/L at licensed child care facilities. As of 2020, only 11 states require lead testing for drinking water at child care facilities (shaded), six of which use a 15 g/L action level.

water samples were collected at 294 fixtures and 14 water heaters from 11 child care facilities in 4 states (Figure 1). Two LSLs were replaced as part of the study but prior to sample collection used in the primary analysis. The data produced served as evidence of the difficulty in achieving health-based standards of lead-in-water and a basis for technical improvements in future studies.

3.1.2 Related Work

A study of child care centers in North Carolina recruited facility staff to collect first draw samples from 86 child care facilities and schools across the state (Redmon et al., 2020). Risk factors such as building age, building ownership, and distance from source utility, were found to affect lead levels at the tap. Widespread lead and high variability within facilities were found both in the North Carolina study and a prior Canadian study of elementary schools (Deshommes et al., 2016). In addition, Deshommes found benefits from flushing to be short-lived, with lead returning to previous levels after 30 minutes of stagnation.

A review of case studies in four American cities emphasizes the importance of collaboration between water utility and the mitigation facility to produce successful remediation (Burlingame et al., 2018). Systematic flushing and increased usage at taps were found to be effective in maintaining lead levels within a 15 μg/L limit, but achievement of lower, safer levels was not reported. Finally, analysis of North Carolina lead in drinking water at schools and child_care facilities found that limitations of ICP-MS testing where quantification levels are not sufficiently low prevents accurate reporting and can be an obstacle for lower, health-based target goals (Carter et al., 2020).

3.1.3 Existing Guidelines

Lead in public drinking water is a result of leaching from pipes, solder, and fixtures during flow to the tap (Elfland et al., 2010). Where LSLs are present they contribute up to 75% of lead in water (Sandvig et al., 2008), and current best practice is removal of LSLs where found. Water utilities use preventative corrosion control treatments to reduce the extent of lead leaching into water, but pipes and connections are not uniform throughout municipalities and changing water characteristics along the flow gradient can create potential for high levels of lead (Del Toral et al., 2013).

Even where LSLs are not present, lead-alloyed fixtures and pipes can leach lead into water (Deshommes et al., 2010) and previous study suggests that fittings may contribute more total lead than non-lead pipes (Pieper et al., 2015). Congress first limited the use of lead in interior plumbing in 1986 – effectively banning LSLs, limiting lead in solder to 0.2%, and limiting lead in alloyed brass to 8%. In 2011, Congress passed the Reduction of Lead in Drinking Water Act (effective 2014) which further reduced allowable lead in brass fixtures and fittings to 0.25%.

The US Lead and Copper Rule (LCR) sets lead-in-water testing and treatment requirements for public water utilities. Until recently, the LCR did not mandate testing at child care facilities. A December 2020 revision of the 1991 rule established a new requirement for utilities to conduct limited sampling at schools and child care facilities. The revision also addresses pre-flush stagnation and flow velocity, though does not ensure preservation of samples, all of which have been shown to obfuscate the true prevalence of lead in individual buildings (Masters et al., 2016); (Triantafyllidou et al., 2013).

The LCR revision maintains an action level of 15 μg/L – this is not health-based, and was determined based on corrosion control feasibility in public water distribution systems in 1986 (HHS, 2020). The World Health Organization (WHO) recommends a limit of 10 μg/L Pb, also based on technical feasibility (SCHER, 2011).

3.2 Methodology

In selecting child care facilities for the study, EDF prioritized facilities with children under six years of age from low-income families. The intent was to provide support to facilities that may not have the resources to address the issue on their own. Five local partners recruited child care facilities for the pilot. Partners found it difficult to recruit both when they lacked a prior relationship with the child care facility and when the facility did not anticipate a testing mandate in the future (Chicago has set a 2 μg/L action level).

Approximately 1,500 samples were collected in total, two LSLs removed, and 26 fixtures replaced based on an action level of 3.8 μg/L, derived from a 2017 EPA report (EPA, 2017); (Neltner, 2017). Three additional fixtures were replaced to match ones replaced in the study, for a total of 29 fixture replacements. This health-based benchmark reflects a 1% increase in the probability that a formula-fed infant living in pre-1950 housing will have a BLL greater than 3.5 μg/dL of blood.

Local study partners were responsible for sampling fixtures at each child care facility using a procedure adapted from EPA's 2006 3Ts guidelines (EDF, 2018). Days on which samples were collected varied by location. Partners collected 250 mL samples after allowing water to stagnate overnight (8+ hours) at all water fixtures including kitchen, classroom, bathroom, staff room, and utility closet sinks; drinking water fountains; and outdoor hose bibs. Samples were analyzed using a paired t-test to detect significance changes in lead levels between sampling days.

3.2.1 LSL Replacement

Before performing any sampling, service lines were assessed through records and visual inspections to determine presence of lead. If found, service lines were replaced through partnerships with local water works or certified plumbers. In each replacement, removal and flushing followed American Water Works Association guidelines.

In the two locations where LSLs were present, samples were drawn before removal and after LSL replacement. These consisted of ten consecutive 1-L samples drawn from the outlet closest to the LSL following overnight stagnation. Flushing was then performed, and samples were drawn after 45-60 days of regular use.

The two LSL replacements occurred in Cincinnati and Chicago and were funded through EDF and municipal grants. As part of a proactive LSL replacement program aiming to replace remaining LSLs over a 15-year period, Greater Cincinnati Water Works covered over half of the $8,680 cost of that replacement and assisted in assessment and installation.

Although the city of Chicago announced an LSL removal program in 2020, no such program was in place at the time of replacement. The City of Chicago mandated use of LSLs up to 2 inches in diameter until they were banned by the LCR in 1986. One Chicago child care facility was served by both an LSL and a newer ductile iron pipe; although the ductile iron pipe could manage the entire flow, the City of Chicago required the LSL be disconnected from the street main rather than simply removing the building connection. The Chicago replacement was conducted by a certified plumber and cost $10,058, including construction costs, city permit fees, lost parking meter revenue, and additional excavation due to inaccurate records. Since then, Chicago has announced an LSL removal program that aims to standardize replacements and waive extra permits and fees (Chicago Mayor's Press Office, 2020).

3.2.2 Sample Collection

Prior to sampling, tape was placed across fixture handles and water allowed to

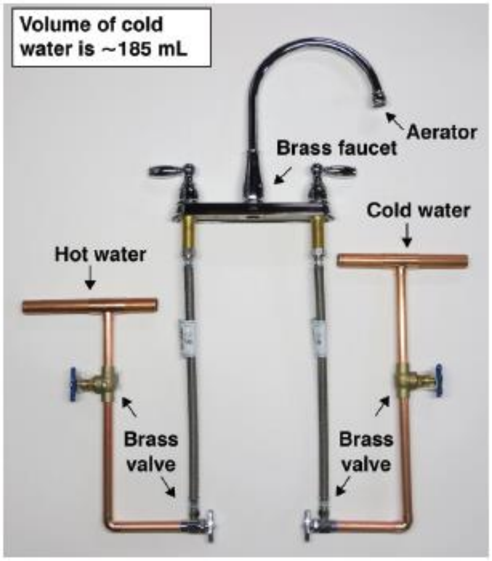


Figure 2: Typical fixture and associated plumbing. A 250-mLfirst-flush sample is sufficient to capture all water stagnating in the fixture components and about 65 mL in the piping beyond.

stagnate overnight. On the first sampling day, two 250-mL samples were drawn at all fixtures including sinks, water fountains, and hose bibs. Each sample was collected at a gentle, pencil-like flow. The first sample approximated the volume of water that had stagnated in the fixture's associated piping overnight (Figure 2). The second sample, taken after 30 seconds of flow, captured water contained in upstream pipes. The type and use of each fixture were recorded as well as the presence or lack of an aerator screen. If the fixture was fitted with an aerator, the aerator was removed, rinsed in the tap water, and returned to the fixture following collection of the two samples. At the end of the day, tape was again placed across all fixtures and water allowed to stagnate overnight.

On the second sampling day, a first draw 250-mL sample was collected at every fixture. At drinking water fixtures, additional samples were collected: after 5 seconds flushing, after 30 seconds flushing, and a hot water sample where hot water was available. After drawing second-day samples, all were packed and shipped to a lab for analysis.

All samples were analyzed following EPA method 200.8, Inductively Coupled Plasma

- Mass Spectrometry (ICP-MS). The level of quantification (LOQ) was 1 μg/L, and the minimum detection limit (MDL) was 0.1 μg/L. No preservation was conducted prior to digestion during lab analysis.

3.2.3 Water Heater Testing

In addition to the point-of-use samples, water heaters were recognized as a possible source of lead or a sink for upstream lead sources. Long-term storage in water heaters has been linked to formation of disinfection by-products (Liu et al., 2015), though the particular concern about lead was based on anecdotal evidence. A pair of samples was collected at the water heater drain outlet. Where possible, the water heater was drained, then flushed for 10 minutes with cold water. Another set of samples was collected after flushing. In some cases, flushing and sampling were repeated a second time. The extent of water heater flushing and sampling was dependent on difficulty and logistical constraints.

3.2.4 Statistical Analysis

For most analysis, a paired t-test was applied to test for significant ($p<0.05$). To test the effect of flushing first draw and 30-second flush samples were compared, from sampling days before and after aerator cleaning; first draws from before and after fixture replacement were also analyzed with a paired t-test. The problems arising from insufficiently low quantification outlined by Carter et al were a particular challenge in aerator cleaning analysis. In this study the lab-reported LOQ of 1 ug/L prohibited determination of the precise effect of aerator cleaning with so many samples containing detectable yet unquantifiable levels of lead.

3.3 Results and Discussion

In all, 1,498 water samples were collected from 11 child care facilities. Table 1 provides a description of the 11 facilities and the results for each. These results affect a total of 1,096 children, with the majority from low-income families. Children served by individual facilities ranged from 25 in Mississippi to 213 in Chicago. Nine facilities were in commercial buildings and two were converted homes. The number of fixtures tested at each facility ranged from 8 to 66 but was not associated with the number of children served or the age of the building.

Approximately eighty percent of samples (80.6%) contained lead levels less than 1 μg/L, below the LOQ and unquantifiable through ICP-MS testing. Where lead levels were above 1 μg/L, 1.0% exceeded the LCR action level of 15 μg/L Pb, 9.9% exceeded EDF's action level of 3.8 μg/L, and 18.4% exceeded the American Academy of Pediatrics' health-based recommendation of 1 μg/L. The frequency of lead in first draw and all samples is reported in Figure 3. Studies of lead in water in both North Carolina (Redmon et al., 2020) and Canada (Deshommes et al., 2016) likewise found variability in samples taken from individual locations was higher than variability between locations, which was also the case in this study.

Table 1: Study location data including location key used in later graphs, building details, LSL status, and sampling/testing data. Sampling lead levels are reported as $\bar{x}$(range).

**Twenty-six fixtures were replaced based on the study's 3.8 μg/L action level. Three more were replaced for cosmetic reasons, to match ones replaced based on action level.*

							All fixtures		**Replaced fixtures**	
Location Key	**Location**	**Building age**	**Child care type**	**# children enrolled**	**LSL found?**	**Total # samples**	**# tested**	**Lead levels (μg/L)**	**# fixtures replaced**	**Lead levels (μg/L)**
GR1	Grand Rapids, MI	1951	Center	60	No	81	16	1.0 (<1-18.9)	4	1.5 (<1-3.8)
GR2	Grand Rapids, MI	1952	Center	65	No	75	17	<1 (<1-1.1)	0	N/A
Stv	Starkville, MS	1957	Center (converted home)	27	No	47	8	2.4 (<1-23.6)	3	2.9 (0.5-5.8)
Tun	Tunica, MS	1993	Center	25	No	51	12	<1 (<1-6.1)	0	N/A
Chi1	Chicago, IL	1956	Center	145	No	165	29	4.2 (<1-91)	13	<1 (<1-1)
Chi2	Chicago, IL	1995	Center	178	No	209	50	0.1 (<1-4.0)	0	N/A
Chi3	Chicago, IL	1995	Center	213	No	211	49	<1 (<1)	0	N/A
Chi4	Chicago, IL	1950-60s	Center	87	Yes (replaced)	59	18	1.3 (<1-5.0)	2	3.8 (1-10)
Cin1	Cincinnati suburb, OH	1910	Center (converted home)	65	Yes (replaced)	66	8	2.2 (<1-8.1)	0	N/A
Cin2	Cincinnati, OH	1956	Center	84	No	124	21	1.1 (<1-35.6)	1	<1 (<1)
Cin3	Cincinnati, OH	1990	Center	147	No	403	66	1.3 (<1-88.4)	6	3.0 (<1-18.2)
				1,096 children	2 LSLs replaced		294 fixtures tested		29 fixtures replaced*	

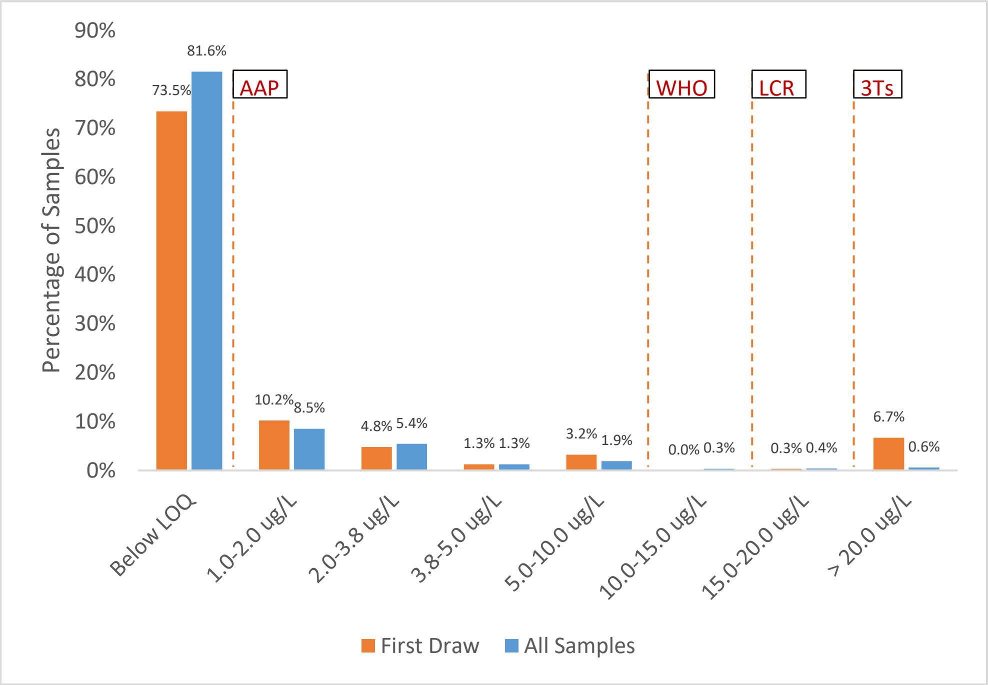


Figure 3: Pb frequency as percentage of first draw samples (n=313) and percentage of total samples (n=1,498) from all study locations. Though most sample concentrations were within regulatory action levels, over 25% of first draw samples and almost 20% of all samples exceeded a health-based limit of 1 μg/L recommended by the American Academy of Pediatrics.

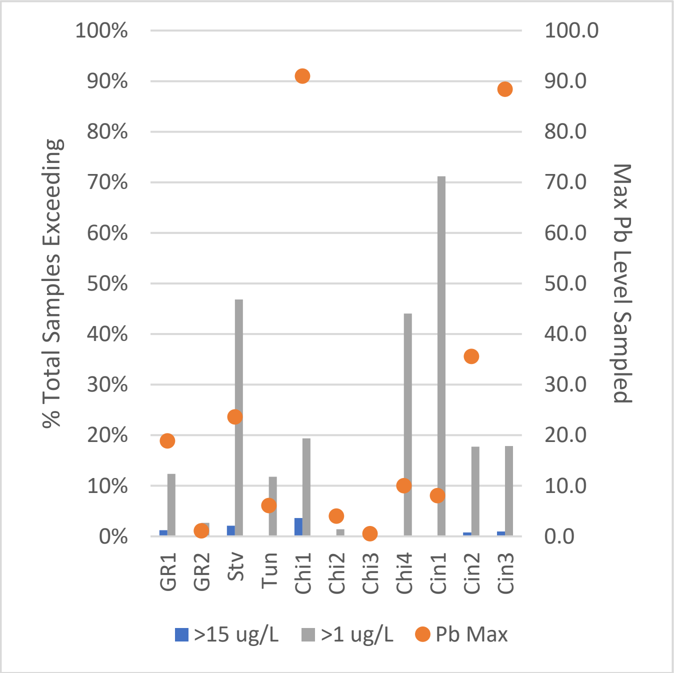


Figure 4a: Total Pb by facility, showing percentage of total samples at each location exceeding LCR action level (15 μg/L) and AAP health-based recommendation (1 μg/L). The percentage of total samples with lead above 15 μg/L was low at all sites. However, >10% of samples at eight locations exceeded the AAP's recommendation. Five locations produced maximum concentrations well above 15 μg/L that could have been missed with limited fixture sampling.

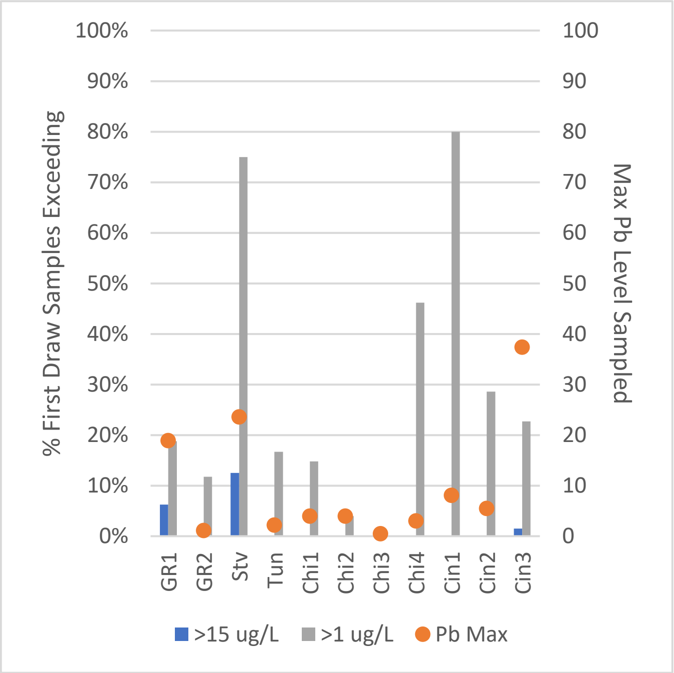


Figure 4b: First draw Pb by facility, showing percentage of first draw samples at each location exceeding LCR action level (15 μg/L) and AAP health-based recommendation (1 μg/L). A sufficiently sensitive action level is imperative for triggering mitigation based on first-draw sampling. Even low-level lead is a threat to children, but the probability of mitigation prompted by one or two samples per building based on 10 or 15 μg/L is very low.

Because exhaustive sampling was conducted at every drinking water outlet, 10 of 11 facilities (91%) produced multiple samples with quantifiable lead. Remediation would have been recommended at two facilities (18%) based on the 2006 3Ts, where lead in first draw samples exceeded the action level of 20 ug/L. Remediation would have been required at three locations (27%) if there were a nationwide standard for child care centers limiting lead in first draws to 15 μg/L. Figure 4a depicts the percentage of total samples containing above 1 μg/L Pb (AAP recommended action level) and 15 μg/L Pb (current LCR action level), along with the maximum lead level detected at each facility location; Figure 4b depicts the same for first draw samples. First draw sampling yielded higher percentages of samples exceeding 15 μg/L Pb, as expected. A maximum concentration appeared after the first draw at 5 facilities (Tun, Chi1, Chi4, Cin2, Cin3), with exceptionally high "spikes" at three locations after aerator cleaning.

Until recently, there was no nationwide standard requiring lead in water sampling at child care facilities. The LCR revision finalized December 2020 will require utilities to collect first draw samples from two drinking water outlets at child care buildings, allowing lead to go undetected at unsampled outlets. Facilities with maximum first draw lead were not consistently the same facilities with the most extensive low-level lead (Figure 4b).

Table 2: Probability of detecting persistent low-level lead at sampled child care facilities with different potential "trigger levels." The child care portion of the LCR revision does not specify an action level, rather that results must be reported to facility directors. Using a trigger level in line with the AAP recommendation would provide the greatest probability of detecting "high" lead at a sampled fixture. A trigger level in line with the rest of the LCR would likely not indicate a need for mitigation even where low lead is widespread.

	Number of Fixtures, n		**Probability of Detecting Quantifiable Lead (> 1 μg/L)**			**Probability of Detecting Low-Level Lead (>5 μg/L)**			**Probability of Detecting Lead Above LCR Trigger Level (>15 μg/L)**		
Location Key	**Fountains**	**Sinks**	**Fountain**	**Sink**	**Combined**	**Fountain**	**Sink**	**Combined**	**Fountain**	**Sink**	**Combined**
GR1	2	14	0.0%	21.4%	21.4%	0.0%	7.1%	7.1%	0.0%	7.1%	7.1%
GR2	3	12	0.0%	16.7%	16.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Stv	0	8	-	75.0%	56.3%	-	37.5%	14.1%	-	12.5%	1.6%
Tun	0	12	-	16.7%	2.8%	-	0.0%	0.0%	-	0.0%	0.0%
Chi1	2	25	0.0%	16.0%	16.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Chi2	4	46	0.0%	4.3%	4.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Chi3	6	43	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Chi4	1	17	0.0%	35.3%	35.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cin1	2	9	0.0%	88.9%	88.9%	0.0%	22.2%	22.2%	0.0%	0.0%	0.0%
Cin2	1	17	0.0%	17.6%	17.6%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cin3	10	56	10.0%	25.0%	35.0%	0.0%	7.1%	7.1%	0.0%	1.8%	1.8%

The LCR revision applicable to child care facilities requires that two outlets be sampled and lead reported to the facility director, but no action level is included. Facility directors and utilities will be responsible for deciding appropriate mitigation. With sampling limited to 2 outlets at child care facilities, selection of an action level is critical to trigger mitigation where low-level lead is widespread. In this study, limited sampling and an action level of 15 μg/L would perhaps have flagged sites with instances of high lead (if the offending outlet were selected for sampling), but low-level lead at many sites would have gone undetected. If a lower action level is used to trigger mitigation, limited sampling is more likely to detect widespread low-level lead and further sampling would increase detection of high lead at individual outlets.

3.3.1 LSL Replacement

At the Chicago and Cincinnati facilities where LSLs were replaced, 10 sequential 1-L samples were collected from the fixture closest to the service line entry point to provide a profile of lead changes in the service line. Profiles were taken before and after LSL replacement and system flushing occurred before further sampling at the location. At the Cincinnati facility, a peak was observed at liter two (5.6 μg/L), followed by levels hovering at 2-3 μg/L in the 10-L profile. After replacement, lead levels declined – all samples were under 1 μg/L except for liters 2-4 from Cincinnati, which ranged from 1.3-1.5 μg/L. At the Chicago facility, the sampling profiles both before and after replacement showed lead levels hovering at 2 μg/L for each liter sample

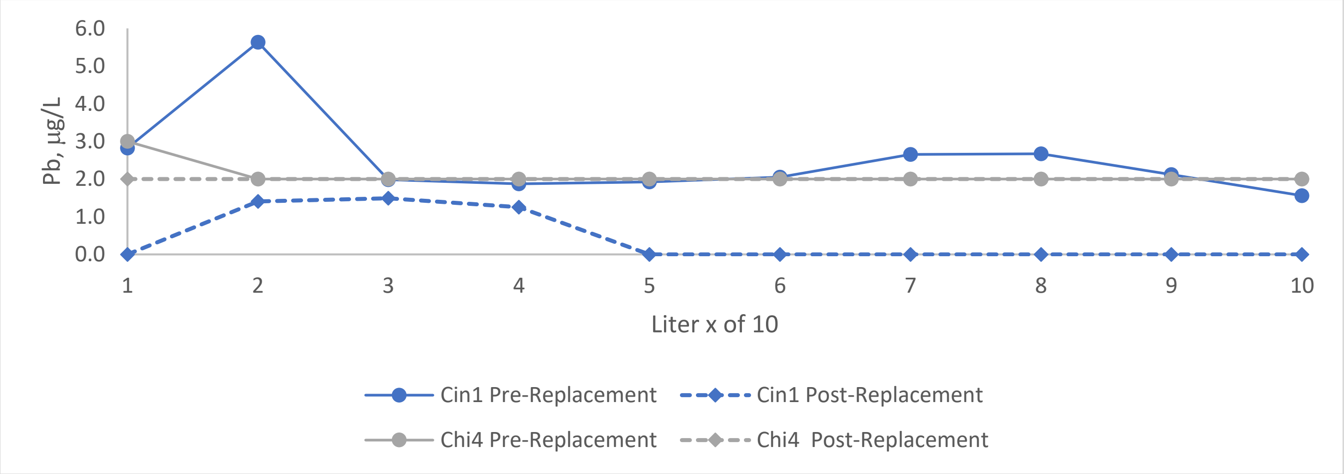


Figure 5: 10-L sampling profile of pre- and post- replacement Pb levels at locations where LSLs were found. Reduction in total lead was only found for one of two LSL replacements. For that replacement, flushing was needed to attain 0 μg/L in a 10-L sampling profile.

3.3.2 Flushing

On average, a 30-second flush reduced lead in samples by 3.7 μg/L, and a 5-second flush reduced lead by 3 μg/L. A paired t-test showed the benefit from 30 seconds of flushing to be significant (P=0.02). However, as flushing relies on consistency and patience from all users, in this case child care staff and children, it was not considered an acceptable primary remediation strategy for child care facilities.

3.3.3 Aerator Cleaning

Routine aerator cleaning is recommended as an important practice to reduce lead in water (EPA, 2020). Aerator cleaning did not reliably reduce lead levels, and in fact where a change was detected after aerator cleaning, over 40% of fixtures showed an increase in lead concentration. The issues raised by Carter et al regarding insufficiently low quantification levels obscure the effects of aerator cleaning in this study where lead was detected below 1 μg/L and therefore unquantifiable. Where lead was quantifiable either before or after aerator cleaning (>1 μg/L), aerator cleaning increased lead levels by an average of 4.5 μg/L. At two facilities aerator cleaning appeared to cause a sharp increase in lead at some fixtures. In one case, though the aerator broke during cleaning and was not replaced, lead increased from 37 μg/L to 88 μg/L.

Aerator cleaning may increase lead levels by disturbing particulate lead lodged in the aerator screen, disrupting protective scale, producing new brass particles from the threading, or some other reason. The aerator cleaning method in this study was limited to rinsing the screen in tap water. Cleaning methods such as soaking in vinegar could produce different results and warrant further study.

3.3.4 Fixture Replacement

Twenty-nine of 294 fixtures (9.8%) were replaced based on post-aerator cleaning sampling results. Twenty-six of these exceeded action levels in samples drawn after aerator cleanings and three were replaced to match. In Chicago three fixtures were replaced based on a 2 μg/L action level according to state regulations. Lead was reduced from an average of 20.1 μg/L after aerator cleaning to an average of 3.4 μg/L after fixture replacement (P = 0.01). However, aerator cleaning apparently induced particularly high lead levels, and comparison to the initial first draws shows a less significant reduction, from an average of 4.1 μg/L to 3.1 μg/L after fixture replacement (P = 0.35).

Fixture replacement was effective when initial lead levels were above 5 μg/L. Where pre-replacement lead levels were already below 5 μg/L, lead increased by 2.0 μg/L on average after fixture replacement. Fixture replacement did not initially reduce lead levels below EDF's 3.8 μg/L action level. However, within 35 days, follow-up sampling produced levels below 3.8 μg/L. Where fixture replacement did not achieve levels below Chicago's 2 μg/L action level after follow-up sampling, filters were installed to further reduce lead levels.

The NSF International standard (NSF/ANSI 61) in place during the study period allowed lead in new brass fixtures to leach up to 5 μg/L under the evaluation protocol. For three types of NSF/ANSI 61 “lead-free” faucets, leaching was found to continue after 19 days, ranging from 1.5 to 3.0 μg/L (Parks et al., 2018). In June 2020, NSF/ANSI 61 was revised to require manufacturers to meet more protective lead limits by January 2024, though fixtures already in place will continue to contribute to lead in water.

3.3.5 Hot Water

Hot water is generally expected to cause more lead leaching and produce higher lead levels than cold water (CDC, 2020). Current testing protocols do not include sampling hot water, but EPA recommends using only cold water for drinking and cooking. However, child care facilities may use hot water for drinking purposes, such as when mixing infant formula or other powdered drinks with water.

Fixtures with hot water capability were sampled after aerator cleaning and at least 30 seconds of flushing. Two 250-mL samples were drawn directly from the drain of every water heater. Water heater sampling produced a wide range of lead concentrations, up to a maximum of 2,680 μg/L (Table 3). A study of water heaters in Flint, Michigan concluded that heavy metals in water heater sediments did not translate to higher lead at the tap (Rhoads et al., 2020). In this study, differences in lead levels between hot and cold flushed samples were not significant (P=0.11).

*Table 3: Water heater Pb sampling results from all study locations. Post flush samples were collected where the water heater was able to be drained and flushed. Pb in water heaters was highly variable and very high sample concentrations suggest that water heaters may act as a Pb sink. However, this study did not undertake any sampling to specifically determine whether water heaters can also act as a source for Pb in hot water. *Only a partial flush was conducted for water heater 14.*

Water Heater	**Preflush**		**Post Flush 1**		**Post Flush 2**	
	Draw 1 (μg/L)	**Draw 2 (μg/L)**	**Draw 1 (μg/L)**	**Draw 2 (μg/L)**	**Draw 1 (μg/L)**	**Draw 2 (μg/L)**
1	120	18	18	12	-	-
2	5	320	-	16	-	-
3	6	3	9	7	-	-
4	2680	184	68.2	32	84.2	-
5	61	14.1	70.9	15.2	-	-
6	10.7	7.84	-	-	-	-
7	8.1	6.61	-	-	-	-
8	127	37.2	61.6	15.2	8.13	4.3
9	19.1	3.73	<1	<1	-	-
10	2.64	1.07	-	-	-	-
11	296	774	4.24	8.85	-	-
12	24.3	5.58	1.76	<1	-	-
13	23.2	9.46	21.3	11.5	-	-
14*	270	18	78	220	-	-

3.4 Conclusions

Child care facilities present both a significant gap and an opportunity in addressing the issue of ongoing childhood lead exposure. Recent revisions to the LCR and NSF standards are definitive improvements to sampling methods and in limiting allowable lead in plumbing components. The improved testing protocols will likely continue to underestimate the true extent of lead in water. Though the 1 μg/L action level recommended by AAP may not be universally achievable, a lower guideline and more thorough testing is appropriate for high-impact sites such as child care facilities.

Flushing for 30 seconds was statistically the most effective temporary method of lead mitigation but cannot be considered a reliable practice for busy caregivers or very young children. Simple rinsing of aerators was not found to reliably reduce lead levels and instead was shown to statistically increase lead levels at taps where the aerator was rinsed. Fixture replacement was sufficient to reliably reduce lead only where levels were initially above 5 μg/L. A more stringent NSF standard will help prevent fittings from serving as a lead source, but only where replacements are considered necessary or in new construction.

Aerator cleaning methods involving soaking or scrubbing could be more effective than simply rinsing and may be appropriate for closer study. Other limitations of this study include a lack of specific procedures to determine whether lead trapped in hot water heaters increases lead levels at the hot water tap. While extremely high levels of lead were detected in water heaters, no significant difference in lead levels was found between hot and cold samples, though it remains a concern and a topic for future study.

The negative outcomes caused by low-level lead exposure merit greater mitigation of risk than is prompted by past and current LCR or the patchwork of state action. At nine facilities (82%), over 10% of first-draw samples contained lead above the AAP recommendation. Only three of those (27%) produced lead concentrations exceeding the general LCR trigger level, and then only if the single offending fixture were selected for sampling. An action level of 5 μg/L coupled with thorough first-draw sampling at child care facilities would enable more reliable detection of persistent lead in water. Though complete lead elimination will be a challenge lower levels may be achievable where a significant lead source, like a LSL, is not identified. A health-based standard is especially prudent for schools and child care facilities, where so many children spend a large portion of their days in centralized locations. Though required sampling and remediation protocols for child care facilities are currently a major gap in the effort to reduce children's exposure to lead from drinking water, they also present a critical opportunity for renewed progress in the future.

4.0 Conclusion and Recommendations

This study revealed two obstacles preventing effective detection of lead in drinking water: (1) action levels are not health-based and are much too high to be useful for triggering mitigation where lead is found in water (2) if action levels are lowered to be more proactive in protecting health, recommended mitigation methods may not be reliable, efficient, and affordable.

EDF thoroughly tested each partner facility and widespread low-level lead was found at most facilities. Assuming these sites are a representative sample, increased testing or lower action levels are needed to increase the probability of detecting lead problems where they exist. Current requirements appear to target very high lead concentrations which, though concerning, were not present at most facilities in this study. Rather, low-level lead, which is harmful to children especially over extended periods, was detected at a majority of fixtures in some locations and at multiple figures in most locations. Low-level lead was shown to be a more common threat, and its remediation should be the goal of regulation at locations that impact so many high-risk individuals.

Even if action levels were lowered to 5 μg/L, or even 1 μg/L, standards for "lead-free" plumbing components may make achieving the goal impossible. "Lead-free" plumbing components are designated as such when they do not exceed the allowable amount of lead in alloy. Lead is still present and the component is a potential source of lead in drinking water. The associated NSF standard was updated in 2020 to limit lead leaching to 0.25 μg/L, but the previous version allowed up to 5 μg/L. This change may be an improvement in future, but at the time of sample collection, changing tap fixtures appeared to switch one source of lead for another in many instances. With a lower standard in place, a future study could determine whether fixture replacement under the new limit would significantly reduce lead concentrations which are already below the LCR action level.

Two locations in the EDF study showed very low risk – one site's samples contained no quantifiable lead, and another had two fixtures which yielded lead levels over 1 μg/L. Two facilities had fixtures which sampled lead above 1 μg/L but resolved after replacement. For the locations in this study, a lower action level would be the most effective way to trigger mitigation at locations with the most extensive low-level lead, even with limited sampling. Even increased limited sampling, without a lower action level, would allow lead prevalence to go undetected.

Even without LSLs, seven facilities exhibited prevalent lead above a health-based limit. Addressing LSLs and removing their contribution to lead in water will be a major achievement, but the results of this study and related work show that significant sources of lead will still be present. Lead in water affects millions of individuals in private buildings, and full elimination would be a formidable economical and logistical challenge. Accessible mitigation measures such as flushing, cleaning, and fixture replacement are not as straightforward as public guidelines suggest and should be further researched to determine more practical and effective strategies, as well as ensure that the problem is not exacerbated.

Locations with high concentrations of high-risk individuals should be prioritized for total replacements if they occur, and other methods should be implemented to avoid the cost of excavation and replacement.

5.0 References

Burlingame, G. A., Bailey, C., Nelson, J., Arnette, V. J., Bradway, S., Holthouse Putz, A. R., . . . Via, S. (2018). Lessons Learned From Helping Schools Manage Lead in Drinking Water to Protect Children's Health. *Journal American Water Works Association, 110*(10), 44-53. doi:10.1002/awwa.1169

Carter, J. A., Erhardt, R. J., Jones, B. T., & Donati, G. L. (2020). Survey of Lead in Drinking Water from Schools and Child Care Centers Operating as Public Water Suppliers in North Carolina, USA: Implications for Future Legislation. *Environmental Science & Technology, 54*(22), 14152-14160. doi:10.1021/acs.est.0c04316

Cartier, C., Arnold, R. B., Triantafyllidou, S., Prévost, M., & Edwards, M. (2012). Effect of Flow Rate and Lead/Copper Pipe Sequence on Lead Release from Service Lines. *Water Research, 46*(13), 4142-4152. doi:10.1016/j.watres.2012.05.010

Cartier, C., Laroche, L., Deshommes, E., Nour, S., Richard, G., Edwards, M., & Prévost, M. (2011). Investigating dissolved lead at the tap using various sampling protocols. *Journal - American Water Works Association, 103*(3), 55-67. doi:10.1002/j.1551-8833.2011.tb11420.x

Centers for Disease Control and Prevention. (2013, April 5, 2013). Childhood Blood Levels in Children Aged <5 Years - United States, 1999-2010. *Morbidity and Mortality Weekly Report.*

Centers for Disease Control and Prevention. (2017). *Morbidity and Mortality Weekly Report: Surveillance Summaries Vol. 66, No. 3*.

Centers for Disease Control and Prevention. (2020, August 31, 2020). Lead in Drinking Water. Retrieved from https://www.cdc.gov/nceh/lead/prevention/sources/water.htm

Chicago Mayor's Press Office. (2020). Mayor Lightfoot Launches Equity-Focused Lead Service Line Replacement Program. Retrieved from https://www.chicago.gov/city/en/depts/mayor/press_room/press_releases/2020/september/EquityFocusedLeadServiceReplacement.html

Cornwell, D. A., Brown, R. A., & Via, S. H. (2016). National Survey of Lead Service Line Occurrence. *Journal - American Water Works Association, 108*, E182-E191. doi:10.5942/jawwa.2016.108.0086

Del Toral, M. A., Porter, A., & Schock, M. R. (2013). Detection and Evaluation of Elevated Lead Release from Service Lines: A Field Study. *Environmental Science & Technology, 47*(16), 9300-9307. doi:10.1021/es4003636

Department of Health and Human Services. (2012). National Toxicology Program

Monograph: Health Effects of Low-Level Lead.

Department of Health and Human Services. (2020). *Toxicological Profile for Lead*.

Deshommes, E., Andrews, R. C., Gagnon, G., McCluskey, T., McIlwain, B., Dore, E., . . . Prevost, M. (2016). Evaluation of exposure to lead from drinking water in large buildings. *Water Research, 99*, 46-55. doi:10.1016/j.watres.2016.04.050

Deshommes, E., Laroche, L., Nour, S., Cartier, C., & Prévost, M. (2010). Source and occurrence of particulate lead in tap water. *Water Research, 44*(12), 3734-3744. doi:10.1016/j.watres.2010.04.019

Edwards, M., Triantafyllidou, S., & Best, D. (2008). Elevated Blood Lead in Young Children Due to Lead-Contaminated Drinking Water: Washington, DC, 2001-2004. *Environmental Science & Technology*.

Elfland, C., Scardina, P., & Edwards, M. (2010). Lead-contaminated water from brass plumbing devices in new buildings. *Journal - American Water Works Association, 102*(11), 66-76. doi:10.1002/j.1551-8833.2010.tb11340.x

Environmental Defense Fund. (2018). Child Care Lead in Water Pilot Project: Testing Protocol. Retrieved from blogs.edf.org/health/files/2018/02/Draft-Protocol_EDF-Childcare-Testing-Pilot-Project.pdf

Environmental Protection Agency. (2012). *Integrated Science Assessment for Lead*.

Environmental Protection Agency. (2017). *Proposed Modeling Approaches for a Health-Based Benchmark for Lead in Drinking Water*.

Environmental Protection Agency. (2020, September 23, 2020). How to Make Your Home Lead-Safe. Retrieved from https://www.epa.gov/lead/how-make-your-home-lead-safe

Gleason, J. A., Nanavaty, J. V., & Fagliano, J. A. (2019). Drinking water lead and socioeconomic factors as predictors of blood lead levels in New Jersey's children between two time periods. *Environmental Research, 169*, 409-416. doi:10.1016/j.envres.2018.11.016

Hauptman, M., Bruccoleri, R., & Woolf, A. D. (2017). An Update on Childhood Lead Poisoning. *Clinical Pediatric Emergency Medicine, 18*(3), 181-192. doi:10.1016/j.cpem.2017.07.010

Katner, A., Pieper, K. J., Lambrinidou, Y., Brown, K., Hu, C. Y., Mielke, H. W., & Edwards, M. A. (2016). Weaknesses in Federal Drinking Water Regulations and Public Health Policies that Impede Lead Poisoning Prevention and Environmental Justice. *Environmental Justice, 9*(4), 109-117. doi:10.1089/env.2016.0012

Kim, E. J., Herrera, J. E., Huggins, D., Braam, J., & Koshowski, S. (2011). Effect of pH on the concentrations of lead and trace contaminants in drinking water: A combined batch, pipe loop and sentinel home study. *Water Research, 45*(9), 2763-2774. doi:10.1016/j.watres.2011.02.023

Levallois, P., St-Laurent, J., Gauvin, D., Courteau, M., Prevost, M., Campagna, C., . . . Rasmussen, P. E. (2014). The impact of drinking water, indoor dust and paint on blood lead levels of children aged 1-5 years in Montreal (Quebec, Canada). *Journal of Exposure Science and Environmental Epidemiology, 24*(2), 185-191. doi:10.1038/jes.2012.129

Levin, R., Brown, M. J., Kashtock, M. E., Jacobs, D. E., Whelan, E. A., Rodman, J., . . . Sinks, T. (2008). Lead Exposures in U.S. Children, 2008: Implications for Prevention. *Environmental Health Perspectives, 116*(10), 1285-1293. doi:10.1289/ehp.11241

Liu, B. N., & Reckhow, D. A. (2015). Impact of Water Heaters on the Formation of Disinfection By-products. *Journal American Water Works Association, 107*(6), E328-E338. doi:10.5942/jawwa.2015.107.0080

Marshall, A. T., Betts, S., Kan, E. C., McConnell, R., Lanphear, B. P., & Sowell, E. R. (2020). Association of lead-exposure risk and family income with childhood brain outcomes. *Nature Medicine, 26*(1), 91-97. doi:10.1038/s41591-019-0713-y

Masters, S., Parks, J., Atassi, A., & Edwards, M. A. (2016). Inherent variability in lead and copper collected during standardized sampling. *Environmental Monitoring and Assessment, 188*(3). doi:10.1007/s10661-016-5182-x

McCormick, L. A., & Lovell, S. C. (2018). *Putting children first: Tackling lead in water at child care facilities*. Retrieved from

Miller-Schulze, J. P., Ishikawa, C., & Foran, J. A. (2019). Assessing lead-contaminated drinking water in a large academic institution: a case study. *Journal of Water and Health*. doi:10.2166/wh.2019.025

National Center for Education Statistics. (2018). Table 202.30: Number of children under 6 years old and not yet enrolled in kindergarten, percentage in center-based programs, average weekly hours in nonparental care, and percentage in various types of primary care arrangements, by selected child and family characteristics: 2016. Retrieved from https://nces.ed.gov/programs/digest/d18/tables/dt18_202.30.asp?referrer=report

Natural Resources Defense Council. Retrieved from https://www.nrdc.org/stories/flint-water-crisis-everything-you-need-know

Neltner, T. (2017). EDF's assessment of a health-based benchmark for lead in drinking water. Retrieved from http://blogs.edf.org/health/2017/02/28/health-based-action-level-for-lead-in-drinking-water/

Parks, J., Pieper, K. J., Katner, A., Tang, M., & Edwards, M. (2018). Potential Challenges Meeting the American Academy of Pediatrics' Lead in School Drinking Water Goal of 1 µg/L. *CORROSION - Journal of Science & Engineering, 74*(8), 914-917. doi:10.5006/2770

Pieper, K. J., Krometis, L.-A. H., Gallagher, D. L., Benham, B. L., & Edwards, M. (2015). Incidence of waterborne lead in private drinking water systems in Virginia. *Journal of Water and Health, 13*(3), 897-908. doi:10.2166/wh.2015.275

Redmon, J. H., Gibson, J. M., Woodward, K. P., Aceituno, A. M., & Levine, K. E. (2018). Safeguarding Children's Health. *North Carolina Medical Journal, 79*(5), 313-317. doi:10.18043/ncm.79.5.313

Redmon, J. H., Levine, K. E., Aceituno, A. M., Litzenberger, K., & Gibson, J. M. (2020). Lead in drinking water at North Carolina childcare centers: Piloting a citizen science-based testing strategy. *Environmental Research, 183*, 109126. doi:10.1016/j.envres.2020.109126

Rhoads, W. J., Bradley, T. N., Mantha, A., Buttling, L., Keane, T., Pruden, A., & Edwards, M. A. (2020). Residential water heater cleaning and occurrence of Legionella in Flint, MI. *Water Research, 171*, 115439. doi:10.1016/j.watres.2019.115439

Sandvig, A., Kwan, P., Kirmeyer, G., Maynard, B., Mast, D., Trussell, R. R., . . . Prescott, A. (2008). Contribution of Service Line and Plumbing Fixtures to Lead and Copper Rule Compliance Issues. *American Water Works Association*.

Scientific Committee on Health and Environmental Risks. (2011). Opinion on Lead Standard in Drinking Water. doi:10.2772/33674

Triantafyllidou, S., Gallagher, D., & Edwards, M. (2014a). Assessing risk with increasingly stringent public health goals: the case of water lead and blood lead in children. *Journal of Water and Health, 12*(1), 57-68. doi:10.2166/wh.2013.067

Triantafyllidou, S., Le, T., Gallagher, D., & Edwards, M. (2014b). Reduced risk estimations after remediation of lead (Pb) in drinking water at two US school districts. *Science of the Total Environment, 466-467*, 1011-1021. doi:10.1016/j.scitotenv.2013.07.111

Triantafyllidou, S., Nguyen, C. K., Zhang, Y., & Edwards, M. A. (2013). Lead (Pb) quantification in potable water samples: implications for regulatory compliance and assessment of human exposure. *Environmental Monitoring and Assessment, 185*(2), 1355-1365. doi:10.1007/s10661-012-2637-6

Trueman, B. F., Sweet, G. A., Harding, M. D., Estabrook, H., Bishop, D. P., & Gagnon, G. A. (2017). Galvanic Corrosion of Lead by Iron (Oxyhydr)Oxides: Potential Impacts on Drinking Water Quality. *Environmental Science & Technology, 51*(12), 6812-6820. doi:10.1021/acs.est.7b01671

Wang, Y., Mehta, V., Welter, G. J., & Giammar, D. E. (2013). Effect of connection methods on lead release from galvanic corrosion. *Journal - American Water Works Association, 105*(7), E337-E351. doi:10.5942/jawwa.2013.105.0088

Zartarian, V., Xue, J., Tornero-Velez, R., & Brown, J. (2017). Children’s Lead Exposure: A Multimedia Modeling Analysis to Guide Public Health Decision-Making. *Environmental Health Perspectives, 125*(9), 097009. doi:10.1289/ehp1605