Independent Research Capstone in the Field of
Sustainability

Addressing Lead in Schools Drinking Water in Greater Boston: Identifying Early Education and Care Facilities with the Highest Risk of Lead Contamination

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Jessica Sibirski
HUID # 40895698

Research Advisor: Dr. Richard Wetzler
Teacher Assistant: Marshall T. Spriggs

Abstract

Lead in drinking water has been gained increased attention after the lead contamination that occurred in Flint, Michigan in 2015, exposed more than 6,000 children to dangerous levels of lead (Hanna-Attisha, LaChance, Sadler, & Champney Schnepp, 2016). Post-Flint, some states across the United States (U.S.) recognized the necessity of protecting children's health against lead exposure in drinking water and focused on creating programs to mitigate lead levels in schools and childcare facilities (Walker, 2019). Today, no federal regulation required educational institutions to test for lead in drinking water. Thus, legislation efforts and voluntary programs are a crucial strategy to prevent lead contamination. In Massachusetts, the Department of Environmental Protection is the designee agency to implement voluntary programs that offer free water testing for public schools and publicly owned early education and care (EEC) facilities. However, since these programs are voluntarily, only about 8% of the more than 10,000 educational facilities in the state have participated. Therefore, there is no accurate knowledge of which facilities may have lead-containing materials that can contribute to lead contamination in drinking water.

The primary objective of this research was to know how many EEC facilities in Greater Boston may be at risk of lead contamination in drinking water. A total of 3,840 EEC facilities were analyzed to identify the variables - like the age of the building, presence of lead service lines and children age – that may contribute to lead leaching into the water. After the identification of variables, a risk model was constructed to develop a Tiering system to determine EEC facilities at risk. For instance, TIER 1 category (more likely to contain high levels of lead) was given to facilities that have lead service lines or lead plumbing materials. TIER 2 category was given to EEC facilities built before 1986 (before the ban of lead-containing plumbing materials) that might have lead plumbing materials, and TIER 3 category (less likely to contain lead) was given to facilities built after the lead ban. Subsequently, tiering categories were pair with the geolocation of each EEC facilities to construct a risk map.

The risk model showed that more than 85% of the EEC facilities located in Greater Boston might be at risk of lead contamination. Therefore, with the help of the Massachusetts Environmental Protection, 108 of the identified facilities were tested and analyzed for lead in drinking water. Overall, the results demonstrated that 69% of the 108 sampled EEC facilities had at least one lead sample result equal or greater to 1 parts per billion (ppb), with the highest results recorded in TIER 1 and TIER 2 categories. The lowest sample results were measured in TIER 3 categories.

This study provides quantitative and qualitative evidence of lead detections for more than half of the analyzed EEC facilities in Greater Boston and highlights the necessity of stricter policies in the state to successfully protect children's health.

Table of Contents

List of Figures

List of Tables

Definitions of Terms

Blood Lead Levels (BLL): A measure of the amount of lead in the blood.

BLL Reference Level: The Center for Disease Control and Prevention (CDC) defined a reference level of 5 micrograms per deciliter (µg/dL) to identify children with elevated BLL.

Child lead poisoning: The Department of Public Health (DPH) defines lead poisoning in children as a lead level concentration of 10 µg/dL or greater in children's blood.

Co-located facilities: EEC facilities placed inside other buildings such as schools or hospitals.

Distribution System: The network of pipes that transports drinking water from a community's treatment plant to a costumer's plumbing system.

EEC programs considered a PWS: Programs using well-water to serve 25 or more people for at least 60 days each year.

First Draw Sample: A tap water sample taken after a stagnation period of time no greater than 18 hours. A minimum of six hours is required.

Flush Sample: a water sample taken after letting cold water run for at least 30 seconds.

Greater Boston: defined as Boston – Cambridge – Newton Metropolitan Statistical Area (MSA) that encompassed Norfolk County, Plymouth County, Suffolk County, Middlesex County, and Essex County (See Appendix A for the list of cities and Town included in the study). Rockingham County and Strafford County in New Hampshire will be excluded from the MSA definition of Greater Boston since they are in a state different than Massachusetts. Thus, they are outside of the scope of this study because they are subject to different regulations.

Lead Service Line: a pipe made of lead that connects the water main under a street to a building's plumbing.

Public Water Supplier (PWS): Facilities that provide drinking water through pipes or other constructed conveyances to at least 15 service connections or serves an average of at least 25 people for at least 60 days a year.

1.0 Introduction

Lead contamination is recognized worldwide as a significant public health risk, especially for infants, children, and pregnant women. Even when lead concentrations in many parts of the world are declining due to global efforts such as public health campaigns, policies, and measurements like mandatory blood lead levels screening for children in developed countries, lead contamination it is still reported across the world (Zartarian, Xue, Tornero-Velez, & Brown, 2017).

In the United States (U.S.) concentrations of blood lead levels in children population have declined by 87% from 13.1 micrograms per deciliter ($\overline{x}$ µg/dL) in the 1970s to 1.75 $\overline{x}$ µg/dL in the 2000 (Zartarian et al.,2017). This decline is partly due to ban of lead-containing paint in 1978, the 1986 ban of lead-containing plumbing materials in drinking water, and the lead ban in gasoline (Zartarian et al., 2017) in the 1990's. See Figure 1 below.

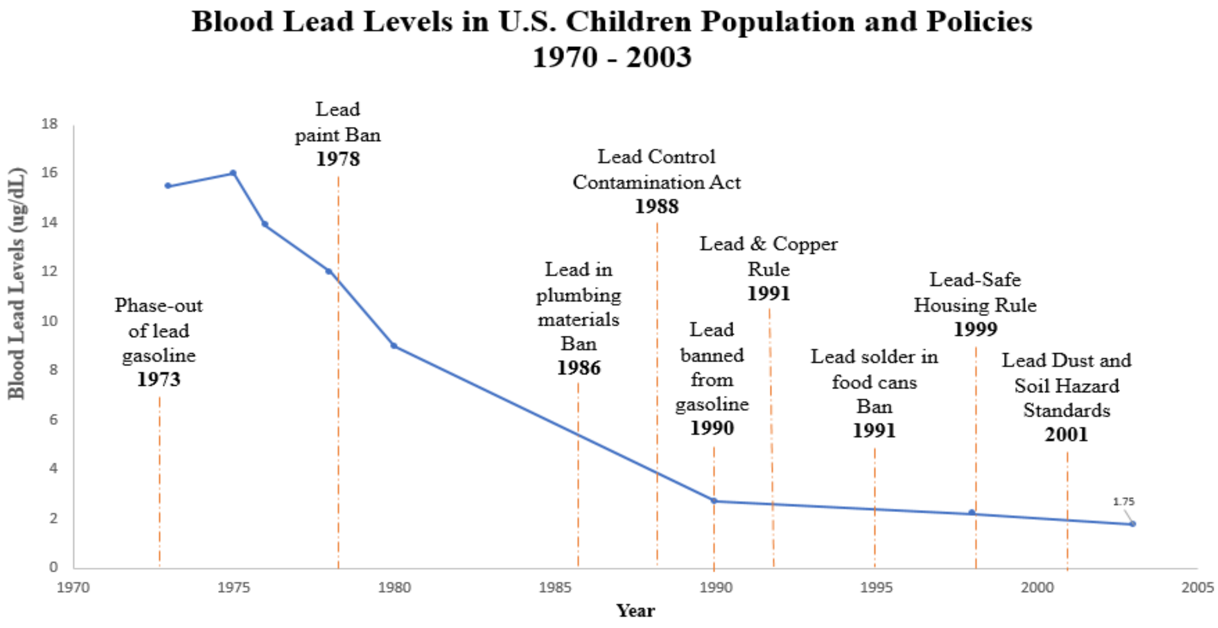

Figure 1. *Timeline of blood lead levels in U.S. children Population and Lead Mitigation Policies by Year in the United States. Adapted from (Brown & Margolis , 2012).*

Despite the decline in blood lead levels across the nation, sources of lead exposure like drinking water continue to threaten human health (Massachusetts Department of Environmental Protection [MassDEP], 2017). Event crises, like the 2014 Flint, Michigan drinking water contamination, have brought attention to the widespread problem of outdated infrastructure across U.S. cities that contributes to lead leaching into drinking water.

After Flint, governmental agencies identified that policies that aim to protect human health from lead in drinking water should be more stringent (Hanna-Attisha, LaChance, Sadler, & Champney Schnepp, 2016). Given that reducing all lead exposure and associated harm to human is considered essential to protect human's health, programs addressing the most vulnerable populations, especially children are favored. Thus, early education and care (EEC) facilities and schools, where children spend more than half of their days, are a critical focus of this research.

Identification of EEC facilities that can be at high risk of lead contamination is vital to mitigate the threat posed by lead in drinking water. By identifying these facilities, the stakeholders could more efficiently allocate resources to offer mitigation efforts and develop strategies for targeting the most vulnerable population. Therefore, this study uses a threefold approach to reduce the lead hazard in EEC facilities in Greater Boston by:

1. Analyzing existing information on EEC facilities, such as a building's age and the population served on a geographically-referenced basis.
2. Performing a risk assessment analysis to identify facilities at high risk of lead contamination. Starting with hazard identification (based on the geographical locations, plumbing age, lead service lines, corrosion control treatment, children's blood lead level

results in MA, and MassDEP's lead and copper rule results for assessed communities), followed by categorizing risk using EPA's tiering system for lead in drinking water.

3. Developing public education materials for EEC facilities.

1.1 Lead Background, Sources, and Health Risks

Lead (Pb) in its elemental form is a bluish-white metal found at low concentrations in the earth's crust, predominantly in the form of lead sulfide (International Agency for Research on Cancer [IARC], 2004). Lead compounds are found frequently combined with other elements and its widespread occurrence in the environment is partly due to anthropogenic activities (IARC, 2004). Over the centuries, lead has been used in many different applications due to its unique properties, such a malleability, softness, and resistance to corrosion (IARC, 2004). It was widely introduced into a variety of products like pipes, paint, or gasoline during the Industrial Revolution and, depending on its application, it is used as a metal by itself or alloyed with other materials. Production of lead is worldwide, with China, Australia, and the U.S. being the top three producers in 2018 (IARC, 2004).

Exposure to lead is worldwide and this poses adverse health effects for all humans (Hanna-Attisha et al., 2016; IARC, 2004). Still, lead sources that contribute to lead exposure by daily intake vary from country to country. In the U.S. for example, significant sources of lead contamination for children are lead in paint, soil/dust, and water ingestion (Zartarian et al., 2017). Lead is a potent neurotoxin that can impair brain development, the central nervous system, and the kidneys. It affects mostly infants, children, and pregnant women (IARC, 2004).

In humans, lead is stored primarily in bone (National Toxicology Program [NTP], 2012). In adults, around 95% of the total burden of lead is stored in bone and teeth, while in young children only a small fraction of total lead is stored in bone, because their continuous growth results in frequent bone remodeling, which enables a greater exchange of lead stored in bone with lead in blood (NTP, 2012). Therefore, even low levels of lead exposure have been associated with negative impacts in children's emotional and behavioral well-being (Malas, Cederna-MekoLauren , & O'Connel, 2018). Several studies have shown that lead exposure can increase the occurrence of anxiety and depression, and pre-natal lead exposure has been associated with schizophrenia (Hanna-Attisha et al., 2017; Malas et al., 2018).

The toxic effects of lead exposure can cause long-term impacts on human health. For instance, a study found that the risk of being arrested for a violent crime as a young adult increases by 50% for every 5 µg/dL increase in blood lead levels (Wright, J. P., Dietrich, K. N., Ris, M. D., Hornung, R. W., Wessel, S. D., Lanphear, B. P., ... & Rae, M. N. 2008). Therefore, the effects of childhood lead exposure may represent a severe threat to societies. See Table 1 below for associated health effects of lead in human health.

Table 1. *Health Effects of Different Lead Concentration in Children.*

Lead concentration	**Associated Health Effect**
< 5 ug/dL "low lead levels"	**Neurological:** Decreased IQ and cognitive measures; decreased hearing; decreased academic achievement; increased behavioral problems. **Reproductive and Developmental:** *Delayed puberty
5 - < 10 ug/dL	+ **Immune:** *Asthma, increased hypersensitivity, eczema. **Reproductive and Developmental:** Delayed puberty; reduced birth weight.
10 - < 44 ug/dL	+ Decreased Vitamin D metabolism. Decreased hemoglobin synthesis. Tiredness, Drowsiness
45 - < 69 ug/dL	+ Colic and cramps. Weight loss.
70 ug/dL or above	+ Encephalopathy, anemia, and nephropathy. Destruction of red cells. Stupor or coma. Death at around 130 ug/dL
* Limited evidence	

Information adapted from Lowry, 2016, and NTP, 2012.

Children less than six years old have been identified as at higher risk of lead poisoning due to several factors such as increased hand-to-mouth behaviors, their developing neurological system, and immature blood-brain barrier that can lead to greater neurotoxicity (Schnur & John, 2013). Children also have four to five times higher water-soluble lead absorption compared to adults, which made them especially vulnerable to lead contamination in drinking water (Schnur & John, 2013). Moreover, children have increased retention of absorbed lead in the body than adults. For example, children less than two years old retain up to 50% of lead compared to 1% retained by adults (Lowry, 2016).

Exposure to lead in the population is estimated using a measure of blood lead concentration. In the U.S., the reference level for blood lead, also known as "blood lead level of concern" is five micrograms per deciliter (µg/dL) at the 97.5th percentile to identify children with blood lead levels much higher than other children's level (Zartarian et al., 2017). This means that children with blood lead results higher than 5 µg/dL are identified as having significant lead exposure. Moreover, the U.S. Environmental Protection Agency (EPA), the American Academy of Pediatrics, and the Centers for Disease Control and Prevention (CDC) recognize that there is no known safe level of lead in children's blood. Therefore, measurable levels of lead in drinking water pose a health risk for vulnerable populations.

1.2 Lead in Drinking Water

Lead rarely occurs in raw (untreated) drinking water. However, it can enter freshwater bodies from the natural weathering of soil and rocks, atmospheric fallout, industrial sources, or stormwater pollution runoff (IARC, 2004). According to the IARC, concentration of lead in the U.S. can typically range between 5 and 30 micrograms per liter (µg/L) for surface water and between 1 and 100 µg/L for groundwater. The highest contributors to the release of lead into drinking water are lead-containing plumbing materials that are used to transport water from the treatment plant to the consumer's drinking water tap (Hanna-Attisha et al., 2016). Lead pipes, lead service lines, lead-containing brass plumbing components, galvanized iron pipes, lead joints, goosenecks or pigtails, lead-containing solder, and lead-containing fixtures are the principal materials that generate a high risk of lead contamination (Burlingame, et al., 2018; Del Toral et al., 2013). Lead in plumbing materials is very insoluble due to its elemental form (IARC, 2004). However, the chemical composition of drinking water in conjunction with microbial activity can contribute to corrosion, which occurs when there is a chemical reaction between water and the plumbing material and the material dissolves or wears away the metal, creating solid precipitates and dissolved complexes (MassDEP, 2017). Critical water quality parameters that affect the concentration of lead particles that can leach into water are pH, water alkalinity, water hardness, chloride, sulfate, and the addition of corrosion inhibitors. Water use patterns in buildings can also influence the amount of lead particles that can be released into drinking water. For example, periods of water stagnation (the period when water sits in the pipe) tend to allow greater water contact with plumbing materials, which together with water quality parameters and the amount of lead in the plumbing material will have an influence on the quantity of lead leaching into water (Burlingame, et al., 2018). Other factors that can increase levels of lead in drinking water are a physical disturbance of the piping or sudden changes in water flow (Burlingame, et al., 2018; Del Toral et al., 2013).

1.3 Federal Regulations for Lead in Drinking Water

Policies for the presence of lead in drinking water are currently covered under the federal regulatory Lead and Copper Rule (LCR) for public water systems and the Lead Contamination Control Act (LCCA) for schools and early education and care facilities. The path for this federal regulation and guidance respectively started in 1974, when Congress passed the “Safe Drinking Water Act” (SDWA) as the federal regulation for quality of drinking water in the U.S. The primary goal of the SDWA was to set minimum national standards for public water systems in order to protect public health by establishing maximum contaminant levels (MCL’s) for all substances that represented a threat to human well-being. (Lambrinidou, Triantafyllidou, & Edwards, 2010). Therefore, in 1975, the National Interim Primary Drinking Water Regulations adopted an MCL for lead in drinking water at 50 parts per billion (ppb), which was derived from the 1962 Public Health Service Act standard for measuring lead levels in water (U.S. Environmental protection Agency [EPA], 2019). However, the regulation required testing for lead only at the entry point of the distribution system in the treatment plant rather than at the tap of the consumer. Thus, the testing method did not account for the lead leaching from plumbing materials.

In 1986, the adoption of a lead ban prohibited the future use of lead pipes, solder, or flux in public water systems and buildings (EPA, 2019). It also defined as “lead-free” pipes that contain up to eight percent of lead and the percentage allowed in solders and flux was reduced from 50 percent to 0.2 percent. At the same time, revisions to the SDWA recognized schools as one of the most vulnerable places where children can be exposed to lead, prompting creation of the Lead Contamination and Control Act (LCCA) in 1988. The LCCA banned the use and manufacture of drinking water coolers with lead-lined tanks in schools. It required the EPA to set up guidance for schools for testing protocols and remediations effort, but most importantly, it recommended that actions should be taken whenever lead levels exceed 20 ppb (EPA, 2019). However, it did not set any regulatory requirements that mandated lead water testing for schools and early education and care facilities.

The Lead and Copper Rule (LCR), enacted in 1991, was the first federal law regulating lead in drinking water with the goal of protecting communities against the harmful effects of lead and copper by decreasing health risks (Pontius, 2007). This rule replaced the old lead maximum contaminant level of 50 ppb with a maximum contaminant level goal (MCLG) of zero for lead measured at the entry point of a public water system's distribution system (MassDEP, 2017). It also mandates that public water systems must test lead levels at residents taps and established a "lead action level" of 15 ppb based on the 90th percentile level of tap water samples instead of a maximum contaminant level. The "lead action level" triggers "water treatment techniques" whenever more than ten percent of all required samples taken are at or above 15 ppb. Some of the actions to be taken are corrosion control optimization, public notification, and the distribution of educational materials (Pontius, 2007). Under the federal LCR, sampling protocols require collecting "first draw" cold-water samples using 1-liter bottles from households' kitchen and bathroom taps (the water needs to sit stagnant during at least six hours) in order to capture what may be the worst-case scenario. The rule uses an approach targeting at-risk households most vulnerable to lead contamination. However, the LCR does not require sampling at schools or early education and care facilities. Only schools that are considered a public water system are required to test for lead by taking five samples per monitoring period. See Table 1.

***Table 2**. Lead in Drinking Water: Testing Requirements for Schools and Early Education and Care (EEC) Facilities in U.S.*

	Schools/EEC facilities regulated as Public Water Systems	**Schools/EEC facilities not regulated as Public Water Systems**
Characteristics	Provides water to at least of the same 25 people for at least six month per year from a private well.	Receive drinking water from a public water system
Prevalence	8-11%	89-92%

Pertinent Regulation	**Lead and Copper Rule (LCR):** require to take 5 samples of lead in drinking water outlets per monitoring period. Remediation and public notification of sample results is mandatory.	**Federal Lead Control Contamination Act (LCCA): Voluntary Program.** Testing for lead in drinking water is not required. Under the LCCA, EPA encourages facilities to test for lead and provides schools with guidance to reduce and prevent lead contamination. **LCCA Massachusetts:** PWSs must take 2 samples from 2 school/EEC facilities (not including family-based programs) located in their distribution system. This sampling does not trigger any required remediation action for the PWS.
Action Level (AL)	**15 ppb**	**Federal: 20 ppb** **Massachusetts: 15 ppb**
Remediation Requirements	If 10% of the samples exceeds the AL, remediation actions such a corrosion control optimization, lead service line replacement and public education is required	Historically, EPA recommended that any water outlet that test 20 ppb or higher be taken out of service or remediated. EPA's new guidance document (3Ts) recommends that any lead detection should be remediated.

Information adapted from (Lambrinidou, Triantafyllidou, & Edwards, 2010).

Currently, the lead action levels for lead in drinking water under the LCR and the LCCA are not based in a “health-based” benchmark. Instead, both action levels are based on assessing the effectiveness of the corrosion control treatment used by a public water system (EPA, 2017). Future revisions to the LCR aim to establish a “health-based action level” for lead in drinking water to maintain children’s blood lead levels below 5 µg/dL. Moreover, EPA is in the process of reviewing modeling approaches to set up a health-based benchmark by utilizing an Integrated Exposure Uptake Biokinetic (IEUBK) model. One model approach suggests that the water lead concentrations that can potentially keep children’s blood lead levels below a proposed 3.5 µg/dL and the current 5 µg/dL target for the 97.5th percentile, ranges from 0 to 4 ppb or 3 to 16 ppb, respectively, when accounting for others sources of lead exposure (Zartarian et al., 2017 & EPA, 2017). The ranges reflect the different age groups that are considered. See figure 2 below.

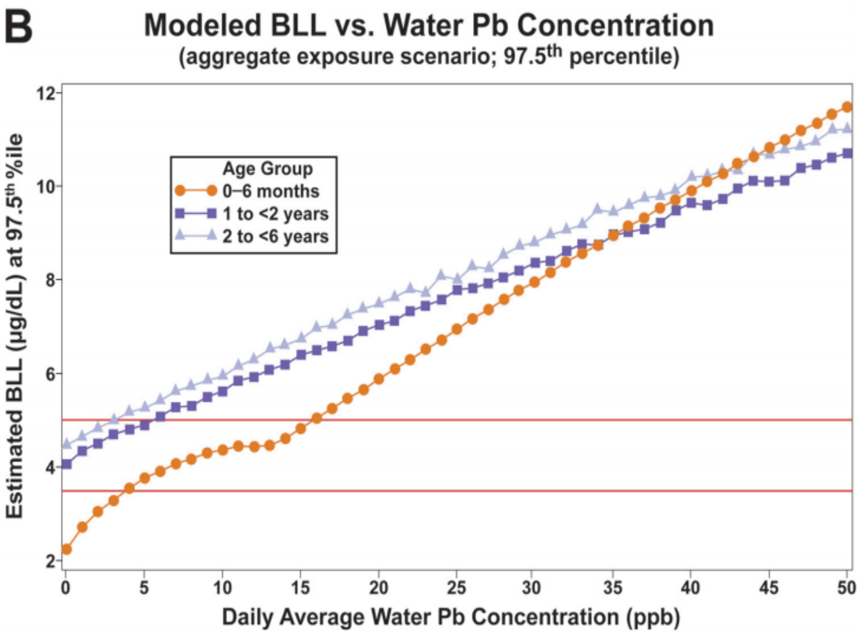

Figure 4. Illustrative graphs for determining household tap water Pb concentrations were calculated for different scenarios. *y*-Axis is modeled blood Pb level at 97.5th percentile of simulated population; *x*-axis is daily average water Pb concentration. The different colored lines represent different ages: orange is infants age 0–6 mo, dark blue is 1- to <2-y-olds, and light blue is 2- to <6-y-olds.

Figure 2. *Calculating a Health-benchmark for Lead in Drinking Water. Aggregate Exposure Scenario Includes Additional Lead Exposures from Soil, Dust, Food and Air.* Retrieved from: *(Zartarian, Xue, Tornero-Velez, & Brown, 2017)*

EPA's goal of including a health-benchmark for lead levels in drinking water is not only to assess corrosion control treatment but to provide the public health community with information that can be used to take prompt actions to mitigate lead risks (EPA, 2017). These changes will affect the LCR. Thus, it will have an impact on lead testing at households and schools/EEC facilities that are considered a public water system.

1.4 Lead Testing in Schools and EEC facilities in Massachusetts

In Massachusetts, the Department of Environmental Protection (MassDEP) is the designated agency to manage the LCR and the LCCA programs. In this state, under the LCR, public water systems are required to take lead samples from two schools per monitoring period. A monitoring period can be every six months, annual, or triennial, according to the public water system compliance and an approved schedule. However, this sampling is voluntary and does not trigger the "lead action level" (Burlingame, et al., 2018).

The LCCA program in Massachusetts is more stringent than the federal requirements by setting the "lead action level" at 15 ppb rather than 20 ppb. Under the LCCA, every five years, schools and EEC facilities are encouraged to complete a "Maintenance Checklist" to provide information related to lead and copper testing results, and actions taken. MassDEP also provides guidance to schools and EEC facilities on how to set up an LCCA program identifying and assessing water fixtures that can contain lead, as well as information on grants and opportunities to eliminate or remove lead sources (Burlingame, et al., 2018).

The latest program developed by the state agency in order to mitigate lead in school drinking water was the Massachusetts Assistance Program for Lead in School Drinking Water launched by Governor Charlie Baker and Treasurer Deborah Goldberg in April 2016. Under the assistance program, free lead and copper sampling, analysis, and technical assistance were offered to public school systems and districts during Phase I of the program. In Phase II, launched in 2018, publicly-owned childcare facilities were eligible for free lead sampling funding.

As of today, more than 70,000 lead and copper samples have been taken from 985 school buildings. Samples were taken in fixtures used for drinking water, as well as in fixtures used for cooking and for medical purposes. According to the results of these samples, 39% of the school buildings exceeded the lead action level of 15 ppb, the highest sample result taken was 39,000 ppb, and the kitchen kettles and classroom faucets were most likely to have lead exceedances compared to water fountains and water bottle filling stations (MassDEP 2017 & Burlingame, et al., 2018). See Figures 3 and 4 below.

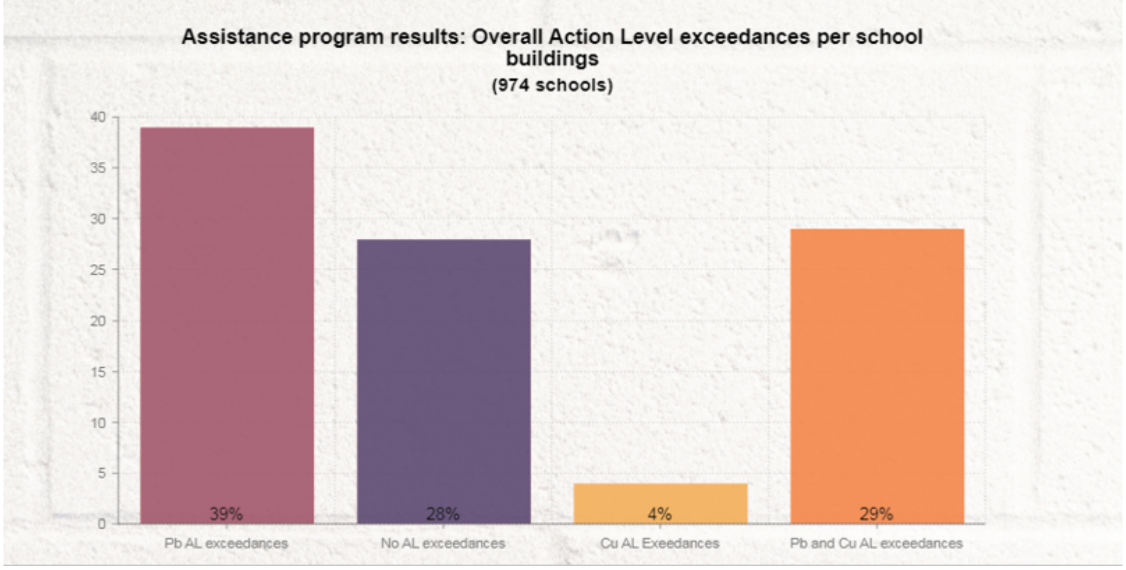

Figure 3. *Assistance Program Results: Overall Lead AL Exceedances*. Source: Energy and Environmental Affairs (EEA) Data Portal, 2019.

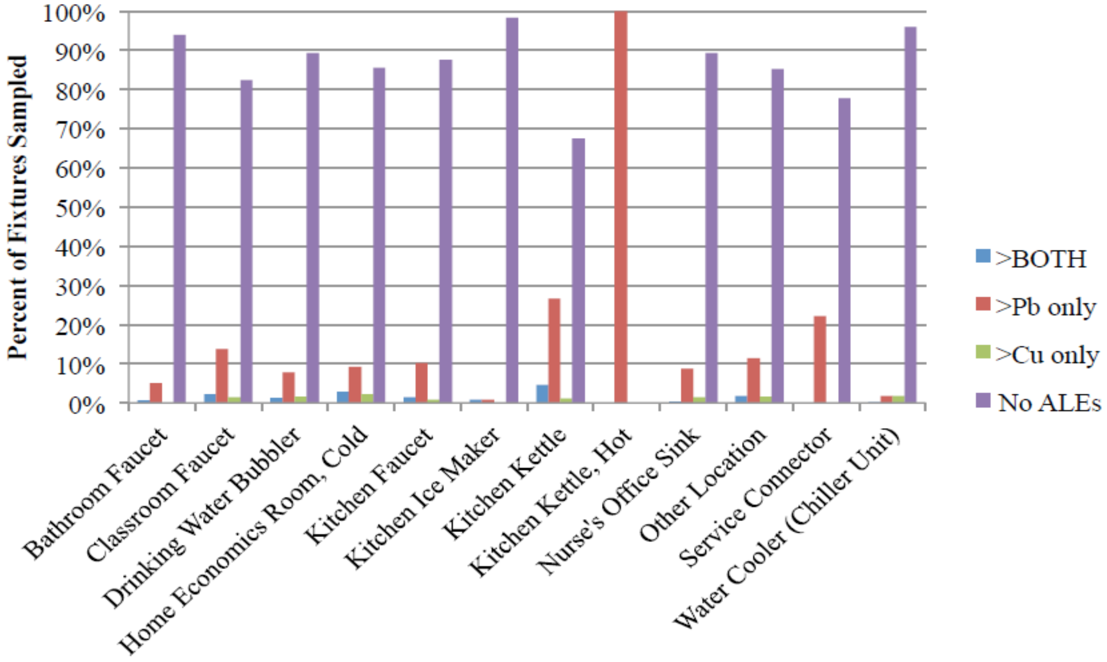

Figure 4. *Assistance Program Results: AL Exceedances in Fixture Types*. Retrieved from: MassDEP, 2017.

1.5 Early Education and Care Facilities in Greater Boston

In Massachusetts, the Department of Early Education and Care oversees the education programs of infants, toddlers, preschoolers, and school-age children (5 to 14 years old) during and out-of-school time (Department of Early Education and Care [EEC], 2019). There are more than 5,000 early education and care programs in Massachusetts offering education and care for more than 50,000 children from all economic backgrounds (EEC, 2019). These programs are divided into two categories, family child care, and center-based programs. Family child care, sometimes referred to as "home daycare," is delivered in a provider's home for no more than ten children ranging in age from infant through school age (EEC, 2019). The center-based programs serve children full or part-time in non-residential buildings, and include programs such as Head Start programs, out-of-school programs, and center-based care for infants, toddlers, preschool, and kindergarten age children (EEC, 2019).

There are 2,160 active EEC facilities located in Greater Boston, of which 1,194 are family child care, and 966 are center-based programs (EEC, 2019). None of these facilities are considered a "public water system." Thus, testing for lead in their drinking water is not mandatory. Moreover, it is estimated that Massachusetts counts with approximately 220,000 lead pipes, also known as lead service lines (Cornwell, Brown, & Via, 2016), and in Boston alone, more than 5,000 properties are connected to water mains by lead service lines (Cornwell et al., 2016). The widespread presence of lead-containing plumbing materials across the state may represent a high risk of lead leaching into drinking water for some of these EEC facilities. Therefore, identifying the possible risk of lead contamination can be key to protect children's health in the most vulnerable population.

2.0 Methods

The primary goal of this research was to determine whether it is possible to identify which early education and care (EEC) facilities in Greater Boston may be at risk of lead contamination in drinking water. In the context of this research, a risk is defined as the opportunity that lead exposure can occur for in EEC facility through drinking water pathways. Thus, the design of this study focused on constructing a risk map by identifying variables that may influence and present exposure to lead. Risk variables for lead exposure such as the age of building, presence of lead service lines, children age, high-risk communities, and blood lead levels results were determined as having the potential to influence the overall risk. It is important to note that the risk model does not directly imply child lead poisoning, but instead highlights the potential risk for lead exposure by children.

This risk map was constructed using Geographic Information System (GIS) technology that allows spatial analysis of a multivariable risk model such as this. The comprehensive map can be used as a powerful tool that will help stakeholders to explore data by location, perform assessments, and conduct community outreach in order to protect children's health.

2.1 Design of the Study

2.1.1 Study Size

A total of 3,869 EEC facilities in Greater Boston (Family child care n= 2,426 and center-based programs n= 1443) were analyzed before constructing the risk model map. Facilities that were considered a "public water system" and co-located facilities that operated in buildings considered "public water suppliers" were excluded from the study because, by law, these facilities are subject to regular lead testing and are required to implement mitigation actions if lead levels exceed 15 ppb. The object of this study is to find EEC facilities where tests for lead are not regularly conducted. After exclusion of these data, 3,840 facilities were included in the risk model. See Figure 1.

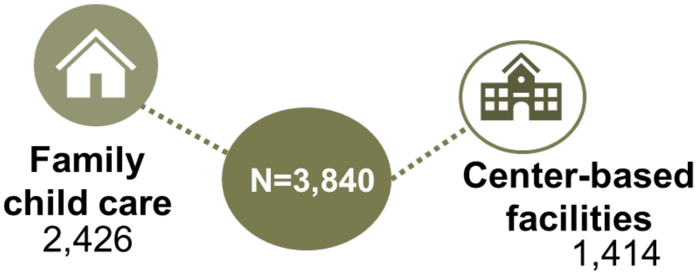

Figure 5. *Study Size*

2.1.2 Variables and Data Collection

Table 3. *Risk Model Variables*

Variable	Description	Data collection
EEC Geolocation	The dataset contains the name of each facility, type of license (center-based or family child care), and current address.	Provided by the Massachusetts Early Education and Care Department.
Year built	This variable was chosen because facilities built before 1986 are most likely to contain lead contaminated service lines and lead plumbing materials (Rabin, 2008). Also, it is important to note that copper pipes with lead solder installed in buildings between 1982 and 1986 are likely to leach lead in drinking water. Copper plumbing with lead solder was widely used in the U.S. in the 1950s, and a critical characteristic of this lead solder is that leaching diminishes over time (National Research Council (US) Committee on Measuring Lead in Critical Populations., 1993). Thus, EEC facilities containing lead solder installed before 1982 are not considered a priority concern for this research. The spatial data information used for this variable was the assessor tax at the parcel level because it contains detailed information such as year of construction, renovations (if any), home value, and ownership status.	Provided by the Massachusetts Bureau of Geographic Information (MassGIS).

Lead Service Lines (LSLs):	LSLs are considered one of the major contributors to lead contamination in drinking water (Rabin, 2008). In Massachusetts, lead pipe installation began in the late 1800s and was banned in late 1950s. A significant problem with identifying LSLs is the lack of location accuracy due to record-keeping issues across the country (Rabin, 2008). However, in Massachusetts, the cities of Boston, Malden, and Northampton located with accurate geolocation the publicly-owned part of LSLs in their distribution system. Using the available data, LSLs were manually identified for each EEC facility geolocation. Also, the MassDEP Lead Service Line survey was used to recognized communities with known LSLs. After identification, an email was sent to public water systems to confirm EEC facilities with LSLs. A total of 10 communities were able to identify 73 EEC facilities with LSLs. The rest of the facilities will need to physically check for LSLs and other lead plumbing materials.	• Available LSL Maps • MassDEP Lead Service Line survey • Public water system's confirmation
Population at highest risk (EEC Capacity by Children's Age)	Infants and children less than six (6) years old have been identified as the most vulnerable population for lead exposure (National Toxicology Program, 2012). Thus, for this research, facilities that provide services for infants and children < 6 years old are categorized as a potential high risk of lead exposure.	Massachusetts Early Education and Care Department
Department of Public Health (DPH) Blood Lead Level Results	Under the Massachusetts Lead Law, MGL c. 111, §§ 189A-199B, and the Lead Regulations (105 CMR 460.00), children between the ages of nine and twelve months must be screened for lead by a physician, and again at age two and three years old (MassDEP, 2017). Blood lead level (BLL) results are available for each community in MA for the last seven years (2010 – 2017). This data was used in the risk model because the presence of historical exposures in each community can potentially influence children's lead exposure (Rustin, R. C., 2013).	Provided by Department of Public Health
High Risk Community	This list was developed by DPH for communities with a five-year incidence of confirmed blood lead levels >= 10 µg/dL. The model accounts for the percentage of low and moderate income and the percentage of housing built before 1978 (lead-paint ban). See Appendix B for the list of high-risk communities for childhood lead poisoning.	Provided by Department of Public Health

Facilities Served by a Public Water System, Corrosion Control Treatment and Water PH	EEC facilities that are served by a public water system may have a lower risk of lead leaching into drinking water if the water system provides corrosion control treatment. Corrosion control treatment decreases lead leaching from plumbing materials into drinking water by using corrosion inhibitors and by adjusting water pH (Rabin, 2008).	Provided by Department of Environmental Protection

2.1.3 Risk Model Construction

The variables used to construct the risk model assessment were year built, presence of lead service lines, population at higher risk, BLLs surveillance data, and high-risk communities. Corrosion control treatment and water pH were not included in the construction of the risk model due to the natural variability of these variables. For example, corrosion control treatment can be disrupted by external factors that can be hard to measure, such as seasonal temperature changes or water treatment changes that can leave the pipes prone to corrosion. Therefore, these variables are better suited to help to understand sample results. Thus, they were included in the assessment of sampling outcomes later in the study.

A tiering system was developed by following EPA's tiering classification for assessing risk under the lead and copper rule (see Appendix C) and by adding a multivariable approach that accounted for other lead exposures rather than the sole plumbing material. The following are the TIER classifications:

A classification of TIER 1 (most likely to contain elevated lead levels) was given to EEC facilities with known LSLs, serving infants and children < 6 years old, located in high-risk communities, and with BLLs results ≥ 5 micrograms per deciliter (µg/dL) detected in the community.

A classification of TIER 2 was given to EEC facilities built before 1986 with possible LSL, possible lead interior piping, copper pipe with lead solder installed between 1982-1986, serving infants and children < 6 years old, located in high-risk communities, and with BLLs ≥ 5 µg/dL detected in the community.

A classification of TIER 3 (less likely to contain elevated lead levels) was given to EEC facilities built after 1986.

Among the TIER categories, TIER classifications were added to capture the variability of the data (see Table 3). Risk was assigned in the map by geocoding the EEC facility's address and spatially joining the tiering category. Other layers of the map show school systems near the EEC facilities with lead detections in drinking water.

Table 4. *EEC Facility Algorithm*

If [LSL]= "Y" And [Cap_Children] < 6 yrs And [HighRiskComm]= "Y" And [BLL] ≥ 5 µg/dL Then Output = **TIER 1**
If [LSL]= "Y" And [Cap_Children] < 6 yrs And [HighRiskComm]= "N" And [BLL] ≥ 5 µg/dL Then Output = **TIER 1A**
If [LSL]= "Y" And [Cap_Children] ≥ 6 yrs And [HighRiskComm]= "Y" or "N" And [BLL] ≥ 1 µg/dL Then Output = **TIER 1B**
ElseIf [yr_built] < 1987 And [LSL]= "Unknown" And [Cap_Children] < 6 yrs And [HighRiskComm]= "Y" And [BLL] ≥ 5 µg/dL Then Output = **TIER 2**

```
ElseIf [yr_built] < 1987 And [LSL]= “Unknown” And [Cap_Children] < 6 yrs And [HighRiskComm]= “N” And [BLL] ≥ 5 μg/dL Then Output = TIER 2A
ElseIf [yr_built] < 1987 And [LSL]= “Unknown” And [Cap_Children] ≥ 6 yrs And [HighRiskComm]= “Y” or “N” And [BLL] ≥ 5 μg/dL Then Output = TIER 2B
ElseIf [yr_built] < 1987 And [LSL]= “N” And [Cap_Children] = “All_ages” And [HighRiskComm]= “Y” or “N” And [BLL] ≥ 1 μg/dL Then Output = TIER 2C
ElseIf [yr_built] ≥ 1987 And [LSL]= “Unknown” And [Cap_Children] = “All_ages” And [HighRiskComm]= “Y” or “N” And [BLL] ≥ 5 μg/dL Then Output = TIER 3
```

2.1.3.1 Limitations

Lead released contribution by fixtures were not accounted for in the model because there is not currently available data for the EEC facilities. However, the testing methodology did account for the contribution of water fixtures in lead testing results.

2.2 Testing Methods

Lead-water testing in ten randomly selected EEC facilities were conducted and analyzed to evaluate the accuracy of the risk map with the help of the MassDEP Drinking Water Program. Also, more than 500 lead-water sample results taken in 98 EEC facilities under the MassDEP Assistance Program with contributions from the author in 2018, were analyzed and included in this study. The sampling protocols for all samples were the following:

- To ensure validity of samples, First-draw water samples were taken after a period of stagnation (at least 6 hours but no more than 18 hours). The samples were taken before any use of water in the facilities while the building was in regular use (not during vacations or after long holidays).

- Samples were collected using wide-mouth 250-ml plastic bottles without pre-acidification.
- Two samples were taken for each fixture. A first-draw sample collected as soon as the water flowed out of the fixture followed by a 30-second flush sample. The flush sample was collected after the water flowed for 30 seconds at a normal rate of flow.
- Samples were taken in fixtures used for drinking, cooking, or medical uses.
- Samples were analyzed using MassDEP certified laboratories.

2.3 Assessment

A correlation analysis was run to statistically determine if an association existed between the risk model and the available test results. Also, an in-depth analysis between two EEC facilities located in different communities with available testing results was developed in order to identified characteristics and similarities among these communities and to evaluate the sources of lead in drinking water.

3.0 Results

This study collected and analyzed the physical information of 3,840 early education and care (EEC) facilities in Greater Boston to study the different variables that can influence the risk of lead contamination in drinking water. Out of the analyzed facilities more than 80% were built before the 1986 lead ban for plumbing materials in drinking water (see Figure 1). Therefore, there is a significant risk that these EEC facilities have plumbing materials that contain lead.

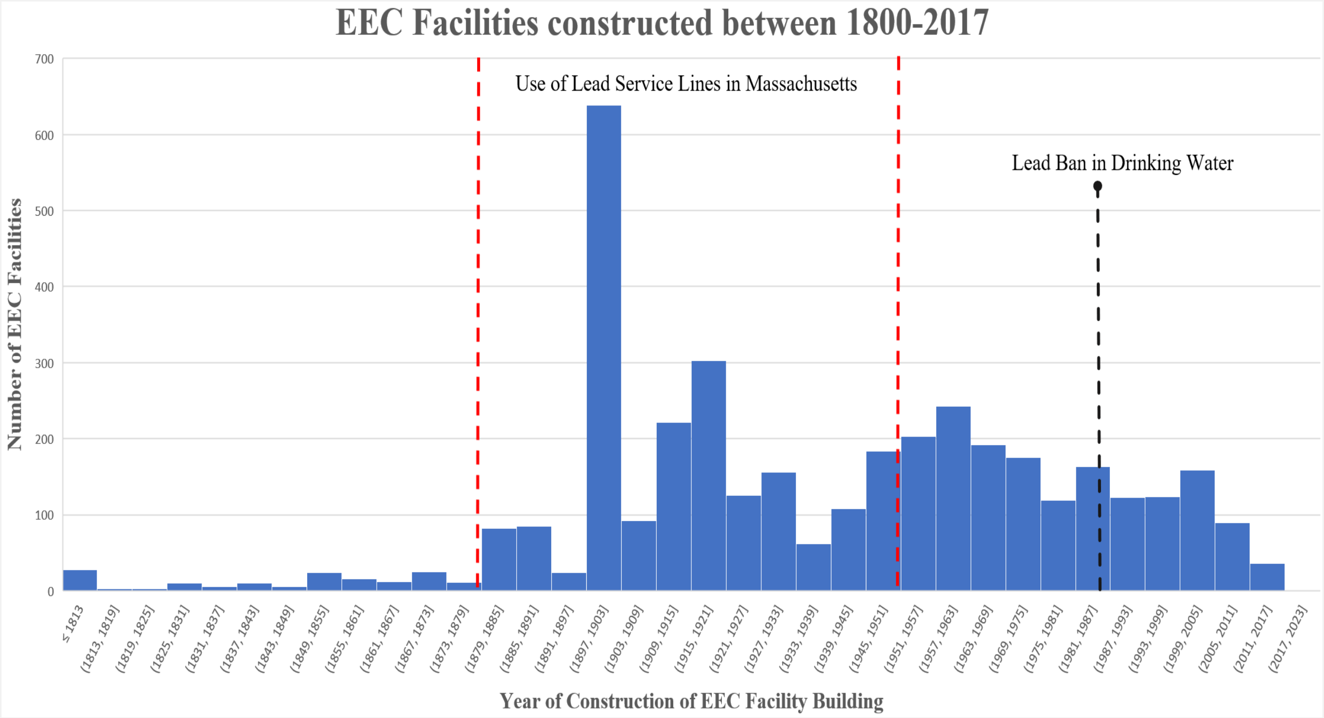

Figure 6. *Number of EEC Facilities per Year Built.*

After analysis of the variables, tiering categories were pair with the geolocation of each EEC facilities to construct the risk map. The final assessment categorized EEC facilities as the following:

- TIER 1: 89 EEC facilities with known lead service lines
- TIER 2: 3,209 EEC facilities with "possible" lead plumbing materials
- TIER 3: 542 EEC facilities (less likely to contain elevated lead levels).

The geographic information system (GIS) risk map displays not only risk category but also the presence of lead service lines in Greater Boston, high-risk communities, environmental justice areas, proximity to schools with lead detections, blood lead levels in selected area and year built (see Figure 2).

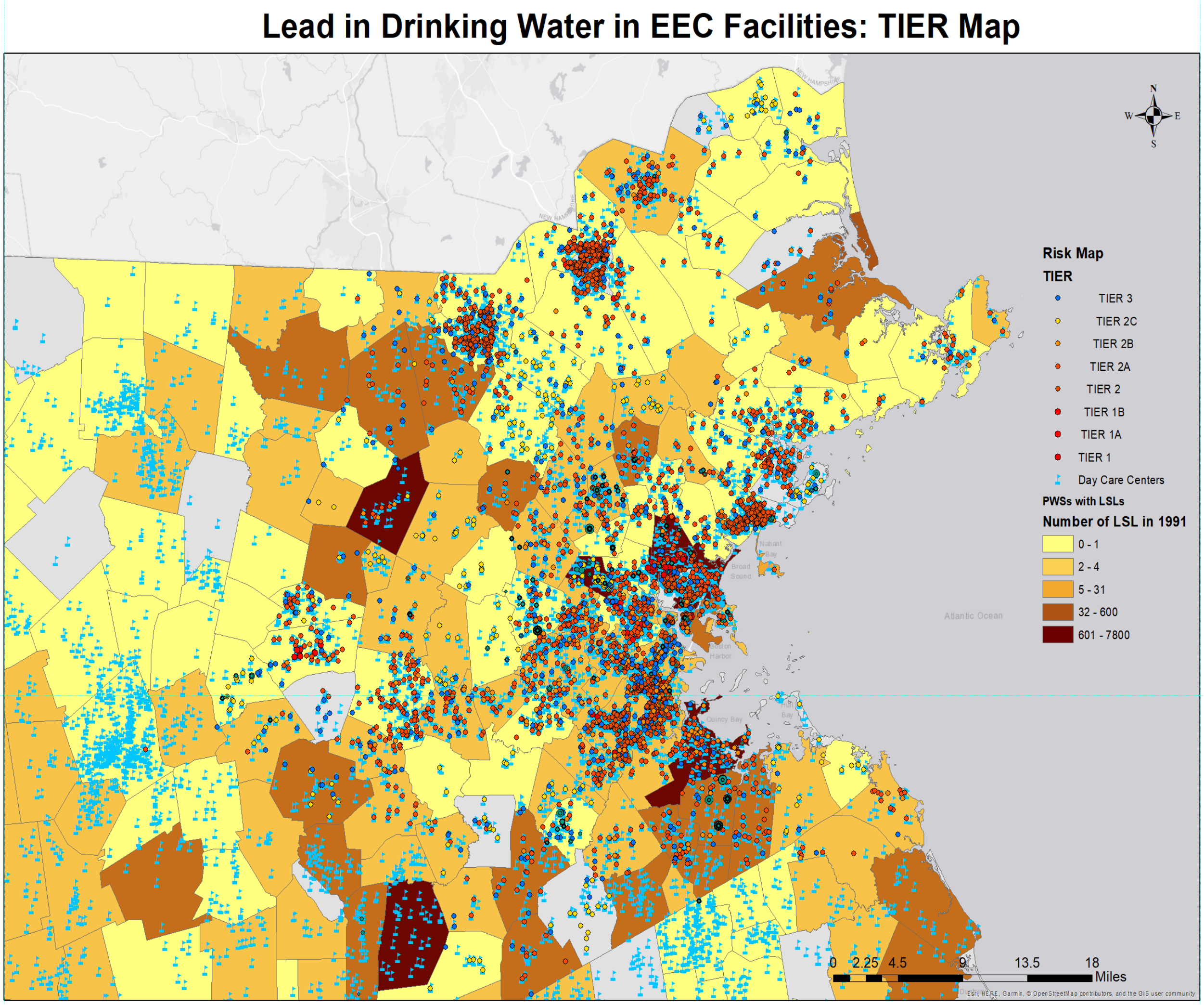

Figure 7. *EEC Facilities in Greater Boston – Risk Map*

3.1 Lead Sampling Results

Overall, 69% of the 108 sampled EEC facilities had at least one lead sample result equal or greater to 1 parts per billion (ppb), and 31% had lead levels ranging from non-detection to less than 1 ppb. Moreover, of the 1,005 lead samples analyzed, 38% detected lead levels greater or equal to 1 ppb (see Figure 3).

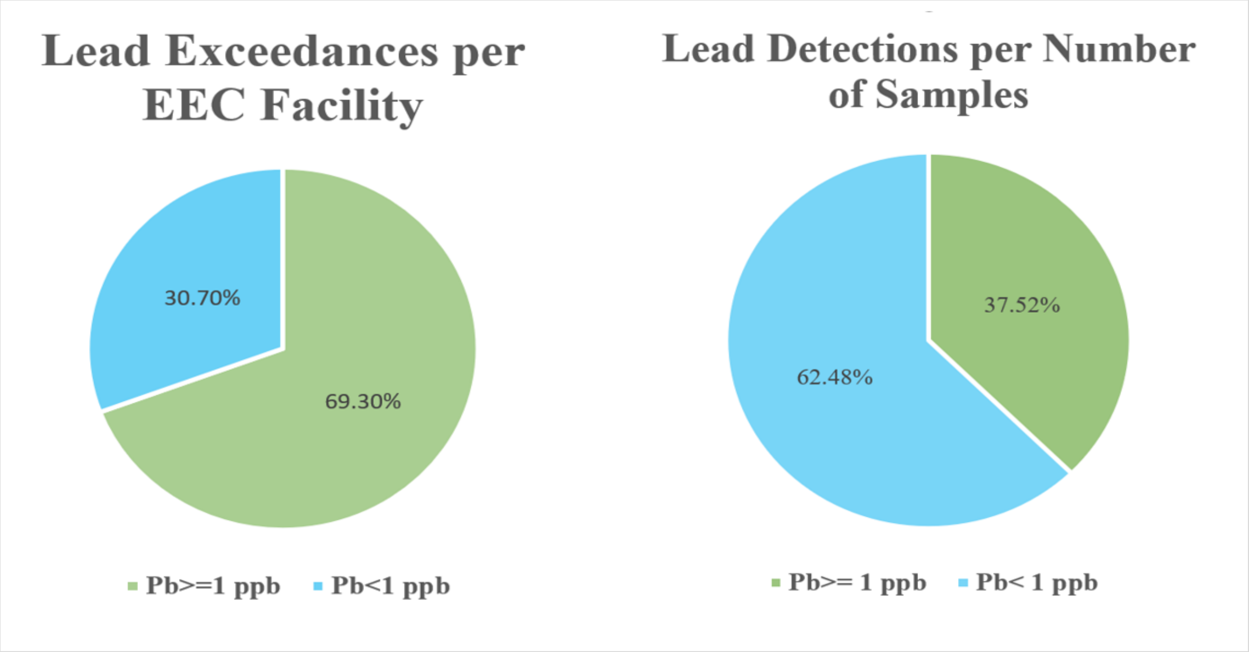

Figure 8. *Percentage of Lead Detections and Exceedances per EEC Facility.*

The highest lead concentrations were measured in EEC facilities classified as TIER 1 and TIER 2 (see Figure 4 and 5). Contrary, the lowest lead concentrations were measured in TIER 3 facilities. Overall, The maximum lead concentration for EEC facilities ranged from non-detection to 1170 ppb. Among the different TIER classes, TIER 2A (facilities with possible lead-containing plumbing materials serving children < 6 years old in non-high-risk communities) had the highest lead sample result.

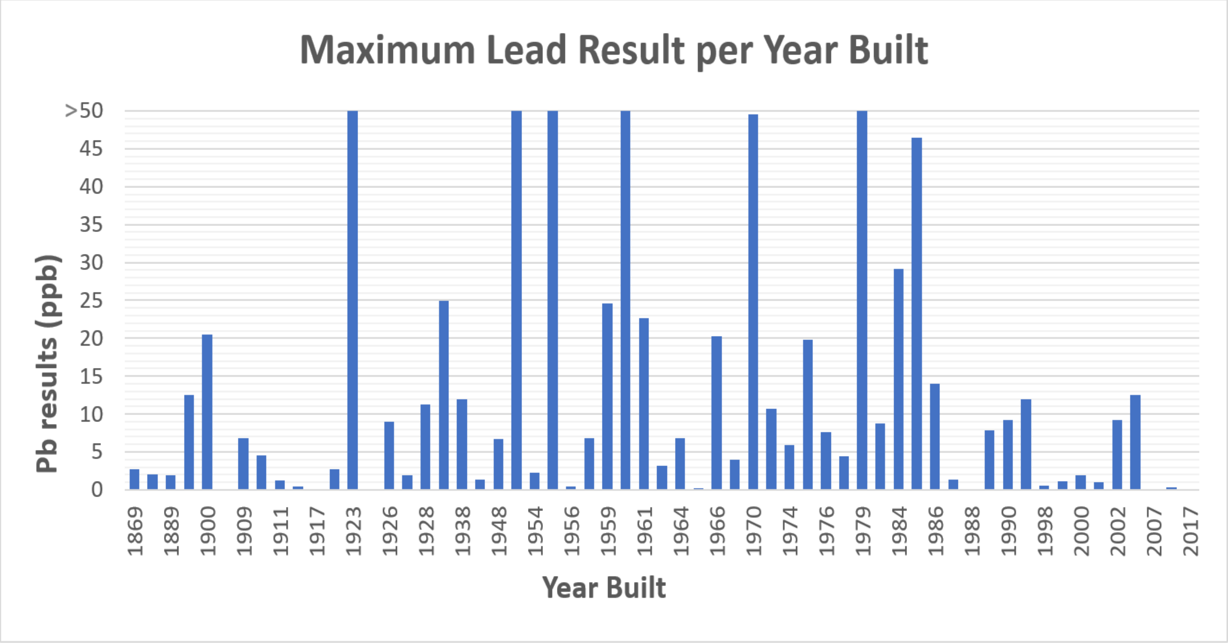

Figure 9. *EEC Facility Maximum Lead Concentration per Year Built.*

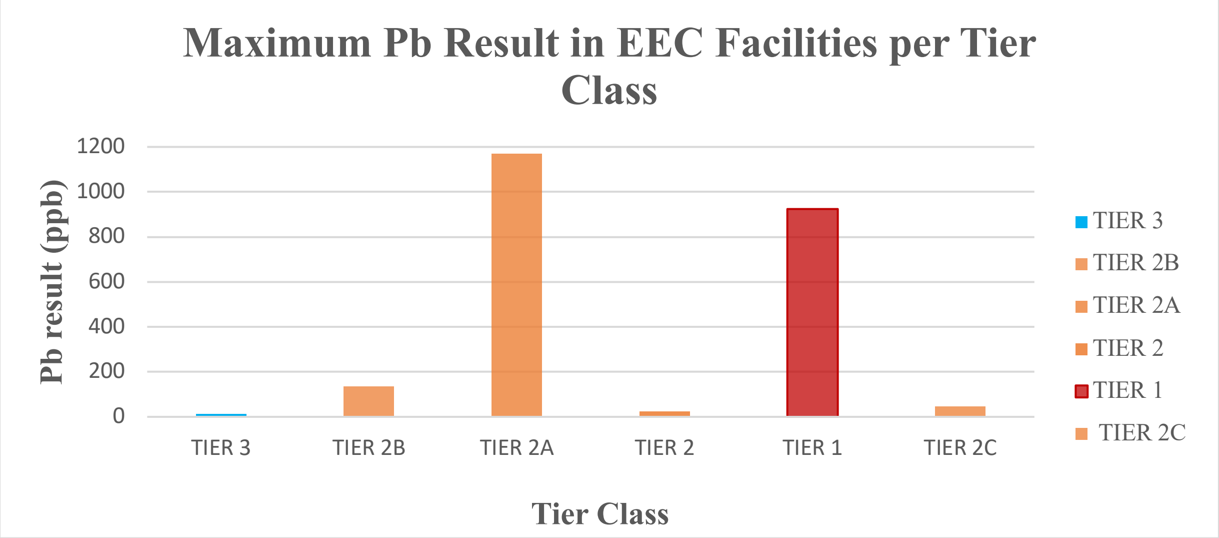

Figure 10. *EEC Facility Maximum Lead Concentration per Tier Category.*

The sample results also highlighted the differences among fixtures types. Overall, the percentage of lead concentrations were higher in classroom faucets (CF), followed by other non-consumption locations (OT), bathroom faucets (BF), and kitchen faucets (KF). Sample results for water bubblers and water fountains (WD) were lower than the other locations (see Figure 6).

Moreover, samples taken at kitchen kettle (KK) measured low lead concentrations, and they only represented a small fraction of the total samples.

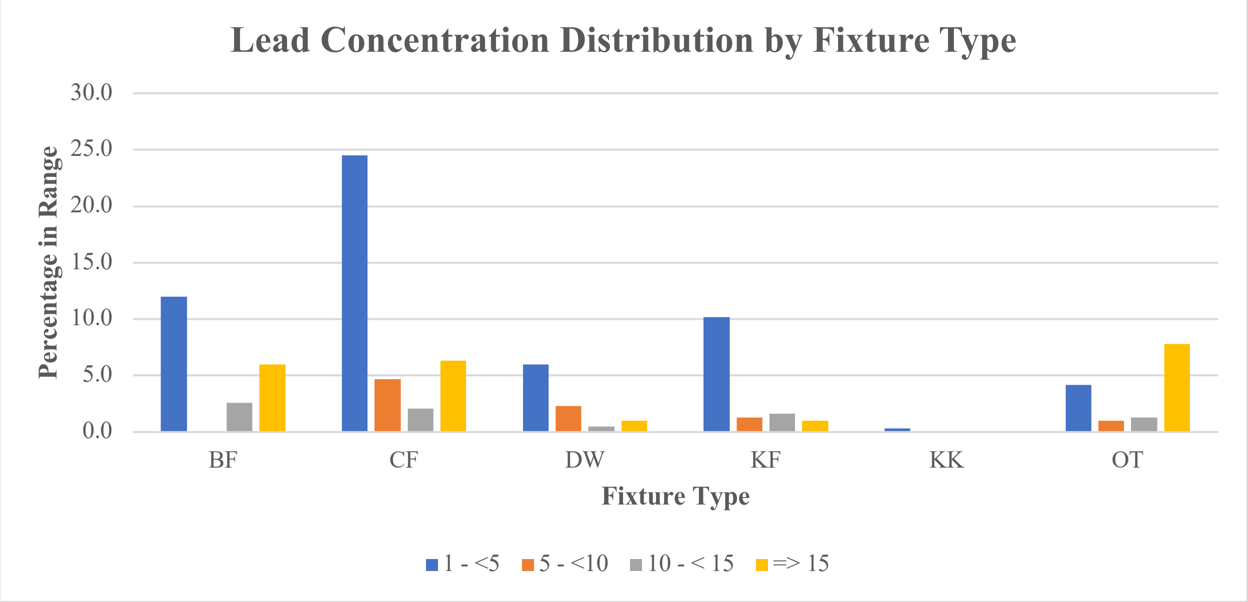

Figure 11. *Percentage of Lead Concentrations per Fixture Type.*

Also, when analyzing the two different sample collection methods, for the majority of the EEC facilities, first-draw (P) samples were more likely to have higher lead levels than flush (P) samples (see Figure 7).

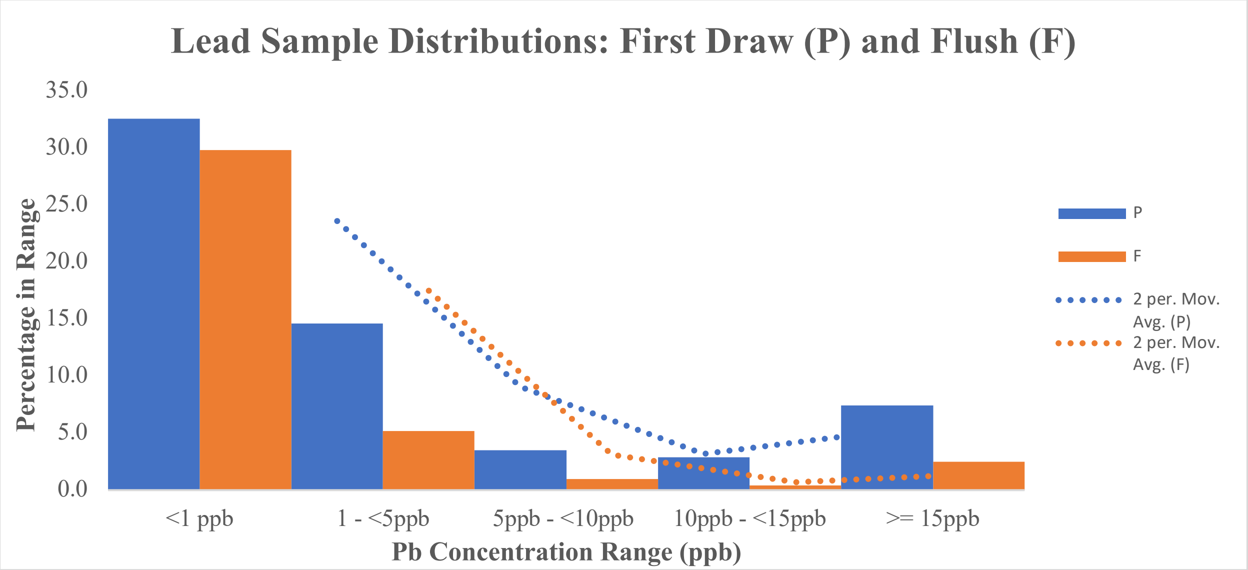

Figure 12. *Percentage of Lead Concentration by Sampling Method.*

Moreover, when analyzing first-draw samples versus flush samples per fixture types, the results show that lead concentrations in other fixtures (OT) were not significantly different between the two sampling methods. Contrary, for the drinking water bubblers, lead was detected in 29% of the first-draw samples and only 3% for flush samples (see Figure 8). The difference between sample collection methods can help to diagnose what is the source of lead in an EEC facility. For example, for drinking water bubblers, the results are suggesting that most of the lead leaching may be coming from the fixture.

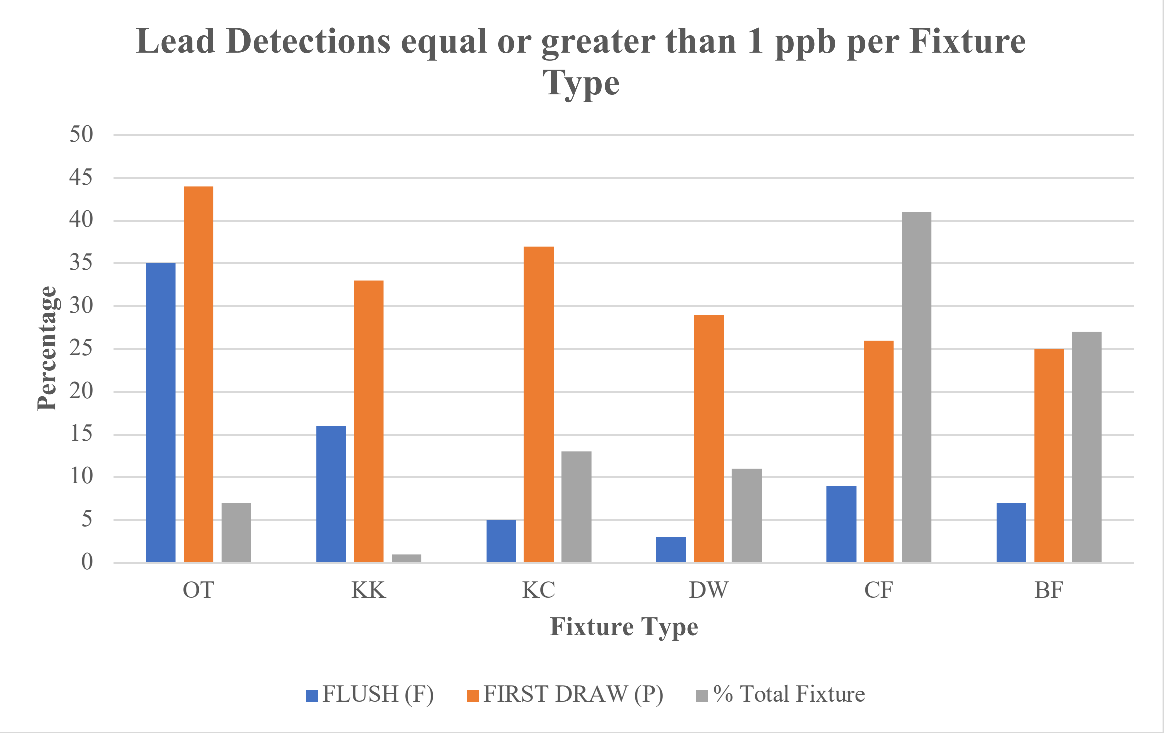

Figure 13. *Percentage of Lead Detections per Fixture Type.*

3.2 Correlation Analysis between the risk assessment and the sample results

The performed analysis for the possible lead-risk contamination in EEC Facilities in Greater Boston indicates that there is a weak correlation between the risk TIER category and the levels of lead in drinking water (See Figure 9).

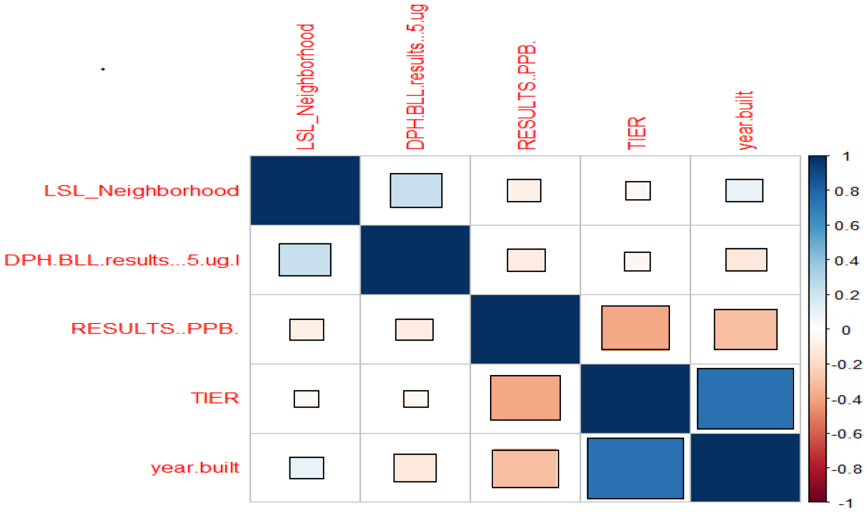

Figure 14. *Correlation Analysis between Variables.*

The effectiveness of corrosion control treatment used by public water systems and the unaccounted lead leaching from the fixtures may help to explain the weak relationship between the risk map and the sampling results. Out of the 105 analyzed EEC facilities, 99% are supplied by public water systems that use phosphates for corrosion control, and only 1% have their source of water (well). Moreover, it can be concluded that there is a negative relation between TIER category and sample results, with the highest sample results found in the lowest TIER category (TIER 1).

3.3 Analysis of Sample Results

Lead in drinking water was detected in more than half of the analyzed facilities. The risk model hypothesized that lead concentrations might be higher in facilities built before 1986. After analyzing the sample results, the study found that the highest lead concentrations were measured in facilities built before the lead ban. However, the statistical correlation analysis only indicated a weak relationship. To better understand the meaning of the sampling results, it is necessary to perform an in-depth analysis of two EEC facilities built in different years and located in different communities. The first facility to be analyzed is in Woburn, MA, and the second facility is in Braintree.

3.3.1 EEC Facility #1: Woburn

The city of Woburn has a population of approximately 39,000 of which 41% are families with children *(United States Census Bureau, 2019)*. According to the Department of Environmental Protection, water resources in the city are provided in its majority by an underground aquifer within the Horn area, and a third of the supply is provided by the Massachusetts Water Resource Authority (MWRA). Moreover, Woburn Water Department applies phosphates to the water as corrosion control treatment to decrease lead leach.

For this study, twelve out of the fifty EEC facilities located in Woburn were tested and analyzed for lead in drinking water (see Table 1). The analysis will focus on a facility that provides care for up to 89 children (from infant to six years old), built in 1979 and classified as TIER 2 in the risk assessment.

Table 5. *City of Woburn: Characteristics*

WOBURN CITY	
Number of EEC facilities	**50**
Family Child Care	30
Center based	20
Year Built Average	1949
Lead Service Lines	YES
High Risk Community	NO
DPH BLL results > 5 µg/l	YES
Number of schools tested	12
Number of samples results	222
Highest Pb sample result (ppb)	559
Lowest Pb sample result (ppb)	N.D
Average Risk Map Classification	TIER 2

After sampling collection, two sets of first-draw (FD) samples taken at a classroom fixture measured lead levels 37 times greater than Massachusetts recommended lead level of 15 ppb. However, after 30 seconds flush (FD) at normal flow, lead levels decreased to 28.4 ppb for both samples. The first diagnostic set of samples highlighted a possible problem with the fixture and the premise plumbing. Thus, remediation actions that included replacement of the fixture were taken to mitigate lead concentrations. After remediations, a new set of samples were taken within a month. Repeated first-draw samples (R FD) measured lead levels greater than 15 ppb, and flush samples lead levels decreased to 2 ppb (see figure 10). New efforts will focus on evaluating all premise plumbing in the building and the components of the service line to discover the source of lead.

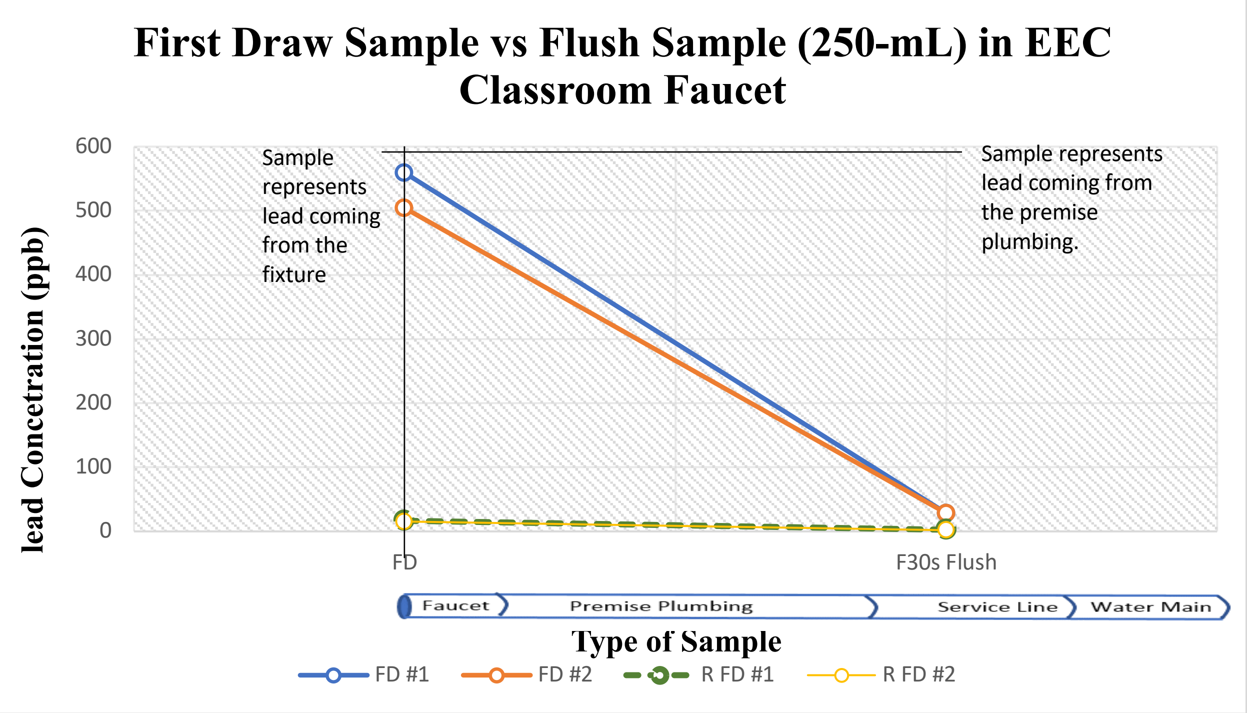

Figure 15. *Diagnostic Lead Samples in an EEC Facility in Woburn.*

This example shows that lead can still leach into drinking water despite the presence of corrosion control treatment and that accurately knowing the source of lead sometimes requires multiple samples.

3.3.2 EEC Facility #2: Waltham

Waltham is a city with a population of 64,442 of which more than 9% are children under nine years old (United States Census Bureau, 2019). Waltham gets its water from the Quabbin and Wachusett reservoirs through the MWRA. The system provides corrosion control since 1996 and is currently using sodium carbonate and carbon dioxide to reduce corrosivity and improve stability (MassDEP, 2019).

There are currently 43 EEC facilities in Waltham of which 20% were tested and analyzed in this study (see Table 2). Out of the analyzed facilities, 56% had lead detections, and the highest sample result was 924 ppb.

Table 6. *City of Waltham: Characteristics*

WALTHAM CITY	
Number of EEC facilities	**43**
Family Child Care	26
Center based	17
Year Built Average	1952
Lead Service Lines	YES
High Risk Community	NO
DPH BLL results > 5 µg/l	YES
Number of schools tested	9
Number of samples results	135
Highest Pb sample result (ppb)	924
Lowest Pb sample result (ppb)	N.D
Average Risk Map Classification	TIER 2

For this example, the study focuses on an EEC facility built in 2003, classified as TIER 3, with a capacity of up to 118 children. The two highest results were measured in a classroom fixture (CF) and a bathroom fixture (BF). However, in this case, lead was not detected after taking flush samples, which could mean that lead was leaching from the fixture instead of the pipes. (See Figure 11).

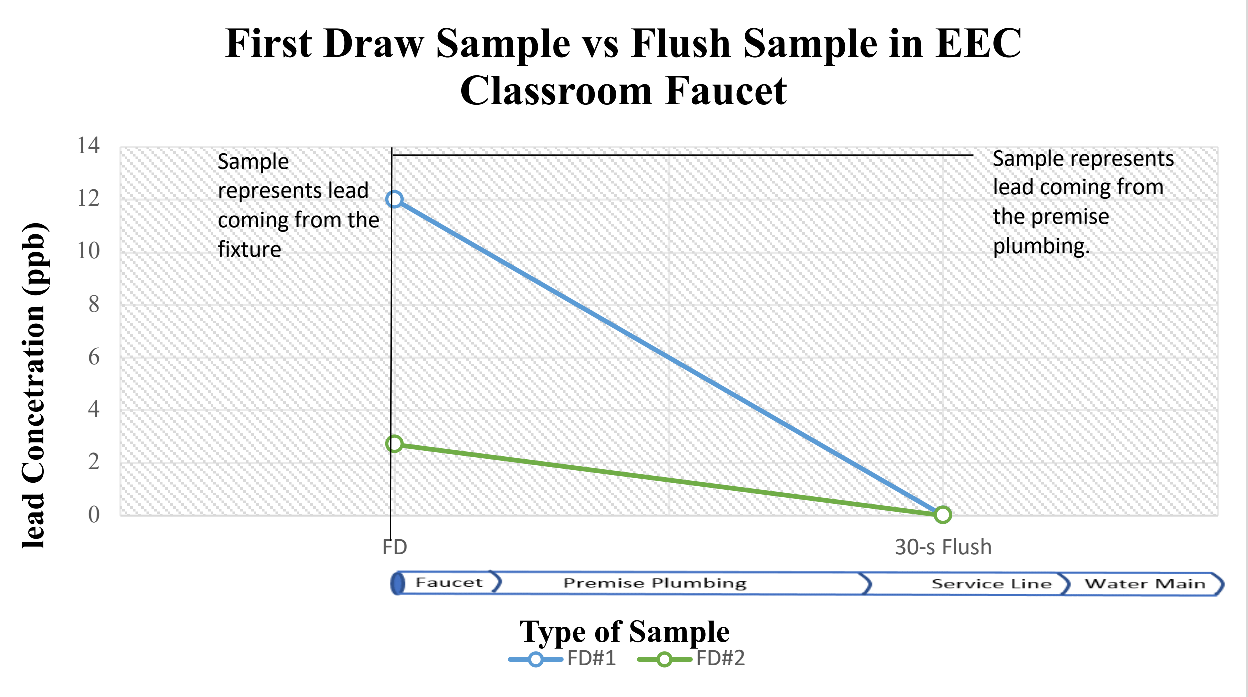

Figure 16. *Diagnostic Lead Samples in an EEC Facility in Waltham.*

After the diagnostic samples, the fixtures are being replaced and a new round of samples will be scheduled to confirm the effectiveness of the corrective actions.

3.4 Discussion

The aftermath of the water crisis event in Flint - Michigan, have pushed some states to work on identifying lead hazards to develop policies that can protect human health because no federal regulation mandates educational institutions to test for lead in drinking water. (Hanna-Attisha et al., 2016). One of the main focus has been addressing lead in drinking water for children. Therefore, schools and childcare facilities have been identified as crucial places to mitigate lead hazards since children tend to spend more than half of their days here (Walker, 2019).

In the last years, dietary changes in the U.S. have also risen the warning of safe drinking water at schools. For example, in 2018, the Center for Disease Control and Prevention (CDC) found that water in schools accounted for 43.7% of children’s total beverage consumption, followed by milk and soft drinks. The slow replacement of sugary drinks for healthier alternatives can be partially due to public campaigns that highlight the health risks related with these type of beverages (Maimaran, Kupor, Weihrauch, & Huang, 2019). Thus, today, the discussion is centering in making sure that if children's water consumption in educational facilities is increasing, sources of water should be free of any contaminant, especially lead (Cradock et al., 2019).

As previously mentioned in the study, even at low levels, lead can impair children’s brain development, well-being, and cognitive skills (Malas, Cederna-MekoLauren, & O’Connel, 2018), which are necessary functions for a child's performance in school. It is important to note that the CDC identified lead poisoning as one of the most common and preventable health hazards for children. For the mitigation, the CDC identified the replacement of plumbing materials and accessories containing lead as the primary strategy to eliminate lead in drinking water (Canfield, Jusko, & Kordas, 2005). The problem is that most cities in the country do not know the exact location of plumbing materials that may contain lead.

Washington D.C. is one of the few states with policies aiming to provide “safe” drinking water for children in schools and childcare facilities (see Table 3). Here, since 2018, all facilities are required by law to test for lead in drinking water yearly. Also, D.C's public water systems are continually working on updating their materials inventories to locate lead service lines.

***Table** 7. U.S. States with Lead in Schools Drinking Water Policies*

State	Mandatory Testing Requirement	Responsibility for testing	Action Level	Description	Are Child Care facilities required to test?
California	Once	Community Water System	15 ppb	Required to test the lead levels at all California public K-12 schools and preschools, and child care facilities located on public school property.	Only child day care facilities located on public school property
D.C	Yearly test	Department of General Services for public schools, and public charter school	5 ppb	Drinking water sources with lead levels below or at 5 ppb will not need to be remediated. Parents will be able to access all their school's test results online.	Yes
Illinois	Once	School districts or administrators	1 ppb	Requires a one-time testing for schools built prior to 2000 serving pre-school to grade 5.	Partially
Maryland	Yearly test	School systems and private schools	15 ppb	Applies to all schools regardless of year of construction.	No
Minnesota	Every 5 years	School systems and charter schools	N/A	Applies to all schools regardless of year of construction. It doesn't apply to pre-schools.	No
New Hampshire	Every 5 years	Schools	15 ppb	Applies to public and private schools and childcare facilities.	Child Care Facilities
New jersey	Every 6 years	Schools and child care facilities	15 ppb	Disclosure of lead testing results online.	Yes
New York	Every 2 - 5 years	School districts and boards of cooperative educational services	15 ppb	Applies to pre-kindergarten to 12th grade schools.	No
Oregon	Every 6 years	School and public charter school districts, education services.	15 ppb	Testing protocols only require firs-draw samples.	Partially

Information adapted from Rumpler & Dietz, 2019.

While testing and filtering fixtures are an excellent way to control and decrease lead levels in educational facilities, removing lead-containing plumbing materials may be the only way to eliminate lead from drinking water. Testing results in this study show that lead is present in 69% of the analyzed EEC facilities in Greater Boston. Moreover, the results indicated that lead could be detected even in facilities that were built after the lead ban. This highlight the potential danger of "lead-free" plumbing materials.

Until 2014, plumbing products such as faucets were able to contain up to 8% of lead and being considered "lead-free." After 2014, the definition of "lead-free" means that plumbing products can contain no more than a weighted average of 0.25% of the "wetted-surface" (Rumpler & Dietz, 2019). As highlighted in the results of this study, even when the highest lead sampling results in Greater Boston were found in EEC facilities built before 1986, newer facilities still have significant lead concentrations. Thus, it is essential to recognize that remediation actions should be taken in all schools and child care facilities regardless of the year they were built, but by prioritizing on addressing first the sites at higher risk of lead contamination with the most vulnerable population.

3.4.1 The Future of Lead in Drinking Water in Massachusetts

In Massachusetts, the department of environmental protection (MassDEP) has been working with different stakeholders throughout the years to ensure that lead levels are kept in control (Sung, 2003). Programs like the requirement of corrosion control treatment for some community water systems have been successfully lowering lead levels in drinking water in MA (Sung, 2003). As an example, looking at historical 90th percentile lead levels for the MWRA, where the untreated source water is corrosive, it can be observed that throughout the years the implementation of corrosion control treatment has indeed lowering lead levels (see Figure 10). However, relying only on corrosion control treatment for mitigating lead can be dangerous due to external factors that can alter how effective the treatment can be (Pontius, 2007).

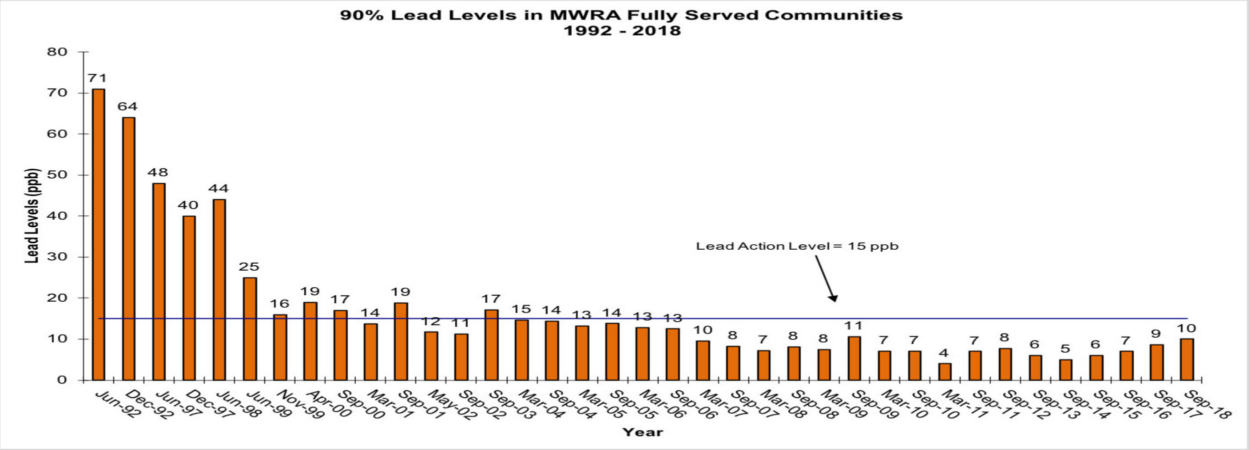

Figure 17. *MWRA's Lead 90th Percentile. Figure retrieved from MWRA's community confidence report.*

Another program in the state that is helping to mitigate lead hazards is the Lead Contamination Control Act (LCCA) program which provides technical assistance to facilities that are being tested for lead under the Lead and Copper Rule (LCR) or the Assistance Program. However, looking at the different types of educational institutions that take advantage of this program, it is noticeable that EEC facilities' participation is minimal, especially for family child care programs (MassDEP, 2017). Today, there are less than 100 available lead-in-drinking-water results that were taken in family child care facilities in MA (MassDEP, 2019).

Nevertheless, MassDEP's efforts to reduce lead in drinking water in schools and EEC facilities are bringing awareness in the community about the ongoing hazards with lead. After the 2017-2018 Assistance Program highlighted that more than half of the schools tested had detected lead in at least one fixture, multiple non-profit organizations and different communities have been demanding actions to establish policies that can prevent lead contamination in schools. Some of the most significant actions are the introduction of a legislative bill that will require all schools and EEC facilities to test for lead in drinking water, and the three million funding awarded to MassDEP for free bottled filling stations and filters for schools and EEC facilities (MassDEP, 2019).

Currently, there are more than 10,000 schools and EEC facilities in MA. Thus, implementing water testing and remediation actions for all these facilities may be costly. However, one study recently showed that the total cost for technical assistance, sampling, analysis, and remediation actions including lead service line replacement could cost up to $24,562,660 for EEC facilities and up to $7,973,235 for public schools in MA (Walker, 2019). Private schools were not included in the study. For the entire country the estimated cost was up to $1.08 billion. This cost is less than the estimated $50.9 billion cost for the annual lead exposure-related cognitive impairments in the U.S (Hauptman, Bruccoleri, & Woolf, 2017). Thus, taking actions actually to eliminate lead from drinking water sources can be financially viable.

3.5 Recommendations

Based on the risk assessment model and the sampling results, the following recommended actions aim to protect children's health by decreasing the likelihood of lead contamination in EEC facilities.

First, this study recommends public water suppliers to develop an inventory of all plumbing materials in their distribution system. Proper disclosure of sites with lead-containing plumbing systems can trigger remediation actions to eliminate the sources of lead. Currently, Massachusetts has available free grants for lead service lines replacement.

Second, the state should require EEC facilities to perform lead testing in drinking water yearly. According to the sample results from MassDEP Assistance Program, EEC facilities usually have an average of two fixtures per building, with the associated cost for sampling (including first-draw and flush samples) of $50 per facility (MassDEP, 2019). Therefore, future studies can develop a cost-assessment analysis to identify who should assume the cost of the testing.

However, if mandatory testing will be required, it is crucial to re-evaluate current testing methods. For example, it is recommended to set up a lead Action Level based on a health standard as well as to consider prioritization of remediation actions based on sample results and the most vulnerable populations. Therefore, fixtures that serve the youngest population with the highest sample results should take priority. Also, sampling methods should be based on a more robust approach. For example, to accurately diagnose the sources of lead, flush samples can be taken after 30 seconds, two minutes, and six minutes depending on the size of the building and length of pipes. The standard 30 seconds flush is only believed to capture lead concentrations in the premise plumbing of the building (Katner et al., 2018), whereas two and six minutes flush samples will accurately capture the levels of lead leaching from the service lines.

In addition to addressing sampling for lead in drinking water in EEC facilities, it is essential to recommend the development of the first fixture material inventory in MA. Per this study results, it was found that lead in new buildings can leach from fixtures containing lead. Thus, the department of education and care (EEC) can require EEC facilities the disclosure of materials in fixtures used for drinking, cooking, and medical purposes during the license application. Having this database can help to target fixtures that need remediation actions.

Lastly, it is vital to target public education for EEC facilities, especially family-based child cares. Massachusetts has multiple programs that can help with the mitigation of lead hazards in drinking water. However, EEC facilities participation is surprisingly low (Massachusetts Department of Environmental Protection (MassDEP), 2017). As part of this study, a website that compiles all available educational materials was created. The idea is to provide EEC facilities with tools for learning on how to take remediation actions and what are the available grants in the state. The website displays information on how to adequately identify lead service lines and lead-containing plumbing materials, as well as how to set up a testing program, and proper maintenance of fixtures.

Moreover, to encourage EEC facilities to take remediation actions, a tool that interprets lead sample results was developed. The tool can help these facilities to take remediation actions by prioritizing sample results based on lead concentration and the most vulnerable population. This website along with the tool is not intended just for Massachusetts and can be used by the whole country. For more information regarding the website and the tool, read Appendix 1.

The outlined recommendations should be applied to EEC facilities as well as to all schools in Massachusetts.

3.6 Conclusions

Educational facilities play an essential role in the development, health, and lives of children. Unfortunately, the presence of lead sources can jeopardize children's well-being, and the lack of federal regulations requiring schools and child care facilities to test for lead in drinking water are contributing to the escalation of a problem.

This study provides quantitative and qualitative evidence of lead detections for more than half of the analyzed EEC facilities. It was observed that facilities classified as at high risk of lead contamination were indeed the ones with the most elevated lead sample results. Coincidentally, facilities classified as at lower risk of lead contamination had lower lead levels.

Childhood lead exposure is a current threat in MA that needs to be addressed by implementing policies that mandate water testing on a regular basis and remediation actions in educational facilities. Until legislation is put in place, the findings in this study can provide information that can be used by the stakeholders to prioritize remediation actions in facilities that serve the most vulnerable populations and that are at risk of lead contamination. As an example, public water systems could fulfill their LCR requirement by prioritizing sampling in TIER 1 EEC facilities, followed by TIER 2, and TIER 3. This prioritization system can help to ensure that children younger than six years old are being monitored the first for lead hazards in drinking water.

Moreover, even with financial programs in place that can help with the replacement of lead plumbing materials, EEC facilities usually do not take advantage of these programs. Thus, the created website can be used as a tool for all the facilities to learn about lead available grants to address hazards, but most importantly, to educate themselves about what actions should be taken in case of lead detections at any fixture.

As of today, in Massachusetts, it is up to the schools and EEC facilities to participate in any of the free available lead in drinking water programs. On the other hand, it is up to the state and different stakeholders to fill the federal gap by continuing to create funding programs to protect children's health by mitigating lead hazards in drinking water.

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Appendix A

List of Cities/Town/Neighborhoods in Greater Boston

Acton
Allston
Amesbury
Andover
Arlington
Ashland
Bedford
Belmont
Beverly
Billerica
Boston
Boxborough
Boxford
Bradford
Braintree
Brighton
Brockton
Brookline
Burlington
Cambridge
Canton
Carlisle
Charlestown
Chelmsford
Chelsea
Chestnut Hill
Cohasset
Concord
Danvers
Dedham
Dorchester
Dover
Dracut
Dunstable
East Boston
Essex
Everett
Foxboro
Framingham
Georgetown
Gloucester
Groveland
Haverhill
Hingham
Holliston
Hopkinton
Hudson
Hull
Hyde Park
Ipswich
Jamaica Plain
Lawrence
Lexington
Lincoln
Littleton
Lowell
Lynn
Lynnfield
Malden
Manchester
Marblehead
Marlborough
Mattapan
Maynard
Medfield
Medford
Melrose
Merrimac
Methuen
Middleton
Millis
Milton
Nahant
Natick
Needham
Newbury
Newburyport
Newton
Norfolk
North Andover
North Billerica
North Chelmsford
North Quincy
North Reading
Northborough
Norwell
Norwood
Peabody
Plainville
Quincy
Randolph
Reading
Revere
Rockport
Roslindale
Rowley
Roxbury
Salem
Salisbury
Saugus
Scituate
Sharon
Sherborn
Somerville
South Boston
South Hamilton
Southborough
Stoneham
Stow
Sudbury
Swampscott
Tewksbury
Topsfield
Tyngsboro
Wakefield
Walpole
Waltham
Watertown
Wayland
Wellesley
Wenham
West Newbury
West Newton
West Roxbury
Westborough
Westford
Weston
Westwood
Weymouth
Wilmington
Winchester
Winthrop
Woburn
Wollaston
Wrentham

Appendix B

High Risk Communities for Lead in MA

High Risk Communities for Childhood Lead Poisoning. January 1, 2013-December 31, 2017
Table retrieved from the Department of Public Health.

Community	% 5 Year Screening	5 Year Cases[1]	Incidence Rate per 1,000[1]	% PIR below 2[2]	% Pre-1978 Housing Units[3]	High Risk Score[4]
BOSTON	79	281	3.2	33	80	6.3
BROCKTON	82	130	7.0	34	83	14.6
CHELSEA	94	25	2.5	41	79	6.0
CHICOPEE	67	22	3.1	30	83	5.7
EVERETT	78	25	3.0	35	90	7.0
FALL RIVER	74	44	3.4	40	82	8.3
FITCHBURG	64	19	3.4	32	77	6.2
GARDNER	56	15	6.8	30	78	11.8
HOLYOKE	74	37	5.1	45	83	14.1
LAWRENCE	71	62	3.8	54	82	12.5
LOWELL	72	94	4.8	37	78	10.3
LYNN	80	105	5.4	35	87	12.2
MALDEN	74	30	3.0	28	78	4.9
NEW BEDFORD	85	111	6.1	40	85	15.4
NORTH ADAMS	89	18	8.8	33	85	18.3
PITTSFIELD	75	26	4.3	32	83	8.5
SOUTHBRIDGE	70	20	9.0	32	79	16.9
SPRINGFIELD	78	175	6.6	50	84	20.5
WORCESTER	80	108	3.7	34	78	7.3
ALL HIGH RISK	**77**	**1347**	**4.4**	**37**	**81**	**9.8**
MASSACHUSETTS	**73**	**2400**	**2.7**	**19**	**71**	**2.7**

Comments:

The percent screened and number of newly identified cases with confirmed blood lead levels ≥ 10 µg/dL (children 9 to 47 months) have been identified for this 5-year period. Communities with at least 15 cases and a High-Risk Score statistically significantly higher than the state High Risk Score of 2.7 for this 5 year period have been included.

Footnotes:

[1] Number and rate of incident cases ≥10 µg/dL per 1,000 children (9 to 47 months) screened during this 5-year period.

[2] Percentage of families with an income to poverty ratio below 2.00 (i.e. < 200% of the poverty threshold).

[3] Percentage of housing units built prior to 1978 as estimated by the 2012-2016 American Community Survey.

[4] (5 Year Incidence Rate by community) * (% PIR below 2 by community / % PIR below 2 MA) * (% pre-1978 by community / % pre-1978 MA).

Appendix C

EPA's Tiering Classification for Public Water Systems

According to CMR 22.06B(7)(a), the tier classification for community (COM) water systems are as follow:

A **Tier 1** site shall consist of single-family structures that:

- a) contain copper pipes with lead solder installed after 1982 or contain lead pipes; and/or
- b) are served by a lead service line. When multiple-family residences comprise at least 20% of the structures served by a water system, the system may include these types of structures in its sampling pool.

A **Tier 2** site shall consist of buildings, including multiple-family residents that:

- a) contain copper pipes with lead solder installed after 1982 or contain lead pipes: and/or
- b) are served by a lead service line.

A **Tier 3** site shall consist of single-family structures that contain copper pipes with lead solder installed before 1983.

According to CMR 22.06B(7)(a) the tier classification for non-transient non-community (NTNC) water systems are as follow:

A **Tier 1** site shall consist of buildings that:

- a) contain copper pipes with lead solder installed after 1982 or contain lead pipes; and/or
- b) are served by a lead service line.

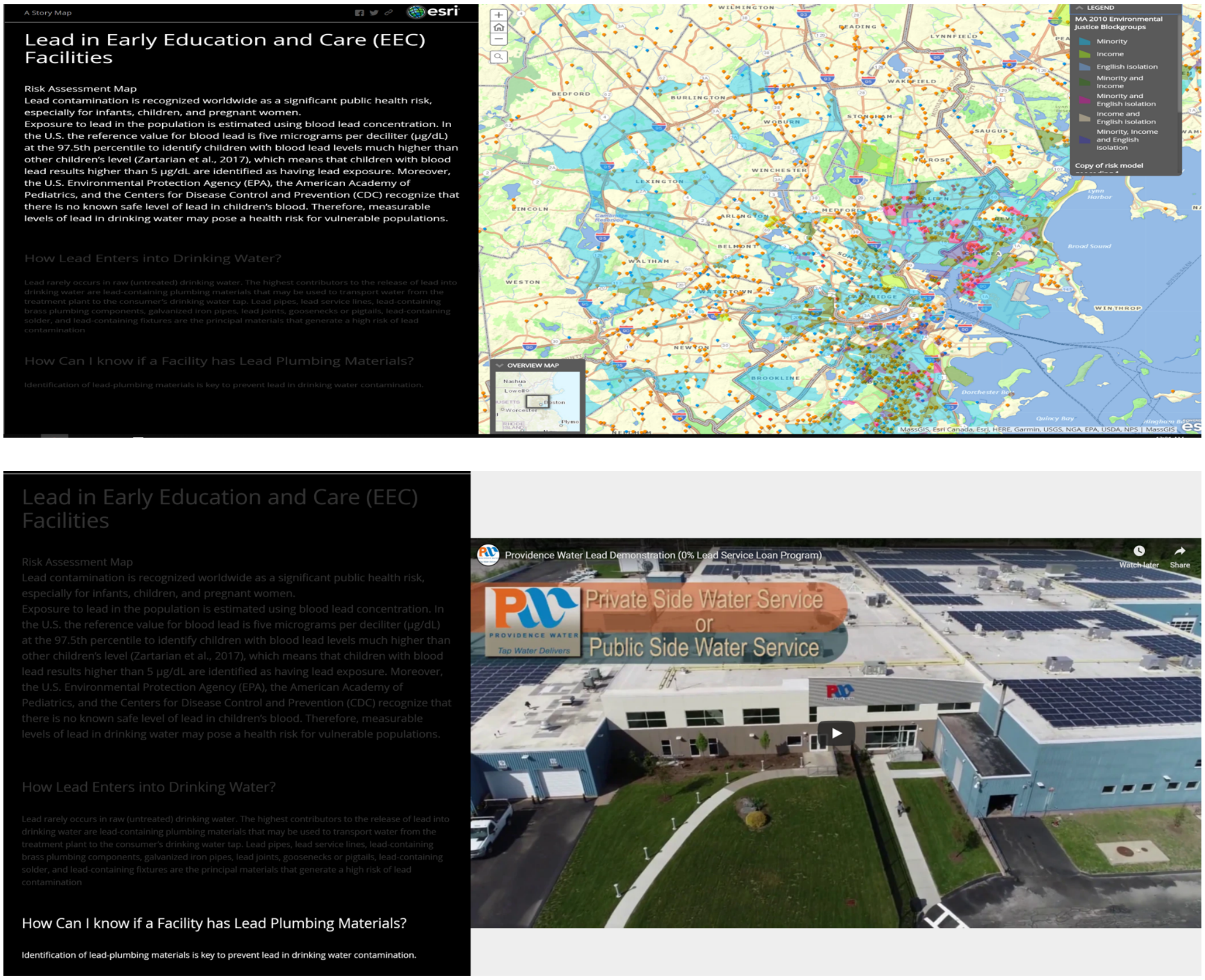
A **Tier 2** site shall consist of buildings that:

- a) Private building with lead pipe or copper pipe with lead/tin solder installed in 1983, 1984, 1985, or 1986.

Appendix D

Lead in Drinking Water in EEC Facilities and Schools Website and Tool

The website was created to help EEC facilities and schools to understand lead in drinking water. The site is composed of different sections, starting by describing how lead enters into drinking water to listing available grants for lead mitigation. Users can navigate this website by looking at risk categories of different EEC facilities in Greater Boston or by analyzing facilities located in high-risk communities. To see the website see: https://arcg.is/X8TSW



Lead in Early Education and Care (EEC) Facilities

Risk Assessment Map

Lead contamination is recognized worldwide as a significant public health risk, especially for infants, children, and pregnant women.

Exposure to lead in the population is estimated using blood lead concentration. In the U.S. the reference value for blood lead is five micrograms per deciliter (μg/dL) at the 97.5th percentile to identify children with blood lead levels much higher than other children's level (Zartarian et al., 2017), which means that children with blood lead results higher than 5 μg/dL are identified as having lead exposure. Moreover, the U.S. Environmental Protection Agency (EPA), the American Academy of Pediatrics, and the Centers for Disease Control and Prevention (CDC) recognize that there is no known safe level of lead in children's blood. Therefore, measurable levels of lead in drinking water may pose a health risk for vulnerable populations.

How Lead Enters into Drinking Water?

Lead rarely occurs in raw (untreated) drinking water. The highest contributors to the release of lead into drinking water are lead-containing plumbing materials that may be used to transport water from the treatment plant to the consumer's drinking water tap. Lead pipes, lead service lines, lead-containing brass plumbing components, galvanized iron pipes, lead joints, goosenecks or pigtails, lead-containing solder, and lead-containing fixtures are the principal materials that generate a high risk of lead contamination

How Can I know if a Facility has Lead Plumbing Materials?

Identification of lead-plumbing materials is key to prevent lead in drinking water contamination.

Lead in Early Education and Care (EEC) Facilities

Risk Assessment Map

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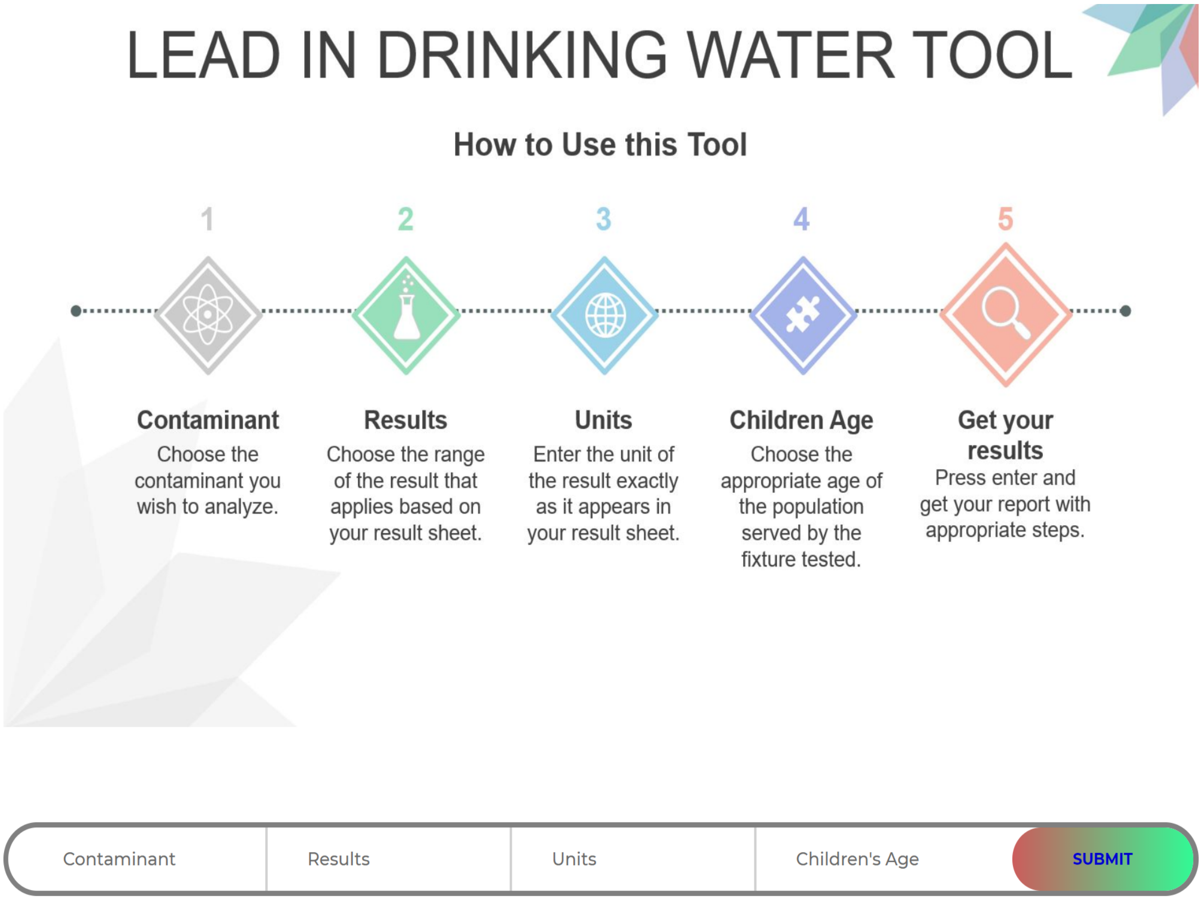
Figure D-1. *Screenshot of the Designed Website.*

The website also displays the “tool” which was designed to help facilities to interpret lead sample results. All provided information in the Tool is based on the Environmental Protection Agency (EPA) guidance for reducing lead in drinking water in schools. Users can enter lead sample results into the Tool to received feedback about remediation actions. See Figure A-2.



LEAD IN DRINKING WATER TOOL

How to Use this Tool

1 **Contaminant** Choose the contaminant you wish to analyze.

2 **Results** Choose the range of the result that applies based on your result sheet.

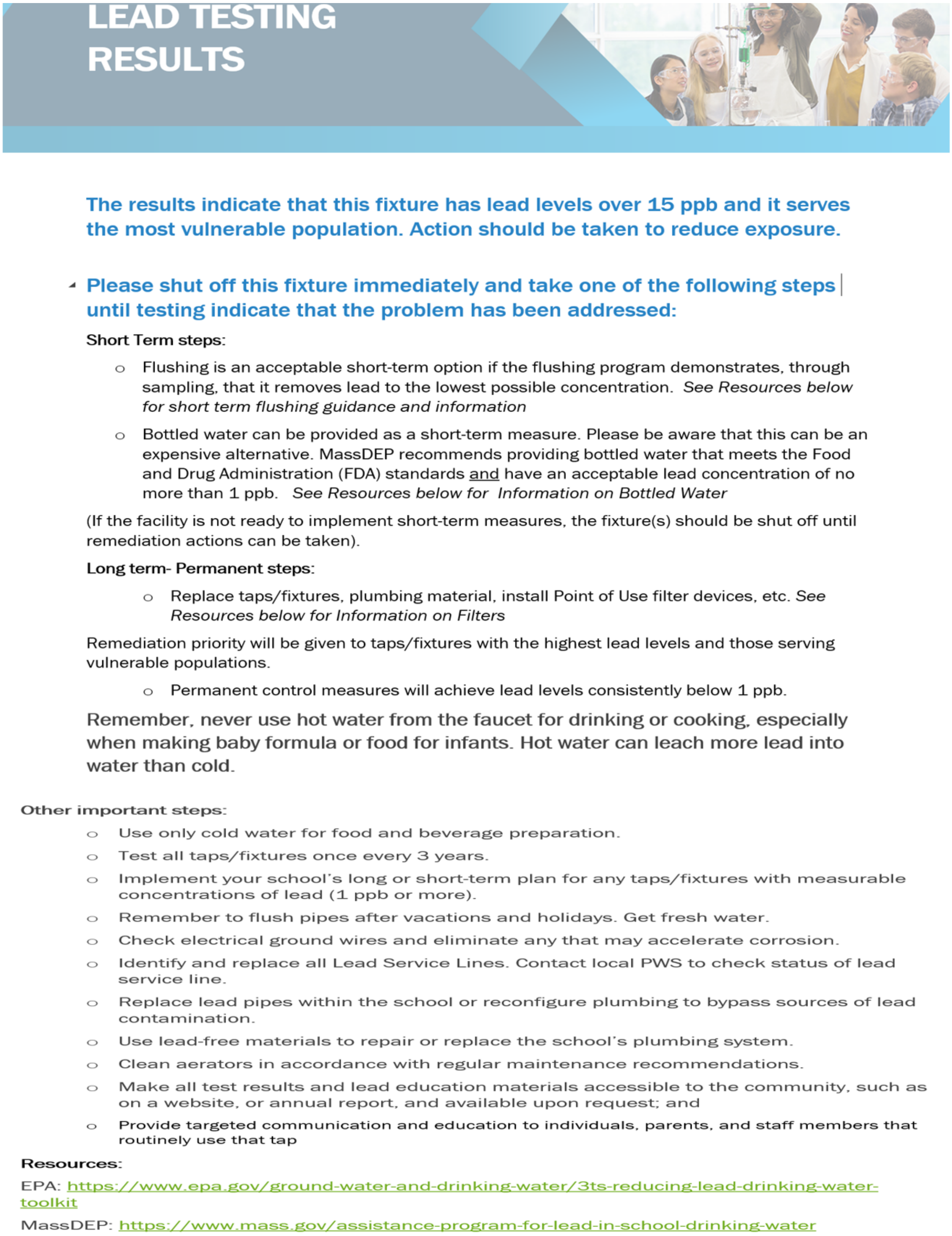
3 **Units** Enter the unit of the result exactly as it appears in your result sheet.

4 **Children Age** Choose the appropriate age of the population served by the fixture tested.

5 **Get your results** Press enter and get your report with appropriate steps.

Figure D-2. *Screenshot of the Tool.*

The following figure is an example of a report that a user will get if the sample is above 15 ppb and the fixture provides water for the most vulnerable population:



LEAD TESTING
RESULTS

The results indicate that this fixture has lead levels over 15 ppb and it serves the most vulnerable population. Action should be taken to reduce exposure.

Please shut off this fixture immediately and take one of the following steps until testing indicate that the problem has been addressed:

Short Term steps:

- Flushing is an acceptable short-term option if the flushing program demonstrates, through sampling, that it removes lead to the lowest possible concentration. *See Resources below for short term flushing guidance and information*
- Bottled water can be provided as a short-term measure. Please be aware that this can be an expensive alternative. MassDEP recommends providing bottled water that meets the Food and Drug Administration (FDA) standards and have an acceptable lead concentration of no more than 1 ppb. *See Resources below for Information on Bottled Water*

(If the facility is not ready to implement short-term measures, the fixture(s) should be shut off until remediation actions can be taken).

Long term- Permanent steps:

- Replace taps/fixtures, plumbing material, install Point of Use filter devices, etc. *See Resources below for Information on Filters*

Remediation priority will be given to taps/fixtures with the highest lead levels and those serving vulnerable populations.

- Permanent control measures will achieve lead levels consistently below 1 ppb.

Remember, never use hot water from the faucet for drinking or cooking, especially when making baby formula or food for infants. Hot water can leach more lead into water than cold.

Other important steps:

- Use only cold water for food and beverage preparation.
- Test all taps/fixtures once every 3 years.
- Implement your school's long or short-term plan for any taps/fixtures with measurable concentrations of lead (1 ppb or more).
- Remember to flush pipes after vacations and holidays. Get fresh water.
- Check electrical ground wires and eliminate any that may accelerate corrosion.
- Identify and replace all Lead Service Lines. Contact local PWS to check status of lead service line.
- Replace lead pipes within the school or reconfigure plumbing to bypass sources of lead contamination.
- Use lead-free materials to repair or replace the school's plumbing system.
- Clean aerators in accordance with regular maintenance recommendations.
- Make all test results and lead education materials accessible to the community, such as on a website, or annual report, and available upon request; and
- Provide targeted communication and education to individuals, parents, and staff members that routinely use that tap

Resources:

EPA: https://www.epa.gov/ground-water-and-drinking-water/3ts-reducing-lead-drinking-water-toolkit

MassDEP: https://www.mass.gov/assistance-program-for-lead-in-school-drinking-water

Figure D-3. *Screenshot of an example of the Tool's Reports.*