Lead in Tap Water from University District Region, Columbus, OH: Evaluation of Lead and Copper Rule and Revisions Sampling Guidance Across Service Line Compositions

By **Kathryn Zic**
The Ohio State University, Spring 2022
Honors Research Distinction, School of Environment and Natural Resource
Advised by **Dr. W. Berry Lyons**

Table of Contents

Abstract

Lead is a potent toxin that can cause a myriad of health effects, most notably adverse effects in pregnancy and neurological changes in children. Due to the health effects of lead exposure, regulations are in place to minimize lead exposure to the public. This study focuses on lead concentrations of tap water in Columbus, OH, and how the presence or absence of a lead service line impacts household tap water lead levels. The change in sampling directives from the EPA's Lead and Copper Rule (1991) to the Lead and Copper Rule Revisions (2021) were also examined, taking both the first and fifth liters of water for analysis. Buildings were selected for sampling in north-central Columbus to include a mix of service line compositions according to published data from the Columbus Department of Public Utilities. Samples were collected using the clean hands/dirty hands technique of trace element sampling, and then analyzed for lead using an ICP-MS. Major cations and anions were also analyzed in the tap water samples. Differences in lead concentration between buildings serviced by lead lines and by non-lead lines were not significant, which may suggest that Columbus's corrosion control treatments are working. Changes in lead levels from the first to the fifth liter were significant in non-lead pipes, with liter one having higher concentrations of lead. These changes were not significant in lead pipes, though notable outliers of 1.09 μg/L and 0.38 μg/L were present in liter five. Our previous work on tap water from numerous Ohio State University campus buildings indicates low, but measurable amounts of lead in all samples with a mean concentration of 1.2 μg/L (n=20). Off-campus buildings had lower levels than the on-campus samples, with a mean concentration of 0.13 μg/L (n=31).

1. Introduction

1.1 Background

Lead is an element so ingrained into the practice of plumbing that the word "plumbing" itself derives from the Latin word, *plumbum*, meaning "lead." After building city after city with pipes made of lead for centuries, we began to realize the health effects of this neurotoxin, though it was already ubiquitous in the environment, and present in our infrastructure. Even though the installation of lead service lines have been halted (Rosenthal & Craft, 2022), there may be up to 9.3 million still in use (EPA, 2021). While lead can occur in tap water as particulate lead (Deshommes et al., 2010), soluble lead and related complexes that have corroded and dissolved from pipes are typically the concern for human health (Santucci & Scully, 2020).

1.2 Health Effects of Lead

Lead is imperative to study mainly due to the extensive health effects following lead exposure. The damage due to lead exposure can be acute, following short-term exposure to high concentrations of lead, or chronic (EPA 2021), which is why even low levels of lead are important to study and regulate. Lead as a toxin is most well-known for the harms it can cause to children who are still developing (CDC 2002), though adults may also suffer from exposure to lead (Spivey, 2007).

Lead causes neurological effects in children, even at low levels. Canfield et al. (2003) found that three to five-year-old children had intellectual performances inversely correlated to the levels of lead in their blood. This study also found that an average of 4.6 IQ points are lost for each 10μg/dL increase of lead in their blood (Canfield et al., 2003). These neurological effects that begin as children are likely to continue into adulthood. Adults who were exposed to lead as children have decreased gray matter volume in a variety of brain regions, most notably parts of the prefrontal cortex. Damage in the affected regions contribute to impairments such as motor skill deficits, decreased intelligence, issues with executive functioning, attention deficit hyperactivity disorder (ADHD), and antisocial behaviors (Cecil et al., 2008).

Despite that most well-known dangers from lead exposure are in children, there are health consequences resulting from lead exposure in adulthood that are similarly concerning. One notable effect is that above-average blood lead levels in adults are often associated with an elevation in blood pressure. This is thought to stem from lead's effect on the kidneys, which is concerning, as detriments to kidney function are even observed at very low blood lead levels. Even in adults, whether there is a "safe" level of lead exposure is not known (Spivey, 2007).

1.3 Legislation Governing Lead

1.3.1 Legislation History

Resulting from these potential health effects is legislation that aims to protect the public to the most extent feasible from the dangers of lead exposure (EPA, 1991), though creating these regulations have not been without struggles. Lead pipes continue to be present in our infrastructure and are expensive to replace (Harvilla, 2021), so replacing them entirely is a difficult and costly solution. In addition to these logistical constraints, there is no scientific consensus on what a "safe" level of lead exposure would be, or even if there is any amount of exposure that can be considered safe. The blood lead level of concern as defined by the CDC has been lowered several times (CDC, 2021), and there have been studies finding negative health effects at blood lead levels lower than all set as standards by the CDC and WHO (Canfield et al., 2003). As of 2012, the CDC no longer sets a blood lead level of concern and instead defines a Blood Lead Reference Value (BLRV). The BLRV is not based on health data and is instead intended to compare whether a child has elevated blood lead levels in relation to most children. This level was set to 3.5 µg/dL in 2021 (CDC, 2021).

Legislation in 1986 caused the installation of predominantly lead service lines to be halted (Rosenthal & Craft, 2022). Pipes installed afterwards that are labelled "lead free" may still be composed of up to 8% lead (Renner, 2008) until 2014, when this changed to 0.25% lead by weight in the wetted surface of the pipe (11th Congress, 2009-2010). While the installation of these high-portion lead pipes were discontinued, many remain in effect today (EPA, 2021).

1.3.2 Lead and Copper Rule (1991) and 2021 Revisions

The Environmental Protection Agency's Lead and Copper Rule (LCR) was initially enacted in 1991 and established a series of regulations and guidelines for regulating lead in tap water. In this legislation, a Maximum Contaminant Level Goal was set, which is the non-legally binding best case scenario regarding the contaminant at hand. In this case, the Maximum Contaminant Level Goal was set to 0 parts per billion (ppb) or µg/L (EPA, 1991); thereby recognizing that there is not a known safe amount of lead exposure that can be permitted. The overarching goal of the 1991 LCR was to mitigate exposure "to the extent feasible." Even if 0 ppb is not possible so far, a series of guidelines can be created to minimize lead entering tap water and identify areas of concern when they arise.

To determine the effectiveness of previous interventions, water quality tests were continually done under the LCR on buildings to check for the levels of lead and copper within drinking water. Homes with copper pipes were prioritized for sampling, and samples were taken of first-draw water after 6 hours of stagnation. In LCR 1991, there is no specific ban on pre-stagnation flushing, which is a practice that may artificially lower the detectable levels of lead in a home. This legislation created an Action Limit of 15 ppb lead (equivalent to 15 µg/L or 0.015 mg/L); meaning that when the 90th percentile of household lead levels in a region surpass 15 ppb in water quality tests, additional measures will be taken to mitigate the elevated lead levels.

This legislation has been critiqued for inaction in certain scenarios. The most notable scenario is the failure to intervene in individual situations where there is an issue. Since the metric that decides whether remediation steps will be taken is the percentage of homes above 15 ppb, the highest 10% of household lead levels can far exceed this limit (Renner, 2008). The metrics depending on percentiles mean that which houses are chosen to be sampled can skew the data (Renner, 2008). A method meant to artificially lower the amount of lead in samples taken is pre-stagnation flushing, which some municipalities would enact to lessen the appearance of the city's lead problems (EPA, 2021), which created inaccurate data. Cleaning or removing the faucet aerator before sampling was sometimes done to decrease the amount of lead found in samples as well (EPA, 2021).

Some critiques were heard and accounted for in the creation of the Lead and Copper Rule Revisions (LCRR) in 2021. One major example is that pre-stagnation flushing is explicitly banned in the 2021 LCRR. Similarly, wide-mouthed bottles were required for sampling so that a greater rate of flow is possible (EPA, 2021), which intends to utilize the greater velocity of water to dislodge more particulate lead from the pipes (Deshommes et al., 2010) and create a more representative view of the maximum lead concentration a building's water will have. Cleaning or removing faucet aerators was also explicitly prohibited (EPA, 2021). In terms of the mitigation changes, the LCRR will place a greater emphasis on replacing publicly owned lead service lines than the 1991 LCR (EPA, 2021).

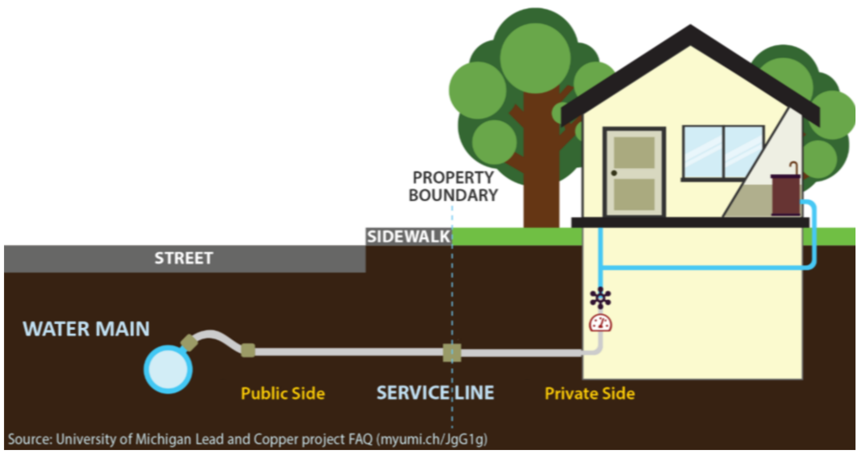

Fig. 1: From *University of Michigan Lead and Copper Project*. Diagram of pipes connecting the water main to the household being serviced.

When the 1991 Lead and Copper Rule began testing household tap water for lead levels, the first-draw water from the tap was sampled for analysis, which is water that has been sitting stagnant in the household pipes prior to sampling (Fig. 1). It is now thought that lead public service lines are the major contributor of lead to tap water (EPA, 2021), and given that the fifth liter of water has been in contact with the public service line more recently than the first liter, sampling the fifth liter of water for analysis may be a better estimate of the maximum lead concentrations a building's residents will be exposed to. The 2021 version of the Lead and Copper Rule Revisions dictate to sample the fifth liter of water in certain scenarios, such as those with a known lead-containing public service line (EPA, 2021).

While the metric that determines whether corrective action is needed remains a percentile, the LCRR institutes a "Trigger Level" of 10 ppb lead, where measures are taken when 10% of buildings sampled exceed 10 ppb. These measures are less extreme than what happens when the Action Limit is reached, and meant to prevent larger problems occurring (EPA, 2021).

While adding measures to be taken at lower concentrations of lead is a step in the right direction, another system of metrics based on percentiles does not mitigate the concerns that individual buildings may have severely elevated levels of lead without remedial action being taken.

1.4 Study Location: Columbus, OH

Columbus, Ohio is the 14th largest city in America by population size, with over 900,000 residents as of the 2020 census (World Population Review, 2022). Within the U.S., there are 6.3 to 9.3 million homes served by lead service lines, not counting those that have service lines made from galvanized zinc that may contain lead, or service lines soldered with lead (EPA, 2021). As of 2016, Ohio had the second-most lead service lines out of any state in the U.S. (Harvilla, 2021). A a map published by the Columbus Department of Public Utilities acknowledges residences within Columbus that have a suspected lead service line or galvanized service line (Columbus Department of Public Utilities, 2017).

Lead is known to be an issue in urban areas, more specifically, low income urban areas (Mueller, 2018), which is a concern in relation to Columbus. By some estimates, Columbus is the second most economically segregated metropolitan area in America (Florida & Mellinger, 2015), which may have environmental justice implications for the residents of the city. This further highlights how necessary proper testing and regulation of Columbus' water is, and that the proposed changes to the LCR may have an impact on this area. This was not accounted for in this study, and this sample is not meant to be representative of the city.

1.5 Study Objectives

This study aims to investigate trends in tap water lead concentration throughout Columbus, OH, based on pipe composition, the age of building in the absence of service line data, and how sampling method changes these values. To analyze lead sampling guidelines, we sampled the first-draw and fifth liter of tap water from buildings to simulate the 1991 LCR guidelines and how results compare to the 2021 LCRR changes, and how results from these guidelines change depending on pipe material. The hypotheses were that lead-containing service lines would have higher lead concentrations than non-lead public service lines, and in the absence of public service line data, older buildings would have higher levels of lead. As per sampling method, it was hypothesized that the 2021 EPA method of sampling the fifth liter of water would be the best estimate of maximum lead concentrations compared to the first-draw water method, and that this effect would be most prominent in buildings served by lead public service lines. These results can have implications on which homes are at higher risk for lead exposure from drinking water, and which sampling methodology best estimates the peak lead concentrations a household will be exposed to.

2. Methods

2.1 Study Design

Sampling sites were chosen mostly throughout Northwest Columbus, OH, with a collection of both lead service lines and non-lead service lines according to the Columbus Department of Public Utilities lead service line map. There were 16 homes served by non-lead service lines, 13 homes served by lead public service lines, and 2 homes served by galvanized service lines sampled. At each sampling location, the first-draw and fifth liter of water was taken from analysis from the kitchen sink. For all other guidelines that differ between the two legislations, the advice present in the 2021 Lead and Copper Rule Revisions was used. Lead concentrations were measured in all samples taken for the purpose of comparing the different service line populations and sampling methods. Major ions (Na^+, Ca^{2+}, Mg^{2+}, K^+, Cl^-, SO_4^{2-}) and major nutrients (NO_3^-, PO_4^{3-}) were measured to determine the chemical speciation of lead and amounts of corrosion inhibitors present.

As the Columbus Department of Public Utilities does not publish data on the composition of public service lines on Ohio State University's campus, a separate set of samples was taken of campus buildings to determine if building age is an adequate predictor of lead concentrations in tap water in the absence of other data. Samples were collected on the different areas of academic campus and across a variety of different building ages, spanning from 1890 to 2021. Twenty campus buildings were sampled. Sample collection methods were the same as the off-campus samples, though only the first liter of water was taken for analysis.

2.2 Contamination Prevention and Sample Collection

2.2.1 Pre-Sampling Preparations

Lead is ubiquitous in the environment, and so careful measures must be taken to avoid contaminating the samples with outside sources of lead. Low-density polyethylene (LDPE) bottles were used for collection of lead samples due to LDPE's tendency to not retain material after being rinsed or washed (C. Gardner, personal communication). High-density polyethylene (HDPE) was used for the collection and analysis of ions and nutrients. Due to the amount of lead present in the environment, the preparation of sampling materials was completed in a positivepressure clean laboratory to prevent lead-containing dust from settling in the sampling bottles. After being rinsed with heavily filtered Milli-Q water three times, the LDPE bottles sat in 10% HCl for 48 hours before being rinsed three times with Milli-Q water again. Samples were doubled bagged using new Ziploc bags in the clean room, not to be opened until sample collection.

2.2.2 Sample Collection

At each sampling site, the Patterson and Settle (1976) Clean Hands/Dirty Hands method was used to obtain the tap water sample for Pb. One person would be designated "dirty hands" and the other "clean hands." The dirty hands person puts on nitrile gloves and opens the outer plastic bag. The clean hands person puts on polyethylene gloves and is careful not to touch anything other than the inner bag and LDPE bottle. The clean hands person removes the LDPE bottle and open the cap, being careful not to touch the bottle lip, and the dirty hands person turns on the faucet. 4.5 liters of water are measured by the dirty hands person before the fifth liter sample is taken, the first 0.5 liters of tap water are not measured to account for water taken for the first-draw sample. The aforementioned process of opening the bags and taking the sample is repeated for the fifth liter sample. Several field blanks were taken (n=5), which were packaged and handled identical to samples, but filled with Milli-Q water prior to sampling. These bottles were taken out of bags and uncapped at sampling sites to determine if contamination was introduced from dust particles in the air during sample collection.

2.2.3 Post-Sampling

After sampling, neither of the two bags containing the lead water sample were opened until analysis preparation. Samples were stored in a refrigerator until time for analysis preparations. Samples were not filtered post-collection, as it was not necessary for the analysis of tap water and introduces another potential method of lead contamination.

2.3 Sample Analysis

After collection, samples were refrigerated until it was time for analysis. In preparation for analysis of lead by Inductively Coupled Plasma-Mass Spectrometer, samples were acidified to 2% nitric acid, and test standards of 0.01 µg/L or ppb, 0.05 ppb, 0.1 ppb, 0.5 ppb, 1 ppb, and 5 ppb were created to calibrate and repeatedly test the instrument. A sample of NIST Standard Reference Material 1643f diluted to 1:100 was run several times and compared to the NIST published value for lead to ensure the calibration was correct. Laboratory blank samples were created in a clean room setting of Milli-Q water. A 0.1 ppb check standard was run every 5 samples and a laboratory blank was run every 10 samples to ensure the instrument continued to function well, and values were as expected. In the event that either the check standard or blank resulted in a different value of lead than was expected, the problem was troubleshooted and every sample run after the most recent quality check standard was rerun.

2.4 Data Analysis

Data of lead concentrations variation with several different variables was analyzed, with statistical tests run in JMP and in Excel. Values are reported as average Lead-208 concentration ± standard error, with standard error calculated as standard deviated divided by the square root of N. For the differences between lead and non-lead service lines, averages were compared and a student's t-test was done to test the likelihood that the observed differences between the populations could be due to random chance. A 95% confidence interval was used. A student's t-test was used as opposed to other variance analyses because in this instance, equal variance cannot be assumed. T-tests were also run to analyze the difference between the first and fifth liter, and again when the data was further subdivided by both pipe type and liter. Box plots comparing the first and fifth liter for lead and non-leaded public service lines were created for the purpose of visualizing both the means and ranges of lead concentrations across these variables. Box plots were created with the intention of comparing sites with known service line compositions with sites of unknown service line composition. In the samples with no data on public service line composition, a scatter plot was created to observe lead levels by the year the building was constructed.

3. Results

3.1 Trace Metal Data Quality

Calibration curves were made to calculate lead levels from the mean net intensity values using known standards of 0.01 ppb, 0.05 ppb, 0.1 ppb, 0.5 ppb, 1 ppb, and 5 ppb. The instrument was recalibrated in the middle of sample analysis and the curve changed by 13% during this recalibration. The method detection limit is 0.002 ppb, or 2 parts per trillion, and this was calculated to be three times the standard deviation of the blank values and then converted from raw counts per second to parts per billion. Two buildings were found to have lead levels below the method detection limit, both off-campus buildings without lead public service lines. Lead levels were below the detection limit in one first and one fifth liter sample taken at these locations. The range of lead concentration in this study varied from below the method detection limit to 5.52 ppb.

Check standards of 0.1 ppb were analyzed every 5 samples and blank checks were analyzed every 10 samples as a quality assurance metric. The relative standard deviation of the data set calculated from check standards was 7.3% for the first set of samples run, and 4.7% for the second. There were also 4 duplicate samples run, the standard deviation of these were similarly low (Table 1). The National Institute of Standards and Technology Standard Reference Material 1643f for Trace Elements in Water diluted to 1:100 was also run as a test, and the lead concentration when run was slightly high, at 0.21 ppb and 0.24 ppb compared to 0.185 ppb.

	0.1 check standards 1	0.1 check standards 2	Campus check standards	Duplicate 1	Duplicate 2	Duplicate 3	Duplicate 4
Relative Standard Deviation	7.3%	4.7%	2.3%	1.9%	0.3%	2.3%	2.4%

Table 1: Relative standard deviation of lead concentrations calculated from different metrics.

3.2 Lead Concentration by Service Lines

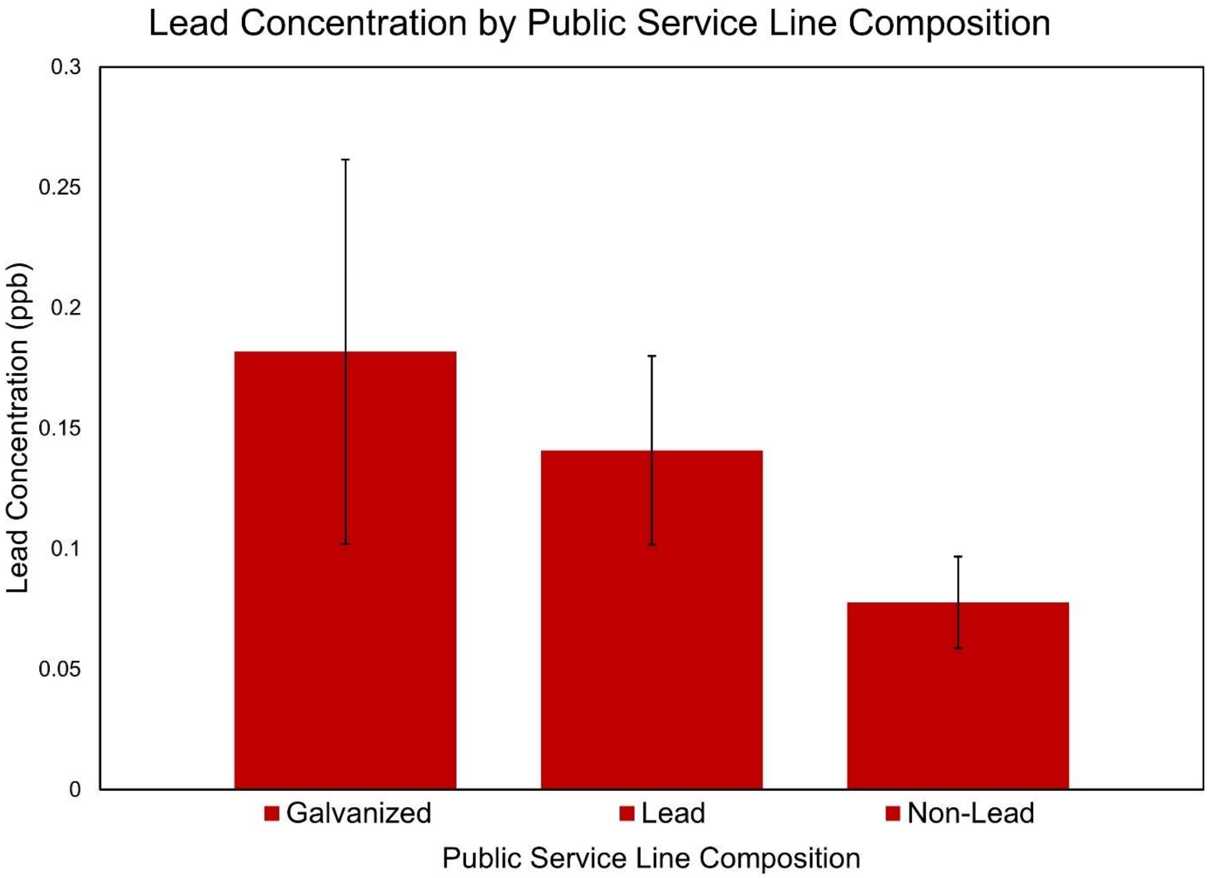

Fig. 2: Bar graph of average lead concentration across each composition of service line.

There was no statistically significant difference in average lead concentration by publicly-owned service line composition (Fig. 2). Average lead concentrations in all galvanized public service line samples were highest, with an average of 0.182±0.081 ppb (n=4) though caution will be taken in interpreting these results as this value is based on a small sample size. Average lead concentrations across all lead public service line samples was 0.14±0.03 ppb (n=28), with a large range of 1.08 ppb. The population that had the lowest average was the group of non-leaded public service lines, at 0.10±0.04 ppb lead (n=32). No statistical difference at a 95% confidence interval was found in average lead concentrations between galvanized, lead, and non-lead public service lines (Student's t-test, p=0.14), though this metric is likely influenced by the additional variable of liter sampled not being accounted for.

When comparing lead and non-lead public service lines, one difference to note is that the lowest lead concentration seen in any non-lead public service line is below the method detection limit, which is lower than the lead public service line minimum value of 0.01 ppb. When comparing the maximum value of the two populations, the public lead service line concentration is again far higher: 1.09 ppb compared to the non-lead public service line value of 0.47 ppb.

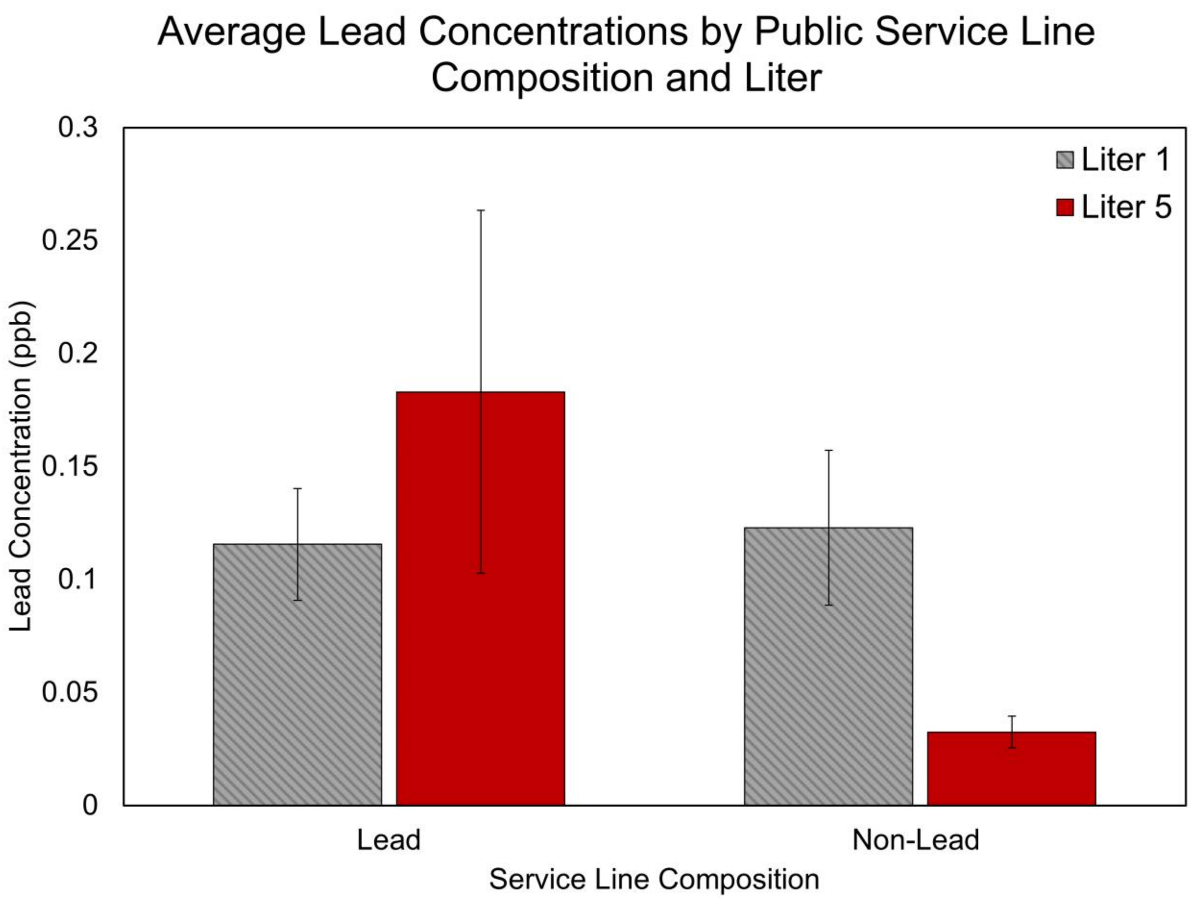

Fig. 3: Bar graph of lead concentration by both service line composition and liter of water analyzed.

When comparing data from the first liter, averages were very similar regardless of public service line material. Lead public service lines had a mean of 0.12±0.02 ppb (n=13) lead concentration, and non-lead public service lines averaged 0.12±0.03 ppb (n=16) lead. Average lead concentrations were very similar in magnitude and not statistically different (Student's t-test, $p=0.87$). Limited galvanized data showed the highest average concentration in this category, an average of 0.22±0.16 ppb lead (n=2) (Fig. 3).

Despite that the difference between the lead and non-lead public service lines were very similar in the first-draw water, these two populations had very distinct fifth liter average lead concentrations, both by the difference in averages and by the results of the student's t-test. In liter 5, lead publicly-owned service lines had a mean of 0.18±0.08 ppb (n=13) lead, which is nearly five times larger than the non-lead public service line concentration of 0.03±0.01 ppb (n=16). The results of the statistical analyses showed a significant difference between the two populations, in which $p=0.04$, lower the alpha value of 0.05 for 95% confidence. The few sampled galvanized public service line sites averaged 0.14±0.10 ppb lead (n=2).

3.3 Lead Concentration by Sampling Method

In the assessment of the EPA's Lead and Copper Rule (1991) and Lead and Copper Rule Revisions (2021), the major difference in sampling guidance is that the 1991 LCR only sampled the first liter draw of water from the tap, whereas the more recent LCRR, allowing the water to run for several liters before taking the fifth liter to sample was adopted in certain scenarios. The 1991 LCR sampling method will be referred to as the "first liter" and the 2021 LCRR method will be referred to as the "fifth liter." Based on averaged values from samples across all service line materials, the first liter showed higher levels of lead than the fifth, at levels of 0.13±0.02 ppb (n=31) compared to 0.10±0.04 ppb (n=31), though this metric is heavily influenced by including multiple different service line compositions.

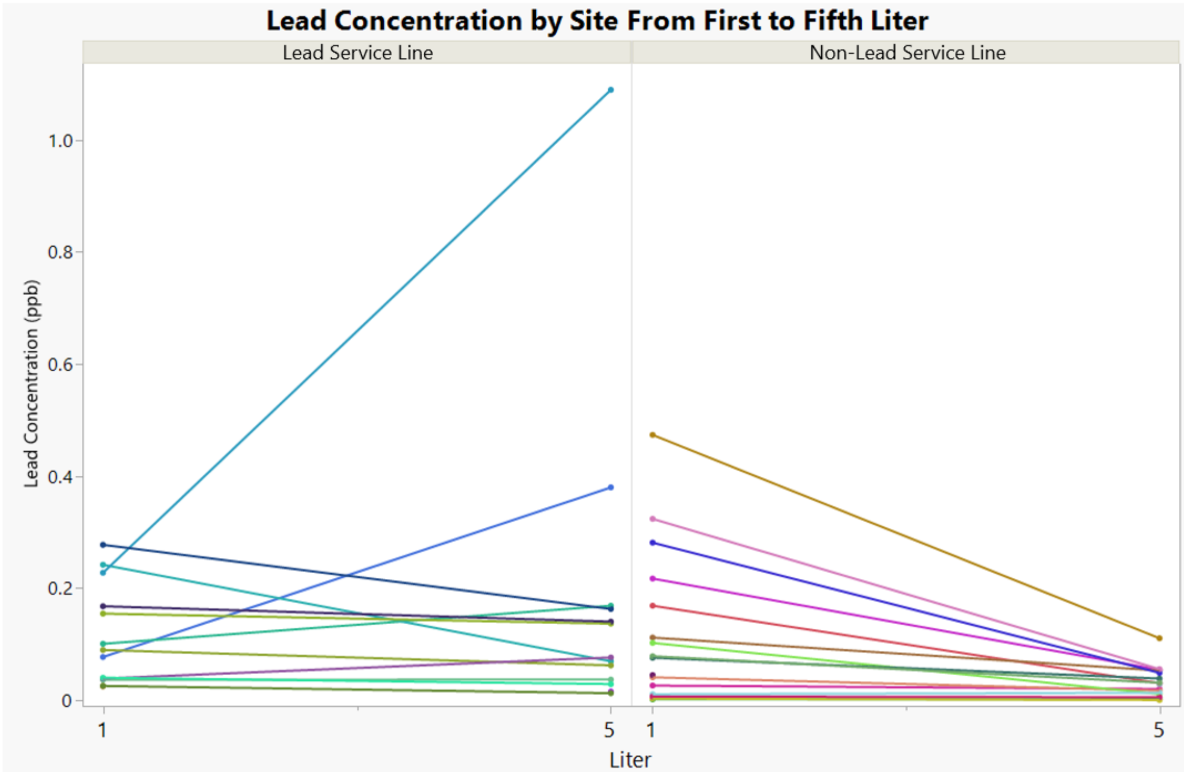

Fig. 4: Lead Concentration change from first to fifth liter, with both samples collected at each site connected.

Among only non-leaded service lines, the fifth liter had lower lead values than the first liter, which is a statistically significant difference (Student's t-test, $p=0.01$). The averaged values for the first and fifth liter are 0.12±0.03 ppb (n=16) lead for the first and 0.03±0.01 ppb (n=16) for the fifth liter, a difference of 0.09 ppb.

Lead levels in homes serviced by lead publicly owned service lines were not considerably different in the first and fifth liters by average alone. The first liter had an average lead concentration of 0.12±0.02 ppb (n=13) and the fifth liter had an average lead concentration of 0.18±0.08 (n=13) ppb (Student's t-test, $p=0.56$). However, one notable difference between the first and fifth liter of water from lead service lines is the presence of several outliers in the fifth liter: 1.09 ppb and 0.38 ppb, both higher than the liter one maximum value of 0.28 ppb (Fig. 4). This is a difference in maximum values of 0.81 ppb, which is important to note as the EPA's limits to take action are based on the highest percentiles of data in a set. The fifth liter also had a larger range than the first liter.

3.4 Ohio State University On-Campus Sites

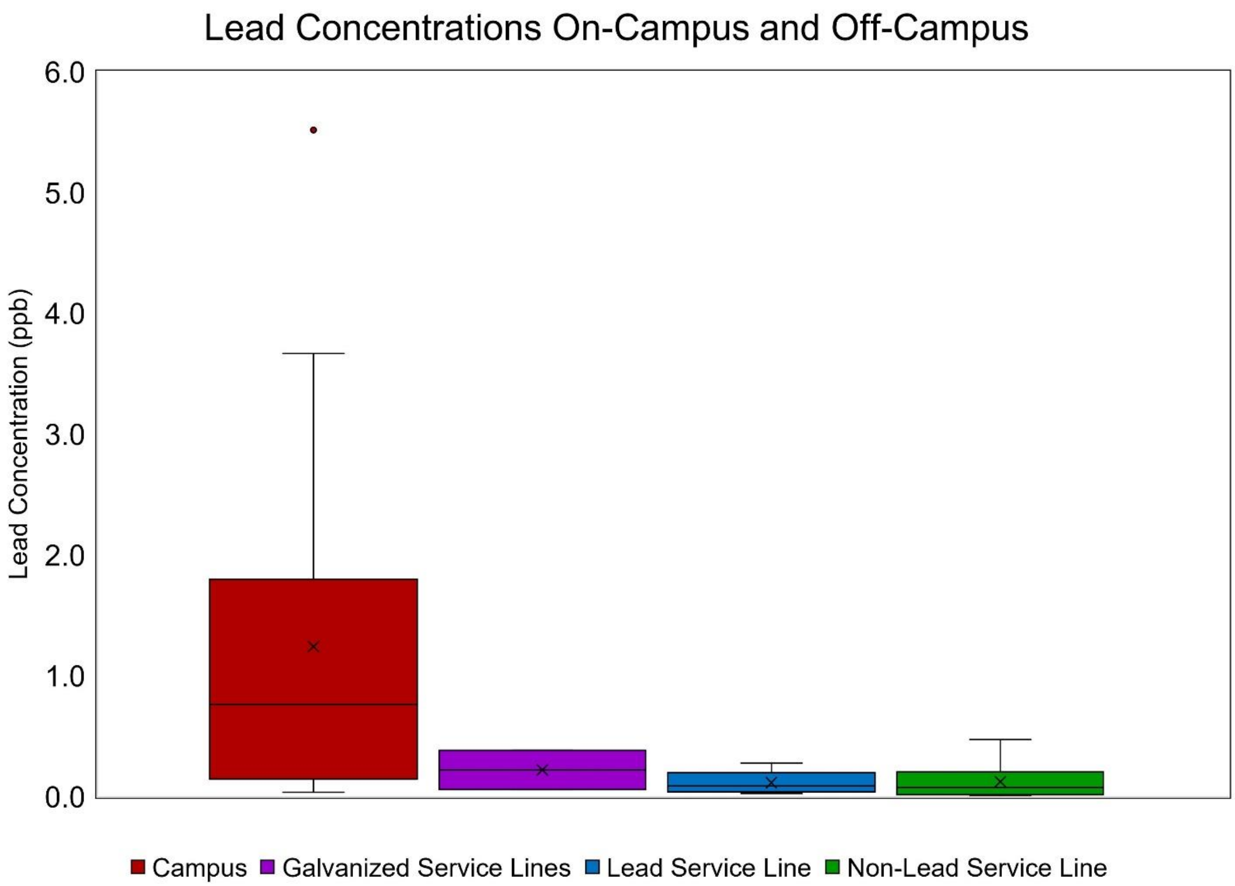

Fig. 5: Bar graph of lead concentration across different sampling populations, with campus buildings of unknown service line included. All samples are first-draw water.

Samples of first-draw water from Ohio State University-Columbus Campus buildings had higher averages than all off-campus populations. The average lead concentration of these samples was 1.2±0.32 ppb (n=20), with a total range of 5.47 ppb. Within this data set, the highest concentration was 5.52 ppb and the lowest was 0.05 ppb. Most buildings sampled are used for teaching or research, though the two residential buildings on campus had levels of lead >1 ppb, at 0.61 ppb and 0.03 ppb.

3.5 Lead Concentration by Age of Building

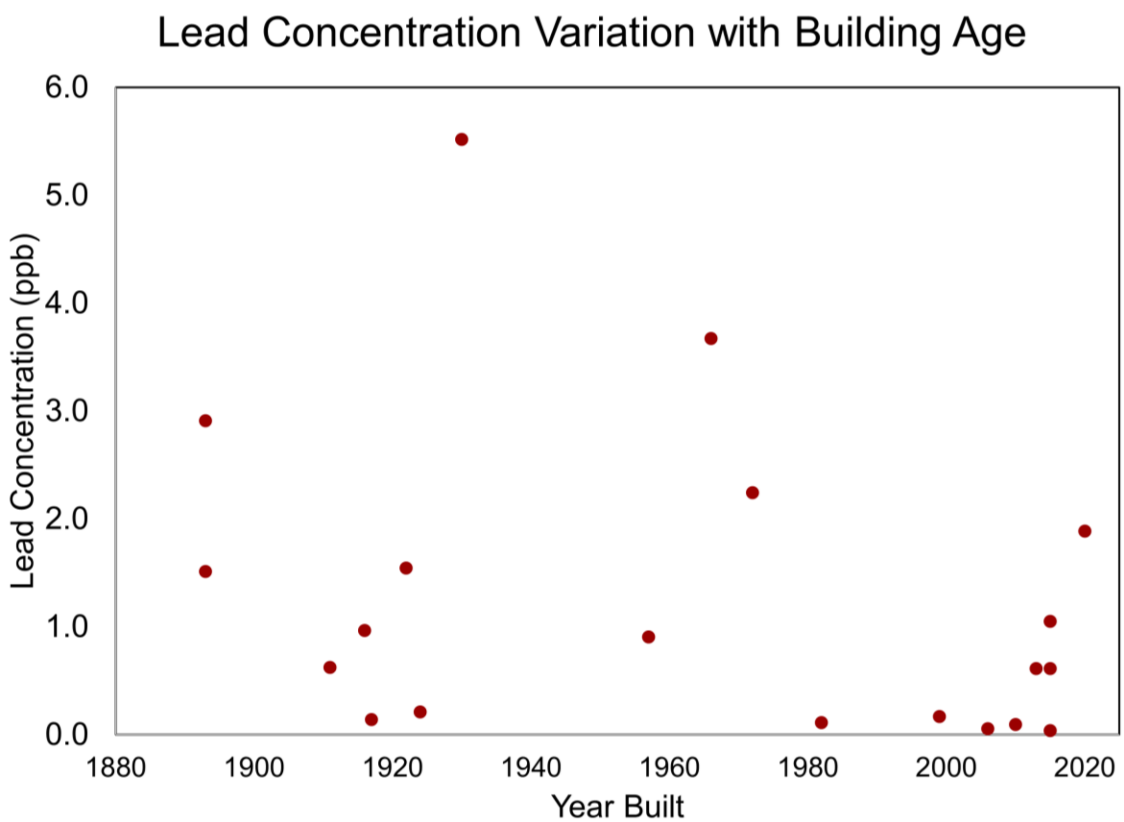

Fig. 6: Scatter plot of liter one lead concentrations by the age of building sampled for Ohio State University-Columbus Campus.

OSU Campus buildings did not have published data for service line composition, and so buildings built between 1890 and 2020 were sampled to investigate using building age as a potential metric to predict lead concentration. The R^2 value resulting from linear regression analysis was 0.101, which is not indicative of a strong correlation.

3.6 Tap Water Chemistry

	Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	PO_4^{3-}	SO_4^{2-}
Water Treatment Plant 1	16 mg/L	24 mg/L	6 mg/L	5 mg/L	27 mg/L	443 µg/L	53 mg/L
Water Treatment Plant 2	52 mg/L	34 mg/L	9 mg/L	7 mg/L	51 mg/L	402 µg/L	106 mg/L

Table 2: Average ion values for the two water chemistry groups observed.

Major ions and nutrients in tap water were not considerably different among different sites (Table 2). All sample sites seemed to belong to a group of samples with very similar values that likely all came from the same water treatment plant. Both within and between groups of similar ion signatures, ion values are all relatively similar. Water chemistry present favored dissolved Pb mostly existing in solution as lead carbonate ($PbCO_3$). Other major species present were free lead (Pb^{2+}) and lead hydroxide ($PbOH^+$).

4. Discussion

4.1 Data Overview

While the sampling methodology differed slightly from the Environmental Protection Agency's Lead and Copper Rule and Revisions by the omission of the stagnation period, which may result in lower lead concentrations, all samples were found to be below both the 15 ppb Action Limit and 10 ppb Trigger Limit. Conversely, there were measurable levels of lead in all but two municipal samples analyzed, and these were statistically different than the analytical blank samples analyzed. All on-campus samples had lead levels above the method detection limit. As the major ion concentrations in the samples were not very different, both within and between water sources, it is likely that their concentrations do not affect the patterns of lead levels seen in this study.

4.2 Public Service Line Composition

Upon initial observation, it may appear surprising that buildings served by lead and non-leaded service lines contain similar levels of lead in first-draw water, with slightly higher levels in the non-leaded service line population. Despite the known difference in public service line composition, the private-side line composition is unknown for many of the buildings. For the sampling sites where both the public service line and private side line are known, there was no apparent pattern between the two pipe compositions, and there was a similar mix of private side service line compositions across both populations. Since the first liter of water was more recently in prolonged contact with the private-side line and household fixtures, it is possible that the private-side service line has more effect on the lead content in first-draw water than the public side line, causing the lead concentration in first-draw water to be statistically similar regardless of public service line composition.

There is a statistically significant difference between the lead and non-leaded public service lines in the fifth liter of water sampled, which is water that has theoretically been in contact with the public service line most recently. In addition to statistical analyses showing the two populations were distinctly different, the magnitude of difference is also notable: leaded pipes had a mean of 0.18±0.08 ppb and non-lead pipes had a mean of 0.03±0.01 ppb. The difference in means is 0.13 ppb, and the lead concentration in buildings serviced by lead service lines is nearly five times that of buildings serviced by non-leaded service lines.

In the buildings served by lead public service lines, the difference between the first and fifth liter is not significantly different, though the average lead concentration is slightly higher in the fifth liter. A difference to note between the first and fifth liter is the outliers of high lead concentration in the fifth liter sampled. This is potentially due to the fifth liter having been more recently in contact with a known leaded service line, whereas not all private side lines that the first liter was in contact with contain lead. Similarly, the highest lead concentrations seen in buildings serviced by non-lead public service lines are within the first liter sampled, as some private side lines that the first liter was sitting in contained lead, whereas the fifth liter of water sampled was recently in prolonged contact with a service line not primarily composed of lead. Lower levels of lead in the fifth liter of water in non-lead public service lines was observed in near all samples.

4.3 Evaluation of EPA Methods

The rationale for sampling the first-draw water as well as the fifth liter of water from the same locations was done to simulate the different sampling methods of the Environmental Protection Agency's Lead and Copper Rule (1991) and Lead and Copper Rule Revisions (2021) respectively. Ideally, the method used to sample lead should best estimate the highest lead concentrations in tap water within a building. As per this study, the highest levels of lead overall were seen in the first liter rather than in the fifth, though this does not equate to the 1991 LCR sampling method being the most effective. While the first liter had less lead in the fifth liter of water, non-lead public service lines generally had less lead leached from pipes and are not the primary target of the LCR or LCRR's efforts. Both versions of the Lead and Copper Rule are percentile-based, and so the concentrations that matter the most in terms of regulation are the exceedingly high values over 15 ppb. In this study, the highest lead concentrations were seen in buildings serviced by lead public service lines in the fifth liter of water sampled. This study supports the EPA's 2021 Lead and Copper Rule Revisions sampling method as the best estimate of the highest levels of lead in households serviced by lead public service lines, as opposed to the 1991 EPA method.

4.4 Potential Limitations

A limitation of this study is that the data available on the composition of public service lines are by the Columbus Department of Public Utilities Lead Service Line Map, of which the data quality cannot be verified, and buildings are labeled to have a "possible" lead public service line. No stagnation period was included in the sampling of this study, so while the same trends are expected to be seen with complete adherence to the LCR and LCRR sampling guidance, the magnitude to which these trends will be observed may differ. This may also indicate that the peak levels of lead found at each location may be an underestimate of that location's highest possible level of lead. This study was conducted with the aim of making comparisons within the dataset, this sample set does not intend to be representative of Columbus, OH.

5. Conclusion

While this sampling method did differ slightly from the EPA's Lead and Copper Rule and Revisions sampling protocol, all buildings were well below both the Action Limit and Trigger Limit of 15 ppb and 10 ppb respectively. Non-lead public service line buildings reached the relative maximum lead concentration in the first liter, but since lead public service line buildings had both a higher average concentration and individual samples with far higher levels of lead in liter five, sampling the fifth liter of water in buildings serviced by lead service lines is likely the best option moving forward, which is what the Lead and Copper Rule Revisions currently plans to do. Future work is needed to determine the source of the lead in each liter. Studies sampling the first and fifth liter that focus on the impact of private side line composition on lead concentration may further explain the changes seen in this study from the first to the fifth liter within the same building.

6. Acknowledgements

Thanks to Dr. Chris Gardner and Dr. Sue Welch for guidance and work in analytical chemistry, and to Devin Smith and Connor Wichterich for sampling. Thanks to Dr. W. Berry Lyons for being an incredible mentor throughout the course of this project. Thanks for funding, from the Byrd Polar and Climate Research Center's McKenzie-Brecher Fund, the Ohio State University School of Earth Science, and the Second-Year Transformational Experience (STEP) program. Thank you to the Ohio State University's Trace Element Research Laboratory for instrumentation use and sample analysis assistance. Thank you to all who allowed water samples to be taken in their homes.

References

Canfield, R. L., Henderson Jr, C. R., Cory-Slechta, D. A., Cox, C., Jusko, T. A., & Lanphear, B. P. (2003). Intellectual impairment in children with blood lead concentrations below 10 µg per deciliter. New England journal of medicine, 348(16), 1517-1526.

Cecil, K. M., Brubaker, C. J., Adler, C. M., Dietrich, K. N., Altaye, M., Egelhoff, J. C., ... & Lanphear, B. P. (2008). Decreased brain volume in adults with childhood lead exposure. PLoS medicine, 5(5), e112.

City of Columbus Department of Public Utilities. (2017, March 6). City Lead Water Service Line Map now Available. From https://www.columbus.gov/Templates/Detail.aspx?id=2147495118

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.

Division of Environmental Hazards and Health Effects. Lead Poisoning Prevention Branch, Harvey, B., Managing elevated blood lead levels among young children: Recommendations from the Advisory Committee on Childhood Lead Poisoning Prevention (2002).

Environmental Protection Agency; National Primary Drinking Water Regulations: Proposed Lead and Copper Rule Revisions; 84 Fed. Reg. 61684 (Nov. 13, 2019).

Environmental Protection Agency; National Primary Drinking Water Regulations: Lead and Copper Rule; 56 Fed. Reg. 26548 (Jun. 7, 1991).

Florida, R., & Mellander, C. (2015). Segregated city: The geography of economic segregation in America's metros. Martin Prosperity Institute.

Harvilla, B. (2021, July 30). Ohio has second most lead water-supply pipes in U.S.; Infrastructure Plan would replace them. The Columbus Dispatch. Retrieved March 2, 2022, from https://www.dispatch.com/story/ news/2021/07/30/ohio-infrastructure-plan-water-supply pipes-lead-poisoning/8018241002/

Muller, C., Sampson, R. J., & Winter, A. S. (2018). Environmental inequality: The social causes and consequences of lead exposure. Annual Review of Sociology, 44, 263-282.

Olson, E. D. (2021, December 7). How can I find out if I have a lead service line? NRDC. Retrieved March 5, 2022, from https://www.nrdc.org/experts/erik-d-olson/how-can-i-find-out-if-i-have-lead-service-line

Patterson, C. C., and D. M. Settle. 1976. The reduction of orders of magnitude errors in lead analyses of biological material and natural waters by evaluating and controlling the extent and sources of industrial lead contamination introduced during sample collection, handing and analysis. *In* P.D. LaFleur [ed.], Accuracy in trace analysis: sampling, sample handling, and analysis. U.S. National Bureau of Standards Special Publication 422, Washington, D.C.

Renner, R. (2010). Exposure on tap: drinking water as an overlooked source of lead. Environmental Health Perspectives 118:2 CID: https://doi.org/10.1289/ehp.118-a68

Rosenthal, L., & Craft, W. (2022, January 6). *How the EPA has left Americans exposed to lead in drinking water*. Buried Lead | APM Reports. Retrieved March 29, 2022, from https://www.apmreports.org/story/2020/05/04/epa-lead-pipes-drinking-water#:~:text=Congress%20banned%20the%20use%20of,known%20as%20%22service%20lines.%22

Santucci, R. J., & Scully, J. R. (2020). The pervasive threat of lead (Pb) in drinking water: Unmasking and pursuing scientific factors that govern lead release. Proceedings of the National Academy of Sciences, 117(38), 23211-23218.

Spivey, A. (2007). The weight of lead: Effects add up in adults.

S.3874 - 111th Congress (2009-2010): Reduction of Lead in Drinking Water Act. (2011, January 4). https://www.congress.gov/bill/111th-congress/senate-bill/3874/text

World Population Review. (2022). Columbus, Ohio population 2022. Columbus, Ohio Population 2022 (Demographics, Maps, Graphs). Retrieved March 29, 2022, from https://worldpopulationreview.com/us-cities/columbus-oh-population