Evaluating the Initial Service Line Inventory and Replacement Plan Processes

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Abstract

Lead exposure can result in severe adverse health effects, yet lead service lines (LSLs) are used to transport drinking water to customers. The Lead and Copper Rule Improvements, published by the Environmental Protection Agency, require all public water systems to complete a service line inventory by October 16, 2024. The goal of this project was to draft an inventory and replacement plan for communities with LSLs. We ranked techniques for identifying LSLs, conducted interviews with experts in communications, reviewed LSL inventory data, and analyzed geospatial trends through geographic information system mapping. Templates for customer communications and decision trees for LSL identification techniques were created. Finally, LSL replacement plans were drafted based on our findings.

Acknowledgements

Our team would like to thank our project advisor, Professor Jeanine Dudle, for her guidance and support in completing this project. Her feedback and mentorship were crucial in meeting the goals of this project. We would also like to thank the utility that graciously shared their inventory data with us so that we could perform our case study and the water utility representatives that offered their expertise in communications.

Executive Summary

There are roughly 150,000 public water systems in the United States and between 6 and 10 million lead service lines (LSLs) in use in those systems. While lead was used for its malleability and corrosion resistance, it is known that lead can cause health problems including decreased cognitive function, developmental disabilities, and even death. Due to these negative health effects, the United States Environmental Protection Agency (U.S. EPA) regulates levels of lead in drinking water to protect consumers. The most recent amendments to lead regulations, titled the Proposed Lead and Copper Rule Improvements (LCRI), require all public water systems to sample for lead in drinking water at schools, create a public inventory of their LSLs, and create a service line replacement plan to replace all LSLs within 10 years. As a result, the goal of this project was to draft a lead service line inventory and replacement plan that can be scaled to fit the needs of different sized communities.

To meet this goal, the following objectives were completed:

1. Evaluate and rank methods for identifying lead service lines.
2. Determine best practices for communicating with customers to obtain authorization for full lead service line replacements and respond to service line identification.
3. Determine best practices for scheduling lead service line replacements.
4. Perform a case study using lead service line inventory data and complete spatial analyses through Geographic Information System (GIS) mapping.
5. Draft a lead service line replacement plan, including the process of creating an initial service line inventory and scheduling the replacement of lead service lines.

Methods for identifying LSLs were analyzed through various peer-reviewed sources and ranked based on four criteria: cost per service line identified; accuracy considering false positives and false negatives; time required per service line; and implementation feasibility. All water systems must begin the inventory creation process by conducting a record review. This method can be accurate, efficient, and cost-effective if records are well kept. Record review has an overall accuracy of 64% due to high false lead results but is 98% accurate when identifying LSLs. Visual inspections are low cost and efficient, while being 75% and 90% accurate when completed by customers and door-to-door inspections by utility staff, respectively. Mechanical excavation is the only method with an accuracy as high as 95%; however, it is more costly and time-consuming. If necessary, other methods such as water sampling or emerging methods can be used.

Methods for utilities to communicate with customers were researched through peer-reviewed sources and an interview with a communications specialist from a water utility. It is important for utilities to openly and effectively communicate with their customers to develop a trusting relationship. To do so, a utility can provide transparent information on its website and make information public throughout the inventory process. To promote customer engagement, mailings such as flyers and pamphlets for those with service lines of lead or unknown materials can be distributed. Other communication methods include phone calls, text messages, emails,

and door-to-door visits. These methods should be attempted multiple times before being abandoned and should avoid alarming residents with overly threatening language or visualizations. Short- and long-term solutions should also be provided.

For replacement of lead or galvanized requiring replacement (GRR) service lines, the cost of a complete service line replacement varies between $7,600 and $37,800, with an average cost of $12,500. Construction related costs can reach an average total of $9,900, making up most of the replacement cost. To help fund these replacements, many programs, funds, and state grants have been established, such as the Drinking Water State Revolving Fund (DWSRF) and Water Infrastructure Improvements for the Nation (WIIN) Act. When scheduling service line replacements, factors such as climate and the number of service lines to be replaced affect when replacement can be done and how long the process will take. Additionally, the locations of LSLs within the water distribution system should be considered, and replacements can be coordinated with other planned projects such as paving to perform replacements in clusters and ensure that excavation and other projects do not interfere with one another. The duration and ease of replacement also depends on many factors that may vary between utilities, such as crew size, equipment used, removal of unwanted materials, and restoration of the site.

A case study was completed using data from a medium-sized (3,301 to 10,000 residents) public water system in New England. All customers were catalogued and the materials of all utility and customer owned portions were provided where known. The material of 87.3% of the utility owned service lines was identified through service cards, while knowledge from this distribution system's staff (10.8%) and record drawings (0.38%) were used far less frequently. Meanwhile, for the customer owned service line segments that were identified, inspections were used most commonly (15.8%). Records (9.2%) and the year-built (7.7%) were used less commonly. In this distribution system, only 0.192% of service lines were found to be lead. However, the material of 65.4% of customer segments and 0.192% of utility segments was classified as unknown. Through record review and GIS, the initial classification of this utility's service lines was determined, and spatial analyses were conducted. With this case study and information attained through literature review and interviews with communications experts, recommendations of various service line material identification methods were made. A service line replacement plan was formed for the case study utility, and a general template was made for all other utilities.

This plan included a template for the EPA required plan overview and summary, a procedure for identifying existing service line materials, recommendations for securing funding for service line replacements, details about notifying customers prior to service line replacements, and an overview of considerations that must be made before beginning the service line replacement process.

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Chapter 1. Introduction

In the United States, more than 90 percent of people rely on drinking water from public water systems (US EPA, 2022a). These water systems, which treat water and distribute it to consumers, use water mains and transmission lines to transport water throughout the service area (National Research Council (US) Safe Drinking Water Committee, 1982). Then, service lines are used to connect the mains to individual homes and businesses (National Research Council (US) Safe Drinking Water Committee, 1982). In the past, service lines were sometimes constructed of lead due to its malleability and corrosion resistance (Dignam *et al.*, 2019). Lead from service lines, solder, and fixtures can dissolve into water depending on the material condition and water chemistry. It is known that lead exposure can have negative health effects including decreased cognitive function, developmental disabilities, and even death (Rhyan *et al.*, 2023). There is no safe level of lead exposure, yet there are millions of LSLs currently in use. Although the exact number is unknown, it has been estimated that there are 9.2 million (US EPA, 2023b), greater than 9 million (US EPA, 2023c), and between 6 and 10 million (Cornwell *et al.*, 2016) LSLs remaining in use. These service lines likely have not been replaced due to difficulties such as loss of pipe installation records, issues regarding pipe ownership, and expenses associated with replacement. Based on the estimate of between 6 and 10 million remaining LSLs, total replacement costs could reach $20 to $80 billion (Bukhari *et al.*, 2020).

The United States Environmental Protection Agency (US EPA) has passed regulations to limit consumers' exposure to lead. The Lead and Copper Rule (LCR) was first promulgated in 1991 and required public water systems to monitor lead concentrations at consumer taps, and if levels exceeded a threshold, to implement strategies to reduce lead exposure (US EPA, 2008). The most recent revisions, the Lead and Copper Rule Improvements (LCRI), require all public water systems to sample for lead in drinking water at schools (US EPA, 2023d), create a public inventory of their LSLs, and create a service line replacement plan to replace all LSLs within 10 years (US EPA, 2023c).

Due to the safety threat posed by lead and the difficulty in identifying a service line's materials, the goal of this project was to draft a lead service line inventory and replacement plan that can be scaled to fit the needs of different sized communities. To meet this goal, the following objectives were completed as part of the project:

1. Evaluate and rank methods for identifying lead service lines.
2. Determine best practices for communicating with customers to obtain authorization for full lead service line replacements and respond to service line identification.
3. Determine best practices for scheduling lead service line replacements.
4. Perform a case study using lead service line inventory data and complete spatial analyses through Geographic Information System (GIS) mapping.
5. Draft a lead service line replacement plan, including the process of creating an initial service line inventory and scheduling the replacement of lead service lines.

The goal and objectives are addressed as part of the subsequent chapters.

In Chapter 2, a background of water systems and their associated concerns, including the spread of disease and corrosion of metal pipes, like lead, is provided. Lead use in water systems and its negative health effects are also discussed, emphasized by case studies of lead exposure in drinking water. This is followed by a review of lead alternatives and a comparison of utility and customer owned portions of service lines.

Then, the methods used to meet each of this project's objectives are discussed in Chapter 3, including the use of peer-reviewed articles, an interview with communications specialists, and a case study of a utility's drafted service line inventory. Associated deliverables are also discussed, including a decision tree regarding methods for identifying service line materials, templates for mailings to customers, and tables summarizing data from the case study.

Chapter 4 consists of the results of research completed on several topics including how to identify LSLs, communications with customers regarding service lines, the process of service line replacement, a case study of a utility's drafted service line inventory, and a drafted LSL replacement plan.

Finally, the conclusions drawn from the results in Chapter 4, as well as recommendations on information that must be further researched by utilities prior to the completion of a service line inventory and replacement plan, are also discussed in Chapter 5.

Chapter 2. Background

In the United States there are more than 148,000 public water systems, which supply drinking water to 90 percent of Americans (US EPA, 2023a). Public water systems utilize a multiple barrier approach to provide safe drinking water to consumers. The multiple barrier approach includes source water protection, treatment, safety during transport and storage, and education. These systems consist of a water source or sources, treatment processes to make the water safer and more desirable for public consumption, and a distribution system to safely transport the water to its users (National Research Council (US) Safe Drinking Water Committee, 1982). The EPA defines a public water system as “a system for the provision to the public of water for human consumption through pipes or other constructed conveyances, if such a system has at least 15 service connections or regularly serves at least 25 individuals at least 60 days out of the year” (US EPA, 2023e). The EPA classifies public water systems based on the population size they serve. The classifications are *Very Small* (25 – 500 residents), *Small* (501 – 3,300 residents), *Medium* (3,301 – 10,000 residents), *Large* (10,001 – 100,000 residents), and *Very Large* (greater than 100,000 residents) (US EPA, 2023e).

To keep drinking water safe in these systems, the Safe Drinking Water Act (SDWA) was passed as an overarching regulation in 1974. As part of the SDWA, multiple rules have been created to establish treatment requirements and maximum levels for harmful or potentially harmful contaminants. To ensure these requirements are met, the quality of water is monitored at the source, throughout treatment, and at consumer taps.

This project focused on the safety of water during transport, particularly through service lines, which are the portion of the distribution system that connects a water main to a building. Although there are many regulations in place to keep drinking water safe during its distribution, materials such as lead are used in existing infrastructure, such as service lines, and can contaminate safe water before it reaches the consumer. Lead has been shown to have many negative health effects and has been removed from numerous products including paints and gasoline. For water systems, the Lead and Copper Rule, which was first passed in 1991, is intended to reduce exposure to lead through drinking water. The following sections provide information on water distribution systems, the health impacts of lead, and regulations to minimize lead in drinking water.

2.1 Water Systems

This section discusses water systems, including the various kinds of water sources, how water is treated for drinking, and how it is distributed to its users. This section focuses on distribution, including commonly used materials and concerns such as pipe corrosion and the presence of microorganisms.

2.1.1 Water Sources and Treatment

Drinking water typically comes from one large surface water body and may be supplemented by groundwater sources (National Research Council (US) Safe Drinking Water Committee, 1982). Surface water bodies can have undesirable characteristics such as color or taste and may contain microorganisms from contaminants such as animal waste, agricultural runoff, and sewage. Groundwater usually requires less treatment than surface water due to sediment’s natural filtration capabilities, though it often contains high mineral concentrations that need to be reduced (National Research Council (US) Safe Drinking Water Committee, 1982). According to a 2015 study, 39 billion gallons of freshwater are used per day in public water systems, of which 61 percent is surface water and 39 percent is groundwater (Dieter *et al.*, 2018).

Raw water is transported from its source to a treatment plant prior to distribution to improve its potability (Centers for Disease Control and Prevention, 2020). At the treatment plant, water is treated to meet the applicable standards established by the SDWA and the local community (Centers for Disease Control and Prevention, 2020). After treatment, water is distributed through pipes or conduits to consumer taps (National Research Council (US) Safe Drinking Water Committee, 1982).

2.1.2 Water Distribution

Components of a water distribution system include mains, valves, service connections, storage facilities, fire hydrants, and pumping facilities (National Research Council (US) Safe Drinking Water Committee, 1982). This project focused on service lines, which carry water from a main to a building. In large cities, a water system's storage, main sizes, and pressure are typically determined by the present or projected use by the public (National Research Council (US) Safe Drinking Water Committee, 1982). However, in smaller municipalities, these properties are based on what would be necessary to fight a major fire. The minimum required water pressure for a fire flow is 20 pounds per square inch gauge (psig) during flow, but higher pressures are typically maintained. In residential areas, 30 to 50 psig is common, whereas in commercial and industrial areas, 60 to 75 psig is often used (National Research Council (US) Safe Drinking Water Committee, 1982).

To meet these pressure requirements, water may be moved through the system by pumps, gravity, or both (National Research Council (US) Safe Drinking Water Committee, 1982). In a pressure system, pumps are used at the treatment plant and within the distribution system if necessary. Meanwhile, in gravity systems, water is stored at elevations so that enough pressure is built up to move the water to where it is needed. Typically, a combined system is used, in which water is stored and both gravity and pumps are utilized. This is either done by pumping water into the distribution system, then pumping excess water into a reservoir or storage facility, or by first pumping water into reservoirs or storage facilities where gravity is then utilized to supply the distribution system. The main benefit of using a combined system is that the treated water that exceeds demand during low-demand hours is stored and can later be used during high-demand hours (National Research Council (US) Safe Drinking Water Committee, 1982). This helps reduce the stress on the treatment system to produce higher flows during peak hours.

In a water distribution system, there is at least one transmission main, which transports water after it is treated (National Research Council (US) Safe Drinking Water Committee, 1982). The water gets distributed to users through progressively smaller mains connected to buildings by service lines (National Research Council (US) Safe Drinking Water Committee, 1982). In the United States, there are 2.2 million miles of pipe that transport drinking water to users (American Society of Civil Engineers, 2021). These systems create grids which utilize loops to prevent dead-ends (National Research Council (US) Safe Drinking Water Committee, 1982). Loops allow for the continuous flow of water, which prevents stagnation and ensures that buildings can be serviced when work is being done to a section of pipe (National Research Council (US) Safe Drinking Water Committee, 1982). A service line begins at the water main connector and ends at the building's isolation valve or meter box, as seen in Figure 1 (Vermont Department of Environmental Conservation, 2023).

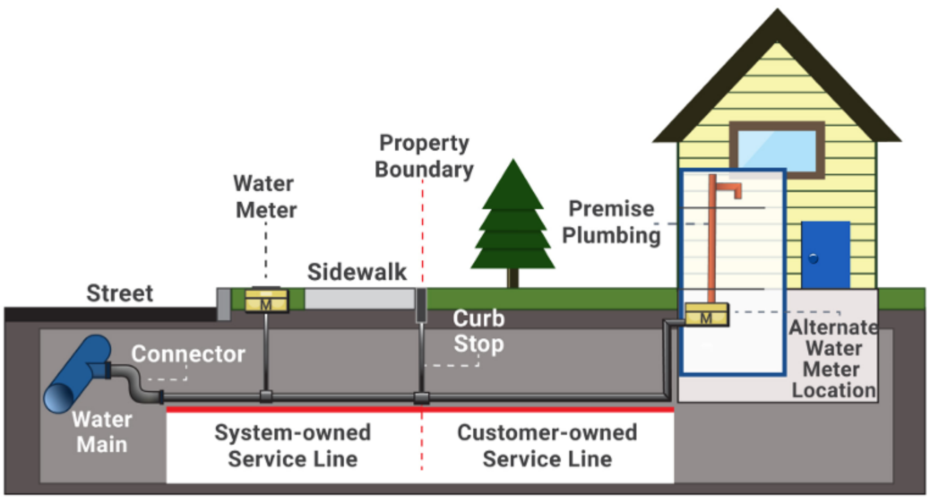

Figure 1. Example diagram of service line structure and ownership by the Vermont Department of Environmental Conservation (Vermont Department of Environmental Conservation, 2023).

2.1.3 Pipe Materials

Water mains are typically made of ductile iron, cast iron, plastic, steel, reinforced concrete, or asbestos-cement, but materials can vary depending on location, pipe size, and cost (National Research Council (US) Safe Drinking Water Committee, 1982). Water mains in the United States are comprised of ductile iron (28%), cast iron (28%), and polyvinyl chloride (PVC) (23%) (Reiff, 2012). The remaining 21% of water mains are constructed of concrete pressure pipe, steel, asbestos-cement, or polyethylene. In the Northeast, where this project's case study was located, ductile and cast iron are the most common materials (Reiff, 2012). It is estimated that the most used material for the construction of service lines is copper, while lead, galvanized wrought iron, galvanized steel, cast and ductile iron, and plastic are also used (National Research Council (US) Safe Drinking Water Committee, 1982). Only estimates for the prevalence of service line materials are possible as there is no national service line inventory. To establish the first national inventory, the Lead and Copper Rule Revisions (LCRR) requires communities to submit preliminary inventories by October 16, 2024 (*40 CFR Part 141 Subpart I -- Control of Lead and Copper*, 2023). Section 2.3.3 provides details about this regulation.

2.1.4 Water Distribution System Concerns

One potential threat that public water systems pose is the spread of disease through microorganisms (Centers for Disease Control and Prevention, 2023). The most common method of minimizing this risk is by adding a chlorine-based disinfectant to provide a residual chlorine concentration in solution. The chlorine inactivates many bacteria and viruses and helps prevent recontamination during storage and transportation, which creates safer drinking water. To prevent stomach discomfort and eye or nose irritation, the EPA has created a maximum residual disinfectant level (MRDL) of 4.0 mg/L for chlorine residuals in drinking water (US EPA, 2015a).

Another health concern with public water systems is the risk of the corrosion of metal pipes (Centers for Disease Control and Prevention, 2013). Water properties such as pH and mineral content can lead to the corrosion of pipes from within the pipe, while soil properties can corrode pipes from the exterior. Water systems practice corrosion control to minimize corrosion in the distribution system. This may include altering effluent pH and other aspects of the water's chemistry or by adding corrosion inhibitors. Corrosion inhibitors are used mostly to prevent the corrosion of pipes within older homes and the distribution system. Additives used to inhibit corrosion include silicates, phosphates, and additives which affect the carbonate system equilibrium. A commonly used group of additives is fluorosilicates (Centers for Disease Control and Prevention, 2013). Despite the use of corrosion inhibitors, pipe corrosion in distribution systems is still a pressing issue, particularly when it comes to lead pipes.

2.2 Lead in Water Distribution Systems

Lead has many useful properties which have led to its widespread use in many industries. Lead has been used in gasoline to increase the octane rating, in paint to brighten colors, and even in foils for wrapping food. Lead has also historically been used as a material for constructing water service lines. In 1991 it was estimated that 10.2 million LSLs were installed in the United States (National Conference of State Legislatures, 2023). Today, it has been estimated that there are about 9.2 million LSLs remaining in use (US EPA, 2023b). Lead is malleable and resists corrosion better than iron and steel alternatives, making it a useful material for service line construction in water distribution systems (Dignam *et al.*, 2019). Because lead is both flexible and durable, LSLs can withstand freeze-thaw cycles without incurring damage. LSLs were typically installed before the 1940s, but some cities required their installment until the 1980s due to lead's excellent physical properties (Hensley *et al.,* 2021). The American Water Works Association (AWWA) estimates these LSLs deliver water to an estimated 15 to 22 million people (LaFrance 2016).

2.2.1 Health Effects of Lead

Lead has been found to result in negative health consequences. Lead is a neurotoxin which can result in decreased cognitive function, developmental disabilities, and death (Rhyan *et al.*, 2023). In children aged six and under, exposure to lead can damage the brain and central nervous system (Roy & Edwards, 2019). Lead exposure to newborn children results in an estimated annual economic impact of 80 billion dollars in the United States due to medical costs, educational impacts, and other associated expenses. Lead exposure from drinking water is expected to account for about 20 percent of total blood lead risk, while lead exposure from lead-based paint, lead contaminated dust, and lead contaminated soils also have a high blood lead risk (Lanphear *et al.,* 2016). After a period of stagnation, LSLs can result in 50-75% of lead at the tap, while other sources of lead such as plumbing fixtures or solder may also contribute to total lead levels found at the tap (Camara *et al.*, 2013). Regulations such as the Clean Air Act and the Residential Lead-Based Paint Hazard Reduction Act were promulgated to reduce exposure to lead once the material's negative health effects began to surface. Regulations regarding lead in drinking water are discussed in Section 2.3.

Because there is no known safe level of lead exposure, lead has been phased out of most products; however, most of the LSLs that were installed in the past are still being used to deliver water to consumers. Measures such as corrosion control plans have been put in place at water treatment plants to prevent lead from leaching into the water, though soluble lead from service lines can still leach into the water during distribution. This often occurs when the water distribution system is disturbed or the chemical balance of drinking water leaving the water treatment plant changes (Baehler *et al.*, 2022). Therefore, LSLs present the risk of contaminating drinking water and causing negative health consequences for consumers.

2.3 Regulations Related to Lead in Drinking Water

The US Environmental Protection Agency (EPA) is the regulatory agency in charge of creating regulations for drinking water with the goal of protecting public health and safety. The EPA has created multiple regulations that set standards for lead levels in drinking water. The regulations regarding lead in drinking water have been revised over time as new information and treatment technologies become available. Regulations that set standards for lead in drinking water have been created through the SDWA and include the Lead and Copper Rule, Lead and Copper Rule Revisions, and proposed Lead and Copper Rule Improvements. While all public water distribution systems are required to adhere to EPA standards, in some cases, the deadline for compliance is delayed for systems serving less than or equal to 10,000 residents (medium or smaller systems). This is done to allow very small, small, and medium water systems to learn from what worked well for large and very large systems. These deadline extensions, known as variances, are a result of the 1996 amendment to the SDWA and can be granted by states if compliance cannot be afforded or met before the given deadline (US EPA, 2015b).

2.3.1 The Safe Drinking Water Act

The EPA was created in 1970, leading to the promulgation of the Safe Drinking Water Act (SDWA) in 1974. The SDWA granted the EPA the authority to set standards for drinking water in the United States (Weinmeyer *et al.*, 2017). The SDWA was created due to mounting concern across the country after over 46,000 cases of waterborne disease were reported between 1961 and 1970. Additionally, a study in 1970 confirmed that 90 percent of drinking water systems evaluated contained significant levels of microorganisms (Weinmeyer *et al.*, 2017). With the EPA being able to regulate synthetic, naturally occurring, and microbial contaminants, the SDWA set consistent standards for drinking water in all states across the country.

A 1986 amendment to the SWDA prohibited the use of pipes, solder, or flux that were not "lead free" in public water systems or plumbing in facilities providing water for human consumption. "Lead free" was defined as solder and flux with no more than 0.2% lead and pipes with no more than 8% lead until 2011. The 2011 Reduction of Lead in Drinking Water Act, which went into effect in 2014, lowered the allowable percent of lead in pipes to 0.25% by weight (Kelechava, 2020).

2.3.2 The Lead and Copper Rule

Under the SDWA, the EPA created the Lead and Copper Rule (LCR) in 1991 with the goal of minimizing lead and copper in drinking water (US EPA, 2008). The LCR set a maximum contaminant level goal (MCLG) for lead in drinking water at zero (US EPA, 2015c). This regulation also established an Action Level (AL) for lead and copper of 0.015 mg/L and 1.3 mg/L, respectively. The ALs are compared to the 90th percentile value of lead and copper concentrations in consumer taps. If the 90th percentile levels of lead or copper exceeded their respective AL, procedures such as public education, water quality parameter monitoring, corrosion control treatment, or LSL replacement would need to take place to educate consumers and reduce the levels of these metals in drinking water (US EPA, 2008).

The LCR was impactful for ensuring consumers were educated on the health risks associated with lead and copper in drinking water. Utilities were required to notify consumers of the dangers of lead through water bill inserts and press releases (US EPA, 2008). During water quality parameter monitoring, samples are taken every 6 months from water at consumer taps and at the entry points to the distribution system. Consumer taps are tested because lead can leach into the water through the service line or through premise plumbing. Water quality parameter monitoring can then be decreased to annual testing if samples meet optimum water quality parameter monitoring standards for 6 consecutive 6-month periods (US EPA, 2008). Source water monitoring and treatment was also required when the action level for copper or lead was exceeded. Source water monitoring is used to determine the amount of lead and copper that is contributed from the system's water source. If the lead or copper levels in source water are higher than the maximum permissible levels (MPLs) set by the state government, source water treatment measures need to be put in place to reduce lead and copper levels in source water (US EPA, 2008).

The LCR ensured that all systems serving over 50,000 people had corrosion control treatment as a part of their water treatment process (Pontius, 1991). Corrosion control can be completed by changing pH, changing alkalinity, or adding compounds such as orthophosphate (Tam & Elefsiniotis, 2009). Corrosion control creates changes in water chemistry which can lessen the amount of lead and copper that leach into drinking water as the water travels through the distribution system. Additionally, the LCR required LSL replacements to remove 7% of total LSLs per year if the lead action level was still exceeded after systems had completed source water treatment and corrosion control treatment (US EPA, 2008). If an LSL is partially replaced, the utility must inform the property owner of possible elevated lead levels and provide sample test results to residents within 3 days of receiving the test results (US EPA, 2008).

2.3.3 The Lead and Copper Rule Revisions: Short-Term

The Lead and Copper Rule Revisions (LCRR) were promulgated in 2007 when the EPA made changes to aid in the implementation of the Lead and Copper Rule and provide guidance for LSL replacements. Changes were also made to ensure public education was available to water consumers (US EPA, 2015c). For small water systems with fewer than 5 taps for human consumption and serving less than 100 people, one sample was required to be taken from each tap on 5 separate days. The sample with the highest concentration of lead is then compared to the action level to determine if any action is required. This revision was crucial for ensuring that small systems could not bypass regulations by taking repeat samples until lower readings are measured (Pontius, 2007).

The LCRR also included definitions to clarify water utility timelines for the three-year compliance period and the monitoring period. One important change the LCRR implemented was that water systems would need to notify the state if any long-term changes such as adding a new water source or changing water treatment processes are planned to be implemented. The state would then make sure that the addition of a water source or change in the water treatment process would not inhibit corrosion control, as changes in water chemistry could cause greater amounts of lead to leach into the drinking water (Pontius, 2007).

Additionally, the LCRR required that all property homeowners and occupants receive lead and copper testing results within 30 days if the tap water is sampled at their residence, regardless of result (Pontius, 2007). The LCRR broadened public education about the health risks of lead and copper by requiring systems to include information such as the health effects of lead, steps to reduce lead exposure, and the action level for lead in drinking water. Information about the health risks of lead must also be included in the annual water quality report or consumer confidence report from each community water system (Pontius, 2007).

LSL replacement processes were also addressed in the LCRR to ensure that water utilities revisited lead levels in all LSLs when completing an LSL replacement program to reevaluate the need for replacement. Under the 1991 LCR, lead service lines did not have to be replaced if lead concentrations were below the action level. However, under the LCRR, these LSLs would need to be retested or replaced to ensure that lead levels remained below the action level (Pontius, 2007).

2.3.4 The Lead and Copper Rule Revisions: Long-Term

Long-term revisions to the Lead and Copper Rule were published in 2021 to create a program that would replace LSLs and identify communities at risk of health problems due to lead in drinking water. One significant change the long-term revisions of the LCRR made from previous versions of the LCR was that communities would need to assemble an initial public service line inventory by October 16, 2024 (*40 CFR Part 141 Subpart I -- Control of Lead and Copper*, 2023). The public service line inventory would identify the material of each service line and allow communities to determine which service lines need to be replaced. At-risk populations would benefit from identifying the material of the service line that provides drinking water to their homes and could take steps to reduce water lead levels while waiting for a service line replacement. As part of the initial inventory, utilities are required to review various records including documents that specify service line materials including plumbing codes and permits; water system records such as historical records on each service connection, capital improvement or master plans, meter installation records, standard operating procedures, and distribution system maps and drawings; other records that would indicate the material of a service line; and anything else required by the state (*40 CFR Part 141 Subpart I -- Control of Lead and Copper*, 2023).

The LCRR also implemented a trigger level (TL) of 10 µg/L. For community water systems serving more than 10,000 people, when the 90th percentile of water lead levels in samples is greater than 10 µg/L, the system must begin LSL replacement at a rate approved by the state (*40 CFR Part 141 Subpart I -- Control of Lead and Copper*, 2023). If the lead action level (15 µg/L) is exceeded, the system must work to replace at least 3% of LSLs every year (US EPA, 2019). Only full LSL replacements can contribute to the system's replacement goal, but partial replacements may also take place if deemed necessary. The system must also analyze and improve the current corrosion control treatment plan that has been put in place if the trigger level is exceeded (US EPA, 2019). After an LSL replacement takes place, the utility must also provide a tap water filter and filter replacement cartridges to the homeowner (Stratton *et al.*, 2023).

The long-term LCRR put measures in place to improve the reliability of water samples by collecting samples with wide neck bottles and prohibiting the practices of flushing and cleaning aerators at the tap (US EPA, 2019). Flushing is a practice that systems could use to reduce the water lead levels obtained in samples by allowing water to run at the tap before a sample is collected. Wide neck bottles ensure that the sampler does not miss the very first drops of water that leave the tap, preventing flushing at any scale. When flushing occurs, much of the lead that has accumulated in the plumbing during a period of stagnation is removed from the system (Katner *et al.*, 2018). Cleaning aerators at the tap can have a similar effect and lower water lead levels in the collected samples.

Community water systems must take samples from schools and provide guidance for lowering lead levels to protect vulnerable populations from lead exposure (US EPA, 2019). For samples collected as residences, the long-term LCRR requires that homeowners be notified within 24 hours if the water lead levels at the tap exceed the action limit. Additionally, outreach to homeowners with LSLs should be completed regularly (US EPA, 2019).

2.3.5 The Lead and Copper Rule Improvements

The Lead and Copper Rule Improvements (LCRI) are set to come into effect at the end of 2024, requiring all public water systems to sample for lead in drinking water at schools (US EPA, 2023d), create a public inventory of their LSLs, and create a service line replacement plan to replace all LSLs within 10 years (US EPA, 2023c). Taking inventory requires locating the pipes through record searching and field verification while also developing a system to effectively keep track of LSLs and their replacement. This is a large task for municipalities, made more difficult by the approaching deadline for inventory creation and submittal. The LCRI will also improve water sampling procedures, aid in determining the source of water lead levels, and help prioritize disadvantaged communities that have been impacted by LSLs (Levin & Schwartz, 2023).

The EPA announced the proposed LCRI on November 30, 2023. One of the goals of the proposed LCRI is to achieve the complete replacement of LSLs over the next 10 years for public water systems (US EPA, 2023f). Therefore, the EPA requires a 10% annual LSL replacement average over a rolling 3-year period. The LCRI will also require that public water systems make annual updates to their initial inventory which must be submitted to the EPA on October 16, 2024. After submittal, the community must continue to update the service line inventory until the material of all unknown service lines has been identified (US EPA, 2023f). The material of all service lines must be known by the end of the 10-year LCRI LSL replacement period. Lead connector materials must also be included in the initial inventory due to changes made by the proposed LCRI. Furthermore, water systems must create LSL replacement plans to ensure they take place effectively over this period (US EPA, 2023f). The LCRI will require full LSL replacements where the service line is under the water system's control. When customer consent is required to complete the full replacement, a minimum of 4 communication attempts must be made by the water system using 2 different communication methods. If the customer does not agree to the full replacement after these attempts, then the water system is not required to complete the full replacement (US EPA, 2023f).

The EPA also proposes that the action level for lead is reduced from 15 ppb to 10 ppb and eliminate the lead trigger level which had previously been set at 10 ppb. Communities will be required to collect first and fifth-liter samples at locations with LSLs. The sample with the higher lead concentration will then be compared to the new 10 ppb action level to determine if action is required to reduce lead levels. Communities with 3 or more lead action level exceedances in a 5-year period must also educate customers about the risks of lead and make lead reducing filters available to these customers (US EPA, 2023f).

The proposed LCRI requires communities to communicate with customers more frequently about the risks of lead exposure and the community's plans to replace LSLs. The LCRI requires the language in annual consumer confidence reports to be changed to make the health effects of lead, water sampling in schools, and the community's LSL replacement plan clearer for customers (US EPA, 2023f). Furthermore, if lead levels in the water system exceed the new action level, all customers must be notified within a 24-hour period. These changes in communication between communities and customers are being put in place with the goal of fostering trust and transparency.

The proposed LCRI is estimated to cost between $2.1 and $3.6 billion per year. Most of these costs are associated with locating, identifying, and replacing LSLs, and making filters available for customers when lead action levels are exceeded. The benefits of the proposed LCRI are estimated to be between $9.8 and $34.8 billion per year which include the reduction of high blood pressure, heart disease, and other health related conditions which may arise due to lead exposure (US EPA, 2023f).

2.4 Case Studies of Elevated Lead in Drinking Water

This section presents two case studies of cities that experienced elevated levels of lead in their drinking water. These case studies provide insight into the magnitude of the impacts that lead contamination can have.

2.4.1 Lead Exposure in Washington, D.C.

An event that resulted in consumer lead exposure occurred in Washington, D.C. in 2004. The Washington Aqueduct, which supplies drinking water for consumers in Washington, D.C., used free chlorine as a disinfectant in the distribution system. In 2004, the system changed to chloramine usage to decrease the concentration of disinfection by-products to levels regulated by the EPA (Edwards *et al.*, 2009). The free chlorine previously used for disinfection reacted with lead in the distribution system and formed a lead pipe scale. This pipe scale kept lead stagnant in the system and acted as an effective corrosion inhibitor (Roy & Edwards, 2019). Once the switch to chloramine was made, the equilibrium conditions within the system were changed and the pipe scale began to deteriorate, releasing significant amounts of lead into consumer drinking water.

In Washington, D.C. there were over 20,000 identified LSLs which contributed to the increase in water lead levels. It took 4 years for action to be taken to add orthophosphate for corrosion control in the water treatment process. Washington, D.C. also partially replaced about 15,000 LSLs to reduce lead exposure (Roy & Edwards, 2019). Partial replacements took place in cases where owners did not want to invest in replacing the section of the service line they owned. Partial replacements can result in more lead leaching into drinking water as the water chemistry within the service line system is altered and physical disturbance occurs. It was only after whistleblowers and the Washington Post exposed the elevated levels of lead in drinking water that the Washington Aqueduct made changes to the treatment process. Furthermore, high water lead levels that were found in testing were omitted from water quality reports, which concealed information from the public and may have prolonged the period of elevated lead exposure (Roy & Edwards, 2019). The events in Washington, D.C. resulted in an estimated 42,000 children being exposed to elevated lead levels for a prolonged period. The water lead levels could have been a contributing factor to the increase in miscarriages and fetal deaths in Washington, D.C. after this period (Roy & Edwards, 2019). The events in Washington, D.C. were important for the creation of the Lead and Copper Rule Revisions which took effect in 2007 (see Section 2.3.3).

2.4.2 Lead Exposure in Flint, Michigan

In 2014, one of the most significant public water system lead exposure events took place in Flint, Michigan. Before the Flint Water Crisis, Flint received its water wholesale from the Detroit Water and Sewage Department whose source was Lake Huron. To reduce costs, officials decided to build a new pipeline for Flint and use raw water from the Flint River as their water source (Masten *et al.*, 2016). This water was not treated in the same way as the water from Lake Huron and was much more corrosive than the water that previously flowed through the distribution system. In addition, corrosion control in the form of orthophosphates was discontinued. Orthophosphates help to form a protective layer inside the pipeline, reducing the potential for water to corrode pipes in the distribution system (Pauli, 2020). When the chemical equilibrium within the distribution system shifted, lead leached into the water from lead pipes and solder. This resulted in water lead levels that were 5 times higher than the EPA's lead action level (Pauli, 2020). Flint continued to use the Flint River as its water source until the summer of 2015, meaning consumers were exposed to elevated levels of lead for over a year.

The events in Flint, Michigan resulted in public attention being turned towards the risks of lead in drinking water in the United States. This event also resulted in a loss of trust between consumers and utilities (Masten *et al.*, 2016). Flint was given hundreds of millions of dollars through the state and federal governments to upgrade its drinking water infrastructure. Flint acted by replacing the city's lead and galvanized steel service lines to reduce the possibility of lead exposure for consumers (Pauli, 2020). Furthermore, this event led to nationwide unrest among water consumers and resulted in criticism of the EPA's Lead and Copper Rule. Testing methods were also criticized as techniques such as flushing the pipe system to reduce lead levels before testing may have been used in communities like Flint, Michigan. Criticisms of the Lead and Copper Rule and the need for updated drinking water infrastructure across the country led to the creation of the Lead and Copper Rule Improvements which will be promulgated in 2024.

2.5 Lead Alternatives

When replacing LSLs, numerous service line materials are available. The replacement material is determined by the existing condition of the service line and connections, associated costs, environmental limitations, water chemistry after replacement, and physical and chemical properties.

Copper service lines are a commonly used replacement for LSLs (CDA, 2023). Copper has excellent corrosion resistance and durability, making it a reliable choice for drinking water systems. Copper's malleability and ease of installation are also advantageous. However, copper can be costly compared to other materials. Additionally, varying pH levels in drinking water can cause the corrosion of copper pipes over time, allowing copper ions to leach into the water. While copper is a natural essential nutrient, concentrations over 1.3 parts per million can lead to health complications (US EPA, 2015a).

Polyvinyl Chloride (PVC) pipes are widely used for water distribution due to their affordability and corrosion resistance. PVC is lightweight, making transport and installation simple and reducing labor costs. PVC is resistant to chemical and biological degradation, ensuring the durability of the piping system. PVC is a brittle material, however, and does not perform well when temperatures fluctuate. In cold regions, installation must be below the frost line. PVC pipe production releases chlorine gas and dioxins, which can have adverse health effects and environmental impacts. Once the pipe is created, however, PVC does not leach chemicals into potable water.

Cross-linked Polyethylene (PEX) is flexible, easy to install, and corrosion resistant. PEX is less expensive than copper, is durable, and can endure extreme temperatures, making it suitable for both hot and cold-water applications. It is also not prone to scaling and is resistant to chemical corrosion. Concerns have been raised about chemicals leaching into potable water. Different varieties of PEX, particularly PEX-B, have shown that they contain and release volatile organic compounds (VOCs) into the water. Primarily, PEX is used for indoor plumbing applications.

Galvanized steel pipes have historically been used for water distribution systems, though other materials have become more favored in recent years. Galvanized steel pipes are typically made of steel coated with a layer of zinc to protect against corrosion. These pipes are durable and can endure high heat and pressure. The zinc coating of galvanized steel pipes can erode over time exposing the raw steel, which is vulnerable to rust and corrosion. Lead based solder and fittings on existing galvanized steel systems can also allow lead to leach into the water.

2.6 Service Line Ownership and Replacement

To complete an LSL replacement program, ownership of each portion of the LSL must be established. Service line ownership is a challenging yet critical topic that impacts which parties are responsible for funding LSL replacements. In some cases, if a property owner is unable or refuses to fund the customer portion of the LSL replacement, a partial service line replacement may take place. Partial and full LSL replacements are distinct processes that can impact water lead levels at the tap.

2.6.1 Service Line Ownership

One challenge with mandating the replacement of LSLs is that in many cases, the portion of the service line from the water main to the curb stop is owned by the utility and the portion of the service from the curb stop to the water meter is owned by the customer (Hensley *et al.*, 2021). While this is common, there are cases where the homeowner or the utility owns the entire service. Difficulties with funding the replacement of the LSL arise when two separate entities own the service. In some cases, the customer owned portion of the service line may be replaced at the expense of the municipality conducting the project. The utility is not required to replace the portion of the service line they do not own, however. If a partial LSL replacement is planned, a notice must be sent to the owner and those affected by the service line replacement (*40 CFR 141.84 -- Lead Service Line Replacement Requirements*). The homeowner can opt to pay for the replacement of the customer owned portion of the service line or they can settle for a partial replacement (*40 CFR 141.84 -- Lead Service Line Replacement Requirements*). When the municipality is to complete a full-service line replacement, they must give a notice to the homeowner and those affected by the replacement; however, the utility is still not responsible for funding the replacement of the customer owned portion of the service line (*40 CFR 141.84 -- Lead Service Line Replacement Requirements*).

In some municipalities, programs with incentives for homeowners may be put in place to encourage the full replacement of LSLs. Public education programs have proven to be valuable for obtaining property owner permission for full LSL replacements (Hiltner *et al.*, 2019). One strategy, which is a requirement for large public water systems under the LCRI, is to make all LSL information publicly accessible through an inventory system. Having a known LSL may decrease property value and incentivize the property owner to fund the replacement of the customer portion of the service line. Homeowners with a known service line may also opt to save for replacement costs and have their service line replaced when other pipework needs to be completed (Hiltner *et al.*, 2019). In Madison, Wisconsin, programs such as rebates have been used to fund half the cost of the customer LSL replacement. Madison also offers loans to customers with repayment only being required once the property has been sold (Renner, 2010). Through the Drinking Water State Revolving Fund (DWSRF), the EPA has allocated $15 billion toward LSL replacement projects (US EPA, 2019b). Municipalities which are to complete full LSL replacements are eligible for these funds which can come in the form of grants or low interest loans (US EPA, 2019b). These funds can be used to finance the full LSL replacement from the water main to the house plumbing regardless of service line ownership (US EPA, 2019b).

2.6.2 Partial Versus Full Lead Service Line Replacement

A partial LSL replacement is when the utility's portion of the service line is replaced with a different material such as copper, while the homeowner's portion of the service line is left as lead (Triantafyllidou & Edwards, 2012). The copper service line is jointed to the lead portion which can be connected through a brass union or by soldering (Clark *et al.,* 2013). A full LSL replacement takes place when the entire LSL is replaced from the water main to the home (Camara *et al.,* 2013). Partial LSL replacement has been associated with elevated lead levels due to the impacts of galvanic corrosion, disturbance of service line materials, and water hammer, or surges in pressure, due to changes in flow within the distribution system as water is forced to stop quickly when valves are opened and closed during replacements (Camara *et al.,* 2013). Full LSL replacements result in a decrease in water lead levels as contact between lead and drinking water no longer takes place (Trueman *et al.,* 2016).

In a study investigating the short and long-term lead release associated with partial LSL replacement, it was found that over a three-month period when copper was used to partially replace an LSL, high lead release took place (Doré *et al.,* 2019). When copper is connected to an LSL, a galvanic cell is created which can increase the rate of lead release in service lines (Triantafyllidou and Edwards, 2011). When the lead, copper, and water cell is created in partial replacement, the lead acts as the anode and is oxidized, the copper acts as the cathode, and the water acts as the electrolyte which allows for the flow of electrons from one metal to the other (Triantafyllidou & Edwards, 2011). The lead donates electrons to the copper resulting in an increase in Pb^{2+} ions. The increased Pb^{2+} at a lead/copper junction can be released or may remain stagnant and contribute to a layer of lead scale within the service line (Triantafyllidou & Edwards, 2011).

An increase in the initial levels of lead in drinking water are likely to arise due to the physical disturbances that take place during the replacement process (Triantafyllidou & Edwards, 2011). When the service line is disturbed due to events such as roadway construction or water main maintenance, the lead scale can be released into the consumer's drinking water supply. Deposition corrosion can also take place when copper ions detach from the copper pipe and settle on the surface of the connected LSL. This can create smaller galvanic cells which may further increase the corrosion of the LSL (Triantafyllidou & Edwards, 2011). From both the physical and chemical disturbances that take place during partial LSL placements, lead release in partially replaced service lines is often greater than that found in undisturbed LSLs. In a study in Cranston, Rhode Island, water samples were tested at eight homes after partial LSL replacement. All samples showed an initial decrease in water lead levels at the tap. After 4 years, water samples were tested at 3 of the 8 homes with one showing a substantial decrease, one showing a slight decrease, and the third showing a substantial increase in water lead levels (Commons, 2015). For this house, water lead levels increased from 0.024 mg/L to 0.058 mg/L after the 4-year period (Commons, 2015).

Corrosion inhibitors are often used to reduce pipe materials from leaching into the water flowing through the distribution system. In the previous study investigating lead release in partially replaced LSLs, when orthophosphate was added to water being transported by full LSLs, lead release decreased by 64%. Meanwhile, when sulfate was added to full LSLs, lead release only decreased by 14% (Doré *et al.*, 2019). When orthophosphate was added to LSLs after junction to copper, lead release significantly increased. When sulfate was added to LSLs after junction to copper, lead release was 26% greater than the initial lead levels (Doré *et al.*, 2019). This increase in lead release is in the form of particulate lead which arises due to galvanic corrosion at the pipe junction and destabilization of the scale. Even with the addition of corrosion inhibitors, partially replaced LSLs can still release lead at a rate comparable to full lead pipes.

Full LSL replacements are the priority for municipalities because this is the only way to limit contact between lead and drinking water (Baehler *et al.*, 2022). In a study evaluating lead release after full LSL replacement, it was found that reductions in water lead levels were seen just 3 days after replacement (Trueman *et al.*, 2016). This decrease in water lead levels came after an initial spike in water lead levels due to disturbances in the water distribution system during service line replacement. One month after full LSL replacement, the highest 10% of water lead levels decreased from the range of 10 to 44 µg/L before replacement to 2 to 12 µg/L after replacement (Trueman *et al.*, 2016). Furthermore, after six months, only 7% of the first draw standing water samples contained lead levels greater than 15 µg/L. The study concluded that the decrease in water lead levels after a full LSL replacement outweighs the initial spike in lead levels, making full LSL replacement a safer option than partial LSL replacement (Trueman *et al.*, 2016).

2.6.3 Galvanized Requiring Replacement Service Lines

Galvanized requiring replacement (GRR) service lines are galvanized water services downstream of an LSL. Because lead tends to adsorb to the iron surface of galvanized pipes, deposits of lead form a scale in regions where the zinc coating has dissipated (Clark *et al.*, 2015). This lead can then be released into drinking water due to physical disturbances or water hammer events (McFadden *et al.*, 2011). Additionally, in a study where orthophosphate was added to galvanized pipes with a history of being downstream from LSLs, corrosion was not inhibited. This indicates that typical corrosion control methods may not be effective in reducing lead release from the lead scale that forms in galvanized pipes (McFadden *et al.*, 2011).

If the utility does not have a record of the material that was upstream at each stage of the galvanized pipe's lifecycle, then the galvanized line is determined to be GRR (Epstein & Kutzing, 2023). If a community determines that the material upstream of the galvanized line has always been non-lead, then the galvanized service line will also be deemed non-lead and will not require replacement (Epstein & Kutzing, 2023). Galvanized service lines that have been downstream of a lead gooseneck or lead solder do not require replacement under federal regulations, however, some states may enact more stringent regulations for what is classified as a GRR service line (Epstein & Kutzing, 2023).

Chapter 3. Methods

The goal of this project was to create a lead service line replacement plan which can be utilized by water systems to aid in the lead service line inventory and replacement process and assist communities in achieving compliance with the EPA's proposed LCRI. The five objectives required to create this plan are as follows:

1. Evaluate and rank methods for identifying lead service lines.
2. Determine best practices for communicating with customers to obtain authorization for full lead service line replacements and respond to service line identification.
3. Determine best practices for scheduling lead service line replacements.
4. Perform a case study using lead service line inventory data and complete GIS mapping analysis to identify geospatial trends.
5. Draft a lead service line replacement plan, including the process of creating an initial service line inventory and scheduling the replacement of lead service lines.

These objectives were used to create an LSL replacement plan which may be applied to water systems of varying sizes. The replacement plan includes a decision tree for LSL identification techniques, the information required in an LSL inventory, and the scheduling and funding process for LSL replacements.

3.1 Methods for Identifying Lead Service Lines

Methods for identifying LSLs were researched through peer-reviewed journal articles and presentations given by subject matter experts at the American Water Works Association Water Quality Technology Conference in Dallas, Texas, November 5-9, 2023. These articles and presentations explained the technologies that may be used to locate service lines and detailed the costs associated with the technologies. The methods were then ranked according to cost, accuracy, time requirement, and implementation feasibility. Costs for each identification method were compared quantitatively based on the average costs of the technique per service line material identified. The accuracy of each identification method was obtained through a presentation given by a subject matter expert at the Water Quality Technology Conference. The time requirement for each technique was determined qualitatively based on the amount of labor needed and the complexity of the methodology associated with the technique. Implementation feasibility was determined qualitatively based on the real-world applicability of the material identification method. A decision tree through which water systems could assess which technologies would be best for locating LSLs was then created based on these rankings using Lucidchart design tools which can be accessed at https://www.lucidchart.com/pages/.

3.2 Best Practices for Communicating with Customers

Techniques for communicating with customers about LSL inventory and replacement programs were determined through communication guides published by the American Water Works Association through AWWA's webpage, "Lead Communications Guide and Toolkit" found at www.awwa.org/Portals/0/AWWA/Communications/2022LeadPageAssets/2022AWWA - LeadCommunicationsGuideAndToolkit.pdf.

Additional information on communication strategies was obtained through an interview with a Senior Utilities Consultant and a Communications Specialist from a very large utility in the southeastern United States. The interview was conducted virtually through Microsoft Teams. Questions were asked about strategies for communicating with the public about the LCR, methods for increasing customer identification of service line materials, and challenges that arise when communicating with customers.

Based on the data collected, templates for mailings were created to aid water systems in increasing customer participation in service line material self-identification, obtaining authorization for full-service line replacements, and warning consumers about the health risks associated with lead exposure.

3.3 Best Practices for Scheduling Lead Service Line Replacements

Funding sources which could be utilized to complete LSL replacement plans were identified through the EPA's webpage on "Identifying Funding Sources for Lead Service Line Replacement" found at https://www.epa.gov/ground-water-and-drinking-water/identifying-funding-sources-lead-service-line-replacement. Laws which allocated funds for LSL replacement projects and additional funding sources were summarized in Table 2 (see Section 4.3.1). The categorization criteria for the funding sources included eligibility requirements, whether applications are approved based on a competitive or non-competitive basis, and how much funding has been allocated for each source.

Factors which need to be addressed when scheduling LSL replacements were determined by researching successful LSL replacement projects. These factors included environmental conditions, service line proximity to other service lines requiring replacement, and replacement taking place during other scheduled construction projects. To obtain this information, case studies from LSL replacement programs in Lansing, Michigan and Gary, Indiana were analyzed and common scheduling practices for both replacement plans were noted. Information about the LSL replacement process including crew size and number of crews needed was obtained through LSL replacement projects undertaken by Denver Water, Madison Water Utility, and Detroit Water and Sewerage Department.

3.4 Case Study using Lead Service Line Inventory Data and GIS Mapping Analysis

To determine how an LSL inventory is completed and which strategies are most used for identifying LSLs, case study data from a municipality in New England was utilized. The data included formatting for an LSL inventory and methods used by the municipality to divide utility and customer owned service line portions into lead, GRR, unknown, and non-lead categories. To analyze the case study data, the customer and utility material of the service lines were reviewed, and the overall service line was then classified as lead, GRR, unknown, or non-lead. Service lines with lead portions and galvanized portions downstream from a lead portion were classified as lead. Service lines with unknown, cast iron with an unknown lining status, or galvanized portions were classified as unknown due to the difficulty of identifying whether a service line is lead-lined. All other service lines were classified as non-lead.

Techniques used by the municipality to identify the materials of LSLs were also included in the inventory data provided. These identification techniques were divided into those used on the customer side and those used on the utility side. On the utility side, service cards, staff knowledge, and record drawings were used for service line material identification. On the customer side, record drawings, inspections, and the year the residence was built were utilized to classify service line materials. Recommendations about techniques that should be utilized for identifying the material of the remaining service lines on the customer and utility side are outlined in the replacement plan created for the municipality.

Inventory data was also used to create GIS maps to determine if any geospatial trends could be identified based on age and material of service lines. Service lines that should be prioritized by the municipality when completing inspections, water sampling, or excavation were determined. The sample data from this case study was used to formulate the LSL replacement plan for the case study utility found in this report.

3.5 Lead Service Line Replacement Plan

Lead service line replacement plans for the case study utility and for utilities of various sizes were created. A replacement plan is highly individualized based on the quantity of LSLs requiring replacement and the amount of funding available to a municipality. Therefore, the replacement plan for the case study utility was drafted to fit its specific needs using the inventory data provided. Information to consider prior to beginning the service line replacement process was provided in both plans. These plans also included approaches for determining communications methods and example mailings which communities may use to request customer verification of service line materials and obtain authorization for full LSL replacements. These mailings were created using design tools in Microsoft PowerPoint and on the Canva graphic design website which can be accessed at https://www.canva.com. Guidance for service line material identification was provided for the case study utility specifically and for other utilities. The scheduling of LSL replacements was documented in the general replacement plan to meet the requirements of the LCRI. Additionally, details about various funding sources and additional information were provided in both plans.

Chapter 4. Results

The goal of this project was to create a lead service line replacement plan for public water systems. This chapter presents the evaluation of different methods for identifying LSLs; a discussion of effective communication between a utility and its customers; and a review of the costs, scheduling, and processes associated with service line replacement. A case study on initial LSL inventory creation was also conducted. Using these findings, guidance was provided for water systems of any size to create a service line inventory and replacement plan.

4.1 Methods for Identifying Lead Service Lines

The first step in replacing an LSL is identifying its existence. This section evaluates and discusses effective methods for identifying LSLs in water systems. Diverse approaches, including historical water service records, machine learning predictions, basic observations, CCTV inspection, X-ray fluorescence analysis, water quality sampling, excavation, and emerging methods are explored. The goal of this section is to provide municipalities with a comprehensive guide, ranking methods based on cost, accuracy, time requirement, and implementation opportunity.

4.1.1 Record Review

As mentioned in Section 2.3.5, the LCRR requires utilities to review a variety of historical records, such as documents that specify service line materials like plumbing codes and permits; water system records such as meter installation records as well as distribution system maps and drawings; other records that would indicate a service line's material; and anything else required by the state (*40 CFR Part 141 Subpart I -- Control of Lead and Copper*, 2023). Particularly useful and inexpensive records are water system records, which typically contain information like relative location, size, and material of water service lines. However, the use of these records comes with its challenges. Installation records are likely to be between 70 and 100 years old and could be damaged, illegible, or lost (Devenyns, 2019; Goodman *et al.*, 2017 as cited in Hensley *et al.*, 2021). In some cases, when a replacement crew unearths a recorded LSL, a more recent copper service line is discovered (Goovaerts, 2017). Some municipalities may have particularly inaccurate or incomplete records. It should also be noted that utilities tend to have more complete records for the water service line that is on the utility side of the curb box than for the customer side (US EPA, 2022a). Despite these challenges, the review of water service records can be effective and inexpensive for communities with accurate and complete records.

Along with reviewing water service records, reviewing plumbing codes and construction specifications can aid in determining service line material (US EPA, 2022a). For example, if state or municipal records are unavailable, the SDWA lead ban in 1986 can indicate that service lines installed after 1986 do not contain lead materials (Perry *et al.* 2018 as cited in Hensley *et al.*, 2021). Utilities can also use the installation date of service lines to determine which locations have the highest risk of LSL materials (Hensley *et al.*, 2021). Other methods for identifying LSLs can then be used in conjunction with record review to determine whether an LSL serves a particular location.

The information found from record review can then be paired with GIS mapping or database development to prioritize sections of municipalities that have a higher likelihood of being served by an LSL (Hensley *et al.*, 2021). Furthermore, many homes located near each other are likely to have been built around the same time. If a municipality does not have a complete set of records, reviewing records from other houses that were built around the same time can aid in determining which houses should be prioritized for LSL investigations. The cost associated with reviewing information from past or current projects to determine the service line material is about $22 to $35 per service line material evaluated (Kutzing, 2023). Record review is a cost-effective method which can be used to accurately determine the service line material if complete records have been maintained. While the overall accuracy of record review is 64% due to the high number of false positives for lead, it can correctly identify 98% of LSLs (Smart *et al.*, 2023). This should be one of the first methods that municipalities use when trying to identify LSLs.

4.1.2 Machine Learning

A method of predictive modeling, machine learning, which utilizes predictive algorithms and geospatial data, can also be used with GIS and digitized records to predict where LSLs may be in place. Information such as the age of housing infrastructure and the presence of vulnerable populations can be incorporated into the algorithm to determine which residences should be prioritized for LSL inspections and replacements (Hensley *et al.*, 2021).

Machine learning can also help municipalities save money by decreasing the likelihood of excavation for pipes which are expected to be constructed of non-lead materials. Flint, Michigan used machine learning to assist in predicting where LSLs were located (Abernethy *et al.*, 2018 as cited in Hensley *et al.*, 2021). Machine learning has also been used in Pittsburgh, PA to predict the most probable locations of LSLs. In this study, the machine learning model utilized information from water service cards, spatial locations of customers, and tap water sampling (Hajiseyedjavadi *et al.*, 2022). From 2014-2019, the Pittsburgh Water and Sewer Authority (PWSA) excavated 9,080 locations to determine the material of service lines. Of these 9,080 locations, 63% of service lines were observed to be lead. If PWSA had excavated the same number of locations but chosen locations with the highest probability of LSLs based on machine learning, the percentage of LSLs would have been 90%. However, when applied to a larger data set of 35,000 service line locations, the machine learning model would have only improved the identification of LSLs by 3% (Hajiseyedjavadi *et al.*, 2022).

While machine learning may save municipalities time and money in some cases, this predictive method is not a certain way to identify service line materials. Incorrect predictions could result in LSLs remaining in use if they are assigned a low lead risk value based on the machine learning technology. Predictive modeling has an associated cost between $1 and $10 per service line material evaluated; however, this method can only be utilized once at least 20% of the service lines have been physically verified (Kutzing, 2023). After this information is gathered, the machine learning model should be able to rule out which service lines are not lead and determine which service lines pose the highest risk of being lead. Due to cost, the need for extensive physical verification, and the potential for incorrect predictions leading to the continued use of LSLs, machine learning is not considered a standalone, reliable option in the identification of service line materials.

4.1.3 Visual Inspection

Visual inspection is an LSL identification technique which can be utilized by customers or utility staff (Hensley *et al.*, 2021). This technique involves performing tests on the customer owned portion of the service line or inserting a flexible fiber optic camera into the curb box to determine the service line material. With the help of customers self-identifying service line materials, utilities can save time and money; however, if a customer is unable to identify the service line material, a visual inspection through door-to-door visits may be required by utility staff.

4.1.3.1 Customer and Utility Inspection

Lead service lines can be identified through basic observations, which can be completed by residents (Hensley *et al.*, 2021). With this method, only the segment of the service line within a building is inspected. Because the materials used for the other segments of the service line may vary, this method cannot be used to determine the materials used for the entire service line. To test the material of the service line within a building, the pipe is scratched with a dull object. If the scratched area turns yellow or orange, it is likely that the material is copper. Meanwhile, if the pipe scratches easily and turns silver, it is either galvanized iron, galvanized steel, or lead. Then, a strong magnet is placed on the pipe to see whether it is magnetic or not. If the magnet attaches to the pipe, then it is made of galvanized iron or steel rather than lead (Hensley *et al.*, 2021). The cost associated with customer-provided-data ranges from $8 to $11 per service line material identified (Kutzing, 2023). This method has an accuracy of about 75% as residents may misidentify their service line material or submit the identification information improperly. Door-to-door inspections can be completed by the utility which are more accurate for identifying service line materials than the self-identifications provided by customers. The cost of door-to-door inspections ranges from $50 to $104 for each service line, and the accuracy of identifying service line materials is 90% (Kutzing, 2023).

Although basic observations are quite accurate, they also have some downfalls. Firstly, resident response rates may be low (Hiltner *et al.*, 2019 as cited in Hensley *et al.*, 2021). Secondly, observation cannot be used to determine whether a pipe is made of lead-lined galvanized iron (Hensley *et al.*, 2021). Overall, when basic observations are used, efforts like economic incentives (Hiltner *et al.*, 2019 as cited in Hensley *et al.*, 2021) and increased public education should be used to improve response rates (Philadelphia Water Department, 2022 as cited in Hensley *et al.*, 2021).

Also, as part of the LCRR, water utility staff must note customer-side service line materials during operations where they are observed, such as service requests and meter readings (US EPA, 2021a as cited in Hensley *et al.*, 2021). If pipes are found to be lead during utility maintenance, the EPA recommends they be replaced (US EPA, 2011).

4.1.3.2 CCTV Inspection

Cameras can also be used to identify pipe material. By lowering a high-resolution camera with a light source and flexible fiber-optic scope down into a pipe through the curb box, viewers can look at the inside of the pipe to determine the pipe material (Conway, 2017 as cited in Hensley *et al.*, 2021). This method has been used by Tuscon Water in Arizona and Green Bay in Wisconsin. The price for this service is about $81 per service line material identified (Kutzing, 2023). This method has many disadvantages. First, water must be shut off at the curb box to inspect the customer owned side of the service line, and at the main to inspect the utility owned side of the service line. Once the camera is inside the pipe, corrosion and mineral precipitates on the pipe's walls can obstruct the view of the pipe material (Hensley *et al.,* 2021). If the camera can obtain a clear image of the service line material to be identified, this can only identify the material in the immediate vicinity, and it cannot be assumed that the entire pipe is of the identified material. Additionally, the camera itself can disturb mineral precipitates and free them from the pipe's surface (Hensley *et al.,* 2021). For the Pittsburgh Water and Sewer Authority, which regularly uses cameras to inspect service lines, the material cannot be identified in about 43% of cases, and curb boxes cannot be found or accessed in another 18% of cases (Conway, 2017).

4.1.4 Water Quality Sampling

Water quality sampling and testing can indicate the possibility of an LSL; however, the presence of an LSL cannot be confirmed through sampling alone. Water quality sampling can be utilized to determine which property locations have elevated water lead levels and should be prioritized for further investigation. Three sampling methods that have been effective in identifying LSLs are targeted, flushed, and sequential sampling (Hensley *et al.*, 2021).

4.1.4.1 Targeted Sampling

Targeted service line water sampling is a method in which water that has been stagnant in the service line for 15 minutes is collected and tested. This 15-minute stagnation period is associated with 15-20% of the lead leaching that takes place in an LSL after a 6-hour stagnation period (Cartier *et al.*, 2012). To accomplish this method of testing, the length of plumbing and estimated volume of water in the plumbing from the service line to the sampling tap must be known. This water is then flushed from the system so that the water collected for testing is from the service line portion of the distribution system (Hensley *et al.*, 2021).

A lead concentration threshold and the volume of water being collected must be determined before samples are taken. These thresholds for lead sampling may be established by governments or agencies. For example, in the United States, an action level of 15 µg/L of lead for first draw sampling after a stagnation period of 6 hours has been established (*40 CFR Part 141 -- National Primary Drinking Water Regulations*, 2023). The volume of water needed for sampling can be determined from the median volume of plumbing services and length of pipe installed (Hensley *et al.*, 2021). Lead concentrations greater than the 15 µg/L threshold could indicate that an LSL may be present and further steps should be taken to determine the service line material, though the action level is based on testing after stagnation and not after flushing.

During the application of targeted service line water sampling in a distribution system in Montreal, Quebec, a threshold of 3 µg/L of lead in water was established as the threshold for further investigation (Cartier *et al.*, 2012). While this method was effective for identifying LSLs, the false negative rate was high: almost 29% of the sites sampled that had lead levels below the 3 µg/L had LSLs (Cartier *et al.*, 2012). Therefore, targeted service line water sampling is not effective for ruling out the presence of LSLs, but testing can be used to determine which service lines are a priority for further investigation. The cost associated with targeted service line water quality sampling ranges between $110 and $240 per service line evaluated, with an average cost of $175 (Kutzing, 2023). Based on the average cost and the inability to accurately determine the material of unknown service lines, targeted service line water quality sampling should not be the primary method for determining service line materials.

4.1.4.2 Flushed Sampling

Flushed sampling is a method in which water flows through the system for a predetermined amount of time before sampling takes place. In a study conducted in Montreal, Quebec, water could flow through the system for 5 minutes (Cartier *et al.*, 2012 as cited in Hensley *et al.*, 2021). In the United States, the EPA does not recommend flushing for sampling but recommends flushing to ensure water is moving through the system regularly. This flushing technique is recommended to be used in schools due to the susceptibility younger populations have to lead related illness. Flushing decreases the age of drinking water and ensures water quality is maintained (EPA Office of Groundwater and Drinking Water, 2018). Flushing right before sampling may yield results with lead levels that are lower than the typical lead levels in the water being sampled (EPA Office of Groundwater and Drinking Water, 2018). The flushed sample is used to help determine if there is lead in the plumbing behind the fixture where the water is being collected from (EPA Office of Groundwater and Drinking Water, 2018). The lead concentration threshold for further investigation is dependent on the community completing the testing and the corrosion control treatment in place.

For flushed sampling that took place in Bennington, Vermont, samples were taken from 41 homes with known LSLs. The average lead concentration was 3.1 µg/L, and the median lead concentration was 2.7 µg/L (Smart *et al.*, 2023). Establishing a sampling threshold below these values would be conservative and decrease the chance for false negative results. For example, in a water system in Montreal, Quebec that did not use corrosion control treatment, a lead concentration of 2 µg/L or greater indicated a high probability of an LSL, while a concentration of 1 µg/L indicated a low probability of an LSL (Cartier *et al.*, 2012 as cited in Hensley *et al.*, 2021). In another community, the lead threshold concentration was based on a value three times the average lead concentration in known non-LSLs (Hensley *et al.*, 2021). This method was able to correctly predict the presence of 63% of known LSLs. However, in a second trial, only 11% of known LSLs were identified through flushed sampling (Hensley *et al.*, 2021). Because flushed testing only requires a collection time of 30 seconds to 5 minutes per sample, the time requirement for this method is low, however the cost of testing per service line is between $110 and $240, with an average cost of $175 as seen with targeted sampling (Kutzing, 2023). Again, the moderate cost and low accuracy associated with flushed sampling prevent this method from being a primary technique for identifying service line materials.

4.1.4.3 Sequential Sampling

Sequential sampling is a method in which successive water samples are collected after a predetermined stagnation period. The stagnation period is typically 6-hours to simulate the highest concentrations of lead that may be found at the tap during routine activities. The lead concentrations for each sample are plotted on a graph along with the cumulative volume of water tested to create a lead concentration profile (Hensley *et al.*, 2021). For sequential sampling, 8-15 samples are collected at a location and a profile is created. The plotted profile creates a view of lead release from each component of the plumbing system from the tap to the water main (Lytle *et al.*, 2019 as cited in Hensley *et al.*, 2021). Methods such as pre-stagnation flushing to remove scale and a low flow rate to reduce mixing can be used to increase accuracy. This method of testing can also be used to determine the plumbing component that is causing lead release if multiple rounds of sequential sampling are performed (Lytle *et al.*, 2019 as cited in Hensley *et al.*, 2021). Through multiple rounds of sampling, spikes in concentrations of particulate lead can be differentiated from consistent lead release to identify which plumbing component is releasing lead (Lytle *et al.*, 2019 as cited in Hensley *et al.*, 2021).

A study conducted by DC Water in Washington, D.C. demonstrated that sequential sampling was accurate for identifying LSLs. This strategy correctly identified 26 LSLs and 2 non-LSLs out of 30 locations that had service line work completed (Hensley *et al.*, 2021). This method is more accurate than other sampling methods, however, a higher associated cost and time requirement are necessary for sequential sampling (Hensley *et al.*, 2021). The estimated cost for sequential sampling is $290 to $1,140 per service line location due to the increased volume of samples that must be collected at each site, with an average cost of $715 (Kutzing, 2023).

4.1.5 Excavation

Excavation involves the unearthing of service lines to allow for visual inspection. In this section, different methods of excavation, mechanical and vacuum, are discussed.

4.1.5.1 Mechanical Excavation

Excavation is an effective means of confirming LSLs in a residential water system. Excavation entails a comprehensive visual inspection of service lines buried underground. Depending on the location of the curb box, excavation may necessitate the removal of soil, sidewalks, driveways, or other obstructive elements. When conducting excavations, it is imperative to prioritize the safety of existing utilities. Thus, it is advisable to schedule an 811 safe dig locator to the site before commencing any work (“811,” 2023). When excavating, machinery can be used to shorten the time spent digging. However, it is common to excavate by hand within 30 inches of any known pipe locations to avoid damaging the utilities (OSHA, 2023). While excavation allows for an accurate identification of the service line material, it is a lengthy, expensive, and labor-intensive process, especially if a service line is found to be non-lead (Hensley *et al.*, 2021). Naturally, homeowners would not choose to perform this themselves. Therefore, contractors and locators will charge about $650 for this service, as quoted by a moderately sized excavation company in the Northeast. While costs for mechanical excavation can start around $650, these costs can be as high as $2,500 for each service line material identified (Kutzing, 2023). Despite the high cost, mechanical excavation has the highest accuracy out of all service line material identification methods with an accuracy of 95% (Kutzing, 2023).

4.1.5.2 Vacuum Excavation

An alternative to mechanical excavation is vacuum excavation. Vacuum excavators are large, truck mounted vacuums that spray water or air into the soil to loosen the earth and allow the vacuum to remove it. The lack of forceful contact with the soil limits the damage that can be done to utilities (Vermeer, 2023). Vacuum excavation requires much less disturbance to the property, creating only an 8-12 inch bore hole (Hensley *et al.*, 2021). The process takes 20 minutes to one hour (Deb *et al.*, 1995 as cited in Hensley *et al.*, 2021) and costs between $80 and $450 (Kutzing, 2023). While vacuum excavation can be safer, cheaper, and more timely than conventional excavation efforts, it is still quite costly and not an ideal solution for identifying large numbers of service lines. Vacuum excavation has an accuracy of about 90% for identifying service line materials while being a less expensive option than mechanical excavation (Kutzing, 2023).

4.1.6 Emerging Methods

There are emerging methods that may be useful for LSL identification, including above ground identification, acoustic wave technology, and electrical testing.

4.1.6.1 Above Ground Identification

For above ground identification, Ground Penetrating Radar (GPR) could be used by transmitting high-frequency radio waves into the ground and analyzing the reflected signals (Annan, 2009). By assessing the differing levels of signal penetration and reflection, known as backscatter, a differentiation can be made between the types of pipe material (Ida, 2019). In communities with pipes less than 15 inches below the surface, metal detectors can be used for material identification (Bukhari *et al.*, 2020 as cited in Hensley *et al.*, 2021). While simple metal detectors can only distinguish ferrous and non-ferrous metals (Bukhari *et al.*, 2020 as cited in Hensley *et al.*, 2021), more sophisticated ones can detect metals with low metallic character and conductivity, including lead (Candy, 2019).

4.1.6.2 Electrical Testing

A service line's material can also be identified by measuring the pipe's electrical properties. One method of doing so involves the use of digital low resistance ohmmeters (DLROs) to measure electrical resistance, in megaohms, of a pipe between the curb box and water meter (Ballinger *et al.*, 2020 as cited in Hensley *et al.*, 2021). While laboratory experiments and field tests were used to confirm that this method can be used to detect lead, difficulties include debris hindering excavation, pipe corrosion interfering with readings, and varying pipe or coupling materials and dimensions interrupting the electric current (Ballinger *et al.*, 2020 as cited in Hensley *et al.*, 2021). Another method involves eddy current technology, which requires two cylindrical coils to be placed near the test material (Rosen, 2023). The alternating current that flows through one of the coils causes an eddy current, which can either be measured by the second coil, or by measuring the changes in the primary coil's current. The conductivity, or the inverse of resistivity (US EPA, 2017), of a test piece can be measured using these methods (Rosen, 2023). The conductivity found through this method can be used to identify a pipe's material (NDT Supply, 2023). According to an AWWA Research Foundation Study, when this method is paired with vacuum excavation, the material can be measured at the curb box in 15-20 minutes and 30-40 minutes when the ground material was soil and asphalt, respectively (Deb *et al.*, 1995 as cited in Hensley *et al.*, 2021).

Although the emerging methods discussed so far require more development, the Swordfish and Swordfish SE, developed by Electro Scan Inc., are particularly promising. Like the concepts in the previously discussed electrical testing methods, these tools measure the electric resistance through the insertion of an auto-fed cable with a low-voltage conductivity probe into curb boxes and water meters (Electro Scan Inc., 2023). The Swordfish and Swordfish SE are both compatible with 0.5- to 3-inch pipes and can be used up to 80 and 100 feet from the pipe opening, respectively, while providing an accuracy of 90% for determining service line materials (Kutzing, 2023). While these devices are convenient to use and can also identify leaks, they are costly as the Swordfish and Swordfish SE cost $70,000 and $74,500, respectively (Electro Scan Inc., 2023) Because the initial cost is so great, the cost for each service line material identified varies based on the number of service lines that require identification. Because there is a large initial investment in this technology, it may be better suited for a municipality with a greater quantity of service lines that need to be identified. One of the disadvantages of this method is that inserting the probe into water meters and pipes may disturb potential scale build up on the pipe's interior. Additionally, it is recommended that customers filter their water after this technology has been used due to possible disturbances within the pipe (Kutzing, 2023).

4.1.6.3 Acoustic Wave Technology

Another identification method involves acoustic wave technology, which is commonly used to detect leaks in pipe networks (Hensley *et al.*, 2021). One application of this technology is active sensing, which works by using a sound source to create sound waves that interact with materials and measure them using a receiver (Yu *et al.*, 2021). The measured frequencies can be used to locate pipe discontinuities (Yu *et al.*, 2021). For acoustic wave technology to be useful in identifying pipe materials, the pipe's diameter must be known, and a library of material types and their associated return frequencies at the given diameter must be established for comparison (Welter, 2009 as cited in Hensley *et al.*, 2021). Even if a library of return frequencies for each potential material and diameter is created, corrosion and pipe buildup can interfere with the readings, making acoustic wave technology inaccurate.

4.1.6.4 X-Ray Fluorescence Analysis

One method of LSL identification in the field is using X-ray fluorescence (XRF) analyzers (Hensley *et al.*, 2021; Adler, 1994). XRF analyzers are handheld tools that emit x-rays towards a material, which displace electrons and cause fluorescent x-rays to be emitted (Thermo Fisher Scientific, 2024). These fluorescent x-rays are received by the analyzer's detector, generating a composition analysis which is displayed on the analyzer (Thermo Fisher Scientific, 2023). In a study conducted at Princeton University with data from Trenton Water Works, it was found that XRF analyzers can help determine whether a lead-lining is present in a pipe (Epstein, 2023). However, false negatives may occur, potentially due to a worn inner lining, a dense outer material, and the presence of lead scales. Therefore, this method should be paired with another method to confirm whether a lead lining is present (Epstein, 2023). Because the only certain way to determine whether a lead lining is present is to cut into the pipe, this method can be particularly useful. This is important when municipalities are completing an LSL inventory because lead-lined galvanized service lines must be treated as LSLs (Epstein, 2023). Despite these potential benefits, due to the limited research and use of this method, the accuracy and cost of its use has not been adequately assessed.

Although the technologies discussed in this section, apart from the Swordfish and Swordfish SE, have the potential to be used to identify a service line's material, further research is necessary to better understand the feasibility of each technology's use. Therefore, the likelihood of acquiring state approval for the use of these methods is not as high as for the other non-EPA approved methods discussed in Section 4.1.

4.1.7. Method Ranking and Identification Technique Flow Chart

The methods for identifying water service line materials have varying costs, accuracies, time requirements, and implementation opportunities (see Table 1). Methods such as record review and visual observations are associated with the lowest costs since labor makes up the largest portion of the total cost. Record review also has the lowest time requirement as records can be digitalized and accessed easily. Record review is typically the first step in the LSL identification process due to the low cost and time commitment. While excavation is extremely accurate, it is also the most time intensive identification method, and is most expensive due to labor, machinery, and fuel costs. Other methods like visual observation by customers and the utility are also accurate with a lower time requirement. Additionally, water quality sampling methods have moderate costs and time requirements, and sequential sampling is more accurate than targeted and flushed. Methods such as above ground identification, electrical testing, and acoustic wave technology are emerging methods which have not yet been sufficiently tested, resulting in an uncertain accuracy for identifying service line materials. However, the Swordfish and Swordfish SE, which are emerging methods, show promise with high accuracy and a reasonable time requirement.

For the "implementation feasibility" column, the ability for each method to be used in the real world was considered. While some methods are logistically sound, their actual implementation may be more difficult than expected. Likewise, methods that seem complicated can sometimes be much easier to implement than expected. Methods approved by the EPA typically ranked "best," methods only requiring state approval typically ranked "average," and emerging methods requiring state approval typically ranked "worst." However, some exceptions were made for record review, CCTV, and the Swordfish and Swordfish SE. While record review can be incredibly useful, if a utility does not have well-documented records, this method can be ineffective. Also, CCTV was ranked "average" due to the many potential challenges associated with its use. Finally, the Swordfish and Swordfish SE were ranked "average" because, despite being an emerging method, there has been a considerable amount of research on these products, and they have been found to be quite accurate.

Table 1. A ranking of the various service line material identification methods

Method Group	Method	Level of Approval	Cost	Accuracy	Time Requirement	Implementation Feasibility
Record Review	Record Review	EPA Approved	Best	Average	Best	Dependent on Available Records
Predictive Modeling	Machine Learning	Requires State Approval	Average	Average	Average	Average
Visual Observation	Customer	EPA Approved	Best	Average	Average	Best
	Utility	EPA Approved	Best	Best	Average	Best
	CCTV	EPA Approved	Average	Average	Average	Average
Water Quality Sampling	Targeted	Requires State Approval	Average	Worst	Average	Average
	Flushed	Requires State Approval	Average	Worst	Average	Average
	Sequential	Requires State Approval	Average	Average	Average	Average
Excavation	Mechanical	EPA Approved	Worst	Best	Worst	Best
	Vacuum	EPA Approved	Worst	Best	Average	Best
Above Ground Identification	Ground Penetrating Radar	Emerging Method - Requires State Approval	Insufficient Data	Insufficient Data	Average	Worst
	Metal Detector	Emerging Method - Requires State Approval	Insufficient Data	Insufficient Data	Average	Worst
Electrical Testing	Digital Low Resisitance Ohmeter	Emerging Method - Requires State Approval	Insufficient Data	Insufficient Data	Average	Worst
	Eddy Current	Emerging Method - Requires State Approval	Insufficient Data	Insufficient Data	Average	Worst
	Swordfish and Swordfish SE	Emerging Method - Requires State Approval	Average	Best	Average	Average
Acoustic Wave Technology	Acoustic Wave Technology	Emerging Method - Requires State Approval	Insufficient Data	Insufficient Data	Average	Worst
X-Ray Fluorescence	X-Ray Fluorescence	Emerging Method - Requires State Approval	Insufficient Data	Insufficient Data	Average	Worst

A combination of identification methods may be used to provide the best results for water service line material identification. Water service records are easily accessible and should be the first source of information for service line material identification. Visual observation through in-person visits and customer identification should then be used to determine the service line material for locations without complete water service records. Water quality testing can also be implemented to identify which residences are at the highest risk of lead exposure. Excavation can be used at locations with the highest water lead concentrations to correctly identify service line materials and complete an LSL replacement if necessary.

The identification techniques approved by the EPA include record review, which is required (*40 CFR Part 141 Subpart I -- Control of Lead and Copper*, 2023), visual observation, and excavation (US EPA, 2022b). Other techniques such as water quality sampling, predictive modeling, and emerging methods can be used if state approval is obtained (US EPA, 2022b). To aid utilities in developing an initial service line inventory, a flow chart depicting the order of EPA approved identification techniques was created (see Figure 2). Because all utilities must complete an initial record review, this serves as the first step in the identification process. Due to the high cost associated with excavation, visual observation was chosen as the second step in the identification process. Visual observation also has a medium-high accuracy for identifying the material of a service line. When used as the second step in the replacement process, it provides utilities with the opportunity to save money and accurately identify service lines. The final step in the identification process should be excavation due to the high cost and time commitment. Excavation is the most accurate method for identifying service line materials but should only be used if service lines cannot be identified through record review and visual observation.

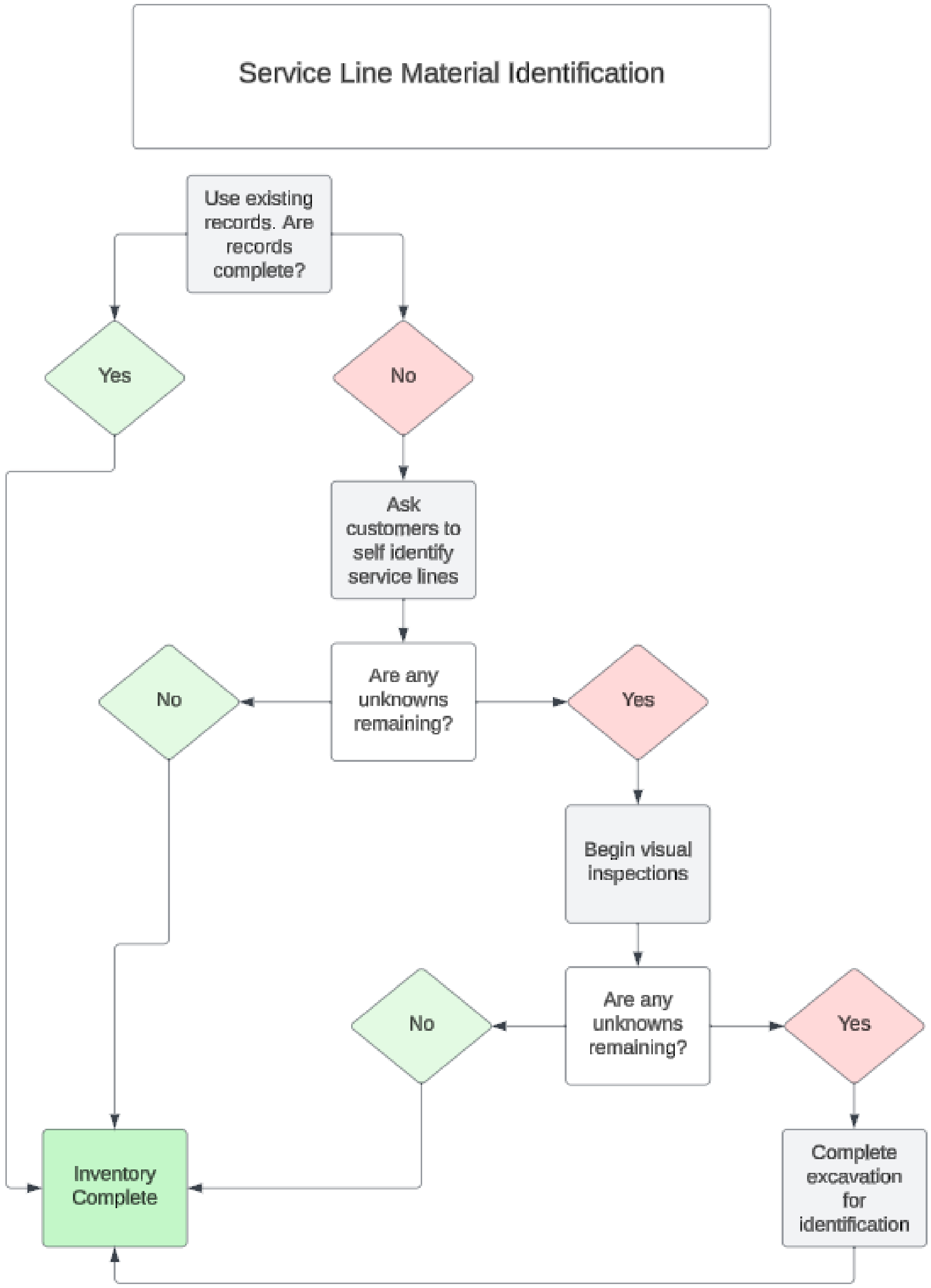

Figure 2. Identification Technique Flow Chart

This flowchart serves as a basic guide for utilities to use during the service line inventory and identification process. Methods that require state approval may be used before the excavation step in the flow chart if permission has been obtained from the primacy agency. Techniques can also be used simultaneously if service line materials need to be identified at a faster rate to meet the initial inventory deadline of October 16, 2024.

4.2 Guidance for Communications about Unknown and Lead Service Lines

When looking to create an inventory to replace LSLs, municipalities must first openly and effectively communicate their goals and reasoning with their customers. In communication, it is crucial that a sense of trust be developed between the utility providing the service and its customers (AWWA, 2022). The Lead and Copper Rule (40 CFR §141.84(a)(8)) requires systems serving over 50,000 individuals to have an online database for publicly sharing the location of LSLs and galvanized service lines requiring replacement. All municipalities must make their inventories publicly available in some way, so municipalities serving less than 50,000 individuals may choose to make their inventories available by mail or in person, but they are highly encouraged to provide an online inventory as well (US EPA, 2022b). To learn more about effective communication, our team met with a Senior Utilities Consultant and a Communications Specialist from a very large utility in the southeastern United States. Both communications experts have experience in disseminating information regarding LSLs. Methods for delivering targeted information to community members with unknown or confirmed LSL material and eliciting responses are further discussed in this section.

4.2.1 Content of Communications

The first step in communication with a water utility's customers is providing trustworthy information through the utility's website. This website should explain the need for a service line inventory, answer commonly asked questions about service lines and service line materials, and provide instructions for self-identifying a service line material and reporting the results. This website should also include an interactive map of the utility's inventory if it can (AWWA, 2022). Further information applicable to those who have LSLs can be provided on a water utility's website, such as the dangers of lead, temporary filtering methods, how lead can enter drinking water, and how to arrange for an LSL to be replaced (AWWA, 2022). Municipalities may also elect to announce the creation of the service line inventory by distributing information to service line owners, establishing alert and contact.

4.2.2 Methods of Communication

The next steps would be individually reaching out to customers through mailing flyers and pamphlets; sending phone calls, text messages, and emails; and visiting door-to-door (AWWA, 2022). These communications may vary based on the municipalities' progress in the LSL inventory and its replacement process. The service line material of the intended audience is another factor which may cause communications to vary. For those with known LSLs, these communications should explain the risks of lead, provide guidance for limiting lead exposure from drinking water, and suggest actions for replacing LSL materials. It can also be helpful to explain how lead can enter drinking water, as this clarifies that the water source is not contaminated (AWWA, 2022).

Residents should be urged to take part in the LSL replacement program for the safety of their family and the community. Meanwhile, contacting the owners of service lines with unknown materials is a much more delicate task. In direct communication, listing the dangers of lead for these residents may strike unwarranted fear. Many such owners will come to find out that their service lines are composed of completely safe materials. Therefore, these communications should focus on explaining the need to complete the service line inventory to meet EPA regulations rather than to protect them from the health effects of lead. It is important to note that the recipient of a letter in the mail or a phone call may not be the service line owner, an example being tenants in a rented space. Tenants may be alarmed to learn that they have an LSL, and that it is up to their landlords to sort out the replacement and sign work authorization forms. Therefore, care should be taken to ensure that owners of service lines are being contacted, not just those residing at the location of the known LSL. If a property owner cannot be reached, tenants should be provided with information and asked to contact their landlord regarding the replacement of their LSL.

4.2.2.1 Mailings

The first method of individually communicating with customers is mailing information such as flyers and pamphlets. These mailings should provide residents with physical information about the LSL inventory and replacement process, as well as the municipality's phone number and a link to the utility's website, as previously discussed (see Figures 4 & 5; all Figures referred to in this section are in the Appendices). To improve response rates, these materials should be eye-catching and contain minimal wording (see Figure 3). Additionally, municipalities should be prepared to send these mailings multiple times as they can easily be disregarded by recipients (AWWA, 2022).

For customers with known lead service lines, the materials should list the risks of lead and offer short-term solutions for minimizing exposure, such as flushing the system after a period of stagnation or purchasing a lead capturing filter (see Figures 6 & 7). The materials should also explain how lead can enter drinking water (AWWA, 2022). Detailed steps for scheduling LSL replacements should be made available to residents, and any incentive programs that the municipality may offer should be emphasized.

For those with service lines of unknown materials, initial contact should explain the need for a service line inventory and state that the town does not yet have a record of the owner's service line material (see Figures 8 & 9). Instructions for how to self-identify service line materials should be included, either as a secondary pamphlet or linked through a QR code that leads to the municipality's service line inventory website. An example of a mailing detailing the service line material self-identification process is shown in Figure 10. While it is ideal for owners to identify the material of their own service lines, offering a free site inspection may lead to more accurate results and better uptake due to the decrease in effort asked of the homeowner.

Also, as part of mailings, utilities should regularly update homeowners about progress in the LSL inventory and replacement process. The replacement process is time intensive and can take years to complete depending on the size of the municipality. By establishing and maintaining a transparent relationship, customers, including those with known non-LSLs or already replaced LSLs, will be more informed and have greater trust in the municipality. This can increase response rates and improve the involvement of those with service lines of unknown material or known LSLs that have not yet been replaced. Additionally, ensuring residents that progress is being made in the replacement process can ease fears in alarmed residents.

4.2.2.2 Phone Calls, Text Messages, and Emails

If a municipality determines that mailings have not warranted sufficient response rates, residents who have not reported their service line material should be contacted by phone call, text message, or email. During a phone call, customers with service lines of lead or unknown materials should be informed of or pointed to information previously mentioned in mailings. This direct communication can allow for relaying information such as health effects associated with lead exposure and describe how lead can enter drinking water (AWWA, 2022). This direct communication can also make financial incentives feel more impactful for customers. Another benefit of conversing over the phone is that it is easier for customers to ask any questions they may have. Information about the purpose of the inventory, self-identification if the customer has a service line of unknown material, minimizing exposure to lead, and the replacement process for those with known LSLs can be relayed in an efficient and personal way through phone calls. Through the direct, personal communication that phone calls offer, a community member's trust in the municipality can also be improved. For these reasons, phone calls can increase the likelihood of an owner self-identifying their service line or scheduling a free site inspection or replacement.

If customers do not answer calls, using text messages and emails offers more flexibility. If physical mail is ignored, online versions can be provided for easy access, highlighting essential information like financial incentives or inventory details. These methods create an open channel for communication, addressing questions and concerns. While updated contact information may be lacking, maximizing these cost-effective communication methods is crucial. Messages and mailings should be sent multiple times, especially if seeking customer action (AWWA, 2022), before resorting to more expensive door-to-door visits, which yield the best results.

4.2.2.3 Door-to-Door

If a service line owner is unable to be reached through phone calls and is unresponsive to text messages and emails, door-to-door outreach may be necessary to finish the identification process. Representatives from the municipality or contracted by the municipality will go to the door of each unresponsive resident, either with service lines of lead or unknown materials, with appropriate resources.

When visiting residents with known LSLs, representatives should bring the previously sent mailings in case they were discarded or not received, and a work authorization form for a replacement. The health effects of lead, the replacement process, how lead can enter drinking water (AWWA, 2022), and any financial incentives should be discussed with the customer. The importance of a replacement to protect the health of the residents and their family members should also be stressed to improve the chances of obtaining approvals. It should be emphasized that owners can sign for a replacement right from their door. If no one answers the door, representatives should leave the mailings and a sticker or business card to notify the resident they missed them (see Figures 11 & 12). This sticker or business card should also provide them with a number to call and a QR code to the previously discussed website for more information. Additionally, annual phone calls should be made to recommend a replacement.

For visits with those who have service lines of unknown materials, representatives should also bring the previously sent mailings and a work authorization form for a service line inspection. This inspection could be scheduled for a future date or completed at the visit. Representatives should discuss the purpose of the inventory and inform residents that their service line's material is unknown, rather than saying it could be lead. As with visits to residents with known LSLs, if no one answers the door, materials should be left indicating that an attempt to meet in person was made. Service lines that remain unknown in the inventory will require yearly reminders that the service line material has yet to be identified and could potentially be lead as per the Lead and Copper Rule (AWWA, 2022).

Through this method, face-to-face conversations with customers can form a deeper connection, personalize the municipality, and better emphasize the importance of replacing an LSL. Also, like with phone calls, this method provides the opportunity for customers to ask questions and provide feedback. For these reasons, it is highly effective in increasing the number of replaced LSLs. However, this method is quite costly and time consuming, so it is important to utilize phone calls, text messages, and emails as much as possible prior to going door-to-door.

4.3 Service Line Replacement

An LSL replacement program requires a substantial monetary and time commitment. Funding sources for LSL replacement programs have been made available through federal and state grants and funds. These funds can aid utilities in procuring materials, paying construction crews, or helping customers finance service line replacements. Scheduling LSL replacements efficiently can help utilities cut costs and save time when completing them. To make the replacement process more effective, service lines can be replaced in clusters and coupled with current projects. Depending on the number of service lines that a utility must replace each year, consideration should be given to the number of construction crews that must be hired and the amount of funding that will be required to complete the program. Lead service line replacement programs that have been undertaken by utilities in the United States are also discussed in this section to provide insight into the replacement process.

4.3.1 Financing Lead Service Line Replacements

The costs associated with a complete LSL replacement are estimated to be between $7,600 and $37,800, with an average cost of $12,500 (Kutzing, 2023). This cost of an LSL replacement includes construction and restoration, engineering, administration, customer outreach, permitting, and post-replacement costs. The largest portion of the cost of an LSL replacement is typically construction costs. The average construction costs for a full LSL replacement are $9,900. The average total cost for restoration, engineering, administration, customer outreach, permitting, and post-replacement is $2,600 for full LSL replacements. For replacements involving the customer side only, the average construction costs are $4,990, while utility side replacements cost an average of $7,150 (Kutzing, 2023). Utility side replacement costs may be greater due to additional restoration measures that may be necessary, such as pavement restoration (Kutzing, 2023). The additional costs associated with restoration, engineering, administration, customer outreach, permitting, and post-replacement monitoring must also be included for cases where the utility or customer side of the service line is being replaced.

Furthermore, there are an estimated 6 to 10 million LSLs remaining in the United States as of 2016 (Cornwell *et al.,* 2016). It is estimated that it will cost between $20 billion and $80 billion to replace all LSLs based on a range of unit costs (Bukhari *et al.*, 2020). In many cases, these costs will be shared between homeowners and municipalities due to the joint ownership of service lines. This can pose a large financial burden for homeowners when an LSL replacement is necessary.

Homeowners may choose to pay out-of-pocket for their service line replacement, however, this can be an unexpected cost for homeowners which may require financing the replacement through loans. In some cases, municipalities may offer a loan program in which the municipality covers the initial cost of the replacement, and the homeowner pays the municipality over a specified period. Some municipalities may even fund the full cost of the LSL replacement which allows for a more streamlined process for the utility as the need for homeowner interaction during the process is limited (MassDEP, 2023a).

Funding is available to municipalities through federal and state grants and funds. One source of funding is the Bipartisan Infrastructure Law (BIL) which has allocated $15 billion to the Drinking Water State Revolving Fund (DWSRF) (US EPA, 2023b). The DWSRF was established by the amendments made to the SDWA and allows Congress to allocate funds for the states which may be used for drinking water infrastructure projects (US EPA, 2015d). The EPA uses the Drinking Water Needs Survey and Assessment to divide the funds between states (US EPA, 2015d). States can use the funds from the DWSRF to pay off debt, take out loans for projects, and make short term investments to earn interest. Typically funds from the DWSRF require a 20% match from the state; however, due to the BIL, no match is required for LSL replacement programs (US EPA, 2023b). The BIL also delivers 49% of the DWSRF funds as grants or principal loan forgiveness for LSL replacements. Municipalities must apply through their respective state to receive money from the DWSRF. For LSL replacement projects, these funds may be used for utility and customer side replacements, public education, planning, and more (US EPA, 2023b).

Municipalities may receive funding for LSL replacements through programs created by the Water Infrastructure Improvements for the Nation (WIIN) Act. One example is the Small, Underserved, and Disadvantaged Communities Grant Program created by the EPA, through the WIIN Act. This program helps communities with fewer than 10,000 individuals obtain funding for projects to comply with the SDWA if the community is classified as disadvantaged by the state in which it is located and does not have the ability to generate debt to finance its projects (US EPA, 2023b). Funding for this grant program is awarded on a non-competitive basis. The Reducing Lead in Drinking Water Grant created through the WIIN Act is an opportunity for water systems to receive funding for LSL replacement projects. This grant program was created with the goal of reducing elevated lead levels in disadvantaged communities and school and childcare facilities. The criteria for the Reducing Lead in Drinking Water Grant are that applicants must be applying on behalf of a community water system, non-transient non-community water system, non-profit organization that works for a public water system, or a municipality (US EPA, 2021b). These applications are then reviewed by the EPA and funding is approved through a competitive process. Other sources of funding include the Water Infrastructure Finance and Innovation Act and HUD Community Development Block Grant which may be used to help municipalities finance or pay for LSL replacements (US EPA, 2023b). The Water Infrastructure and Finance act may be used for DWSRF projects by governments, partnerships, and joint ventures. Funding for this program is distributed based on a competitive basis (US EPA, 2020b). Communities utilizing the HUD Community Development Block Grant must have development needs and applications are accepted based on a competitive process (US Department of Housing and Urban Development, 2024). Funding for this program has been allocated at $5 billion (Housing and Urban Development Department, 2024). A summary of the funding sources mentioned in this section can be found in Table 2.

Table 2. Summary of funding sources for lead service line replacement programs

Program	Eligibility	Competitive vs. Non-competitive	Available Funds
DWSRF – Lead Service Line Replacement Projects	Communities undergoing LSL replacement projects	Competitive	$15 Billion
Small, Underserved, and Disadvantaged Communities Grant Program	Community must be classified as disadvantaged or have a population of less than 10,000 people	Non-competitive	$50 Million
Reducing Lead in Drinking Water Grant Program	Must be a disadvantaged community or school	Competitive	$20 Million
Water Infrastructure Finance and Innovation Act	Eligible to governments, partnerships and joint ventures, corporations, and DWSRF projects	Competitive	$7.5 Billion
HUD Community Development Block Grant	Communities with development needs	Competitive	$5 Billion

4.3.2 Scheduling of Lead Service Line Replacements

Proper scheduling is a crucial step for the replacement of LSLs because doing so can save a municipality time, money, and resources. Factors such as climate, the number of service lines to be replaced, and the location of LSLs within the water distribution system must be considered when creating a replacement schedule.

Climate is important to consider, especially in the northeast where there are vastly different seasons. Frost can make excavation difficult and time consuming due to the additional resources required to break frozen ground (Mikula, 2021). Replacing an LSL removes a building's access to water, which can be problematic in the summer months when heat-related injuries are at their peak (Echt *et al.*, 2020). During hot weather customers need access to bottled water for drinking and cooking while service lines are being replaced.

The proximity of an LSL to other LSLs should be given thought before scheduling service line replacements. By looking at the number of LSLs that need to be replaced in each municipality and identifying which LSLs are near each other, a plan can be made to replace service lines in clusters. This can minimize the movement of resources, making the total replacement effort more time and cost efficient. Lead service line replacements can be made more cost effective by coupling them with other projects that also require excavation. This was implemented in Lansing, Michigan, where LSLs were replaced with combined sewer overflow separation projects (Bukhari *et al.*, 2020). By doing this, Lansing was able to coordinate excavation efforts to cut costs. Similarly, in Gary, Indiana, LSL replacements were performed in conjunction with various other piping projects, allowing the city to coordinate crews that could perform both projects at each site (Bukhari *et al.*, 2020).

Another scheduling consideration a municipality should make is coordinating paving projects around LSL replacements. On the utility side of a service line, roadways and sidewalks may have to be excavated to reach the water main and service line. Scheduling street paving should avoid paving streets that need LSL replacements in the future. On the customer side, service lines may cross walkways or driveways, requiring these areas to be excavated. When multiple driveways in a small area need to be repaired after a service line replacement, many paving companies offer better rates for having multiple jobs in one area, which will alleviate some of the service line owner's financial burden. This makes the clustering of service line replacements even more important.

4.3.3 Lead Service Line Replacement Process

The process of replacing LSLs is a multi-aspect and time-consuming endeavor that requires in-depth planning and proper execution. The timeline for LSL replacement changes depending on factors such as the project's scale, existing infrastructure, and local ordinance and labor laws. During an LSL replacement program completed in Lansing, Michigan, crews completed between 2 and 4 LSL replacements per day (US EPA, 2019c). The replacement involves assessment, planning, permitting, excavation, and installation of new pipes. After a lead pipe has been located and identified, the planning phase, which involves coordination with various owners and ordinances, can begin. Acquiring permits and regulatory approvals can also increase the overall duration. Excavation and replacement of the LSLs themselves usually only demands one day of labor according to a moderately sized general contractor located in the northeast.

For initial assessments and planning phases, a smaller team of engineers and surveyors may be sufficient. However, as the project advances to excavation and replacement, a larger crew comprising skilled laborers, plumbers, and heavy equipment operators becomes essential for expeditious progress. Depending on the number of LSLs that need to be replaced in a municipality, multiple crews may need to be recruited to meet the LSL replacement deadline. For example, Denver Water required 7 to 13 crews to replace 2 to 4 LSLs per day to meet the annual

7% LSL replacement requirement. This was due to the estimated 75,000 LSLs under Denver Water's jurisdiction (Denver Water, 2019). Equally important to crew size is the selection and deployment of appropriate equipment. Excavators, trenching machines, and specialized pipe installation tools are integral for streamlining the replacement process. Contractors should be contacted to determine if they have adequate labor and equipment to complete LSL replacements. Qualified contractors should be compared and chosen based on the lowest bid price and sufficient responsiveness (Denver Water, 2019).

The water utility in Madison, Wisconsin began an LSL replacement plan in 2000 and finished 12 years later. Crews from Madison Water Utility completed the replacement for the utility owned portion of the service line, while private plumbers replaced the LSLs on the customer side (City of Madison, 2016). More crews will be needed if a utility hires crews to replace both the customer and utility owned portions of LSLs. Madison Water Utility also required customers to fund the replacement of the customer owned portion of the service line replacement. After the replacement, customers would be eligible for a $1,000 reimbursement (City of Madison, 2016).

For an LSL replacement program in Detroit, Michigan, the replacement goal for 2023 was 5,000 LSLs. Detroit was also looking to hire 17 field service technicians to create 3 in house crews which would contribute to the replacement goal and support the work of contractors. Detroit also planned to replace all LSLs free of cost to customers due to a $100 million budget with funding from the American Rescue Plan Act, Michigan DWSRF, EPA WIIN grant, and the Detroit Water and Sewerage Department Capital Improvement Program. This budget will be used to replace the estimated 80,000 LSLs in Detroit by 2038 (Detroit Water and Sewerage Department, 2023).

Due to the number of LSLs being replaced, the amount of funding available to the municipality, and the parties responsible for funding replacements, LSL replacement plans are highly individualized. For example, the number of service lines that need to be replaced per year impacts the number of construction crews that will need to be hired to meet the replacement goal. The amount of funding available for a municipality may be used to determine if customers are required to fund the customer owned portion of the service line replacement or if other strategies such as increasing water rates should be used to fund the project. The individualistic nature of an LSL replacement plan makes it difficult to create a plan which can be directly applied to each municipality; however, a replacement plan can be scaled to fit the needs of municipalities of varying sizes.

Once LSLs are removed, it is crucial to handle the disposed materials responsibly. Considering the potential environmental impact of lead and scrap metals, recycling becomes a pivotal aspect of the process (OSHA, 2008). Specialized facilities can process and recycle lead pipes, diverting them from landfills and minimizing environmental harm. Collaborating with recycling centers and adhering to established recycling practices ensures that the materials are repurposed responsibly. Recycled lead from service lines can be used in lead-acid batteries, lead shielding for x-rays, and other applications (Wisconsin Department of Natural Resources, 2024). This commitment to eco-friendly practices not only aligns with sustainability goals but also contributes to the overall success of LSL replacement projects by mitigating environmental risks and promoting responsible resource management.

The restoration of soil and surfaces like asphalt and cement is a crucial phase in completing LSL replacement projects. Skilled crews engage in backfilling techniques, incorporating nutrient-rich soil to promote vegetation growth and prevent erosion (Risse, 2023). This includes proper compaction of the soil subbase and asphalt or cement application. The goal is not only to restore the surface aesthetically but also to guarantee its longevity and functionality.

4.4 Lead Service Line Inventory Case Study

The LCRR requires that all municipalities submit an initial LSL inventory by October 16, 2024. The service line inventory must include information identifying the material of all service lines in the municipality's jurisdiction (EPA Office of Groundwater and Drinking Water, 2023). In municipalities where the municipality owns one portion of the service line and the customer owns the other portion of the service line, the inventory must include the service line material for both portions. The service lines must be classified as lead, non-lead, GRR, or unknown based on the identified service line materials (EPA Office of Groundwater and Drinking Water, 2023).

To understand the extent of a service line inventory, a case study of a medium-sized system in New England was analyzed. The utility requested anonymity, therefore identifying information is not presented. The inventory was initially created by an international engineering and construction firm and then updated by the authors of this report. The inventory included data from service card records, individual home assessments, and other means. Geographic information system (GIS) data was then created by the authors from this inventory to visually analyze the data. This was done not only to inventory the service lines in the case study system, but to create recommendations for the most efficient identification of unknown service lines and replacement of lead and GRR service lines.

4.4.1 Inventory Template

The EPA has established an LSL inventory template which municipalities can utilize, however, the requirements for service line inventories may vary by state. The inventory template provided by the EPA includes sections for a location identifier, which may be a street name and location address or other information which may be used to determine the location of the service line. The template also includes sections for both the utility owned and customer owned portions of the service line which may include information such as the service line installation date, size, material classification (lead, non-lead, GRR, and unknown), how the service line material was determined and verified, and additional notes (Smith, 2023). A section for the classification of the entire service line material is also included to aid in determining if service lines are lead, non-lead, GRR, or unknown.

A pipe is classified as non-lead if the service line is confirmed to not be lead or GRR, which is a galvanized service line that is, or was, downstream of an LSL, or is downstream of a pipe of unknown material (EPA, 2022g). A pipe is classified as unknown if the material is not known to be either lead, non-lead, or GRR (EPA, 2022h). Additionally, a pipe is classified as lead if any portion of it is made of lead (EPA, 2022f). A section for other possible sources of lead is also included for instances where a gooseneck, lead solder, or lead-containing fittings were used to construct the service line. Additionally, testing and LSL replacement status are also included in the template provided by the EPA (Smith, 2023).

In addition to meeting the federal requirements for the initial inventory deadline, municipalities must ensure that their inventory complies with the applicable state requirements (MassDEP, 2023b). State regulations are required to be at least as stringent as federal regulations, so municipalities should verify their state's regulations (MassDEP, 2023b).

A review of the service line inventory of a medium-sized system in New England was completed. The inventory for this community contained information for location identifiers for each service line through street addresses, customer account numbers, parcel numbers, and building type. Although not required for inventories, in-depth information about service line connectors and goosenecks was also detailed, including the current and previous connector material, date of installation, and additional comments. The inventory also divided the service line materials based on ownership. The portion of the service line from the water main to the curb stop was noted as the utility owned portion of the service line, while the portion from the curb stop to the water meter is the privately owned portion, which will be referred to as the customer owned portion. This section of the inventory included service line information such as the material used in the service line and the overall classification of the service line, as well as the size, installation and verification dates, previous service line materials, verification source, and additional comments for both the utility and customer owned portions of the service lines. The presence of lead solder was noted, and the service line identification was classified as complete or missing information. The last section of the inventory summarizes the metrics which must be reported to the EPA, such as the utility and customer side service line materials, material verification sources, and the lead status for each service line.

4.4.2 Inventory Case Study

As previously mentioned, the inventory of a medium-sized system (3,301 to 10,000 residents) was reviewed to create an LSL inventory and replacement program which can be applied to communities of varying sizes. This water system, with a population of approximately 7,000 residents and 2,600 service lines, requested to remain anonymous in this review. All numbers in the following case study analysis sections have been rounded for anonymity and may not add up to 100%.

This system has a design capacity of approximately 3.5 million gallons of water per day (MGD). Approximately 1.2 MGD of the water supply comes from surface water sources and wells. Information about the municipality's water treatment process was obtained from an annual water quality report. The surface water is sourced from a lake and is treated at the municipality's water treatment plant. This water is first pre-disinfected with chlorine and chlorine dioxide. Then, the water enters a mixing tank, and a coagulant is added which neutralizes particles and aids in settling. The water is then filtered, and then chlorine, potassium hydroxide, and an orthophosphate are added to kill bacteria, adjust the pH, and protect pipes, respectively. Finally, the water is pumped to storage tanks where it then gets distributed to customers. The well water is sourced from a well field which includes multiple production wells. This water is treated by first mixing the water in a treatment building. The water is then transferred to a newer treatment building, where potassium hydroxide and dissolved oxygen are injected into it. The water then passes through filters and enters a storage tank. Then the treated water is pumped to the water distribution system where sodium hypochlorite and phosphate are added for disinfection and corrosion control, respectively.

4.4.3 Inventory Data Collection

To identify LSLs, municipalities must employ techniques approved by the EPA or the state. Presently, the only techniques endorsed for use by the EPA are record review, which is required (*40 CFR Part 141 Subpart I -- Control of Lead and* Copper, 2023), excavation, and visual inspection (US EPA, 2022b). Other methods, such as predictive modeling, water quality sampling, and emerging methods, will necessitate state approval for implementation (US EPA, 2022b).

For this case study, the methods utilized by the municipality to identify service line materials were inspection, reviewing record drawings and service cards, and leveraging staff knowledge and year-built data.

For the utility owned portions of the service lines, the material of about 2,560 (98.4%) were identified through various techniques, shown in Table 3. The most used technique was the review of service cards, which was utilized to identify 2,270 service lines (87.3%). Record review is a valuable resource for municipalities if accurate records have been maintained. This is a time-effective and inexpensive method and may be one of the first methods utilized for identifying service line materials. Project specific knowledge from utility staff and record drawings were used to identify 10.8% and 0.38% of the service lines, respectively. Through participation in current or past projects, utility staff may be able to identify the service line material used during a project. This is also a time-efficient and inexpensive method which was effective for identifying service line materials for this municipality. There are 2 remaining unknown utility owned segments in this water system.

Table 3. Case study methods of identification of utility and customer owned service line segments

Method of Identification	Utility Owned		Customer Owned	
	Number of Uses	Percentage of Service Lines	Number of Uses	Percentage of Service Lines
Service cards	2,270	87.3%	N/A	N/A
Staff knowledge	280	10.8%	N/A	N/A
Record drawings	10	0.38%	240	9.2%
Inspections	N/A	N/A	410	15.8%
Year built	N/A	N/A	200	7.7%
Total	2,560	98.4%	850	32.7%

For the customer owned portion of service lines, information was gathered by inspections, records, or using the date of construction of the residence. A total of 850 out of the approximately 2,600 customer owned portions (32.7%) of service lines were identified, as shown in Table 3. This means that about 1,750 portions (67.3%) were considered unknown. Other methods of service line material identification should be used to complete this portion of the inventory. Of the customer owned segments with identified materials, the primary method of identification was inspection, which was used to identify 410 segments (15.8%). Inspections include door-to-door visits performed by the utility staff and customer-identification of service line materials. Record review was used to classify the materials for 9.2% of customer owned service lines. Record review includes the examination of service cards, record drawings, and other resources. Lastly, the year the service line was constructed was used to classify 7.7% of customer owned service lines. Due to the nationwide lead ban in 1986, which fully went into effect part way through 1988, any locations with service lines that were constructed during or after 1989 were classified as non-lead (ASDWA, 2023). For municipalities with many new developments, this method for classifying service line materials could be critical during the inventory process.

The major difference between the identification of utility and customer owned portions of service lines was that, as previously mentioned, the materials of 67.3% of customer owned portions were unknown, compared to just 1.6% of utility owned portions. One reason for this difference may be due to the record-keeping procedures for the different portions of service lines. Record review was utilized to identify materials for almost 90% of utility owned portions of service lines. For utility side service lines, however, records could only be used to determine the material of less than 10% of service lines, and additional material identification methods had to be utilized.

4.4.4 Service Line Material Distribution

The materials used for the utility and customer owned portions of service lines for this case study are shown in Table 4. For the utility owned portions, the most used material was copper, which was used in approximately 1990 out of the 2600 service lines (76.5%), followed by galvanized (15.4%). Ductile iron (1.92%) and brass (0.385%), while far less common than copper and galvanized, could contain up to 8% lead if installed before 2014 (Kelechava, 2020). Prior to the Reduction of Lead in Drinking Water Act, effective in January 2014, pipes for public use could only have up to 8% lead, but the enactment of this regulation changed this limit to a weighted average of 0.25% lead (Kelechava, 2020). Additionally, the materials of approximately 5 (0.192%) utility owned segments were unknown.

On the customer side, the material of approximately 65.4% of the segments are unknown. The most used known material was copper, with 350 (13.5%) total private side segments, followed by "non-lead" (7.69%) and galvanized (5.38%). "Non-lead" segments include service line segments that were installed after 1989, because of the nationwide ban of lead in 1986 (ASDWA, 2023). Ductile iron was found in approximately 40 (1.54%) customer owned segments, which, as mentioned earlier, may contain up to 8% of lead if install prior to 2014 (Kelechava, 2020).

Table 4. Case study materials used for utility and customer owned service line segments

Material	Utility Owned		Customer Owned	
	Number of Uses	Percentage of Service Lines	Number of Uses	Percentage of Service Lines
Copper	1,990	76.5%	350	13.5%
Galvanized	400	15.4%	140	5.38%
Ductile Iron	50	1.92%	40	1.54%
Wrought Iron	40	1.54%	40	1.54%
Cast Iron (Unknown Lining Status)	30	1.15%	30	1.15%
Plastic	30	1.15%	40	1.54%
Enameled	10	0.385%	N/A	N/A
Lined Cast Iron	10	0.385%	5	0.192%
Brass	10	0.385%	N/A	N/A
Lead	5	0.192%	5	0.192%
Unknown	5	0.192%	1,700	65.4%
Unlined Cast Iron	5	0.192%	N/A	N/A
Non-Lead (installed after 1989)	N/A	N/A	200	7.69%
Total	2,600	100%	2,600	100%

Only approximately 5 out of the 2,600 (0.192%) service line segments were confirmed to be lead. Only 1 (0.038%) utility owned segment was confirmed as lead. The customer owned segment of this service line was found to be galvanized, and the gooseneck upstream of it was found to be lead, meaning the galvanized section may require replacement.

4.4.5 Overall Service Line Classification

When analyzing the system's inventory, it was observed that some of the service line classifications were either not filled out or did not appear to follow the EPA's definitions. Therefore, every service line was reviewed and classified as either lead, non-lead, GRR, or unknown using the EPA's definitions discussed in section 4.3.1. As part of our analysis, service lines with portions made of cast-iron with unknown lining status were considered unknown. All galvanized pipes were also classified as unknown due to uncertainties about whether they are lead-lined or not. A similar approach was taken in Trenton, New Jersey, where all galvanized lines were treated as lead due to the difficulty of identifying whether a galvanized line is lead-lined (Epstein, 2023).

After classifying the service lines, it was found that a significant portion of this utility's service lines were unknown, and very few were confirmed as lead. As shown in Table 5, service lines of unknown material made up about 1,950 (75.0%) out of the system's approximate 2,600 service lines. Meanwhile, about 620 (23.8%) service lines were non-lead, and only about 5 (0.192%) were lead. Although there are very few confirmed LSLs, the significant amount of service lines with an unknown status indicates a potential for others to be found. It should be noted that although 75.0% of this utility's service lines are currently classified as unknown, this is almost entirely due to unknowns on the customer owned side. Through the previously discussed methods for service line material identification on only customer owned segments, many of these unknowns can be changed to lead, non-lead, or GRR depending on the utility's view of this classification.

Table 5. Service line classifications

Service line classification	Number of service lines	Percentage of service lines
Unknown	1950	75.0%
Non-lead	620	23.8%
Lead	5	0.192%

Note that the number of service lines for each classification will not necessarily be the sum of the utility and customer owned portions shown in Table 4 as the materials can be double counted. For example, a service line with a galvanized utility owned portion and an unknown customer portion would only be classified as 1 unknown service line.

4.4.6 GIS Mapping Analysis

Using GIS to analyze data spatially can be an effective tool in visualizing an LSL inventory. Maps in the appendix of this report were created using the data from our case study's service line inventory. Borders have been removed from the maps for anonymity. Each of the ten maps have the same scale, reference point, and orientation.

A major concern with the case study's inventory, as highlighted by Figures 21 and 22, is the number of service lines of an unknown material. Figure 25 shows service lines where either the customer or utility side of a service line is of unknown material, while Figure 26 shows service lines where both sides of the service line are of unknown material. Having such a substantial portion of service line materials listed as unknown significantly limits the effectiveness of predicting the material of unknowns with spatial analyses. In the case study, even the year of construction for many residences was unknown (see Figure 16). Knowing that LSLs could not be installed during or after 1989, Figure 15 shows the residences broken down by year of construction, grouping residences with no data with residences built before 1989. Each green dot in Figure 15 indicates a service line that cannot be lead. Verifying the year of construction for the residences missing data in Figure 16 may allow the municipality to confirm a non-lead status for additional residences.

Figure 14 shows about five separate locations where an LSL or a lead gooseneck affixed to a galvanized service line is present. Due to the number of unknowns under the purview of the municipality in our case study, the number of LSLs may be higher than those currently known. While the municipality works to identify more service line materials and address current unknowns, the service lines in Figure 14 should be replaced as soon as possible.

Figures 17 and 18 show the locations of galvanized service lines. As addressed previously, galvanized service lines require replacement if they are downstream of any other LSLs or are affixed to a lead gooseneck or connector. As with the locations confirmed as lead, there are likely more galvanized service lines within the municipality than currently known due to the unknown material service lines. This case study also had most goosenecks and connectors listed with unknown material. Because lead goosenecks on galvanized pipes will require replacement, identifying gooseneck material is also important. Figure 27 shows where lead goosenecks have already been identified, while Figure 28 shows which goosenecks still require identification.

Points identified as non-lead or non-galvanized can be found in Figure 19 (utility side), Figure 20 (customer side), and Figure 24 (both sides). Figure 24 shows service lines that will not have to be replaced due to their potential for lead, and identifying more unknowns can increase the number of points on this map. Figure 23 shows service lines that are classified as non-lead on both sides of the service line, though this map allows for galvanized service lines which may need replacement if they have been exposed to lead.

4.5 Lead Service Line Replacement Plan

The proposed LCRI indicates that all community water systems and non-transient non-community water systems replace an annual 3-year rolling average of 10% of the LSLs identified in their initial inventory. Additionally, service lines designated as unknown in the initial inventory will be considered towards the 10% annual replacement goal. Furthermore, the LCRI requires water systems to submit an LSL replacement plan to the responsible primacy agency if an LSL or GRR service line is identified during initial inventory (Vermont Department of Environmental Conservation, 2024). To aid municipalities in planning for LSL replacement and achieving compliance with the proposed LCRI, a general LSL replacement plan was created. Recommendations for a specific LSL replacement plan were formulated for the utility that provided data to complete the case study found in this report. The information required in an LSL replacement plan includes a plan overview and summary, procedure for identifying existing LSLs, steps to identify remaining service lines, funding sources for the replacement project, replacement process, procedure for notifying customers, and a prioritization strategy for replacing LSLs (Vermont Department of Environmental Conservation, 2024).

4.5.1 Plan Overview and Summary

Each water system must prepare a plan overview and summary. This overview contains brief information about the major sections of the LSL replacement plan. An example of this overview is provided below. The water utility can tailor this plan overview by filling in the information enclosed in brackets and adding additional details as needed. Note that this example includes multiple methods of identification. The water system can delete those techniques that they do not use in their inventory development.

> This lead service line replacement plan is being submitted on behalf of [MUNICIPALITY] to [PRIMACY AGENCY] in compliance with the requirements of the Lead and Copper Rule Improvements. In an initial inventory, X service lines were identified requiring replacement, including X lead service lines, X galvanized requiring replacement service lines, and X unknowns. To achieve 10% replacement of the initial X service lines requiring replacement [ADD LEAD SERVICE LINES + GALVANIZED REQUIRING REPLACEMENT + UNKNOWNS], X lead service lines must be replaced each year.
>
> To identify existing lead service lines, [INSERT IDENTIFICATION TECHNIQUES] were used. Record review included the review of [INSERT RECORDS REVIEWED]. Service line inspections were completed by municipality staff in which staff entered the residence of customers and identified the service line material at the water meter. Customers were also given the opportunity to self-identify their service line material and submit photos of their service line at the following website [INSERT WEBSITE LINK]. The photos were reviewed by municipality staff to ensure the identified material was accurate. Water quality sampling was approved by [PRIMACY AGENCY] and was used to identify which service lines had a greater risk of being constructed out of lead. Predictive modeling was approved by [PRIMACY AGENCY] and was used after 20% of service lines had been identified. Predictive modeling ruled out service lines not classified as lead service lines. To identify the remaining service lines of unknown material, [INSERT IDENTIFICATION TECHNIQUES] will be used.
>
> Funding sources for the service line replacement program include the [FUNDING SOURCES]. The total funds allocated for this replacement program are X from grants, X from loans, X from [DEFINE OTHER SOURCES]. Completed replacements will comply with standards for the replacement and flushing of lead service lines. Customers will be notified of lead service line replacements through [INSERT COMMUNICATION METHODS]. Customers will be given lead-reducing filters that comply with NSF Standard 53 and information about procedures for flushing service lines after replacement.

4.5.2 Procedure for Identifying Existing Service Line Materials

A procedure for identifying existing service lines should incorporate techniques described in Section 4.1 of this report. Identification of service line materials must commence with a record review process, leveraging all available written and digital records. These records encompass water service records documented during service line installation, local plumbing codes, construction specifications, and any other applicable resources. This section of the LSL replacement plan should delineate the types of records employed to identify service line materials.

After the record review is finalized, the techniques utilized by the utility to identify service line materials and validate the materials identified through the record review should be enumerated and expounded upon.

The methods the utility may employ to verify and identify service line materials include visual inspection by either service line owners or representatives of the utility, as well as excavation. Other methods such as water quality sampling, CCTV, predictive modeling, and other emerging methods necessitate approval from the appropriate primacy agency before utilization for identification purposes. For guidance, a flow chart depicting the order of EPA approved identification techniques was created in Section 4.1.7 (see Figure 2). It is recommended that methods which require state approval be used before the excavation step in the flow chart if permission has been obtained from the primacy agency. Additionally, methods can be used simultaneously to identify the material of service lines at a faster rate.

This section should furnish comprehensive procedures for the methods employed in identifying service line materials.

4.5.3 Funding Sources for Service Line Replacements

The utility should provide the primacy agency with information about funding sources that the utility plans to use to procure materials, pay construction crews, and assist customers with financing the costs associated with service line replacement. Only full LSL or GRR service line replacements count toward the 10% annual replacement goal. Utilities are not required to fund the customer owned portion of the service line replacement; however, the utility should provide funding opportunities to customers to incentivize replacement. Strategies like raising water rates, offering reimbursement, or utilizing grant programs may help fund full service line replacements. Grant programs include the applicable DWSRF, WIIN Act, and WIFIA. Application status for grants should be included in this section of the LSL replacement plan.

4.5.4 Customer Notification of Lead Service Line Replacements

Customers must be notified when service line replacements take place and should be given information about the replacement process. When a service line replacement impacts a customer directly, the customer should be given advance notice about when the replacement will take place and how long the customer will be impacted by the replacement. Information about the flushing process after the replacement is completed should be provided to prevent lead exposure. Methods used to communicate with customers such as e-mails, mailings, and phone calls should be outlined in the service line replacement plan. Four communication attempts must be made using at least two different communication methods to try to obtain access for full service line replacements as required by the proposed LCRI. These methods should be outlined in the LSL replacement plan submitted to the primacy agency.

4.5.5 Lead Service Line Replacement Process

The replacement process for full service line replacements should be outlined in this section to meet the 10% annual replacement requirement. The number of service lines that must be replaced should be calculated by the total number of LSLs, GRR service lines, and lead status unknown service lines. These numbers should be determined based on the initial inventory submitted to the appropriate primacy agency on October 16, 2024.

Details about how access will be obtained to complete customer-side replacements, how labor and material costs will be calculated, and how LSL replacements will be prioritized should be included in this section. Information about obtaining access for full service line replacements should include the methods that will be used to communicate with customers about the importance of full LSL replacements. Based on the number of service lines identified for replacement, the approximate crew size and labor required should be determined. Prioritization of LSL replacements should be addressed to demonstrate that the scheduling of replacements will be based on the groups that are most vulnerable to lead exposure. Some factors that may cause a service line to have a higher priority include whether the service line serves a school or childcare facility or if the service line is near other services requiring replacement. Other factors and ranking criteria may also be used in a replacement prioritization strategy at the discretion of the utility and primacy agency.

4.5.6 Case Study Lead Service Line Replacement Plan Recommendations

Through the analysis of the case study, the following recommendations for the New England utility to create an LSL replacement plan have been made:

1. To identify the remaining service line materials, the utility should encourage customers to identify the material of their own service lines. The utility has 99.9% of service line materials identified on the utility side, however, only 32.8% of service line materials on the customer side have been identified. If customers do not self-report the material of their service line, inspections should be conducted by the utility staff due to this method's cost-effectiveness and accuracy. The remaining service lines on the utility side should be identified using excavation because this is the most accurate identification technique and will not be as time consuming once the number of service lines that need to be identified is reduced.
2. The utility should attempt to apply for funding through the DWSRF and WIFIA funding programs. Applications for these programs are competitive and a strong application prepared with the help of an engineering firm can help the community obtain funding. The community may consider covering the cost of the customer owned portion of the service line replacement to increase the likelihood that authorization is obtained for full service line replacements that count toward the utility's replacement goal. Alternatively, the utility may offer reimbursement of a percentage of the customer owned replacement costs if a customer agrees to grant authorization for a full replacement. This method may save the utility money; however, it may decrease customer participation in full service line replacements.
3. The utility should draft communications to customers with service lines of lead, GRR, or unknown materials. These communications should be tailored to the customer they are trying to reach. A customer with a lead or galvanized service line should receive a communication that details the importance of a service line replacement and cites the health risks associated with lead exposure. A customer with an unknown service line

material should receive a communication explaining the importance of the service line inventory process and ask customers to self-identify service line materials or grant authorization to utility staff to complete a visual inspection. Before door-to-door visits are conducted, mail, text message, email, and phone call communication attempts should be made multiple times. Additionally, the utility should draft communications requesting permission to replace the customer owned portion of service lines to streamline the replacement process.

4. The combined number of LSLs, GRR, and unknowns for the utility is approximately 1,950 service lines. Therefore, the annual 10% replacement goal would be to replace 195 service lines per year in the absence of any additional information on unknowns. To potentially lower this number, the utility should focus on identifying the material of unknown service lines. Based on LSL replacement programs that have been completed by other utilities, during 200 working days per year and an estimated 2 to 4 LSLs replaced per day per crew, this utility would require a single crew to reach the replacement goal. The utility should also create prioritization criteria for LSL replacements based on service lines that need to be replaced near each other or if the service line serves a vulnerable population. Based on GIS mapping analysis of the utility, service line replacements should be prioritized in the northwest region serviced by the utility due to the substantial number of unknowns, confirmed galvanized service lines, and the few confirmed LSLs.
5. Finally, the utility should create a replacement plan as well as a replacement plan summary and overview similar to the one seen in section 4.5.1. The replacement plan should include methods of service line material identification, the number of lead, GRR, and unknown service lines; the funding sources available; and how the replacement process will be communicated to customers.

Chapter 5. Conclusions and Recommendations

The results of this paper were analyzed to form conclusions about the effectiveness of various service line material identification techniques, public communication methods, financial options, and the replacement plan process. These results were used to draft recommendations for creating an LSL inventory and replacement plan.

5.1 Conclusions

Despite the health risks associated with lead exposure, millions of LSLs remain in use in the United States. To address this issue, the U.S. EPA has passed numerous regulations to limit the levels of lead in water. Most recently, the Proposed Lead and Copper Rule Improvements (LCRI) require all public water systems to sample for lead in drinking water at schools, create a public inventory of their LSLs, and create a service line replacement plan to replace all LSLs within 10 years. Therefore, the goal of this project was to draft a lead service line inventory and replacement plan that can be scaled to fit the needs of different sized communities.

Through the review of various sources, the following conclusions were drawn:

- <u>LSL Identification</u>: The most accurate and cost-effective means to identify LSLs are record review and visual inspection. Record review is 64% accurate due to high false positive lead results and is particularly useful for utility owned portions. Visual inspection is 75% accurate for customers and 90% for door-to-door inspections and is useful for customer owned portions. Excavation is 95% accurate but costly and time-consuming. If necessary, other methods such as water sampling or emerging methods can be used after obtaining state approval.
- <u>Communication</u>: Timely and transparent communications from a utility contribute to building trust. For LSL identification and replacement, this can be done by reaching out to customers through mailing flyers and pamphlets; sending phone calls, text messages, and emails; and visiting residents at their doorstep. These communications should use an appropriate tone depending on the message. Residents with unknown service line materials should be presented with the importance of obtaining information, while residents with LSLs should be provided short- and long-term solutions.
- <u>Financing Replacements:</u> The replacement of LSLs and GRR service lines can be costly for both customers (when applicable) and utilities, with an average full service line replacement cost of $12,500. Payment for the replacement of a service line may come from the customer, the utility, or a combination of the two. Customers seeking loans may receive loans from the utility or from an independent institution. Utilities can seek financial assistance through grants such as the Drinking Water State Revolving Fund (DWSRF) and the Small, Underserved, and Disadvantaged Communities Grant.
- <u>Replacement Plan:</u> When creating a replacement plan, utilities should use the appropriate equipment needed for replacement, properly remove old materials, and restore the site. Replacements can be prioritized based on factors such as the presence of LSL clusters (found through spatial analyses using GIS) and whether vulnerable populations are served (e.g., schools and childcare facilities). Additionally, replacements can be coordinated with other projects that require excavation and with paving projects to

increase convenience and save money. Other factors that may affect the replacement process, such as climate, crew size, and number of service lines requiring replacement will vary between utilities.

5.2 Recommendations

This project's scope was to review the process for creating an initial service line material inventory and replacement plan. As part of this review, a case study of a medium-sized utility was conducted. For a utility to create its own initial inventory and replacement plan, the following recommendations are made:

- Utilities should further research material identification techniques and consider which techniques would be most effective for their utility, noting that all methods apart from record review, excavation, and visual inspection require state approval.
- Utilities should verify the applicable state requirements for the initial inventory as they can be more stringent than the federal requirements.
- Smaller utilities should access resources directed at them based on size. For example, the LCRR created a compliance guide for small and very small entities, and the LCRI has invited small and very small entities to participate as representatives for the Small Business Advocacy Review (SBAR) Panel to ensure that small entities are engaged in solutions.
- Utilities should conduct an in-depth analysis of the various state and federal grants and funds available to widen their funding options.
- Factors such as climate and a utility’s crew size must be considered on a case-by-case basis to get a better estimate of the cost and duration of service line replacement.
- Further research on methods of LSL replacement, the removal of old materials, and site restoration should be conducted.

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Appendices

Figure 3. Front of Flyer for Confirmed Lead Service Lines

Figure 4. Back of Flyer for Utilities Offering Replacement

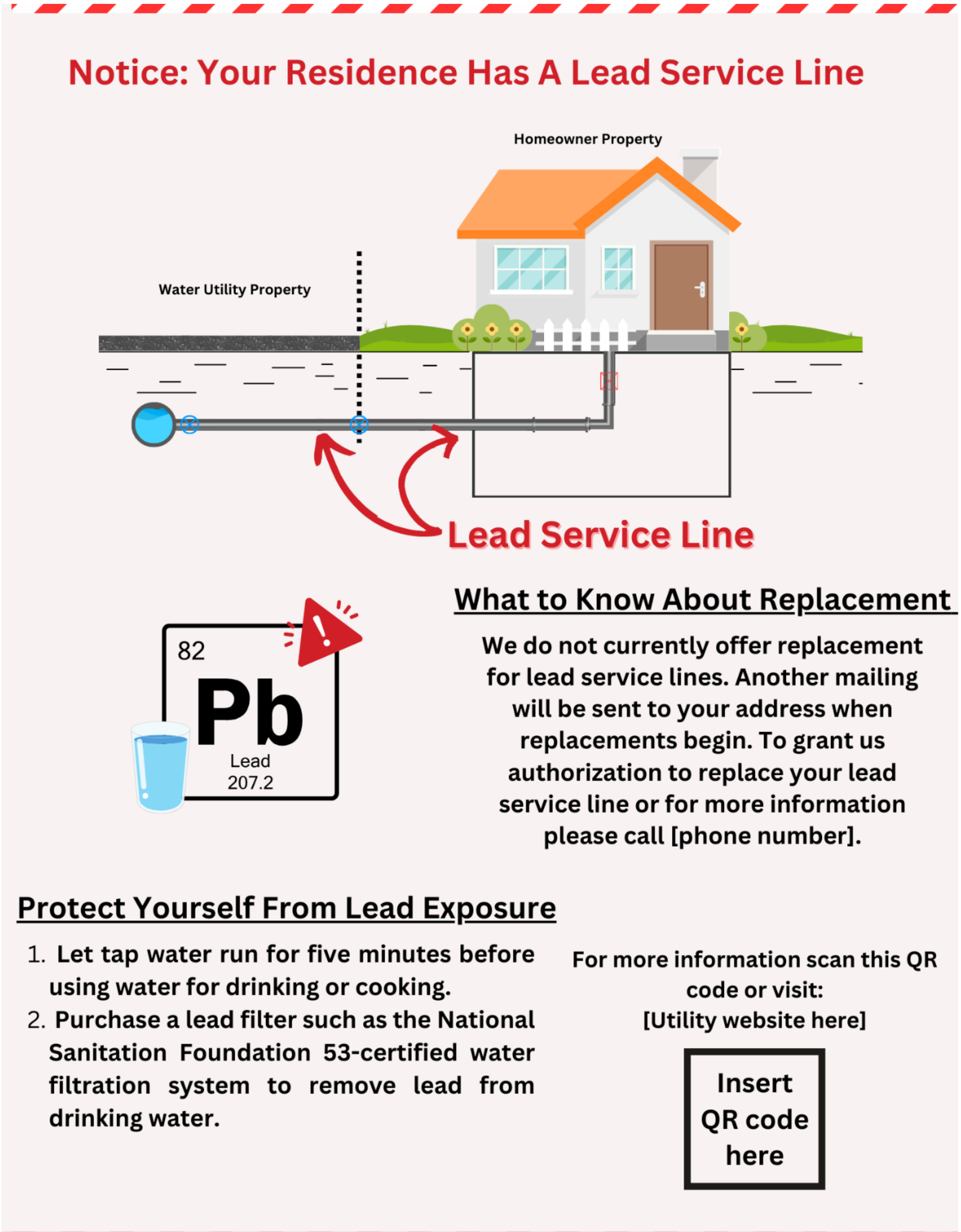

Figure 5. Back of Flyer for Utilities Not Currently Offering Replacement

Figure 6. Front of Postcard for Customers with Identified Lead Service Lines

Figure 7. Back of Postcard for Customers with Identified Lead Service Lines

Figure 8. Front of Postcard for Customers with Unknown Service Lines

Figure 9. Back of Postcard for Customers with Unknown Service Lines

Figure 10. Trifold for Customer Service Line Material Self-Identification

Figure 11. Front of Postcard for Door-to-door Visits

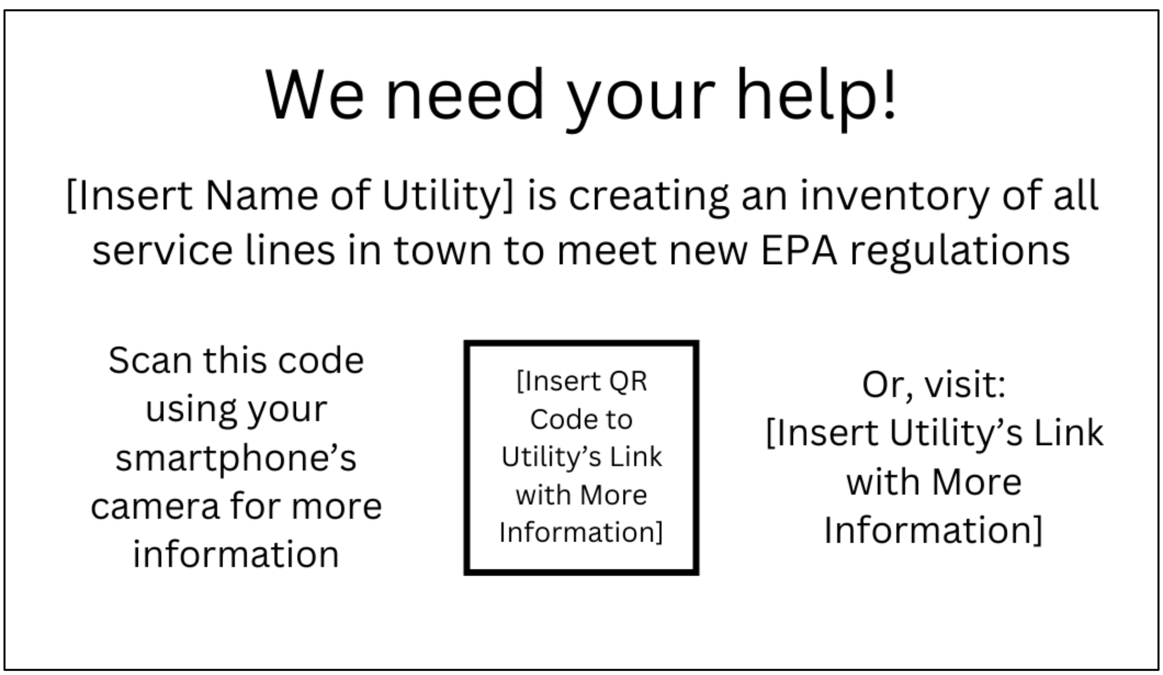

Figure 12. Back of Postcard for Door-to-Door Visits

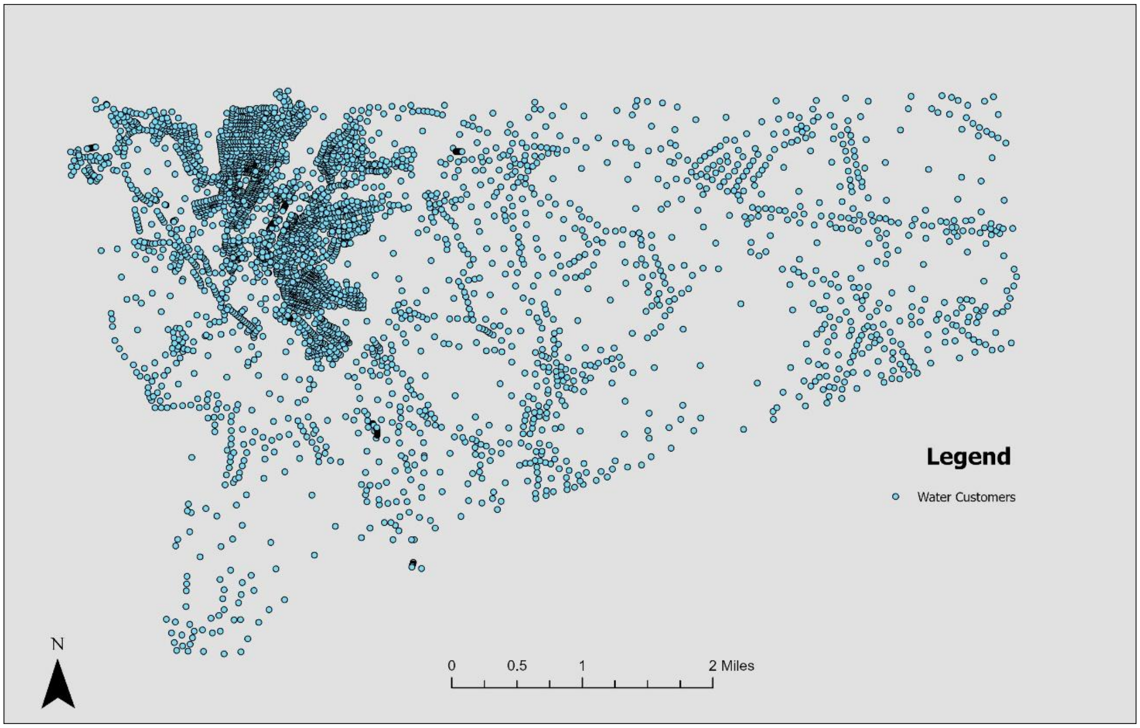

Figure 13. All water customers served by the studied utility

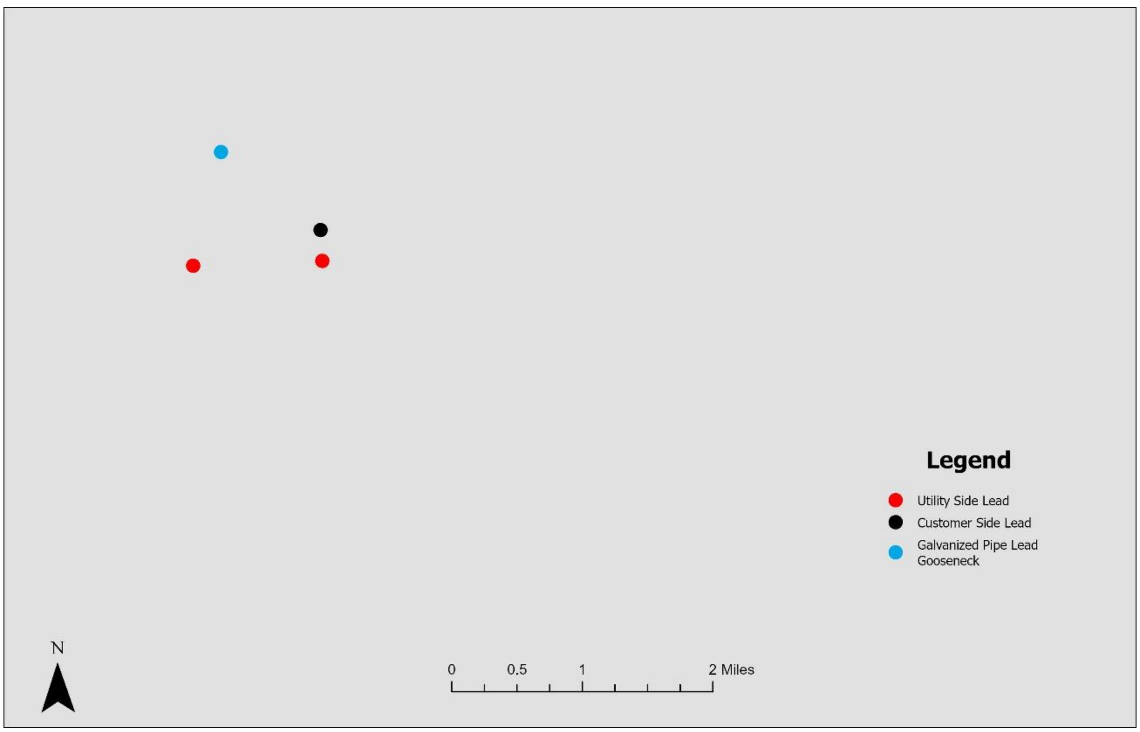

Figure 14. Locations where the use of lead service lines or connectors has been confirmed

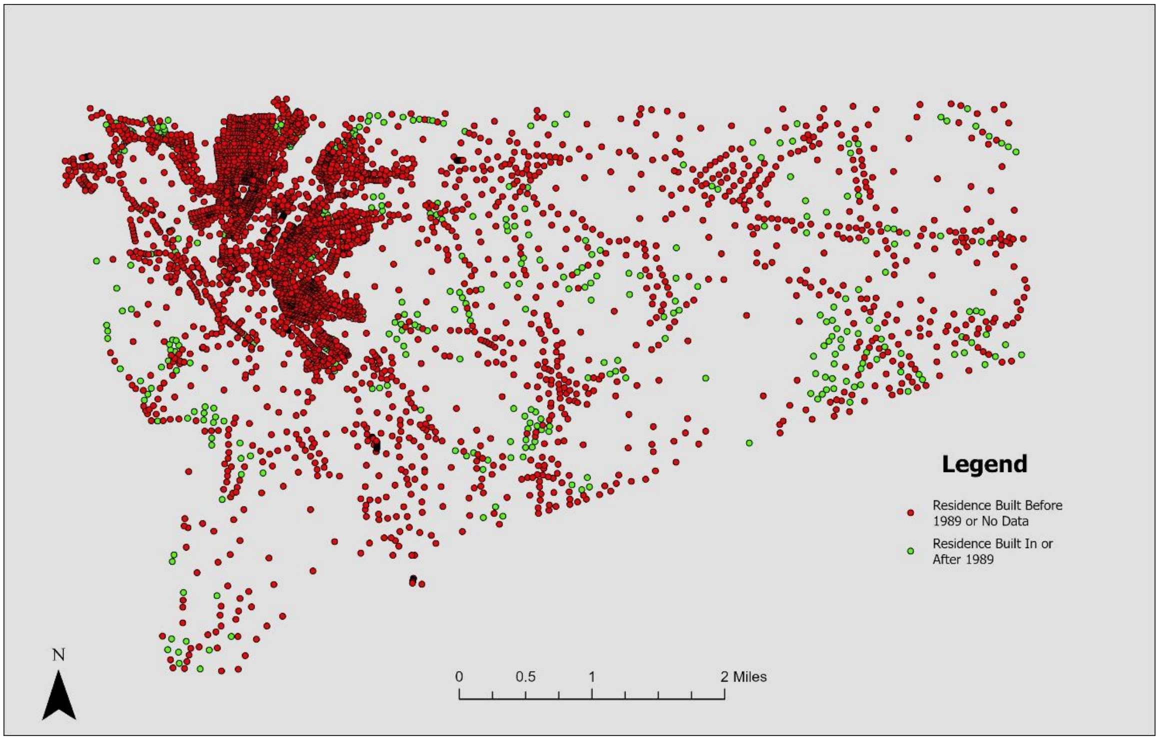

Figure 15. Residences by year of construction

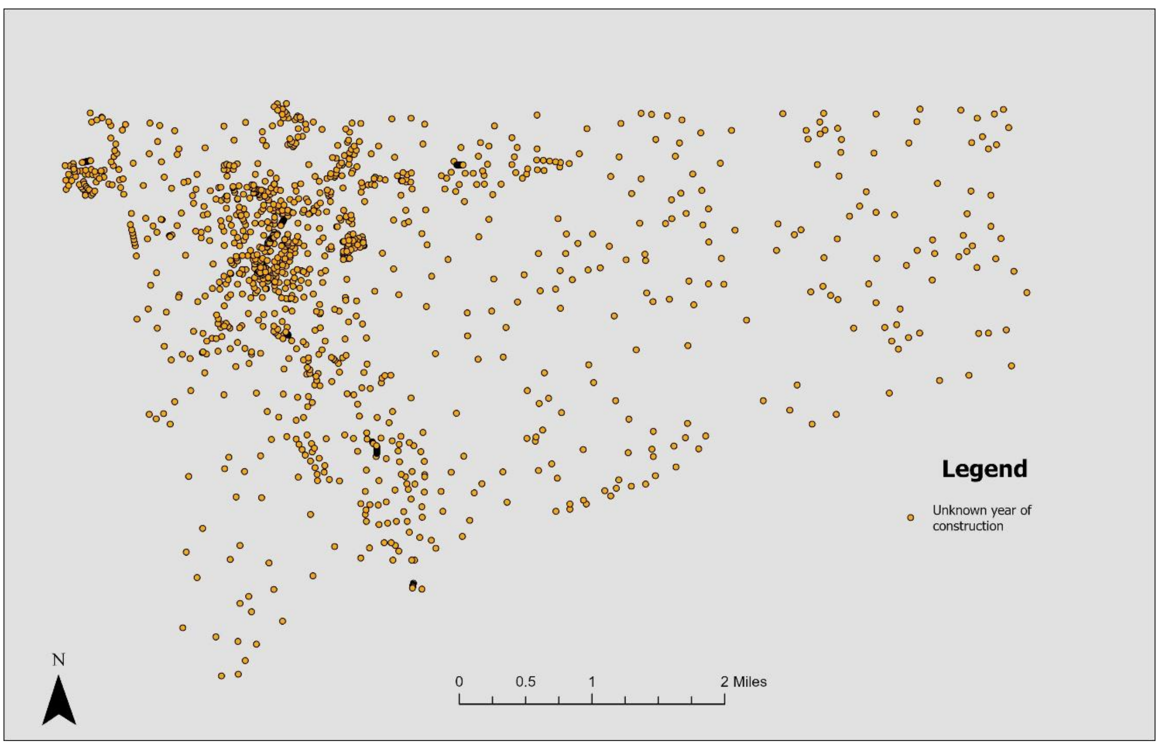

Figure 16. Residences with an unknown year of construction

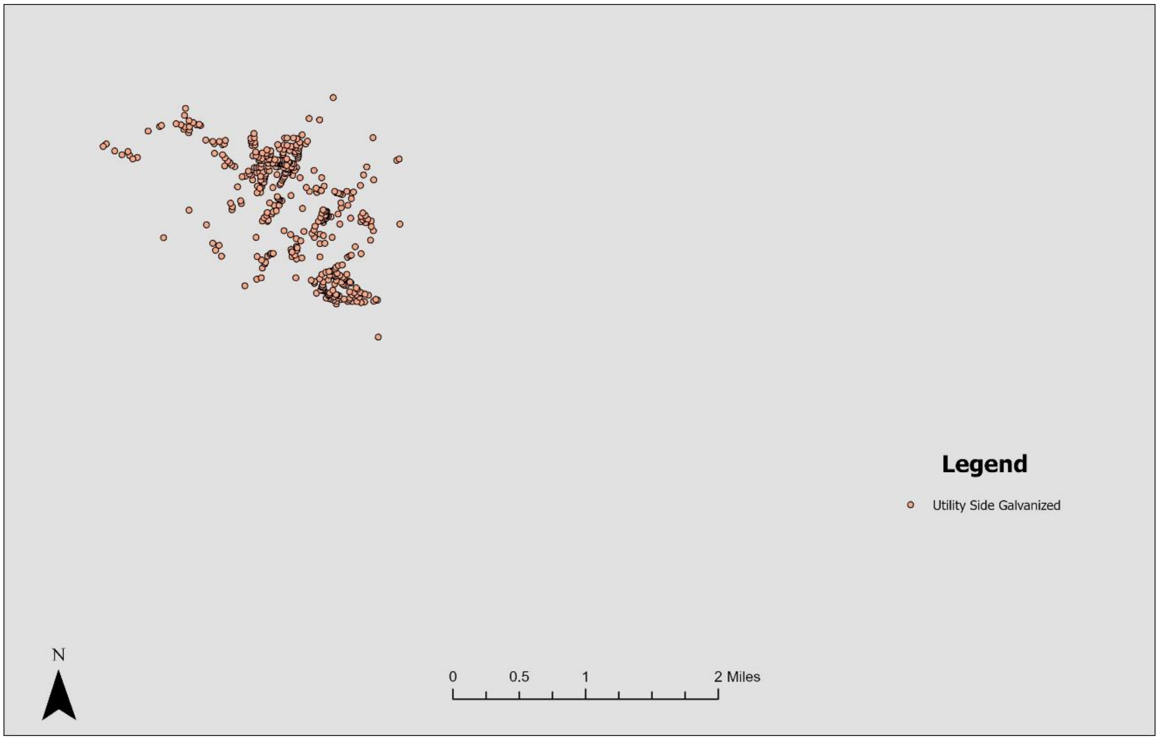

Figure 17. Locations where the utility side of a service line has been confirmed as galvanized

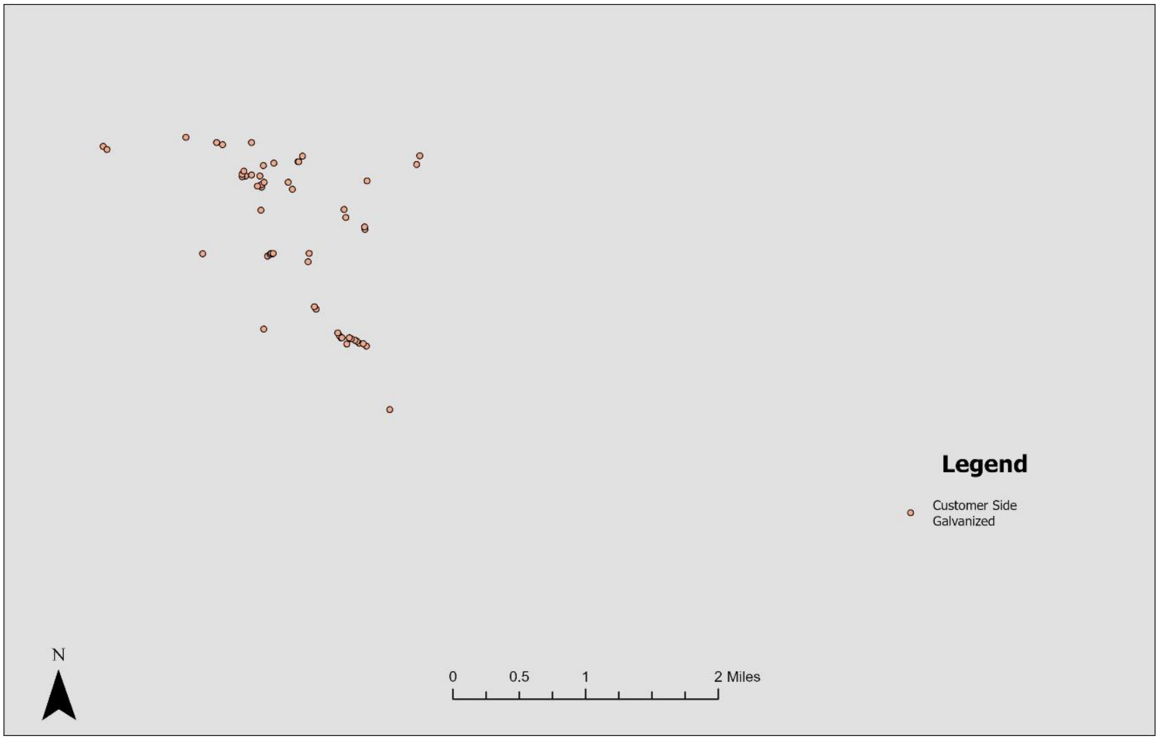

Figure 18. Locations where the customer side of a service line has been confirmed as galvanized

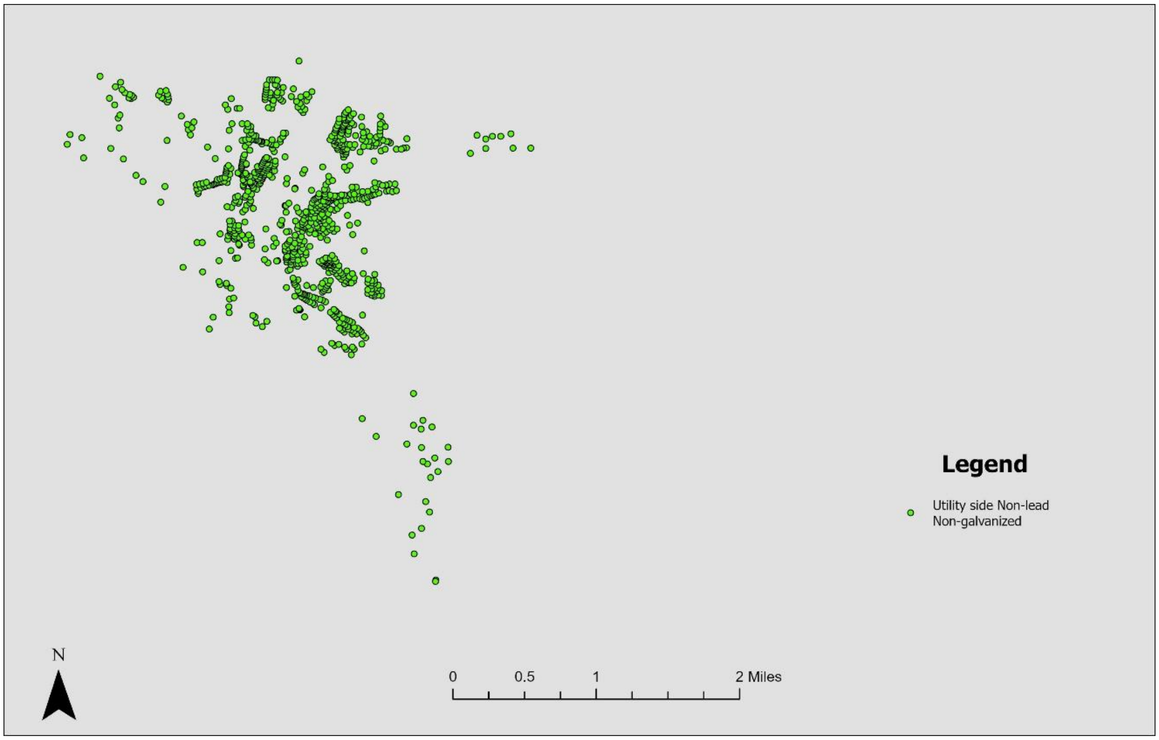

Figure 19. Locations where the utility side of a service line has been confirmed as non-lead and non-galvanized

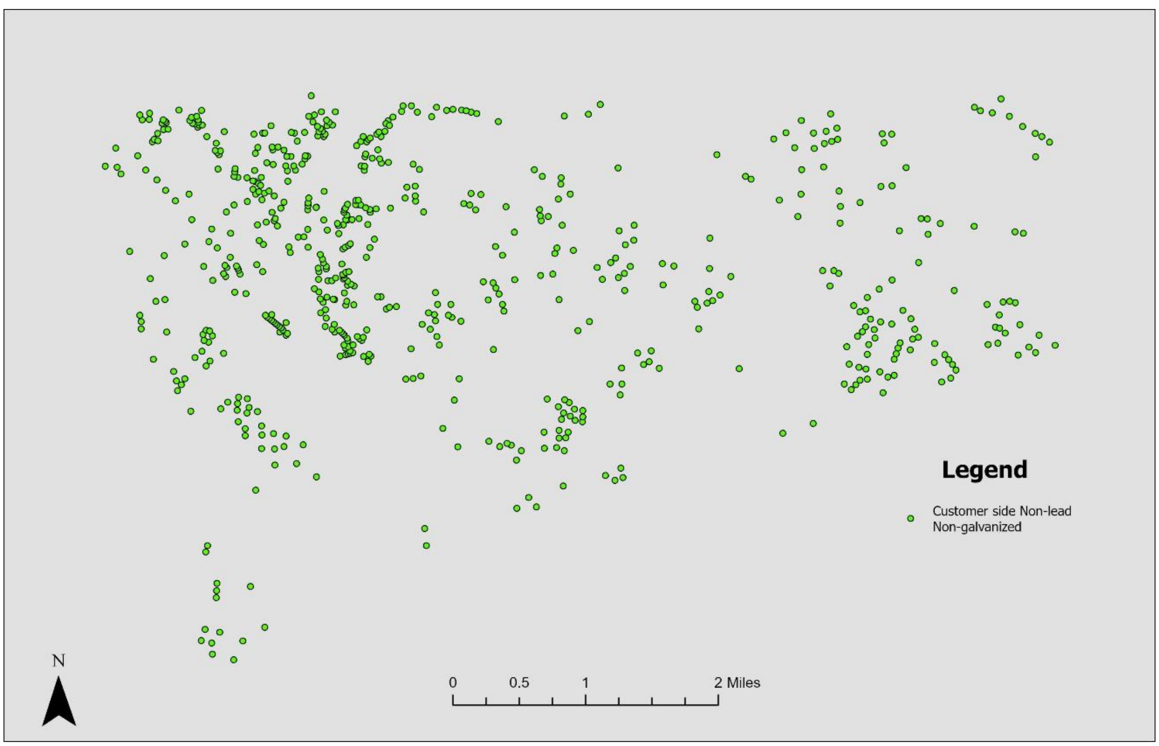

Figure 20. Locations where the customer side of a service line has been confirmed as non-lead and non-galvanized

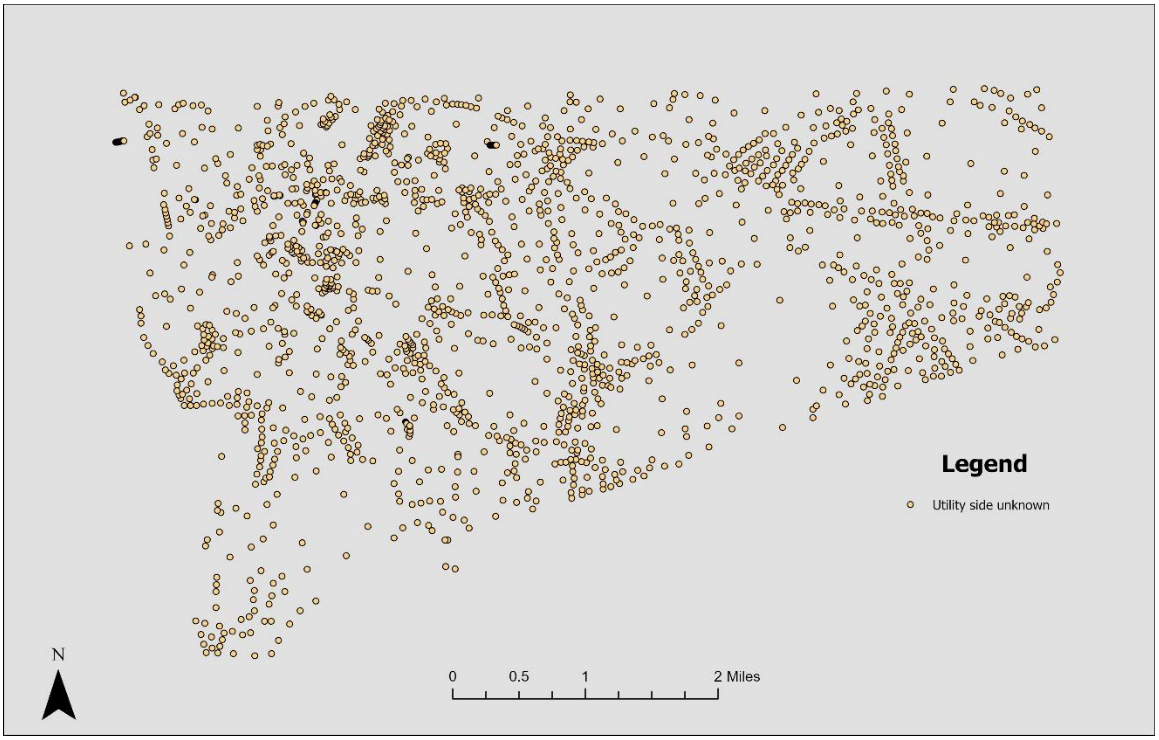

Figure 21. Locations where the utility side service line material is unknown

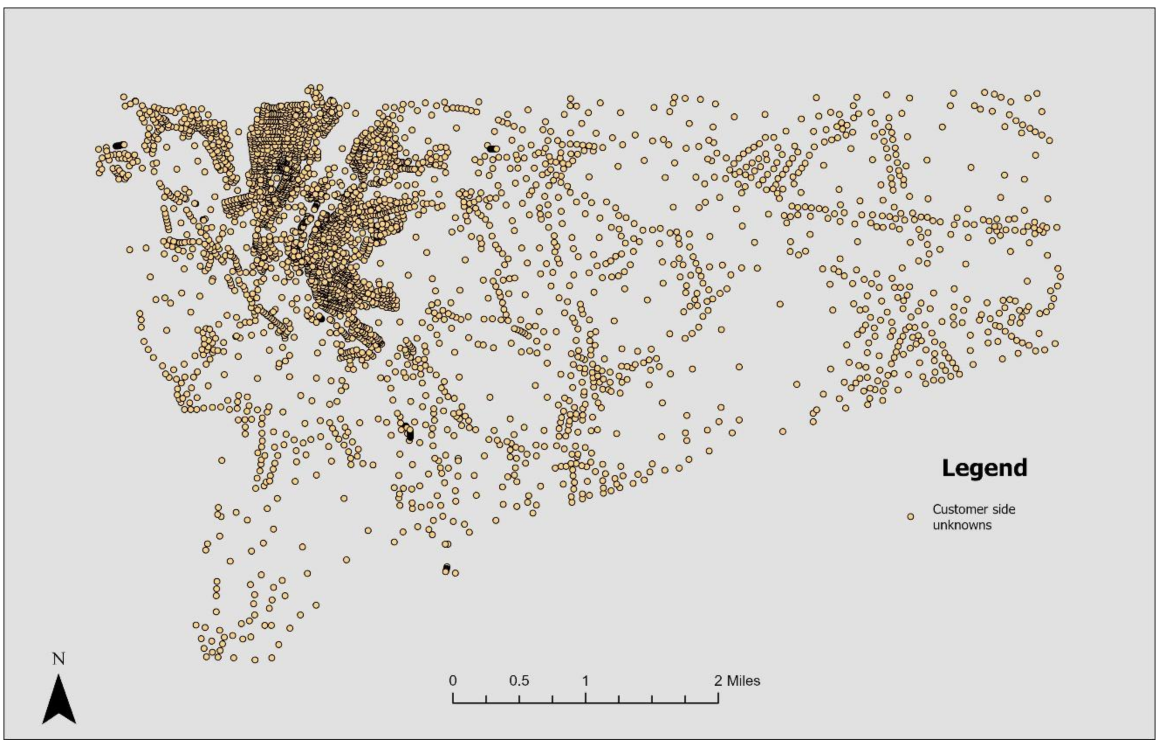

Figure 22. Locations where the customer side service line material is unknown

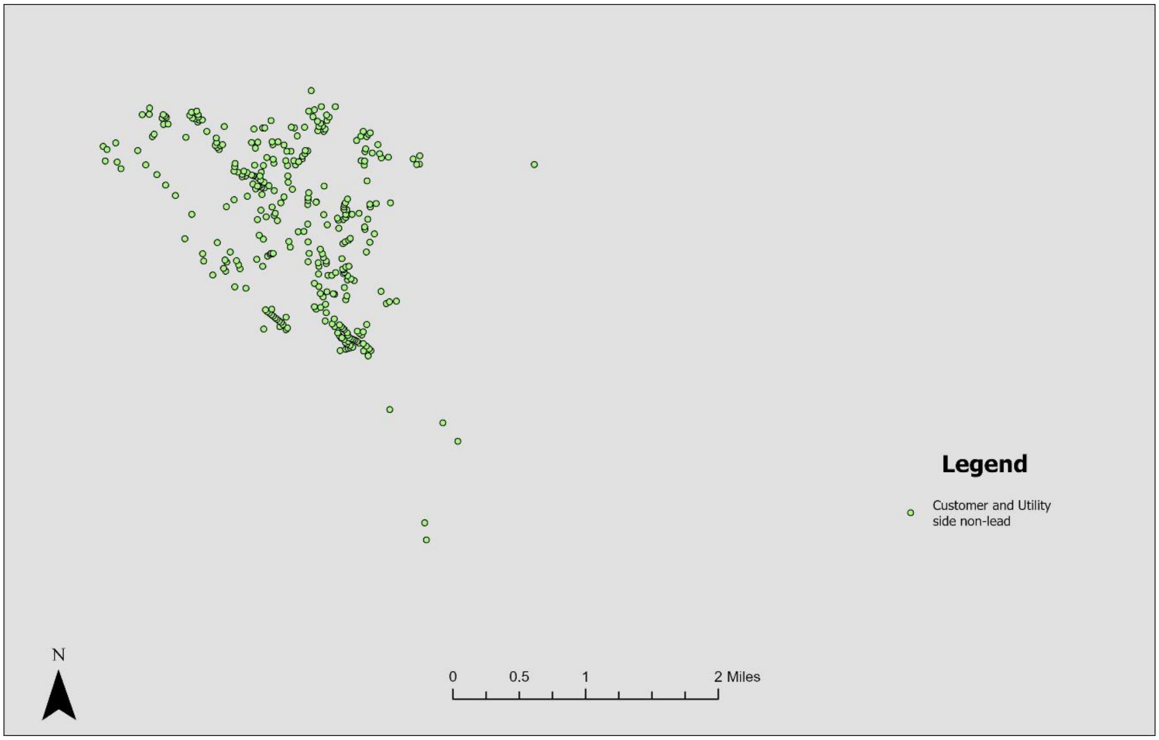

Figure 23. Locations where the customer and utility side of the service line have both been confirmed as non-lead

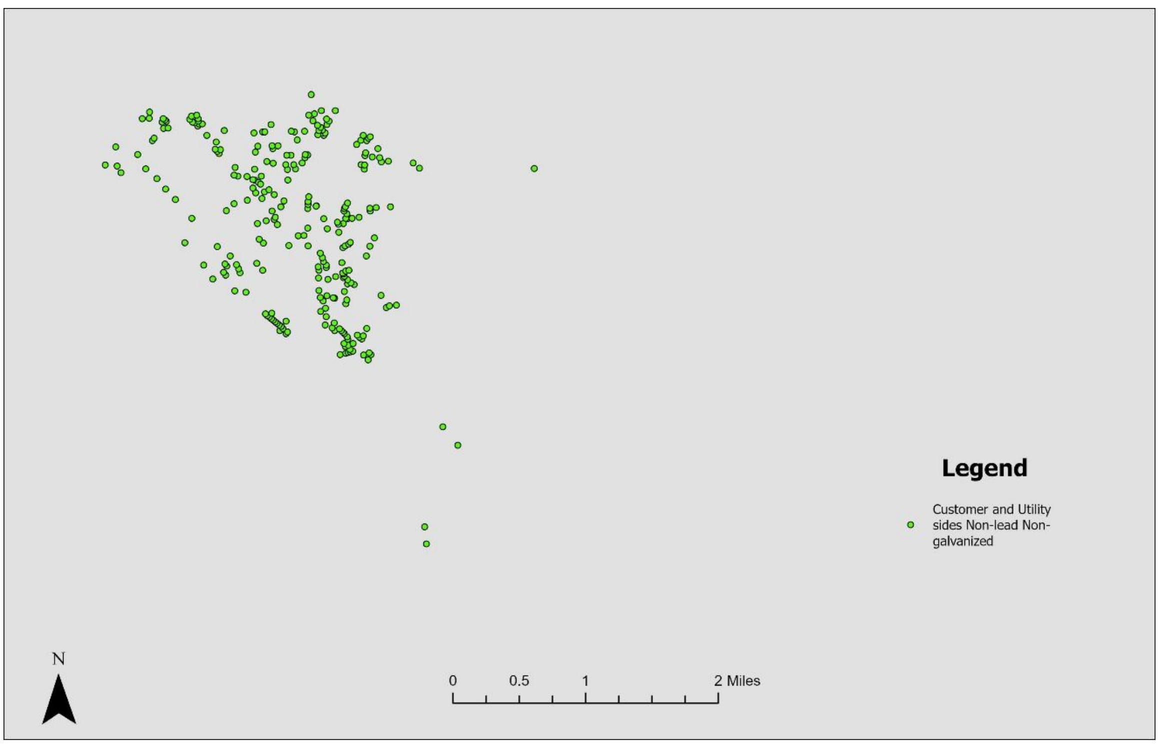

Figure 24. Locations where the customer and utility side of the service line have both been confirmed as non-lead and non-galvanized

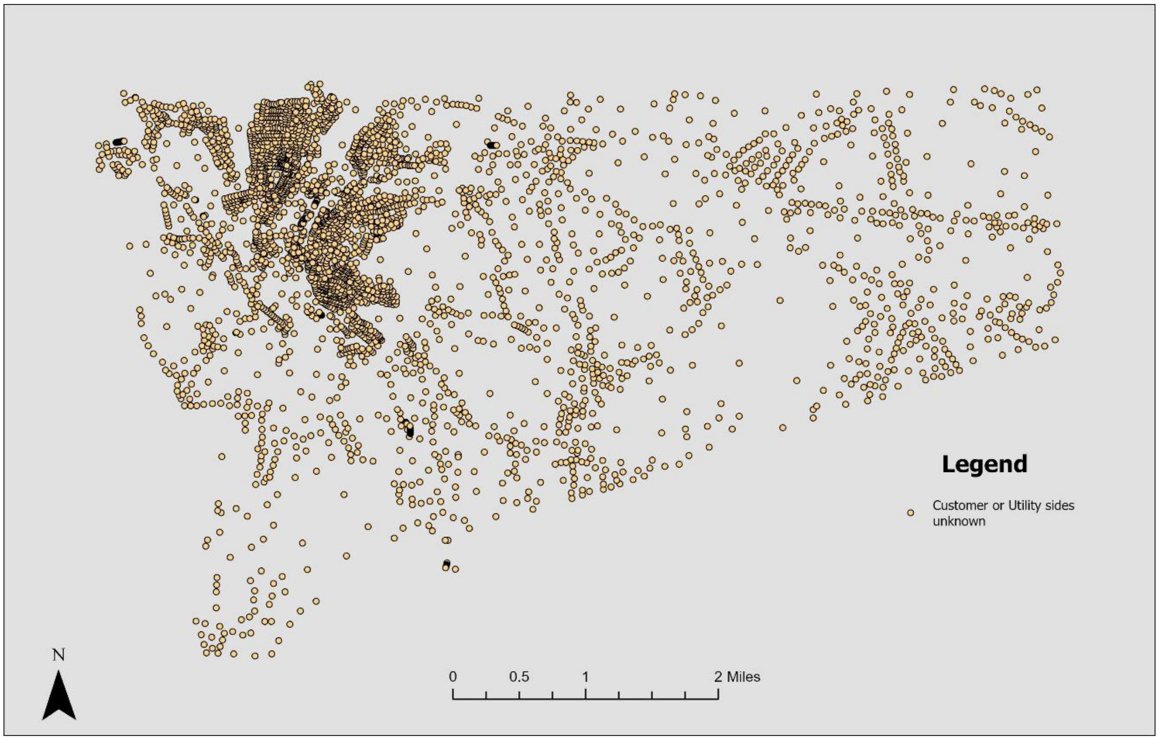

Figure 25. Locations where either the customer or utility side service line material is unknown

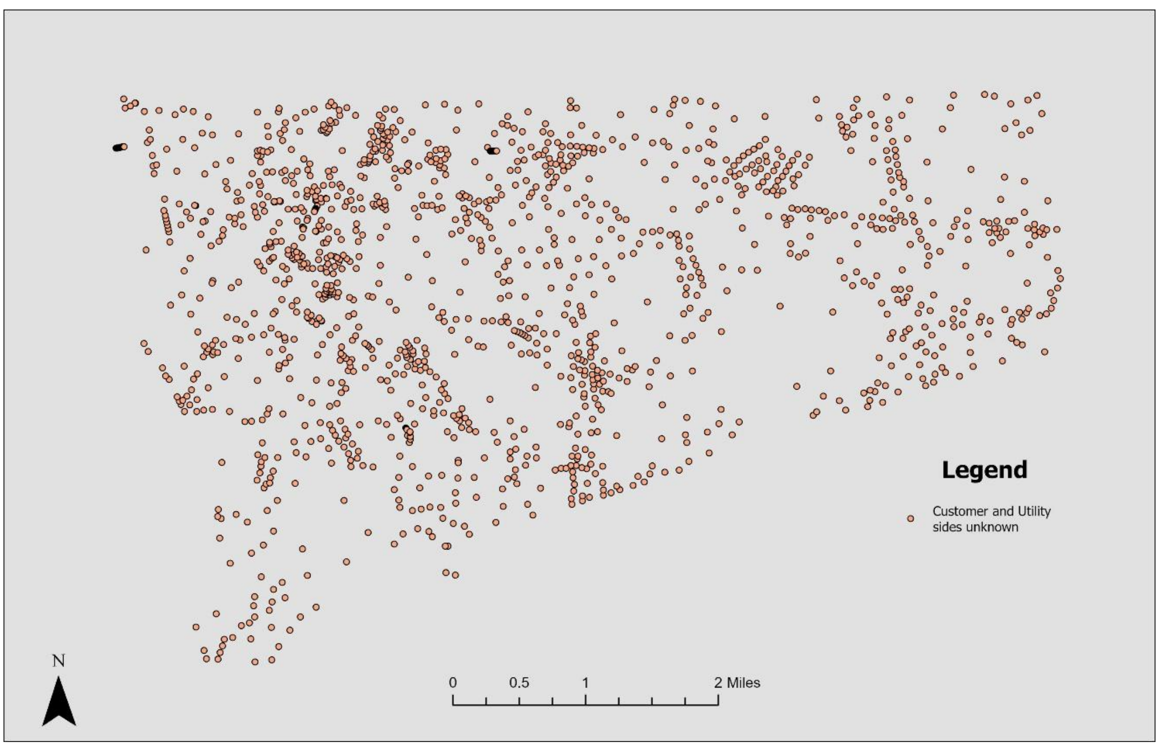

Figure 26. Locations where the customer and utility side service line material are both unknown

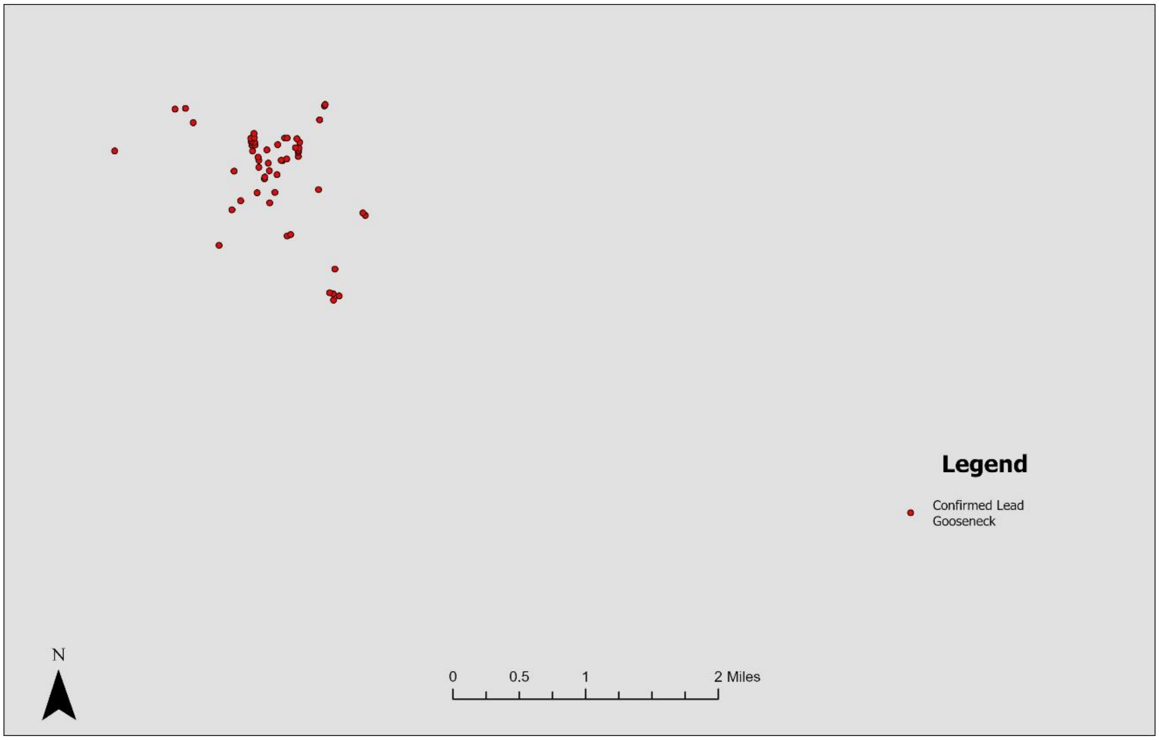

Figure 27. Locations where the gooseneck or connector material has been confirmed as lead

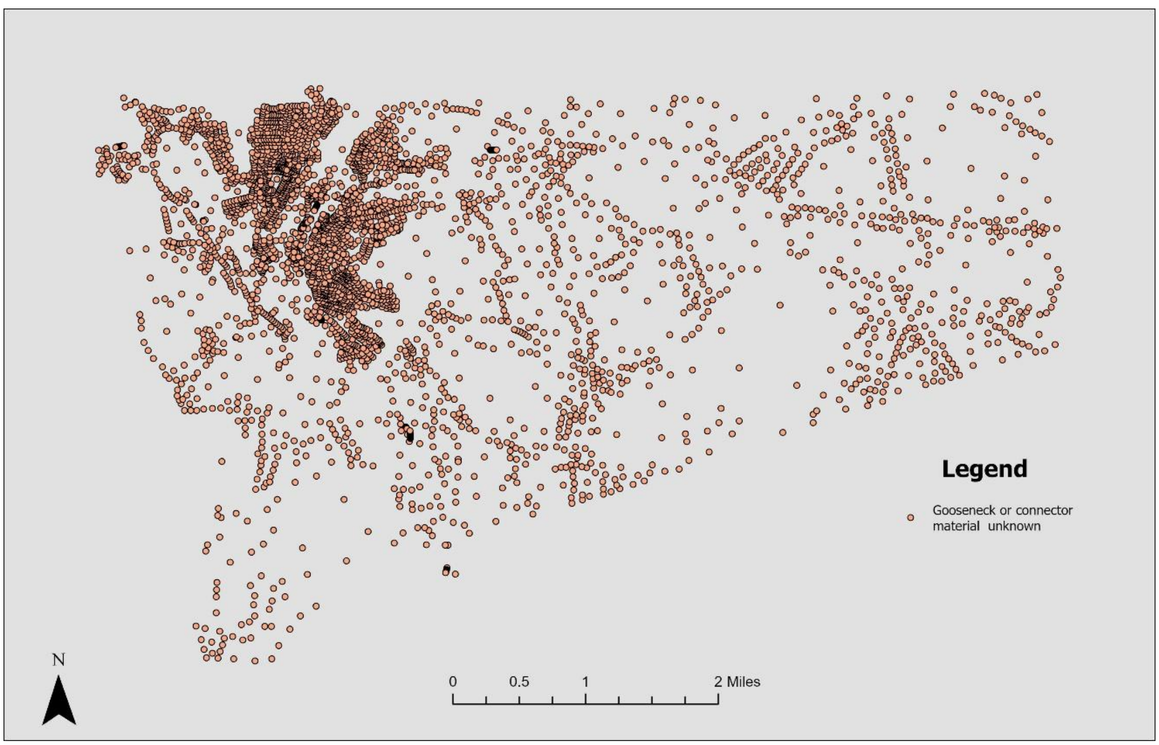

Figure 28. Locations where the gooseneck or connector material is unknown