Appendix B
Lead Service Line
Investigation Methods

Lead Service Line Investigation Methods

Developed for:

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Community Solutions Teams Pilot Effort

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Appendices

1.0 OVERVIEW OF EPA LEAD AND COPPER RULE REGULATIONS

In June of 2021, the United States Environmental Protection Agency (EPA) published the Lead and Copper Rule Revisions (LCRR) which further strengthens the requirements of the 1991 Lead Copper Rule (LCR) to better protect communities from the risks of lead exposure in drinking water. The LCRR will require an initial inventory of lead service lines (LSLs) to be completed by all public water systems. The original deadline for these was set for October 16th, 2024; however, the EPA announced its intent to revise the LCRR in what is being referred to as the Lead and Copper Rule Improvements (LCRI). While the LCRI is expected to delay certain requirements of the LCRR past the original compliance date of October 16th, 2024, the LSL inventory requirements will not be pushed back.

LSL inventories must be publicly available and updated annually or triennially. This applies to all community water systems (CWS) and non-transient, non-community water systems (NTNCWS). If a water system serves over 50,000 customers, then the inventory must be published online. If LSLs are identified, then the affected homeowners must be notified. All customer- and water system-owned service lines must be classified as one of the following:

- Lead – Any portion of the service line is made of lead.
- Galvanized Requiring Replacement (GRR) – A galvanized service line exists, and the system is unable to demonstrate it is not downstream of an LSL at any point.
- Non-Lead – All portions of the service line are not lead and any galvanized lines are confirmed to have never been downstream of an LSL or line whose lead status is unknown.
- Lead Status Unknown – Portions or the entirety of the service line don't have an evidence-based material classification.

Currently the LCRR is not considering lead pipe fittings as a source of lead in service lines. Therefore, a galvanized line downstream of a lead gooseneck, pigtail, or fitting or is not considered a GRR. However, it has been recommended that these be added to the LCRI as they are potential lead sources. Therefore, it is good practice to track these fittings as part of a complete LSL inventory if possible.

1.1 LSL Inventory Guidance

The EPA published their Guidance for Developing and Maintaining a Service Line Inventory in August 2022. It includes all requirements for the LCRR inventory and provides step-by-step recommendations for water systems to complete the process. The EPA recommends starting records review as soon as possible when gearing up to conduct an LSL inventory (LSLI) as this is a required step that can be time consuming and challenging. The LCRR requires that water systems undergo a record review of all public records and information pertaining to service lines including:

- All construction and plumbing codes, permits, existing records or other documentation that indicate the service line materials used to connect structures to the distribution system.
- All water system records, including distribution system maps and drawings, historical records on each service connection, meter installation records, historical capital improvement or master plans, and standard operating procedures.
- All inspections and records of the distribution system that indicate the material composition of the service connections that connect a structure to the distribution system.
- Any resource, information, or identification method provided or required by the state to assess service line materials.
- Any local codes and information on how long materials were in stock before they were phased out

An expected challenge when creating an LSL inventory is the availability of records. Some records may only be available physically (i.e., not electronically), be illegible, or missing. Staff capacity to review records might also be an issue, particularly for smaller systems. Additionally, depending on how long staff have been with the water utility, they may have limited familiarity with record keeping systems used in the past.

1.2 Documenting an LSL Inventory

The EPA provides an Excel template to help water systems document their LSL inventories. Some states have developed their own templates. A table that includes these is provided in the appendix (Table A.1). Systems are allowed to use an alternative inventory format, but will need to collect and save the same critical information required by the LCRR.

ESRI has developed a free tool called the Lead Service Line Solution to help communities create and maintain an LSL inventory[1]. This tool can also be used for predictive modeling LSL investigation techniques. A video describing this tool and how to use can be found here.

2.0 LSL INVESTIGATION STRATEGIES

The EPA's August 2022 guidance[2], includes approved methods to identify LSLs. Some methods are universally approved, while others are approved on a state-by-state basis. Consequently, it's important for water systems to communicate with their state agencies and be aware of state-specific requirements. The following sections provide a brief overview of various LSL investigation methods ranging from methods already in practice to emerging methods. The following will be discussed:

- Visual inspection
- Excavation
- Water quality sampling
- Alternative methods

Table 1 summarizes the methods discussed in subsequent sections as well as key advantages and disadvantages. A comprehensive LSL inventory will involve a combination of multiple methods.

[1] "Use Lead Service Line Inventory." Use Lead Service Line Inventory-ArcGIS Solutions | Documentation. Accessed July 8, 2023. https://doc.arcgis.com/en/arcgis-solutions/11.0/reference/use-lead-service-line-inventory.htm#:~:text=The%20Lead%20Service%20Line%20Inventory,share%20information%20with%20the%20public.

[2] U.S. Environmental Protection Agency, Office of Water, *Guidance for Developing and Maintaining a Service Line Inventory,* August 2022, https://www.epa.gov/system/files/documents/2022-08/Inventory%20Guidance_August%202022_508%20compliant.pdf

Lead Service Line Investigation Methods

Table 1. Summary of LSL investigation methods as well as key advantages, disadvantages, and resources.

Investigation Method	Description	Advantages	Disadvantages	Resources
Visual Inspection[1]	Differentiating between different pipe materials can often be done based on appearance. Copper, brass, and PVC are easily identified as non-lead because of their color. Distinguishing between galvanized and lead pipes often requires an additional step using either a scratch test, magnet test, or a lead swab test kit.	• Can be done with or without excavation • Lends itself well to public reporting • Abundance of existing public education materials	• If done only on exposed plumbing then buried portions of the service line are missed • Excavation is required to test the buried service lines	• Detailed description of how to determine pipe materially based on appearance provided by the LSLR Collaborative • List of EPA-approved lead test kits
External CCTV Inspection[1]	External CCTV inspections are performed by inserting the CCTV into the curb box to view the outside of the pipe on either side of the shut-off valve. A bulb-shaped wiped joint indicates an LSL.	• Can be done without entering the customers property • Typically requires only minimal excavation at the curb box	• Has produced unreliable results because it only inspects the service line immediately on each curb box • Can be difficult to access curb box or obtain photo clear enough to make an identification	• Section 5.1.2 of the EPA's 2022 Guidance Document provides a more detailed description
Internal CCTV Inspection[1]	Internal CCTV inspections involve feeding a high-resolution camera with a fiber-optic scope and light source down a pipe. The pipe material is identified based on the images of the inside of the pipe.	• Allows for a longer section of pipe to be inspected • Requires no or minimal excavation depending on the entry point of the scope	• If there is excessive build up or scale in the pipe it can be difficult to accurately identify pipe material • Forcing the scope through a pipe with build-up can dislodge contaminants or damage pipe	• Section 5.1.2 of the EPA's 2022 Guidance Document provides a more detailed description

Lead Service Line Investigation Methods

Investigation Method	Description	Advantages	Disadvantages	Resources
Mechanical Excavation[1]	Mechanical excavation involves using a backhoe or other mechanical excavator to dig a test pit or a full trench to expose portions of the pipe. Then visual inspection or swab tests are typically used to determine type material.	• If an LSL is identified it can be replaced immediately	• Invasive and requires access to customers property • Risks damage to pipes and customers property • Process is expensive and requires significant staff time	• Section 5.3.1 of the EPA's 2022 Guidance Document provides a more detailed description
Vacuum Excavation[1]	Vacuum excavation uses a water jet or compressed air to loosen soil then vacuum up a small hole to access the service line. Typically, this is done at multiple points along the service line. Then visual inspection or swab tests are typically used to determine type material.	• Faster, less intrusive, and less likely to damage pipes than mechanical excavation	• Requires access to customers property • Process is can be expensive and require significant staff time	• Section 5.3.2 of the EPA's 2022 Guidance Document provides a more detailed description
Flushed Sampling[1]	A water sample is collected from an outlet within the building after allowing the water to sit stagnant for at least 6 hours then letting the outlet run for a prescribed amount of time. The water sample is then tested for lead. Lead concentrations above a certain threshold, which depends on the stagnation period, indicate the presence of a lead service line.	• Sample collection can be done by trained professionals or by the public • Doesn't require excavation • Doesn't risk damage to pipes • Sampling protocol is easiest to follow of all water quality samples • Can detect lead solder	• Most prone to inaccuracy of all water quality sampling methods • Depending on size of building it can be difficult to ensure that water sample is coming from the service line not indoor plumbing	• Information from Virginia's Office of Drinking water on flush sampling

Lead Service Line Investigation Methods

Investigation Method	Description	Advantages	Disadvantages	Resources
Targeted Service Line Sampling[1]	This water sampling protocol involves estimating the volume of water inside the buildings plumbing based on the length and diameter of the pipes. A water sample is collected from inside the building after flushing this estimated volume following a stagnation period of at least 6 hours. If a lead concentration above a certain threshold, which depends on the stagnation period, then it indicates an LSL.	• Sample collection can be done by trained professionals or by the public • Doesn't require excavation • Doesn't risk damage to pipes • Can detect lead solder	• Inaccurate estimation of flush volume could lead to sample coming from inside of the building not service line • Relies on customer to follow sampling protocol or adhere to the stagnation period prior to professional samplers' arrival	• Example of a targeted service line sampling protocol from Nevada
Sequential Sampling[1]	In this water sampling protocol, a series of 1-liter samples is collected from an outlet inside the building moving immediately to the next sample so	• Sample collection can be done by trained professionals or by the public • Doesn't require excavation • Doesn't risk damage to pipes • Can detect lead solder	• Most complex of all the water sampling protocols • Inaccurate estimation of flush volume could lead to sample coming from inside of the building not service line • Relies on customer to follow sampling protocol or adhere to the stagnation period prior to professional samplers' arrival	• Video by CDM Smith describing a sequential sampling protocol • Information from Virginia's Office of Drinking water on sequential sampling

Lead Service Line Investigation Methods

Investigation Method	Description	Advantages	Disadvantages	Resources
Electrical Resistance Testing[2]	In this method a probe detects and transmits an electrical resistance signal of the service line material the probe is in contact with. Pre-established resistance ranges for common pipe materials then allow the user to identify service line materials	• Allows for a longer section of pipe to be inspected • Requires no or minimal excavation depending on the entry point of the probe	• Forcing the probe through a pipe with buildup can dislodge contaminants or damage pipe • Cannot detect lead solder	• More detailed description can be found in this literature review
Acoustic wave technology[2]	Acoustic wave technology is commonly used to detect leaks and determine thickness of underground pipes. In order to use it for pipe material identification, a library of return frequencies for common pipe materials would have to be developed.	• Does not require excavation • Does not risk damage to pipes	• Requires basic knowledge of service line locations which may not be available for the customer-side of service lines • Still requires significant research and adaptation to be able to reliably identify service line material • Cannot detect lead solder	• More detailed description can be found in this literature review
Ground Penetrating Radar (GPR)[2]	Currently, GPR can be used to determine the dimensions of an underground pipe but not identify the material. Pipe dimensions can rule out the possibility of lead materials if the diameter is 4 inches or greater. However, for pipes with a diameter less than 4 inches, a library of pipe materials' responses to GPR scatter would be needed	• Does not require excavation • Does not risk damage to pipes	• Requires basic knowledge of service line locations which may not be available for the customer-side of service lines • Still requires significant research and adaptation to be able to reliably identify service line materials • Cannot detect lead solder	• More detailed description can be found in this literature review

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Investigation Method	Description	Advantages	Disadvantages	Resources
X-Ray Fluorescence Testing[2]	An emerging testing method for exposed plumbing is handheld X-ray florescence testing (XRF) devices. These can be used to determine the lead content with enough resolution to determine if it meets the EPA's limit of 25ppb (0.25%).	• Determines the lead content of pipes and solder joints more accurately than swab tests or other visual inspection methods • Some devices are precise enough to be used on solder	• Requires testing be done by trained professionals • Handheld XRF devices can be a significant investment • Requires excavation to test any part of the service line that is not exposed	• More detailed description can be found in this literature review

[1] *Established Methods (no additional EPA approval required)*
[2] *Alternative Methods (requires specific EPA approval)*

Lead Service Line Investigation Methods

2.1 Visual Inspection

Visual inspection methods can either be done by the water system or rely heavily on public involvement. It is does not require specific state approval. The physical appearance of a service line can be an effective way of identifying pipe material. Copper, brass, and plastic pipes can be easily identified as non-lead materials due to their color and texture (Figure 1 c, d, e)[3]. Copper piping is similar in color to a penny, PVC pipes are typically either a white or blue plastic, and brass is a darker red-brown color. Brass piping is more commonly found in indoor plumbing than service lines. However, if brass service lines are identified, their lead content should be tested using either a swab test or other EPA approved method described later in this section as older brass alloys can have a lead content significantly above the current EPA limit of 0.25%.

Differentiating between lead and galvanized pipes requires additional testing because both are a dull-silver gray color (Figure 1 a,b)[4, 5]. There are a couple different methods used to determine whether a pipe is lead or galvanized steel. The "Scratch and Magnet" test is often recommended (Figure 2)[6]. If a pipe can be easily scratched with a key or coin revealing a shiny silver color, it is likely lead. To confirm this a magnet can be used. A magnet will stick to a galvanized pipe, but not a lead pipe. Another method of differentiating between lead and galvanized pipes is EPA-approved lead paint or surface swab tests. A list of EPA-approved lead test kits can be found here. These tests will change color when they come in contact with lead. If testing painted pipes, the paint should be completely removed from the test area so that lead paint won't cause a false positive. If there are exposed pipe connections, another visual cue to identify lead pipes is if they are connected with "wiped joint". A wiped joint is when the soldering at a pipe connection is smooth and rounded (Figure 3)[7]. This technique was used to connect lead pipes to non-lead pipe.

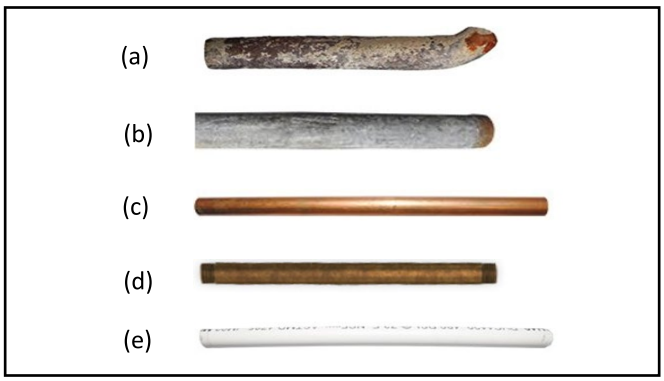

Figure 1. Examples of common pipe types and differences in visual appearance[3]. (a) lead pipe - a dull silver-gray color with external corrosion. (b) galvanized - a dull silver-gray color. (c) copper pipe - similar in color to a penny. (d) brass pipe – a dark red-brown color. (e) PVC pipe – white hard plastic, also commonly blue

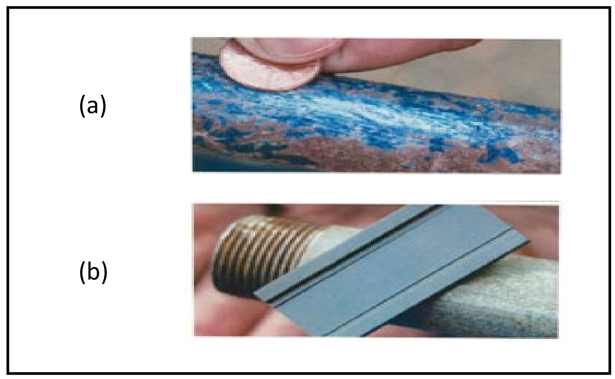

Figure 2. Visual example of the scratch and magnet test to differentiate lead and galvanized pipes[6]. (a) Lead pipes can be easily scratched with a penny or key revealing a shiny silver color. (b) A magnet will stick to a galvanized pipe but not a lead pipe.

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[3] "Do You Have Lead Pipes? Let Us Help You Find Out." Do you have Lead pipes? Let us help you find out | DCWater.com. Accessed May 6, 2023. https://www.dcwater.com/do-you-have-lead-pipes-let-us-help-you-find-out.

[4] EPA. Accessed July 8, 2023. https://www.epa.gov/sciencematters/epa-researchers-share-approaches-identify-lead-service-lines.

[5] "Identifying Service Line Material." LSLR Collaborative. Accessed May 6, 2023. https://www.lslr-collaborative.org/identifying-service-line-material.html.

[6] Survey. Town of Dickinson. Accessed May 6, 2023. http://townofdickinson.com/survey.aspx.

[7] "Testing Your Water Service Line for Lead." Water Safety | Testing Your Service Line. Accessed July 5, 2023. https://www.myutility.us/sunshinewater/water-safety/lead-lead-service-lines/testing-your-service-line.

Figure 1. Example of a wiped joint connecting a lead pipe to non-lead pipe connector and stop valve.[8]

Visual inspection methods can be done with or without excavation. In cases where no excavation is used to expose the service line, only the exposed plumbing is used to identify material. This is typically located around the water meter (Figure 4). However, it is common for multiple pipe materials to be used within both the public and private portions of the service line especially in the case of repairs where only a portion of the line was replaced. Any LSL located underground will be missed if these methods are used alone. Additionally, this method does not identify lead soldering, pipe fittings, or angle stops which can be a lead source in drinking water. While tracking information about solder, pipe fitting, or angel stop materials used in the distributions system isn't currently required by the LCRR, it has been recommended for inclusion in the LCRI. Still these methods are an essential tool for water systems because they lend themselves well to public-involved efforts.

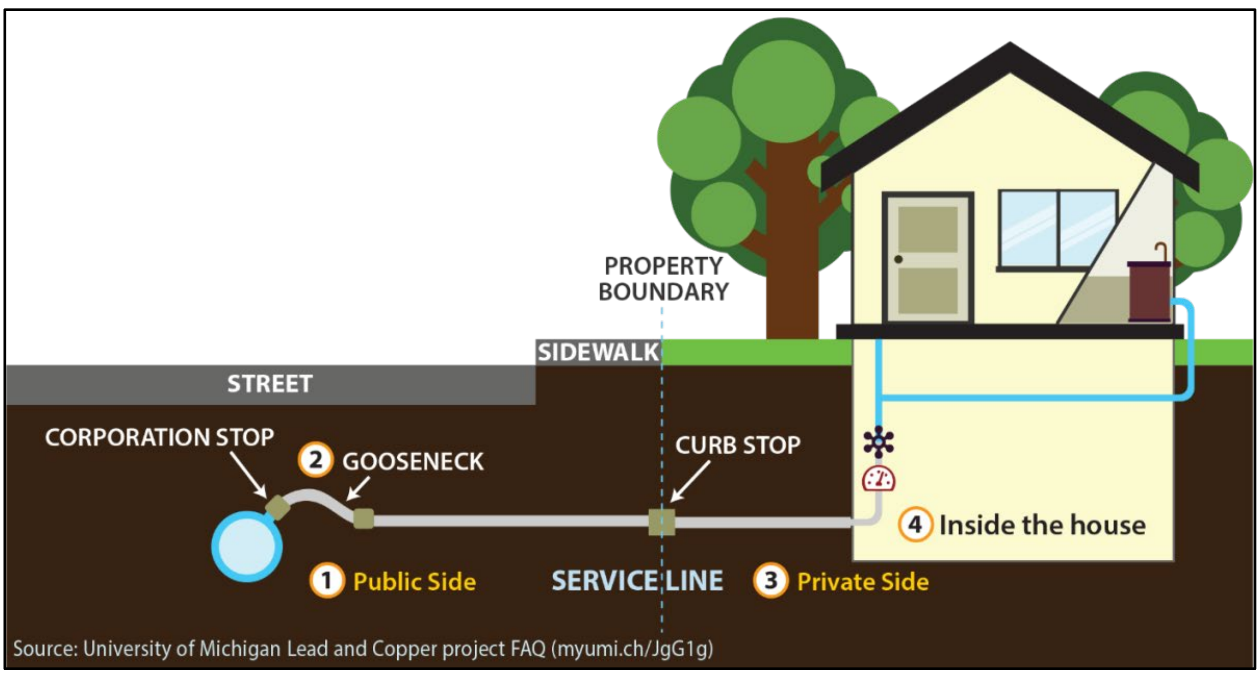

Figure 2. Diagram showing the public and private portions of a service line. Typically, only the service line around the water meter can be seen without excavation.

8 "Lead in Drinking Water." Drinking Water Inspectorate, November 15, 2022. https://www.dwi.gov.uk/lead-in-drinking-water/.

Lead Service Line Investigation Methods

2.1.1 Public Reporting

A common approach is for utilities can incorporate one or multiple of the previously mentioned visual identification methods into a public outreach campaign. The intent is to have customers determine the material of the exposed portion of the service line at their water meter and report it to the water system. This is an incredibly accessible way for water systems to identify service line materials as it doesn't require access to the customers' homes. There are extensive public outreach materials available to help customers determine the material of pipes in their home or building. Some examples can be found in the case studies provided later in this document.

While these methods are less invasive, they require extensive public outreach and education by the water system and ultimately rely on public participation. When relying on public reporting, the EPA recommends water systems take additional steps to confirm material identification. Examples of this are asking customers to submit a photograph or asking water system staff or licensed plumbers to conduct site visits. If site visits are needed, a water system should determine if there are existing ordinances giving them access rights to the inside of the home for inspections of the service line material or work within the framework of local laws to request access to the customer-side of the service line. Allowing the public to report through a website can make data collection more stream-lined. An example of self-reporting through a website can be found in the Greater Cincinnati Water Works Case Study later in this section. However, internet access must then be considered as a barrier to data collection and appropriate accommodations made for equitable inventorying, especially for rural communities.

2.1.2 CCTV Inspection

Another visual inspection method is external or internal CCTV inspection. CCTV inspections will be performed by the water system or by a consultant hired by the water system but oftentimes don't involve entering a customer's property. External CCTV inspections are performed by inserting the CCTV into the curb box to view the outside of the pipe on either side of the shut-off valve. A bulb-shaped wiped joint indicates an LSL. The external method has produced unreliable results when used by water systems as it only examines the connection to the curb box and can miss LSLs on either side of this connection. For example, a curb box inspection might show the pipes on both side of the shut-off valve are connected via a threaded pipe connection indicating a galvanized service line. This doesn't rule out that a section of the pipe, either before or after the shut-off valve, is lead. Internal CCTV inspections involve feeding a high-resolution camera with a fiber-optic scope and light source down a pipe. This method is more reliable as it allows a longer section of pipe to be inspected. However, if the inside of the pipe is coated with corrosion scale it can be impossible to accurately determine the material using CCTV.

2.1.3 Case Studies

City of Golden LSL Inventory[9]: The city of Golden, Colorado started by identifying homes suspected to have LSLs through public records and other predictive methods. A survey was sent to the property owners where LSLs were expected to be found that included a free lead swab test. A description of their program can be found on their website.

Greater Cincinnati Water Works[10]: Instructions on how to perform a visual inspection and a scratch test are provided on the Greater Cincinnati Water Works website. Along with the instructions is a fillable form that asks customers for a name, email, return phone number and property address. Customers select the materials they identified and are asked to upload a picture of their meter setting to help confirm identification. The responses to this form are used to identify households that require further inspection by

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[9] "Lead Service Line Inventory Project." Guiding Golden. Accessed July 3, 2023. https://www.guidinggolden.com/lead-service-line-inventory.

[10] "Replace Your Lead Service Line." Greater Cincinnati Water Works. Accessed July 3, 2023. https://la.mygcww.org/replace-your-lead-service-line/.

the water system. Information about this program as well as an interactive LSL inventory map can be found on their website.

City of Grand Rapids[11]: The City of Grand Rapids offers free video conferencing software to guide homeowners through the material verification process. Information about this program as well as an interactive LSL inventory map can be found on their website.

Pittsburgh Water Authority: The Pittsburgh Water Authority performed an external CCTV curb-box inspection program to identify LSLs. They concluded this was not a reliable method for LSL identification. At 75% of locations, they were unable to access the curb-box or get a picture clear enough to make an LSL identification due to dirt and debris. Additionally, because only the pipe connection on either side of the shut-off valve was inspected, this method produced a significant number of false negatives. A lead source was found at 35% of the locations determined to be non-LSL by the external CCTV inspection.

2.2 Excavation

If the service line is not accessible for visual inspection, a portion of the soil surrounding the line can be removed in order to identify its material. This may require removing portions of the sidewalk or road if necessary. Excavation methods are feasible for inspecting lines on public property but are often too invasive to be used for private properties. Coordinating with residents to get access to the property can be extremely difficult and is exasperated by resistance to excavation on the resident's property. Depending on local ordinances, utilities will have varying rights to access or responsibility to pay for any repairs to damaged property.

Two excavation LSL investigation methods are mechanical and vacuum excavation. Mechanical excavation involves using a backhoe or other mechanical excavator to dig a test pit or a full trench to expose portions of the pipe. The larger the area of pipe exposed; the more accurate identification is. However, this process is invasive and risks damage to pipes. Pipes that are most likely to be lead or GRR also tend to be the oldest and frailest. Vacuum excavation uses a water jet or compressed air to loosen soil then vacuum up a small hole to access the service line. This process is faster, less intrusive, and less likely to damage pipes. To limit the possibility of missing an LSL, vacuum excavation can be done at multiple points along the service line.

One advantage of excavation methods, especially mechanical, is when an LSL is identified it can be replaced immediately. However, this method is very costly and time consuming. It can be a good option where LSLs are highly likely.

2.3 Water Quality Sampling

Another option for water systems to detect the presence of LSLs is water quality sampling. This method requires state-specific approval. Water samples are collected at a residence or public building and tested for their lead concentrations. Thresholds are state specific but are typically between 5 and 15 µg/L. Lead concentrations above a certain threshold indicate an LSL. Depending on the volume of water collected, the sample can indicate lead in the fixture, building's plumbing, or the service line (Figure 5). Utilities should make sure that their sampling procedure allows a sufficient volume to pass through the outlet within the residence so the collected sample is coming from the service line not internal plumbing.

There are a variety of sampling protocols that vary in complexity, cost, and accuracy. Samples can either be collected by customers or trained professionals. Testing protocols can typically be classified as flushed sampling, target service line sampling, or sequential sampling.

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[11] Lead in drinking water. Accessed May 6, 2023. https://www.grandrapidsmi.gov/Government/Departments/Water-System/Lead-in-Drinking-Water.

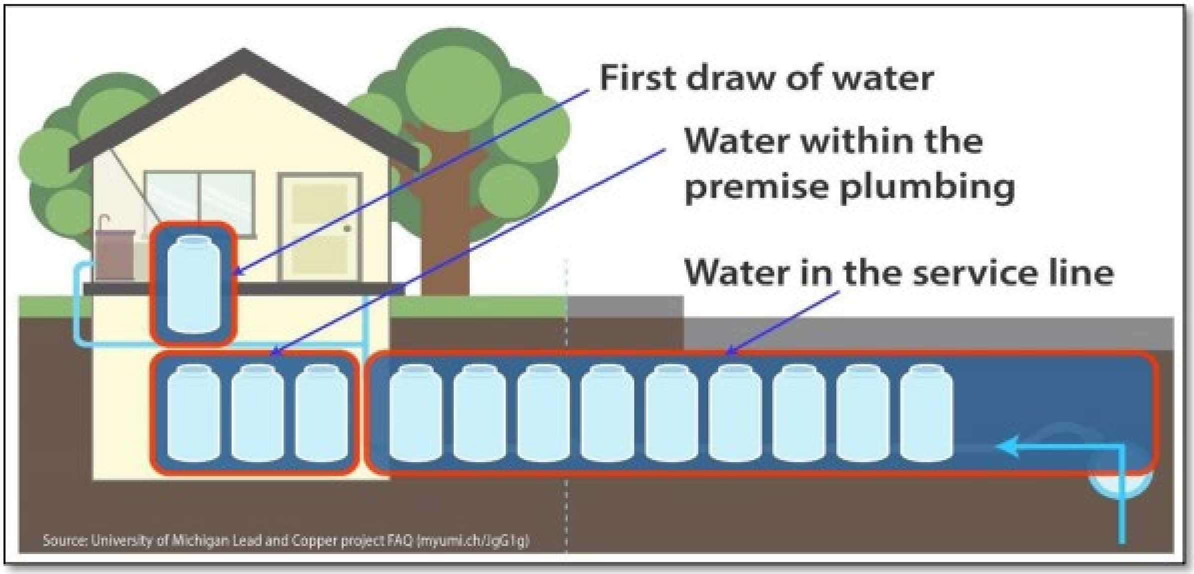

Figure 3. Example of sequential water quality sampling showing the difference between the first four 1-liter samples coming from the premise plumbing and the fifth and subsequent 1-liter samples coming from the service line.

2.3.1 Flushed Sampling

In this method a sample is collected after letting the water run from an outlet within the residence for a set period of time following a stagnation period of 6 hours or more[12]. This process is referred to as flushing. The flush volume at each site is not standardized, but the flushing time is. Therefore, the prescribed flushing time must be chosen carefully to ensure the water sampled is coming from the service line. This type of sampling is the easiest to follow but the most prone to inaccuracies.

2.3.2 Targeted Service Line Sampling

This protocol involves estimating the volume of water on the premise then flushing out the estimated volume of water after a stagnation period[13]. In order to target the service line, the sample must be collected from the selected outlet after the estimated volume on the premise has been flushed. The threshold lead concentration that indicates the presence of an LSL can depend on stagnation time as well as other water quality parameters. An example of a threshold is "concentrations of 3ug/L in the second liter of water following a 15-minute stagnation period".

An example method comes from the Nevada Department of Environmental Protection, in which the stagnation period is 6 hours and the action level threshold is 15 ug/L. An overview of the sampling procedure can be found here.

2.3.3 Sequential Sampling

This method uses a series of consecutive samples collected from an interior tap following a set stagnation period of 6 hours or more. The number of samples needed can depend on the length and diameter of pipe in the building. In some cases, only 5 liters may need to be sampled to reach the service line outside the building. In other cases, up to 15 liters may be needed. This method provides the most in-depth information

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[12] Water quality sampling for LSL identification - Virginia department of ... Accessed July 6, 2023. https://www.vdh.virginia.gov/content/uploads/sites/14/2023/05/Water-Quality-Sampling-for-LSL-Identification.pdf.

[13] Tools for lead service line identification - US EPA. Accessed May 6, 2023. https://cfpub.epa.gov/si/si_public_file_download.cfm?p_download_id=544746.

however it is the most complex and might be difficult for customers to follow because it requires collecting multiple samples and keeping track of the collection order.

Under the LCRR, the EPA has outlined a desired sampling protocol that specifies the sample collected for lead testing should be the fifth liter of water coming out of the outlet. For the majority of residences, the fifth liter is water from outside the internal plumbing within the private portion of the service line. This regulation goes into effect January 2025, and some water systems are asking their customers to start the new collection method now. A video created by CDM smith explains this sampling protocol in further detail.

2.4 Alternative Methods

Many other LSL investigation methods are being developed and can be approved for use on a state-by-state basis. These methods seek to address the main limitations of previously discussed methods: invasiveness, reliance on public participation, and cost.

2.4.1 Electrical Resistance Testing

Electrical resistance testing is a form of subsurface identification. This method is approved in the EPA's guidance released in August 2022 under alternative methods. In this method a probe detects and transmits an electrical resistance signal of the service line material the probe is in contact with[14]. Pre-established resistance ranges for common pipe materials then allow the user to identify service line materials. These ranges vary slightly based on soil characteristics, so utilities that choose this method must consider their site-specific conditions. This method doesn't require water service to be shut off or a stagnation period. However, it does typically require access to the customer's property and excavation to access the curb box.

Some practitioners are adapting this method, such as by using technology similar to CCTV inspections to feed the conductivity probe through the service line. Scale and buildup on pipes do not impact the electrical reading, though buildup on pipes might make it difficult or impossible to feed the probe through the line. In this case alternative methods must be considered. Additionally, this method cannot identify galvanized piping downstream of an LSL or lead soldering by electrical conductivity alone. However, the probe can be swabbed with a standard lead test kit after use. If the swab test is positive for lead when no LSLs were found, this indicates either galvanized downstream of an LSL or lead solder joints. This method is limited by the length of the line the probe is attached to. Depending on the distance between the residence and the curb box this may not be enough. The line can be fed from both the curb box and the residence's entry point (i.e., hose bib) to allow for a longer length of the line to be inspected.

2.4.2 Other Subsurface Material Identification Methods

In addition to electrical resistance testing, other methods of subsurface material identification are being developed. The main draw of subsurface material identification methods is they do not require excavation. Two of the most notable are acoustic wave technology and ground penetrating radar (GPR)[15]. Both of these methods come from other disciplines such as utility mapping and leak detection and will require significant research and adaptation to be able to identify service line materials. Acoustic wave technology is commonly used to detect leaks and determine thickness of underground pipes. In order to use it for pipe material identification, a library of return frequencies for common pipe materials would have to be developed. Like acoustic wave technology, GPR can be used to determine the dimensions of an underground pipe but not identify the material. Determining pipe dimensions can rule out the possibility of lead materials. LSLs

[14] Hensley, Kelsey, Valerie Bosscher, Simoni Triantafyllidou, and Darren A. Lytle. "Lead Service Line Identification: A Review of Strategies and Approaches." AWWA Water Science 3, no. 3 (April 2021). https://doi.org/10.1002/aws2.1226.

[15] Hensley, Kelsey, Valerie Bosscher, Simoni Triantafyllidou, and Darren A. Lytle. "Lead Service Line Identification: A Review of Strategies and Approaches." AWWA Water Science 3, no. 3 (April 2021). https://doi.org/10.1002/aws2.1226.

typically don't have a diameter greater than 2 inches, although LSLs with a 3-inch diameter have been found on rare occasions[16]. Still any pipe with a diameter of 4 inches or greater can be ruled out as a potential LSL with relatively high confidence. However, for pipes with a diameter less than 4 inches, a library of pipe materials' responses to GPR scatter would be needed to differentiate between pipe materials. Another limitation of both acoustic wave technology and GPR is they require basic knowledge of service line locations which may not be available for the customer-side of service lines. While these methods are promising, they currently have significant limitations.

2.4.3 X-Ray Fluorescence Testing

An emerging testing method for exposed plumbing is handheld X-ray florescence testing (XRF) devices. These can be used to determine the lead content of pipes and solder joints more accurately than swab tests or other visual inspection methods. Devices can determine the lead content with enough resolution to determine if it meets the EPA's limit of 25ppb (0.25%)[17]. Some devices are precise enough to be used on solder. However, this method requires testing be done by trained professionals, not the public, limiting its viability for widespread testing. Additionally, it can only be used on areas of exposed plumbing thus excavation would be required for any underground service lines.

3.0 FOCUSING INVESTIGATORY EFFORTS

On the ground LSL investigation techniques are time intensive and, depending on the method selected, expensive. It is important to develop an approach to conducting LSL investigations. Physically verifying the material of every service line in a water system using one of the methods discussed in the "Predictive Modeling" section below is likely infeasible by the LCRR's deadline for service line inventories. Limited funding and staff capacity are other barriers. Therefore, knowing which parts of the water system to investigate first in order to make the highest impact is crucial.

Focusing on the ground efforts in locations where the water system is most likely to have lead service lines can save time and resources as well as remove LSLs from the distribution system more quickly, thereby limiting community exposure to lead. Predicting areas likely to have LSLs is typically done through data analysis. The information collected during the records review phase is essential to this step. The year a building was constructed or a service line was installed is a crucial piece of information when determining the likelihood that lead pipes were used. A good place to start is looking for any buildings constructed prior to 1986, the year EPA's nationwide ban of lead pipes or solder in drinking water supply when into effect. Any part of the water system constructed before this date is more likely to have lead. Local plumbing and construction codes can offer more information about when lead pipe and solder were phased out as well as give an idea of how prevalent their use was prior to the ban.

Any additional records that document maintenance, repairs, new connections, meter installations, or maps of the distribution system may contain information about service line materials. These can be used to help identify the areas of the water system where lead is the most prevalent.

3.1 3.1 Predictive Modeling

Predictive modeling is one strategy to prioritize locations for on the ground lead investigation. This method involves creating a geospatial model that looks for patterns in datasets to develop rules or algorithms and

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[16] U.S. Environmental Protection Agency, Office of Water, *Guidance for Developing and Maintaining a Service Line Inventory,* August 2022, https://www.epa.gov/system/files/documents/2022-08/Inventory%20Guidance_August%202022_508%20compliant.pdf

[17] Gingras, Eric. "Identifying Lead Water Pipes with Handheld LIBS." Web log. Hitachi High-Tech Analytical Science (blog). Hitachi High-Tech Global, May 25, 2021. https://hha.hitachi-hightech.com/en/blogs-events/blogs/2021/05/25/identifying-lead-water-pipes-with-handheld-libs/.

then predicts where lead service lines are most likely located. It's a helpful tool to fill in gaps in water system data where service line materials are unknown.

Datasets include basic water system information gathered in the records review as well as in-field verification. Often parcel-level data that includes the construction dates of structures are used as proxy to assess the potential presence of lead in water service lines. Older structures on parcels indicated a greater likelihood of lead, whereas recent construction suggested a lower probability. Identifying areas where the presence of lead service lines is expected, based on the age of structures, can help prioritize LSL investigation efforts

3.2 Machine Learning Modeling

Machine learning modeling goes beyond the analysis of basic datasets used in predictive modeling and uses a self-learning algorithm to make predictions. This method often relies on not only water system data such as building age but socioeconomic or environmental factors to identify areas that should be prioritized. One example is socioeconomic factors from census data. Parts of the community that earn below the median household income or are classified as disadvantaged are often less likely to have significant capital investment to their water system. Therefore, it is less likely that any lead service lines have been replaced. Alternative data set such as this can help to minimize the exposure of the most vulnerable populations.

Appendix A: State LSLI Templates

Table A.1. A list of states that have developed their own LSLI template(s)

State	Responsible Party	Description
Alaska	Alaska Division of Environmental Health	Provides both a GIS template and an excel template
California	California State Water Board	Provides an excel template and with an accompanying PDF document with instructions
Illinois	Illinois Environmental Protection Agency	Provides an excel template
Indiana	Indiana Department of Environmental Management	Provides an excel template
Iowa	Iowa Department of Natural Resources	Provides two separate excel templates one for over systems serving over 10,000 and systems serving under 10,000
Louisiana	Louisiana Department of Health	Provides separate templates for small, medium, and large systems on their webpage
Massachusetts	Massachusetts Department of Environmental Protection	Provides an excel template and with an accompanying instructions document
Missouri	Missouri Department of Natural Resources	Provides separate excel templates for small/medium systems and large systems
Montana	Montana Department of Environmental Quality	Provides separate excel templates for community systems and non-transient, non-community systems
New York	New York Department of Health	Provides separate templates for systems over 500 connections and systems under 500 connections
North Carolina	North Carolina Department of environmental quality	Has separate templates for systems under 500 connections, between 500 and 50,000 connections, and over 50,000 connections
Oklahoma	Oklahoma Department of Environmental Quality	Provides an excel template
Tennessee	Tennessee Department of Water Resources	Provides an excel template
Texas	Texas Commission of Environmental Quality	Provides an excel template