APPENDIX K

FINAL REPORT

Considerations when Costing Lead Service Line Identification and Replacement

American Water Works Association

November 2022

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Section 1

Introduction

Following revisions to the U.S. Environmental Protection Agency's (EPA) Lead and Copper Rule (LCR), drinking water utilities are required to identify and make the locations of lead service lines (LSLs) publicly available. If LSLs exist in the water distribution system, utilities must prepare a plan to replace LSLs. The replacement plan must be developed by October 2024. The most recent attempts to quantify the number of LSLs in the United States estimate between 6.1 and 10.2 million LSLs across the nation (Cornwell et al. 2016). While some federal funding is available to aid in LSL replacement costs, identification and replacement of LSL costs may exceed EPA's original LSL replacement program cost estimate included in the Economic Analysis for the Final Lead and Copper Rule Revisions (December 2020).

The American Water Works Association (AWWA) is interested in informing the EPA's development of the Lead and Copper Rule Improvements (LCRI). AWWA's goal is to determine a more complete cost of service line material identification and LSL replacement. The full identification and replacement costs reflect not just the cost of construction to replace an LSL at an individual service location, but additionally the administrative preparation; coordination with other utilities, departments and funding organizations; outreach and coordination with property owners and inhabitants; design, bidding construction management and inspection; data management; public education; restoration; permitting; program management and other costs.

1.1 Study Scope

A growing number of water utilities serving communities across the U.S. now have experience identifying which service lines are lead, which are galvanized steel or iron that requires replacement, and which are non-lead service lines per 40 CFR 141.84(a). Water utilities also have experience replacing LSLs, including both the utility and private sides of the line. Since the current widely used cost estimates consider only certain components of the total cost such as the physical replacement, this study sought to provide a more comprehensive review of costs associated with these activities by means of a literature review and utility surveys. The study tasks included:

1. Review of data in published articles, presentations, and other relevant resources; email-administered survey responses from 34 utilities; and phone surveys with 9 utilities that characterized planning level costs and/or manhour estimates of:
    a. Identification of service line materials, and
    b. Replacement of lead service lines.
2. Organization and presentation of the range in costs and key factors that may contribute to variability in full costs of either of these two activities.
3. Summarize generalizable trends in costs of these two activities.

1.2 Literature Review and Utility Surveys

The study team gathered and compiled service line material identification and LSL replacement cost data from the literature. The sources reviewed are provided in the reference section.

The project team also developed an LSL identification and verification techniques survey which was shared with over 50,000 of AWWA's members. Each of the 34 respondents provided information about what service line identification methods they utilize or plan to utilize. Survey respondents provided labor hour and/or cost estimates for each identification method they utilized. Finally, the team developed a phone questionnaire for the LSL replacement costs for interview of key personnel at nine utilities. The phone survey sought program management cost data and other costs related to an LSL replacement program.

The summary of key results and cost data collected during the literature review, email surveys, and phone interviews are presented as part of this technical memorandum. Cost data, where possible, was converted to a cost per service line activity (e.g., inspection, replacement, etc.) so that costs could be compared and averaged across programs and locations.

1.2.1 Cost Variability Considerations

The cost of implementing a replacement program can vary widely based on site specific conditions. For example, the cost to dig a pit typically would be less for a service line buried 30 inches below a low-traffic road compared to a service line buried 8 feet below a high-traffic concrete road. Cost is further affected by contractor's experience, other simultaneous activities such as main replacement, local labor prices, soil conditions, the linear footage of the service line, the type of main connection, construction methods, permitting requirements, bidding conditions, the size of the project and other factors. Cost estimates based on the literature review and utility surveys are provided herein to serve as a comparative reference point for utilities.

To convert all costs to 2022 dollars, the project team utilized the Construction Cost Index at Engineering News Record (ENR).[1] In the case that the month of a previous year cost was not known, the indices across the year were averaged and utilized. Costs were categorized according to the EPA region from which the cost was obtained. See **Figure 1-1** below for a map of the EPA regions.

[1] Construction Cost Index, Engineering News Record

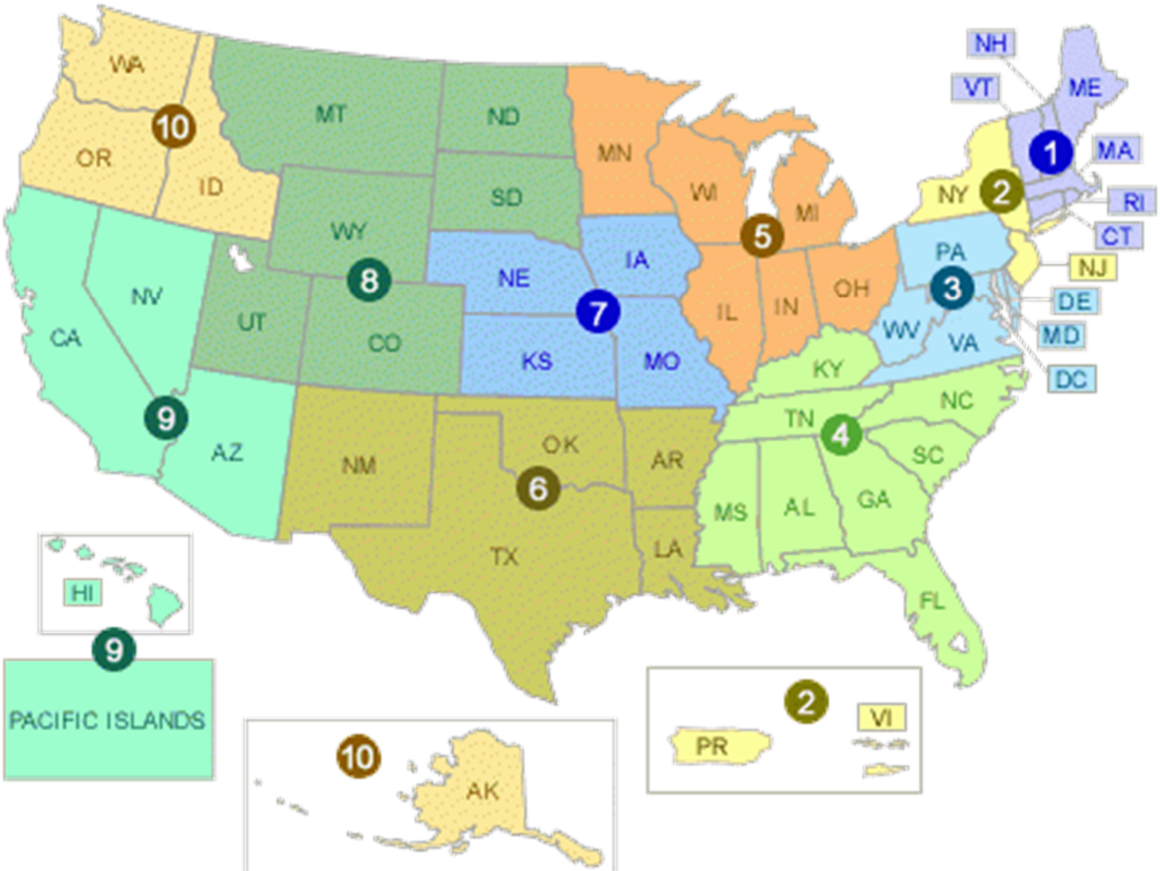

Figure 1-1 United States Environmental Protection Agency Regions (USEPA, 2022b)

1.3 Labor Rates for Cost Estimates

Much of the data provided through the email survey of AWWA members or through phone interviews was presented as number of manhours for each identification or replacement scope of work. For purposes of this technical memorandum, the national-level base hourly wage rate estimates from the Labor Costs for National Drinking Water Rules (USEPA 2011) were used to calculate weighted system labor rates. The system labor rates (in 2022 dollars) were used to convert provided utility labor hours to utility costs throughout this technical memorandum. To account for the variation in labor rates across all systems, the labor rate estimates are based on utility size (i.e., population served).

Table 1-1 presents the baseline hourly wage rates and final utility labor rates. First, the base hourly rates were adjusted from 2007 dollars to 2022 dollars based on the general employment index (ECI) multiplier of 1.43. The labor rate was further adjusted using a 1.62 loading factor that reflect additional employee benefits from the BLS Employer Costs for Employee Compensation report, March 2022. Moreover, based on USEPA 1999, rates also should include the cost of overhead and fringe benefits, as appropriate. The labor rate is further adjusted using a 1.1 multiplier (typical) that reflects overhead costs associated with expenses for office space, furniture, equipment and computers, and supplies.

To be consistent with economic analysis used for the LCRR, 80/20 proportions were used as a general assumption to develop system labor costs for this technical memo. To account for the general composition of staff at systems of smaller sizes (i.e., those serving 3,300 or fewer people), only the technical rate was used. For systems serving more than 3,300 people, proportions of 80 percent technical labor and 20 percent managerial labor were used to arrive at weighted labor rate. It is important to recognize that the actual proportions between technical and managerial rates employed may vary by utility system and among the different compliance activities under the final LCRR.

Table 1-1 Weighted Hourly Labor Cost by CWS Size (Population Served)

System Size (Population Served)	Base Hourly Wage Rates (2007$)[1]		Base Hourly Wage Rates (2022$)[2]		Wages + Benefits (2022$)[3]		Wages+ Benefits + Overhead (2022$)[4]		Weighted System Labor (2022$)[5]
	A	B	C = A*1.44	D = B*1.44	E = C*1.62	F = D*1.62	G = E*1.1	H = F*1.1	I = H for PWSs ≤ 3,300); J = (0.8*H) + (0.2*G) for PWSs > 3,300
	Managerial	Technical	Managerial	Technical	Managerial	Technical	Managerial	Technical	Managerial & Technical
≤500	$24.06	$16.97	$34.65	$24.44	$56.13	$39.59	$61.74	$43.55	$43.55
501-3,300	$24.06	$16.97	$34.65	$24.44	$56.13	$39.59	$61.74	$43.55	$43.55
3,301-10,000	$27.52	$18.10	$39.63	$26.06	$64.20	$42.22	$70.62	$46.45	$51.28
10,001-50,000	$30.65	$19.11	$44.14	$27.52	$71.50	$44.58	$78.65	$49.04	$54.96
50,001-100,000	$35.76	$19.95	$51.49	$28.73	$83.42	$46.54	$91.76	$51.19	$59.31
100,001-500,000	$38.21	$23.32	$55.02	$33.58	$89.14	$54.40	$98.05	$59.84	$67.48
>500,000	$40.51	$24.24	$58.33	$34.91	$94.50	$56.55	$103.95	$62.20	$70.55

Notes:

1 From Exhibit ES-1 (USEPA, 2011). Based on 2006 CWSS (USEPA, 2009). Technical Rate = Operator Rate & Managerial Labor = Engineering Rate.

2 Values adjusted to 2022 dollars through applying BLS state and local government compensation values from Q2 2007 (38.61) and Q2 2022 (55.47). Multiplier used was 55.47/38.61 or 1.44.

3 The 1.62 loading factor reflects additional employee benefits from the BLS Employer Costs for Employee Compensation report, Table 1, March 2022. Percent of total compensation - Wages and Salaries - All Workers - State and Local Government Workers.

4 Labor rates adjusted to include overhead costs through using a standard multiplier of 1.1. Overhead costs include facility operation and maintenance costs such as insurance, rent and utilities along with general administrative costs such as human resources, legal, regulatory compliance, and accounting.

5 To account for the general composition of staff at systems of smaller sizes, (i.e., those serving 3,300 or fewer people), only the technical rate was used. For systems serving more than 3,300 people, proportions of 80 percent technical labor and 20 percent managerial labor (i.e., manager rate) were used to arrive at weighted labor rate. The actual proportions between technical and managerial rates employed may vary by PWS and among the different compliance activities under the final LCRR. However, for simplicity, 80/20 proportions were used as a general assumption to develop system labor costs for this technical memo which is consistent with economic analysis sued for the Lead and Copper Rule Revision.

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Section 2

Typical Service Connection

Typical service connections for a residential water customer are illustrated in **Figure 2-1** and **Figure 2-2,** for interior meters and exterior meters in pits, respectively. Typically, the water utility owns the service line extending from the water main to the curb stop or property boundary; the service line between the curb stop or property boundary and the entry to the structure is owned by the property owner. However, in some systems, the utility or the property owner owns the entire service line.

For this technical memorandum, pipe segments of the water service are defined as follows:

- Corporation Stop – a shut off valve that joins a water service line to a street water main.
- Gooseneck or Pigtail – a short section of pipe used to connect the service line pipe to the water main.
- Curb Stop – a water control valve used to help facilitate isolation of water supply to the customer, typically located just inside the property line of most private or commercial properties.
- Utility Owned Pipe — the service line from the water main to the curb stop or boundary of the customer property. In locations where this portion of the pipe is owned by the property owner, it is referred to as the "street side" or "utility side" pipe.
- Privately Owned Pipe – the service line from the curb stop or customer property boundary to the building. In locations where this portion of the pipe is owned by the utility, it is referred to as the "home side" or "customer side" pipe.
- Lead Service Line – a service line made of lead which connects the water main to the building inlet and any galvanized pipe currently or formerly located downstream of a lead pipe.
- Plumbing – piping inside the building between the water meter and the various water taps (e.g., faucets, bibs, etc.). There should be no plumbing connections (such as a lawn sprinkler system, ancillary building) off of the service line upstream of the water meter unless they have a separate water meter or with permission from the utility (such as for a fire line).
- Shut off valve – these valves could be upstream and downstream of the water meter and are used to stop water flow to the interior of the building and to stop water flow prior to disconnecting a water meter.
- Water meter – the water meter is owned by the utility and used to measure the amount of water used by the service connection. It should be located to measure all water use by the customer. If it is located inside the building, it will usually be on the lowest floor or in a

crawl space near the water service entry point. Water meters can be made of brass or plastic. If the water meter is located outside, it will be underground inside of a vault.

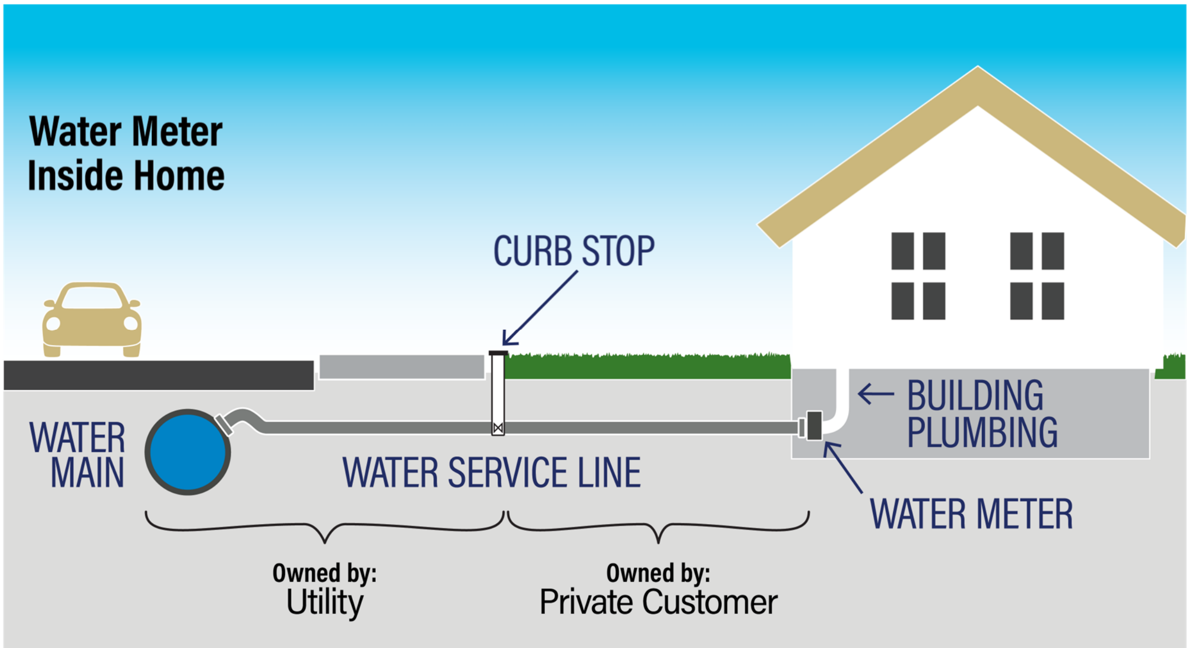

Figure 2-1 Schematic of Typical Residential Service Connection with an Interior Meter

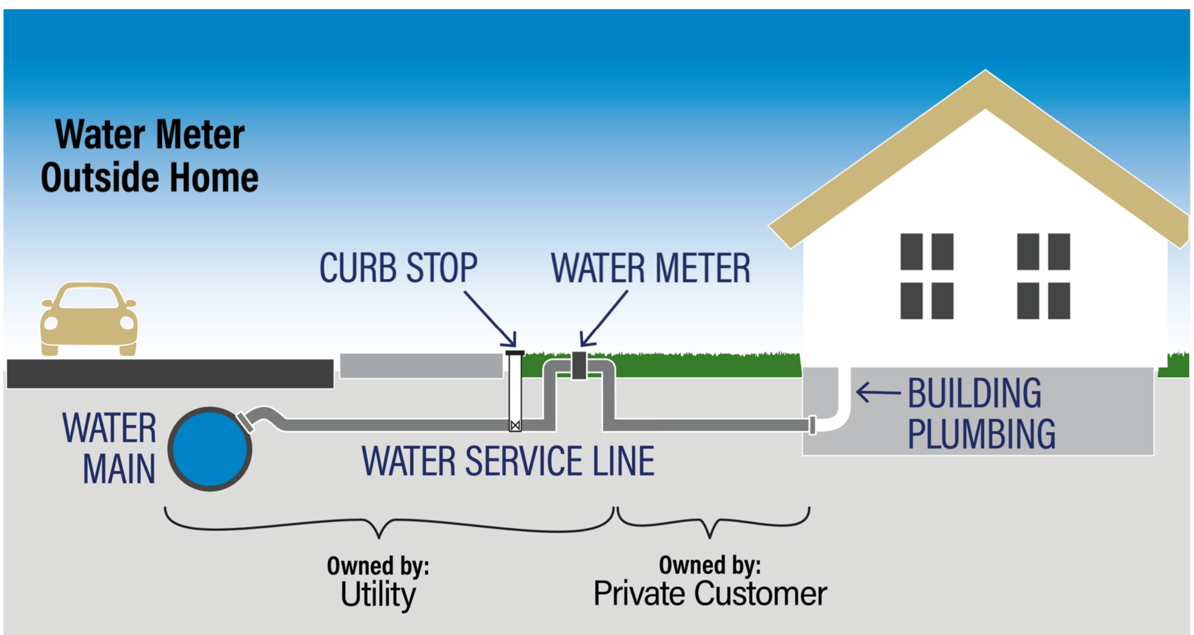

Figure 2-2 Schematic of Typical Residential Service Connection with an Exterior Meter

Section 3

Identification of Service Line Materials

Service line material verification methods have varying degrees of cost, accuracy, and complexity. Often, the methods that are the costliest and require the most effort will yield results with higher accuracy. A utility is likely to use a mixture of multiple identification methods to identify service line materials to increase the accuracy of their results. A service line material inventory is a living and iterative resource that must be continuously updated when new information is available. A utility may initially update the inventory with historical records and provide a secondary verification through excavation, for example. This section presents a description of verification methods (Section 3.1), characteristics of the utility respondents to the survey (Section 3.2) and the results of the survey and cost data from other sources (Section 3.3).

3.1 Descriptions of Service Line Identification Methods

Utilities have a range of methods available to determine service line material within their distribution system. The most commonly used and discussed methods were included in this evaluation. Descriptions of the verification methods evaluated in this study, including advantages and disadvantages, ratings for accuracy (fair, good, best), and general cost category (low, medium, high), are included in **Table 3-1**. All methods shown in **Table 3-1** were included in the survey, however, some methods did not have any respondents providing cost information and therefore are not included in the writeup herein.

Emerging verification methods are methods that are not guaranteed to be accurate in all systems or that are not widely available. While Bukhari et al. (2020) states that “no convenient methodology is currently commercially available that is capable of directly identifying buried LSLs,” there are several emerging technologies that may provide vital service line information and may be used in conjunction with other methods or records to improve accuracy.

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Table 3-1 Service Line Material Verification Methods Advantages, Disadvantages and Qualitative Cost Comparison

Verification Method Type	Verification Method	Advantages	Disadvantages	Accuracy	Cost
Desktop Verification Methods	Historical Records	Does not require going door-to-door Historical records are typically readily available as utilites already maintain documentation	Record drawings may be non-existent or may not include pipe materials Subsequent work may have been done on a service line, thus rendering the as-built null and void Process of going through the record drawings can be time consuming EPA recommends that tap card data be verified/supplemented by other sources Accuracy can vary significantly	Good	Low
	Predictive Modeling and Machine Learning	Reduces the number of physical verifications required Can help utilities prioritize where to perform verifications and replacements Can be used to check accuracy of historical records	Based on assumptions and will have some margin of error Requires visual validation through other methods described herein Data may be skewed if system consists of various towns with different installation practices Data may be skewed if data is not randomly distributed Requires state approval prior to use as an identification method	Better (highly depends on the quality of data input)	Low
Interior Verification Methods	Door-to-Door Inspections	In-person relationship building with a customer More accurate than homeowner-provided photos Can load information from a mobile app directly into inventory database Can supplement inspection with a lead swab or water sample High response rate when people are home	Only provides information on the interior private side of the line and the interior material may differ from the private side buried material Some interior service line pipes are inaccessible (i.e. crawl spaces) Method is very time and resource intensive Better to do in evenings and weekends to catch people at home but this may require paying overtime	Better (buried pipe is not confirmed with this method)	Medium
	Customer-Provided Data	Provides higher accuracy data than desktop review alone Does not require in-person inspections, can be done over mail and electronically Online survey can be linked directly to the addresses in the master inventory database Opportunity to communicate with customers and empower them to assist in this effort Can reach many people quickly	Survey and photos may have data inconsistencies and data must be reviewed by the utility Some interior service line pipes are inaccessible (i.e. crawl spaces) Only provides information on the interior private side of the line and the interior material may differ from the private side buried material Homeowners that are not technologically savvy may not be able to complete the online survey Lower response rate than door-to-door inspections	Good (buried pipe is not confirmed with this method)	Low
	Past/Current Projects Inspections	Optimizes utility efforts and funding Minimal additional effort by utility personnel	Likely only a single point of inspection on the service line which can change throughout the line Outside contractors may not input data directly into data management system requiring additional time and possible errors in copying over data Not likely to result in a large number of inspections quickly (with the exception of a meter replacement project) but can provide verifications over time	Best	Low
Exterior Verification Methods	Meter Inspections	Avoids having to go into the house if the meter is outside Depending on the type of meter box, can provide the buried private-side and utility-side materials	Method is time and resource intensive Pipe attached to meter inside the meter box may not represent the material of the service line Meter boxes can be filled with dirt over time and pipe may not be easily accessible	Better	Medium
	Mechanical Excavation	Considered to be the most accurate verification method Can capture both the buried private-side and utility-side materials Can be done simultaneously with a replacement program to minimize disturbance and cost	Method is very time and resource intensive Unless a full trench is dug, only captures a small section of the buried service line and pipe materials can vary along the line Conducting test pitting in customer's yards is disruptive and requires restoration May disturb a lead service line and release particulate lead into the drinking water May need to dig on private property to obtain private-side material Requires heavy equipment (backhoe)	Best	High
	Vacuum Excavation	Can be less invasive and cheaper than mechanical excavation Can capture both the buried private-side and utility-side materials Can be done simultaneously with a replacement program to minimize disturbance and cost Can be done faster and requires less restoration than mechanical excavation	If smaller hole is created from vacuum excavation, there is a higher risk service line material cannot be accurately verified Requires heavy and specialized equipment (vacuum truck) May have to perform two vacuum excavations for each home if need both utility and private side materials May need to dig on private property to obtain private-side material May disturb a lead service line and release particulate lead into the drinking water	Better/Best	High
Emerging and Other Methods	CCTV/Camera	Non-destructive testing method that does not require excavation Potential to see entire private-side service line including buried section A greater length of pipe can be analyzed than other identification methods	CCTV/camera typically used for general pipe condition/leak assessment, and less for pipe material identification Corrosion or scaling on the pipe may not allow for the pipe material to be identified Access inside the home would be required if inserting at meter and meters are located inside Dismantling the interior meter or some pipe joints would be required to insert the camera if curb stop does not allow for access into the pipe May disturb a lead service line and release particulate lead into the drinking water Less likely to confirm the absence of LSLs than presence of	Better (higher if the pipe wall is visible)	High
	Water Quality Sampling	Expands data available to the utility and to the homeowner with a water sample Opportunity for public education with customers May incentivize homeowner to allow for the replacement with high lead levels	Accuracy and cost depends on which sampling protocol is used (e.g. targeted service line vs. flushed vs. sequential sampling) Invasive to residents with stagnation and sampling If sampling performed by resident, quality of data can vary Water quality sampling is better at confirming the presence of a LSL, may not rule out the absence of an LSL Requires state approval prior to use as an identification method	Good (Better for detection of LSL than determining absense of)	Medium
	LiDAR	More accurate the visual inspection alone Non-destructive testing method that does not require extensive excavation	Pipe must be exposed so that the hand-held laser analyzer can be used on it requiring interior access or a test pit Process is time and resource intensive Requires state approval prior to use as an identification method	Better	Medium
	Sound or Magnetic Waves	Non-destructive testing method that does not require extensive excavation Does not require going inside the house May be able to determine if pipe material changes within the service line	Technology is in development and not yet commercially available Equipment required to be purchased Time and resource intensive May be impacted by traffic or presence of other utilities Requires state approval prior to use as an identification method	Unknown	Unknown

3.2 Utility Respondent Characterization Data

The study team developed and sent a survey to AWWA members to assess typical costs for service line material identification. Over 50,000 recipients were sent the "AWWA – Lead Service Line (LSL) Identification and Replacement Techniques Survey" and 34 recipients provided responses to the survey. The charts in this section present an overview of the respondent characteristics.

Figure 3-1 below shows the sizes of the Community Water Systems (CWSs) who provided responses. Fourteen of the 34 respondents represent utilities that serve populations in the range of 100,000 to 500,000 customers.

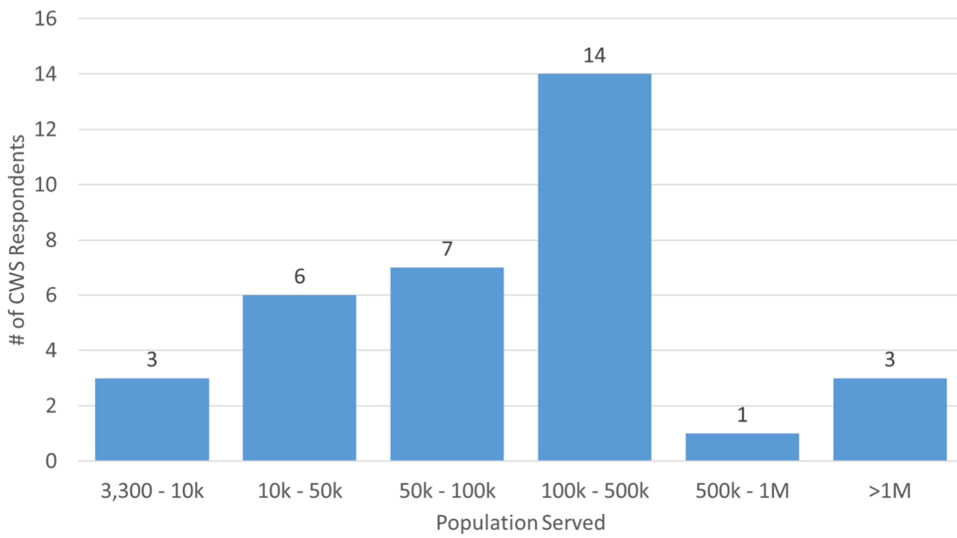

Figure 3-1 Population Served Histogram (n=34)

Figure 3-2 shows the number of LSLs reported. The cumulative number of estimated LSLs reported by all survey respondents was 467,651. The median number of LSLs across all systems was 212 LSLs, not including the utilities that stated that they have an unknown number of LSLs. Eight (8) of the respondents reported no LSLs in their system. Eleven (11) utilities did not know how many LSLs they have.

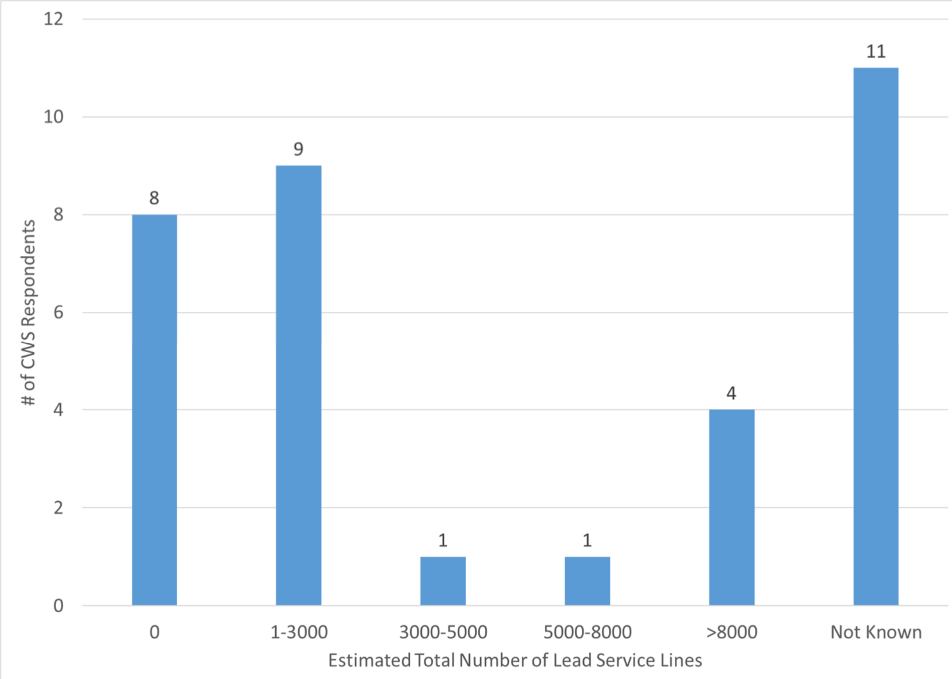

Figure 3-2 Estimated Total Number of Lead Service Lines per CWS Histogram (n=34)

Figure 3-3 displays the number of unknowns reported by respondents. The average number of unknowns reported by each utility was 31,000. The median number of unknowns was 4,300. Four (4) utilities reported zero unknowns in their systems.

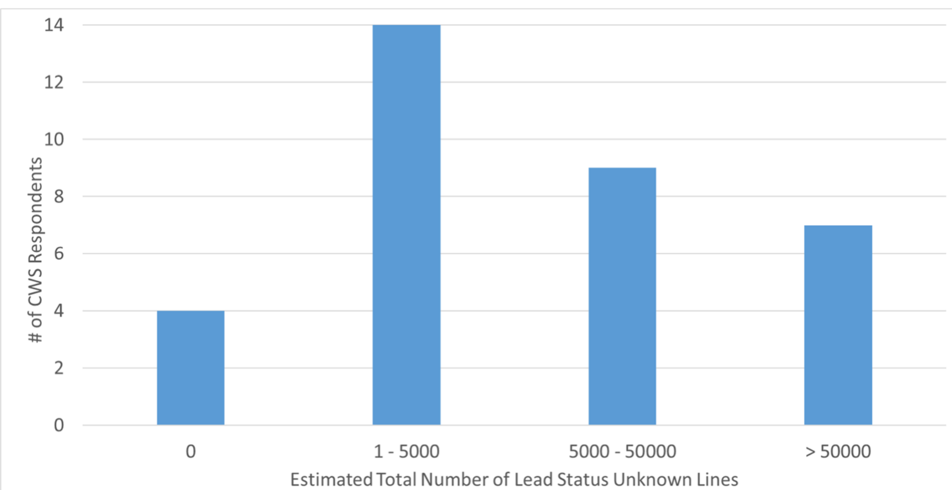

Figure 3-3 Estimated Total Number of Lead Status Unknown Service Lines per CWS Histogram (n=34)

Respondents also reported their estimated number of galvanized service lines requiring replacement and those that do not. Results are presented in **Figure 3-4** below.

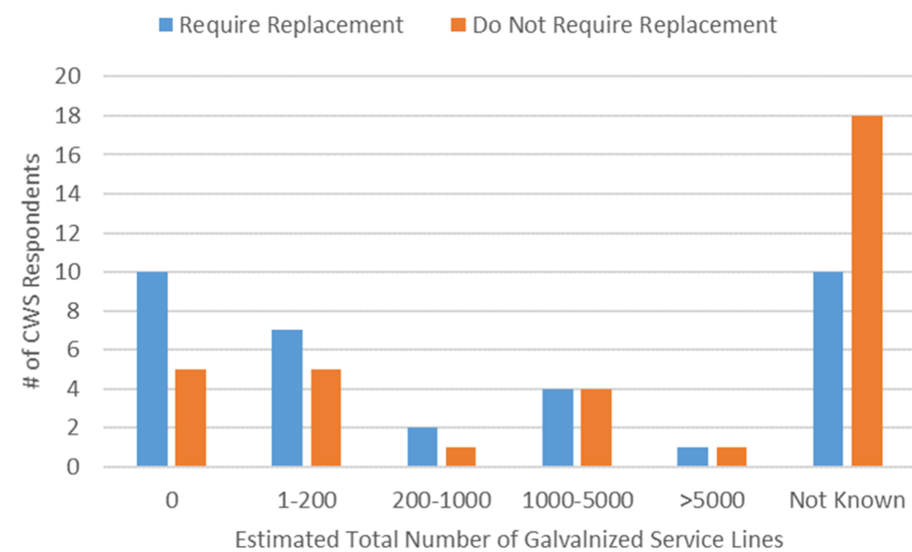

Figure 3-4 Estimated Total Number of Galvanized Service Lines Requiring Replacement and Not Requiring Replacement per CWS Histogram (n=34)

Figure 3-5 below shows the states in which the respondents are located. The respondents represent CWSs in 23 states.

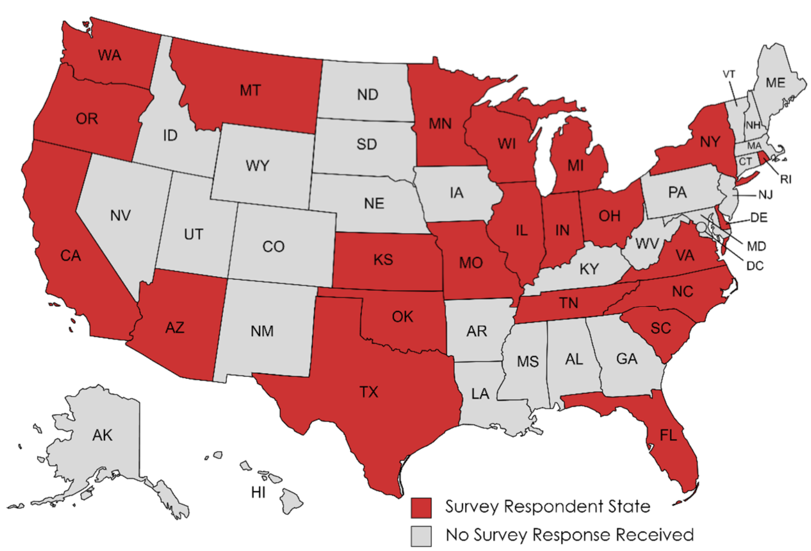

Figure 3-5 States of Survey Respondents

The surveys listed the 10 methods shown in **Figure 3-6** and asked respondents to identify which of these they have used or are planning to use. Each CWS respondent had the following four options per material identification technique:

1. Yes, with staff

2. Yes, with a consultant or contractor

3. No but planning to use

4. No and not planning to use

As shown in **Figure 3-6**, over 70% of survey respondents utilize historical records and inspections with past/current projects to discern service line material information. The survey respondents are least likely to utilize predictive modeling and machine learning, door-to-door inspections, or CCTV/camera to identify service line materials.

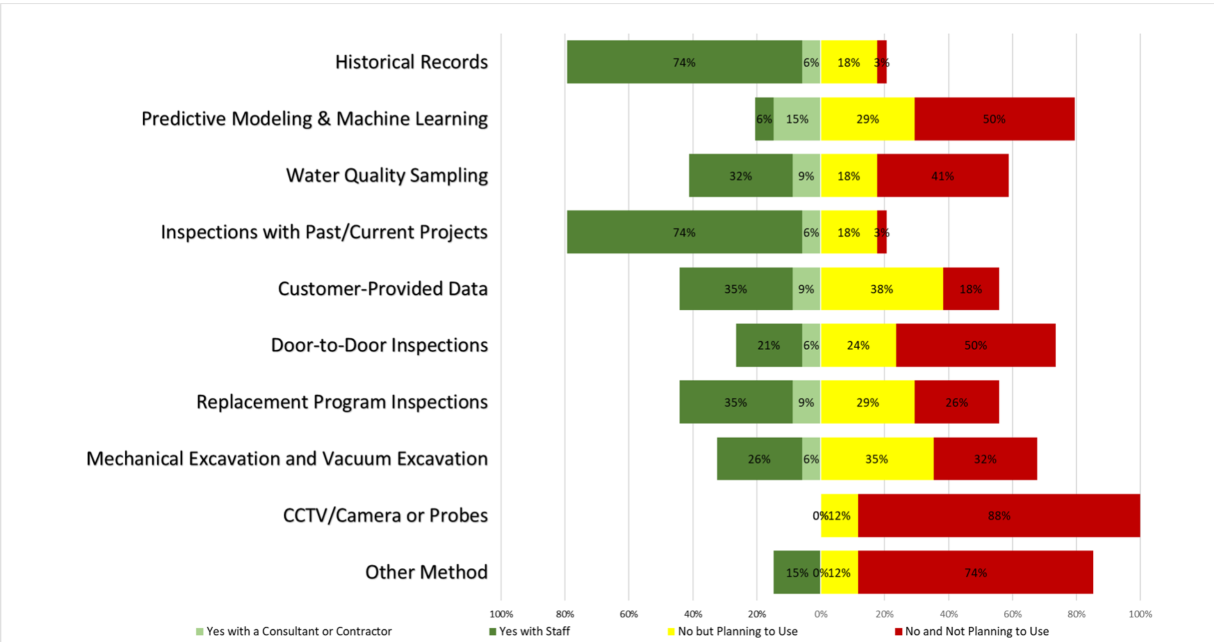

Figure 3-6 Percentage of CWS Respondents Using Each Pipe Material Identification Methods

The respondents were asked to identify the "Other" method used if it was selected. The list below represents the other methods utilized as reported within the survey:

- "Lead swab"
- "Neighborhood profiling (estimation based on year built)"
- "Scratch tests/magnet"
- "Customer-owned reporting with photos"

The survey also asked each respondent to indicate which identification method was used for the utility side and/or the customer side. **Figure 3-7** shows the frequency of each method utilized on either the utility or the customer side. As shown, field inspection with past and current projects was the most frequent method of identification used for both the utility and customer side by 79% of respondents. Additionally, 53%of the respondents used the customer provided data the most frequently to identify the lateral pipe material at the customer-owned side only.

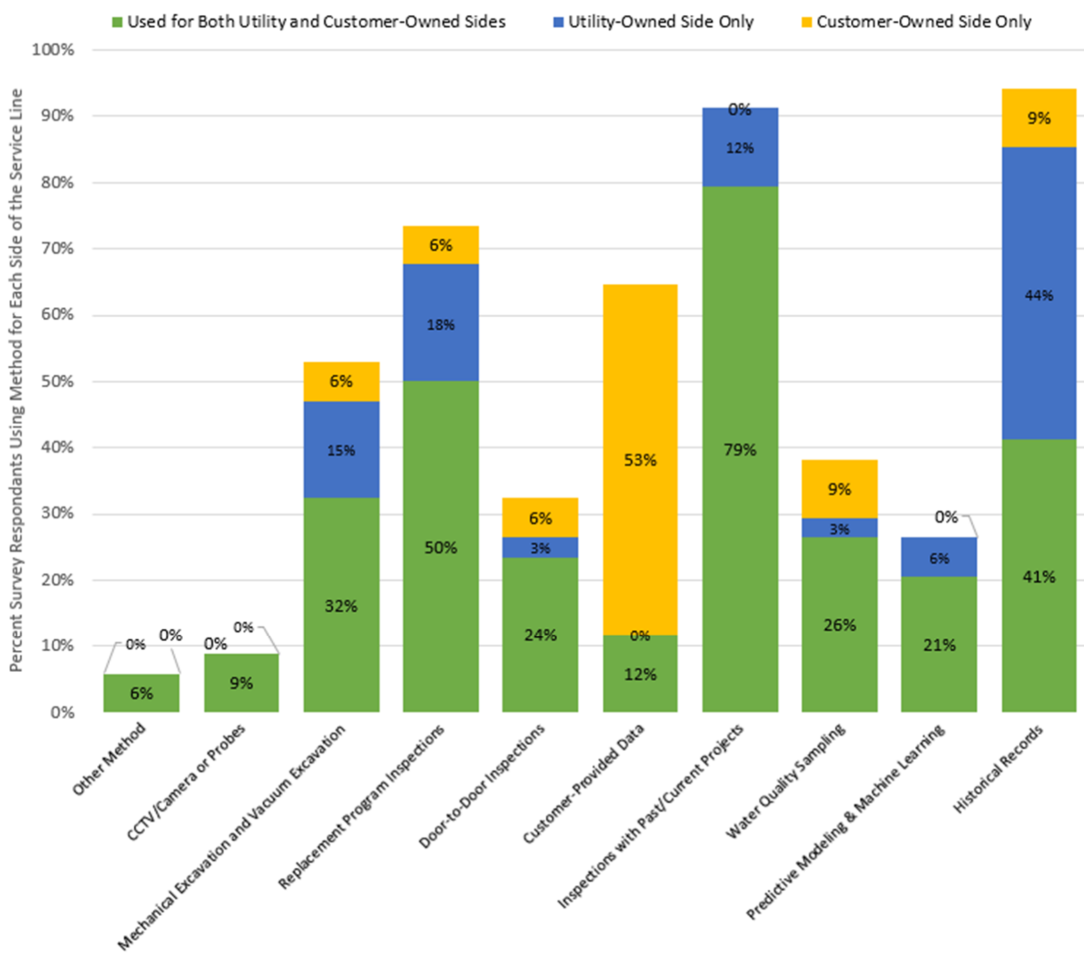

Figure 3-7 Material Identification Method Used for Utility-Owned Side, Customer-Owned Side or Both

The results of the survey developed through this study were compared to data presented in previously published literature. According to a study conducted by Deshommes, et al. (2018), "A total of 25 utilities with a known or potential presence of LSLs were contacted in 2015–2016, including 24 in Canada (located in six provinces) and one in Ohio, United States" to assess the frequency of service line identification method use. **Figure 3-8** below shows the percentage of use among the surveyed utilities of the listed identification methods.

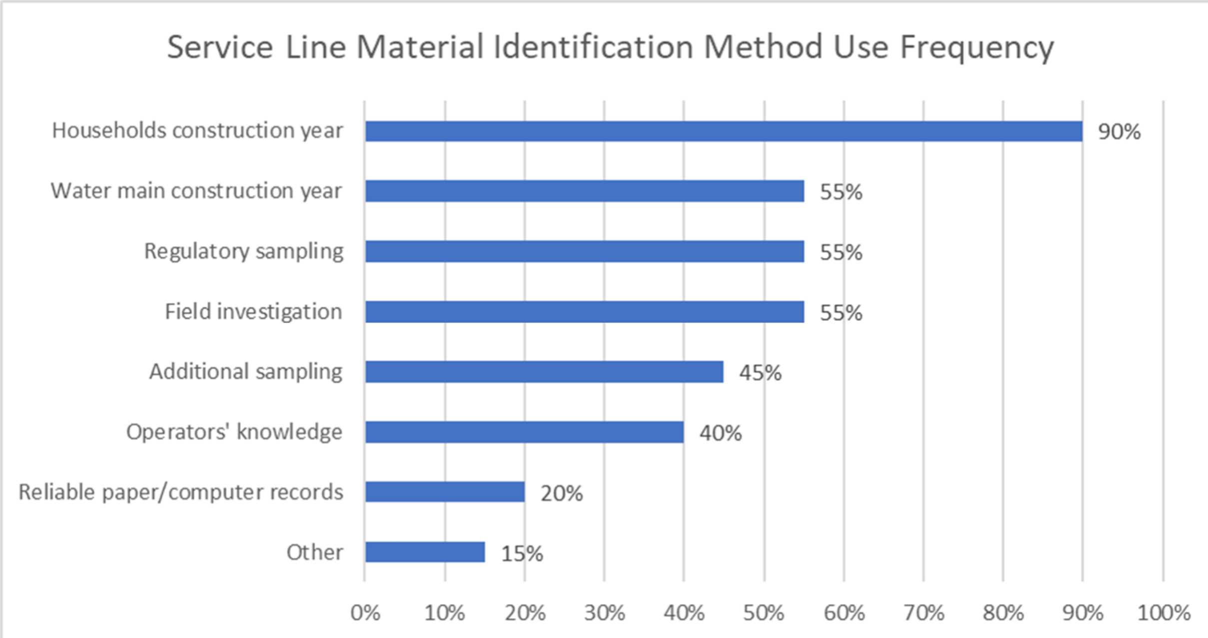

Figure 3-8 Percentage of Use of Each Lead Service Line Identification Method in Deshommes et al. (2018)

That Deshommes et al. (2018) study reports that the construction year is one of the most utilized forms of service line material identification. While this particular method was not listed as a choice in the survey associated with this study, it is assumed that "construction year" would be included in "historical records." Thus, the survey conducted as part of this study and Deshommes et al. (2018) suggests a similar frequency of historical data use as found in this study.

According to Deshommes et al. (2018), water sampling was used by 45% of respondents to identify service line material. This result is consistent with the findings of this study in which 38% of respondents indicated that they utilized water quality sampling as an identification method for either customer, utility or both sides.

3.3 Service Line Material Identification Costs

This study conducted a literature review and sent a survey to AWWA members to estimate average service line material identification costs. The unit cost calculated is the dollars per service line (SL) material evaluated through each identification method. Later in this section, method accuracy is discussed which should be taken into account to calculate cost to confirm the materials of a SL. The costs obtained through the literature review were converted to 2022 dollars utilizing the ENR construction cost indices. As shown in **Figure 3-4**, costs were provided from utilities across the country. When budgeting for identification of materials, consider adjusting the costs for year and geographic location.

3.3.1 Historical Records

Review of the historical records includes tap cards, distribution system maps and record drawings, meter installation records, historical capital improvement or master plans and standard operating procedures. Additionally, historical records include construction and plumbing code information for when lead was permitted for use in a water system and/or banned from use. By crosschecking records with the year of installation of a service line, a utility may be able to eliminate the possibility a service line is made of lead. Some advantages and disadvantages of using historical records to identify service lines is provided in **Table 3-2**.

Table 3-2 shows the costs per service line material evaluated through historical records collected through the survey and literature review. The wide range of cost is in part due to varying levels of historical record organization between utilities. For a new historical records review program specific to the inventory, as shown in **Table 3-2**, the average cost will be higher due to a greater level of effort. On the other hand, utilities that already have a database compiled with service line information developed as part of a previous effort can more efficiently develop an inventory. Where the data is available, the accuracy rate of historical records review is presented in the table for each utility surveyed or gleaned from the literature review.

Table 3-2 Cost of Historical Record Analysis for LSL Identification

US EPA Region	# of SL Material Confirmed	# of Confirmed LSLs	$/SL Material Evaluated	Source
New Historical Record Analysis Program				
1	100	64	$57.71	Survey
2	120,000	N/A	$2.25	Survey
2	340,000	504	$1.67	Survey
3	239,564	0	$1.15	Survey
6	7,900	175	$42.18	Sweeney, S., 2020
6	196,000	0	$0.59	Survey
6	166,000	N/A	$0.10	Survey
7	72,981	20,000	$7.42	Survey
AVERAGE $/SL Material Evaluated (NEW PROGRAM)			**$14.13**	
Previous Historical Record Analysis Program				
3	135,612	2,121	$0.01	Survey
4	280	0	$5.08	Survey
4	4,000	4,000	$6.43	Survey
5	2,800	1,200	$0.85	Survey
5	2,800	2,500	$6.35	Survey
10	6,528	0	$0.73	Survey
AVERAGE $/SL Material Evaluated (PREVIOUS PROGRAM)			**$3.24**	

The cost per service line material evaluated versus the number of service lines confirmed using historical methods is shown graphically in **Figure 3-9**. As shown in the graph, a trend is observed whereby the unit cost to evaluate materials decreases as the number of total confirmed service lines increases. This trend is only applicable to new historical records analyses for the inventory development (blue data points) and is likely due to efficiencies gained when there is a larger dataset analyzed. The data points in the lower lefthand corner (green data points) of the graph represent utilities whereby data had already been compiled through a previous effort, thus a much lower effort was required to convert the compiled records to an inventory.

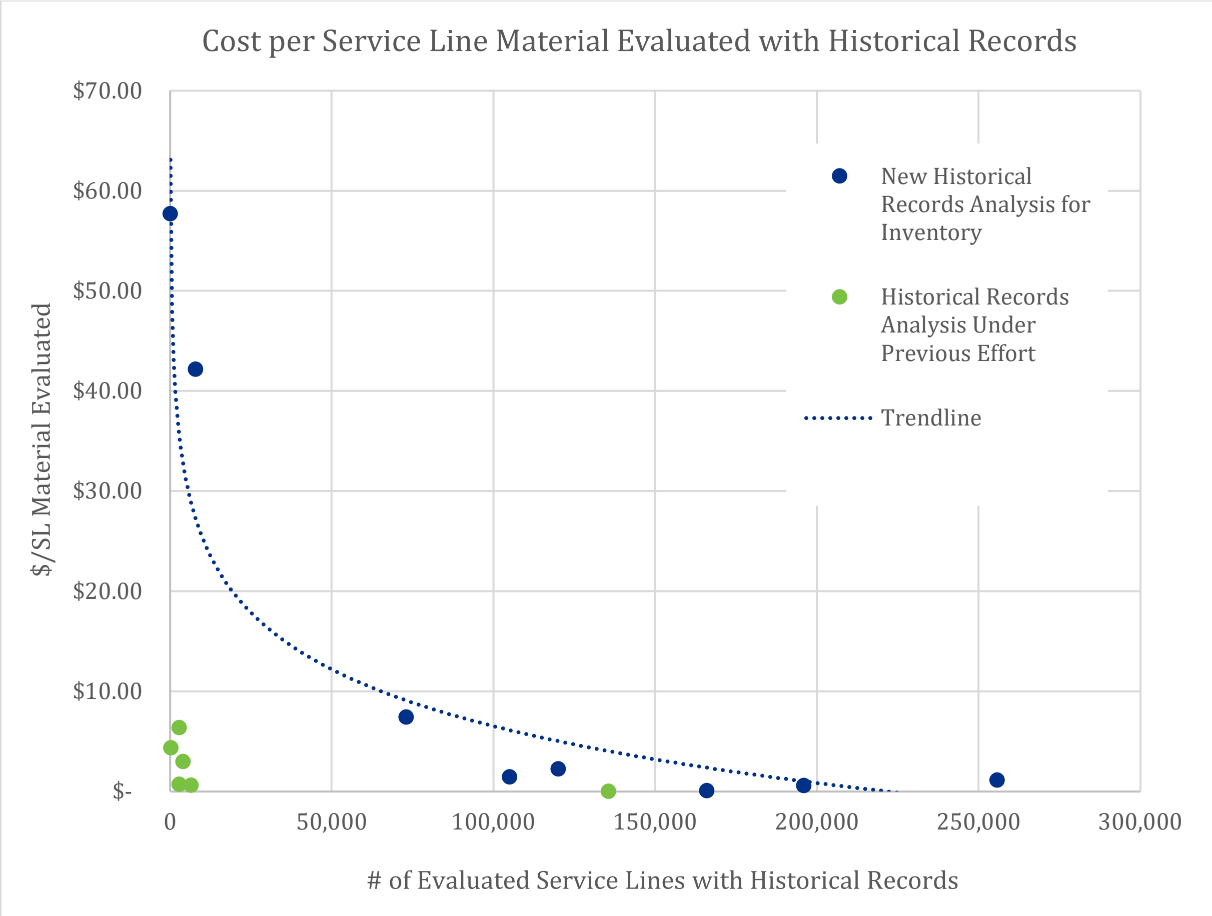

Figure 3-9 Cost per Evaluated Service Line Material with Historical Records

It should be noted that records are typically only available or only include information about one side of the water service line (utility side or private side). For example, tap cards or service cards only typically include the utility side information. Building records or plumbing records may only include the private side. The historical records may include abbreviations or lingo that requires interpretation by a technician, field personnel, etc. In one survey responders' records phrase such as "copper coming out" means the that private side of the line is made of copper material. In another case, a certain fitting is only used with one type of service line material (i.e., male Adams adapter was used to connect copper to private side galvanized in one utility's service area), so the fittings listed on the tap card indirectly indicate the material on the private side of the line. If tap cards are scanned by conversion software, some of these subtleties may be missed and/or require more effort and cost to review.

3.3.2 Water Quality Sampling

Water quality sampling can be conducted to provide insight into whether a service line upstream of the faucet may contain lead. According to USEPA (2022a), three sampling methods are proposed which have varying degrees of accuracy and cost associated. The three methods identified as per USEPA (2022a) are targeted service line sampling (water in contact with the service line), flushed sampling and sequential sampling. Both flushed sampling and targeted service line sampling begin with a flushing period followed by targeted sampling. In targeted service line sampling, a known volume of water is flushed based on a calculation of the volume of piping from the tap to the service line, whereas flushed sampling may commence after a specific time period of flushing. Sequential sampling is a methodology whereby a series of consecutive samples are taken to represent the volume in premises plumbing through the service line. Some advantages and disadvantages of using water quality sampling for material identification are included in **Table 3-1**. Water quality sampling is best used as a screening tool and can help with locating potential LSLs. It is less effective at identifying non-lead service lines since an LSL can still result in low lead levels with good corrosion control treatment or if a resident did not stagnate the water for a long enough period prior to sampling. Conversely, the presence of lead in the water sample does not always provide the location of the source of the lead, which could be anywhere upstream of the tap where the sample is collected.

Another thing to consider is what happens with the analysis results. For some utilities, they may be required to be reported to the regulatory agency as compliance samples or as non-compliance samples and may affect the utility's overall LCR sampling program. If the results are higher than trigger levels, there are notification and action requirements, as well, that may increase costs.

Survey results for water quality were inconclusive from this study as not enough utilities have used this method or accurately tracked level of effort. According to USEPA (n.d.), "Lead analysis of one water sample by a certified commercial laboratory may cost between US$20 and $100." Of the three water quality sampling methods, sequential sampling is considered to be the most accurate method to estimate service line materials using water quality sampling and is also the costliest with an estimate of 8 to 15 samples per service line (Hensley et al. 2021, as cited in USEPA 2022a). It is recommended that a utility in the United States planning to estimate water quality sampling for service line identification budget an amount within the range of $110 to $240 for one flushed sample to a range of $290 to $1,140 for sequential sampling per service for the analysis. In addition, labor and/or shipping to a third party would need to be added to that cost. Assuming an average of 10 samples per location at a cost of $20 to $100 per sample ($200 to $1,000) and two hours of labor per house for travel, coordination, and sampling ($90 to $140), the estimated cost for using sequential sampling method ranges between $290 and $1,140. The cost for one flushed sample would range from $20 to $100 with an estimated two hours of labor for bottle drop-off, pick-up and coordination with the residents would be an estimated $90 to $140. The overall cost for one flushed sample would range between $110 and $240. **Table 3-3** presents the cost ranges for sampling methods.

Table 3-3 Water Quality Sampling Costs per Service Line Identification

Water Quality Sampling Method	Cost Range per Service Line Evaluated	Average Cost/Evaluated SL Material
Sequential Sampling	$290 - $1,140	$715
Targeted Service Line or Flushed Sampling	$110 - $240	$175

Another source found in the literature was from a Canadian study, which listed a cost of $7.75 (USD) for a sampling method developed at École Polytechnique de Montréal (Chen M.J. et al 2018). This source was not included in the range of costs summarized in Section 3.2.7, as it appears to be much lower than typical reported water quality testing costs.

Since flushed sampling and targeted service line samples are not typically able to confirm absence of a lead pipe, the cost for using this method to confirm SL materials is likely to be higher when taking into account accuracy than shown in **Table 3-3** as only a percentage of the lines, those with higher lead results, would be able to be confirmed. However, when combined with other methods, such as historical records evaluation or interior inspections, water quality testing can be used as an additional verification step.

3.3.3 Inspections with Past and Current Projects

For some meter configurations, when a utility conducts a meter replacement or excavates a service line for any reason, the service line materials may be inspected and recorded at the same time. A utility may utilize this opportunity to not only complete the scope of current projects, but also to achieve material verification requirements for their service lines as stipulated under the Lead and Copper Rule Revisions (LCRR). While pre-planning and training is required to identify materials and document them properly, this identification method presents possible efficiencies in the use of utility funds.

The study team assumed that the additional time required above and beyond the time already devoted to the inspection would be an estimated 30 minutes of staff time to see the material, record the information, take photographs and then update the inventory per service line. This would also apply to outside contractors providing data in a spreadsheet or hard copies and a staff person copying the data into the inventory database management system. Based on the weighted labor rates for utilities ranging in size from smallest population served to largest, the range in cost could be from **$21.78 to $35.28 per SL material evaluated.**

3.3.4 Customer-Provided Data

One common method of obtaining interior service line material information is to query the customers for the information (when the lateral pipe is visually accessible). Typically, an online survey is set up with instructions on how to inspect your service line. The EPA recommends that all responses from customers be accompanied with a photograph and checked (USEPA 2022a). Some advantages and disadvantages of this method are provided in **Table 3-1**.

Table 3-4 presents the cost data collected from the survey from three utilities who utilized this method. The costs include the time to develop and host an online survey, printing, and mailing costs to advertise the survey and the time to review the response and photo, estimated at 2 minutes per response. The cost assumes sending the postcards to a large pool of unknowns with a 25% response rate and the cost is per response received. **Table 3-4** does not reflect the costs borne by the customer in expended time to identify, document, and report service line materials.

Table 3-4 Customer-Provided Data for LSL Identification (Survey Data)

US EPA Region	Scope	# of Returned Surveys	# of LSLs	$/SL Material Evaluated
2	Postcard campaign	2,700	NA	$10.00
		25,158	504	$8.44
5	Postcard & Web Survey	800	400	$11.12
			AVERAGE	**$9.85**

Care should be exercised with customer-provided data. Requesting photographs for independent verification helps increase confidence in the data collected and may be expected by some state primacy agencies given EPA guidance. Reviewing photographs adds time and cost per identification. Furthermore, in some areas of the country, especially in some communities in New Jersey, New England, and the Mid-West, galvanized iron or galvanized steel water service pipes may be lead-lined, which is not distinguishable through visual inspection or lead swabbing of the exterior of the pipe. Further work would be necessary to determine whether galvanized material should be considered the same as lead until proven otherwise.

3.3.5 Door-to-Door Inspections

Utilities may elect to go door-to-door to conduct service line material inspections rather than relying on the resident. Some advantages and disadvantages of this method are listed in **Table 3-1**. An advantage of this method is more consistent evaluations. Lead swabs can also be used to identify lead pipe materials, although the lead swabs would not identify lead-lined galvanized lines as discussed in Section 3.2.4. A pack of 8 lead swabs currently costs approximately $35, or $4.50 per lead swab. If lead swabbing will be conducted during a door-to-door inspection campaign, a cost of $4.50 per service line should be added to the cost of door-to-door inspections. If conducting a lead swabbing program whereby lead swabs are sent to customers, utilities must account for lost investment when swab materials are sent to non-responsive customers. **Table 3-5** below presents the costs provided by utilities through the study survey.

Table 3-5 Door-to-Door Inspection Data for LSL Identification (Survey Data)

US EPA Region	Scope	# of Confirmed Material	# of LSLs	$/SL Material Evaluated
5	Door tags if customer not home, approx. 15 min per inspection	550	250	$53.92
5	Utility personnel conduct home service line inspection (0.5 hr – 3 hr per inspection)	300	100	$103.79
9	Contractor inspections	6,000	0	$50.00
			AVERAGE	**$69.23**

3.3.6 Mechanical Excavation and Vacuum Excavation

As discussed in the most recent EPA guidance for developing a service line material inventory (USEPA 2022a), the two categories of service line material verification excavation can be segmented into vacuum or mechanical excavation. In vacuum excavation, excavation can be conducted by discharging a high-pressure jet of water or air to displace the subgrade. Typically, air jetting excavation is used in locations where sensitive utilities may be located. Excavation using a water jet is faster than air excavation but can cause additional disturbance to the utilities. A vacuum truck is used to remove the spoils from the area and expose the service line for material verification. Potholing utilizing a vacuum truck minimizes the amount of restoration required to the street, sidewalk, and/or yard over the service line as compared to mechanical excavation. Mechanical excavation often requires the use of a backhoe and by necessity involves digging a larger pit. As mechanical excavation can expose a longer length of a service line, higher accuracy of material verification can be seen using this method. Excavation can be a highly disruptive process interfering with traffic, noise, and obstructing access to buildings. It also requires restoration of street, sidewalk, and yard. Properly conducted, vacuum excavation is less likely to disturb lead scales within the pipes than mechanical excavations. If both the utility and customer sides of a service line need to be verified, two or more excavations or test pits would be needed and the cost of at least two excavations must be accounted for in budgeting and planning. **Table 3-1** provides some advantages and disadvantages of these methods.

Table 3-6 below presents the cost data collected through the identification survey and through a literature review. The costs below do not consider the location of lead connectors as those require an excavation in the street. The data was provided by utilities in EPA regions 1, 2, 3, and 5. Additionally, cost data from Canada were included. This table includes only excavations performed separate from a replacement program. When conducted with a LSL replacement program or water main replacement project, costs are typically less since the equipment is already there and test pits can be done during downtime.

Table 3-6 Cost Ranges for Mechanical and Vacuum Excavation Methods

US EPA Region	# of Confirmed Material	# of LSLs	$/SL Material Evaluated	Source
Mechanical Excavation				
1	Not Provided	Not Provided	$1,000	Survey
1	Not Provided	Not Provided	$1,700	Survey
2	Not Provided	8,000	$1,000-$1,500	Survey
5	209,313	163,042	$700	Survey
5	7,000	1,470	$1,700-$2,500	Hensley et al., 2021
International	53	700	$590	Chen, M.J. et al., 2018
International	Not Provided	Not Provided	$500	Deshommes, E. et al., 2018
Vacuum Excavation[1]				
2	Not Provided	Not Provided	$240	Survey
3	Not Provided	Not Provided	$380	Survey
3	730	776	$450	Survey
8	7,150	4,205	$280	Survey
General	Not Provided	Not Provided	$80-$400	Hensley et al., 2021
		MECHANICAL EXCAVATION AVERAGE	**$1,120**	
		VACUUM EXCAVATION AVERAGE	**$320**	

Note:
1 To identify both sides of a service line (utility and customer), two potholes are often required, meaning the cost may have to be doubled.

3.3.7 CCTV/Camera or Probes

Another option for service line identification is to utilize closed circuit television (CCTV) or probes to verify the service line materials. CCTV can be done with an interior inspection (entering the pipe by disconnecting the meter or curb box) or an exterior inspection (inserting the camera into the curb box housing). Probes, including electro-scanning, can be inserted into pipes from either the disconnected meter or curb box.

For interior inspections, if a corrosion scale has formed on the inside of the pipe, it may be difficult to see the material of the pipe. For curb boxes with telescoping pipes extending vertically with an arched bottom section, an exterior inspection can be performed by lowering the camera to see the service line on both sides of the valve box without entering the pipe. If a "wiped joint," or bulb-shaped, connection is seen, the pipe can be classified as an LSL. Identifying non-LSLs is more challenging and not as accurate as a small portion of the line may have been replaced adjacent to the curb box valve (USEPA 2022a). Additionally, internal CCTV cameras or probes are likely to disturb the scale and increase the lead concentration in the drinking water. Therefore, flushing and other post-disturbance protocols, such as providing a point-of-use filter, should be considered in the effort and costs of this technique, as well.

None of the utilities from the survey conducted through this study provided indication of cost of utilizing CCTV or probe methods, nor did they indicate that they had utilized it as a method for service line material verification. However, the study team reached out to two utilities (EPA Regions 3 and 5) that are currently using the CCTV method and their reported costs are provided in **Table 3-7**. One utility uses the internal CCTV method and the other uses the external method. The utility using the external method reported a cost of $286 per curb box inspection using CCTV. However, only approximately 7% of the total number of curb boxes inspected were able to identify the pipe material and the remaining service lines remained unknown. Therefore, a cost of $3,000 is the true cost per confirmed material to account for the inspections that did not result in a confirmed material. This cost does not include the filter or time for flushing. The utility using the internal CCTV method stated that they send out two technicians for half an hour each, at a labor rate of $80 per hour. The camera itself costs $150 and assuming it can be used over 100 times, an additional $1 per service line material inspected was added to the labor cost, to give a total per service line inspected cost of $81.

Table 3-7 Average Costs of CCTV for Service Line Material Verification

US EPA Region	Service Line Material Verification Method	$/SL Inspected
3	CCTV Camera – External	$286
5	CCTV Camera – Internal	$81
8	Electro-scan Interior Probe	$168.20

The study team also reached out to one manufacturer of an electro-scanning interior probe device. This device is an emerging technology for material identification purposes and there are no completed case studies with utilities using this device. The company's reported costs are estimated based on the average cost of the device ($80,000) and an assumed number of 1,000 scans for the first 2 years of the device which would be a total cost of $80 per SL material evaluated. The manufacturer states that two workers can complete 15 service line scans in an 8-hour day, so the study team conservatively applied 1.25 hours of labor at the highest rate for the largest utility size as shown in **Table 1-1**, or an additional $88.20 per service line evaluated, The manufacturer reports 100% accuracy for detecting lead, however, accounting for human error, an accuracy of 90% is assumed until field data is available showing a higher accuracy. It should be noted that this cost estimate assumes that the utility will purchase the device and use internal staff for the investigation.

Contractors may also purchase the electro-scanning device and charge the utilities at their own rate for their service to scan the service lines. This is estimated to be approximately $500 per SL evaluated. For this method, if there are a high number of unknowns, it may be economical for a utility to purchase the unit and conduct the investigation themselves. Alternatively, small systems or those with fewer unknown services may experience cost savings hiring a contractor to do the work with the contractor's device. An advantage of this device is that it can evaluate both sides of the service line. A disadvantage is that it may cause disturbance to any scale that has formed on a lead or galvanized pipe and temporary increased lead concentrations in the drinking water are possible. It is recommended that a point-of-use filter is provided along with a detailed flushing protocol for each service line inspected using this device or any device that inspects the interior of the pipe.

3.3.8 Predictive Modeling & Machine Learning

Predictive models, or machine learning models, estimate the probability that a service line of unknown material is lead based on known service lines with similar attributes. Predictive modeling requires continuous updates as new information is available, such as newly physically verified service lines that were previously unknown. It is also a useful tool to confirm and improve the accuracy of historical records to determine if the records can be relied on for the remaining unknowns. In USEPA (2022a), the USEPA requires state approval before using predictive modeling as a service line classification method.

None of the utilities from the survey conducted provided cost information for machine learning. The study team received a cost range from a company that performs predictive modeling/machine learning for service line identification. The cost is not linear and typically not expressed as cost per service line identified. This is because the greatest effort is in the building and setting up of the model, which is similar for small and large utilities. Therefore, the cost of predictive modeling per service line will generally be less for larger utilities than smaller utilities. **Table 3-8** provides typical costs for predictive modeling in systems with 5,000 and 100,000 unknown service lines. This cost does not account for the physical verifications that need to be completed in order to develop the model. If a utility is planning to utilize this method, the cost of conducting physical verifications must be included. The State of Michigan requires systems with fewer than 1,500 unknowns to physically verify 20% of the total number of unknown service lines (EGLE 2020). For systems with more than 1,500 unknowns, enough service lines need to be verified to reach a 95 percent confidence level in the predictions. For planning purposes, an estimated 20% of service lines in a system should be assumed to need to be physically verified to improve the accuracy of the model enough to consider it a verification method.

Table 3-8 Average Costs of Predictive Modeling

Number of Service Lines	Predictive Modeling Cost	$/SL Material Evaluated (After Initial Approximately 20% Physical Verifications)
5,000	$15,000 - $25,000	$3.00 - $5.00
50,000	$30,000 - $60,000	$0.60 -$1.20
100,000	$45,000 - $100,000	$0.45 - $1.00
500,000	$100,000 - $120,000	$0.20 - $0.24
AVERAGE Based on Survey Responses – 31,000 unknowns on average	**$40,000**	**$1.30**

Notes:
1 Estimated costs do not include the required additional costs associated with physically verifying approximately 20% of the unknowns to develop and calibrate the model.
2 Costs are estimated and can vary significantly based on system variability. Costs may be higher than listed for systems with high variability in their system.
3 Estimated costs assume confirmation of accuracy of records yields some correlation. When no records are available or if they are found to be inaccurate, costs can be expected to be higher than listed.

3.3.9 Conclusion

Estimating the actual cost involved with service line material verification is complex. Many utilities do not track separate manhours and costs spent on service line identification activities, as often activities conducted by utility staff serve multiple purposes. Additionally, internal costs are often not tracked, therefore, the costs for reviewing historic data and documents, for example, are likely low estimates. Due to EPA requirements, historical records review is required to complete the service line inventory. Thus, the cost of historical records review must be planned for, and any additional identification costs added to this cost.

Table 3-9 provides a summary of cost ranges and averages for each type of service line material verification method evaluated in this study. These planning-level costs may be used by utilities budgeting for a service line material verification program. A utility is likely to utilize multiple verification techniques in the process of developing and updating their service line material inventory. The utility must plan for the cost of utilizing multiple verification methods, sometimes even for the same service line (e.g., historical records analysis followed by predictive modeling followed by vacuum excavation confirmation).

Table 3-9 Cost Ranges and Averages for Service Line Material Verification Methods

Identification Method	Cost Range ($/SL Material Evaluated)	Average Cost ($/SL Material Evaluated)	Identification Method Used For (Utility-Side, Customer-Side or Both)
Historical Records (New Program)	$0.10-$57.71	$14.13	Utility-Side (and sometimes Customer-Side)
Water Quality - Sequential Sampling	$290-$1,140	$715	Both
Water Quality - Flushed/Targeted Service Line Sampling	$110-$240	$175	Both
Inspections with Past & Current Projects	$21.78-$35.28	$28.53	Both
Customer-Provided Data	$8.44-$11.12	$9.85	Customer-Side
Door-to-Door Inspections	$50.00-$103.79	$69.23	Customer-Side
Mechanical Excavation	$500-$2,500	$1,120	Both
Vacuum Excavation	$80-$450	$320	Both (double cost)
CCTV/Camera – External	$286	$286	Both
CCTV/Camera – Internal	$81	$81	Both
Electro-scan Interior Probe (1,000 inspections)	$168.20	$168.20	Both
Predictive Modeling (after initial ~20% physical confirmation)	$0.20-$5.00	$1.30	Both

Figure 3-10 below displays the service line material verification method average costs in a graphical form. As shown in the figure, costs vary widely based on method. The costs represent the approximate cost prior to considerations of accuracy.

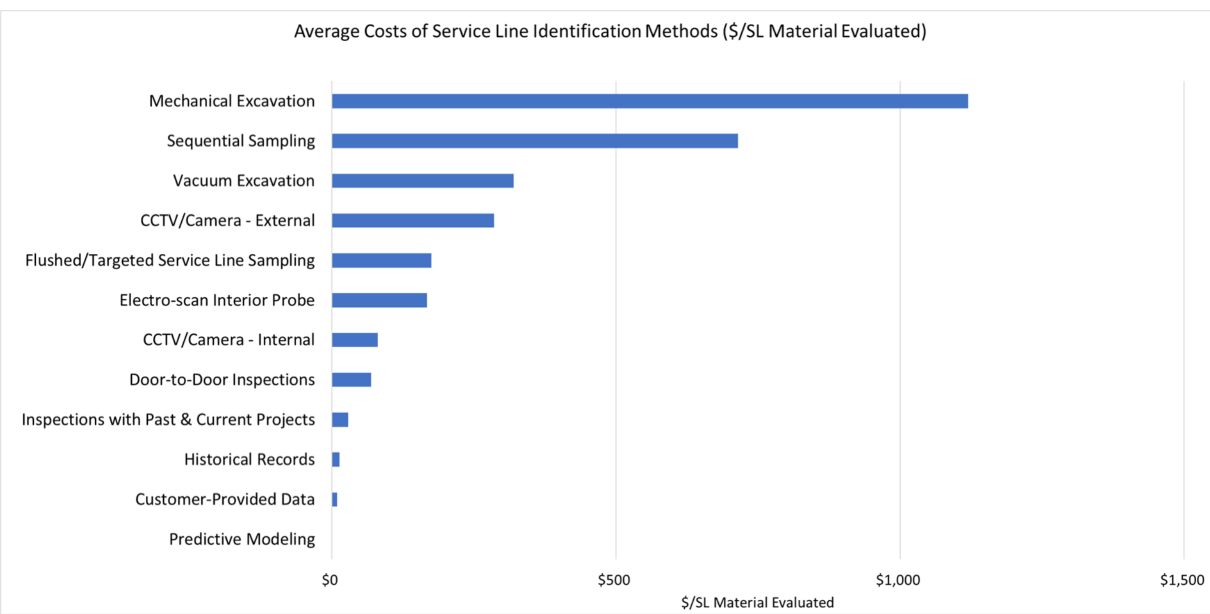

Figure 3-10 Average Costs of Service Line Identification Methods ($/SL Material Evaluated)

The costs presented in **Table 3-9** and **Figure 3-10** do not take into account accuracy. The accuracy rate of a given material identification method will influence the overall cost borne by the utility since another method will need to be used for a service line unable to be identified by the first method. An example would be if a water sample is unable to confirm a service line material and a follow-up physical inspection is required. Another example would be if a utility were to conduct a test pit (mechanical excavation) program, where 1,000 test pits are performed, but only 900 of the test pits result in identification of the service line material. In this case, if taking into account accuracy in the cost of a program, the cost of the test pitting program per service line should be divided by the number of service line materials confirmed, rather than the number of test pits performed resulting in a higher unit cost.

Table 3-10 presents an estimated accuracy rate of each method in being able to identify service line materials. The accuracy rates presented in **Table 3-10** are estimated from case study data and from the authors' experience. Accuracy rates will vary widely based on a given system, as noted in the table.

Table 3-10 Average Cost and Accuracy for Service Line Material Verification Methods

Identification Method	Average Cost ($/SL Material Evaluated)	Estimated Accuracy in SL Material Determination	Average Cost ($/Confirmed Material)
Historical Records	$14.13	60%-95%	$14.87-$23.55
Water Quality - Sequential Sampling	$715	Since only used to confirm LSL rather than to confirm non-lead, depends on % of LSLs in system - 50% used for comparison purposes	$1,430
Water Quality - Flushed/Targeted Service Line Sampling	$175	Since only used to confirm LSL rather than to confirm non-lead, depends on % of LSLs in system and effectiveness of corrosion control - 20% used for comparison purposes	$875
Inspections with Past & Current Projects	$28.53	90%	$31.70
Customer-Provided Data	$9.85	75%	$13.13
Door-to-Door Inspections	$69.23	90%	$76.92
Mechanical Excavation	$1,120	95%	$1,179
Vacuum Excavation	$320	90%	$355.56
CCTV/Camera – External	$286	7%	$4,086
CCTV/Camera – Internal	$81	80%	$101
Electro-scan Interior Probe (1,000 inspections)	$168.20	90%	$186.90
Predictive Modeling (after initial ~20% physical confirmation)	$1.30	Highly dependent on input data – possible to get over 90% accuracy (80% accuracy used for analysis purposes)	$1.63

Figure 3-11 below displays the service line material verification method average costs in a graphical form when accounting for estimated accuracy. As shown in the figure, the order of methods is different from **Figure 3-10** when accounting for accuracy.

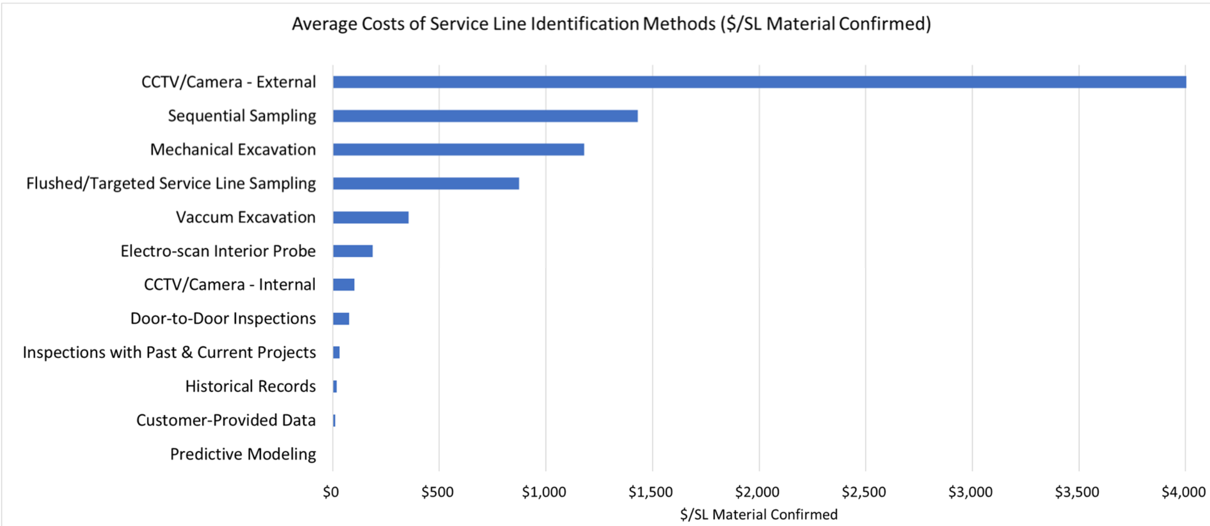

Figure 3-11 Average Costs of Service Line Identification Methods with Estimated Accuracy ($/SL Material Confirmed)

3.3.10 Case Study Examples

As previously stated, a utility will likely use a combination of these methods to build their inventory. Using the method presented in Hensley et al. (2021), a stepwise approach would start with the methods with the lowest costs and least disruptive to the customers to reduce the number of unknowns, saving the most costly and disruptive methods for only those unknowns that cannot be determined by other methods. The stepwise approach for two fictional example utilities is provided in **Figure 3-12** and **Figure 3-13**. **Figure 3-12** is a fictional utility that has 100,000 service line connections. **Figure 3-13** is a fictional utility that has 5,000 service line connections. The costs provided include approximate accuracy to account for the service lines evaluated with the method without resulting in a confirmed material. For historical records, **Figure 3-9** was used to estimate the historical records cost for each utility and an accuracy of 70% was applied. For predictive modeling, **Table 3-8** was used to account for the higher unit cost of implementing a model with a smaller utility compared to the unit cost of a utility with more water services.

Total estimated costs for the 100,000 services example are provided in **Table 3-11**. Total estimated costs for the 5,000 services example are provided in **Table 3-12**.

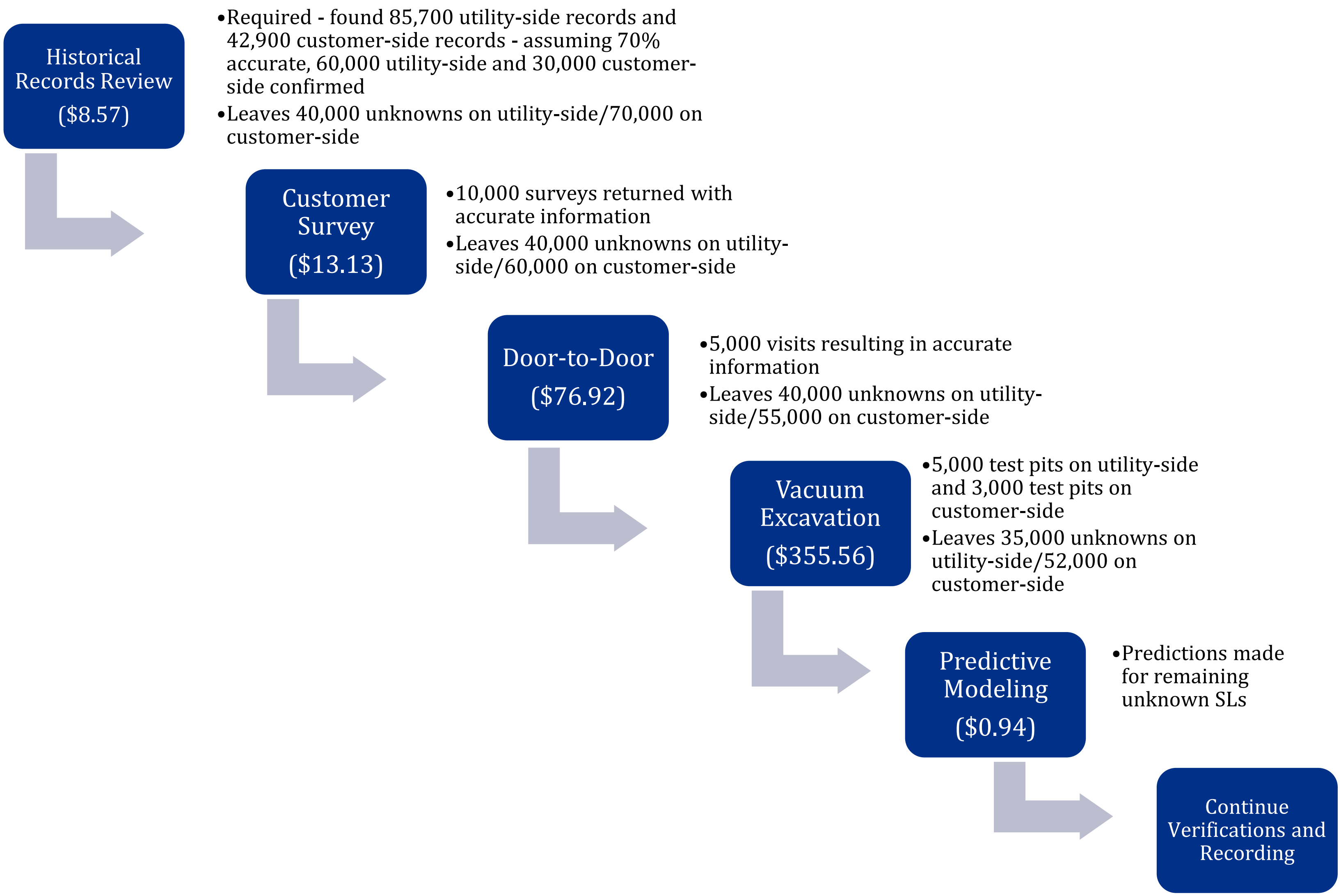

Figure 3-12 Stepwise Method Used to Estimate Cost for Fictional Utility with 100,000 Service Lines (with $/SL Material Evaluated Costs)

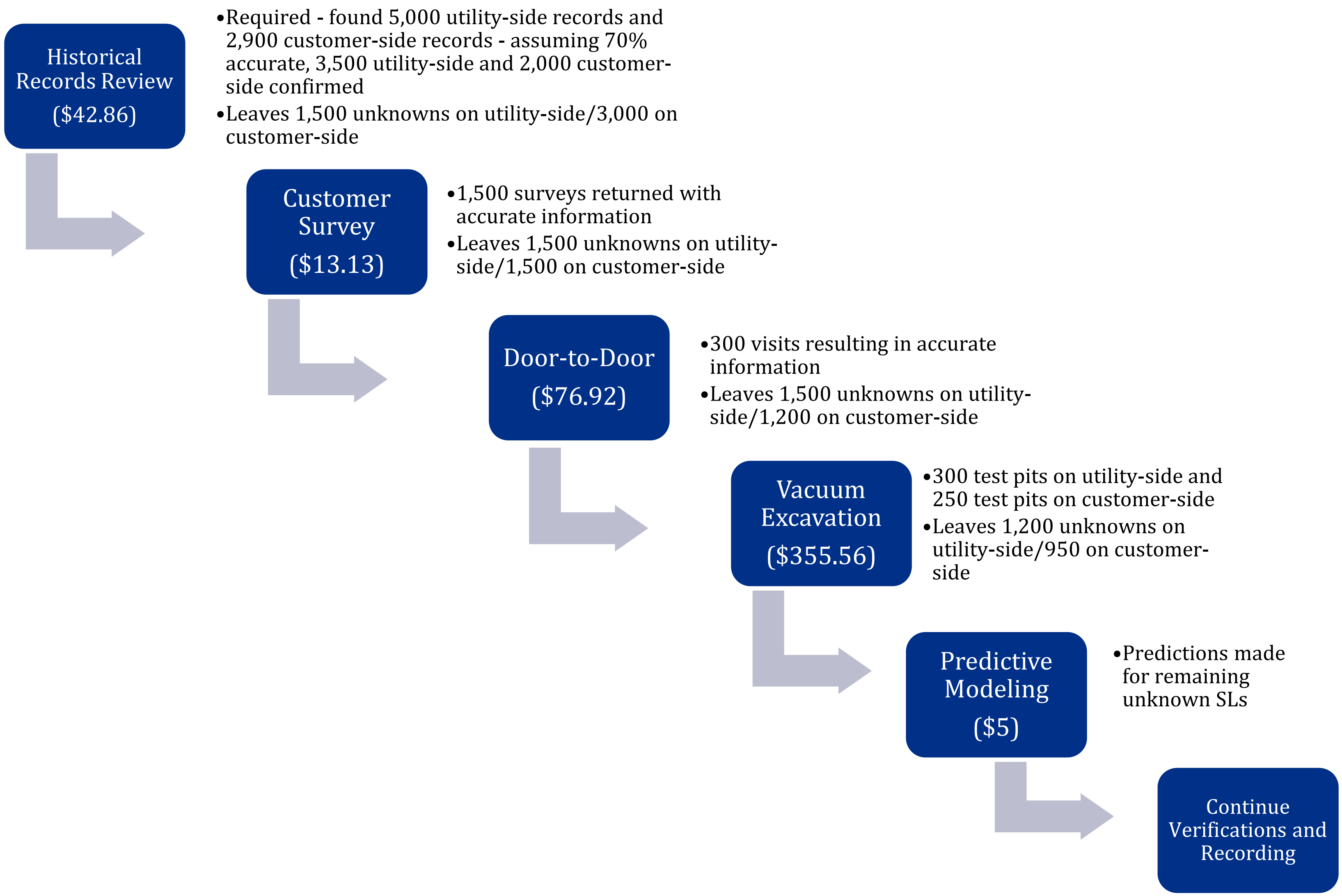

Figure 3-13 Stepwise Method Used to Estimate Cost for Fictional Utility with 5,000 Service Lines (with $/SL Material Evaluated Costs)

Table 3-11 Fictional Utility Example Identification Program Cost Summary (100,000 Service Lines)

Identification Method	$/SL Material Evaluated Unit Cost	Estimated Accuracy	$/SL Material Confirmed Unit Cost[1]	No.Utility-Side Identified	No. Customer-Side Identified	Total Cost of Method	*No. Utility-Side Unknowns Remaining*	*No. Customer-Side Unknowns Remaining*
Historical Records Review[2]	$6	70%	$8.57	60,000	30,000	$771,429	*40,000*	*70,000*
Customer Survey	$9.85	75%	$13.13	0	10,000	$131,333	*40,000*	*60,000*
Door-to-Door Inspections	$69.23	90%	$76.92	0	5,000	$384,611	*40,000*	*55,000*
Vacuum Excavation	$320	90%	$355.56	5,000	3,000	$2,844,444	*35,000*	*52,000*
Predictive Modeling	$0.75	80%	$0.94	35,000	52,000	$81,563	*0*	*0*
Total Estimated Identification Program Cost (Fictional Utility with 100,000 SLs)						**$4,273,192**		

Notes:
1. $/SL Material Confirmed accounts for estimated accuracy and the need to overlap methods at some properties (i.e. historical records and an interior inspection for example).
2. The unit cost of historical records review for a 100,000-service line utility was estimated from the trendline at $6/SL Material Evaluated. With a 70% accuracy, the estimated unit cost is $8.57.

Table 3-12 Fictional Utility Example Identification Program Cost Summary (5,000 Service Lines)

Identification Method	$/SL Material Evaluated Unit Cost	Estimated Accuracy	$/SL Material Confirmed Unit Cost[1]	No.Utility-Side Identified	No. Customer-Side Identified	Total Cost of Method	*No. Utility-Side Unknowns Remaining*	*No. Customer-Side Unknowns Remaining*
Historical Records Review[2]	$30	70%	$42.86	3,500	2,000	$235,714	*1,500*	*3,000*
Customer Survey	$9.85	75%	$13.13	0	1,500	$19,700	*1,500*	*1,500*
Door-to-Door Inspections	$69.23	90%	$76.92	0	300	$23,077	*1,500*	*1,200*
Vacuum Excavation	$320	90%	$355.56	300	250	$195,556	*1,200*	*950*
Predictive Modeling	$4.00	80%	$5.00	1,200	950	$10,750	*0*	*0*
Total Estimated Identification Program Cost (Fictional Utility with 5,000 SLs)						**$484,797**		

Notes:
1. $/SL Material Confirmed accounts for estimated accuracy and the need to overlap methods at some properties (i.e. historical records and an interior inspection for example).
2. The unit cost of historical records review for a 5,000-service line utility was estimated from the trendline at $30/SL Material Evaluated. With a 70% accuracy, the estimated unit cost is $42.86.

Section 4

Replacement of Service Lines

To quantify LSL replacement costs, this study conducted a literature review and utility phone survey of utilities that were performing full LSL replacements including both the utility and private sides of the line. The replacement costs obtained in this study are categorized into direct construction costs and auxiliary costs. The direct construction costs are well reported in literature and include the costs associated with hiring a contractor. This would typically include mobilization, excavation, pipe installation, backfill, restoration, traffic control, etc. The auxiliary costs quantified in this study are not as well reported in the literature or as well defined. These costs typically include planning, design, bidding, data management, permitting, engineering services, utility labor, construction management, customer outreach, and/or filters and follow-up sampling. The auxiliary costs were provided by utilities through a phone survey conducted as part of this study. This study seeks to account for auxiliary costs which may previously been excluded from LSL replacement program costs.

4.1 Description of Service Line Replacement Technologies

The following are typical methods for service line replacement:

- Open Trench Replacement — traditional technology for installing or replacing a service line.
- Trenchless Replacement Using New Route — a pipe replacement technology whereby the discarded pipe is left in the ground and a new pipe is installed along a different route using a trenchless method such as impact moling or horizontal directional drilling.
- Trenchless Replacement Using Existing Route — a pipe replacement technology whereby the existing lead pipe is removed or displaced while simultaneously replacing it with a new pipe. Techniques include pipe pulling which remove the pipe enables the new pipe to be installed along the original line.

4.2 Previously Available Service Line Replacement Cost Data

Estimating total construction costs associated with LSL replacements can be challenging due to the following factors which will fluctuate from project to project:

- Lengths of the service line to be replaced
- Geographical location of the service line
- Competitive public bidding, in-house construction or select preferred contractors
- Construction method (open trench, trenchless, etc.)

- Service line location (under pavement, driveway, paired with another service line is the same trench, etc.)
- Depth of service line and required excavation support based on depth
- Permitting and local code requirements
- Location and conflict with nearby utilities and features such as rocks, porches, trees, water table, etc.
- Restoration requirements

Prior to this study, LSL replacement construction costs have widely been reported in available industry literature. Cost data for lead service line replacement (LSLR) from the EPA and a previously conducted AWWA survey originally reported in 2020 (Economic Analysis for the Final Lead and Copper Rule Revisions (EA), December 2020) and subsequently revised by AWWA are shown in **Table 4-1**. The revised final costs were compiled by AWWA after the EA comments period. Since, the LSLR costs obtained from the survey responders represent a range of years they were converted to $2022. ENR's Construction Cost Index History (2016-2022) was used to convert the results of all surveys from $2016 to $2022.

Table 4-1 Summary of LSLR Construction Costs from Previously Published Surveys ($/LSLR, $2022) [2]

	LSLR Cost		
	EPA	AWWA	
	(Average)	(Average)	(Range)
Utility-Side Replacement	$2,978	$7,981	$5,625 - $10,338
Private-Side Replacement	$3,974	$4,620	$3,036 - $6,250
Full Replacement	$6,154	$10,194	$8,651 - $13,374
Planned Utility-Side Replacement (CIP)[1]	$2,436	$4,718	NA
Planned Full Replacement (CIP)[1]	$4,978	$5,140	$4,030 - $11,449

Notes:

1 LSLR conducted as part of a capital improvement program (CIP).

2 Costs escalated from 2016 to 2022 dollars in table from Economic Analysis for the Final Lead and Copper Rule Revisions, December 2020.

The reported EPA and AWWA LSLR costs shown in Table 4-1 were assumed to include field inspection, removal and replacement of the LSL, mobilization, utility coordination. In addition, LSLR costs presented in **Table 4-1** assumed inclusion of site restoration and street paving restoration except for the AWWA LSLR cost for the Planned Utility-Side Replacement. As part of the EA 2020, EPA average LSLR costs were increased by 5% to account for mobilization, utility coordination, and street paving coordination. The Planned Utility-Side and Planned Full Replacement costs are from LSLRs that were performed during infrastructure/capital improvements projects (i.e., planned projects which capture mobilization costs by the larger project effort such as crews are already in the area coordinating with other utilities and/or performing a water main replacement). Moreover, the EPA's Planned Utility-Side and Planned Full Replacement costs assumed (as part of the EA 2020) a reduction of 20% of the Utility-Side and Full Replacement costs, respectively.

The cost data presented in **Table 4-1** are the results from four surveys:

1. 2011 AWWA Lead Service Line Survey (AWWA 2011). Targeted online survey of AWWA-member systems serving > 500,000 in which 774 systems responded and 75 systems provided cost data. Costs were updated in 2016.
2. 2006 National Survey for WaterRF project, "Contribution of Service Lines and Plumbing Fixtures to Lead and Copper Compliance Issues" (Sandvig et al. 2008). Survey targeted 90 systems.
3. 2007 Drinking Water Infrastructure Needs Survey (2007 DWINSA). Survey targeted 15 systems and costs were assumed to be for utility-side replacements.
4. 2004 Survey from the AWWA, published in: "Strategies to Obtain Customer Acceptance of Complete Lead Service Line Replacement". AWWA (2005). Survey targeted 11 utilities that provided LSLR cost estimates for a 2004 AWWA survey.

To provide a complete summary of LSLR costs, including auxiliary costs, additional data were gathered as part of this study through phone interviews and an updated literature search to expand on the previous studies and published information.

4.3 Study Data Sources

The study team conducted a LSLR costs phone interview with 9 utilities across five states in the continental United States that are currently, or have previously, conducted full LSLRs. Utilities surveyed were in Illinois, Michigan, New Jersey, Pennsylvania, and Wisconsin. Among these utilities, the size of population served varied from 10,000 to almost 6,000,000. Costs provided were updated to 2022 dollars for comparison. **Figure 4-1** below displays the states where the 9 utilities interviewed are located.

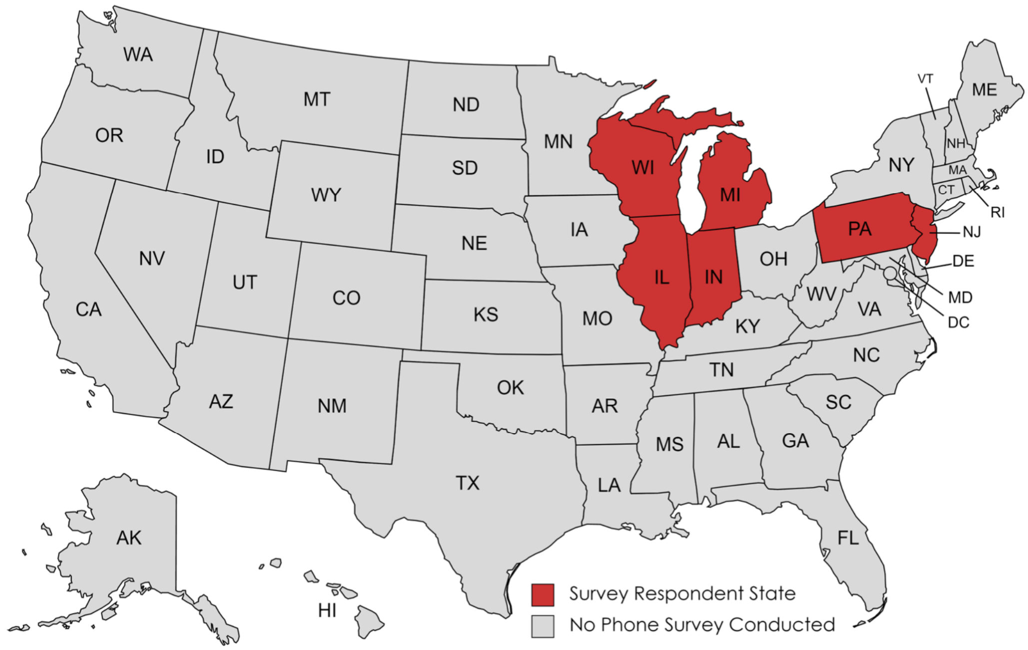

Figure 4-1 Map of Phone Survey Respondent Locations

In addition to the phone survey, this study conducted an expanded literature review to determine additional average LSLR costs. The costs obtained through the literature review were converted to 2022 dollars where applicable for comparison.

4.4 Service Line Replacement Costs

LSLR costs presented in this section are separated into the following categories:

- Construction costs – Construction costs include the costs associated with the actual physical replacement and typically involve hiring a contractor. This typically includes mobilization, excavation, pipe installation, backfill, some restoration, traffic control, etc.

- Restoration costs – Restoration costs are sometimes not included in the construction cost of LSLR. The costliest component of restoration is paving. Some towns and cities require a utility to pave curb-to-curb rather than patching only the disturbed portion. This can add significant cost to a project.

- Auxiliary costs – Auxiliary costs are not as well reported in the literature or as well defined as construction costs. Auxiliary costs typically include planning, design, bidding, data management, permitting, engineering services, utility labor, construction management, customer outreach, filters, follow-up sampling and any costs or labor associated with the replacements that is not included in the contractor's bid.

4.4.1 Construction Costs

A complete summary table of construction costs obtained through the literature review process and phone interviews is presented in **Table 4-2**. The construction costs presented include bid results and internal utility data from 45 contracts in the United States and Canada. The typical project scope items included in the construction costs are listed below:

- Mobilization/demobilization
- Full-side service line replacement
- Traffic control
- Permitting
- Excavation, excavation support and disposal of excess material
- Interior plumbing installation
- Backfill, compaction, and material testing
- Environmental protection (erosion control, dewatering)
- Restoration

When known, exclusions to the typical project scope items are noted in the "Project Scope Exclusions" column in **Table 4-2**.

Table 4-2 LSLR Construction Cost Data[1]

US EPA Region	Replacement Type	Total LSLRs	Unit LSL Replacement Costs ($/LSL) 2022 Dollars	Project Scope Exclusions	Data Source
1	Utility/Private Side Replacement	176	$6,817	None noted	Massachusetts Water Resources Authority, n.d.
1	Utility/Private Side Replacement	403	$3,276	None noted	Massachusetts Water Resources Authority, n.d.
1	Utility/Private Side Replacement	433	$7,938	None noted	Massachusetts Water Resources Authority, n.d.
1	Utility/Private Side Replacement	300	$8,131	None noted	Massachusetts Water Resources Authority, n.d.
1	Utility/Private Side Replacement	113	$6,300	None noted	Massachusetts Water Resources Authority, n.d.
1	Utility/Private Side Replacement	156	$5,842	None noted	Massachusetts Water Resources Authority, n.d.
1	Full Replacement	206	$8,014	None noted	Massachusetts Water Resources Authority, n.d.
2	Full Replacement	---	$7,399	None noted	Survey
2	Full Replacement	---	$7,669	Permit fees waived by City	Survey
2	Full Replacement	---	$8,489	Private side restoration is not included	Survey
2	Full Replacement	---	$10,822	None noted	Survey

US EPA Region	Replacement Type	Total LSLRs	Unit LSL Replacement Costs ($/LSL) 2022 Dollars	Project Scope Exclusions	Data Source
2	Full Replacement	8,000	$6,000 - $12,000	None noted	Survey
3	Full Replacement	---	$13,213	None noted	Survey
3	Full Replacement	---	$9,904	None noted	Survey
5	Full Replacement	---	$10,000	Unknown	Survey
5	Full Replacement	---	$9,253	None noted	Survey
5	Full Replacement	---	$6,391	None noted	Survey
5	Full Replacement	---	$8,670	None noted	Survey
5	Full Replacement	100	$15,000 - $30,000[2]	None noted	Survey
5	Full Replacement	---	$10,000	None noted	Survey
5	Full Replacement	---	$7,500	Unknown	Survey
5	Full Replacement	---	$12,000	Only patching included in restoration, no other exclusions	Survey
6	Full Replacement	115	$2,407 (not included in average due to limited scope)	Equipment, restoration, traffic control, permitting, environmental protection (erosion control, dewatering)	Sweeney, 2020
Canada	Full Replacement	680	$6,526	None noted	Chen et al., 2018
8	Full Replacement	5,200	$10,651	Unknown	Hawthorne, 2021
1	Private Side Replacement	---	$4,500	None noted	Jeznach and Goodwill, 2021
2	Private Side Replacement	8,000	$3,700	None noted	Survey
3	Private Side Replacement	---	$7,277	Does not include full city-required street or sidewalk restoration.	Survey
3	Private Side Replacement	---	$4,993	Does not include full city-required street or sidewalk restoration.	Survey
5	Private Side Replacement	100	$5,000 - $10,000	None noted	Survey
Canada	Private Side Replacement	259	$4,927	None noted	Krkošek et al., 2022
3	Private Side Replacement	---	$2,300-$3,400	None noted	Survey
5	Private Side Replacement	---	$4,170	None noted	OAWWA, 2020

US EPA Region	Replacement Type	Total LSLRs	Unit LSL Replacement Costs ($/LSL) 2022 Dollars	Project Scope Exclusions	Data Source
2	Utility Side Replacement	---	$8,549	None noted	Survey
2	Utility Side Replacement	8,000	$5,000 - $6,000	Does not include final restoration.	Survey
3	Utility Side Replacement	---	$5,542	None noted	Survey
3	Utility Side Replacement	---	$4,330	None noted	Survey
5	Utility Side Replacement	---	$6,472	None noted	Survey
5	Utility Side Replacement	---	$7,263	None noted	Survey
5	Utility Side Replacement	---	$4,150	None noted	Survey
5	Utility Side Replacement	---	$5,310	None noted	Survey
5	Utility Side Replacement	100	$10,000 - $25,000	None noted	Survey
5	Utility Side Replacement	---	$5,000	Unknown	Survey
Canada	Utility Side Replacement	1,437	$7,800	None noted	Krkošek et al., 2022
3	Utility Side Replacement	---	$6,000-$10,700	None noted	Survey

Notes:
1 Costs provided for work conducted prior to 2022 were escalated to 2022 dollars.
2 Cost includes open cut construction and sewer drain replacements.

A summary of the minimum, average, and maximum construction costs based on the information presented in **Table 4-2** above for full replacement, private side replacements and utility side replacements is presented in **Table 4-3** below. The average cost for a full LSLR is approximately $9,900 per LSL, while the average costs for a private and utility side replacement are $4,990 and $7,150 per LSL, respectively. In general, cost per LSLR does not vary significantly with the length of the service line since only the material cost is impacted if using trenchless methods.

Table 4-3 Summary of Construction Costs Only per LSL Replacement Type (without Auxiliary Costs)

Unit	Replacement Type	Minimum	Average	Maximum
$/LSLR	Full Replacement	$6,000	$9,900	$30,000
	Private Side Replacement	$2,300	$4,990	$10,000
	Utility Side Replacement	$4,150	$7,150	$25,000

4.4.2 Restoration

Restoration work is conducted after an LSL is removed and replaced and is not always included in the construction cost per LSLR. Restoration can include anything from patched paving to curb-to-curb paving, as well as landscaping work. In this study, the most extreme restoration cost provided by a major urban area utility in US EPA Region 3 was 46% of construction costs. This utility provided bid data for an LSL replacement program that included milling and overlay, concrete sidewalks, brick and block sidewalks, sodding, and plain cement concrete pavement repair. Restoration costs for this utility were over $9,000 per LSLR. In US EPA Region 2, an urban utility's restoration costs from bid results were approximately $2,800 per LSLR, or 30% of total construction costs, while another utility in US EPA Region 2 documented restoration costs around $450-$750 per LSLR, or 10%-15% of construction costs. It should be noted that these restoration costs did not include the potentially higher costs of restoration needed in historical districts. Certain specialty construction methods and materials needed in these areas would likely be more costly. Furthermore, as more utilities progress with LSLRs, costs for materials and/or restoration work may increase.

4.4.3 Auxiliary Costs

A survey, administered over the phone, was conducted to determine the other auxiliary costs such as planning, design, bidding, data management, permitting, engineering services, utility labor (classified under the section titled "Internal Labor Administration"), construction management, customer outreach, filters and/or follow-up sampling. Additionally, auxiliary cost data found from the study's literature review was extracted and is presented in this section.

4.4.3.1 Engineering and Inspection Services

Often, utilities or community water systems hire an outside engineering consulting firm to provide engineering services for an LSLR program. The engineering services included for an LSLR program may include, but are not limited to, the following services:

- Planning
- Design
- Bidding
- Data management
- Construction management
- Construction oversight
- Permitting
- Funding
- Public education and outreach

The scope of engineering services provided for an LSLR program can vary significantly. As shown in **Table 4-4**, the project team provided cost of overall program percentages for engineering services. These costs will vary depending on location of service offered, the scope that is covered, maturity of the water systems prior efforts, and economies of scale. The study team found that the percent of engineering service cost (often supplied by an external consultant) ranged from 2–20% of the overall LSLR construction cost. The percentage of engineering services of the overall construction will vary depending on the scope and level of effort required of the engineering services.

Table 4-4 Cost of Engineering Services for LSL Replacements (Survey Data)

Utility Location US EPA Region	% Cost of Engineering Services of Overall Construction Costs	Scope
1	20%	Design and program coordination
	8%	Design, SRF funding assistance, minimal field work investigations
	2%	Design, SRF funding assistance, bidding assistance
2	5%	Engineering design & permitting, bid services, construction admin/management, resident project representative services, GIS e-Builder, customer outreach
	7%	Engineering design & permitting, bid services, construction admin/management, resident project representative services, GIS e-Builder, customer outreach
	11%	Water quality sampling, construction management
	11%	Field inspection, construction management, payment application, data management
3	12%	Program management, construction management, inspection
5	20%	Planning, construction management, construction oversight
	10-15%	Planning, design, bidding, data management, construction management and oversight, permitting, funding, public education, and outreach
	11%	Program management, inspections, GIS analysts, laboratory services
11% (or $1,090/LSLR based on the average cost of a full LSLR in Table 4-3)		**AVERAGE**
2% (without construction management)) **to 20%** (includes construction management and inspection)		**RANGE (Project and Scope Dependent)**

4.4.3.2 Internal Labor Administration

LSL replacement programs require a utility to undertake labor administration tasks, such as project management. Even in the case that an external engineering consultant is hired to support a utility in providing engineering support, a utility must still provide their own staff labor to manage the consultant and coordinate with internal departments. Additionally, a utility will often provide staff to conduct public education and outreach within the communities where the LSLR program is taking place, perform mark-outs for the contractors and respond to emergencies and leaks. **Table 4-5** presents the internal labor administration cost data obtained through this study.

Table 4-5 Cost of Internal Labor Administration for LSL Replacements (Survey Data)[1]

Utility Location - US EPA Region	Total Annual LSL Replacements	Unit Labor Administration Cost ($/LSLR)
2	790	$345
	2,000	$281
3	2,331	$241
	AVERAGE	**$289/LSLR**

Note:
1 Costs provided for work conducted prior to 2022 were escalated to 2022 dollars.

4.4.3.3 Customer Outreach

When developing an LSL replacement program, utilities may be required to plan for costs associated with outreach and education to help communicate the LSLR program with their customers. Outreach and education may involve development of educational flyers, doorhangers, postcards, websites, facilitate public or virtual events, and more. A summary of customer outreach costs for LSL replacements are summarized below in **Table 4-6**. A cost that was identified by a utility in region 5, but is not included in the table, is the cost to have lawyers develop ordinances and customer agreements.

Table 4-6 Cost of Customer Outreach for LSL Replacements (Survey Data)[1]

Utility Location - US EPA Region	Total LSL Replacements	Unit Outreach Cost ($/LSLR)
2	23,800	$22
2	3,965	$22
3	2,331	$482
5	1,200/year	$190
8	4,800	$175
	AVERAGE	**$178/LSLR**

Note:
1 Costs provided for work conducted prior to 2022 were escalated to 2022 dollars.

4.4.3.4 Permitting

Permitting costs should also be considered when developing an LSLR program. Permitting may include local or state roadway permits, local plumbing permits, etc. Data for permitting costs associated with LSLRs were obtained and summarized below in **Table 4-7**. On average, utilities reported that permitting, including plumbing permits and road opening permits, costs approximately $950/LSLR. The permitting cost in **Table 4-7** for $3,400 is the permitting required in a densely populated urban center in EPA Region 5 and includes a sewer tap permit as the sewer is replaced in most locations where the water service line is replaced.

Table 4-7 Cost of Permitting for LSL Replacements (Survey Data)[1]

US EPA Region	LSL Replacement Type	Total LSL Replacements	Unit Permitting Cost ($/LSLR)
2	Full and Partial	4,609	$297
2	Full and Partial	3,965	$231
3	Full and Partial	Unknown	$727
3	Full and Partial	Unknown	$275
5	Full and Partial	100	$3,400
2	Full Replacement	9,500	$325-$1,200
		AVERAGE	**$950/LSLR**

Note:
1 Costs provided for work conducted prior to 2022 were escalated to 2022 dollars.

4.4.3.5 Post Lead Service Line Replacement Provisions

After an LSL replacement occurs, often a utility will provide follow-up sampling and/or filters to customers affected by the LSLR. Starting October 2024, utilities will be required to provide follow- up tap sample 3 to 6 months after a LSLR. As discussed in Section 3.2.2, Water Quality Sampling, a utility can expect to pay between $20 and $100 for one sample. Utilities will also be required to provide a filter with 6 months' worth of filter cartridge replacements starting in October 2024. Estimated filter costs were calculated in a parallel AWWA study based on four utilities and are presented in **Table 4-8**.

Table 4-8 Cost of Filters for LSL Replacements and Samples

US EPA Region	Scope	Data Source	Cost/LSLR
Various	Pitcher style filter with 6 months of cartridges	Survey	$57.50
Various	Water Sample ($20-$100)	Survey	$60
	AVERAGE TOTAL	**$117.50/LSLR**	

4.4.4 Summary Tables

This section presents a summary of the costs presented in Sections 4.4.1, 4.4.2 and 4.4.3.

The costs associated with an LSLR program that are not typically included when referring to LSLR costs, including engineering services, internal labor administration, customer outreach, permitting and post-replacement provisions are provided in **Table 4-9** as a percentage of the LSLR construction costs based on the auxillary costs in **Tables 4-4 through 4-8** and the average cost of a full LSLR of $9,900. For a full LSLR, utilities could expect to pay these auxiliary costs, an additional 26.5%, in addition to construction costs.

Table 4-9 Summary of Major Auxiliary Costs as a Percentage of the LSLR Construction Cost

Unit	Auxiliary Cost	Auxiliary Cost as a Percentage of the LSLR Construction Cost
% of LSLR Construction Cost	Engineering Services	11%
	Internal Labor Administration	2.9%
	Customer Outreach	1.8%
	Permitting	9.6%
	Post-Replacement Provisions	1.2%
	TOTAL	**26.5%**

These costs, along with construction and restoration, should be accounted for when planning for any LSLR program. A summary of the total costs associated with a LSLR are presented in **Table 4-10** and represented graphically in **Figure 4-2**. Costs used in the table are based on percentages in **Table 4-9** of the LSLR construction costs provided in **Table 4-2**.

Table 4-10 Full LSL Replacement Summary Costs

LSLR Component	Minimum Cost ($/LSLR)	Average Cost ($/LSLR)	Maximum Cost ($/LSLR)
Full Replacement (Utility and Private Side)	$6,000	$9,900	$30,000
Restoration[1]	*$1,769*	*$8,847*	*$2,919*
Engineering Services	$660	$1,090	$3,300
Internal Labor Administration	$175	$289	$876
Customer Outreach	$108	$178	$539
Permitting	$576	$950	$2,879
Post-Replacement Provisions	$78	$118	$158
Totals (rounded to nearest hundred)	**$7,600**	**$12,500**	**$37,800**

Note:

1 Restoration costs are not added to the other LSLR component costs when determining the total LSLR cost, as they are assumed to be included in the full replacement costs.

In summary, a full LSL replacement, when accounting for auxiliary costs, is estimated to cost an average of $12,500. When accounting for minimum and maximum costs in each category, the cost can vary between $7,600 and $37,800. However, it is not likely to have all minimum and all maximum costs in each category. The minimum and maximum values, therefore, only provide the range of cost possibilities. Costs will vary depending on utility size, geographical location, contract mechanism, unique restoration or permitting requirements and several other factors discussed in Section 4.2. The minimum and maximum costs for each item are the extremes and should not be used for estimating cost except under special circumstances with specific criteria for replacements. These are costs from actual utilities, however, and the higher costs should not be dismissed especially if planning in a large urban area. It is recommended that the typical utility use the average replacement costs with a 20% contingency and an escalation factor to the midpoint year of a replacement program for estimating program costs.

Section 5

Conclusion

As a result of this study, costs have been compiled that can be used to update current planning-level cost estimates of service line verification and LSLR programs. All costs obtained in this study are location and date specific; however, the project team took steps to standardize costs such that they could be compared, by converting all dollars to 2022 where possible.

For inventory development, identification costs can range significantly depending on the service line verification method used and the quality of the historic records. Identification costs are higher if reliable records are not available as shown in **Table 3-9** and **Figure 3-9**. Two fictional example utilities are provided in Section 3.3.10 with material service line identification programs to demonstrate that even with the stepwise program of starting with the least costly methods, some more costly methods are likely to be needed to fully identify all materials in a system and the costs can be significant.

When considering LSLR replacement costs, an average planning level cost of $12,500 was calculated based on 45 different contracts which includes restoration and auxiliary costs (engineering, internal labor administration, customer outreach, permitting, post-replacement provisions) in addition to construction costs. The average cost for an LSLR determined by this study was compared with the EPA's estimate published in the Economic Analysis for the Final Lead and Copper Rule Revisions which were provided in **Table 4-1**. As shown in **Table 5-1** below, the costs determined in this study were more than double the EPA estimates. The costs for service line identification as presented in Section 3 are not included in the costs in **Table 5-1** and will be additional costs to be included in a utility's full program to locate and replace LSLs.

Table 5-1 Average LSLR Cost Compared to EPA's Average LSLR Cost Estimate Published in the Economic Analysis for the Final Lead and Copper Rule Revisions, December 2020 (escalated to 2022 costs)

LSL Replacement	EPA Estimate	Study Estimate
Full Replacement (Utility and Private Side)	$6,154	$12,500

As shown in this study, costs for identification and replacement of LSLs vary greatly from program to program. The study team recommends that utilities track the costs of service line identification and replacement programs, including auxiliary costs, and these costs be updated in the future when data from additional utilities are available.

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Section 6

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