FINISHING THE JOB OF GETTING SAFE WATER TO THE TAP: HOW MUCH DOES IT COST TO REPLACE LEAD SERVICE LINES?

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Executive Summary

The Environmental Protection Agency (EPA) estimates that there are up to 10 million lead service lines (LSLs) delivering water to homes in the United States, and a variety of funding proposals have been made over the past year to accelerate the pace of lead service line replacement (LSLR).[1] Where present, LSLs are the largest source of lead in drinking water and they provide a constant risk of exposure to lead even in water systems with consistent corrosion control treatment.[2]

This paper describes and quantifies the cost of bold, large scale LSLR programs that include resident-focused outreach and risk mitigation activities. This cost benchmarking is intended to assist in the proper planning and funding of these types of programs. LSLR programs across the country will take different approaches based on the number of LSLs, age of the city and past construction codes, income levels, and historical development. The cost of FLSLR will vary from city to city, but will average out over time and quantity as creative solutions evolve and experience develops efficiency, especially in cities with a large number of LSLs. Nevertheless, LSLR programs in every city will ultimately need to incorporate three different programmatic approaches to LSLR in order to get all LSLs out of the ground: 1) Planned full lead service line replacement (FLSLR) associated with water main replacement, 2) Planned FLSLR in neighborhood-based programs that do not include water main replacement, and 3) Individual FLSLR where unique circumstances require replacing a small number of LSLs at a time.

Protective public health policy requires realistic cost estimates in order to propose and sustain funding for protective infrastructure maintenance and replacement. Inflated cost predictions slow health protective policy and provide an environment where contractors are enabled to overcharge for their services, further delaying resolution for vulnerable populations who have had no option but to drink water from LSLs for decades. Inflated cost estimates, especially those developed without the context of quantified benefits, should not be used to delay lead service line replacement and permit further generations the daily risk of exposure to lead in drinking water.

Cost estimates for water distribution renewal needs historically have not included LSLR, making the cost of LSLR appear to be "extra" even though the service line is the final critical pipe that affects the quality of all water delivered to an individual home. Adding the cost of replacing all LSLs to water distribution needs estimates results in a mere 3% increase in the national cost estimate for water main renewal.

Per the cost analysis provided here, replacing the nearly 30,000 LSLs in Washington, DC is projected to cost $142 million, but could range from a low of $78 million up to $228 million. The cost of replacing the estimated 400,000 LSLs in Chicago is estimated at $2.3 billion over 25 years, although the cost could range from $1.4 billion to $3.7 billion. Meanwhile, the cost estimates provided by each of these cities is more than two times greater than the maximum costs projected in this paper based on real benchmarking data.

Policy barriers that contribute to elevated cost estimates can be removed or reduced when transparency and public accountability are coupled with dedicated resident-centered outreach and inclusion. Engineering cost efficiencies are achieved through practice, creativity, and innovation. When LSLR is communicated and addressed as the public health necessity that it is, it is inevitable that the current barriers and costs will decrease over time. New cost information must be published as it becomes available, to keep a realistic accounting of overall costs, while identifying efficiencies and bottlenecks as this work expands. Now is the perfect time to initiate work on protective LSLR programs, especially in cities with the largest quantities of LSLs, supported by new and expansive state and federal infrastructure funding initiatives.

Introduction: Quantifying Costs and Benefits of Lead Service Line Replacement

The Environmental Protection Agency (EPA) estimates that there are up to 10 million lead service lines (LSLs) delivering water to homes in the United States, and a variety of funding proposals have been made over the past year to accelerate the pace of lead service line replacement (LSLR).[1] Policy makers need realistic cost estimates for lead service line replacement (LSLR) so that funding can be allocated and used effectively for planning and efficiently removing LSLs in individual communities. Community Water Systems (CWSs) vary widely by population served; technical, managerial, and financial capacity; and number of LSLs. Each of these characteristics factor into a CWS's ability to manage and reduce the cost per replacement. The purpose of this paper is to describe the necessary costs of a health protective LSLR program, and to share representative cost data from water utilities with dedicated LSLR programs. This paper uses cost data from CWSs with over 10,000 LSLs in cities that have either taken initiative to develop comprehensive LSLR programs or have been required to as a result of legal action. Finally, this paper estimates the cost of LSLR programs in two major US cities.

Where present, LSLs are the largest source of lead in drinking water and they provide a constant risk of lead exposure, even in CWSs with consistent corrosion control treatment.[2] Experts and health agencies have recommended residents filter all water used for drinking or cooking in homes with LSLs.[4,5] Lead is a potent, irreversible neurotoxin with no safe level of exposure. The health effects of lead exposure are well documented and can be found in other publications.[6-8] The only way to permanently stop exposure to lead in water is to remove lead from contact with drinking water. While there are additional sources of lead in plumbing like lead solder, galvanized steel, and brass fittings and fixtures, LSLR programs remove the largest magnitude source of lead in water, greatly reducing the risk of every day lead exposure in homes with LSLs and reducing the potential for catastrophic consequences during treatment modifications. Health officials[1,2] and advocates[9] have called for the removal of all LSLs and the provision of filters until LSLs can be removed; this is to eliminate the legacy of long-term lead exposure through drinking water and the multigenerational impacts of lead exposure.

This paper describes and quantifies the cost of bold, large scale LSLR programs that include resident-focused outreach and risk mitigation to assist in the proper planning and funding of these programs. It is always critical to keep the benefits of LSLR in focus when considering costs, and available research demonstrates that the benefits of LSLR outweigh the costs. One study estimates benefits of $1.33 per dollar spent to replace LSLs in the homes of children born in 2018,[10] and another estimates a twofold return on investment in LSLR.[11] These studies do not include the full range of documented health effects for all affected consumers, so the actual benefits are expected to be much greater than those quantified in these studies.

Definitions and Background

Service Lines, Inventories, and the Legacy of Partial Lead Service Line Replacements

A ***service line*** is a small diameter pipe that connects a water main to an individual building where one or many people consume the water. Water is delivered to the residents through the service line. The material of the service line is frequently prescribed by the water utility, plumbing code, or city code; and the current pipe was inherited or installed by the current resident. In many cases, LSLs were mandated by the water utility. In some cases neither the water utility nor the customer have access to accurate information about service line material for the entire length of the service from the water main to inside the home. All residents receive their water through a single service line; there is no alternative water pipe. When the service line is made of lead, all water in the home is a potential source of lead exposure because all water must pass through this singular pipe to reach the consumer.

Many water utilities have divided service lines into two portions for record keeping and management purposes. The first portion is typically located in the public right of way starting at the water main and runs to the property boundary. This is where the curb stop and shutoff valve are typically located (see Figure 1). The rest of the service line continues under private property until it enters the building. Many water systems say the water utility is responsible for the service line only under public property, and the property owner is responsible for the section under private property. As a result of different codes, building practices, and changes in practices over time, the water main side and the building side of the service line may be made of different materials. This may have always been the case, or they may be made of different materials due to partial repairs and replacements over time.

The 1986 Amendments to the Safe Drinking Water Act (P.L. 99-339) banned the installation of LSLs, but did not require existing LSLs to be replaced. As a result, when water supplies disconnect an LSL while doing maintenance and repair work, they are not allowed to reconnect it to the water main. The utility removes the LSL only where the LSL is under public property, a practice known as ***partial lead service line replacement*** (PLSLR). PLSLRs are also used when LSL removal is required due to a lead action level exceedance under the Lead and Copper Rule. As a result, most water supplies have historically completed many PLSLRs, leaving partial LSLs in place, when they do work on or near LSLs.

PLSLR increases lead in drinking water over the short term and does not reliably reduce lead over the long term.[3] Concerns have been raised about this practice going back to the 1991 Lead and Copper Rule.[12] Several studies, including a report by the Environmental Protection Agency's Science Advisory Board, documented an increase in water lead levels after partial replacement.[9] Studies have shown that PLSLR releases particulate lead,[13-16] increases regular corrosion on fresh surfaces[10,11] and can create galvanic corrosion,[17-19] the corrosion that occurs when two dissimilar metals come in contact with each other. Likewise, although another study demonstrates that flushing can prevent spikes after PLSLR, lead concentrations were not substantially reduced following PLSLR because a large section of lead pipe remains in contact with the water.[20]

The Legacy of PLSLRs in Washington, DC

From 2001-2004, Washington, DC experienced the nation's most severe lead-in-water crisis to date, which involved a two-and-a-half year cover-up by the water utility (then named DC WASA), the DC Department of Health (DOH), and EPA Region 3.[21,22] Peer-reviewed scientific research subsequently showed that the DC crisis resulted in over 800—and possibly up to 42,000—cases of elevated blood lead levels in young children and that the city's fetal death rate rose by 37 percent.[23,24]

In 2004-2008, as part of DC WASA's remediation program, DC WASA spent over $100 million in ratepayer money to partially replace over 14,000 LSLs. In 2011, the Centers for Disease Control and Prevention (CDC) published a study showing that District children in homes with a partially replaced LSL were over three times as likely to have blood lead levels above 10 mcg/dL (the blood lead level that was considered "elevated" at the time) as children in homes that never had an LSL.[25]

Resident activists also point out that, today, DC Water's LCR compliance samples reveal ongoing lead-in-water contamination in the majority of sampled homes.

At this time there are no national requirements for ***service line inventories***, so different states and water utilities categorize services in a variety of different ways. In general, service line inventories tend to include the following categories of LSLs at each service location:

A. Full lead service line: the entire service line is made of lead, from the water main to inside the house

B. Partial lead service line, water main side: The only portion of lead in the service line is between the water main and the property boundary, curb stop, and/or shutoff valve.

C. Partial lead service line, building side: The only portions of lead in the service line are found between the property boundary, curb stop, and/or shutoff valve and the inside of the house.

D. Lead gooseneck or pigtail: a short portion of lead pipe that is used to connect the water main to the service line.

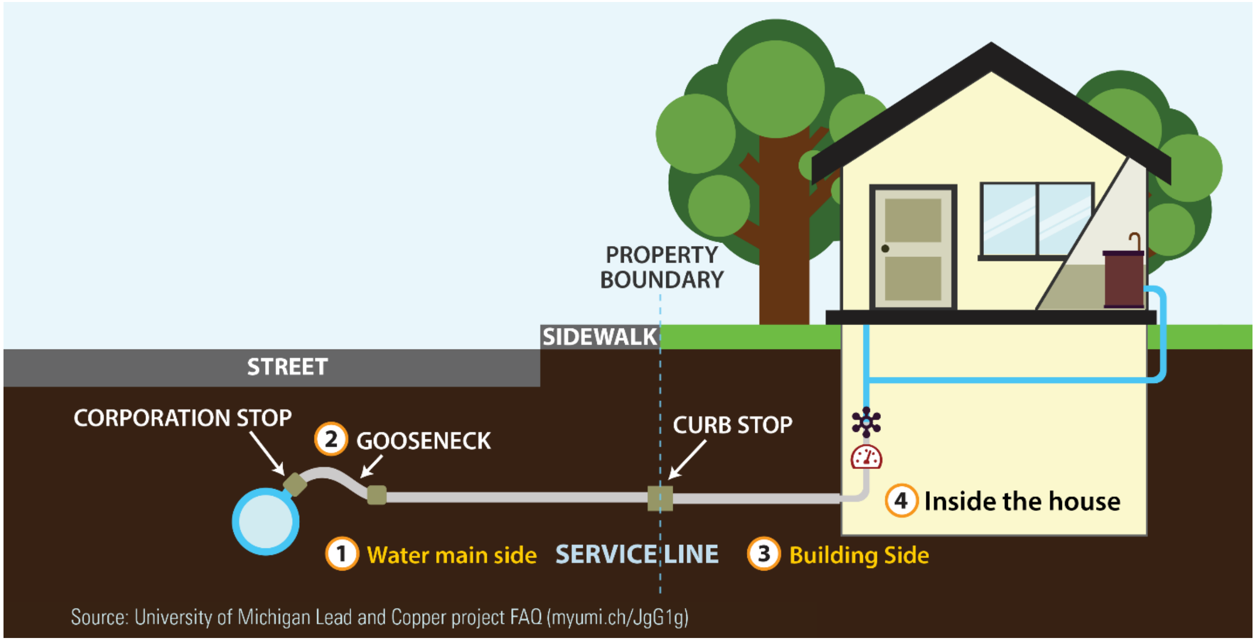

Figure 1: Visual Representation of Service Line Portions. Source: University of Michigan Lead and Copper Project.[26]

For this paper, and purposes of a service line inventory, any service line with any one of these portions containing lead is considered an LSL. A service line is no longer an LSL when all portions of lead are removed from the service line.

Types of Lead Service Line Replacements

The following section describes categories of LSLRs that have different cost implications and are used for the cost estimates in this document. The American Water Works Association published a standard for Replacement and Flushing of Lead Service Lines in 2017 that states "every effort shall be made to avoid partial replacements."[27] This paper only quantifies the cost of LSLRs in which all existing portions of lead in a service line are removed. **Therefore, each of the replacement cost categories presented here results in a complete LSLR that makes progress toward an LSLR goal.** Water utilities tend to group LSLRs into different categories because the costs tend to fall in different ranges based on the circumstances; these categories vary by utility. This paper groups LSLRs into four cost categories. The cost of an LSLR typically depends on how the LSLR was initiated, other infrastructure work happening simultaneously, and the quantity of lead that must be replaced. These categories are as follows for the remainder of this paper:

A. **Planned full lead service line replacement (FLSLR).** These are LSLRs associated with planned water main replacement and/or other buried infrastructure replacement. This also refers to FLSLRs as part of a planned neighborhood FLSLR program where many replacements are completed in the same geographic area at the same time. This category accounts for cost where up to the entire length of the service line is expected or known to be made of lead.

B. **Individual FLSLR.** This category includes unplanned, emergency, customer requested, or "one-off" FLSLRs. Due to service leaks, high lead levels, emergency repairs, new homeownership, etc. there are a variety of reasons why CWSs will have an ongoing need to replace LSLs outside the scope of planned FLSLR programs. Nevertheless, it is important to ensure that these replacements are equally protective of the affected residents and the costs are accounted for. Although the costs of individual FLSLRs can vary greatly, they are consistently higher than for planned FLSLR replacements where economies of scale and other programmatic efficiencies can be achieved. This category accounts for cost where up to the entire length of the service line is expected or known to be made of lead.

C. **LSLR Building side only.** This category accounts for locations where a previous water main side replacement may have already been completed or there never was an LSL on the water main side. This cost category is used only when the LSL is documented only on the building side.

D. **LSLR Water main side only**. This category accounts for locations where a customer has previously replaced the LSL on the building side, or there never was an LSL on the building side. This cost category is used only when the LSL is documented only on the water main side. This category is also used for locations where only a lead gooseneck or pigtail must be replaced.

For purposes of this report, cost categories A and B above assume that the entire service line is made of lead and it is all removed at the same time, even when the actual lead composition of the LSL is unknown. This conservative assumption results in an overestimate of total cost because many LSLs are not consistently lead from the water main to the interior of the building. The cost of removing all remaining lead in a partial LSL is reflected in categories C and D. It is used in this report only when the actual lead composition of the LSL is known by the water utility. These LSLR cost categories typically cost less than FLSLR, but they cost more than half of an FLSLR because many of the steps, such as mobilization, pipe exposure, and paving must be repeated during a second visit to remove the remaining piece(s) of lead pipe.[27] Regardless of whether a partial or full lead service is in the ground, the resident-protective replacement of that LSL involves many common steps (pre-construction contact with the property owner and resident, mobilization, restoration, flushing, and filters).

This legacy of PLSLR over the past 30 years has drastically increased the overall cost of LSLR in the United States while unnecessarily contributing to lead exposure of unknowing residents. Returning to complete the LSLRs at the locations of these previous partials will cost less than new FLSLRs, but it would have been least costly and most protective to complete FLSLRs in the first place. If FLSLRs had been mandated in the 1991 Lead and Copper Rule, the comprehensive cost of replacing all remaining LSLs in the United States would be significantly less than it is today.

Planned Full Lead Service Line Replacement Programs

The need for water infrastructure investment and renewal has been well documented by the American Society of Civil Engineers.[28] The EPA Drinking Water Infrastructure Needs Survey has quantified infrastructure needs, but only recently has begun to include LSLR in the cost of needed water infrastructure renewal.[29] This has created a perception that the cost of LSLR is an optional separate cost that is disassociated from the cost of water infrastructure renewal for which communities and the water industry have been advocating for years. In this infrastructure planning narrative, LSLR has been painted as unaffordable and unrealistic. However, LSLR must be reframed as an essential component of water infrastructure renewal in any conversation about water infrastructure renewal cost and funding designed for public health protection and economic stability.

"ASSET MANAGEMENT IS A PROCESS WATER AND WASTEWATER UTILITIES CAN USE TO MAKE SURE THAT PLANNED MAINTENANCE CAN BE CONDUCTED AND CAPITAL ASSETS (PUMPS, MOTORS, PIPES, ETC.) CAN BE REPAIRED, REPLACED, OR UPGRADED ON TIME AND THAT THERE IS ENOUGH MONEY TO PAY FOR IT."[31]

The water industry frequently presents the argument that it is most cost effective to replace LSLs through planned FLSLR, the first cost category described in this report. On the other hand, it must be noted that the historic practice of PLSLR has unnecessarily driven up the overall cost of LSLR while increasing lead in water exposure risk over the past three decades.[3] An appropriate remedy for this legacy is to use LSLR as a driver and prioritization factor in asset management for water main replacement, to accelerate the replacement of water mains in areas where resources can be leveraged for the most LSLRs and the greatest near-term public health benefit.

As water utilities have pivoted toward coordinated asset management plans,[31] the cost of water main replacement has been estimated and included in infrastructure budgets and capital improvement plans. LSLR is an additional cost that is minimized when completed at the same time. It is a waste of money and a public health hazard to replace a water main without replacing every full LSL so that no lead services remain. ***FLSLR is a necessary cost to be incorporated in every water main replacement where LSLs may be encountered.*** This paper considers the costs of water main renewal itself to be already accounted for in existing utility planning cost estimates because it is a necessary cost of good management.

When completed as part of a water main replacement, the incremental cost of LSLR includes only the additional tasks that are necessary to safely replace LSLs that would not have been necessary if only non-lead service lines had been present. This is why FLSLR is the least expensive when associated with a water main replacement. Table 1 summarizes the primary costs associated with LSLR; items in italics would already be covered by the water main replacement project when LSLR is completed as part of that project.

Planned neighborhood-based FLSLR programs are also able to achieve cost efficiencies and are not dependent upon water main replacement. A neighborhood-based planned FLSLR program limits mobilization costs; consolidates service line verification and property restoration within a geographic area; and allows for consolidated outreach, public education, and efficient filter distribution. When these activities are planned and implemented with intentionality, they can build community support for the neighborhood-based FLSLR program thereby reducing the need for water utility investment in repeat customer contacts to earn program participation. Examples of programs that rely on neighborhood-based FLSLR programs include Flint, Denver, and Newark.

Since LSLR is often portrayed as unaffordable, it is important to consider the cost in relation to the cost of water main renewal programs that should incorporate LSLR programs. In 2016, the American Water Works Association (AWWA) estimated that it would cost around $30 billion to replace all the remaining LSLs in the country, on top of the already identified $1 trillion needed to repair and replace buried water mains.[32] Using these numbers, adding the cost of LSLR represents just a 3% increase to the national cost estimate for water main renewal, replacing the final critical pipe that ultimately determines the quality of all water available inside the home.

For FLSLR acceleration programs where LSLR may come ahead of or without water main replacements, some concerns have been raised about new service lines installed on old water mains that are approaching their design life and may require replacement soon after the completion of the LSLR program. This has frequently been used as a rationale for avoiding and delaying FLSLR programs, and continuing water main replacements in non-LSL areas.

REPLACING ALL LEAD SERVICE LINES ADDS ONLY 3% TO THE ESTIMATED COST OF WATER MAIN REPLACEMENT ACROSS THE UNITED STATES.

While each city has their own unique conditions that must be addressed, **water utilities must reprioritize asset management and capital improvement plans, bringing failing water mains with the most LSLs to the top of the list to maximize cost savings and public health benefits where both programs are urgent**. If water main failure is not imminent, and ongoing leaks or recurring main breaks do not present an immediate health hazard, neighborhood-based planned FLSLR must be prioritized over water main replacement where limited resources prohibit doing both simultaneously.

A water utility's choice to prioritize water main replacements in areas without LSLs, particularly areas of downtown or commercial development, cannot be used as justification to reject or delay neighborhood-based planned FLSLR programs when people drink water in LSL homes every day. **Water utilities must incorporate public health risk into their asset management risk models and be transparent about how health equity is built into decision making.**

Neighborhood-based planned FLSLR programs, without associated water main replacement programs, are a good fit in neighborhoods where water mains are in good condition and areas where previous water main replacements resulted in partial LSLRs, leaving building side partial LSLs in place. In this last case, finishing previous PLSLRs should be priority projects due to the history of elevated risk of lead

WATER UTILITIES WITH LSLS WILL NEED TO IMPLEMENT A COMBINATION OF THREE COMPLIMENTARY LSLR APPROACHES TO EFFICIENTLY REMOVE ALL LSLS:

1) **PLANNED FLSLR ASSOCIATED WITH WATER MAIN REPLACEMENT,**
2) **PLANNED FLSLR IN NEIGHBORHOOD-BASED PROGRAMS, AND**
3) **INDIVIDUAL FLSLR.**

THE EXISTENCE OF ANY ONE OF THESE PROGRAMS DOES NOT NEGATE THE NEED FOR THE OTHERS.

exposure in these homes from previous PLSLRs. Future data collected in Flint, Newark, and Denver, cities that did not do simultaneous water main replacement, will inform on how neighborhood-based planned FLSLR programs may impact water main replacement needs.

Given the large number of LSLs that continue to deliver water to residents across the United States and the ongoing infrastructure renewal needs at every water utility, all water utilities with LSLs will need to implement a combination of three complimentary LSLR approaches to efficiently remove all LSLs: 1) Planned FLSLR associated with water main replacement, 2) Planned FLSLR in neighborhood-based program (both fall under the first, ***Planned FLSLR,*** cost category), and 3) Individual FLSLR (the second cost category) . The existence of any one of these programs does not negate the need for the others.

Lead Service Line Replacement Costs

A comprehensive, protective FLSLR program has a variety of associated costs that go beyond the traditional costs of construction and construction management. The types of costs that should be included in a comprehensive program are listed in this section. The various types of expenses can be performed through construction contracts, in-house staff, additional support contracts or departments, or combinations of all of the above. The necessary types of costs for a protective LSLR program are described here, and actual costs from current programs are described in the next section. Approximate costs for specific line items are not provided here, because effective LSLR programs achieve cost efficiencies using coordinated oversight, combined staff functions, bulk purchasing, and integration in every day water utility standard operating procedures.

Each of the program elements presented in Table 1 are essential components of protective, comprehensive LSLR programs. It is important to examine these costs to ensure they are included in the program but are not unnecessarily inflating the overall project cost or used as an excuse to not proceed. Most of these cost line items offer an opportunity for further innovation and efficiencies to continue cost reduction over time.

Table 1: Essential Costs Associated with Lead Service Line Replacement

Traditional construction costs[a]	Proactive health protective measures	Not LSLR costs
• Field inspection • Utility coordination • Property restoration • Lead service line replacement • Curb stops • *Mobilization* • *Street paving* • *Recordkeeping* • *Corporation stops* • *Traffic enforcement* • *Permit fees* • *Contract management* • *Trees*	• Proactive customer engagement and consent in advance of construction • Community meetings • Customer engagement and education before and during construction • Verification of service line material • Filter and/or bottled water distribution and education • Outdoor flushing post replacement • Household flushing post replacement per ANSI/AWWA C810-17 • Water lead testing before and after replacement	• The water main replacement itself • Emergency water main replacements that necessitate LSLR • Upgrades driven by other codes, e.g., sewer lead relocation

[a] LSLR costs in italics are covered by water main replacement project when LSLR is completed as part of a water main replacement project

Field Inspection, or Service Line Verification

Field inspection programs, also called service line verification programs, can vary widely in scope, purpose, cost, and funding strategy. ***Service line verification should always be incorporated into any water main replacement project to ensure the water utility has an accurate inventory of service line material.*** In this case service line verification does not represent an additional cost. If the water main needs to be replaced, other nearby appurtenances like the curb box and shutoff valve are also likely to need replacement. The lowest cost time to replace curb boxes and/or shutoff valves is when the construction crew is already mobilized for the water main replacement. Where inconsistent records exist, which is the case for many if not most water utilities, all curb boxes on water main replacement projects should be excavated, inspected, and material verified on both sides with a minimum of 18 inches of exposure on both sides to verify lead and non-lead service line materials.[33] This work is an opportunity to fill those large data gaps.

Likewise, service line verification is an important part of LSLR programs that are conducted separately from water main replacements. When working at a neighborhood level it is important to verify lead and non-lead service line material. If all unknown service lines are assumed to be lead (the default in the EPA Lead and Copper Rule Revisions (LCRR)) and excavation at the curb box reveals a given service line is *not* lead, then the cost of service line verification brings down the overall cost of the project by avoiding the cost of replacement. For LSLR programs in areas with a high probability of LSLs, the cost of service line verification will be smaller in relation to the cost of LSLR. To minimize cost and maximize public health protection, strategies should be used to prioritize verification efforts in areas with a high probability of LSLs, with the capacity to immediately replace confirmed LSLs.[34]

The cost impact of a service line verification program on projected LSLR costs across a water utility depends on the inventory strategy used at an individual water utility. If a water utility assumes all unknown service lines are lead, which is the most protective strategy for reducing resident exposure to LSLs, service line verification programs will reduce the anticipated cost of LSLR across the system.

Finally, for water systems with poorly documented records and a low likelihood of LSLs, service line verification still plays an important role in water system management. However, in this case, when services need to be excavated to confirm material but there is a low chance of identifying LSLs, it is not appropriate to consider this part of the cost of an LSLR program. This is the cost of good asset management. The most protective inventories have always been those that document all service line materials at each individual service location, regardless of ownership or responsibility, because every service line material inherently affects the water quality at the tap and water utilities cannot manage what they have not documented.

A Resident-Centric approach to Lead Service Line Replacement

Water utilities typically design, drive, and implement LSLR programs and can encounter challenges during implementation. A collaborative approach that includes impacted communities and individuals as true partners in the design and implementation of such programs can help with public education about lead in water and water quality in general, developing trust with the water utility, and willing participation in the LSLR program. ***Including impacted, non-water industry community members as experts in the lived experience on the design team, just as water utilities hire experts in construction and water quality management, will create programs that address ongoing challenges faced in the community.*** Active, meaningful participation and citizen oversight over program implementation is critical for ensuring health equity in implementation, ensuring public accountability for commitments made, and building trust with the water utility. Utilities can incorporate community participation through general advisory committees and project specific advisory committees using a participatory decision-making model.[35]

A resident-centric LSLR program allows for justice and equity concerns to be addressed through the local water utility LSLR program. Consumer protective practices, including proactive education and outreach, filter education, and proactive water quality management (e.g., appropriate shutoffs, flushing, and aerator cleaning) should be incorporated into boilerplate programs, contracts, and standard operating procedures. Partnering with a trusted messenger in the community can lift these messages to those who might be most resistant to participating in an LSLR program, allowing for potential overall cost reductions due to high participation rates. ***The proactive health protective measures listed in Table 1 cannot be considered "extra" to the program; they must be inherent and integrated at all times.*** The upfront investment in a resident-centric approach will pay dividends in the end when an informed and involved community are willing and supportive participants.[36] The cost of this work and community investment must be incorporated into every LSLR program. At this time water utilities may not yet incur these expenses or these expenses are tracked in a department separate from the LSLR program; they are not yet easily quantified on a per LSLR basis.

Cost Benchmark Data

Table 2 summarizes LSLR costs reported by EPA, AWWA, and specific CWS LSLR programs. These specific CWSs were selected because it is estimated that they each have over 10,000 LSLs and are located in cities that fall in one of the following categories: 1) took initiative to develop comprehensive LSLR programs, 2) have mandated LSLR requirements resulting from legal settlements, or 3) are under an administrative order. CWSs with 10,000 or more LSLs were selected for the examples in this paper because it is more practical to launch and build a robust LSLR program when a large number of LSLs are present that can sustain a dedicated LSLR program for several years. Programs with more LSLs are better able to staff up and average costs across the larger number of homes where LSLs must be replaced. Cost data from these types of programs are appropriate for estimating the overall cost of large scope LSLR programs, for cities like Washington, DC and Chicago, IL. Different cost data and planning strategies may be appropriate for smaller magnitude LSLR programs.

Table 2: LSLR Cost Benchmarking

Source of LSLR Cost Data	Planned FLSLR (with water main replacement)	Individual FLSLR	Building side only (e.g., meter or property line to building)	Water main side only (e.g., water main to meter or property line)
Detroit, MI[a]	$2,500	$5,000	$1,625	$2,661
EPA LCRR Final Economic Analysis[b]	$3,991	$4,989	$3,222	$3,824
Cincinnati, OH[c]	$4,950	$4,535	$3,853	$2,155
AWWA LCRR comments[d]	$5,204	$6,106	$4,767	$4,191
Denver, CO[e]	$9,000	$9,000	$3,900	$6,250
Flint, MI[f]	--	$4,603	$4,200	$4,200
Newark, NJ[g]	--	$7,000	$6,130	$4,980

[a] *Source:* D. Fielder, Personal communication, May 6, 2021
[b] Range is presented in the Economic Analysis;[37] average is used here
[c] *Source:* L. Moening, Personal communication, April 30, 2021
[d] *Source:* American Water Works Association[30]
[e] *Source:* A. Woodrow, personal communication, April 30, 2021
[f] *Source:* Flint contracts from NRDC
[g] *Source:* Newark bid document, plus Newark presentation[38]

The specific CWSs consulted for this paper have developed comprehensive FLSLR programs that include traditional construction costs, as well as proactive customer engagement, filter distribution, material verification, and lead testing. Although each of these programs reported here incorporate these elements, the cost is not consistently represented in the cost data provided. The Detroit, Denver, Flint, and Newark programs profiled here include the cost of building side LSL replacement through differing funding mechanisms and do not require payment from the customer.

Table 3 summarizes the types of costs included in the numbers as provided by the individual utilities in Table 2. Construction plus paving costs are frequently the largest dollar value line items of an LSLR. As discussed above, the impact of field inspection on overall LSLR cost depends on the type of program implemented.

For additional support programs (e.g., outreach, water quality sampling, filter provision) that are not consistently included in the cost data presented in Table 2, these costs are not nearly as large as construction costs. It is relatively straightforward to access the unit costs that contractors are paid to perform the work, but it is more complicated to report costs when the work is done by utility staff. It is further complicated to get accurate costs for the "soft" features, which can be delivered by utility staff and/or contractors. Although LSLR programs at the CWSs surveyed for this report include these support programs, cost data from the supporting departments was not available at the time of writing. As these support programs become more standardized it will be important to quantify the costs so they can be consistently projected and integrated in all LSLR programs.

Table 3: Costs Accounted for in Table 2

	Cincinnati	Denver	Detroit	Flint	Newark
Mobilization	x	x	x	x	x
Utility Coordination	x	x	x	x	x
Site Restoration	x	x	x	x	x
Traffic Control	x			x	x
Outdoor Flushing	x	x			
Field Inspection		x	x	x	
Street Paving		x	x		
Record Keeping		x	x		
Indoor Flushing per AWWA FLSLR Standard		sometimes	x		
Outreach to Individual Residents		x	x		
Permit Fees		x			x
Community Wide Program Outreach			x		
Contract Management			x		

It is notable that the lowest and highest cost per planned FLSLR come from the two most comprehensive programs noted here, Detroit and Denver, respectively. At this writing, Denver is replacing approximately 5,000 LSLs per year. Detroit is still ramping up its program and has replaced 1,155 since 2018.[36] Per personal communication (A. Woodrow, May 4, 2021), Denver's cost data for planned FLSLR likely represents an overestimate since they stopped tracking planned and unplanned separately a few years ago. Cincinnati notes that their costs have dropped significantly over the course of implementation of their program. The cost presented for Cincinnati in Table 2 is the average for the period from FY18-FY21, which started at $7,716 and came down to $3,517 in FY21. Table 4 summarizes the overall range of LSLR cost per replacement from the data collected for this report. Because the resident-support costs were not consistently included in the cost benchmarking data, an additional $270 was added to the low, mean, and high unit cost per LSR type to account for one year of filter provisions, the cost of flushing, multiple individual customer contacts, community meetings, and sampling.

Table 4: Summary Unit Cost per Lead Service Line Replacement Type

Cost Summary	Planned FLSLR (with water main replacement)	Individual FLSLR	Building side only (e.g., meter or property line to building)	Water main side only (e.g., water main to meter or property line)
Low	$2,770	$4,805	$1,895	$2,425
Mean	**$5,399**	**$6,160**	**$4,227**	**$4,307**
High	$9,270	$9,270	$6,400	$6,520

As happened in Cincinnati, new LSLR programs in other cities are likely to begin at the high end of the cost per LSLR range provided in Table 4 and decrease over time as they become more efficient. Likewise, as a comprehensive LSLR program approaches its end and only the most difficult to reach homes remain and economies of scale diminish, the cost per replacement may increase in the last years of a program. ***The average cost per LSLR is likely to vary substantially over the course of an LSLR program***. Consequently, the calculated means for each type of LSLR represent a reasonable estimate of the average cost per LSLR over the duration of a program, but the low and high estimates also represent real potential outcomes during any given year.

It is also timely and notable that LSLR programs are currently in the process of formation and expansion. ***New cost information should be published as it becomes available, to keep a realistic accounting of overall costs, as well as to identify efficiencies and bottlenecks as this work expands.*** If a reader has data that is inconsistent with the information published in this paper, please contact the author so additional data sources can be incorporated and estimates revised appropriately based on real world transparent data.

Case Study 1: Estimated Total LSLR Cost in Washington, DC

Table 5: Estimated LSLR Program Costs for Washington, DC

Replacement Type	Washington, DC[a] (Number of replacements)
Planned FLSLR	11,942
Individual FLSLR	5,000
Building side Only	11,033
Total LSLs	**27,975**
Total Replacement Cost Estimate	
Low	$78,011,875
Mean	**$141,909,194**
High	$227,663,540

[a] *Source:* DC Water's Lead Service Line Replacement Plan, p. 8.[39]

Table 5 presents the estimated cost of replacing all LSLs in Washington, DC based on the cost data provided in this report and LSL data from DC Water.[39] The DC Water Lead Service Line Replacement Plan describes removing 27,975 LSLs, where 4,501 FLSLRs are planned as part of water main replacement projects and 7,441 FLSLRs are planned as block-by-block projects, resulting in 11,942 Planned FLSLRs. As presented on page 8 of the plan, there are 11,033 building side only LSLs, and 5,000 FLSLRs projected to be replaced "by premise" and are incorporated here in the cost category of Individual FLSLRs.

Table 5 presents a projected total cost of $142 million to replace all the LSLs in Washington, DC using the mean costs of replacement from Table 4. This is the incremental cost of a comprehensive protective LSLR program, which would be incurred in addition to already planned and necessary water infrastructure renewal in the city. Of the 11,033 building side replacements, DC Water estimates that 1,975 will be completed through Planned FLSLR, so the cost estimate of Table 5 represents an overestimate on that line item. In contrast, DC Water states that an additional $300 million to $500 million is needed to replace all LSLs in Washington, DC. Even when the maximum unit costs from Table 5 are used, from real benchmarking data from other cities, the current cost model estimates a maximum of $228 million total for the entire Washington, DC Lead Service Line Replacement Program. The DC Water program estimate is more than two times greater than the maximum cost projected for the protective, proactive resident-centric LSLR program modeled in Table 5.

Looking at differences in cost estimates, the building side replacement program presents an obvious opportunity for reducing projected LSLR costs in Washington, DC. As described in DC Water's LSLR plan, most building side only replacements will be completed as part of a premise-based process. To the extent that DC Water can implement the entire program as a utility initiated, planned block by block replacement program, the cost of replacing these LSLs will be lower than projected by DC Water.

Case Study 2: Estimated Total LSLR Cost in Chicago, IL

Table 6: Estimated LSLR Program Costs for Chicago, IL

Replacement Type	Chicago, IL[a] (Number of replacements)
Planned FLSLR	275,000
Individual FLSLR	125,000
Building side Only	--
Total LSLs	**400,000**
Total Replacement Cost Estimate	
Low	$1,362,375,000
Mean	**$2,254,769,643**
High	$3,708,000,000

[a] *Source:* City of Chicago Lead Service Line Replacement Program Report, April 2021.[40]

Table 6 presents the estimated cost of replacing all LSLs in Chicago, IL based on the cost data provided in this report and LSL data from Chicago. The city's Lead Service Line Replacement Program Report[40] projects the city could replace 10-12,000 LSLs over 25 years with water main replacement in an aggressive replacement plan. Using an average of 11,000 per year for 25 years, this results in 275,000 Planned FLSLRs in Chicago. The remainder of the estimated 400,000 LSLs in Chicago are assumed to be completed as Individual FLSLRs per the Chicago report. Chicago does not provide estimates for building side only LSLs, but there are many in the city that resulted from the water main replacement program initiated in 2012 with the intent of replacing 900 miles of water mains. This program relied upon PLSLR as described in Batterman et al., 2019.[20] While the water industry frequently points to the risk of installing new non-lead service lines to old water mains, the completed water main work in Chicago negates this concern due to the recently installed water mains, new corporation stops, and new non-lead pipe on the water main side. Even though it is not clear whether the entire water main side LSL was replaced during the Chicago water main replacements, it is fair to expect the cost of the remaining LSLR to be substantially less than a FLSLR because it does not require a new corporation stop and is less likely to disturb pavement on one side of the street.

While the estimate in Table 6 assumes that all 400,000 LSLs will be replaced as a FLSLR, this calculation represents an overestimate of the overall program cost in Chicago, IL because service lines on 900 miles of water main will be building side only LSLRs. In this case it is appropriate to look at the estimated cost of $2.3 billion and toward the low estimate of $1.4 billion to replace all the LSLs in the city of Chicago. Learning from Cincinnati's example, even if LSLR costs start high with the launch of a new program, they are likely to reduce quickly as cost-efficient strategies become apparent.

In contrast, the Chicago Lead Service Line Replacement Program Report states that the LSLR program is an $8.5 billion program.[41] Even when the maximum unit costs from Table 6 are used, from real benchmarking data from other cities, the current cost model estimates a maximum of $3.7 billion for the entire Chicago Lead Service Line Replacement Program. Like the DC program, the Chicago program estimate is more than two times greater than the maximum cost projected for the protective, proactive resident-centric LSLR program modeled in Table 6. The Chicago Report suggests that the excessive LSLR cost estimates are based on changeable factors that can be overcome through creativity, policy, and fee structure changes.

Conclusion

LSLR programs across the country will take different approaches based on the number of LSLs, age of the city and specific construction codes, income levels, and historical development. The cost of FLSLR will vary from city to city, but will average out over time and quantity, especially in cities with a large number of LSLs. It is important to note that certain LSLR cost factors can be highly dependent on locality. The cost benchmarking data presented in this report come from a limited number of LSLR programs that evolved under a variety of different circumstances and requirements; they may not encompass city specific challenges in other locations. Such challenges can include unique building or pavement materials, unique permit fees, employee residence or certification requirements, city ordinances, and others. ***Policy barriers to cost reduction can be removed when transparency and public accountability is coupled with dedicated resident-centered outreach and inclusion.*** Engineering cost efficiencies are achieved through practice and innovation. When LSLR is communicated and addressed as the public health necessity that it is, it is inevitable that the current barriers and costs will decrease over time.

Per the cost analysis provided here based on real benchmarking cost data from large utility LSLR programs, replacing all the LSLs in Washington, DC is projected to cost $142 million, but could range from a low of $78 million up to $228 million. This is the incremental cost of a comprehensive protective LSLR program, which would be incurred in addition to already planned and necessary water infrastructure renewal in the city.

As the city with the most LSLs in the country, the cost of replacing 400,000 LSLs in Chicago is estimated at $2.3 billion over 25 years. The total cost of LSLR in Chicago could range from $1.4 billion to $3.7 billion, but as noted in the discussion above the actual cost is likely to be toward the lower end of this range, between $1.4 billion and $2.3 billion. Meanwhile, the cost estimates provided by each of these cities is more than two times greater than the maximum costs projected in this paper. ***Inflated cost estimates distort conversations with decision maker about LSLR requirements and funding and perpetuate unnecessary delays in removing harmful LSLs.***

Lead is a potent neurotoxin with no safe level exposure and multigenerational health impacts. Where LSLs are present, they are the largest source of lead exposure in drinking water. Everyone must drink water to live, and homes with LSLs receive all their water through one very high-risk pipe. Removing LSLs makes economic sense, not only from the increase in jobs and economic productivity to remove the pipes, but also from the societal decrease in health care, education, and criminal justice costs from decreased lead exposure.[10,11] It is necessary to initiate work on aggressive, protective LSLR programs, especially cities with the largest quantities of LSLs, supported by new and expansive state and federal infrastructure funding initiatives.

Protective public health policy requires realistic cost estimates to generate funding proposals for critical public health protective infrastructure maintenance and replacement. Inflated or irrational cost predictions slow critical health protective policy and provide an environment where contractors are motivated to overcharge for their services, further delaying progress and continuing to harm vulnerable populations who have had no option but to drink water from LSLs for decades. Inflated cost estimates, especially those developed without the context of quantified benefits, cannot be used to delay LSLR and permit further generations the daily risk of exposure to lead in drinking water.

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