LEAD SERVICE LINE REPLACEMENT: A GEOMATIC APPROACH TO INTEGRATE COST AND WATER QUALITY AND STUDYING THE RELATIONSHIP BETWEEN THEM

by

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DEDICATION

I dedicate my research work to my family. A special feeling of gratitude to my loving parents, Gulshan and Madhu Gilhotra whose words of encouragement and push for tenacity ring in my ears. My sister Angela has never left my side and is very special.

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Abstract

Lead toxicity has been extensively studied in humans based on blood lead levels (BLLs). Scientists say there is no safe level of lead and that children are especially vulnerable since their bodies can absorb more of the neurotoxin than adults. Infants and children are susceptible to specifically the reduction of Intelligence Quotient (IQ) score and attention-related behaviors. Homes built in the 1950s or earlier have a higher risk of being serviced by a lead service line (LSL). The best way to permanently address sources of lead in drinking water is to remove all components containing lead and to replace all LSLs. North American communities are taking essential steps to accelerate the replacement of LSLs through online tools and financial incentives.

The purpose of the research is to examine the features that were most effective in prompting potential homebuyers or renters to replace LSL through compiling and analyzing information collected for 35 North American utilities. This study examines the "cost" as one of the significant barriers in all the LSLs and provides a solution through the development of a web application called GIS Cost Estimation portal that will help homeowners know their replacement cost as per the features and location of their house. Over time, the lead content decreases in a service line going to a 100% reduction. However, the cost cannot be correlated with the improvement factor in drinking water quality.

Abbreviations and Symbols used

AMI Advanced Metering Infrastructure

API Application Program Interface

AWWA American Water Works Association

BLL Blood Lead Levels

CDWQG The Guidelines for the Canadian Drinking Water Quality

CWS Community Water Systems

CWRS Centre of Water Resources

DNR Department of Natural Resources

EDF Environment Defence Fund

EPA Environment Protection Agency

FAQs Frequently Asked Questions

GCWW Greater Cincinnati Water Works

GIS Geographic Information System

GST Goods and Services Tax

HRM Halifax Regional Municipality (Halifax)

HTML Hypertext Markup Language

HW Halifax Water

IQ Intelligent Quotient

LCR Lead and Copper Rule

LSL Lead Service Line

LSLR Lead Service Line Replacement

m Meters

MAC Maximum Acceptable Concentration

Mg/L Milligrams per liter (equivalent to parts per billion)

NPC National Plumbing Code

Ppb Parts per billion

µg/dL Micrograms of lead per deciliter of blood

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CHAPTER 1: Introduction

1.1 Project Rationale

Lead is a naturally occurring element found in rock and soil, and this, together with its widespread anthropogenic use, has resulted in its universal presence in the environment (Health Canada, 2013). Lead is found in all environmental elements (EPA, 2018) (i.e., the air, the soil, and the water). Lead service lines (LSLs) were installed in drinking water systems in many countries, including Canada and the US. The amount of lead released into the water depends on the plumbing materials used, the corrosiveness of the water, and the length of time the water sits in the plumbing (Health Link BC, 2019). Lead may be found in brass and bronze fittings, such as faucets and valves, and fixtures, such as refrigerated water coolers and bubblers commonly used in schools and other non-residential buildings (U.S. EPA, 2006). In the US, legislation limiting the weighted average lead content of lines, pipe fittings, and plumbing fittings to 0.25% became effective on January 14 (U.S. EPA, 2011). The National Plumbing Code of Canada (NPC) was amended in November 2013 to reference plumbing standards with requirements for a 0.25% lead limit (NRCC, 2013).

Lead toxicity has been extensively studied in humans based on blood lead levels (BLLs). The effects that have been studied include neurological effects (Goyer, 1990), increased blood pressure, and kidney dysfunction in adults (Klaassen, 2008), as well as adverse neurodevelopmental and behavioral effects in children. Infants and children are susceptible to specifically the reduction of intelligence quotient (IQ) score and attention-related behaviors (A Pruss-Ustun, 2011). Researchers suggest that an incremental increase in BLLs of 1 µg/dL is associated with an approximately 1 IQ point deficit (M.L. Miranda, 2007). LSLs can contribute 50-75% of the total lead at the tap after extended stagnation times (Sandvig, 2008). Scientists say there is no safe level of lead and that children are especially vulnerable since their bodies can absorb more of the neurotoxin than adults. The best way to permanently address sources of lead in drinking water is to remove all components containing lead and to replace all LSLs. Typically, the complete removal of lead from the distribution system is a shared responsibility between the homeowner and the municipality (**Figure *1***). Municipalities pay for replacing service lines on their side of the property line, and property owners pay for their portion.

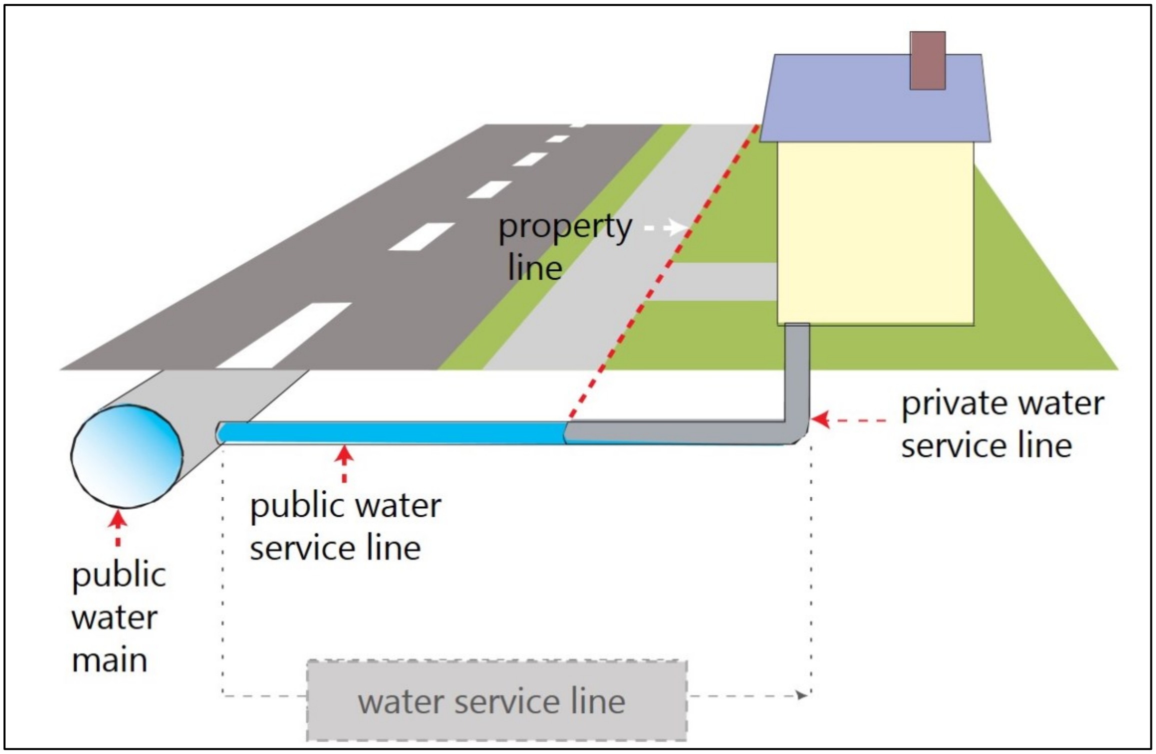


Figure 1 Water distribution system from the water main to the house. Reprinted from 'Halifax Water,' n.d., Retrieved from https://www.halifaxwater.ca/Lead -water-quality.

Several states and provinces are taking essential steps to accelerate the replacement of LSLs in their cities, further elaborated in the following chapters. In the 1970s, over a 2-3-year period, the Dartmouth Water Utility (now known as Halifax Regional Municipality (HRM)) replaced the vast majority of lead service connection pipes in the public right of way. Many programs are still strictly restricted to partial replacement – replacing only the portion of the LSL on public property, which commonly arises when rehabilitating the main and existing lines. Partial replacement is likely to increase, at least temporarily, lead levels in drinking water in homes and may not reduce lead exposure in the end (Nelter, 2019). Connecting the lead line to the copper line may result in an electrochemical process that can cause the water to dissolve some of the lead in the drinking water, thereby creating a severe long-term problem (Renner R. , 2010). Full replacement of both portions of the LSLs provides the best reduction of lead levels in the water entering the building (Trueman, 2017).

1.1.1 Guidelines to remove Lead in Drinking Water in Canada

Scholars have long been aware of potential health threats from lead, and the toxicity of lead in public water systems began receiving attention from health experts in the 19th century (L.W. May, 2017). Canada has a Federal-Provincial-Territorial Committee on drinking water to make *The Guidelines for Canadian Drinking Water Quality*. Health Canada works in collaboration with the provinces and territories on the Guidelines for Canadian Drinking Water Quality in order to protect the health of all Canadians for exposure over a lifetime. All provinces and territories use the guidelines as a basis to establish the requirements for drinking water quality in their jurisdiction (Government of Canada, 2016). The Government of Canada is committed to safeguard the health of all Canadians and to protect the environment from toxic substances, including lead. In collaboration with other provinces, territories and other federal departments, Health Canada has updated their drinking water guideline to reduce the Maximum Acceptable Concentration (MAC) from 0.01 mg/L, set in 1992 to 0.005 mg/L (typical stagnation= 0.5

hours) for total lead in drinking water, based on a sample of water taken at the tap and using the appropriate protocol for the type of building being sampled.

1.1.2 The USA's Lead Copper Rule

Drinking water guidelines, standards or guidance from other national and international organizations may vary due to the age of the assessments as well as different policies and approaches. In 1991, US Environment Protection Agency (EPA) established Lead and Copper Rule (LCR), as a part of the Safe Drinking Water Act (SDWA), which requires water utilities to conduct regular lead testing according to a standard procedure. Since 1991 the LCR has undergone various revisions. The treatment technique for the rule required systems to monitor drinking water at homeowners' taps. If lead levels above 0.015 mg/L are detected in more than 10% of tests of homes with LSLs, the utility must undertake the number of additional actions, including steps to control corrosion, steps to provide public education and steps to limit exposure (US EPA, 2011). Variations in methods of taking samples from homeowners' tap mean that there are different implications relating to actual exposure of a customer. For example, the US LCR methodology is significantly different from that used in the European Union and Canada (Preston, 2016).

1.2 Problem Statement

Initially, in the USA, the LCR required the replacement of the entire lead pipe (or line), both the public and privately-owned sections (**Figure *1***). However, requiring water utilities to remove privately-owned LSLs raised constitutional and legal issues in terms of private property and eminent domain. A 1994 challenge in the District Columbia (DC) Circuit Court by the American Water Works Association (AWWA) limited the EPA's jurisdiction to just the public portion of the service line. As a result, the LCR was revised in 2000 to allow for partial service line replacement, although utilities may offer homeowners the option of replacing their portion of the line at the homeowner's cost (Renner R. , 2010). However, over the years, research shows that replacing only a portion of the LSLs may increase the lead content in drinking water; especially right after the partial replacement (Trueman et al, 2016)

At the time of the adoption of the LCR in 1986, there were 10.2 million LSLs in the US. In North America, some individual water utilities have maps of LSLs within their network, but no one has a complete nationwide assessment (Farquhar, 2018). Homeowners need reliable and timely information about LSLs. Additionally, there is an information gap around whether a homeowner's service line is lead or not. If it is, homeowners do not know approximate replacements costs so that they can plan for it. It involves an inductive and exploratory approach by using correlational research techniques to examine, across studies, and different utilities to bridge the gap between homeowners and utilities. Homeowners need to understand the risk posed by an LSL, why it is their interest to have it replaced, and what they need to do to make it happen. There are some uncontrollable factors influencing the replacement cost, for example, length of the service lateral, depth of the excavation, sidewalk replacement, lawn/landscaping, and driveway replacement. Hence, this research analyzes, if a homeowner or the utility is getting the value for money or getting a required water quality by spending a substantial amount of money for the replacement.

1.3 Research Objectives

This research is divided into three objectives:

- **COMPILE:** First, it is to study and compile the Lead Service Line Replacement programs and approaches used by North American utilities to reach out to the residents and minimize lead exposure from the drinking water. It also further analyses the concerns and challenges faced by the utilities and the approaches taken by them.
- **DEVELOP:** Second, to develop a Geographic Information System (GIS) Cost Estimation Portal that will help homeowners to get the approximate cost of replacing their portion of the service lines; provide useful links to contractors and utility resources, and
- **ANALYZE:** Third, study the correlation between the renewal/replacement costs of Lead line replacement with water quality improvement.

1.4 Thesis Organization

The background information for each of these subject areas is divided into separate chapters:

Chapter 1 is the introduction to this thesis and provides a summary of the background of the lead service lines. The problem statement and research objectives are also provided.

Chapter 2 covers the **first objective** of this research. It is the literature review compiling information on LSLs, corrosion control, education, and outreach programs, and an estimated average cost of private service line replacement for 35 utilities across North America. It also differentiates the three diverse approaches used by Ohio and Indiana to build the lead line inventory.

Chapter 3 includes analysis (**first objective)** of the study on 35 North American utilities to draw conclusions on different effective methods used for full LSLRs and the challenges faced by those utilities.

Chapter 4 focusses on the **second objective** of this research. It gives an introduction to the development of the cost estimation portal with a description of the workflow.

Chapter 5 examines the relationship between the replacement cost of an LSL for a house with an improvement in drinking water quality. It focuses on the **third objective** of this research.

Chapter 6 states the conclusion drawn from the research and suggests possible directions for future work.

CHAPTER 2: Literature Review

2.1 Introduction

Lead in drinking water is a serious and well-documented issue. There has been expedited and heightened awareness around it after the incident in Flint, Michigan. The water crises in Flint, MI began in 2014, when the city switched its drinking water supply from Detroit's system (S.J. Masten, 2016) to the Flint river in a cost-saving move. Inadequate treatment and testing of the water resulted in a series of major water quality and health issues for Flint residents (Denchak, 2018). In February 2015, the City of Flint sampled Flint residents home and found lead in the tap water at a concentration of 104 µg/L (Flint Water Advisory Task Force, 2016). In the area of Flint that had the highest lead levels in the water; the BLLs in children who were tested increased by a factor of about 2.5 (S.J. Masten, 2016). Since 2016, crews have inspected more than 20,000 service lines, replacing roughly 8,000 lead and galvanized pipes (City of Flint , 2016).

Flint MI is not only the one with the problematic pipes, there are several other utilities having lead service lines (LSLs) in their system. Various utilities have various ownership criteria over the public, and the private side of the service line (**Figure *1***), different legislative requirements, different funding structures for service line replacements. This chapter details the **Compile objective (first objective)** of this research that is to study the potential locations of LSLs, and compile the innovative solutions including record management for the lead service line replacements (LSLRs) of some of the leading utilities across North America.

2.2 Likelihood of the Lead Service lines

Most of the lead in drinking water comes from old pipes, fittings, lead-based solder within a building or from the service pipe connecting the property to the main supply at the curb stop (or shut off valve). The age of the home and neighborhood is essential. The NPC allowed lead as an acceptable material in pipes until 1975 and solder until 1986 in Canada. Older neighborhoods may have LSLs, while more recent homes may have lead fittings or solders in their plumbing systems (Government of Canada, 2016).

2.3 Funding for Lead Service Line Replacements

One of the most significant challenges is determining who pays for replacing the portion of an LSL on private property. It is challenging to put the responsibility solely on the homeowner since they are unlikely to have been told they have an LSL by the seller, or they might not be aware of the lead issues in the drinking water. The cost of replacing an LSL is very site-specific (Farquhar, 2018). **Table *1*** compiles and compares the information on 35 North American utilities.

In the US, there are several state-wise options to fund replacements of the LSLs on private property like State Drinking Water Revolving funds, Community Development Block Grant, and several other loans or rebate programs for private side replacements. Several NA utilities have long term plans to replace old water pipes that connect homes to the water main. The Wisconsin DNR established a two-year program to assist disadvantaged municipalities in replacing LSLs on private property for projects that result in full LSLRs. Funding for LSL replacement on private property is in the form of principal forgiveness, which means no debts are incurred on behalf of the municipality for these funds (Wisconsin DNR). US has state policies that support LSLR programs. The Illinois

General Assembly enacted SB550 in January 2017 regarding lead in drinking water and in 2017, enacted HEA-1519, allowing the Commission to approve an investor-owned utility's request to fold the cost of LSL replacement into the rates paid by customers. In 2018, the Massachusetts Clean Water Trust, in coordination with the Massachusetts Department of Environment Protection announced the development of the Incentivized LSLR Program. Pennsylvania has passed laws expressly describing the conditions under which rate funds paid by customers can be used to replace LSLs on private property for both municipal-owned and investor-owned community water systems (EDF, 2019). Madison water utility began leasing space on its water towers to mobile telephone companies, which installed their cellular antennas on the towers and used that money to finance the service line replacements (Joyce, 2017).

Table 1 Compiles the information for 35 North American Utilities working to have an effective and efficient lead service line replacement (LSLR) program. The table lists down the cut off year (use of lead in service lines, fixtures, or solders), approximate number of lead service lines (LSLs), financial aid program by the utilities to the homeowners, corrosion control, record management techniques used to reach out the residents, and the average cost predicted for the private side of replacement.

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
1.	Boston, Massachusetts[1,2,3]	1950; Lead solder used up till 1986[1]	4500 [2]	Credit up to 2000 USD, can pay over 48 months interest-free. The program is in place since 2005[1]	Orthophosphate[1]	Interactive web pages and education materials[1]	2,500-3,000[3] USD
2.	Brantford, Ontario[4,4(a),5,6]	1955[4]	19 public and 2,530 private service lines[5]	Offers a grant of up to $1,000 to eligible property owners. Also, the City offers an interest-bearing loan to property owners for eligible work. The amount of each loan will not exceed a maximum of $3,000. [4(a),]	Unknown (Information not available)	Lead and suspected lead services map; filter program[4]	1,800 CAD[6]
3.	Calgary, Alberta[7,8]	1960s[7]	630 private connections[7]	No financial assistance for homeowners to replace their LSLs; $100 rebate toward the	Orthophosphate[7]	Water quality testing, education, and rebate for	5,000-10,000 CAD[8]

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
				purchase of a certified tap mounted filter[8]		filtration devices mail an annual notice to those residents with identified Lead connections[7]	
4.	California[9,10,11]	1985[11]	65,000[10]	No financial assistance	Unknown (Information not available)	Service Line Inventory Status map[9], FAQs for residents in the resources/supplemental materials; LSLR website; provide residents with consumer confidence reports (annual	n/a

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
						water quality reports)	
5.	Chicago, Illinois[12,13,14]	1986[12]	Illinois: 730,000[12] 392,614 (75% of the total) in chicago[13]	No financial assistance	Orthophosphate [14]	Free testing kits; FAQs for residents in the resources/supplemental materials; LSLR website;	USD 10,000 - 20,000[14]
6.	Cincinnati, Ohio[15,16,]	1927[16]	Zero (replaced all 27,000 in 2016)	If utility replaced – 40-50% off the cost of replacement up to $1,500 and balance added to homeowner's property assessment (0% interest). [16]	Unknown (Information not available)	Detailed interactive map (Figure 5)[15]; Customer Assistant Program (HELP) for low-income customers[16]	USD 5,500[16]
7.	Detroit, Michigan[17, 18, 27]	1945[18]	125,000[17]	Replace the entire LSL, gooseneck, or galvanized steel line at CWS's expense[27]	Orthophosphate [18]	LSL online tool (FAQs and	5,000-7,000 USD [17]

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
						definitions)[18]; testing kits	
8.	Denver, Colorado[19,20]	1951[19]	50,000-90,000[20]	Low interest loans (0-2%) as per homeowner's income[19]	Unknown (Information not available)	brochures before and after LSLR[19]	3000-5000 USD[20]
9.	Eau Claire, Wisconsin[21]	1986	1200	Reimburse the homeowner for the actual cost of replacement up to a maximum of $2,000.	Lime	Online lookup to see pipe material on the public side	USD 2248-3500
10.	Evanston, Illinois[25]	1960; Lead solder in 1987	Information not available	Zero-interest loans- up to USD 4800 will be payable back to the city in the 48-month period	Blended phosphate	Water service information map	USD 7000
11.	Flint, Michigan[22, 23, 24,27]	1950[22]	4000 LSLs and 11,196 as unknown[22]	Replace the entire LSL, gooseneck, or galvanized steel line at CWS's expense[27]	Phosphates	lead disclosure to the homebuyers[27]	USD 7,000[24]
12.	Geneva, New York[26, 27]	1939[26]	Unknown	Grants will be used to replace residential LSLs from the	Unknown (Information not available)	Press release, website information, social media,	Information not available

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
				municipal water main to the residence[26]		water bill notices[27]	
13.	Green Bay, Wisconsin[27]	1990	1299 out of a total of more than 36,400 service lines in the city	Forgivable principal loans (grants) from Wisconsin DNR	Unknown (Information not available)	Map detailing utility-owned service lines;	Information not available
14.	Guelph, Ontario[28,29,]	1960[29]	4450 [29]	Two grant options; full or private Option 1, Full – CAD 581 for full LSLR where homeowner replaces private side at the time as the city of Guelph replaced city side Option 2, Private – 1500 cad where city side has already been replaced, and Lead remains on the private side Additional crawl space grant 500 CAD – where service	Unknown (Information not available)	Water tests, free kits, [28]	CAD 1000-4000[29]

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
				entry and meter located in the crawlspace[28]			
15.	Halifax, Nova Scotia[30, 31]	The 1950s[31]	2000 (public) and 3500 (private) [30]	Lead line rebate and service line loan program[31]	Orthophosphate [31]	HRM integrated plan; Customer care; Home inspections, filter kits, lead boundary map[31]	CAD 3500[30]
16.	Hamilton, Ontario[32]	1955	20,000	Loans up to CAD 2000 for ten years	Orthophosphate	Home inspections, filter kits	CAD 1500-2000
17.	Indiana[27]	1986	50,000[27]	Customers have to pay for significant costs – those above USD 7000 per line.	Use orthophosphate, but also checking for sodium hexametaphosphate	Successful inventories – through a voluntary survey and developed a map	Entire line averages $3,500

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
18.	Kingston, New York[33, 27, 34, 36]	1940[33]	59% of the total. [34] Estimated LSLs are N/A	The city will cover the cost of replacement for most owner-occupied properties and non-owner-occupied rental properties required to contribute USD 750 for replacement[27]	sodium hydroxide to increase pH and Food-grade phosphoric acid to create a protective film that reduces the release of lead [36]	Information not available	Information not available
19.	Lansing, Michigan [35, 27]		Zero [35] (10 years to replace 14,000 pipes)	The line replacement cost was covered out of total utility revenue. [35]	No corrosion control program	Brochures; free testing kits [35]	City responsibility USD 3500 per line[27]
20.	Madison, Wisconsin[37, 38, 39]	1930[37]	Zero (8,000 were replaced)[38]	USD 1,000 max for low-income homeowners[37]	Orthophosphate [38]	Brochures with FAQs; the replacement was mandatory[37]	1400 USD[39]

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
21.	Marlborough, Massachusetts [40, 41, 27]	28,000 [41]	1200[27]	10 year no interest loan[27]	Unknown (Information not available)	Static map to see suspected LSL location or list of addresses provided by the city[27]	3000-5000 USD[40]
22.	Montreal, Quebec[42,43]	1970[43]	60,000 (50,000 to be individual replacements and 10,000 to be done as water main projects)[42]	No grant or loan	Orthophosphate and silicates [43]	Information pamphlets, optional water testing (building owners must pay certified labs to charge between cad 150-250; [42]	CAD 9000 – individual and CAD 4000 – as part of water main projects[42,]
23.	Milwaukee, Wisconsin[44, 45]	1951[44]	77,585 (46% of the total)[44]	Special assessment financing- 10 years repayment period[44]	Orthophosphate	A published list of properties with LSLs[45]	USD 7000 [45]

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
24.	Newark, New Jersey[46,47,]	1986[47]	15,000 full or partial LSLs in system[46]	Discounted rate for replacement through the program – no more than USD 1,000 paid over 12 months at zero interest[46]	Used sodium silicate and now switching to orthophosphate [47]	A database showing the location of all the Lead service lines, as inventoried by the city; distributing filters door – to- door; [46]	USD 4,000-10.000 [47]
25.	Philadelphia, Pennsylvania [48,49]	1978 (usually found in pre-1950 houses) [48]	Estimated 60,000 properties with LSLs of unknown age, but no location maps exist.[49]	Interest-free loans[48]	Zinc orthophosphate [48]	In-home water sampling programs; address-based database of lead lines; “one-stop” page for customers with lead pipes or those concerned[48]	USD 3000-8000 [48]

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
26.	Pittsburgh, Pennsylvania [27, 48, 50,51]	1978 (found in pre 1950)[48]	15-20,000 [50]	Loans up to USD 10,000 @ 3% interest [27]	Orthophosphate [50]	Interactive map; curb box inspections[50]	USD 5000-10000 [51]
27.	Richmond, Virginia[55]	1950	14000-public side	LSL Grant - Up to USD 2500	phosphate	Information not available	USD 2500-5000
28.	Regina, Saskatchewan[52, 54]	Houses built before 1940; cut off the year was 1989[52]	3900 [52]	No grant or loan program[52,54]	Unknown (Information not available)	Filters; water bill notices[54]	5,200-6,000 CAD[54]
29.	Saskatoon, Saskatchewan[52,53, 54]		5300 [53]	The city pays 60; owners pay 40% of the final bill[54]	Unknown (Information not available)		5,200-6,000 CAD[54]
30.	Tucson, Arizona[56]	The 1980s	496 (replaced 126)	Reimburses the property owner up to $4,341 in replacement costs.	Unknown (Information not available)	GIS map shows the potential locations of LSLs and the status of investigations	Unknown (Information not available)

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
						and replacements.	
31.	Toronto, Ontario[57, 5]	1950s[57]	31,520 [57]	Interest-free loans[57]	Orthophosphate [57]	Mailouts; free water test, map showing potential locations[5]	CAD 10,000[5]
32.	Washington, DC[58]		48,000 (46% of the total)[58]	Grant for combination income/household size qualified homeowners – 5000 USD max; low-income loans are also available; loan payment can be four monthly installments[58]	Orthophosphate [58]	Mailouts; GIS Map[58]	2,000-4,000 USD[58]
33.	Waterloo, Wisconsin[59, 27]	Early 1960s[27]	250 homes[59]	A grant equal to 75% of the cost of private side LSL replacement[27]	Unknown (Information not available)	Mailouts, handing out education materials, sampling programs, [27]	Up to USD 2300[27]

#	Cities	Cut off Year	Estimated LSLs (Approx.)	Financial Aid (From utilities to Homeowners)	Corrosion Control	Reaching out residents	The average cost of Private side Replacement (Approx.)
34.	Winnipeg, Manitoba[60]	1950; plumbing materials were used until 1990[60]	25,740 [60]	Unknown (Information not available)	Orthophosphate [60]	Mailouts, handing out education materials, sampling programs[60]	Unknown (Information not available)
35.	York, Pennsylvania [27]	1934[27]	1660[27]	Partial reimbursement[27]	Unknown (Information not available)	Outreach materials[27]	Unknown (Information not available)
** curb box inspections- sending a camera down into curb box or vertical shaft found in front yard or sidewalk							

1. (Boston Water and Sewer Commission, 2019)
2. (Brokhof W. , 2018)
3. (Rocheleau, 2016)
4. (City of Brantford, 2019)
4(a) (City of Brantford, 2019)
5. (Keogh, Do you have lead in your tap water? What you can do to find out in Ontario, 2019)
6. (Mercanti, 2019)
7. (Alberta Water, 2019)
8. (A.Page, 2019)
9. (B.Robertson, 2018)

10. (Neltner T. , California requires replacement of all lead service lines – but vigilance needed on implementation, 2017)
11. (Cal Water, 2019)
12. (D.A. Cornwell, 2016)
13. (Neltner T. , Where are Illinois' lead pipes? Chicago Water has nearly 60%, and small systems don't know., 2019)
14. (Brackett, 2016)
15. (Greater Cincinnati Water Works (GCWW), 2019)
16. (DeLaet, 2018)
17. (Cwiek S. , 2018)
18. (City of Detroit, 2019)
19. (Denver Water, 2019)
20. (Kenney, 2019)
21. (Hantke, 2018)
22. (Smith L. , 2016)
23. (City of Flint, 2019)
24. (Dolan, 2016)
25. (City of Evanston, 2019)
26. (City of Geneva, 2019)
27. (EDF, 2019)
28. (City of Guelph, 2019)
29. (Lovell, 2016)
30. (Bundale, 2019)
31. (Halifax Water, 2019)
32. (Hamilton, 2019)
33. (Kirby, 2018)
34. (Daily Freeman, 2019)
35. (The Detroit News, 2016)
36. (NYC Environment Protection, 2016)
37. (Madison Water Utility, 2014)
38. (US EPA, 2018)
39. (Madison Water Utility, 2019)
40. (Malachowski J. , 2017)
41. (Arsenault, 2016)
42. (Riga, 2016)
43. (Prevost, 2015)
44. (Jannene, 2018)
45. (City of Milwaukee, 2019)
46. (Yi, 2018)
47. (City of Newark, 2019)
48. (Jaramillo, Philadelphia's building boom gives rise to another hidden lead risk, 2017)
49. (Gass, 2016)
50. (Pittsburgh Water and Sewer Authority, 2019)
51. (Smeltz, 2017)
52. (Taylor, 2017)

53. (Reid Corbett, 2017)
54. (Wilson, 2019)
55. (Small, 2016)
56. (City of Tucson, 2019)
57. (City of Toronto, 2019)
58. (Neltner T. , City of Washington, DC requires lead pipe disclosure and tackles past partial LSL replacements, 2019)
59. (Graff, 2018)
60. (City of Winnipeg)

2.4 Record Management and Innovative techniques used to Replace Lead Service Lines

Halifax Water (HW) has historically worked with the municipality on street reconstruction projects to replace LSLs economically (Halifax Water, n.d.). With the utilization of the Advanced Metering Infrastructure (AMI) project, HW visited all 83,000 service connections, and the meter installers provided written notification to homes where they observed a private LSL (Krkosek, 2018). This allowed HW to confirm LSLs and inform customers of the risks and current programs in place to aid them in the LSL renewal process. In 2019, they launched an improved website, including a comprehensive section on the lead line program. One of the highlights of the improved website is a searchable map designed to allow customers determine if they are at risk of an LSL; the map does not provide service-specific information, only a geographic "Lead Boundary" beyond which the water infrastructure is too young to have LSLs (**Figure *3***). Likewise, Brantford released a map (**Figure *4***) of the lead zone on the city's website. Ontario has also publicly shared the lead test results for schools and daycares. Nearly a third of all Ontario schools and daycares had at least one test result that was above 5 ppb between April 2016 and March 2018 (Keogh, 2019).

Figure 2 Map shows the material type public and private service line with the representation of green, grey and white dots. District of Columbia Water and Sewer Authority. (2019). [DC Water Service Information]. 1:100m. Retrieved from https://geo.dcwater.com/Lead/

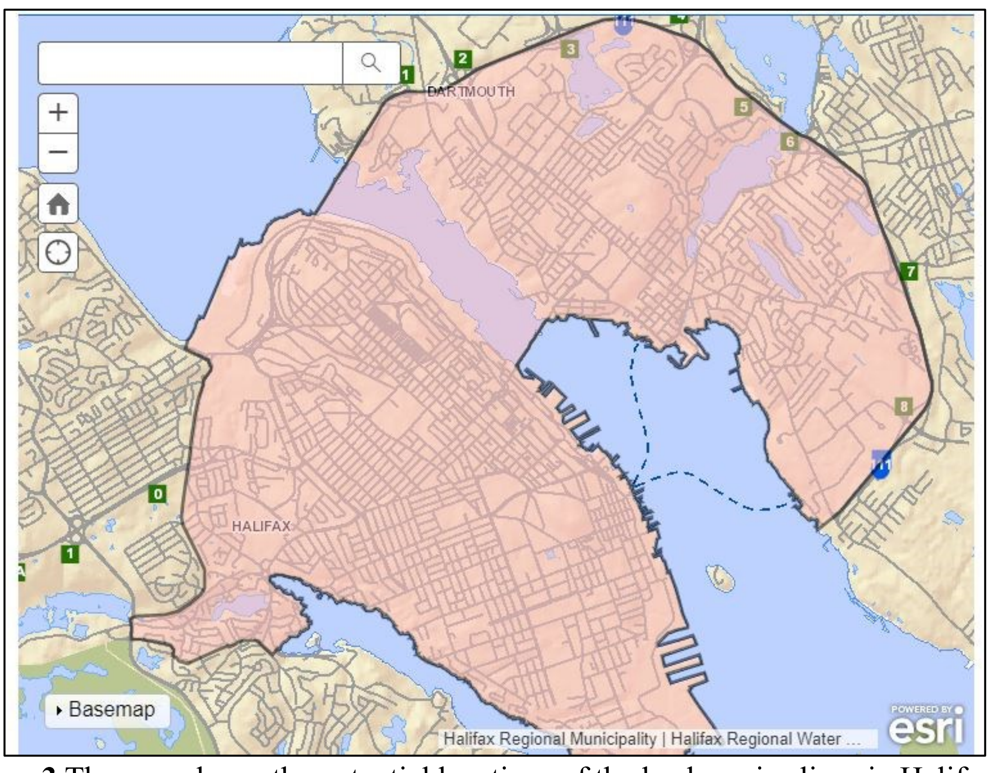


Figure 3 The map shows the potential locations of the lead service lines in Halifax. Halifax Water. (2019). [Lead Boundary Map for Halifax, NS]. Retrieved from https://www.halifaxwater.ca/lead-drinking-water

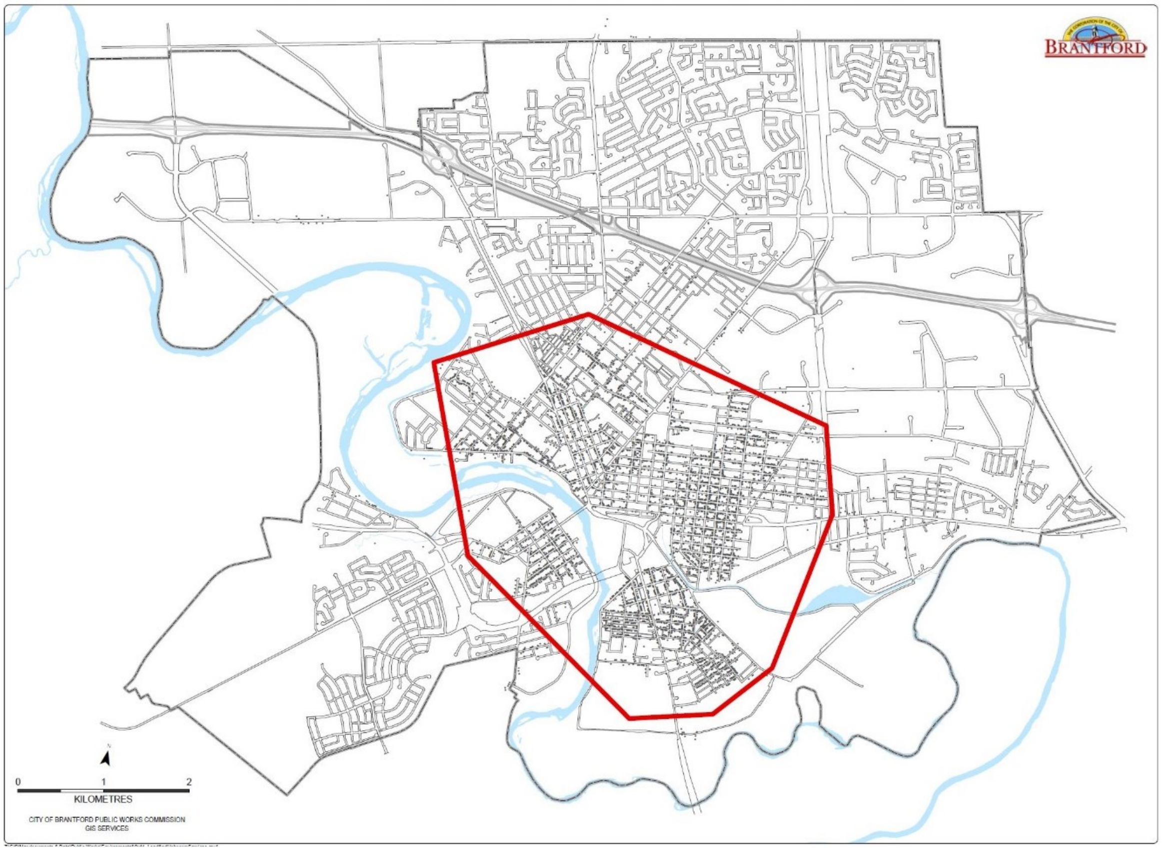


Figure 4 The map represents the lead boundary as per the age of the service lines located in the system. City of Brantford. (2019). [Lead and Suspected Lead Services]. Retrieved from https://www.brantford.ca/en/living-here/lead-in-tap-water.aspx.

Montreal, which has tens of thousands of known LSLs within the city limits, recently announced that it would replace the lead pipes on both sides of the property line and bill the homeowners for their portion of the work, giving them 15 years to pay the city back (Page, 2019). However, they have no grant/loan programs to help homeowners pay for those replacements.

Evanston is one of several municipalities in Illinois that have created online inventories. DC Water has been a leader with its online, interactive map (**Figure *2***) providing the public with access to what is known (and unknown) about service line material at individual properties (Neltner T. , 2019). Cincinnati Water Works has a new interactive lookup map that provides Cincinnati residents with information about the water service line to their home.

States passed a new law in which it first requires property owners to disclose the presence of the LSL to potential homebuyers and renters. Cincinnati and Philadelphia require disclosure to renters and New York, Delaware, Connecticut, and Pennsylvania requires disclosure to homebuyers. Second, it redresses past partial LSL replacements by providing financial support to homeowners who did not replace the portion on private property (Neltner T. , 2019). Property owners must provide a "lead disclosure form" to the tenant before the person is obligated under any contract to lease or renew the lease of the dwelling unit.

With trenchless replacements Lansing MI was able to reduce the cost of replacement from USD 9000 to 3600 for every lead pipe, and it took about 4 hours for the replacement (Gerstein, 2016).

2.5 Case Study: Using online communicative tools to promote replacements –Cincinnati, Cleveland, and Indiana

Given the diverse approaches taken to display LSL locations by different utilities, this case study evaluates the two online tools used by Ohio's cities, i.e., Cincinnati and Cleveland to promote replacements of the LSLs and to build an inventory effectively and efficiently (example: Indiana). Cincinnati posted an interactive map (**Figure 5**) of LSLs modeled after one posted by Washington, DC, in 2016 (**Figure** *2*). The next year, Cleveland posted a search engine enabling anyone to check the service line material at an address supplemented with the static color-coded map (**Figure 6**). Cleveland's tool only provided address specific information on the public side of the service line but not the private side. If the user enters an existing address, including zip code, the webpage responds by indicating whether the property "likely" or "unlikely" has a Lead pipe on the public side of the service line.

2.5.1 Background

Public water systems are required to monitor for the lead in drinking water they distribute to consumers and take corrective action where levels exceed a federal action level of 15 ppb. Greater Cincinnati Water Works (GCWW) oversees the public water systems in Cincinnati, to ensure compliance with all federal SDWA requirements.

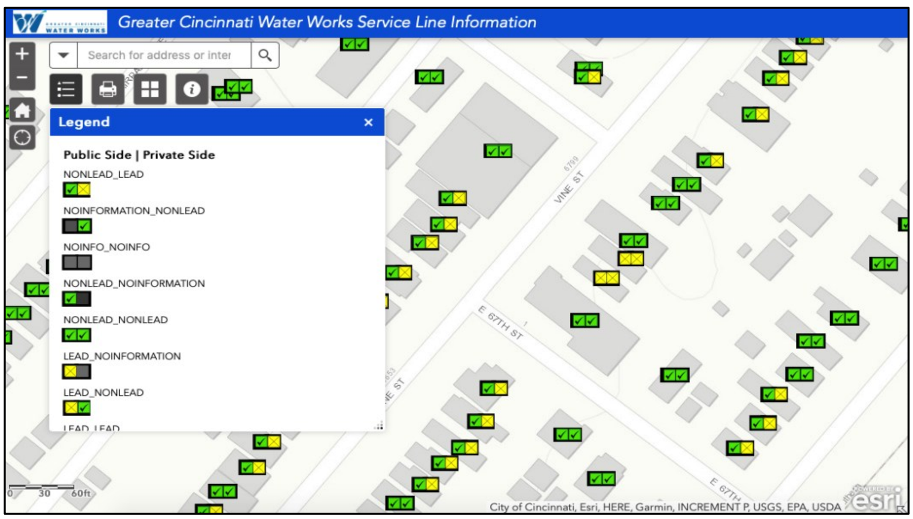


Figure 5 The map shows the private and public service line material. Greater Cincinnati Water Works. (2019). [Greater Cincinnati Water Works Service Line information] Retrieved from lead.mygcww.org.

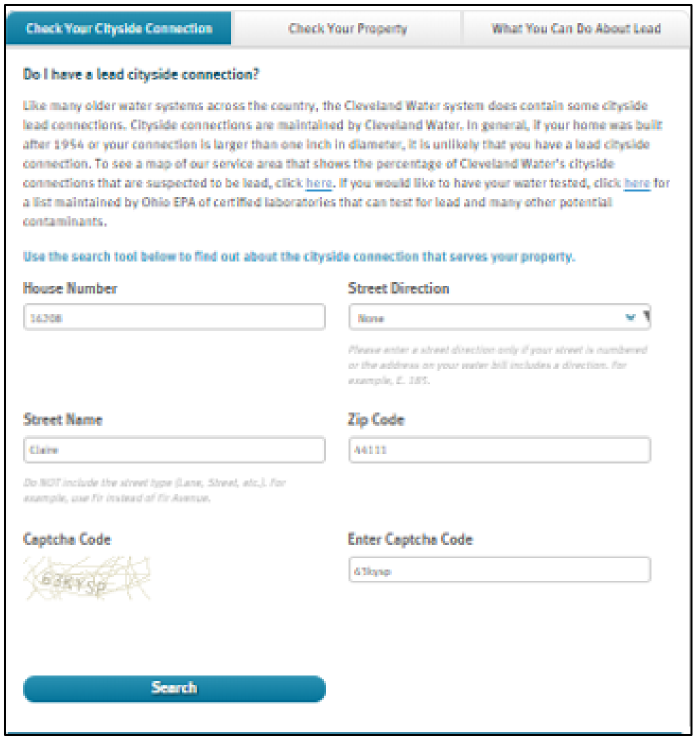


Figure 6 Showing the screenshot of Cleveland's Database. Adapted from "Mapping of the Lead Service Lines: Charting a Path to Engage a Community Webinar" by Lead Service Line Replacement Collaborative, 2019, March 13

Cincinnati's tap water comes from both surface and groundwater sources. Surface water from Ohio River is treated at Miller Treatment Plant located in Eastern Hamilton County, and groundwater from one of 13 wells drawing from the Great Miami Buried Valley Aquifer, is treated at the Bolton Treatment Plant in Southern Bolton County (Schultz, 2019). In Cincinnati, there are 43,500 water services, out of which 16,500 as full LSLs and 27,000 as a private LSL (GCWW, 2016). The city stopped the use of lead in 1927. Earlier, Cincinnati started with an online lookup tool for the homeowners where they can search specific address.

Cleveland Water uses surface water drawn from Lake Erie as the source of drinking water. Cleveland's public water system, which serves more than 1.5 million customers in

80 northeast Ohio communities, is required by federal and state law to routinely test drinking water from home faucets for lead and copper. Since Cleveland began regularly adding a chemical called orthophosphate to the water, levels of lead in tap water tests have dropped nearly 90 percent and have not exceeded the EPA "action level" of 15 parts per billion (Dissell, 2018).

Indiana American Water, a subsidiary of American Water, is the largest investor-owned water utility in the state, providing high quality and reliable water and wastewater services to approximately 1.3 million people (Indiana American Water, 2018). Indiana American Water estimated 50,000 LSLs might be present at one time at locations served by the company around Indiana. Homes built before 1930 are more likely to have lead plumbing systems.

2.5.2 Building an Inventory

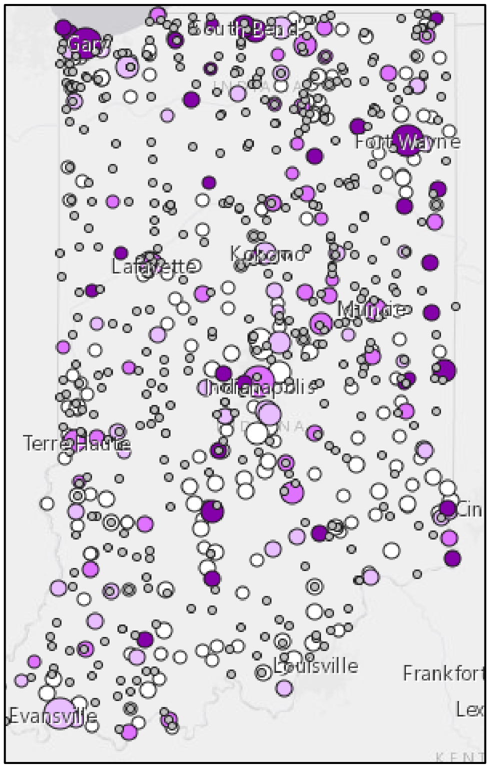
Cincinnati assumed records for the private portion of the service line according to the age of the pipe (i.e., built before 1927). The records are also compiled as per field visits and inspector reports. Cincinnati used the ArcGIS platform to develop maps and indicate two sides of the service line (as shown in **Figure 5**). Cleveland Water started with addresses of nearly 420,000 customers it serves in Northeast Ohio. About 326,000 of those connections were installed from 1856 through 1954 when Lead was used for service lines. After removing addresses of lines installed after 1954, as well as one with larger pipes that do not contain lead and pipes that were replaced over the years, Cleveland water deemed pipes at more than 187,000 addresses were "likely to be lead " (Dissell, 2016). Cleveland Water estimates the actual number of LSLs is actually between 106,000 and 160,000.

The state of Indiana gathered information on LSLs from its water utilities through a voluntary survey. Compared to other states, Indiana has one of the most robust voluntary surveys with a reasonable response rate. The survey (S. H. Schlea, 2019) requested detailed information on six types of service line materials, i.e., 1. No Lead pipe in any portion of the line. 2. Material is unknown. 3. The only lead pipe is a gooseneck. 4. The entire line is a lead pipe. 5. The lead pipe from main to external shut off, curb, or property line (on public property). 6. The lead pipe from external shut off to home (on private property).

Indiana's two-page voluntary survey asked some questions on (EDF, 2018):

- Unknown service line material, i.e., potential LSLs
- Sources of record checked for service line information
- Ownership of the public and private portions of the service line
- Legal citation or ordinances that establishes the ownership of the service lines

Environment Defense Fund (EDF) acquired the responses to the survey and developed a map of LSLs in Indiana as a model (**Figure 7**).



Dot size: Number of service connections in a community water system

Dot color: Percentage of service connections with a Lead portion

Dot color (grey): Water systems that either did not respond to the survey at all or that did not respond to the questions on LSLs.

Clickable Dots: Clicking on any dots shows more detailed information for a single community water system, including the exact number of service connections and percentage with lead portion.

Figure 7 Potential Lead Service Line Locations. Adapted from "Mapping State Level Lead Service Line Information: Indiana as a model" by L. McCormick, 2018, October 8, Environment Defense Fund

Of the 781 active water utilities surveyed in Indiana, only about half (446 utilities) responded to the survey. However, those who responded represent 92% of the state's 1.9 million service lines, as non-respondents were primarily smaller utilities (EDF, 2018).

2.5.3 Challenges and Concerns

The public had concerns about posting information about LSLs on private property on a public website, as this will impact property values. The municipalities/utilities had challenges, for example, limited resources, i.e., time, staff, and funding to conduct surveys or complete inventories. Given the diverse approaches taken to display LSL locations, EDF conducted a study evaluating the online tools from three Ohio cities – Cincinnati, Cleveland, and Columbus, as examples to determine what features were most effective in prompting potential homebuyers or renters to replace LSL. Participants overwhelmingly indicated that they would be likely to pressure the seller to replace the LSL as a condition of purchase and only 5% of survey participants said they would consider moving into a home without taking some action. EDF's results demonstrate that participants found it useful to be informed if the service line material is unknown and did not appear to be confused with such information. The most transparent approach is to explicitly indicate if service line material is unknown and update the map over time as applicable.

Cleveland database: Originally, 52.1% of the respondents understood that the tool provided information about public-side LSLs, and only 36.7% of respondents understood that the tool would not give them access to information about the presence or absence of a private-side LSL (Neltner et al, 2019). The outcome of the survey was that the respondents didn't understand what the information was displayed through the Cleveland's database and they were confused about the material displayed for the public and the private service line.

2.6 Summary

It is ubiquitous across North America to have a shared responsibility for the service lateral, but still there are few states (like Michigan), which have full responsibility of the service line. Typically, the utility/municipality owns the service line to the curb stop or the property line after which it becomes a homeowner's responsibility. This shared responsibility is one of the biggest challenges in terms of replacing LSLRs as the utility or municipality can only work on and replace their portion. Most of the utilities across North

America had very similar barriers in terms of leaving the responsibility to the homeowner to replace their side of the lead lateral. These barriers are listed below:

i. Financial burden
ii. Not enough time to plan appropriately for replacements
iii. Do not perceive them to be at risk
iv. Do not perceive it as a wise investment in their property

Based on the literature review, it is quite evident that if the municipality does have the data, there is a disconnect between providing this data to the public because of various privacy and jurisdictional controls, as well as the fear from the homeowners that it might lower the value of the property.

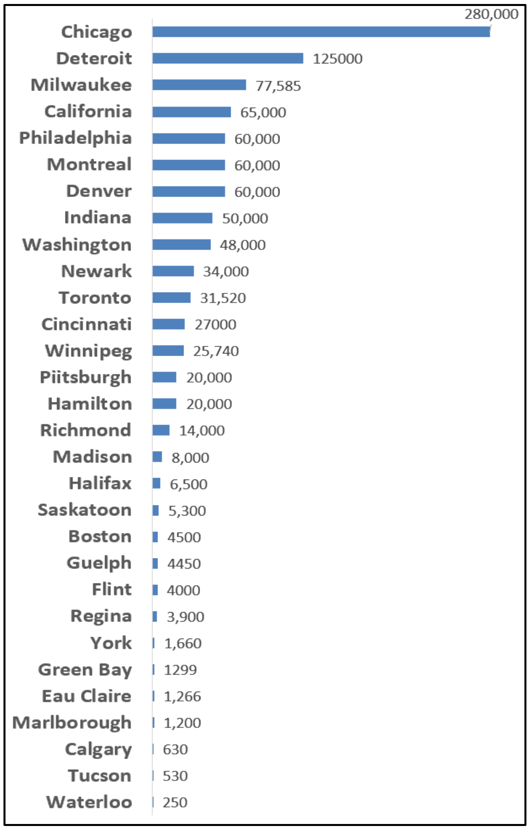
CHAPTER 3: Creating an Effective Lead Service Line Replacement Program

3.1 Introduction

Lead service lines (LSL) are a consistent high source of lead and contribute 50-75% of the total lead at the tap after extended stagnation times (Health Canada, 2017). This chapter analyses and investigates the several tools municipalities across North America have used in order to develop their Lead Service Line Replacement (LSLR) programs and their challenges while developing those programs, which vary from incomplete and inaccurate data, low customer uptake, lack of resources to jurisdictional pressure. The analysis will help to achieve the second objective for this research that is to develop a cost estimation tool to help homeowners and utilities. This research recognizes states and communities across the country that are making progress towards LSLR, including developing maps, estimates of the known and potential LSL locations.

3.2 Data Gathering and Inventory Management

There are an estimated 6.1 million homes across the US with LSLs (EDF, 2019). Building a comprehensive inventory for LSLs in community water systems (CWS) is a critical part of any effort to eliminate lead pipes, and also one of the biggest challenges in creating an effective LSLR program. This is a result of the varied history of the utilities with many independent predecessors and their shared ownership of service lines, legacy records, and mergers.



Record keeping over the years have been inconsistent. LSLs are generally in the houses built before the 1970s (NPC), and that is why some records from the early last century have been lost or are in handwritten service cards (for example in Halifax, tap cards and vintage service maps in Tucson, Arizona). Many utilities have estimated the approximate number of service lines (**Figure *8***) in their system as per the age of the service lines and historic non electronic records.

Figure 8: Estimated total number of Lead Service Lines (LSL) for 35 North American utilities compiled and studied in the literature review. Those utilities which have no predictions of the total number of service lines are not included in this graph (*Note:* these are the estimates only that have been found through their websites. The actual numbers can vary significantly because legacy record keeping has been inconsistent over time.)

In January 2017, the Illinois legislature passed a law (Neltner, 2019) designed to include a requirement that CWSs submit annual reports to Illinois Environmental Protection Agency (IEPA) regarding a "water distribution system material inventory". EDF analyzed the Illinois inventory management to be more effective than Indiana's approach (Section **2.4**) as it requires regular annual updates to track progress from CWSs rather than a one-time voluntary survey. However, the procedures to develop inventory for a utility can be somewhat labor-intensive and utilities must account for this in planning the scope and cost of the replacement programs.

3.3 Publishing available data and Customer Engagement

Once a municipality collects data, it is very important to see how that can be made available to the public and how that data can lead to purposeful customer engagement. **Figure *9*** below shows the different methods employed by municipalities in order to present their data to the customers.

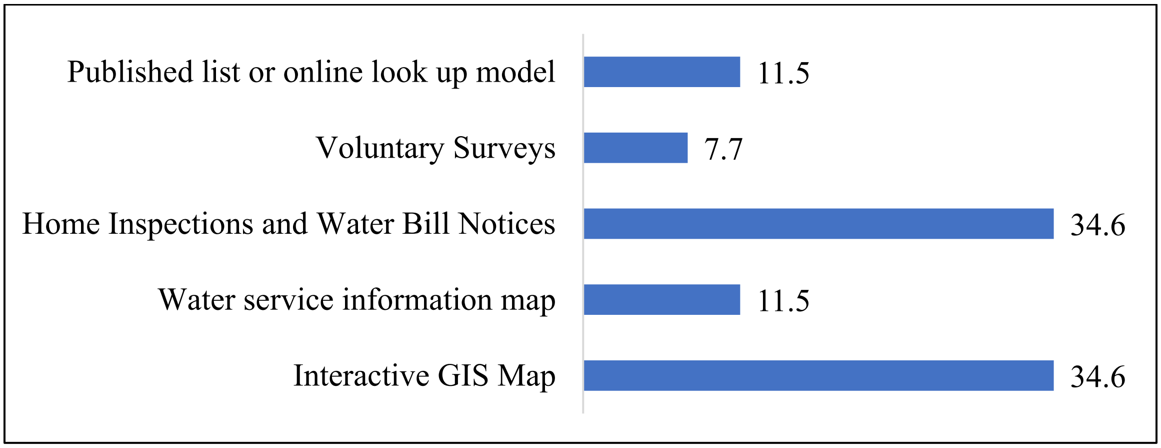


Figure 9 Graph showing the methods used by North American utilities compiled in table 1 to reach out to the residents and update inventories, 2018-19 (Total no. of utilities, n =35)

Home inspections and sending out water bill notices method remains to be a widely used method in terms of reaching out to the residents by informing about lead in drinking water, potential location of LSLs, and lead toxicity. However, the interactive map and online lookup model approach has also become popular for displaying LSL locations (**Figure *9***). There are other methods of communication, for example, one-on-one communication between the utility and homeowner, web-based information, telephone contact, written correspondence, and mass media. However, despite comprehensive LSLR programs, financial aid programs, and customer and educational outreach, there is still LSLs in the system. This can be resolved by displaying information through interactive maps of whether the material information for a particular lateral is known or unknown.

This brings awareness of lead lines to the residents so that they can make an informed decision on whether their lateral needs replacement or not.

The maps may vary in the icons the municipalities use, how they present what is unknown, and whether they encourage residents to send the information to the utility or to update the map of potential locations of the lead lines. Based on the literature review and researches done in the past, the interactive map should include:

1. Information on both the public and private side of a service line
2. Be clear about what is not known
3. Careful consideration of legends and icons to present known and unknown materials
4. Proper advertisement of the maps to the public, such as direct mailings, water bill notices, and phone calls to property owners with potential LSLs.

Some utilities can adopt to show the locations of the service lines as per the age of the service lines. As an example, **Figure *9*** shows the hot spot areas as per the age of service lines in Halifax, Nova Scotia, which are likely to have lead plumbing systems. Red areas are those where high age values cluster (i.e., more than 40 years old) and blue areas where low age values cluster (i.e., less than 40 years old). This will help homeowners know if they are more likely to have an LSL or not and therefore, they can contact the utility for further updates.

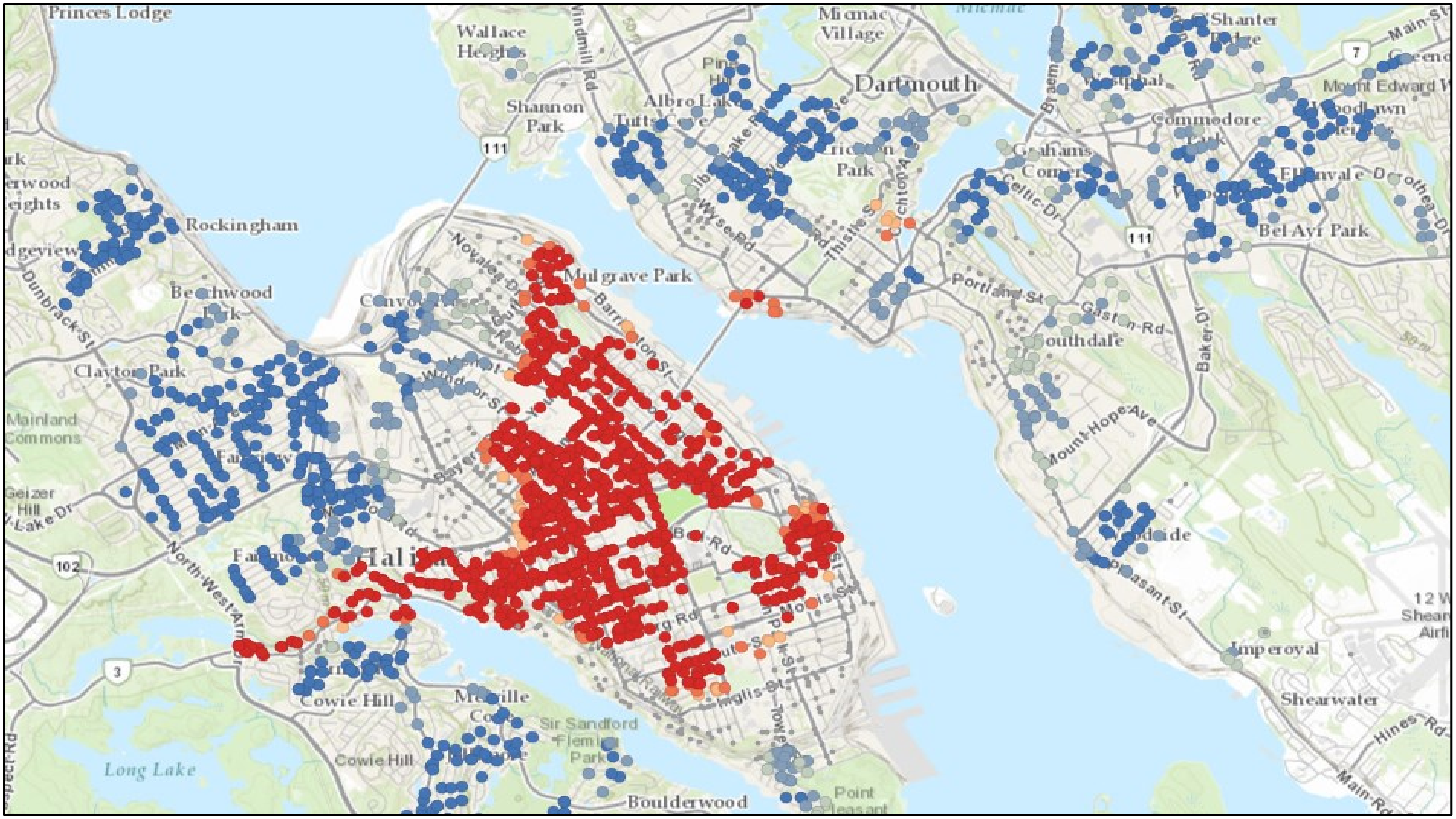


Figure 10 Shivani Gilhotra. (2019). [Hot Spot areas of the Halifax, NS with potential lead locations as per the age of the service lines]. Data retrieved from Halifax Regional Municipality (HRM)

3.4 Budget and Jurisdictional Challenges

Both the US EPA and Health Canada have been working towards making the LCR and CDWQG more stringent. Midwestern cities in the US, especially those with aging water infrastructure, are faced with challenges on how to pay for drinking water improvements. In Canada, while the federal government has specific responsibilities relating to health and infrastructure, the management of drinking water treatment and distribution falls within provincial jurisdiction and is most often managed by a municipal water authority in urban areas (Government of Canada, n.d.).

As per the information collected for 35 utilities in North America, 36% of the utilities (**Figure *11***) use Grant and Loan programs for their residents to fund replacements on the private side, if they have an LSL in their house. There are only a few utilities like Lansing, MI for which it is the city's responsibility to replace the LSLs on both sides (public and private). Some utilities have opted to provide financial incentives to homeowners as motivation to replace the private side of the lateral. For example, Halifax, Nova Scotia has a service line loan and rebate program. 15% of utilities (**Figure *11***) are still treating the private portion as complete homeowner's responsibility and have no incentives in place. For example, Charlottetown, Prince Edward Island has about 2,000 lead pipes but has no financial aid (Bundale, 2019).

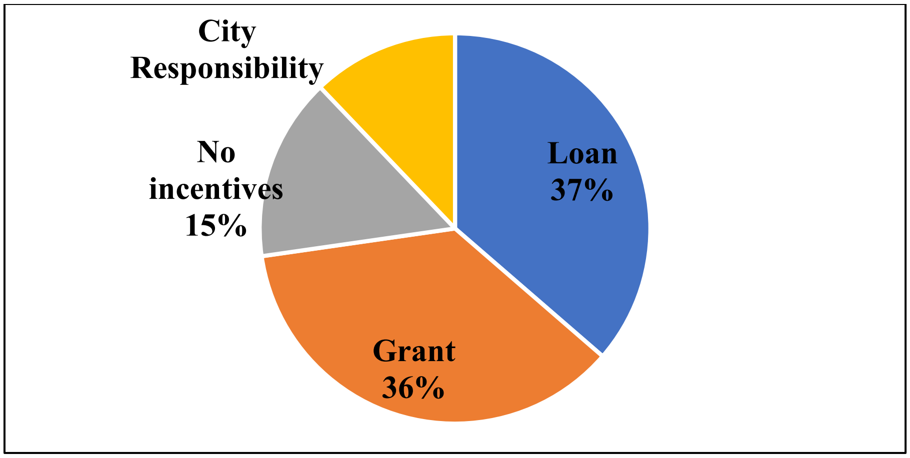


Figure 11 Funding methodologies used across North American Utilities listed in Table 1 to Replace Lead Service Lines (Total no. of utilities, n =35)

Examples of financial assistance offered to residents to offset the economic burden of LSLR include:

- Reduction of the homeowner's property taxes
- Financing with grants or loans with special interest rates
- Credit limit toward the replacement cost and the owner is responsible for any costs over and above the credited limit.
- Reimbursement to the homeowner for one half of the cost of replacement. Some utilities have established a specific limit to reimburse for LSLR.

3.5 Summary

One of the important things to do for a municipality is to provide homeowners with a cost estimation on a lateral replacement. Cost is normally the biggest hurdle in homeowners going for the LSLR. According to the research done on 35 North American utilities, **Figure *12*** shows the average cost for replacing private portion an LSL ranges from CAD 5,000 to 10,000 (as per the estimated values private replacement cost listed in **Table *1***) . Hence, several municipalities have taken steps to encourage homeowners to take advantage of low or no-interest loans/ grants available for the replacements and coordinate replacement of private LSL replacement with public side LSL to optimize costs.

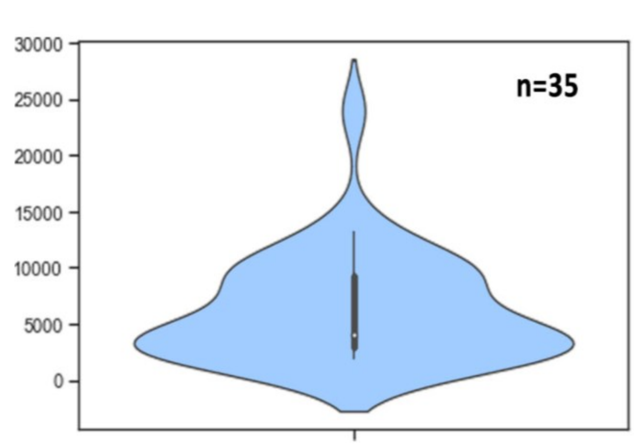


Figure 12 Graph showing the probability distribution of the private service line replacement cost (y-axis) across North America listed in Table 1 (Total number of utilities, n=35)

Municipalities try their best to provide a cost estimate, however, the actual cost varies locally and on multiple factors for each replacement. These factors include:

- The length of the service line
- The technique used to install the new service line and excavation depth
- Location of the curb stop – for example in lawn or driveway
- Type of driveway – asphalt, gravel, stone, brick, concrete, exposed aggregate
- Presence of retaining wall
- Trees or flower bed or other landscaping features

Although there were concerns and challenges faced by the utilities when making effective and efficient LSLR program, still there were some utilities which were able to get 100% replacements, for example, Lansing MI, Madison WI, Framingham MA, Springfield MA, Sioux Falls S. Dak. One of the reasons they got the replacements done were because of the financial aids and the full ownership of the service lines. The utility replaced the whole service line together.

The second most successful technique used by the utilities were the visual representation of the potential location of LSLs through interactive GIS maps, online static map or published list of addresses on the website. Since it is difficult to do much about the utility taking the full responsibility of the lead line, this research focused on the use of interactive maps and enhancing that technique through the development of the cost estimates in the cost estimation portal (i.e., **second objective**).

CHAPTER 4: Cost Estimation Portal- A GIS-based Web Application

4.1 Abstract

An estimated 6.1 million lead service lines (LSL) are across North America, posing a significant threat to human health. Some utilities are providing online tools to reach out to the homeowners. Tools are varied by whether they include a visual database showing the information about individual properties or interactive maps showing information on both public and private sides of the service line. One of the biggest issues in replacing LSLs is lack of full information to the homeowners. Homeowners should be aware of the approximate cost of replacement, in order to schedule an appointment for contractor to replace it and to explore their financial options. Focusing on this issue, a web application through ArcGIS called cost estimation portal, to calculate the estimated replacement costs as per homeowner's house features, the location of curb stops, and service line length is developed. Homeowners can search their address to determine if they are within the area of concern as per the lead boundary map of Halifax Water (HW). The collected study on the features for the houses which got replacement recently was analyzed to get a private cost breakdown for the cost estimation portal.

Keywords: Lead Service Line (LSL), Lead Service Line Replacements (LSLRs), Cost Estimation portal, web application

4.2 Introduction

There are an estimated 6.1 million homes across the US with LSLs (AWWA, 2016) and hundreds of thousands of homes in Atlantic Canada have been unwittingly exposed to high levels of lead in their drinking water, despite efforts by utilities to raise awareness about the issue and offer financial aid to replace old service lines. A yearlong investigation by more than 120 journalists from nine universities and 10 media organizations, including the Associated Press and the Institute for Investigative Journalism at Concordia University in Montreal (Le Devoir, 2019), collected test results that properly measured exposure to lead in 11 cities across Canada. Out of 12,000 tests since 2014, one-third – 33% – exceeded the national safety guideline of 5 ppb; 18% exceeded the US limit of 15 ppb. The only long-term solution to protect public health is to remove these lead pipes. But, to accomplish this, we first need to identify the locations of the LSLs in a community. Knowing the locations of LSLs is difficult in areas with older neighborhoods where there is a higher probability of having an LSL because records for that time are particularly weak and there are long histories of repairs.

Creating an effecting LSLR program is difficult for the utilities as it requires to document and disclose the information of what is known and/or unknown about LSLs with their customers and the public. However, it is considered a critical step in building inventories. Communities are posting interactive online maps and lookup models to help their residents determine if a specific address (whether a potential home, childcare facility or restaurant) may or may not have an LSL.

Replacing an LSL can be cost-prohibitive, especially for low-income families. Many homeowners are not even aware of the total replacement cost for the LSL. The homeowners need to be aware of the estimated cost of replacement, hence, they can plan for the funding or apply for rebate/loan or grant programs. The objective of this study is to **develop** a web application for the homeowners to know the replacement cost of an LSL as per the features of their house and location of the curb stop.

4.2.1 Application Architecture

Application architecture is the design of an entire software application, including all components, sub-components, and external application interchanges. Web application architecture defines the interactions between applications, systems, and databases to ensure multiple applications can work together (Stringfellow, 2017). Web architecture is essential as the majority of global network traffic uses web-based communication. It deals with scale, effectiveness, and security. The application architecture consists of:

1. Frontend architecture, which is a collection of tools in **Figure *13*** and processes that aims to improve the quality of the frontend code while creating a more efficient and sustainable workflow (Godbolt, 2016). Frontend development runs along a spectrum. At one end of the spectrum is the look and feel of a web page and at the other end is the logic that governs the complex behaviors of that web page (Chris Aquino, 2016). It is also known as client-side development (for this research, a homeowner is a client), is a practice of producing HTML, CSS, and JavaScript for a web application (Frontend Masters). JavaScript Frameworks help in building complex web interfaces by bringing to frontend development the best practices that are typical of server-side systems, like model-view-view model, dependency injection, routing and many others (Chiaretta, 2018).

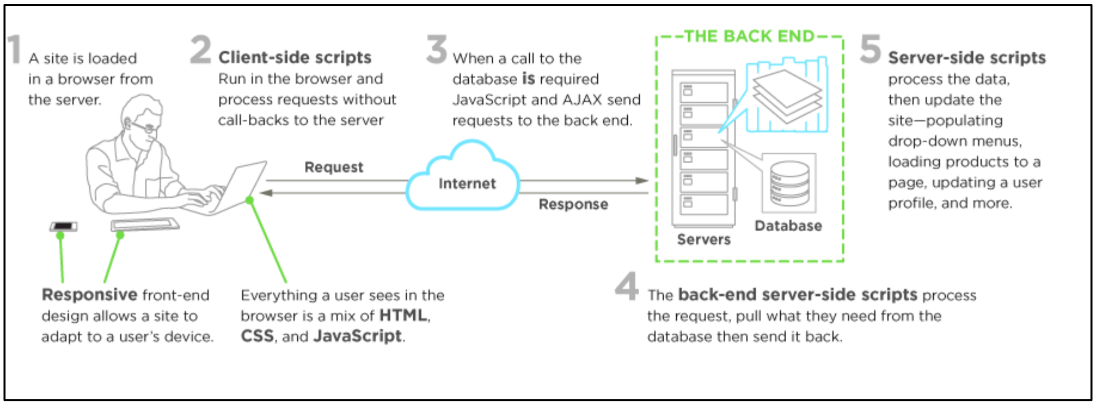


Figure 13 Example of Frontend and Backend development. Adapted from "The Role of a Front-End Web Developer: Creating User Experience and Interactivity" from Upwork, n.d., https://www.upwork.com/hiring/development/front-end-developer/

HTML (Hypertext Markup Language) is a standard markup language used to create webpages. HTML describes the structure of the web application semantically. Cascading Style Sheets (CSS) is a style sheet language used for describing the look and formatting of a document written in a markup language. CSS is a technology used by most websites to create visually engaging webpages, user interfaces for web applications, and user interfaces for mobile applications.

2. Backend: The technology requires to process the incoming request and generate and send a response to the user as shown in **Figure *13*** which includes three parts: the server, the app, and the database. In this research, ArcGIS JavaScript API is the server used for the development of the application.

4.3 Methodology

4.3.1 Study Area

The study area for this research was Halifax, Nova Scotia, Canada (**Figure *14***) with HW being the data provider, along with using open databases provided by the Halifax Regional Municipality (HRM). Halifax is located in eastern Canada and is one of the largest municipalities east of Montreal. It serves a population of approx. 380,000 with around 85,000 customer accounts.

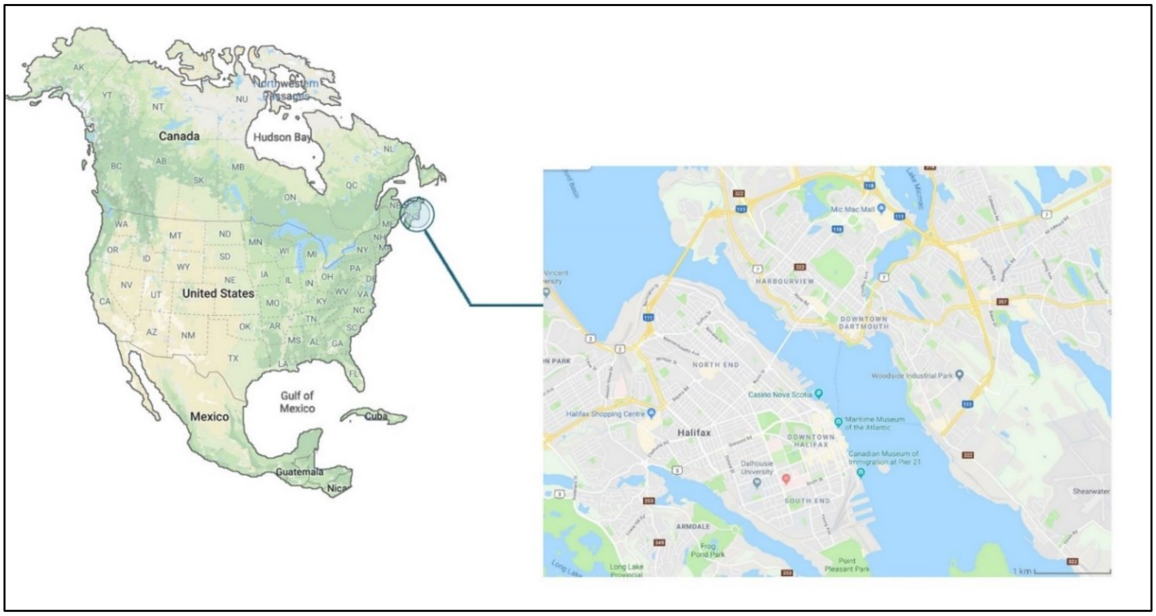


Figure 14 shows the study area for the research and development of the web application, i.e., Halifax, Nova Scotia, Reprinted from “Google Maps,” 2019

HW has been very active in terms of research around the LSLs and its initiatives around motivating residents on getting LSLRs as discussed earlier in Chapter 2. Based on the reports submitted to the Utility and Review Board, they have the goal of removing all lead laterals from their system by 2050 (Halifax Water, 2017).

4.3.2 Data collection

The study used the available data from HW to identify gaps and the next appropriate steps. The data was compiled by first identifying the features and attributes on which the individual service line replacement cost depends (chapter 2), and second, to research on new techniques used for building a web-based application (or portal). The combined data (existing and new) was used to complete the cost estimation database (Appendix A **Table**

2) and develop the portal. Google street views, HW lead boundary map, and HRM's property boundaries are used as layovers.

4.3.3 Maps and Views

The frontend consists of a single view. Views are used to display the map layers and handle user interactions (popups, widgets, map location, and map zoom level). Maps are containers used to manage references to layers and base maps. The following code first creates a new map from the Map class, and then adds the map to the view.

```javascript
// create map
const webmap = new Map ({
  basemap: "topo"
});
// create view
const view = new MapView({
  container: "viewDiv",
  map: webmap,
  center: [-63.582687, 44.651070],
  zoom: 13
});
```

JavaScript

Figure 15: Code to create the Basemap and map view for the cost estimation portal

<u>Adding Widget to the View:</u>

The view is also a container for overlaying widgets and HTML elements. Here, view.ui.add method was used to add a custom-made widget (or an HTML element). The code snippet below adds the top bar widget - defined in the HTML file at the top-right position of the view.

```javascript
// add the toolbar for the measurement widgets
view.ui.add("topbar", "top-right");
```

JavaScript

Figure 16: Code for creating a toolbar for the measurement widgets

Following is the definition of the top bar widget defined in the HTML file.

```html
<div id="topbar">
<button
  class="action-button esri-icon-search"
  id="searchButton"
  type="button"
  title="Search your address"
></button>
<button
  class="action-button esri-icon-polyline"
  id="distanceButton"
  type="button"
  title="Service Lateral Renewal Cost"
></button>
<button
  class="action-button esri-icon-refresh"
  id="refresh"
  type="button"
  title="Refresh"
></button>
<div
  class="info"
  id="info"
  style = "display:block;"
>
<!-- Description of the application and steps -->

</div>
<div
  class="info"
  id="costcalculation"
  style="display:none; overflow-y: auto; height: 14em;"
>

<!-- Initially hidden list of checkboxes and cost calculations -->

  </div>
</div>
```

JavaScript

Figure 17: Code to create the top bar widget of the cost estimation portal defined in HTML file

4.4 Workflow

When a user types in a URL and taps “Go,” the browser will find the website and requests that particular page. The server then responds by sending files over the browser. After that action, the browser executes those files to show the requested page to the user, i.e., known as a user interface. The code is interpreted by the browser and has all the instructions on how to react to a broad group of inputs. The user interface (UI) is divided into three main components (**Figure *18***): 1. The Map. 2. Zoom In/ Zoom out and 3. Descriptive Toolbox.

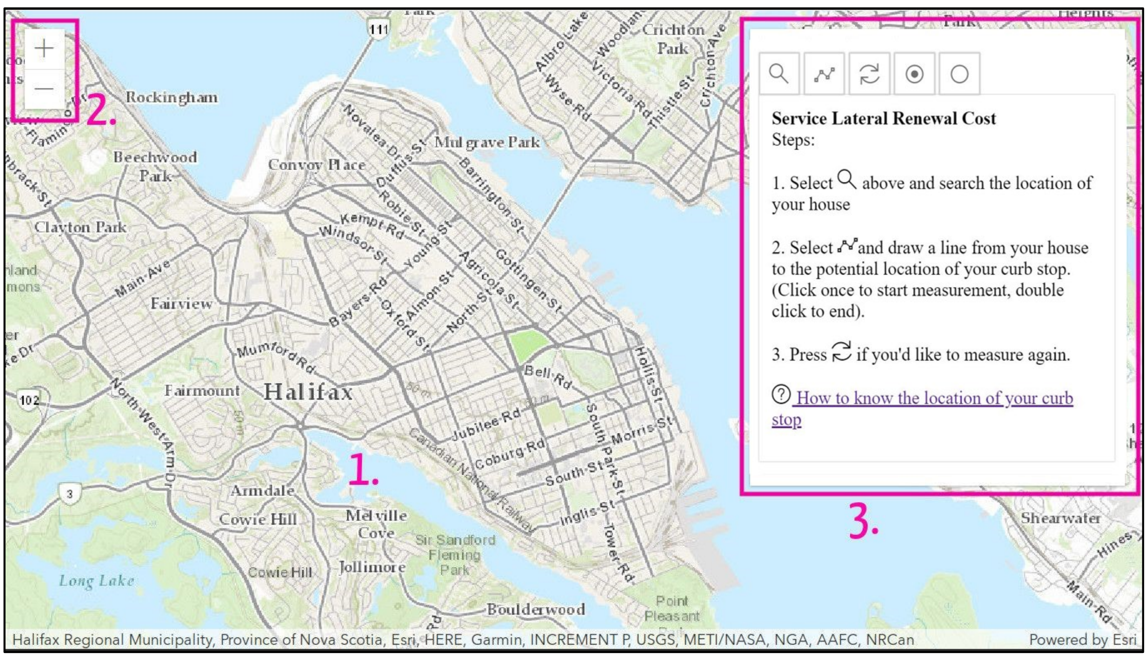
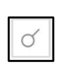


Figure 18 Showing the screenshot image of the User Interface from the Cost Estimation Portal

Apart from displaying a helpful description of the menu items and the steps to be followed, the toolbox consists of the following five buttons (**Figure *19***):

- Search location  - user can either allow location access to detect location or enter an address

- Distance measurement - once the map displays the required location, the user can select two points on the map to measure the distance from the house to the curb property boundary (approximate location of curb stop). There is an attached link to help the user understand what curb stop is and how they can know the location on their property.
- Refresh - to take a new measurement

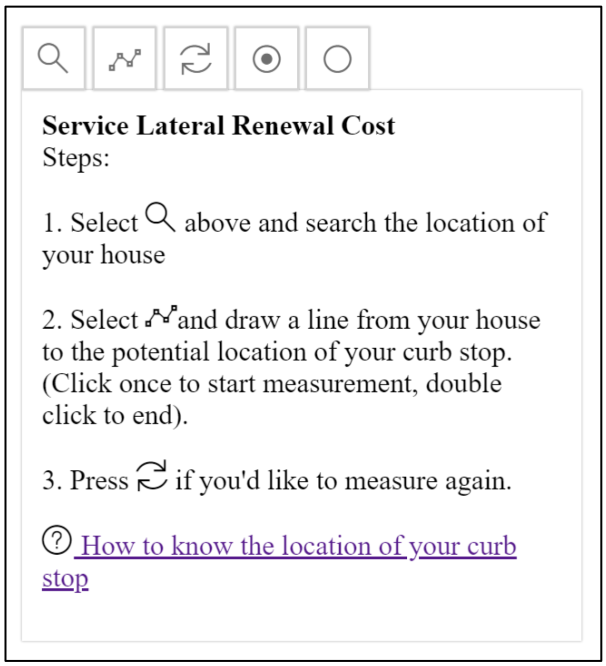


Figure 19 Showing the screenshot image of the toolbox used in the Cost Estimation Portal

- View and Hide - To view Lead Boundary map generated by Halifax Water on the portal (Figure 16).

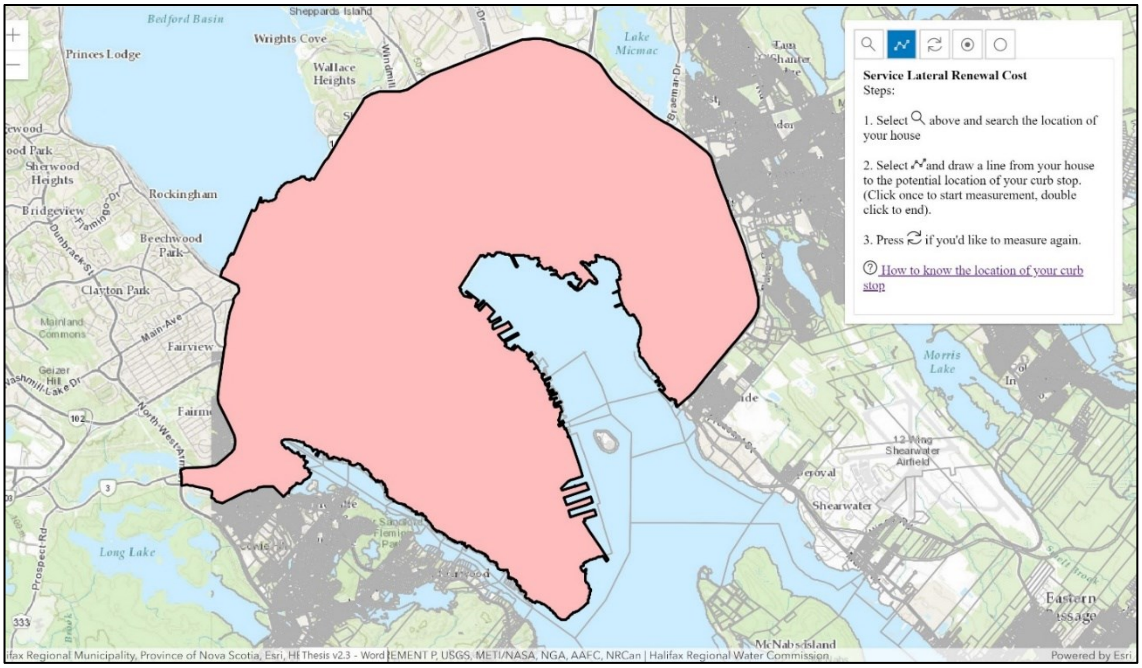


Figure 20 Screenshot image of the Lead Boundary Map generated by Halifax Water in the Cost Estimation Portal

Once the user completes measurement, an overflow menu is displayed with the following checklist:

- Sidewalk
- Trees
- Landscaping/lawn
- Plant clusters
- Any overhead power lines
- driveway - which when selected displays the following sub-menu
    - asphalt
    - gravel
    - exposed aggregate
    - concrete
    - stone

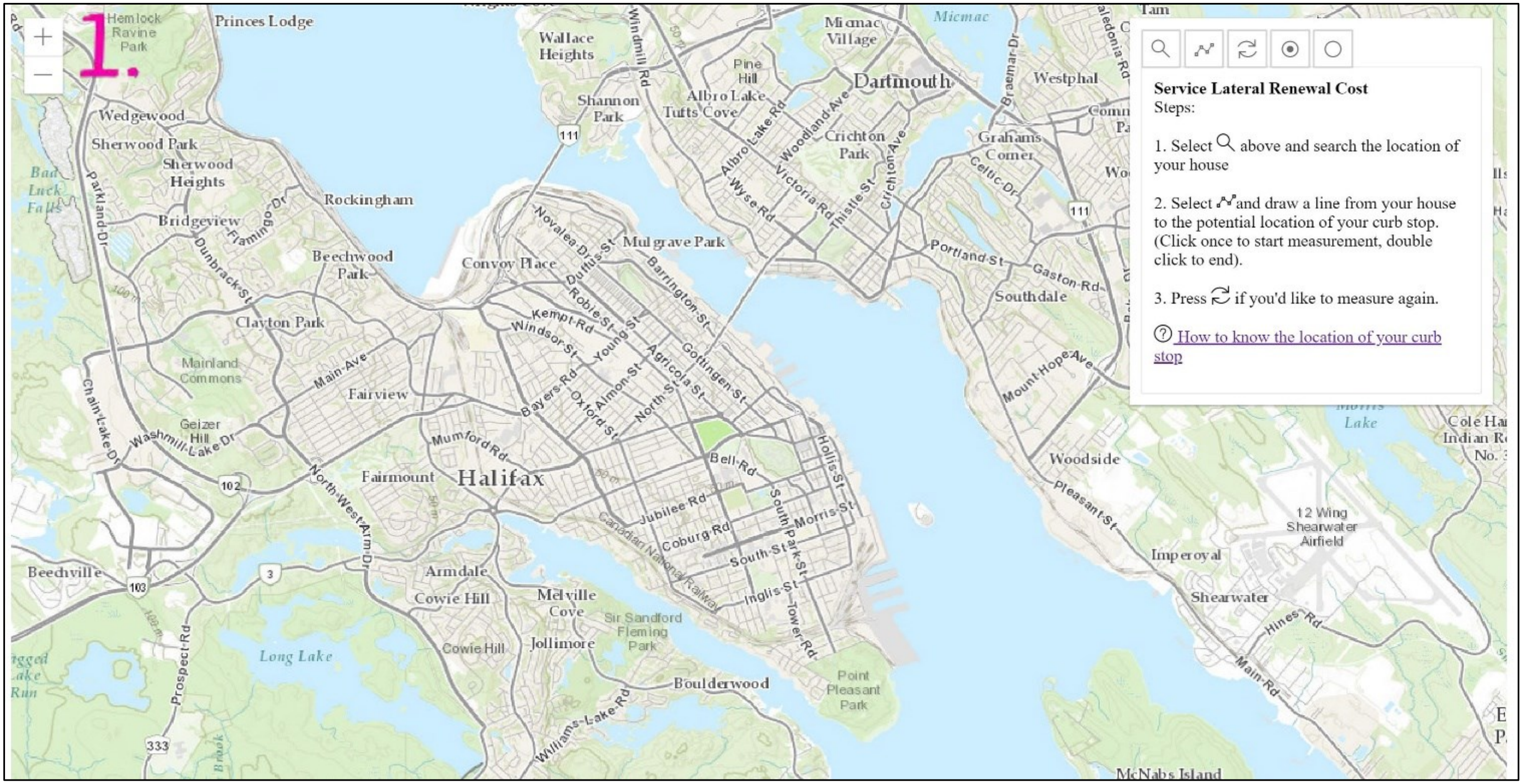


Figure 21 Screenshot of the Workflow of the Cost Estimation Portal -1

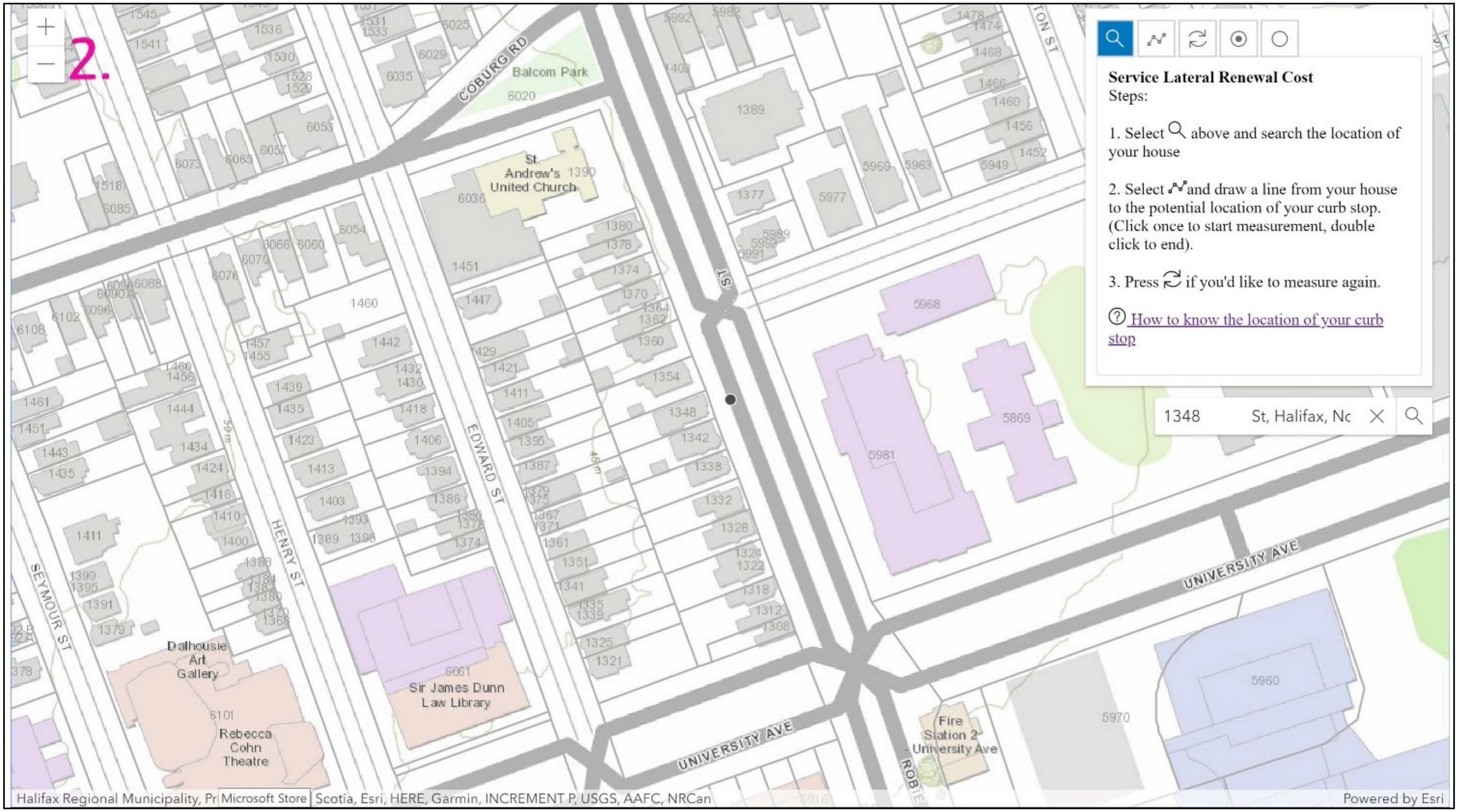


Figure 22 Screenshot of the Workflow of the Cost Estimation Portal -2

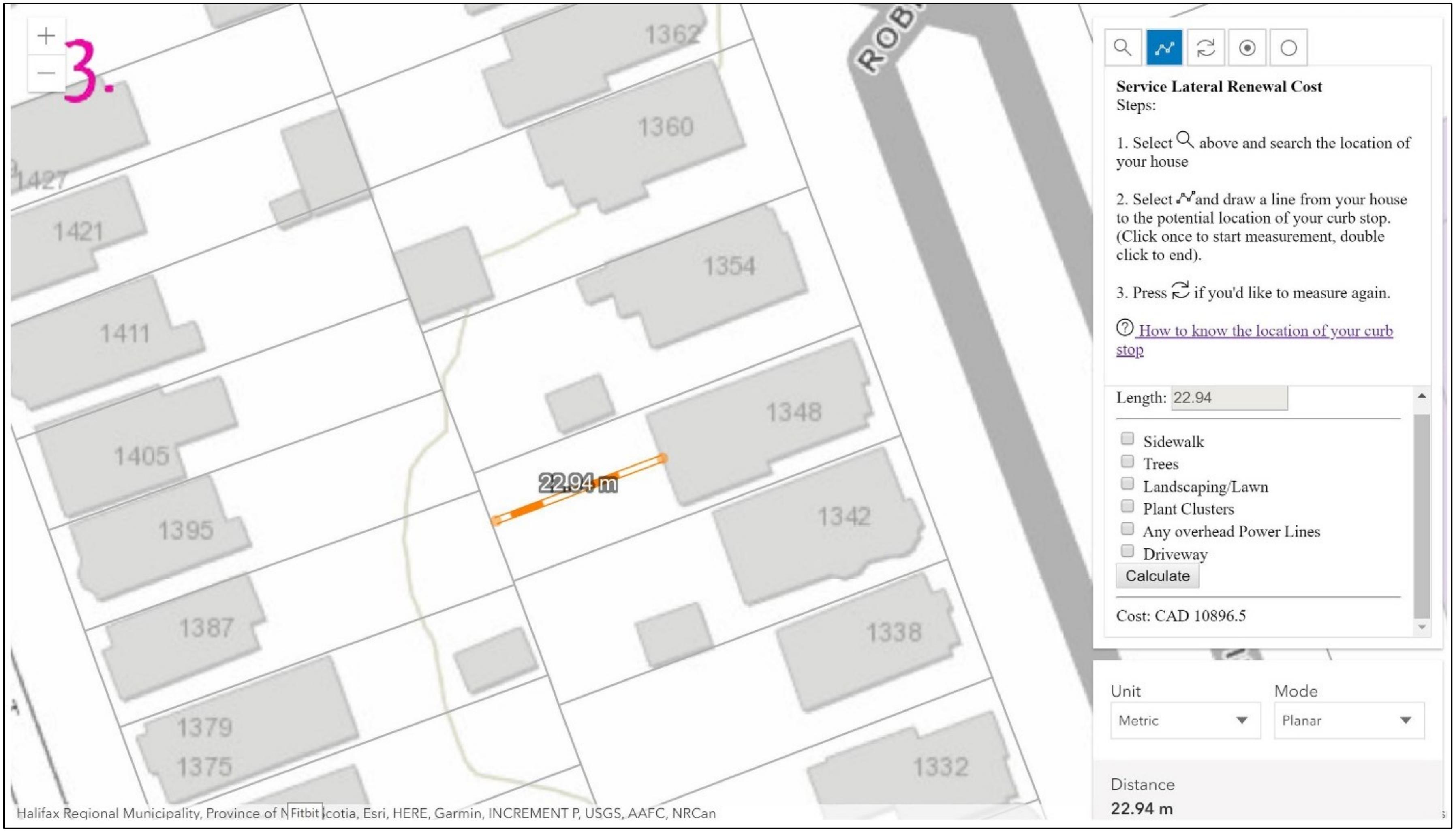


Figure 23 Screenshot of the Workflow of the Cost Estimation Portal -3

Clicking on calculate displays the estimated cost in CAD-based upon the measured distance and the selected items from the displayed checklist (**Figure *23***). The calculations of the cost are given in Appendix A.

4.5 Discussion

There is a need for greater transparency in real estate transactions regarding LSLs. If a potential homebuyer learns of an LSL on the property before they sign a contract, they have an option to decide to add the cost of replacement to the mortgage, deduct the estimated cost from the sale price, demand replacement before purchase, or plan to replace it later. Communities cannot rely solely on interactive maps or tools to communicate the locations of LSLs. For example, only 3.7% of Ohio-based sample surveyed had previously heard about these types of online tools. Further, some users will inevitably misunderstand the tools (Schlea, 2019). It is therefore critical not only to further advertise such tools to the public but also to reinforce this message through other communications, such as direct mailings and phone calls to property owners

CHAPTER 5: Water Quality Improvements after the Service Line Replacements in Halifax, Nova Scotia

5.1 Abstract

Lead service lines (LSLs) are the primary source of lead in drinking water in Canada. Full replacements require both municipalities and homeowners to agree to replace their portion. It isn't easy for utilities and homeowners to pay CAD 3000-5000 to replace an LSL running into a home. Thus, it becomes imperative to understand if the money spent on a replacement corresponds to a percent improvement in the water quality and if there are any correlations between the two. This chapter explores whether the replacement cost of an LSL affects the reduction of lead content over time in a house. Results indicate that there is no significant relationship (p-value=0.03) between the replacement cost of an LSL with the reduction of lead content over time. There are various factors influencing replacement cost: the size of the lawn, excavation depth, location of the curb stop, presence of retaining wall, overhead power lines, and type of driveway. These factors determine the increase or decrease of the cost and hence, it is cannot be correlated to the drinking water quality.

Keywords

Lead service line (LSL), Lead service line replacement (LSLR), replacement cost, sample profile, curb stop

5.2 Introduction

Halifax Water (HW) operates three broad states of the art, water supply plants, and six modern smaller community supply plants to provide water to 380,000 customers throughout the Halifax Municipality (Halifax Water, n.d.). Homes built in the 1950s or earlier have a higher risk of being serviced by an LSL. However, even if the home is serviced by a copper service line (Halifax Water, n.d.), there is still a risk of lead solder, which was banned in 1986 (NPC) or leaded brass fittings. Beginning in the 1950s, both the Public Service Commission of Halifax and the neighboring city of Dartmouth Water Utility (now known as HRM) undertook Lead Service Line Replacement (LSLR) programs (Halifax Water, n.d.). In the 1970s, Dartmouth launched an aggressive program for LSL replacement and was successful in replacing almost all of the known public LSLs. Some lead services remain in areas targeted in the 1970s, presumably due to severe construction conditions encountered at the time. The exact number remaining is unknown but is estimated to be 500 LSLs in Dartmouth (Halifax Water, 2017). The period between 1950 and 1990 served as a transition period when cities began shifting away from the toxic material. Buildings erected after 1990 are far less likely to feature lead service lines.

One challenge with LSLR, however, is that the service line is divided into public (from watermain to the curb stop) and private property (from the curb stop to internal plumbing of the house) as shown in **Figure *1***. In addition, homeowners are solely responsible to pay some or all of the cost of replacement, which can range from CAD 3,000 to CAD 15,000. It is critical to remove both sides of the LSL (a full replacement) because a partial replacement does not reliably reduce lead levels and may even increase lead content (Trueman et al, 2016). This raises the question if we can measure improvement in water quality with the replacement cost. The objective of this study is to study the correlation between the replacement cost of an LSL with the percentage removal of lead content over time in a house.

5.3 Methodology and Analysis

5.3.1 Study Area

The study area comprised of residences in Halifax, NS, Canada within the lead boundary (marked by HW in **Figure *3***) which got their private side lead replacements between 2016 and 2018. Participating residences were predominantly older homes; in areas of widespread pre-1950 construction, thousands of LSLs are still in use (Trueman, 2017).

5.3.2 Data Collection

The data used in this study was obtained from several sources. Two of the primary sources were private renewal cost dataset from HW's LSLR program from 2016-18. The second dataset comprising lead content profile (72hour, 1 month, 3 months, and 6 months) for before and after lateral replacements in Halifax was obtained from the Center of Water Resources Studies (CWRS), Dalhousie University Lab. Five 1-Litre (first four litres are first draw samples after the stagnation period and the fifth is a flushed sample after 5 minutes) samples were collected from all the houses after six hour stagnation time (Appendix B - **Table *6***). Appendix C lists the sample instructons provided for the residents to follow for the water sample collection by Halifax Water.

The dataset used for the analysis is different from the dataset used to make the cost estimation portal. As there were many houses, which didn't participate in the lead water testing after the replacements. The original data set obtained from HW was extrapolated for missing values and screened for outliers with a confidence interval of 95%. Then, the descriptive statistics for all variables were examined to make sure they fell within an acceptable range and is normally distributed. The complete series of lead profiles from pre and post replacement samples were not available for every residential site owing to incomplete resident participation. For this reason, sample sizes for before and after replacements differ.

5.3.3 Analytical Method and Hypothesis

Simple Linear Regression analysis is used to draw a correlation between the percentage removal of Lead content (from the before and after sample profiles) and the replacement cost. Second, predictive modeling was derived from missing or incomplete data. Hence, the hypothesis in this research was:

- H_0 : β1 = 0 (The relationship between replacement cost and percentage removal of lead content after the replacement is not significant) i.e., the perecentage of lead content removal does not depend on the replacement cost.
- H_0 : β1 ≠ 0 (The relationship between replacement cost and percentage removal of lead content after the replacement is significant) i.e., the perecentage of lead content removal depends on the replacement cost.

5.3.4 Analysis

LSLR cost provided by HW was analyzed to estimate the probability density function to understand the average cost of replacement and the factors on which it is dependent on by using a kernel density graph. Data analysis was done using Anaconda (Jupyter Notebook), a platform for running python, libraries as pandas and matplotlib. For regression analysis, three assumptions were studied: Linearity and equal variance, no multicollinearity, and no autocorrelation.

As per the three assumptions, it seems like the residual plot is reasonably random. To confirm that, the Harvey-Collier multiplier test for linearity was done, which gave us p-value = 0.22 and statistic = -1.24. For testing equal variance, Breusch-Pagan test gave p-value = 1.35(>0.05). It tests whether the variance of the errors from regression is dependent on the values of independent variables. In that case, heteroscedasticity is present. Hence, in this case with a p-value higher than 0.05, shows that there is a violation of homoscedasticity.

For the assumption of no multicollinearity (i.e., a lack of high correlation between the independent variable, i.e., renewal cost) – tolerance statistics are below 0.01, and none of Variance Inflanatory Factor (VIF) statistics are above 10. Since none of the VIF values were below 0.1 and none of the tolerance values were above 10, the assumption of no multicollinearity has been met. Durbin-Watson statistics (Appendix B-**Table *5***) fell within an expected range. Thus indicating that the assumption of no autocorrelation of residuals has been met as well. Finally, the scatterplot of standardized residual on standardized predicted value did not funnel out or curve (Appendix B – **Figure *30***), and thus the assumptions of linearity and homoscedasticity have been met as well.

The factors influencing the replacement cost were further analysed using factor analysis method. The data used for the analysis is listed in Appendix A –**Table *3***.

5.4 Results and Discussion

5.4.1 Effects on Replacement Cost

The graph in **Figure *24*** represents the shape of this function f. The average cost of service line replacement is CAD 5,000 for the Halifax residents, but there are some residents that had replacement costs in the range of CAD 10,000 to 15,000 depending on various factors. These factors include the length of the service line, the location of the curb stop at driveway or lawn. Furthermore, the replacement cost of the driveway can vary as per the material used (concrete, brick, exposed aggregate) and same as for lawn (if they have trees, flower bed, retaining wall). Additionally, proximity to and interference with other utility infrastructures can also increase the cost such as sidewalk replacement, utility pole, and gas line relocations.

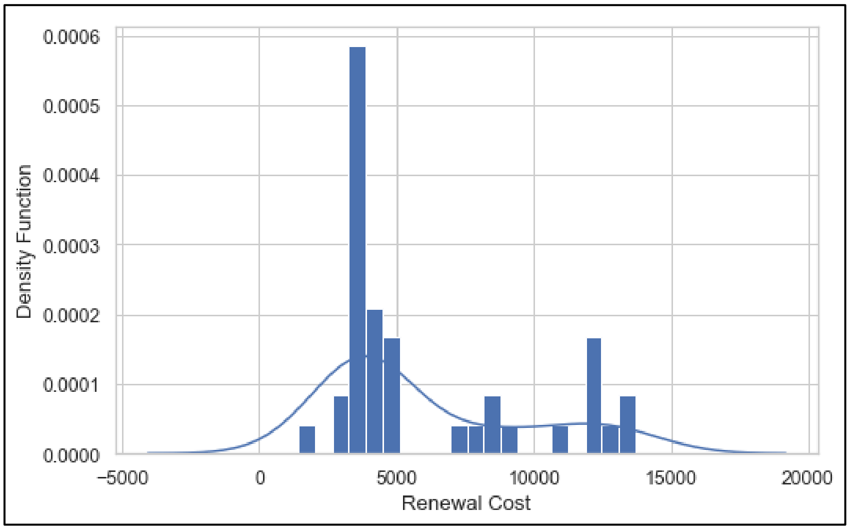


Figure 24 Kernel density function (probability distribution) graph showing the distribution of private replacement/renewal cost of service lines for 126 houses within "Lead Boundary" in Halifax, NS from 2016-18

5.4.2 Factors influencing the Private side Replacement Cost

As, we have studied that there are various factors influencing the LSL replacement cost. There are certain factors which have higher influence on the replacement cost i.e., length of the service line and depth of the curb stop or the excavation required to install new pipe. Because of the high cost of the concrete sidewalk replacement, it also shows as the one of the factor influencing the replacement cost.

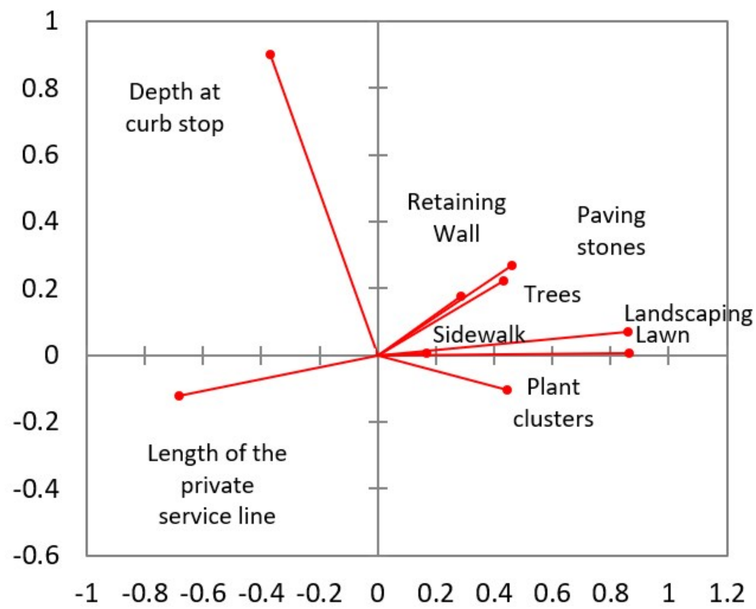


Figure 25: Graph showing the factors influencing the replacement cost. Closer to +1 and -1 represents higher influence and closer to 0 has weaker influence. The data used for this graph is from the houses, which got their replacements done in the year 2016-18.

5.4.3 Post-Replacement Lead Levels

Lead content reduction representing over six months of the first litre sample taken from the houses with LSLRs following a 6-h stagnation. Full LSLR reduced lead levels in every liter of sample profile within 1 month (**Figure *26***). For reference an action level of 15-ug/L is provided for reference that is related to this particular samling approach. In many cases, full LSLRs were not often completed on the same day, and a delay of several months was not uncommon. In the case of full LSLR, public and private LSL replacements were not often performed simultaneously, and disturbances associated with the two replacements may have contributed to elevated lead release and accumulation within the plumbing (Trueman, 2016).

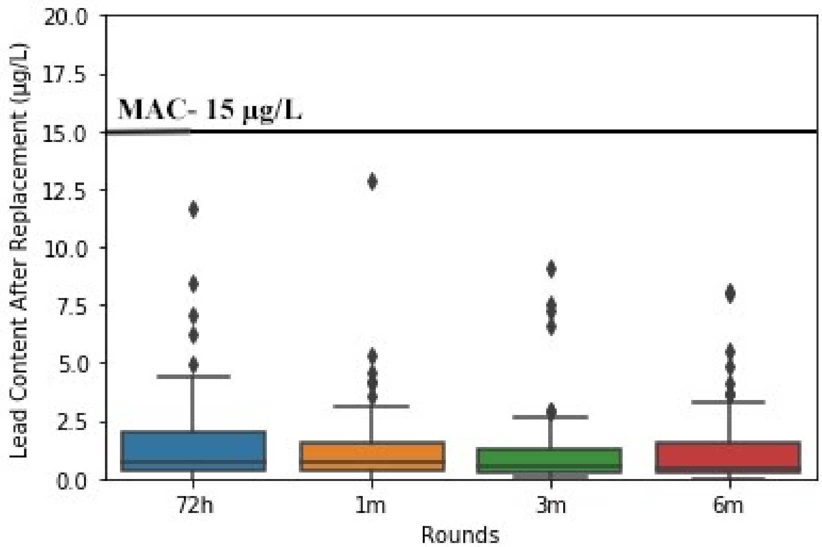


Figure 26 Reduction in lead content (µg/L) over six months of the first litre sample taken from the houses within "Lead Boundary" in Halifax, NS who got their service lines replaced in between 2016-18 and compared with an action level of 15 µg/L (stagnation time = 6 hrs)

5.4.4 Correlation between Lead Content Reduction and Replacement Cost

None of the variability of the response data around its mean and relatively weak relationship between the replacement cost and the percentage of lead content reduction after replacements (**Figure** *27*). A lack of relationship was expected as construction costs primarily relate to construction costs that are associated with landscaping and household featrues (as described previously) and water quality is driven by lead occurrence in service lines (Trueman et al, 2016).

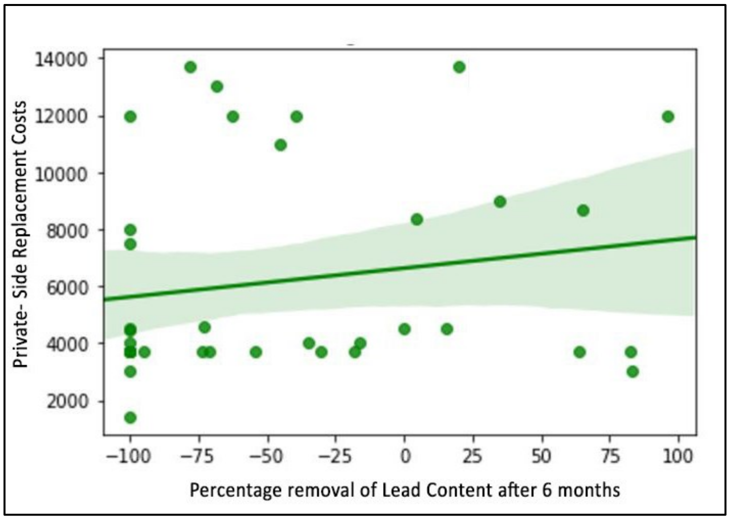


Figure 27 Relationship between private side replacement costs and percentage removal of the lead content after six months of full LSLR for the residents in Halifax, NS (2016-18)

According to the findings of the final model, there was no significant relationship between the replacement cost and the percentage removal of lead content over time. The replacement cost cannot be used as a tool to find the value of lead content removal in a house. Based on the study and findings, the replacement costs vary with different factors from house to house (**Figure *25***). For one house (H1) located on the sidewalk as compared to the other house (H2) with the lead service line going through the asphalt driveway, the cost of the replacement will be different. The cost for H1 will be higher than H2 as presented in **Figure *25***; however, that cost won't determine water quality improvement level for the two houses.

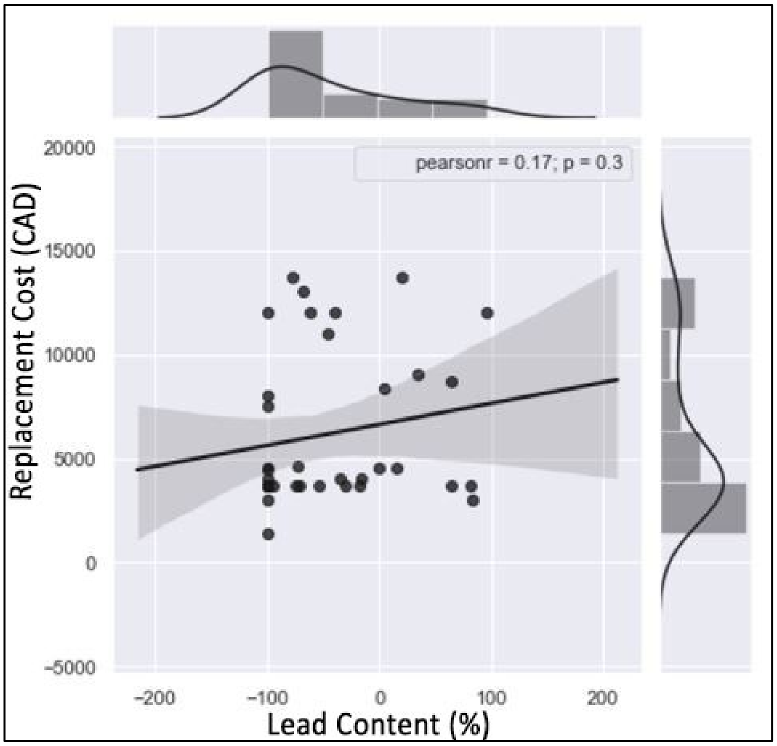


Figure 28 shows the joint plot to visualize the relationship between replacement cost (CAD) and percentage removal of Lead content after six months of Full LSL.

There are some uncontrollable factors that may have caused unexpected results in the increase in the replacement cost or decrease/increase in the lead content after replacement. Many of the participants were from the LSLR program of 2011, of which there was no contractor cost as the private-side service line cost was not relevant to Halifax Water at that time. As a result, only renewals since the rebate came into effect were included. There are cases in the data set where a private renewal occurred, but the homeowner never submitted a rebate application, these have been noted in the file and not used for data analysis. HW did not have a lot of private cost data as they only need to see individual invoices to issue the Lead service line rebate. This program is still new, resulted in a small dataset (n= 126 houses).

Though many renewals occurred following the rebate, on both the public and private sides, few were participants in the LSLR program. The WRF program impacted last year's uptake in this program. There has been one public cost exclusion from the data set due to the complexity of the work. This service line required abandonment and relocation to another mainly due to location issues outside of Halifax Water’s control and resulted in more of a new service than a renewal.

CHAPTER 6: Conclusions & Recommendations

6.1 Concluding Remarks

The research studied three general approaches that provide a framework to help the utilities in developing a comprehensive lead service line replacement program (LSLR), and also assist the homeowners to prepare themselves financially for the replacement costs. The three objectives of this research work are concluded with brief summary and key findings:

COMPILE: Canada is in the midst of setting up a better regulatory framework in most jurisdictions in order to lower the risk of human exposure to lead through water. This framework embarks on making utilities accountable for lead monitoring along with evaluating the effectiveness of their corrosion control program, and any related customer exposure to lead in drinking water. Based on the literature review, it is quite evident that both the homeowner and the municipality have very little information on the inventory of potential location of LSLs. Additionally, if the municipality does have the data, sharing this information publicly raises various privacy and jurisdictional issues, as well as the resistance from the homeowners that it might lower the property value. To overcome that, the majority of the North American utilities are using GIS portals to reach out to their homeowners and to communicate the potential of having LSLs. However, utility bills remain the number one source for municipalities to advise their customers about lead.

DEVELOP: Updating and improving access to information about the location of both full and partial lead service lines is critical and essential for successful, proactive outreach to customers who are most likely to have an LSL. The municipalities have varying levels of LSL information in their GIS system. The accuracy of GIS data combined with a cost estimation portal will go a long way in improving the customer service and uptake of the various LSL replacement programs since homeowners are responsible to pay some or all of the cost of replacement. The portal is developed on ArcGIS platform using Python and overlayed on Google street view. It uses the property line information to estimate the location of the curb stop. The user has flexibility to get a better estimate by turning on or off layers and in selection of various options like type of driveway, landscaping, sidewalk, and/or any overhead power cables.

The portal will help homeowners know their estimated replacement costs and utilities to have an estimated budget of the replacements. It is therefore critical not only to further advertise such tools to the public but also to reinforce this message through other communications, such as direct mailings and phone calls to property owners.

ANALYZE: Over time, the lead content decreases in a service line going to 100% removal of lead content and thereby improving the water quality for drinking water. The purpose of this task was to see if there is a correlation between the money spent and the improvement in lead content in drinking water. However, since the replacement cost of lead line is dependent on various physical attributes like type of driveway, type of landscaping, interference with sidewalks or other municipal infrastructure, there was no proven correlation. Perhaps, there might be a better correlation on water quality improvement and length of service lateral. The lead content in a service line may depend on the length of the service lateral as it is well documented that the longer the stagnation, higher will be the lead content (Katner, et al., 2018) in a service line. However, it is difficult to correlate the value of increase/decrease of replacement cost for the private side (curb stop to internal plumbing) of a house is directly related to the improvement of drinking water quality.

6.2 Recommendations

Given the complexity of the LSLR process and the presence of the service line on both public and private properties, LSLR requires the cooperation of utilities and homeowners. In order for homeowners to take action, they must be aware of the LSLR programs, financial assistance and must be able to determine whether their home is serviced by an LSL or not. The availability of clear information about the known and unknown locations of LSL is of utmost importance. The interactive maps used to show information should have complete information on the locations of the LSLs, complemented materials of the location of curb stop, factors influencing the cost of replacement, risks imposed by the use of LSL and the contractor information. Overall, Washington DC and Cincinnati interactive GIS maps stood out as a model. They include property-specific information of the known and unknown.

Based on the patterns observed in this study, the researcher further offers the following recommendations:

1. *Develop inventory*. Municipalities should try their best to first evaluate how many Lead laterals they have in the system to better understand the scope of what they are dealing with. The inventory should be explicit about what is unknown. Develop business cases and processes to look at avenues to gather information on lead. This can include dedicated resources to look at all historical records, do field investigations, and develop GIS models.
2. *Provide information about specific properties.* It is very important to be specific about where lead is right down to the property level. For example, the Lead Boundary map of Halifax Water doesn't show information on specific properties,

the Cleveland Static Map communicates the percentage of public side LSLs, and the Columbus database lists down the properties that may have LSLs. As such, homeowner cannot see their if own house has LSL. Showing information to public, will raise concerns in homeowners and will encourage them to replace the LSL as this will affect their potential buyers or sellers or if they are renting. A targeted communication plan can be effective in gaining acceptance of LSLR for a homeowner.

3. *Cost is a challenge when it comes to the replacement*. There are several financial assistance programs provided by the municipalities to help homeowners fund their replacements. But, these incentives are not enough for the replacement costs ranging from CAD 5,000 – 15,000 (**Figure *12***). The homeowners should have information on what can be the replacement cost for their service line as per their features of the house so that they can plan for the financial assistance. More cost-sharing or subsidies can also be helpful for Full LSLRs. Financial assistance to homeowners is very important as this is a cost that most homeowners would not have budgeted for. It also helps utilities get the lead out of their system at a faster pace thus saving them in additional administrative headache as well as potential cost savings in terms of corrosion prohibitive chemicals at the treatment plant.
4. *Work with the local jurisdictions to waive the privacy impact over where do lead lines exist.* It is important for a person already living at the property or a potential new homeowner or renter to know if there is a lead line existant at the property.

References

A Pruss-Ustun, C. V. (2011). *Knowns and unknowns on burden of disease due to chemicals: a systematic review.* Switzerland: Environ Health.

A.Page. (2019). Calgary doesn't know how many homes have lead pipes that could make water unsafe. *Global News*. Retrieved from https://globalnews.ca/news/6113641/calgary-water-lead-levels/

Alberta Water. (2019). *Do you fell mis-LEAD by your water?* Retrieved from Alberta Water Portal Society: https://albertawater.com/misconceptions/lead

Alberta Water. (n.d.). *Do you feel mis-LEAD by your water?* Retrieved from Alberta Water Portal Society: https://albertawater.com/misconceptions/lead

Arsenault, C. (2016, March 28). *MWRA Approves funding to remove Lead Service Lines in Marlborough.* Retrieved from Patch: https://patch.com/massachusetts/marlborough/mwra-approves-funding-remove-lead-service-lines-marlborough-0

AWWA. (2016). National Survey of Lead Service Line Occurrence. *American Water Works Association*. Retrieved from https://www.edf.org/health/where-are-lead-service-lines

B.Robertson. (2018). State Water Board Launces Online Map Showing Which Community Water Systems have Lead Fittings. Retrieved from https://www.waterboards.ca.gov/press_room/press_releases/2018/pr20181206_lead_service_lines_map.pdf

Boston Water and Sewer Commission. (2019). *Lead Replacement Incentive Program.* Retrieved from https://www.bwsc.org/environment-education/lead-your-water/lead-replacement-incentive-program

Brackett, E. (2016). Chicago's Lead Pipes: What You Need to Know. *WTTW*. Retrieved from https://news.wttw.com/2016/02/18/chicago-s-lead-pipes-what-you-need-know

Brokhof, W. (2018, Jan 31). *4500 Boston properties fed by lead water pipes.* Retrieved from Boston Home Team: https://thebostonhometeam.com/4500-boston-properties-fed-lead-water-pipes/

Brokhof, W. (2018, January 31). *4500 Boston Properties fed by Lead Water Pipes.* Retrieved from Boston Hometeam.com: https://thebostonhometeam.com/4500-boston-properties-fed-lead-water-pipes/

Bundale, B. (2019, November 4). *Lead water pipes a 'legacy contaminant' in thousands of Atlantic Canadian homes.* Retrieved from The Chronicle Herald: https://www.thechronicleherald.ca/news/local/lead-water-pipes-a-legacy-contaminate-in-thousands-of-atlantic-canadian-homes-371774/

Cal Water. (2019). *Lead*. Retrieved from https://www.calwater.com/waterquality/lead-water/

Chiaretta, S. (2018). *Front-end Development with ASP.NET Core, Angular, and Bootstrap.* Wiley Publishers.

Chris Aquino, T. G. (2016). *Front-End Web Development: The Big Nerd Ranch Guide.* Atlanta: Big Nerd Ranch, LLC.

City of Brantford. (2019). *Lead in Tap Water*. Retrieved from https://www.brantford.ca/en/living-here/lead-in-tap-water.aspx

City of Brantford. (2019). *Lead Service Replacement Financial Program*. Retrieved from https://www.brantford.ca/en/living-here/lead-pipe-replacement-grant.aspx

City of Detroit. (2019). *Lead Service Line Replacement Program*. Retrieved from https://detroitmi.gov/departments/water-and-sewerage-department/programs-and-initiatives/making-detroit-lead-safe/lead-service-line-replacement-program

City of Evanston. (2019). *Lead in Drinking Water*. Retrieved from Public Outreach: https://www.cityofevanston.org/government/departments/public-works/public-outreach/evanston-water-sewer-service/lead-in-drinking-water

City of Evanston. (n.d.). *Lead in Drinking Water.* Retrieved from City of Evanston: https://www.cityofevanston.org/government/departments/public-works/public-outreach/evanston-water-sewer-service/lead-in-drinking-water

City of Flint . (2016). Flint, Michigan.

City of Flint. (2019). *FAST Start Pipe Replacement Program*. Retrieved from https://www.cityofflint.com/fast-start/

City of Geneva. (2019). *Lead Service Line Replacement Program*. Retrieved from http://cityofgenevany.com/lead-service-line-replacement-program/

City of Guelph. (2019). *Drinking Water and Lead*. Retrieved from https://guelph.ca/living/environment/water/drinking-water/drinking-water-and-lead/

City of Milwaukee. (2019). *Lead Service Line Records*. Retrieved from Milwaukee water Works: https://city.milwaukee.gov/water/WaterQuality/Lead-Awareness-and-Drinking-Water-Safety/Lead-Service-Line-Records#.XdavMFdKiwd

City of Newark. (2019). *Lead Sevice Lines replacement Program ready to move forward after final council vote.* Retrieved from https://www.newarknj.gov/news/lead-service-line-replacement-program-ready-to-move-forward-after-final-council-vote

City of Newark. (n.d.). *Lead Sevice Lines replacement Program ready to move forward after final council vote.* Retrieved from https://www.newarknj.gov/news/lead-service-line-replacement-program-ready-to-move-forward-after-final-council-vote

City of Toronto. (2019). *Lead and Drinking Water.* Retrieved from https://www.toronto.ca/services-payments/water-environment/tap-water-in-toronto/lead-drinking-water/

City of Toronto. (n.d.). *Lead and Drinking Water.* Retrieved from https://www.toronto.ca/services-payments/water-environment/tap-water-in-toronto/lead-drinking-water/

City of Tucson. (2019). *Lead and Copper*. Retrieved from Tucson Water: https://www.tucsonaz.gov/water/lead-and-copper

City of Winnipeg. (n.d.). *Lead Control Program.* Retrieved from City of Winipeg: https://winnipeg.ca/waterandwaste/water/leadQA.stm

Cwiek, S. (2018, June 26). *Detroit water department head says city needs help removing lead service lines.* Retrieved from Michigan Radio: http://www.michiganradio.org/post/detroit-water-department-head-says-city-needs-help-removing-lead-service-lines

Cwiek, S. (2018). Detroit water department head says city needs help removing lead service lines. *Michigan Radio*. Retrieved from https://www.michiganradio.org/post/detroit-water-department-head-says-city-needs-help-removing-lead-service-lines

D.A. Cornwell, R. S. (2016). *National Survey of Lead Service Line Occurrence.* Washington: AWWA. Retrieved from http://media.mlive.com/news_impact/other/jaw201604cornwell_pr.pdf

Daily Freeman. (2019). Kingston aims to replace residents' lead water pipes. *Daily Freeman*. Retrieved from https://www.dailyfreeman.com/news/local-news/kingston-aims-to-replace-residents-lead-water-pipes/article_929d0292-b30b-11e9-b4d8-0bd2fcb8ff9c.html

David A. Cornwell, R. A. (2016, April). *National Survey of Lead Service Line Occurence.* AWWA.

DeLaet, J. (2018). *Target 2033- Cincinnati's Program to Eleminate Lead Pipes.* Cincinnati: Greater Cincinnati Water Works. Retrieved from https://la.mygcww.org/replace-your-lead-service-line/

Denchak, M. (2018, November 8). *Flint Water Crisis: Everything You Need to Know.* Retrieved from NRDC: https://www.nrdc.org/stories/flint-water-crisis-everything-you-need-know

Denver Water. (2019). *Lead Service Lines*. Retrieved from Water Quality: https://www.denverwater.org/your-water/water-quality/lead/lead-service-lines

Dissell, R. (2016, October 12). *Lead Pipes: What you need to know about newly released (searchable) Cleveland Water data.* Retrieved from cleveland.com: https://www.cleveland.com/metro/2016/10/lead_pipes_what_you_need_to_kn.html

Dissell, R. (2018, September 16). *Cleveland Water tests city employee taps for lead, not highest-risk areas.* Retrieved from CLEVELAND.COM: https://expo.cleveland.com/news/erry-2018/09/ff5423b9168298/-cleveland-water-tests-city-em.html

Dolan, M. (2016). Replacing Flint's lead pipes is double the estimate. *Detroit Free Press*. Retrieved from https://www.freep.com/story/news/local/michigan/flint-water-crisis/2016/05/27/flint-lead-lines-water-crisis/85032096/

EDF. (2018, January). *Mapping Lead Pipes by water utility (visualizing Indiana's data).* Retrieved from Environment Defense Fund: https://www.edf.org/health/mapping-lead-pipes-water-utility

EDF. (2019). *Community and utility efforts to replace lead service lines*. Retrieved from https://www.edf.org/health/recognizing-community-efforts-replace-lsl

EDF. (2019). *State efforts to support LSL replacement.* Retrieved from https://www.edf.org/health/state-efforts-support-lsl-replacement

EDF. (2019). Where are the lead service lines? Retrieved from https://www.edf.org/health/where-are-lead-service-lines

EDF. (n.d.). *Community and Utility efforts to replace lead service lines.* Retrieved from EDF: https://www.edf.org/health/recognizing-community-efforts-replace-lsl

EPA. (2018). *Lead* . Retrieved from United States Environment Protection Agency (EPA): https://www.epa.gov/lead/learn-about-lead

EPA. (2018, July 30). *Revealing the Complicated Nature of Tap Water Lead Contamination: A Madison, Wisconsin Case Study.* Retrieved from https://www.epa.gov/sciencematters/revealing-complicated-nature-tap-water-lead-contamination-madison-wisconsin-case

Farquhar, D. (2018, Feb 15). *NCSL.* Retrieved from http://www.ncsl.org/research/environment-and-natural-resources/lead-water-service-lines.aspx

Flint Water Advisory Task Force. (2016). *Final Report.* Michigan: Google Scholor.

Frontend Masters. (n.d.). Retrieved from https://frontendmasters.com/books/front-end-handbook/2018/what-is-a-FD.html

Frost, J. (2013, May 30). *Regression Analysis: How Do I Interpret R-squared and Assess the Goodness-of-Fit?* . Retrieved from The Minitab Blog: https://blog.minitab.com/blog/adventures-in-statistics-2/regression-analysis-how-do-i-interpret-r-squared-and-assess-the-goodness-of-fit

Gass, E. C. (2016, November 15). *Mapping the Lead in our Water Lines.* Retrieved from Civic Mapper: https://www.civicmapper.com/2016/11/15/lead-pipe-mapping/

GCWW. (2016, November 23). *There's a Map for That!* Retrieved from City of Cincinnati: https://www.cincinnati-oh.gov/water/news/there-s-a-map-for-that/

Gerstein, M. (2016, Dec 14). Retrieved from The Deteroit News: https://www.detroitnews.com/story/news/local/michigan/2016/12/14/lansing-lead-service-line/95435604/

Godbolt, M. (2016). *Frontend Architecture for Design Systems.* O'Reilly.

Government of Canada. (2016). Water Talk: Reducing your exposure to lead from drinking water.

Government of Canada. (n.d.). *Water Governance and Legislation: shared responsibility*. Retrieved from Government of Canada: https://www.canada.ca/en/environment-climate-change/services/water-overview/governance-legislation/shared-responsibility.html

Goyer, R. (1990). Lead toxicity: from overt to subclinical to subtle health effect. In *Environ Health Perspect* (pp. 177–81). Environ Health Perspect.

Graff, D. (2018, January 18). *Lead found in Waterloo's drinking Water.* Retrieved from The Courier: http://www.hngnews.com/waterloo_marshall/news/local/article_bcef7e3f-4792-5212-83e8-1673c7026656.html

Greater Cincinnati Water Works (GCWW). (2019). *Replace your Lead Service Line*. Retrieved from https://la.mygcww.org/replace-your-lead-service-line/

Halifax Water. (2017, February 23). An application by the HW for approval of amendments to the Halifax regional water commission to provide for repair and replacement of lead service lines in the provision of water service. Halifax, Nova Scotia, Canada: NOVA SCOTIA UTILITY AND REVIEW BOARD.

Halifax Water. (2019). *Lead Line Rebate.* Retrieved from Halifax Water: https://halifaxwater.ca/lead-line-rebate

Halifax Water. (n.d.). *Water Services*. Retrieved from https://www.halifax.ca/home-property/halifax-water/water-services

Hamilton. (2019). *Corrosion Control.* Retrieved from https://www.hamilton.ca/home-property-and-development/water-sewer/corrosion-control

Hamilton Water. (n.d.). *Corrosion Control.* Retrieved from https://www.hamilton.ca/home-property-and-development/water-sewer/corrosion-control

Hantke, A. (2018, June 28). *City offering more money to replace lead-lined pipes*. Retrieved from Weau.com: https://www.weau.com/content/news/City-offering-more-money-to-replace-lead-lined-pipes-486895491.html

Health Canada. (2013, February). *Risk Management Strategy for Lead.* Health Canada.

Health Canada. (2017). Lead in Drinking Water: Document for Public Consultation. Ottawa.

Health Link BC. (2019, March). *Lead in Drinking Water.* Retrieved from HealthLinkBC: https://www.healthlinkbc.ca/healthlinkbc-files/lead-drinking-water

Indiana American Water. (2018, July 31). *Indiana American Water Lead Service Line Replacement Plan Approved by the Indiana Utility Regulatory Commission.* Retrieved from https://amwater.com/inaw/news-community/rss-in/id/2394988

Jannene, J. (2018, January 24). *$750 Million to Replace Lead Pipes.* Retrieved from https://urbanmilwaukee.com/2018/01/24/eyes-on-milwaukee-750-million-to-replace-lead-pipes/

Jaramillo, C. (17, July 2017). *Philadelphia's building boom gives rise to another hidden lead risk.* Retrieved from Plan Philly: http://planphilly.com/articles/2017/07/17/philadelphia-s-building-boom-gives-rise-to-another-hidden-lead-risk

Jaramillo, C. (2017, July 17). *Philadelphia's building boom gives rise to another hidden lead risk.* Retrieved from Plan Philly: http://planphilly.com/articles/2017/07/17/philadelphia-s-building-boom-gives-rise-to-another-hidden-lead-risk

Joyce, S. (2017, March 28). *Getting the Lead Out: Midwest cities take different Tracks.* Retrieved from https://www.bna.com/getting-lead-midwest-n57982085862/

Katner, A., Kelsey, P., Brown, K., Lin, H. Y., Parks, J., Wang, X., . . . Edwards, M. (2018). *Effectiveness of Prevailing Flush Guidelines to Prevent Exposure to Lead in Tap Water.* Int J Environ Res Public Health.

Kenney, A. (2019). Denver Water proposes to replace all lead pipes in system. *The Denver Post*. Retrieved from https://www.denverpost.com/2019/07/01/denver-water-lead-pipes-epa/

Keogh, D. (2019). Do you have lead in your tap water? What you can do to find out in Ontario. *Global News*. Retrieved from https://globalnews.ca/news/6128756/safe-water-lead-testing-ontario/

Keogh, D. (2019). Do you have lead in your tap water? What you can do to find out in Ontario? *Global News*. Retrieved from https://globalnews.ca/news/6128756/safe-water-lead-testing-ontario/

Kirby, P. (2018). Kingston launching lead pipe replacement effort. *Daily Freeman*.

Klaassen, C. (2008). *Casarett and Doull's toxicology: the basic science of poison.* New York: McGraw Hill.

Krkosek, W. (2018). Get the Lead Out: A comprehensive Lead Service Line Replacement program. *ACWWA.* ACWWA.

L.W. May, J. R. (2017). *Informing Piitsburgh's Options to Address Lead in Water.* RAND Corporation.

Le Devoir. (2019, October 16). *The Duty and the Institute of Investigative Journalism at Concordia University .* Retrieved from Quebec underestimates lead in water: https://www.ledevoir.com/societe/564865/enquete-ce-plomb-que-quebec-refuse-de-voir

Lovell, J. (2016). Water woes south of the border lead to heightened interest in Guelph's lead pipe removal program. *Guelph Mercury Tribune*. Retrieved from https://www.guelphmercury.com/news-story/6329445-water-woes-south-of-the-border-lead-to-heightened-interest-in-guelph-s-lead-pipe-removal-program/

M.L. Miranda, D. K. (2007). *The Relationship between Early Childhood Blood Lead Levels and Performance on End-of-Grade Tests.* Environmental Health Perspective.

Madison Water Utility. (2014). *EPA seeks details of Madison's Lead Service Replacement Program*. Retrieved from https://www.cityofmadison.com/water/insidemwu/epa-seeks-details-of-madisons-lead-service-replacement-program

Madison Water Utility. (2019). *Information for utilities on lead service replacement*. Retrieved from Water Quality: https://www.cityofmadison.com/water/water-quality/lead-service-replacement-program/information-for-utilities-on-lead-service

Malachowski, J. (2017, June 29). *Marlborough aiming to replace lead service lines.* Retrieved from Wicked Local: https://marlborough.wickedlocal.com/news/20170619/marlborough-aiming-to-replace-lead-water-service-lines

Malachowski, J. (2017). Marlborough aiming to replace lead water service lines. *Wicked Local*. Retrieved from https://marlborough.wickedlocal.com/news/20170619/marlborough-aiming-to-replace-lead-water-service-lines

Mercanti, C. (2019). *Lead Water Service Replacement Loan Program Amendments (FCS19025) (City Wide).* Retrieved from https://pub-hamilton.escribemeetings.com/filestream.ashx?DocumentId=187491

National Drinking Water Council. (2015). *Lead and Copper Working Group to the National Drinking Water Advisory Council.*

Nelter, T. (2019, January 10). *EDF considers potential health equity impacts of partial lead service line replacement.* Retrieved from EDF: http://blogs.edf.org/health/2019/01/10/health-equity-partial-lead-service-line-replacement/

Neltner, S. H.-C. (2019). *Using online tools to publicize lead service line locations and promote replacement.* AWWA.

Neltner, T. (2017, Jan 19). *California requires replacement of all lead service lines – but vigilance needed on implementation*. Retrieved from Environment Defense Fund (EDF): http://blogs.edf.org/health/2017/01/19/california-sb1398-on-lsls/

Neltner, T. (2017, April 14). *Lead Sevice Lines on private property - 3 states' approaches to the challenge.* Retrieved from EDF: http://blogs.edf.org

Neltner, T. (2019). *City of Washington, DC requires lead pipe disclosure and tackles past partial LSL replacements*. Retrieved from EDF: http://blogs.edf.org/health/2019/01/28/dc-lsl-disclosure-partial-lsl-replacements/

Neltner, T. (2019, January 28). *DC requires lead pipe disclosure and tackles past partial LSL replacement.* Retrieved from EDF Health: http://blogs.edf.org/health/2019/01/28/dc-lsl-disclosure-partial-lsl-replacements/

Neltner, T. (2019, January 28). DC requires lead pipe disclosure and tackles past partial LSL replacements. *EDF*.

Neltner, T. (2019, April 4). *EDF analysis: Lead service lines in Illinois communities.* Retrieved from EDF: http://blogs.edf.org/health/2019/04/04/analysis-lead-service-lines-community-water-systems-in-illinois/

Neltner, T. (2019, September 25). *Where are Illinois' lead pipes? Chicago Water has nearly 60%, and small systems don't know.* Retrieved from EDF: http://blogs.edf.org/health/2019/09/25/llinois-lead-service-line-inventory-chicago-small-systems/

NRCC. (2013). *National Plumbing Code of Canada.* Ottawa. Retrieved from www.nrc-cnrc.gc.ca/obj/doc/2010_npc_revisions_november2013.pdf

NYC Environment Protection. (2016). *New York City 2016 Drinking Water Supply and Quality Report.* Retrieved from http://www.nyc.gov/html/dep/pdf/wsstate16.pdf

Orbus software. (n.d.). *What is Application Architecture?* Retrieved from Orbus Software: https://www.orbussoftware.com/us/application-architecture/what-is-application-architecture/#targetText=Application%20Architecture%20is%20the%20process,is%20scalable%2C%20reliable%20and%20manageable.

Page, A. (2019). Calgary doesn't know how many homes have lead pipes that could make water unsafe. *Global News*. Retrieved from https://globalnews.ca/news/6113641/calgary-water-lead-levels/

Pittsburgh Water and Sewer Authority. (2019). *Lead Map*. Retrieved from Community Lead Response: http://lead.pgh2o.com/your-water-service-line/planned-water-service-line-replacement-map/

Preston, N. (2016, OCTOBER 24). Digging Deeper: Blocking leaden dangers. *Water and Wastewater Treatment (WWT)*.

Prevost, D. M. (2015). *Lead in Tap Water: Assessing Consumer Exposure and Identtifying corrective actions(2008-12).* Canadian Water Network.

PWSA. (n.d.). Creating a Lead Service Line Inventory with Michael Baker International. Pittsburgh, Philadelphia.

Quon, A. (2017, August 22). *Halifax to help homeowners with cost of replacing thousand of lead pipes.* Retrieved from Global News: https://globalnews.ca/news/3687446/program-to-replace-the-lead-pipes-halifax/

Region News Team. (2018, July 31). *Indiana American Water Lead Service Line Plan Approved.* Retrieved from Indiana 105: https://indiana105.com/region-news/indiana-american-water-lead-service-line-plan-approved/

Reid Corbett, D. o. (2017, March 24). Saskatoon accelerated lead pipe removal. (C. S. Friday, Interviewer)

Renner, R. (2010, May). Reaction to the Solution: Lead Exposure Following Partial Service Line Replacement. *Environ Health Perspect*, pp. 118(5): A202–A208.

Renner, R. (2010). *Reaction to the Solution: Lead Exposure Following Partial Service Line Replacement.* Environ Health Perspect.

Riga, A. (2016, September 30). *Montreal will spend $300 million more than expected on lead pipes.* Retrieved from Montreal Gazette: https://montrealgazette.com/news/local-news/montreal-will-spend-300-million-more-than-expected-on-lead-pipes

Rocheleau, M. (2016). Do you have lead in your water? City of Boston wants to help. *Boston Globe*.

S. H. Schlea, D. K. (2019, March 3). *Mapping Lead Service Lines.* Retrieved from LSLR Collaborative: https://www.lslr-collaborative.org/webinars/mapping-lead-service-lines-charting-a-path-to-engage-a-community

S.J. Masten, S. D. (2016). *Flint Water Crisis: What happenend and why?* J Am Water Works Assoc.

Sandvig, A. K. (2008). Contribution of service line and plumbing fixtures to lead and copper rule compliance issues. *Awwa Research Foundation Project No. 90721*.

Schultz, E. (2019, july 24). *What you Need To Know About Cincinnati Drinking Water.* Retrieved from Hydroviv: https://www.hydroviv.com/blogs/water-quality-report/cincinnati

Small, L. (2016, March 29). *Here's why Ridding Richmond of Lead Pipes is Balancing Act.* Retrieved from style weekly: https://www.styleweekly.com/richmond/heres-why-ridding-richmond-of-lead-pipes-is-balancing-act/Content?oid=2304868

Smeltz, A. (2017, July 19). *Lead Line replacements could cost PWSA customers.* Retrieved from Pittsburgh Post Gazette: https://www.post-gazette.com/local/city/2017/07/19/pwsa-lead-line-replacements-pittsburgh-water-bills/stories/201707190158

Smith, L. (2016). Where are lead water pipes in Michigan? Here’s our best guess. *Michigan Radio*. Retrieved from https://www.michiganradio.org/post/where-are-lead-water-pipes-michigan-here-s-our-best-guess

Smith, L. (2016, April 5). *Where are lead water pipes in Michigan? Here's our best guess.* Retrieved from Michigan radio: https://www.michiganradio.org/post/where-are-lead-water-pipes-michigan-here-s-our-best-guess

Stringfellow, A. (2017, September 21). *What is web application architecture? How it works, Trends, Best practices and More.* Retrieved from Stackify: https://stackify.com/web-application-architecture/

Taylor, S. (2017, June 18). *City of Regina wants to give residents filters, free lead testing kits.* Retrieved from CBC: https://www.cbc.ca/news/canada/saskatchewan/saskatchewan-city-of-regina-lead-1.4166232

The Detroit News. (2016). Lansing replaces city's final lead service line. Retrieved from https://www.detroitnews.com/story/news/local/michigan/2016/12/14/lansing-lead-service-line/95435604/

Trueman. (2016). Evaluating the effects of partial and full lead service line replacement on lead levels in drinking water. *Environmental Science and Technology*, pp. 7389-7396.

Trueman. (2017). *Controlling Lead Release To Drinking Water: Impacts Of Iron Oxides, Complexing Species, Orthophosphate, And Lead Pipe Replacement.* Halifax: Dalhousie University.

U.S. EPA. (2006). *Inorganic contaminant accumulation in potable water distribution system.*

U.S. EPA. (2011). *Reduction of Lead in Drinking Water Act, Safe Drinking Water Act (SDWA), Section 1417.* U.S. Environmental Protection Agency, Washinton. Retrieved from www.gpo.gov/fdsys/pkg/BILLS-111s3874enr/pdf/BILLS-111s3874enr.pdf

US EPA. (2011, Sept 28). *SAB Evaluation of the Effectiveness of Partial Lead Service Line Replacement.* Retrieved from https://yosemite.epa.gov/sab/sabproduct.nsf/02ad90b136fc21ef85256eba00436459/964CCDB94F4E6216852579190072606F/$File/EPA-SAB-11-015-unsigned.pdf

US EPA. (2018, July 30). Revealing the Complicated Nature of Tap Water Lead Contamination: A Madison, Wisconsin, Case Study. *Science Matters*. Retrieved from https://www.epa.gov/sciencematters/revealing-complicated-nature-tap-water-lead-contamination-madison-wisconsin-case

Wilson, K. (2019). Saskatchewan residents have some of highest levels of lead-tainted water in Canada. *Global News*. Retrieved from https://globalnews.ca/news/6120813/saskatchewan-lead-tainted-water/

Wisconsin DNR. (n.d.). *Private Lead Service Line (LSL) Replacement Funding Program.* Retrieved from Wisconsin DNR: https://dnr.wi.gov/Aid/documents/EIF/privateLSLreplacementFundingProgram.html

Yi, K. (2018, August 16). *Pipes in N.J. city were installed in the 1880s. There's lead in them, and it's a problem.* Retrieved from NJ.COM: https://www.nj.com/essex/2018/08/newarks_lead_level_in_its_tap_water_is_high_again.html

APPENDIX A – Supporting data for Chapter 4 (Cost Estimation Portal Database)

Table 2: Values used for the Cost Estimation Portal

Parameter	**Unit of Measurement**	**Cost (CAD)**
Water service line	m	440
Sidewalk *	Sq. m.	190
Trees	Each	200
Curb and gutter	Trench width	240
Landscaping	Sq. m.	30
Plant Clusters	each	200
Driveway- Asphalt	sq. m.	100
Driveway – gravel	sq. m.	50
Driveway- concrete	sq. m.	200
Driveway – stone	sq. m.	200

Assumptions:

1. Trench width is 2 meters
2. Sidewalk reinstatement is 3 sq. m. (1.5 m wide * trench width)
3. Length of curb and gutter reinstatement = trench width
4. 100% of the laterals run under driveway or lawn (whichever feature selected by the user). Area is calculated by length of the service line *trench width.
5. All costs are for demonstration purpose only. The user creating this application will need to get local cost estimates from contractors.

APPENDIX B – Supporting data for Chapter 5

Table 3: Database used to do factor analysis

(1-Yes; 2- No)

Replacement cost	Length of the private service	Depth at curb stop (m)	Retaining Wall	Lawn	Sidewalk	Trees	Plant clusters	Paving stones	Landscaping
$12,414.26	0.30	1.90	2	2	1	2	2	2	2
$3,450.00	0.9144	1.070	2	2	2	2	2	2	2
$2,645.00	0.97	1.220	2	2	1	2	2	2	2
$575.00	1.00	1.80	2	2	2	2	1	2	2
$575.00	1.00	1.800	2	2	1	2	1	2	2
$2,673.75	1.00	1.200	2	2	1	2	1	2	2
$2,645.00	1.40208	1.220	2	2	1	2	2	2	2
$1,610.00	1.62	1.37	2	1	1	2	2	2	1
$1,840.00	1.80	1.100	2	2	1	2	2	2	2
$1,150.00	1.83	1.800	2	2	1	2	2	2	2
$2,990.00	1.83	1.37	2	2	1	2	1	2	2
$3,565.00	1.9	1.1	2	2	1	2	2	2	2
$1,017.75	2	1.2	2	2	1	2	1	2	2
$1,052.25	2	1.6	2	2	1	2	1	2	2
$1,052.25	2	1.6	2	2	1	2	1	2	2
$2,679.50	2.20	1.00	2	2	1	2	2	2	2
$3,013.00	2.74	1.4	2	1	1	1	1	2	1
$1,420.25	3	2	2	2	1	2	1	2	2
$2,300.00	3	1.5	2	1	1	2	1	2	1
$3,501.75	3	1.5	2	1	1	2	1	2	2
$6,325.00	3	1.37	2	2	1	2	1	2	2
$1,380.00	3.20	1.500	2	2	1	2	1	2	2
$4,427.50	3.35	1.83	2	2	1	2	1	2	2
$2,587.50	3.60	1.500	2	2	1	2	1	2	2
$1,610.00	3.6	1.4	2	2	1	2	1	2	2
$4,082.50	3.70	1.200	2	2	1	2	2	2	2
$2,070.00	3.80	1.300	2	2	1	2	1	2	2
$1,081.60	3.96		2	2	1	2	2	2	2
$2,875.00	4.00	1.600	2	2	1	2	1	2	2
$6,645.33	4	2.5	2	1	1	2	1	2	1
$5,750.00	4	2.5	1	1	1	2	1	2	1
$2,875.00	4.30	1.520	2	2	1	1	1	2	2
$3,220.00	4.3	1.6	2	1	1	2	1	2	1
$2,300.00	4.3	1.68	2	1	1	2	1	1	1
$4,025.00	4.57	1.52	2	1	1	1	1	2	1
$4,140.00	4.57	1.600	2	2	1	2	2	2	2
$2,070.00	4.8		2	2	1	2	1	2	2
$3,841.00	4.9	1.5	2	1	1	2	1	2	1
$2,903.75	5.00	1.400	2	1	1	2	1	2	1
$3,910.00	5.1	1.4	2	2	1	2	2	2	2
$6,325.00	5.18		2	2	2	2	2	2	2

Replacement cost	Length of the private service	Depth at curb stop (m)	Retaining Wall	Lawn	Sidewalk	Trees	Plant clusters	Paving stones	Landscaping
$2,530.00	5.18	1.52	2	2	1	2	1	2	2
$4,025.00	5.2		2	1	1	1	1	2	1
$3,565.00	5.3	1.52	2	2	1	2	1	2	2
$2,875.00	5.33	1.370	1	1	1	2	1	2	1
$3,162.50	5.40	1.220	1	2	1	2	1	2	1
$4,117.00	5.50	1.50	2	2	1	1	1	2	2
$6,215.00	5.50	1.30	1	1	1	1	1	2	1
$1,150.00	5.70	1.370	2	1	1	2	1	2	1
$8,337.50	5.75	1.500	2	1	1	2	1	2	1
$4,455.00	6.00	1.300	2	2	1	2	1	2	2
$2,300.00	6.00	1.800	1	2	1	2	1	1	1
$2,875.00	6.10	1.98	2	1	1	2	1	2	1
$2,875.00	6.10	1.37	1	2	1	2	2	2	2
$2,300.00	6.50	1.500	2	1	1	1	1	2	1
$4,111.25	6.5	1.52	2	1	1	2	1	2	2
$5,347.50	6.71	1.200	1	1	1	2	1	2	1
$2,875.00	6.71	1.500	2	1	1	2	1	2	2
$4,600.00	6.71	1.98	1	1	1	2	1	1	2
$3,225.75	6.90	1.200	1	1	1	1	1	1	1
$3,737.50	7.00	1.500	2	2	1	2	1	2	
$6,261.21	7.00	1.350	1	1	1	2	1	1	1
$3,662.75	7.3	1.600	2	2	2	2	1	2	2
$2,760.00	7.70	1.500	2	1	1	2	1	2	1
$9,100.00	7.80	1.830	2	1	1	1	1	2	1
$3,316.50	7.9	1.52	1	1	1	2	1	2	1
$4,582.75	7.9	1.6	2	1	1	2	1	2	1
$5,865.00	7.9	1.2	2	2	1	2	2	2	2
$3,869.75	7.92	1.52	2	2	1	2	1	2	2
$3,547.75	8.00	1.300	1	2	1	1	1	2	2
$3,547.75	8.00	1.700	1	1	1	2	1	2	1
$4,416.00	8	1.6	1	1	1	2	1	2	1
$2,875.00	8.04672	1.520	2	1	1	2	1	2	1
$1,767.50	8.23	1.37	2	2	2	2	2	2	2
$2,990.00	8.40	1.100	1	1	1	2	1	2	1
$4,180.25	8.5	1.6	2	1	1	2	1	2	1
$2,530.00	9.00	1.500	1	1	1	2	1	2	1
$6,974.75	9	1.68	2	1	1	2	1	2	1
$2,530.00	9.20	1.300	2	1	1	2	1	2	1
$2,875.00	9.80	2.10	1	1	1	2	1	1	1
$4,082.50	9.8	1.8	2	1	1	2	1	2	1
$4,370.00	10	1.9	2	1	1	2	1	2	1
$7,705.00	11.00	1.520	2	1	1	2	1	2	1
$3,622.50	11	1.8	2	1	1	2	1	2	1
$4,025.00	11	1.5	2	2	2	2	2	2	2
$2,875.00	11.30	1.370	1	1	1	1	1	1	1
$4,094.00	11.8	1.4	2	1	2	2	1	1	1
$2,760.00	11.89	1.50	2	1	1	1	1	2	1
$4,611.50	11.9	1.5	1	1	1	1	1	1	1

Replacement cost	Length of the private service	Depth at curb stop (m)	Retaining Wall	Lawn	Sidewalk	Trees	Plant clusters	Paving stones	Landscaping
$9,430.00	12.96	1.68	2	2	2	2	1	2	2
$6,590.14	13.40	1.80	2	1	1	1	2	2	1
$6,152.50	14.70	2.00	1	1	1	1	1		1
$4,007.75		1.520		1	1	1	1	1	1
$3,409.75			1	2	1	2	1	1	2
$2,070.00				1	1	1	1		1
$2,875.00			2	2	1	2	1	2	2
$3,967.50			1	1	1	2	1	2	1
$2,875.00			1	2	1	2	1	2	1
$4,887.50			2	2	1	2	1	2	2

Table 4 The descriptive statistics of the dataset of the residents who got their lead service line replacements in 2016-18 in Halifax, NS

	Replacement Cost (Y)	**The percentage removal of Lead after six months of replacement (X)**
Mean	6177.58 CAD	-44.59
Median	4000.00	-69.92
Mode	3700.00	-100.00
Skewness	0.97	0.93

Table 5 The Ordinary Least Squares (OLS) model for the dataset of the residents who got their lead service line replacement in 2016-18 in Halifax, NS

Dep. Variable	Replacement Cost (Y)	**R -Squared**	0.030
Model	OLS	**Adj. R Squared**	0.003
Method	Least Squares	**F-statistic**	1.108
Date	Wed, 25 Sep 2019	**Prob (F-Statistic)**	0.300
No. of Observations	40	**Log-Likelihood**	-364.79
Df Residuals	38	**AIC**	733.6
Df Model	1	**BIC**	736.9
Covariance type	Non-robust		

	Coef.	Std. error	T	P>|T|	[0.025	0.975]
Const	6628.028	733.106	9.041	0.000	5141.22	8113.837
X	10.10	9.596	1.053	0.300	-9.360	29.562
Omnibus		6.089	**Durbin-Watson**		1.239	
Prob (Omnibus)		0.048	**Jarque-Bera (JB)**		5.923	
Skew		0.926	**Prob (JB)**		0.0518	
Kurtosis		2.444	**Cond. No.**		94.1	

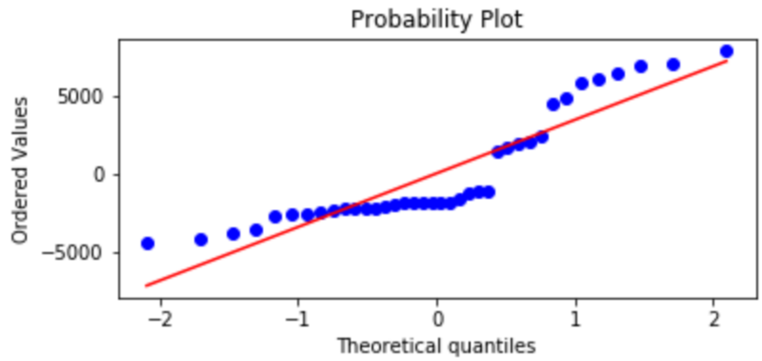


Figure 29 The probability plot to understand the relationship between replacement cost and the Lead content reduction after 6 months in the Halifax, NS for residents who got their service lines replaced between 2016-18

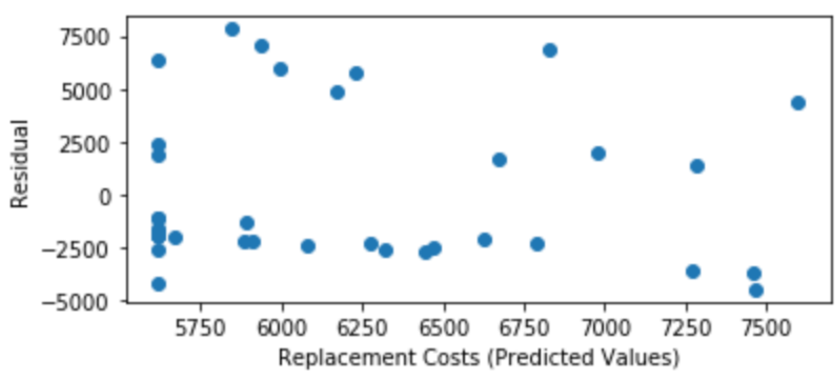


Figure 30 Scatterplot of standardized residual on standardized predicted values for Halifax's residents who got their service lines replaced between 2016-18

Table 6: Dataset used for analysis in Chapter 5. (Addresses are not used because of the privacy concerns). The data is obtained from the CWRS lab, Dalhousie University and replacement cost obtained from Halifax Water (Water quality team).

Replacement cost	Litres	Before	72h	1m	3m	6m
$12,000	1	9.80	9.52	2.37	0.29	3.68
	2	21.33	4.06	0.41	1.93	1.47
	3	28.71	0.89	0.17	5.31	0.29
	4	25.84	0.82	0.16	0.25	0.29
	5	4.33	0.45	-0.27	0.21	0.13
$4,600	1	12.94	7.79	3.87	2.95	3.54
	2	17.86	8.56	5.04	3.91	3.67
	3	16.41	4.56	3.79	2.43	2.09
	4	42.09	2.22	2.90	2.21	1.06
	5	4.34	0.61	0.25	0.21	0.48
$9,000	1	14.89		23.26		20.08
	2	15.57		26.59		18.53
	3	17.69		27.46		19.21
	4	19.10		29.17		22.28
	5	12.03		12.90		7.97
$9,000	1	15.72		19.69	19.94	34.83
	2	6.82		6.35	5.03	4.21
	3	3.89		2.58	1.75	1.89
	4	3.89		2.61	1.48	1.52
	5	1.47		2.70	0.74	0.38
$3,000	1	2.58	2.79	4.32		
	2	1.66	2.73	3.03		
	3	1.82	3.94	2.75		
	4	2.04	3.50	2.90		
	5	3.71	0.77	0.92		
$3,000	1	2.33		2.36	1.46	
	2	7.42		2.83	1.08	
	3	10.58		0.73	0.69	
	4	15.16		0.45	0.52	
	5	3.67		1.03	0.16	
$3,000	1	3.37		7.58		
	2	1.50		2.89		
	3	7.66		2.22		
	4	3.70		1.68		
	5	1.26		0.55		
$3,000	1	0.82	4.30	1.68	0.65	
	2	1.00	2.98	0.63	0.91	
	3	14.62	1.51	0.09	0.47	
	4	9.17	0.55	0.16	0.21	
	5	1.25	0.23	0.04	0.05	
$7,500	1	1.11	6.63		2.72	
	2	9.03	8.58		1.36	
	3	1.64	21.51		0.76	
	4	0.94	36.08		0.27	
	5	1.82	2.55		0.11	

Replacement cost	Litres	Before	72h	1m	3m	6m
$9,226	1	3.31	0.86	0.86	0.61	
	2	1.41	1.26	0.82	1.89	
	3	14.01	1.22	0.58	1.26	
	4	1.85	1.17	0.50	0.63	
	5	1.35	0.26	0.21	0.12	
$12,000	1	4.17			5.39	
	2	6.14			8.72	
	3	8.66			7.86	
	4	11.60			4.92	
	5	4.30			0.57	
$6,700	1	11.68	20.32	13.62	5.95	5.00
	2	15.43	61.57	21.26	4.17	3.74
	3	18.11	45.43	29.02	4.18	5.78
	4	30.42	80.48	29.55	2.44	3.23
	5	5.34	4.97	4.16	0.25	0.17
$4,500	1	1.95	1.99	2.92	2.95	2.26
	2	2.06	4.66	2.52	2.78	2.15
	3	17.06	1.82	0.81	0.35	1.03
	4	3.93	0.38	0.15	1.22	0.45
	5	1.34	-0.02	-0.12	0.09	0.16
$12,000	1	7.49	52.11	41.03		42.02
	2	6.38	28.64	24.86		28.31
	3	6.78	39.04	28.43		23.03
	4	6.35	19.09	47.97		25.61
	5	7.03	6.25	5.33		4.82
$12,000	1	1.54	4.25	3.30	2.51	3.02
	2	1.91	13.46	4.57	2.98	4.35
	3	2.53	25.66	6.23	4.35	2.42
	4	3.08	28.27	15.98	5.86	6.36
	5	1.82	4.18	3.07	1.50	1.17
	1	7.85	2.85	2.25		
	2	6.40	2.88	2.42		
	3	7.87	5.78	2.95		
	4	21.94	5.16	2.38		
	5	2.80	0.22	0.26		
	1	2.03	0.44	0.40	1.03	
	2	1.85	0.78	0.48	1.56	
	3	6.29	1.36	0.06	1.27	
	4	1.09	0.00	-0.04	0.20	
	5	0.42	-0.42	-0.10	0.03	
	1	4.61	9.25	7.71	8.86	1.33
	2	4.70	4.63	5.11	8.94	1.21
	3	4.13	3.39	4.30	6.92	1.31
	4	8.44	2.57	3.46	2.72	1.19
	5	1.33	0.60	0.72	0.59	0.22
$8,700	1	2.92	43.72	3.75	6.77	8.31
	2	2.45	22.11	2.66	7.33	8.28
	3	2.79	678.70	2.63	6.83	8.53
	4	3.86	241.40	15.36	9.95	9.82

Replacement cost	Litres	Before	72h	1m	3m	6m
	5	2.76	230.00	2.40	2.67	5.50
	1	3.35	4.38	7.68		
	2	6.66	3.41	2.65		
	3	5.63	0.96	4.40		
	4	1.67	1.12	1.07		
	5	2.37	1.35	1.46		
$4,500	1	6.75	4.56			
	2	7.40	3.61			
	3	22.94	1.57			
	4	22.47	0.70			
	5	4.01	0.50			
$4,500	1	8.95	7.58	11.89	9.32	8.93
	2	5.99	4.26	7.08	4.79	4.62
	3	7.27	3.85	4.39	4.68	3.69
	4	10.11	3.11	3.52	3.39	2.94
	5	2.92	0.44	0.28	0.21	0.46
	1	14.87	14.23	7.60	18.34	12.20
	2	11.57	10.76	8.23	24.88	6.30
	3	16.30	10.09	6.83	21.23	3.32
	4	53.34	8.02	4.47	6.95	2.88
	5	6.39	1.87	1.79	1.59	1.30
	1	8.66		4.90		
	2	6.81		4.55		
	3	24.52		3.96		
	4	29.67		1.29		
	5	4.09		0.79		
$11,000	1	3.49	27.43			20.10
	2	3.40	9.37			7.21
	3	5.11	7.42			5.79
	4	4.01	3.58			5.00
	5	1.56	1.41			3.70
	1	36.84	27.43			20.10
	2	14.42	9.37			7.21
	3	30.16	7.42			5.79
	4	44.86	3.58			5.00
	5	6.51	1.41			3.70
$8,377	1	4.62	5.17	4.52	5.63	4.83
	2	4.38	4.70	2.78	4.01	3.88
	3	12.13	1.75	0.74	0.49	0.55
	4	14.46	5.96	0.63	0.36	0.56
	5	2.15	0.84	0.38	0.16	0.23
$8,000	1	4.74	1.52			
	2	5.48	3.87			
	3	5.90	4.71			
	4	4.66	3.30			
	5	1.61	0.23			
$8,623	1	12.74	324.30	97.26	26.10	28.64
	2	12.19	27.54	23.37	8.27	10.56
	3	14.23	20.31	37.07	10.14	9.33

Replacement cost	Litres	Before	72h	1m	3m	6m
	4	13.71	49.30	32.27	20.08	11.46
	5	4.90	7.02	4.22	2.92	3.30
	1	4.12		2.88	6.24	
	2	5.15		2.93	9.52	
	3	25.74		3.13	16.88	
	4	11.62		1.99	2.29	
	5	3.45		1.50	0.79	
	1	3.91		6.67	4.81	
	2	4.13		5.05	6.24	
	3	7.89		14.37	4.79	
	4	8.90		74.78	3.19	
	5	3.66		4.55	1.28	
	1	11.16	63.18		17.79	15.34
	2	9.84	25.16		19.13	7.07
	3	26.73	65.84		63.87	8.15
	4	44.01	110.90		70.92	9.55
	5	7.39	11.62		7.20	4.15
	1	29.70			62.88	
	2	25.47			29.09	
	3	74.36			100.60	
	4	103.10			120.80	
	5	16.66			6.63	
$ 12,000	1	27.69	3.90	3.03	5.46	2.37
	2	27.88	5.08	2.52	5.87	1.11
	3	23.46	2.24	0.98	2.81	0.55
	4	34.64	1.53	0.82	1.33	0.38
	5	5.05	0.72	0.37	0.95	0.23
$12,000	1	7.54		2.61		
	2	7.11		0.91		
	3	22.40		0.68		
	4	24.89		0.55		
	5	4.51		0.38		
$12,000	1	8.34		5.66	5.88	4.89
	2	11.60		11.33	7.31	2.71
	3	38.22		11.00	2.70	1.18
	4	46.35		4.16	1.16	0.80
	5	10.56		1.06	0.35	0.41
	1	5.17	6.91		3.82	3.59
	2	5.46	31.46		5.94	0.98
	3	9.27	24.37		2.94	0.78
	4	13.54	4.92		1.21	0.46
	5	1.85	1.99		0.34	0.20
$13,000	1	5.96	4.60	12.77	14.40	16.41
	2	8.97	1.13	14.20	16.15	15.69
	3	9.72	0.38	10.61	12.68	8.93
	4	11.18	0.23	2.33	2.87	1.42
	5	3.35	0.19	1.02	0.58	0.30
$12,000	1	52.37	4.60	12.77	14.40	16.41
	2	21.91	1.13	14.20	16.15	15.69

Replacement cost	Litres	Before	72h	1m	3m	6m
	3	25.59	0.38	10.61	12.68	8.93
	4	41.83	0.23	2.33	2.87	1.42
	5	6.78	0.19	1.02	0.58	0.30
$11,000	1	2.31	1.37			
	2	2.38	1.27			
	3	2.31	1.42			
	4	2.45	1.28			
	5	3.13	1.19			
	1	5.83		3.78		
	2	5.40		2.49		
	3	10.40		1.39		
	4	18.21		0.89		
	5	4.99		0.34		
	1	5.08		4.19		
	2	5.22		5.02		
	3	4.56		2.77		
	4	25.61		1.40		
	5	2.42		0.45		
	1	3.25		4.19		
	2	4.48		5.02		
	3	21.19		2.77		
	4	15.38		1.40		
	5	4.96		0.45		
$11,000	1	4.22	4.31	3.58	3.60	1.12
	2	4.53	5.63	4.10	4.09	1.14
	3	5.88	6.16	4.53	3.92	1.94
	4	12.09	8.40	5.13	5.03	3.03
	5	4.91	1.31	0.85	0.63	0.77
$11,000	1	2.21		2.89		
	2	2.06		0.91		
	3	1.29		0.68		
	4	1.39		1.03		
	5	1.00		0.60		
	1	3.87		1.84		6.67
	2	2.66		1.20		6.56
	3	2.76		1.13		13.10
	4	2.50		1.33		18.37
	5	18.31		2.03		1.02
$13,698	1	8.53	8.51		6.53	5.15
	2	18.52	7.08		5.79	8.31
	3	52.61	2.17		0.68	5.05
	4	50.44	1.84		0.45	0.77
	5	6.75	0.36		0.28	0.50
$13,698	1	39.76	21.49	18.50		8.84
	2	18.67	13.34	9.61		6.28
	3	74.17	6.25	1.83		1.62
	4	88.22	1.63	0.94		0.51
	5	5.73	0.61	0.50		0.37
	1	1.93	6.97	2.83	3.33	2.31

Replacement cost	Litres	Before	72h	1m	3m	6m
	2	2.54	3.42	7.28	4.98	2.45
	3	2.83	4.44	13.07	5.44	2.64
	4	3.35	23.89	16.05	24.92	5.85
	5	2.74	1.95	1.41	1.17	0.97
	1	6.10	12.83	11.18	12.09	6.32
	2	14.73	102.60	11.48	14.89	4.01
	3	23.91	8.05	54.35	7.36	2.20
	4	22.35	7.55	35.53	2.84	1.73
	5	13.57	4.35	2.81	1.74	1.28
	1	7.61	6.07			
	2	6.68	7.11			
	3	8.97	8.50			
	4	11.58	3.73			
	5	3.39	3.52			
	1	2.33				3.20
	2	2.79				2.39
	3	14.24				0.34
	4	25.87				0.30
	5	3.82				0.17
	1	4.11	4.38	3.74		
	2	4.10	3.53	3.25		
	3	5.87	9.53	3.69		
	4	27.79	3.52	1.39		
	5	2.94	0.49	0.30		
$2,760	1	16.86	2.16	0.55	2.78	
	2	23.10	0.40	0.44	0.40	
	3	21.60	0.40	0.40	0.40	
	4	18.51	0.81	0.44	0.40	
	5	2.82	0.40	0.40	0.40	
	1	10.01	10.34	256.30	50.57	
	2	28.18	93.47	30.81	7.60	
	3	28.37	39.83	39.92	13.37	
	4	33.29	10.72	21.00	4.71	
	5	4.05	8.45	3.57	2.96	
	1	12.75			2.69	3.35
	2	30.59			2.10	1.66
	3	11.20			1.12	1.05
	4	8.52			0.39	0.20
	5	5.75			0.21	0.04
$1,420	1	22.41	4.38	1.41	1.00	1.16
	2	13.77	5.53	2.95	2.58	2.65
	3	16.04	2.18	0.59	0.77	0.36
	4	14.90	2.21	0.36	0.41	0.10
	5	1.25	0.30	0.21	0.31	0.02
	1	5.14	4.16		1.69	
	2	4.89	3.26		1.90	
	3	4.92	2.97		1.60	
	4	5.13	1.83		1.53	
	5	1.02	0.22		0.11	

Replacement cost	Litres	Before	72h	1m	3m	6m
$4,000	1	5.32	9.77	7.02	2.99	2.45
	2	4.49	4.67	22.73	3.14	1.98
	3	14.14	3.67	2.92	1.84	1.09
	4	1.82	10.47	2.08	1.35	0.63
	5	4.65	0.74	0.76	0.56	0.17
$4,000	1	39.76	21.49	18.50	83.43	68.75
	2	18.67	13.34	9.61	126.30	116.90
	3	74.17	6.25	1.83	165.30	184.90
	4	88.22	1.63	0.94	144.90	203.00
	5	5.73	0.61	0.50	9.13	8.09
	1	3.49	4.04			
	2	4.08	3.31			
	3	4.51	1.58			
	4	3.45	1.08			
	5	2.89	0.62			
	1	14.11	13.52		15.80	11.87
	2	23.27	14.18		17.32	11.22
	3	26.00	14.60		25.89	11.62
	4	23.75	15.87		21.90	13.44
	5	6.31	3.14		2.59	2.24
$3,000	1	7.19	4.71	7.89	3.34	4.67
	2	19.58	1.45	1.86	0.84	0.43
	3	19.43	1.15	1.18	0.79	0.75
	4	16.42	0.90	0.73	0.68	4.50
	5	1.76	0.17	0.16	0.25	0.38
	1	6.67		13.35	25.40	12.23
	2	7.17		9.30	14.80	13.60
	3	11.34		2.62	4.30	6.82
	4	20.08		1.05	1.40	2.40
	5	2.55		0.32	0.60	0.55
	1	4.54			7.38	
	2	3.60			3.28	
	3	3.36			0.55	
	4	1.92			0.48	
	5	1.84			0.30	
$4,000	1	30.25			26.27	
	2	29.27			17.90	
	3	13.63			15.71	
	4	28.54			15.76	
	5	8.69			7.55	
$4,455	1	15.37		8.57	1.67	
	2	24.50		3.55	0.83	
	3	52.82		0.59	0.29	
	4	48.58		0.69	0.21	
	5	5.31		0.50	0.13	
$4,117	1	15.37	29.98	53.03	9.07	
	2	24.50	18.57	29.17	8.05	
	3	52.82	8.02	8.06	4.13	
	4	48.58	5.12	3.52	1.05	

Replacement cost	Litres	Before	72h	1m	3m	6m
	5	5.31	1.06	1.19	0.56	

APPENDIX C – Sampling Instructions given by Halifax Water to the residents

Sample Bottles 1, 2, 3, and 4

1. Locate sample bottles 1, 2, 3 and 4. Remove the caps and arrange the bottles in sequence from 1 through 4 on the counter near the sink, taking care to place the caps on a clean surface to avoid sample contamination.
2. Hold bottle 1 under the cold-water faucet. Open the cold-water faucet fully and begin to fill bottle 1.
3. When bottle 1 is filled approximately 1 cm from the top, remove it from the flow and quickly replace it with bottle 2, without adjusting the faucet.
4. Repeat Step 3 for bottles 3 and 4.
5. After collecting the bottle 4 sample, tightly cap all 4 of the sample bottles. Leave the water running.
6. Note the date, time and faucet location below and then proceed to the sampling procedure for bottle 5.

Sample Bottle 5

1. Leave the cold-water faucet fully open and allow water to flow for a **minimum of 10 minutes**. Hold bottle 5 under the faucet until it is filled approximately 1 cm from the top, remove it from the flow and tightly cap.
2. Note the date, time and faucet location below.