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4698

Evaluation of Lead Pipe Detection by Electrical Resistance Measurement

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Abstract and Benefits

Abstract:

The goal of this project was to evaluate the possibility of detecting the presence of lead pipe in a water service line by measuring the electrical resistance of the water service line. Using a digital low resistance ohmmeter (DLRO), measurements in the laboratory were made on water service lines containing copper and lead pipes and components previously removed from the field. The measurements demonstrated that this technique is sensitive enough to distinguish between a lead pipe and a copper pipe. In the field, measurements were made between the curb stop valve and the water meter (located inside properties). The DLRO was used with specially designed and extended test leads to measure the electrical resistance. Field measurements confirmed that the presence of lead pipe can be determined in comparison to other materials. However, while demonstrating sensitivity to the presence of lead, measurements were complicated by the presence of practical (in-field) issues including:

- The testing leads being too large in diameter to fit into some of the access pipes of the curb stop, or
- A poor electrical connection due to the presence of corrosion or debris at the surface where the testing leads touched the water service line.

The above issues resulted in uncertainties in determining the estimated fraction of lead pipe in the service line and required excavation to gain access for a better connection to the pipe. Future work will be needed to improve or develop new tools to be used for field testing so that excavation to gain access for pipe connections will not be needed.

Benefits:

- Determination of the presence of lead in a water service line.
- No excavation needed (new test leads will need to be designed).
- No interruption of water service.
- Fast, simple, and low-cost verification

Keywords: service lines, service line inventory, service line detection, lead pipe, electrical resistance, low resistance ohmmeter, copper pipe.

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Acronyms and Abbreviations

AC	Alternating current
Cu	Copper
DLRO	Digital low resistance ohmmeter
Thermal EMF	Thermal electromotive force
LRO	Low resistance ohmmeter
Pb	Lead
POD	Probability of detection
PVC	Polyvinyl chloride
WRF	The Water Research Foundation

Executive Summary

ES.1 Key Findings

- Electrical resistance measurements from the lab and field confirmed that the presence of lead pipe can be discriminated from other materials.
- Additional field testing is needed to better understand potential interferences and overcome obstacles typically encountered in the field.
- The electrical resistance technique has the potential to quickly determine the presence of lead between any two points on a service line without excavation or service disruption.

ES.2 Background

This report presents the results of initial work done on the evaluation of determining the presence of lead in a service line using electrical resistance measurements of the water service line. A literature search found no available techniques to detect the presence of lead without visual examination of the service line. Commercially available low resistance ohmmeters (LRO) were used to measure the electrical resistance of the service line. Through laboratory measurements of copper and lead samples removed from the field, a ratio of 6-11 to 1 was calculated between the resistivity of copper and lead. This differed from the expected 12.5 to 1 theoretical ratio. This is probably due to oxidation and differences in composition of the sample measured versus theoretical value. This ratio is different enough to make the measurement of the electrical resistance a viable technique to detect the presence of lead in the line. Other laboratory measurements showed that while a copper-copper coupling does not affect the electrical resistance, a lead-copper coupling will increase it. This will further help to determine the presence of lead. Field measurements were made for the portion of the water service line between the curb stop and the water meter inside a building. Unique test leads were designed and fabricated for those measurements. While excavation to the curb stop was needed, the field measurements confirmed that lead can be detected with this technique. The new design test leads did not have any measurable effect on the determination of the resistances when compared to the commercial leads provided with the LRO. More work is still needed to improve the technique and achieve the goal of accurately detecting the presence of lead in a service line without excavation. While field measurements for this technique were made from the curb stop to the water meter inside a building, this technique can also be used on other parts of the water service line as long as the test leads can contact the pipe being tested.

ES.3 Related WRF Research

- Controlling Lead in Drinking Water (project 4409)
- Evaluation of Lead Sampling Strategies (project 4569)
- Full Lead Service Line Replacement Guidance (project 4713)
- Service Line Material Identification Techniques (project 4693)

CHAPTER 1

Introduction

The presence of lead pipes in water supply lines is an important health concern that has attracted national media attention in recent years. Detecting lead in service lines is critical as utilities refine their service line inventory. Identification of pipe materials without any excavation is of utmost importance for easier, faster identification and cost savings. The subject of this work is to evaluate one possible technique: detecting the presence of lead pipes in the water supply lines by the measurement of the electrical resistance of the pipe(s) as the resistivity of copper and lead are significantly different.
This report summarizes a literature search on techniques to detect buried lead pipe and equipment used to measure low resistance. The theory of the measurement approach is presented, along with experimental laboratory tests and results. Last, the report presents the results of field tests using this approach, a conclusion to discuss the interest of this technique, and future work needed to utilize this technique in the field.

CHAPTER 2

Literature Search

2.1 Technique to Detect Buried Lead Pipe

A literature search on the detection of lead pipe without excavation was performed. Only one reference (Dacres et al. 2006) was found which describes a technique enabling the material identification of a buried pipe without any contact. In this technique, the electrochemical pipe to soil potentials are measured at different locations. The soil and pipes are electrified through a groundbed. Measurements are made at the location of the sensing electrodes. The advantage of this technique is that it is contactless. The disadvantage of this technique is it appears to be only a local measurement of the pipe, and a function of the number and location of the sensing probes. For this technique to be performed, it is important to know the location of the pipe in the ground. There was no mention on the possible interference of nearby utilities or other pipes with this technique.

In 1995, WRF published a report on techniques to locate lead pipes (Deb et al. 1995). No demonstrated contactless techniques were identified at that time, only theoretical possibilities. A technique relying on Eddy currents was studied and a field test was conducted using it. This method relies on measuring the changes in the impedance of a test coil. The test coil is inserted in the water line. An AC current is applied to the test coil which creates a magnetic field. This magnetic field induces eddy current in the surrounding pipe. The eddy current will create a secondary magnetic field that changes the impedance of the test field. The material of the test water line was identified through this method. However, more work was needed to be able to go through sharp bends, turns, and valves. Also, the water service needed to be interrupted during measurement.

Other indirect techniques to identify lead pipe without excavation rely on examination of data from water services. Those techniques will combine data such as year in which lead was banned in this community, age of the house, building permits, etc. to establish neighborhood/houses with higher potential of presence of lead in the service lines. An indirect technique was used with success in Flint (Abernethy et al. 2018). The authors developed an algorithm to help with the location of lead pipe. This algorithm was improved regularly using data from excavation. A success rate of 98% was reached.

2.2 Low Resistance Measurements

For the work presented in this report, the goal is to take advantage of the significant difference of resistivity between copper and lead. The published resistivity of copper is 1.71×10^{-8} Ω.m while that of lead is 21.3×10^{-8} Ω.m, a ratio of 12.5 for lead to copper resistivity. This difference is large enough that measurement of the resistance of pipes will be affected even by the presence of a small amount of one of the metals. Resistance of pipes will be below 1Ω due to the low resistivities of metal pipes and limited water line lengths. Thus, a Low Resistance Ohmmeter will be needed.

The following paragraph provides an overview of the need for low resistance measurements in other industries, the important parameters affecting the measurement, and the features available on commercial apparatus to measure low resistance.

Low resistance ohmmeters are used in several industries and on a variety of components (Langan et al. 2004, Seaward Electronics Ltd. 2007). For those industries, an increase in the electrical resistance of a device will result in increased heating of the components which could lead to loss of energy, possible damage and loss of reliable electrical connection. Changes in the resistance can be due to temperature, chemical corrosion, vibration, loss of torque between mating surfaces, fatigue, etc. The difficulty of a low resistance measurement is the potential interference due to the resistance of the leads used to perform the measurements, the resistance of the contact between those leads and the part measured or thermal electromotive force (EMF) due to temperature variations across the part being measured.

The most accurate method to measure low electrical resistance is to use a four-wire ohmmeter. Two leads are used for current (C1 and C2) and two other leads for potential measurements (P1 and P2), as illustrated in Figure 2-1.

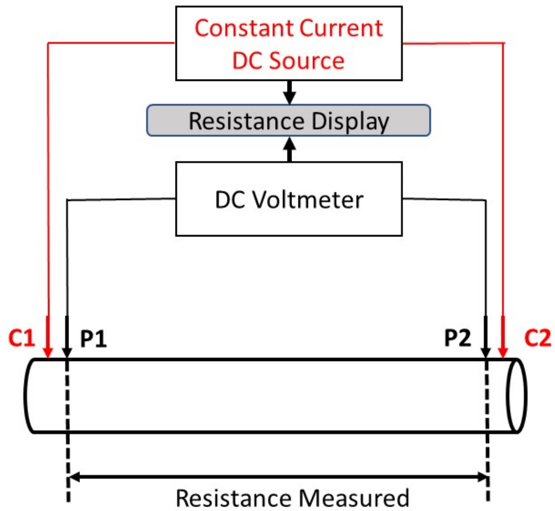

Figure 2-1. Basic Operation Diagram of a 4-wires Low Resistance Ohmmeter.

The advantage of the four-wire method is that no current flows into the potential leads and, the electrical resistance of those leads as well as their contacts are not measured. Current and potential measurement leads can be separated or incorporated in the same probe. If separated, the distance between probe C and P should be 1.5 times the cross-sectional perimeter of the material measured (ASTM International 2019). It is important that the potential lead is always placed on the inside compare to the current probe. Also, to eliminate errors created by thermal EMF, measurements are made in forward and reverse polarity. The two results obtained are averaged to determine the resistance of the material.

Some important parameters to consider when measuring low resistance are:

- Temperature: Resistivity is function of temperature
- Surface preparation: to have a good electrical contact between the test leads and the material being measured.
- Interference with strong electrical field.

Two different instruments were used in the course of this study:

1. The Megger DLRO 10HD was used during the laboratory testing (see Figure 2-2).
2. The Megger DLRO 10 was used during field testing and for some laboratory testing (see Figure 2-3).

Those two models are quite comparable in terms of performances. The DLRO 10 is more suited for field testing due to its relatively compact design and the automatic selection of the applied current by the instrument. The DLRO 10HD lacks the automatic current selection feature, the operator must select the current to be applied.

Figure 2-2. Picture of Megger DLRO 10HD, Low Resistance Ohmmeter.

Figure 2-3. Picture of Megger DLRO 10, Low Resistance Ohmmeter.

2.3 Measurement Approach

The electrical resistance of a water service line composed of lead and copper parts, will be determined by the formula below:

$$R = R_{Cu} + R_{Pb} + \sum_{n=0}^{x} R(\mathrm{Cu}-\mathrm{Pb}) = [\rho\frac{L}{S}]_{Cu} + [\rho\frac{L}{S}]_{Pb} + \sum_{n=0}^{x} R(\mathrm{Cu}-\mathrm{Pb}) \qquad \text{(Equation 2-1)}$$

where: R_{Cu} is the resistance of the copper portion of the water line [Ω],
R_{Pb} is the resistance of the lead portion of the water line [Ω],
R(Cu-Pb) is the resistance of the coupling between the copper and lead part of the water line [Ω],
x is the total number of Cu-Pb coupling,
ρ is the resistivity for each material [Ω.m],
L is the length of the pipe for each material [m],
S is the surface area of the metal for each material [m^2].

with $S = 0.25\pi(OD^2 - ID^2)$; OD: external diameter, ID: internal diameter for a pipe.

- Remark 1: The number of couplings will vary depending on the configuration of the water service line. The value of the resistance for each coupling might be different from one another.
- Remark 2: The value of electrical resistance of a coupling of copper-copper is not accounted for in

this formula.

- Remark 3: Conductivity (σ, S/m) is the inverse of resistivity: $\sigma = 1/\rho$.

Examples of calculated values for a water line with a mix of copper and lead pipes are presented below in Table 2-1. The resistance due to the coupling of two different pipes were not included in those calculations.

Table 2-1. Example of Calculated Values of the Electrical Resistance of Water Lines with Copper and Lead Pipes.

External Diameter (in)	Internal Diameter (in)	Length Copper Pipe (m)	Length Lead Pipe (m)	Resistance Water Line (mΩ)
Cu: 1.125 Pb: 1.49	Cu: 1 Pb: 1	100	0	12.7
		99	1	12.9
		50	50	23.6
		0	100	34.4
		10	0	1.27
		9	1	1.49
Cu: 0.87 Pb: 1.06	Cu: 0.71 Pb: 0.6	100	0	13.5
		99	1	13.9
		50	50	38.4
		0	100	55.0
		10	0	1.35
		9	1	1.77

As seen above, the theoretical value of the resistance of a water pipe will be changed even if only 1 meter of lead (3.28 feet) is present. The change in the resistance value is in the order of a 1/10 of a mΩ. This can be distinguishable with a low resistance Ohmmeter measurement.

Measurement of a section of water service line was completed first in a laboratory setting and then in the field.

CHAPTER 3

Laboratory Testing

The purpose of the laboratory testing was to determine if measuring the electrical resistance of pipes in the field can be used to determine the presence of lead. To reach this goal, the following questions will need to be answered:

1. What is the resistivity/conductivity of lead and copper pipe that were removed from the field?
2. Do pipe conditions such as holes, cracks, affect the results?
3. Is the pipe environment: water inside, dirt outside, affecting the results?
4. What is the contribution of pipe coupling (Cu-Pb and/or Cu-Cu) on the overall resistance of the water line?
5. What is the minimum length of a lead pipe that can be detected?

3.1 Description of Samples

Several samples removed from the field were received for evaluation. The samples were water supply service lines for residential dwellings. They are listed in Table 3-2.

Pictures of the samples listed in Table 3-2 are presented in Appendix A (Figure A-1 to Figure A-8). Four of those samples have couplings between the lead and copper pipes. Pictures of those couplings are presented in Figure A-9 to Figure A-13. Most of the lead pipe samples are damaged (see Figure A-14 to Figure A-18). Lead pipe from sample 16-0209-CP-2 have holes (Figure A-17 and Figure A-18).

Exterior (OD) and interior (ID) diameter of the pipes were measured (Table 3-2). OD and ID are data necessary to calculate the theoretical electrical resistance of the pipes. An overview of the OD and ID values of the pipes for each material is presented in Table 3-1.

Table 3-1. Overview of OD and ID Values for Pipe Materials Collected.

Material Types	Copper Pipe		Lead Pipe		Brass Pipe
OD (in)	0.88	0.63	1.07	1.07	1.06
ID (in)	0.78	0.52	0.86	0.55	0.81
Occurrence	7/8	1/8	3/5	2/5	1/1

Table 3-2. Description of Samples Removed from the Field.*

Sample names	Description	Connection	Copper pipe			Lead Pipe			Brass Pipe		
			Length (in)	OD (in)	ID (in)	Length (in)	OD (in)	ID (in)	Length (in)	OD (in)	ID (in)
16-0209-Cu-1	Cu pipe	None	11.5	0.88	0.79	–	–	–	–	–	–
16-0209-Pb-1	Pb pipe	None	–	–	–	12.5	1.06	0.82	–	–	–
16-0209-Pb-2	Pb pipe	None	–	–	–	215	1.09	0.86	–	–	–
16-0209-Brass-1	Brass pipe	None	–	–	–	–	–	–	15.625	1.06	0.81
16-0209-CP-1	Cu-Pb-Cu pipe	2	1 (side A) 3 (side B)	0.88	0.79	14.5	1.06	–	–	–	–
16-0209-CP-2	Cu-Pb pipe Several holes in the lead pipe	1	4.6	0.88	0.76	102	1.07	–	–	–	–
16-0209-CP-3	Cu-Cu (smaller diameter)-Pb pipe	2 (Cu-Cu & Cu-Pb)	0.75 4.25	0.88 0.63	0.79** 0.52	1.5	1.05	0.89**	–	–	–
16-0209-CP-4	Cu-Valve-Cu-Pb pipe with curb stop valve	1	3 10.25	0.89 0.88	0.80** –	52	1.07	0.58	–	–	–
16-0209-CP-5***	Cu-Pb pipe	1	33	0.89	0.65	69.75	1.07	0.51	–	–	–

*Dimensions are an average of at least 4 measurements.
**ID was obtained from measurements of the thickness of lead pipe as direct ID measurement were deemed but as accurate due to the deformation of the pipe.
***Sample was removed from location 6.

Dimension of pipes can be different from location to location. Common lead pipe dimensions are presented in Table 3-3. According to Equation 2-1, for the same pipe's length, the resistance of thicker-wider pipe will be lower than one that is thinner and narrower.

Table 3-3. Lead Pipe Dimensions.

I.D. (inch) and Lead Pipe Type	O.D. (inch)
½" Extra Strong	.876
½" Double Extra Strong	1.012
5/8" Strong	1.019
5/8" Extra Strong	1.082
5/8" Double Extra Strong	1.137
¾" Strong	1.156
¾" Extra Strong	1.212
¾" Double Extra Strong	1.336
1" Strong	1.428
1" Extra Strong	1.492
1" Double Extra Strong	1.596
1 ¼" Extra Strong	1.765
1 ½" Extra Strong	2.076
2" Extra Strong	2.751

3.2 Experimental Procedure for the Measurements of Pipe Resistance

The Low Resistance Ohmmeter (LRO) used for laboratory measurement was a Megger DLRO 10HD Digital Micro ohmmeter (Figure 2-2) or Megger DLRO 10 (Figure 2-3) for the samples 16-0209-CP-3, -4 -5 and Brass-1.

Before any electrical resistances were measured, two points on the pipe were chosen for where to apply the test leads. The distance between those two points was then measured.

Test leads (see Figure 3-1) were applied on the pipe with the position of probe C1 and C2 on the outsides while probes P1 and P2 were placed on the inside of C1 and C2, respectively (see Figure 2-1). A solid connection of both leads was made simultaneously to create a full circuit which resulted in the LRO providing a resistance measurement. The DLRO 10HD was first set on 10A, the most sensitive setting. If the resistance was undetectable because out of the range, the DLRO was then set to 1A for a lower current. The current applied for DLRO 10 was determined by the equipment and visually indicated by a red light next to its value (see Figure 2-3). Measurement was repeated three times for accuracy purposes.

Figure 3-1. Megger Duplex Probe with Current and Measurement Potential Leads (Commercial Lead).

Measurement of 16-0209-Cu-1 and 16-0209-Pb-1 were done with both the DLRO 10 and the DLRO 10HD; no difference in the result was observed for the copper, however the resistivity measured for the lead was higher with DLRO 10 than with DLRO 10HD (see Table 3-4).

Table 3-4. Resistivity Measurements with DLRO 10HD and DLRO 10 (Ω.m).

Instrument	DLRO 10HD	DLRO 10
16-0209-Cu-1	1.91 x 10^{-8}	1.88 x 10^{-8}
16-0209-Pb-1	15.2 x 10^{-8}	29.8 x 10^{-8}

The difference in values observed for lead pipe cannot be due to the equipment used, otherwise a difference would have also been observed for copper pipe. Changes of resistance of a material can have different origins: chemical corrosion, temperature changes, connection issues (between the measuring head and the material). The reason of the resistance change was not fully investigated as this was not the purpose of this work and it did not have any significant consequences on the conclusion of this work. The resistivity calculated, when DLRO 10HD was used, was always in the range of 15.2 x 10^{-8} Ω.m. The resistivity calculated when DLRO 10 was used, was always in the range of 29.8 x 10^{-8} Ω.m. Calculation made using the resistivity of lead considered which equipment, DRLO 10HD or DRLO 10, was used for the measurement.

3.3 Experimental Testing Results

3.3.1 Determination of the Resistivity of Pipes Removed from the Field

3.3.1.1 Resistivity Measurements

The resistivity of the samples from the field was measured. The results were first obtained in the as found condition of the sample. However, for some samples, the resistivity could not be measured without cleaning of the surface of the pipe in contact with the measuring lead. Other samples were also tested prior to and after cleaning the contact surface of the pipe to assess if there was a difference in the results obtained. Subsequently, the contact area between the measuring lead and those pipes was abrasively cleaned. The results are shown in Table 3-5 for copper, Table 3-6 for lead, and Table 3-7 for brass. Some samples (CP-1 to CP-5) have both copper and lead pipe. For those samples, results presented in Table 3-5 were obtained by measurement of the copper part of the sample and results presented in Table 3-6 were obtained by measurement of the lead part of the sample.

Table 3-5. Determination of the Resistivity of Copper from Samples Removed from the Field.

Sample Names	Length* [in]	Copper Pipe Resistivity [Ω·m]	
		As Found	After Abrasively Clean Contact Area
16-0209-Cu-1	11.5	1.9 x 10^{-8}	–
16-0209-Cu-2 (New Pipe)	16.0	2.6 x 10^{-8}	–
16-0209-CP-4	9.5	1.98 x 10^{-8}	
16-0209-CP-5	30.25	No measurement possible	3.2 x 10^{-8}
Average	–	**2.4 x 10^{-8}**	–
Standard Deviation	–	**0.6 x 10^{-8}**	–

*Length between the two probes (P1 and P2 from Figure 2-1)

The average conductivity for a copper pipe was found to be 41.3 x 10^{6} S/m, and the resistivity at 2.4 x 10^{-8} Ω.m. No results were obtained when trying to measure the resistance of the copper pipe section from sample 16-0209-CP-5 without cleaning. This pipe was dirty, and a good contact could not be established between the measuring head and the pipe. Good contact could not be established even after the pipe was washed with water and wiped. Abrasively cleaning the area where the measuring heads were placed into contact with the pipe solved this issue.

Table 3-6. Determination of the Resistivity of Lead from Samples Removed from the Field.

Sample Names	Length* [in]	Lead Pipe Resistivity (Ω.m)	
		As Found	After Abrasively Clean Contact Area
16-0209-Pb-1	12.5	15.2×10^{-8}	15.2×10^{-8}
*16-0209-Pb-1***	*9.625*	–	*29.8×10^{-8}*
16-0209-Pb-2	215	13.6×10^{-8}	13.3×10^{-8}
16-0209-CP-1	50.5	14.7×10^{-8}	15.9×10^{-8}
16-0209-CP-2***	106.6	14.7×10^{-8}	–
*16-0209-CP-4***	*49*	*26.8×10^{-8}*	–
*16-0209-CP-5***	*30*	*24.9×10^{-8}*	*24.8×10^{-8}*

*Length between the two probes (P1 and P2 from Figure 2-2)

**Measurements made with DLRO 10. All other measurements were made with DLRO 10HD.

***Sample 16-0209-CP-2 had several holes and cracks.

As discussed earlier, different resistivity and conductivity values were determined depending on which DLRO used. When using DLRO 10HD, the average resistivity calculated was 14.7×10^{-8} Ω.m and the conductivity of 6.8×10^{6} S/m. When DLRO 10 was used, the average resistivity calculated was 26.6×10^{-8} Ω.m and the conductivity of 3.8×10^{6} S/m.

Table 3-7. Determination of the Resistivity of Brass from Sample Removed from the Field.

Sample Name	Length* [in]	Brass Pipe Resistivity (Ω.m)	
		As found	After Abrasively Clean Contact Area
16-0209-Brass-1	14.625	8.56×10^{-8}	–

*Length between the two probes (P1 and P2 from Figure 2-2.

The resistivity of a sample of brass pipe was found to be 8.6×10^{-8} Ω.m (conductivity: 11.7×10^{6} S/m). This value is in between the resistivity values of both copper and lead pipe.

The data shows that the copper pipes have a higher experimental resistivity 2.4×10^{-8} Ω.m when compared to the theoretical values 1.71×10^{-8} Ω.m. The lead pipes experimental resistivity values were 14.8×10^{-8} Ω.m and
26.6×10^{-8} Ω.m when measured by DLRO 10HD and DLRO 10, respectively. The experimental resistivity values are at a similar level than the theoretical value of 21.2×10^{-8} Ω.m. For both values, the resistivity of lead is much higher than that of copper by a factor of nearly 6 to 11.

While no difference in the resistivity values were observed for samples whether the surface was cleaned abrasively for the lead pipe, the dirt and oxide layer prevented the measurement of the resistance of the copper pipe of sample 16-0209-CP-5. It is preferable to clean the surface where the measuring leads will be applied prior to testing in order to have a sound electrical contact.

3.3.1.2 Influence of Pipe Defects

As mentioned earlier, pipes removed from the field were not cleaned prior to any experiments. Dirt and oxidation could be found on the pipes. The sample needing the least surface preparation (cleanest) was 16-0209-Pb-1 while the sample needing the most surface preparation (dirtiest/with most defects) was 16-0209-CP-2. There was no significant difference in the conductivity values obtained between those two samples (Table 3-6). Also, sample 16-0209-CP-2 had several holes and cracks. The conductivity value obtained for 16-0209-CP-2 (Table 3-6) shows that there is no difference in value compared to the results obtained with the other lead pipes.

3.3.1.3 Influence of Pipe Environment

In the field, the pipe to be measured is buried in soil and filled with water. Measurement of the resistance of pipes filled with tap water was performed. The comparative conductivity measured for the empty and filled pipe are shown in Table 3-8. The results show that the presence of water in the pipes does not interfere with conductivity measurements.

Table 3-8. Experimental Testing Results of Samples with Water in Lead Pipe Section.

Sample Names	Resistivity (Ω.m) Without Water	Conductivity (Ω/m) With Water
16-0209-CP-1	16.1×10^{-8}	16.1×10^{-8}
16-0209-Pb-2	13.5×10^{-8}	13.5×10^{-8}

Tap water is a better conductor of electricity than soil. Presence of tap water in the pipe did not alter the resistance measurement. Soil being less conductive than water will have even a less effect on measurements.

Many homes have their grounding connected to the water lines. Experiments with and without grounding were performed on sample 16-0209-CP-4 (Figure A-8). The electrical resistance was measured from one side of the curb stop to the other side with and without the pipe extremity being connected to the laboratory electrical circuit ground. Results are presented in Table 3-9. Each result is an average of five measurements.

Table 3-9. Electrical Resistance Measured with and without Grounding.

Measurement Conditions	Electrical Resistance (μΩ)	Standard Deviation (μΩ)
No Grounding	579.3	2.0
With Grounding	579.5	0.6

Connection of the pipe to the ground or not did not change the value of the electric resistance measured.

One parameter that could not be studied in the laboratory setup was the presence of high electrical field in the proximity of the pipes tested.

3.3.2 Electrical Resistance of Coupling

Two coupling types were evaluated, a Cu-Cu coupling and a Cu-Pb coupling.

A Cu-Cu coupling, sample was prepared in the laboratory for investigation into the effects of a soldered coupling and if it contributes to electrical resistance. There was no measurable difference in resistance for the Cu-Cu coupling as compared to a straight piece of copper pipe of the same overall diameter and length. A Cu-Cu coupling does not contribute to the total measurable resistance of the water delivery system.

Several types of copper – lead couplings were measured. The images of those couplings are presented in Appendix A (Figure A-9 to Figure A-13). Some of the measurements of the electrical resistance included the coupling and sections of the copper and lead pipe. For those, the resistance of the coupling was determined by subtracting the resistance of the copper and lead pipes to the resistance measured (see Equation 2-1).

The results obtained for the different coupling Cu-Pb are presented in Table 3-10.

Table 3-10. Electrical Resistance of Cu-Pb Couplings.

Samples Ref.	Resistance coupling (μΩ)
16-0209-CP-1, Connection A	55
16-0209-CP-1, Connection B	Resistance too high, out of range
16-0209-CP-2	6.5
16-0209-CP-4	12,240
16-0209-CP-5	15.9

From the results obtained, we notice that:

- All the connections between copper and lead pipe contributed to an increase in electrical resistance.
- In a few instances, the electrical resistance of a Cu-Pb coupling is very high (16-0209-CP-1 connection B and 16-0209-CP-4). Those two couplings all have a similar type of connection (see Figure A-10 and Figure A-12).
- The lowest resistance value measured in connections was 6.5 μΩ for 16-0209-CP-2 and then 15.9 μΩ for 16-0209-CP-5. Those two connections have a similar design (see Figure A-11 and Figure A-13).

3.3.3 Electrical Resistance of Curb Stop Valve

In the field, the goal was to perform measurements by accessing the water service line through the curb stop access (see Figure 3-2). Through this access point, the test leads will be in contact with the curb stop and, the curb stop will contribute to the overall electrical resistance. The general formula of the electrical resistance of the water service line will then be:

$$R = R_{Cu} + R_{Pb} + \sum_{n=0}^{x} R(Cu - Pb) + R_{Curb\ Stop} \qquad \text{(Equation 3-2)}$$

Where: R_{Cu} is the resistance of the copper portion of the water line [Ω],
R_{Pb} is the resistance of the lead portion of the water line [Ω],
R(Cu-Pb) is the resistance of the coupling between the copper and lead part of the water line [Ω],
x is the total number of coupling Cu-Pb
$R_{Curb\ Stop}$ is the resistance of the curb stop valve

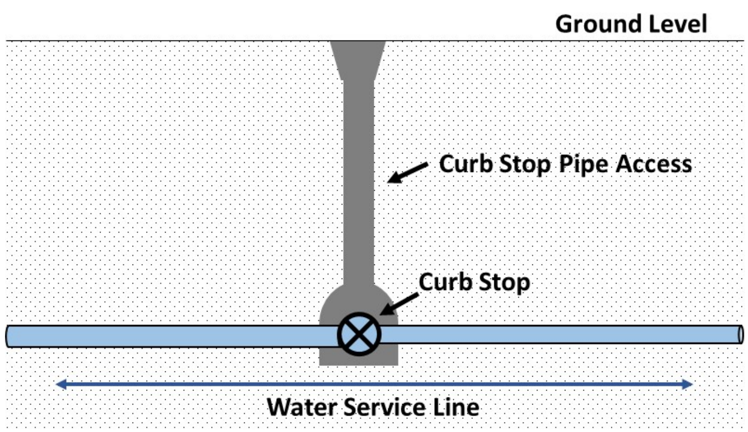

Figure 3-2. Schematic Representation of a Curb Stop Access.

Curb stops have different shapes and sizes while performing the same basic function (see Figure 3-3). The different shapes and dimensions affect the value of the electrical resistance of the curb stop as electric resistance is a function of the amount of matter. Electrical resistance measured for the different curb stops are presented in Table 3-11.

Figure 3-3. Picture of Different Curb Stops.
New curb stop (16-0209-V1) and curb stops removed from the field

Table 3-11. Electrical Resistance of Curb Stop Valves Removed from the Field.

Samples	Electrical Resistance*	Standard Deviation
16-0209-V2**	139 μΩ	62 μΩ
16-0209-V3***	235 μΩ	40 μΩ
16-0209-CP-4	258 μΩ	0.2 μΩ

*Measurements were made from the top of the knob to the pipe connected to valve, except for 16-0209-V3 where measurement was made from the side of knob instead of the top.
**16-0209-V2 was removed from location1.
***16-0209-V3 was removed from location 4.

Curb stops are made of several components (see Figure 3-4). A poor electrical connection between any of those components can increase the electrical resistance of the curb stop.

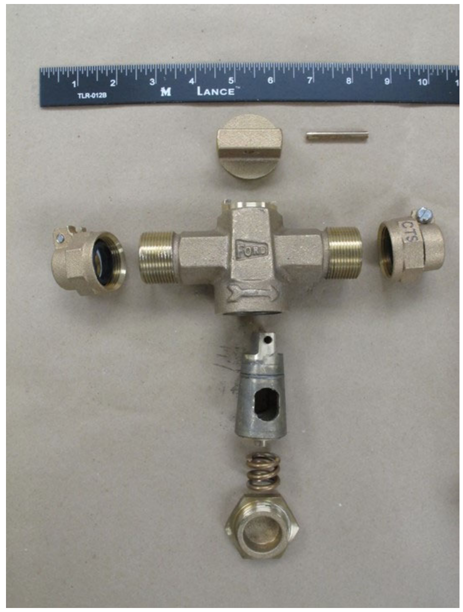

Figure 3-4. Curb Stop 16-0209-V1 Dismantled.

To obtain an electrical resistance measurement, electrical current needs to go through the curb stop and then to the water line. For curb stops in the field, dirt and rust can contribute to poor electrical contact and increase the measured resistance. Obtaining reproducible data from a curb stop connection can be challenging even for measurements made in the laboratory. Table 3-12 presents location dependent electrical resistance values obtained from curb stop sample 16-0209-CP-4. Location of those measurements are shown in Figure 3-5.

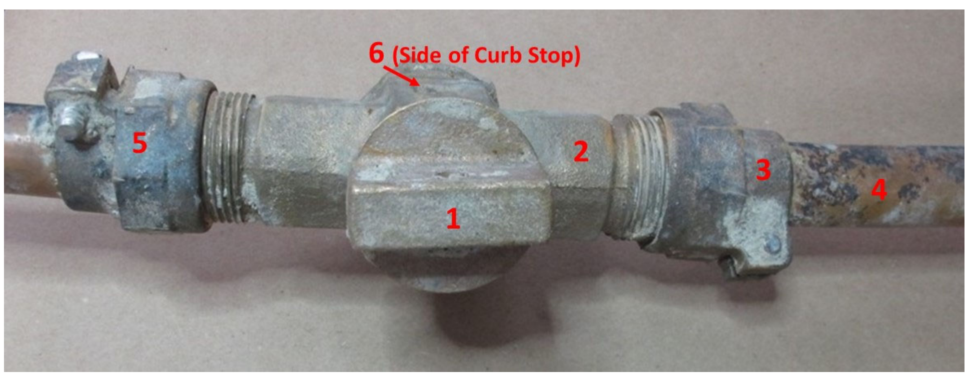

Figure 3-5. Curb Stop Valve from 16-0209-CP-4 with Location of Measurements for Table 3-12.

Table 3-12. Electrical Resistance of Curb Stop Valve 16-0209-CP-4 as a Function of the Measurement Location.

Measurement Location	Resistance (μΩ)	Standard Deviation (μΩ)
1 to 2	186	0.4
1 to 3	216	1.5
1 to 4	258	0.2
1 to 5	789	1.0
2 to 4	86	0.4
6 to 4	98	0.9

From the electrical measurements presented in Table 3-12:

- The electrical connection of the knob of the valve to its body is high: 186 μΩ compared to other values in the Table 3-12. This can be explained by the construction of the valve (Figure 3-4), the connection between the top of the knob and the body of valve goes through several junction points (pin, valve opening, spring, etc.).

- The electrical resistance is different when measured between 1-3 and 1-5 (see Figure 3-5). There is no reason for these two measurements to be so different, except for a poor electrical connection on 1 to 5 side of the valve.
- The lowest electrical resistance measurements were obtained when one of the test leads included the main body of the curb stop as one of the measurement points (2 to 4 and 6 to 4 - Figure 3-5). When measurement is made from the knob, junction points to electrically connect the knob to the body of the valve and/or pipe add to the overall resistance.

3.4 Conclusion of Laboratory Testing

In conclusion, the laboratory testing confirmed that the difference in the resistivity between lead and copper is high enough to distinguish a water line that contains lead and one with only copper. Based on the laboratory results, the research team developed an initial field tool to assist in the interpretation of field measurements. In a postulated field scenario, a resistance measurement would be performed between the house (at copper piping inside home or other accessible location) and the street curb stop. The resistance measurement performed between those two locations would need to be interpreted to determine the presence or the absence of lead. Figure 3-6 below, is a graph of the value of the resistance of a pipe with increasing amount of lead.

The calculation demonstrates that for such a length (15 feet) the presence of lead will always be detectable. This will be the case for a total pipe length up to 100 feet. This is a positive finding; this method seems sensitive enough to always detect lead.

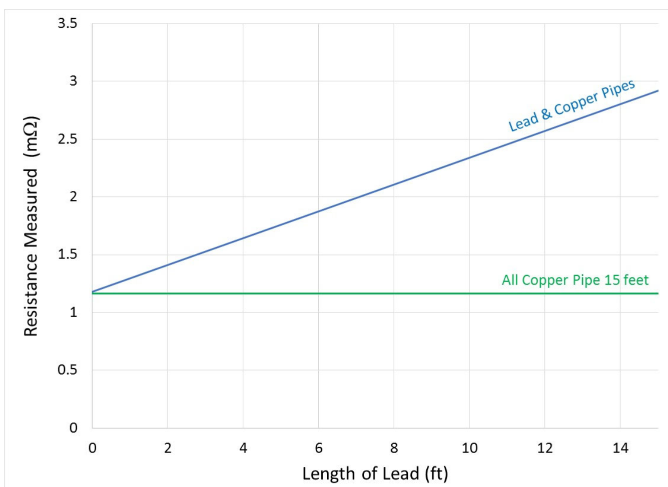

Figure 3-6. Detectability Limit Tool.
Example Assuming 15ft Length of Pipe.
Green: All copper pipe; Blue: Pipe with increasing amount of lead.

CHAPTER 4

Field Measurements

The goal of this project was to determine the presence or the absence of lead in the water service line without excavation. Field measurements were carried out at several locations in Boston, MA.

New and modified tools were necessary to perform the measurements. The design requirements and the tools used for the field measurement are presented below, as well as the results obtained during those field measurements.

4.1 Tools for Field Experiments

The purposes of these tools are to clean the curb stop, to achieve a sound electrical contact without excavation, and the ability to access the water meter inside the house utilizing existing doors, stairs or window openings.

A wire brush with an extension mounted on a drill was used to clean the dirt from the curb stops. The length of the test lead wires was extended in order to connect the LRO machine on both ends, curb stop and water meter inside the house.

New test leads were designed to access the curb stop without excavation. This part of the report will focus on the modifications made to the test leads.

4.1.1 Design Requirements for Test Leads

Measurements were performed from the curb stop to the pipe inside the house, just before the water meter. A schematic representation of the curb stop access was presented in Figure 3-2.

Requirements of the design of the test leads are:

- The dimension of the tube to access the curb stop valve can vary from 1 to 2 inches in diameter.
- The lead can access valves up to 8 feet in depth.
- The lead needs to have two contact points, one for the current and one to measure the electrical potential (see Figure 2-1).
- The wire and contact point for the current need to be safe with current up to 10A.
- Safe design with no risk of electrocution.

4.1.2 Test Lead Designs

The first design (see Figure 4-1) for a new test lead was inspired by the curb stop key. This lead design No. 1 is designed to make electrical contact with the curb stop at the top of the knob.

Figure 4-1. Experimental Lead Design No. 1.

The lead design No. 2 was made to have contact on the main body of the valve as contribution of the valve to the resistance measurements from this position are usually low. The disadvantage of the second design is that it is large and will not fit a 1-inch wide access tube. A picture of this second experimental head is presented in Figure 4-2.

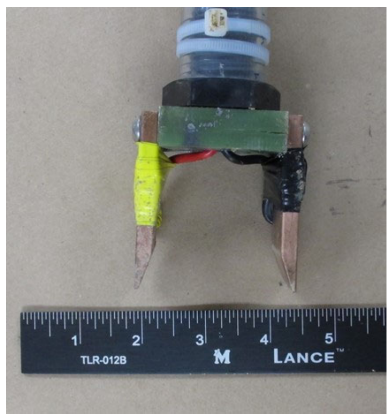

Figure 4-2. Experimental Lead Design No. 2.

Both test lead designs were mounted on a PVC tube long enough to reach the curb stop.

Laboratory experiments were conducted to assure that the use of those new test leads and the extension cords (of several tens of feet) used will not change the measurement of electrical resistance. Testing was done on sample 16-0209-CP-4 (Figure A-8). Results obtained are presented in Table 4-1.

Table 4-1. Electrical Resistance Measured with Commercial Lead and New Design Leads at the Curb Stop.

Sample	Lead	Resistance	Standard Deviation
16-0209-CP-4 (From top of knob's valve to pipe next to valve)	Commercial	249 μΩ	1.3 μΩ
	New Design 1	246 μΩ	6 μΩ
16-0209-CP-4 (From top of knob's valve to end of lead Pipe)	Commercial	2.5 mΩ	0.3 μΩ
	New Design 1	1.9 mΩ	0.05 μΩ
	New Design 2	1.7 mΩ	0.09 μΩ

The new design leads were used on the curb stop. The test lead used inside the house next to the water meter was always the commercial lead (Figure 3-1). Resistance measurements made with the different test lead designs are quite similar. More differences were observed for measurements made from the top of the knob to the end of the lead pipe. However, the electrical resistance values obtained with the two new design leads are similar and lower than the measurement made with the commercial lead. A cause of a higher resistance value can be due to a poor electrical contact during the measurement made with the commercial lead.

4.2 Field Test Measurements

Measurements were made in six different home locations. Figure 4-3 is a schematic representation of the setup to perform the electrical resistance measurement.

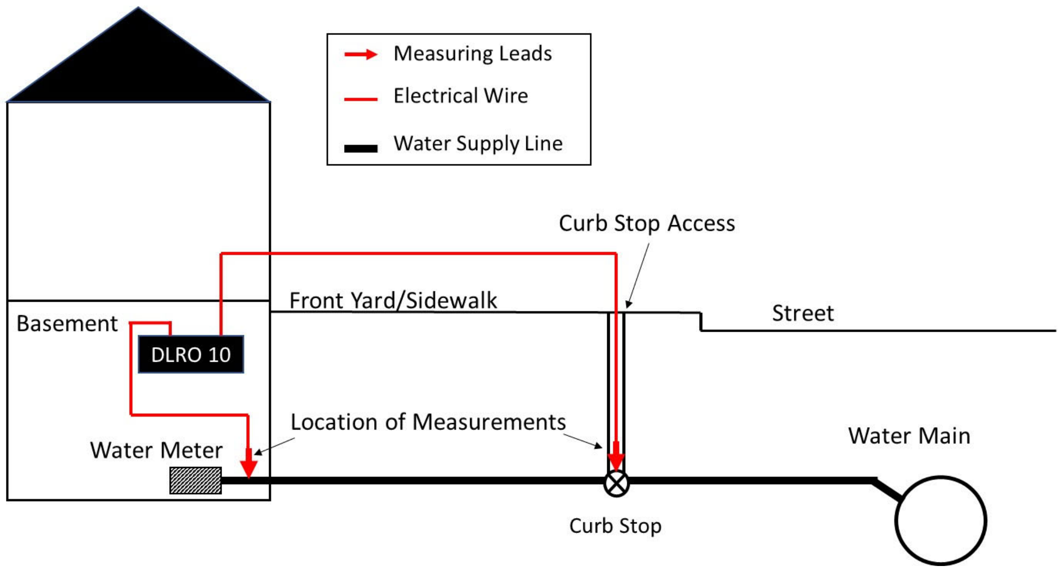

Figure 4-3. Schematic Representation of the Location of the Electrical Resistance Measurement.

The testing lead used inside the house was the lead provided with the machine, the commercial lead (see Figure 3-1). For the curb stop, the commercial lead as well as the two experimental leads were used as described in Table 4-2. It was not possible to use the new design lead in the first two experiments. Modifications of the design were made afterwards to better accommodate the changing geometry of curb stops. Results obtained during field testing are presented below in Table 4-2. When possible, the measurement was made on the existing water supply line and then on the replaced all copper water supply line. The results for copper service line are highlighted in orange in Table 4-2.

The following was observed from those measurements:

1. The resistance measurement results for copper and non-copper lines were significantly different.
2. For a service water line all in copper, there is a good agreement between the calculated value and the measured value (location 3 and 5) except for the last location 6.
3. There is no significant difference between a measurement made with a commercial lead (supplied with the DLRO) and the experimental leads (location 3, 4 and 5). Resistance measured with new design 2 for location 5 is expected to be different as the measurement is made on the body of the curb stop valve and not on top of the valve.
4. Standard deviation calculated from the measurement is low for most cases. High standard deviation is an indication of a poor electrical contact during the measurements.
5. Two measurements were relatively high (location 2 and 6) with the resistance and the standard deviation in the range of Ohms. Such a high dispersion is an indication of a poor electrical contact.

This would explain that the same measurement made for location 6 with the new design lead 1 was so different than the one made with the commercial lead (158 mΩ compared to 8.4 Ω). The top of the knob of the curb stop valve in location 6 was not a very smooth surface (see Figure 4-4), that would help to explain the difficulty in achieving a good contact for the commercial lead. The leads designed for this project were made to accommodate for such occurrence.

Figure 4-4. Curb Stop Valve at Location 6.

Table 4-2. Field Testing Results.

Field Test Location	Testing Lead on Curb Stop	Position of Testing Lead on Curb Stop	Testing Lead next to Water Meter	Pipe Length	Calculated Resistance if Line is all Copper	Resistance Measured	Number of Measurements	Standard Deviation for Field Measurement	Pipe Material Composition
1	Commercial	Pipe	Commercial	13 feet	0.63 mΩ	2.02 mΩ	1	NA	Lead and Brass
2	Commercial	Pipe	Commercial	30 feet	1.4 mΩ	28.5 Ω	7	10 Ω	Lead present
3	Commercial	Nut of Curb Stop	Commercial	7 feet	0.34 mΩ	71.4 mΩ	5	0.8 mΩ	Copper/Lead
3	Commercial	Pipe	Commercial	7 feet	0.34 mΩ	70.7 mΩ	5	1.5 mΩ	
3	New Design No. 2	Pipe	Commercial	7 feet	0.34 mΩ	69.3 mΩ	5	0.9 mΩ	
3	Commercial	Nut of Curb Stop	Commercial	5 feet*	0.24 mΩ	0.26 mΩ	5	0.0001 mΩ	Copper
3	Commercial	Pipe	Commercial	5 feet*	0.24 mΩ	0.225 mΩ	5	0.001 mΩ	Copper
4	Commercial	Pipe	Commercial	27 feet	1.30 mΩ	8.2 mΩ	2	0.02 mΩ	Lead present
4	New Design No. 2	Pipe	Commercial	27 feet	1.30 mΩ	8.2 mΩ	4	0.04 mΩ	
5	Commercial	Top of Valve	Commercial	8 feet	0.385 mΩ	9.51 mΩ	5	0.006 mΩ	Lead present
5	New Design No. 1	Top of Valve	Commercial	8 feet	0.385 mΩ	10.85 mΩ	5	1.2 mΩ	
5	New Design No. 2	Body of Valve	Commercial	8 feet	0.385 mΩ	5.36 mΩ	5	0.008 mΩ	
5	Commercial	Top of Valve	Commercial	8 feet	0.385 mΩ	0.59 mΩ	5	0.002 mΩ	Copper
6	Commercial	Top of Valve	Commercial	11 feet	0.530 mΩ	8.37 Ω	5	5 Ω	Copper/Lead
6	New Design No. 1	Top of Valve	Commercial	11 feet	0.530 mΩ	157.8 mΩ	5	0.003 mΩ	
6	New Design No. 1	Top of Valve	Commercial	11 feet	0.530 mΩ	129.3 mΩ	5	0.6 mΩ	Copper

*At the homeowner request, the water meter was moved closer to the outside wall resulting in a shorter pipe length.

Issues encountered in the field were:

1. No measurements were made without excavation to access the curb stop:
   a. Despite some progress, cleaning of the valve was not efficient enough to assure a good electrical contact.
   b. Experimental test leads No. 1 and No. 2 were too large in diameter to fit in the curb stop access point.
2. Even after gaining access to the curb stop by excavation, measurements were difficult.
   a. It was often difficult to have a good electrical connection on the curb stop. Progresses were made with better cleaning of the curb stop and modification of the new design leads to have better contact on uneven surface. Measurements after those modifications became easier and more reproducible.
   b. Due to its dimension, it was not possible to perform some measurements with experimental test lead design No. 2. The large dimension prohibited it from entering most of the access pipes. In one instance, the contact plates were not long enough to reach the body of the valve.

The field measurements showed that the method can detect an all copper service line versus a service line with lead. Higher resistance was measured when lead is present (see Table 4-3).

Table 4-3. Comparison of Measured Electrical Resistance of Service Lines with Lead and Service Lines with Only Copper.

Location	Service Line Length	Resistance with Lead Pipe in the Service Line	Resistance for All Copper Service Line	Difference in Resistance
3	7 feet	70.5 mΩ*	–	–
3	5 feet	–	0.24 mΩ*	–
5	8 feet	10.2 mΩ*	0.59 mΩ	9.61 mΩ
6	11 feet	158 mΩ	129 mΩ	29 mΩ

*Resistances are an average of values obtained with different testing leads.

The value measured for a service line with only copper was close to the calculated value except for location 6. As outlined in Chapter 3, other components of the service line will contribute to the electrical resistance measurement: connection between Cu-Pb, curb stop, presence of pipe material different from copper or lead. The electrical resistance of the connection Cu-Pb (Figure A-13) for location 6 is not a big contributor to the total electrical resistance (R= 15.9 μΩ, see Table 3-10). The curb stop is the reason the value of the electrical resistance is so high for location 6 compared to other locations. Improvement of the new lead design is one way to help reduce the contribution of the curb stop towards the overall electrical resistance measured.

CHAPTER 5

Conclusion and Future Work

5.1 Conclusion

The goal of this work was to evaluate the possibility of detecting the presence of lead pipe in the water service line by measuring the electrical resistance of the service line. Using a Digital Micro-ohmmeter (DLRO), measurements in the laboratory were made on pipes containing a mixture of copper and lead previously removed from the field. The measurements demonstrated that this technique is sensitive enough to distinguish between a lead and a copper pipe.

New tools were designed in order to perform field testing. The results from field testing demonstrated that experimental test leads and wire extensions did not change the value of the resistance measured. Field measurements confirmed that the presence of lead pipe can be determined in comparison to other materials. However, while demonstrating sensitivity to the presence of lead, measurements were complicated by the presence of practical (in-field) issues. These issues prevented testing without excavation:

1. The testing leads being too large in diameter to fit into some of the access pipes of the curb stop or,
2. A poor electrical connection due to the presence of corrosion or debris at the surface where the testing leads touched the water service line.

As highlighted in this report, several contributors, besides lead or copper pipe, can add to the electrical resistance and interfere with the result. Some of the contributing factors are:

- The curb stop
- Coupling of pipes: Cu-Cu, Cu-Pb or others.
- Pipe dimensions
- Pipe material besides copper and lead such as brass, galvanized iron, or even plastic
- Ground loops
- Environmental factors such as soil or structure interactions

Knowledge acquired from field testing will help improve the tools and the procedure so that no excavation will be needed in the future. Field tests presented in this report were made from the curb stop to the pipe inside the house, just before the water meter. This technique is not limited to this configuration and can be used for other parts of the water service line. To measure the electrical resistance, it is necessary to have contact of the test leads onto the water service line section of interest. Some adaptation of the tools and the method presented might be needed to determine the presence of lead in other parts of the water service line.

5.2 Future Work

Future areas of work are:

1. Improve or redesign the test leads at the curb stop.
2. Improve cleaning processes at the curb stop for better electrical contact.
3. Continue field testing.

Improvements 1 and 2 above are needed to be able to measure the electrical resistance without any excavation. The third task is necessary to validate that the changes made for cleaning and measuring the electrical resistance will permit to test the water service line with no excavation. Also, the third task will increase our knowledge of the difficulties and unknowns present in the field. The main goal of this study was to determine the presence or absence of lead in the service line and possibly estimate the length of the lead pipe. This task is complicated by the presence of other contributors to the electrical resistance such as the curb stop, pipe coupling, pipe dimensions, pipe materials other than copper and lead. Environmental factors such as the nature of the soil or structure interactions are not fully understood yet.

To help mitigate such factors, a simulation-based probability of detection (POD) software will be used. The purpose of the simulation-based POD algorithm is to determine the probability that the result obtained is valid. POD software is commonly used in non-destructive testing. Parameters important for the simulation (listed above) will be input into the POD. Other parameters can be added as needed. Data collected from laboratory and field testing (present and future) will be used to improve the simulation. With such a software, the measurement of the electrical resistance of the water line will be able to determine the presence of lead, the length of the lead pipe and the probability of those results to be true.

APPENDIX A

Pictures of Samples Removed from the Field and Measured in the Laboratory

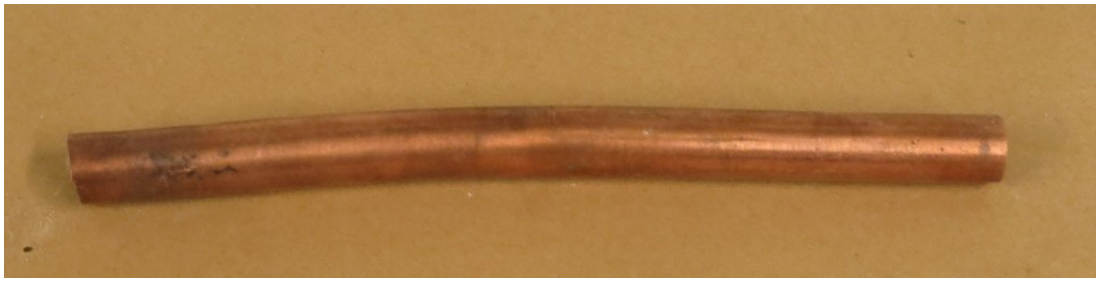

Figure A-1. Sample 16-0209-Cu-1, Copper Pipe.

Figure A-2. Sample 16-0209-Pb-1, Lead Pipe.

Figure A-3. Sample 16-0209-Pb-2, Lead Pipe.

Figure A-4. Sample 16-0209-Brass-1, Brass Pipe.

Figure A-5. Sample 16-0209-CP-1, Lead Pipe with Two Couplings Cu-Pb.

Figure A-6. Sample 16-0209-CP-2, Lead Pipe with One Coupling Cu-Pb.

Figure A-7. Sample 16-0209-CP-3, Sample with Two Types of Copper Pipe and a Lead Pipe.


Figure A-8. Sample 16-0209-CP-4, Copper and Lead Pipe with Curb Stop Valve.


Figure A-9. Coupling between Lead and Copper Pipes – Sample 16-0209-CP-1 Side A.

Figure A-10. Coupling between Lead and Copper Pipes – Sample 16-0209-CP-1 Side B.

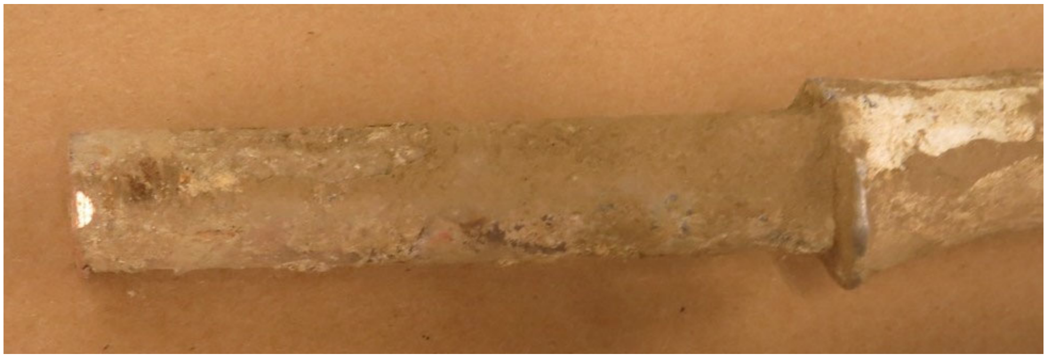

Figure A-11. Coupling between Lead and Copper Pipe – Sample 16-0209-CP-2 Side A.

Figure A-12. Coupling between Lead and Copper Pipe – Sample 16-0209-CP-4.

Figure A-13. Coupling between Lead and Copper Pipe – Sample 16-0209-CP-5.

Figure A-14. Damages on the Surface of a Lead Pipe from Sample 16-0209-Pb-1.

Figure A-15. Damages on the Surface of the Lead Pipe from Sample 16-0209-CP-1.

Figure A-16. Damages on the Surface of the Lead Pipe from Sample 16-0209-CP-2.

Figure A-17. Damages on the Lead Pipe from Sample 16-0209-CP-2.

Figure A-18. Hole in the Lead Pipe from Sample 16-0209-CP-2.

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