The Use of Electrical Resistance Testing to Accurately Locate Buried Lead Water Service Lines and Other Pipe Materials Commonly Found in Drinking Water Pipes

Chuck Hansen[1], Mike App [2], Paul Pasko, P.E.[3], Bansari Doshi[4], and Matt Campos[5]

[1] Chairman & CEO, Hansen Analytics LLC and Electro Scan Inc., Sacramento, California, USA, chuck.hansen@hansen.com
[2] Executive Vice President, Operations, Electro Scan Inc., Syracuse, New York, USA, mike@electroscan.com
[3] Vice President, International Business Development, Electro Scan Inc., Minnetonka, MN, USA, paul@electroscan.com
[4] Manager, AI, Cloud, and Data Architecture, Electro Scan Inc. bansari@electroscan.com
[5] Vice President, Pressurized Pipe, Electro Scan Inc., Fair Oaks, California, USA, matt@electroscan.com

Abstract

In 1991, the U.S. Environmental Protection Agency (US EPA) published the 'Lead and Copper Rule' (LCR) regulation to address the widespread use of lead pipes for potable water delivery and service lines. Lead, which poses serious health risks to both children and adults, is sometimes found in drinking water, primarily due to it leaching from lead plumbing in homes, or from lead service lines connecting homes to the water distribution system. Because plumbing and a portion of service lines are privately-owned, and service lines connecting to water mains are utility-owned, Federal drinking water rules intended to reduce lead in drinking water have been complex, confusing, and controversial.

In June 2021, the US EPA published a decision to delay compliance dates of the National Primary Drinking Water Regulations: Lead and Copper Rule Revisions (LCRR). The delay allowed time to review the rule in accordance with Presidential directives. Given lead pipe's significant and continued risk to public health, President Biden signed the Bipartisan Infrastructure Law (BIL) in November 2021 authorizing up to $1.2 trillion to support various federal public programs, including $15 billion for the removal of all buried lead service lines (LSL) that convey potable water. Setting a deadline to inventory service line pipe materials of October 16, 2024, the LCCR states that every service line in the U.S., whether utility or privately-owned, must be inventoried & mapped, and made available online to the general public.

Furthermore, all service lines of unknown material must be assumed lead unless specifically proven otherwise. This has a significant potential to impact the real estate industry and the 50,765 Community Water Systems (CWS) affected by the rule.

This paper discusses how electrical resistance testing can be used to assess drinking water pipes without digging. Using a machine-intelligent technology for assessing pressurized and unpressurized water pipes, electrical resistance technology has emerged as the only known method for identifying one or more pipe materials, including copper, galvanized metal, lead, and plastic pipe, without excavating and removing topsoil. Identified specifically by the US EPA as an emerging technology to locate lead pipes, electrical resistance testing allows a probe to enter, transit, and exit a water pipe with minimal pipe disturbance or customer disruption. This paper also covers the continued risk of lead exposure – including in large diameter asbestos cement pipes with lead soldered joints - and the potential impact of the LCCR on future real estate transactions, which requires sellers to disclose the existence of lead service lines starting after the EPA October 2024 deadline.. While lead service lines are under the spotlight, a continued risk of lead remains in larger diameter asbestos cement pipes and in soldered lead joints that made pipes watertight.

1.0 INTRODUCTION

In 1991, the US EPA published the 'Lead and Copper Rule' (LCR) regulation to address the widespread legacy use of lead pipes for potable water delivery and service lines. While well-intended, the regulation received immediate push-back from municipal and publicly-owned water utilities that cited compliance with the regulation was too difficult to implement in the LCR's timeframe and owner utility responsibilities were ill-defined.

As a result, in 1993 the American Water Works Association (AWWA) sued the EPA and a Federal Appeals Court partially sided with the AWWA.

In 2000, the LCR was amended to allow for water utilities to perform partial replacements of water delivery lines. This made the problem worse as it allowed for water utilities to replace water main lines, but leave the lead service lines intact, passing the responsibility to the landowner to complete the replacement. As a result, many homeowners were left unsure of whether their service lines were made of lead or included lead components.

As seen in cities like Flint, Michigan, nearly all urban areas have used and continue to use lead service lines and distribution main lines, despite the banned use of lead in 1986. This problem is particularly worse in older and larger cities including Washington DC, Boston and Philadelphia due to poor recordkeeping of original pipe installations, especially on private properties which have traditionally not been the responsibility of drinking water providers.

In June 2021, the US EPA published a decision to delay compliance dates of the National Primary Drinking Water Regulations: Lead and Copper Rule Revisions (LCRR),[1] originally published in January 2021, to allow time to review the rule in accordance with Presidential directives. Finally, in November 2021, President Biden signed the Bipartisan Infrastructure Law (BIL) that authorizes up to $1.2 trillion to support federal public programs, including $15 billion for the removal of all buried lead service lines (LSL) conveying potable water. While the BIL has led to nearly 35,000 projects across

Figure 1. Lead Pipe at Curbstop.

Source: Philadelphia Water.

Table 1. U.S. Community Water Systems Required to Inventory Lead Pipes.

Community Water System Size By Number of Service Connections	Number of Agencies	Population Served In Millions	Percent of Total Popultation
Very Small (25-500)	27,937	4.6	1.4%
Small (501-3,300)	13,906	19.2	6.1%
Medium (3,301-10,000)	4,822	29.5	9.4%
Large (10,001-100,000)	3,702	114.5	36.4%
Very Large (>100,000)	398	147.0	46.7%
Total	50,765	314.9	100%

Source: U.S. EPA

4,500 communities totaling $220 billion in planned spending,[2] the pace of dispersed funding from the State Revolving Fund (SRF) to its recipients – the 50,765 U.S. water systems subject to the LCRR (Table 1) – has been slow.

Considering the history of legislation and continued health risks of lead drinking water pipes, there exists a current need to rapidly and cost effectively identify the service line pipe materials supplying water to homeowners and residents in urban areas; especially in disadvantaged neighborhoods. While visual inspection from excavated pipes (Figure 2) and water sampling are the most common ways to conduct line material testing, industry experts acknowledge that visual inspection continues to be time consuming, inaccurate, and incomplete, while water testing at individual taps is costly, unreliable, and unable to identify specific locations of lead pipes.

Figure 2. Visual Inspection of Exposed Pipe to Test for Lead Pipe.

Source: Hansen Analytics LLC, 2023

2.0 FLINT, MICHIGAN

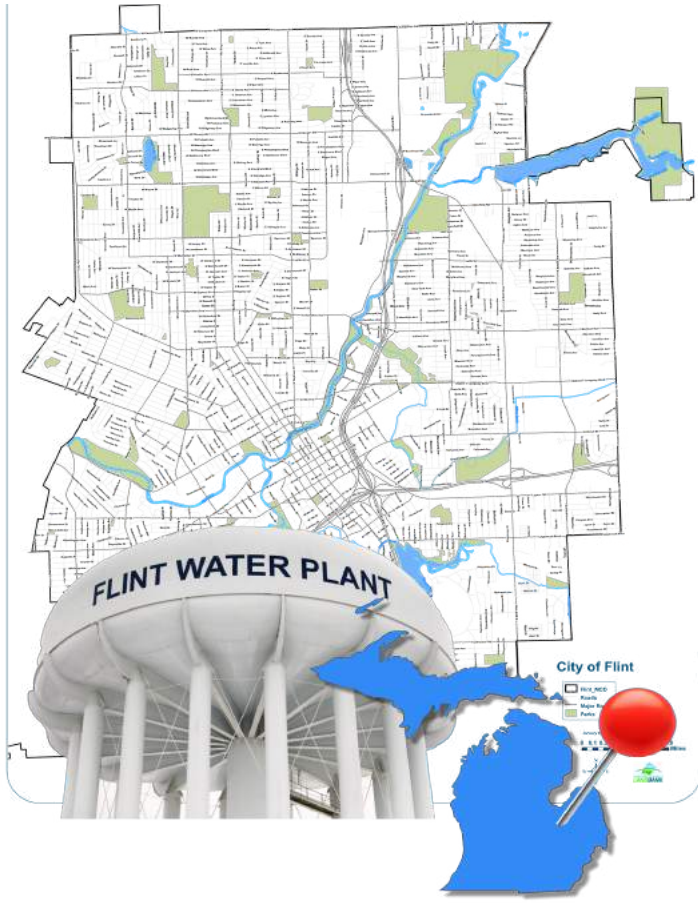
A review of past and present conditions at the City of Flint, Michigan, Figure 3, including missteps and mismanagement once the risk of lead was well-established, provides important lessons to other water utilities in the inventory and replacement of lead pipes.

Flint's troubles began in 2011 when the state of Michigan took over Flint's finances.[3] Flint was looking at a $25 million deficit, in part because General Motors scaled back its Flint-based factory a few years prior. One of the cost cutting measures the city made was to switch its water source from the Detroit Water and Sewerage Department to the Karegnondi Water Authority.

Officials estimated that the city would save close to $200 million over the next 25 years after making the switch and this decision is where the trouble started.

After deciding to make the change, Flint received a notice from the Detroit Water and Sewage Department that their water supply would be shutoff before they completed construction of a pipeline to the Karegnondi Water Authority. Flint needed a temporary water

Figure 3. City of Flint, Michigan.



supply and decided to rely on the Flint River.

Shortly after switching to the Flint River, the city started to receive reports from the public about their tap water smell, taste, and overall look, including other issues mentioned in Figure 4.

By 2015, the situation with Flint's water transition became tumultuous. At the start of the year, Flint announced that it did

Figure 4. Health Effects Associated with Exposure to Lead Through Water Main & Service Pipes

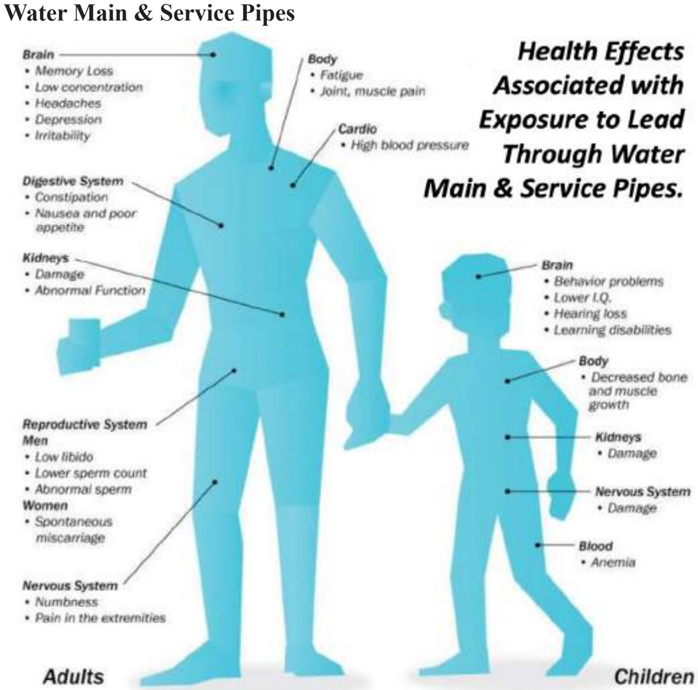
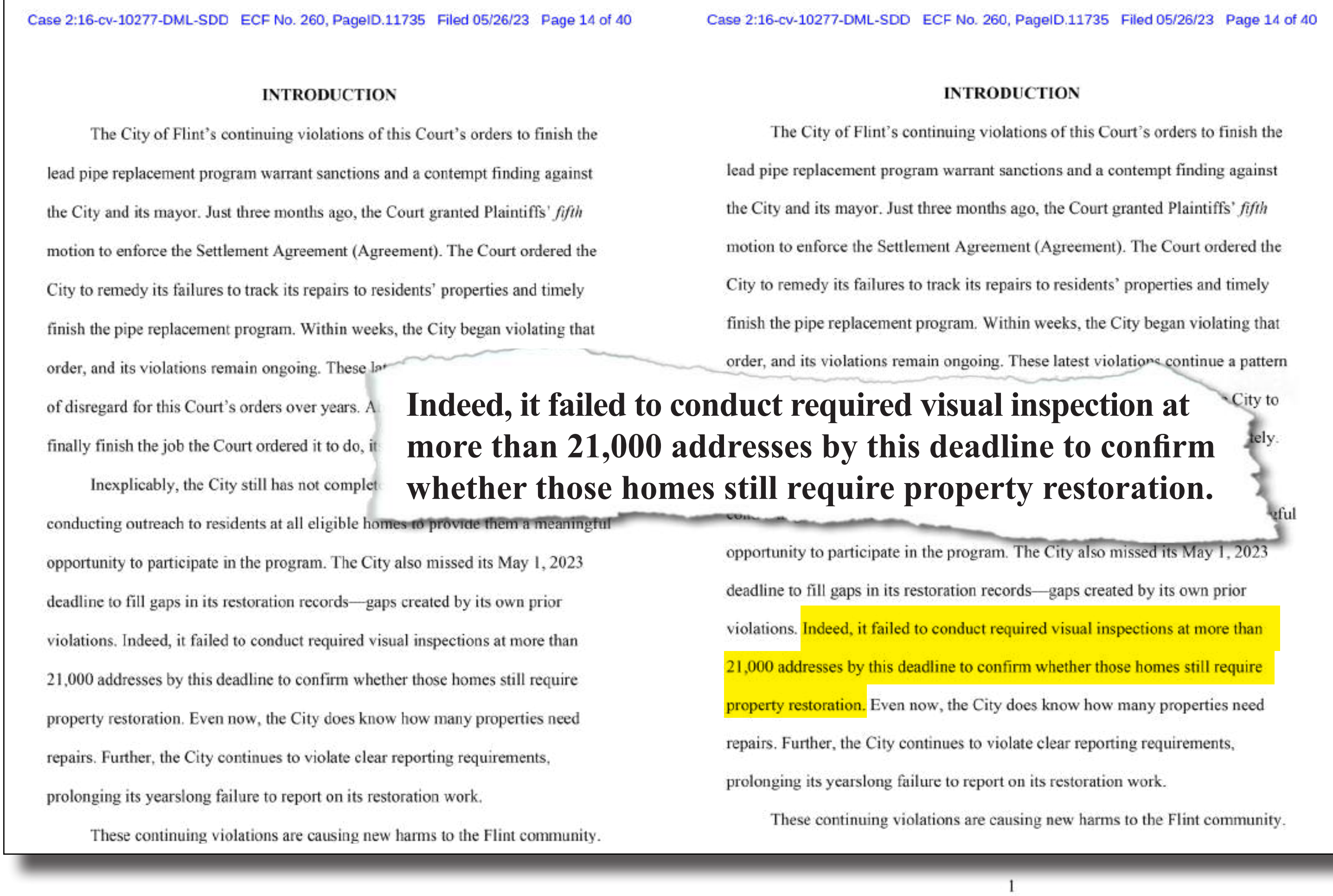


Figure 5. Plantiffs' Motion for Contempt Against the City of Flint, Michigan, Filed May 26, 2023.



Case 2:16-cv-10277-DML-SDD ECF No. 260, PageID.11735 Filed 05/26/23 Page 14 of 40

INTRODUCTION

The City of Flint's continuing violations of this Court's orders to finish the lead pipe replacement program warrant sanctions and a contempt finding against the City and its mayor. Just three months ago, the Court granted Plaintiffs' *fifth* motion to enforce the Settlement Agreement (Agreement). The Court ordered the City to remedy its failures to track its repairs to residents' properties and timely finish the pipe replacement program. Within weeks, the City began violating that order, and its violations remain ongoing. These latest violations continue a pattern of disregard for this Court's orders over years. A... City to finally finish the job the Court ordered it to do, it... ...ely.

Inexplicably, the City still has not complet... conducting outreach to residents at all eligible homes to provide them a meaningful opportunity to participate in the program. The City also missed its May 1, 2023 deadline to fill gaps in its restoration records—gaps created by its own prior violations. Indeed, it failed to conduct required visual inspections at more than 21,000 addresses by this deadline to confirm whether those homes still require property restoration. Even now, the City does know how many properties need repairs. Further, the City continues to violate clear reporting requirements, prolonging its yearslong failure to report on its restoration work.

These continuing violations are causing new harms to the Flint community.

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Indeed, it failed to conduct required visual inspection at more than 21,000 addresses by this deadline to confirm whether those homes still require property restoration.

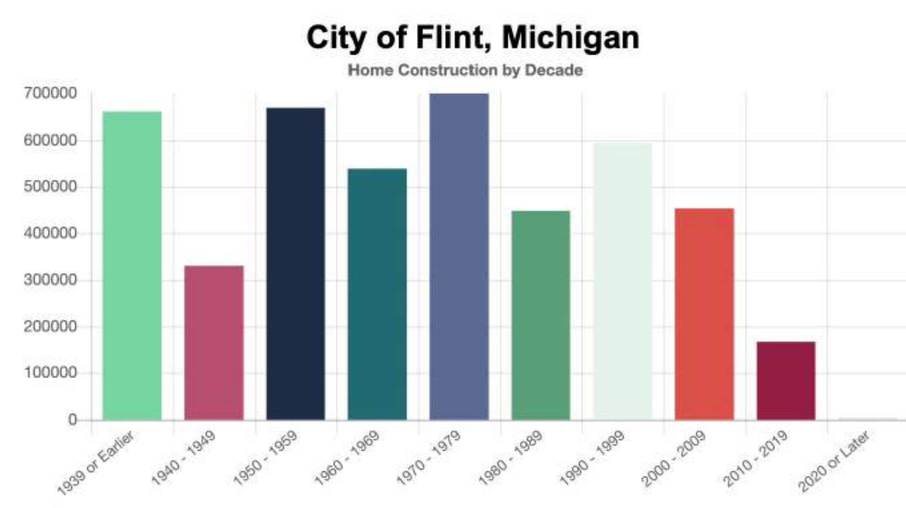
not meet treatment requirements and their water contained high levels of trihalomethanes (TTHM), a disinfection by-product that was found to be carcinogenic after a long period of exposure. These by-products are often produced after chlorine, a water disinfectant, interacts with certain particles in water.

Then, in February 2015, the US EPA reported that they found high levels of lead in a resident's water sample. In the months following this revelation, more tests from the US EPA showed high levels of lead, but Flint officials told residents that "there was nothing to worry about." Finally, in September, Virginia Tech researchers visited Flint and tested hundreds of homes finding incredibly high levels of lead in public drinking water. In October, Flint reverted back to using Detroit's Lake Huron water supply, but even with properly treated source water, lead was still coming out of water taps inside homes. The damage was done.

And, many high lead readings inside homes are occuring where no lead service lines exist.

Despite a fairly average housing age profile as shown in Table 2, major national publicity, intervention from the Federal Government spanning three different presidential administrations, millions spent by State and Federal governments, and innovative

Table 2. City of Flint, Michigan, Housing Age By Decade



Total Population 83,312

Housing Units	43,259
Median Year Built	1954
Built in 1939 or Earlier	10,342
Built between 1940 and 1949	5,382
Built between 1950 and 1959	13,620
Built between 1960 and 1969	7,060
Built between 1970 and 1979	3,794
Built between 1980 and 1989	1,309
Built between 1990 and 1999	985
Built between 2000 and 2009	642
Built between 2010 and 2019	125

venture-based technology claiming to locate lead pipes with nearly 90% accuracy, another lawsuit[4] was filed on May 26, 2023 (Figure 4), by the American Civil Liberties Union of Michigan and National Resources Defense Council (NRDC) accusing the City of Flint of the following:

- Failure of conducting required inspections of more than 21,000 addresses (later increased to 26,000).
- Not knowing which properties still needed repair and replacement.
- Failure to make timely repairs of streets, sidewalks, and private property landscaping,
- Failure to conduct proper community outreach.
- Repeatedly missed court-ordered deadlines.

The motion also stated that only 5,000 of the planned 26,000 planned inspections had been completed, out of the total 31,578 properties.

3.0 THE WATER RESEARCH FOUNDATION

The Water Research Foundation (WRF) is the water industry's leading research organization that advances the science of water to meet the needs of the public. A 501(c)(3) nonprofit, WRF is an educational organization that funds, manages, and publishes research on the technology, operation, and management of drinking water, wastewater, reuse, and stormwater systems — all in pursuit of ensuring water quality and improving water services to the public.

Formed in 2018, WRF resulted from the merger of three research collaboratives, including (1) WateReuse Research Foundation, (2) Water Environment Research Foundation, and (3) Water Research Foundation. Separately, these organizations focused on research to support varied segments of the water sector—water reuse, wastewater and stormwater, and drinking water, respectively. Now a One Water organization, WRF delivers the research and innovation programming the sector needs to address the most pressing water issues holistically.

3.1 WRF Lead and Copper Research

Lead and copper in service lines and household plumbing have been a major research area of WRF. Representing the primary drinking water corrosion compounds of concern, WRF acknowledges that lead is a toxic metal that is harmful to human health even at low exposure levels.

With persistent exposure, lead can accumulate in the body over time, affecting young children. In particular because of the physical and behavioral effects of lead. As a result, a dose of lead that would have little effect on an adult can have a significant effect on a child.

Separately it has been found that people who drink water containing copper in excess of 1.3 mg/L may experience short-term nausea with long-term exposure affecting the liver and kidneys.

Lead is rarely found in source water and usually enters drinking water through corrosion of water main lines and service lines, lead soldered joints and lead pipes in household plumbing. Lead at the tap can come from a variety of sources, including lead service lines, lead piping inside the home, lead-based soldered joints and brass components.

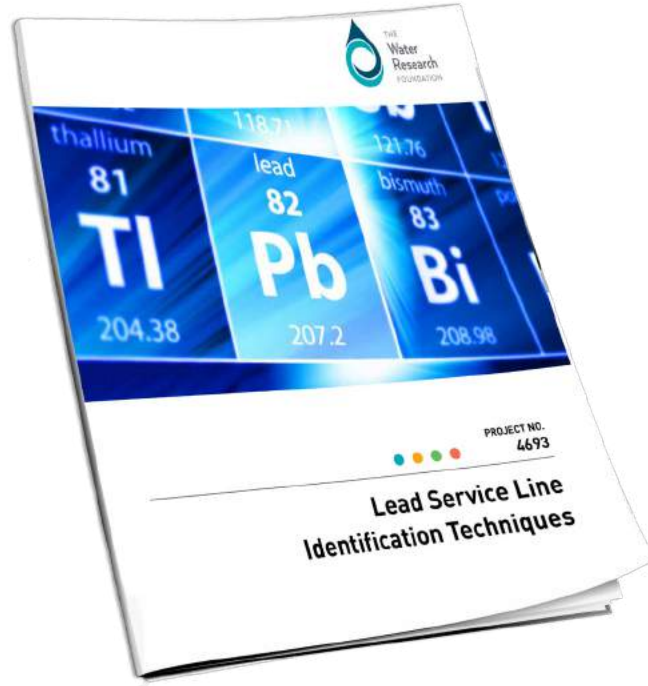
The concentrations of lead and copper in water are regulated by the US EPA's Lead and Copper Rule Revision (LCRR), with numerous studies already completed on lead pipes, with several already planned.

3.2 Lead Service Identification Techniques, WRF Report #4693

In August 2016, WRF released a Request for Proposal for a project entitled "Service Line Material Identification Techniques" (#4693). The purpose of the project was to develop a literature review and multiple case studies to identify innovative lead service line identification technologies, and if feasible, recommend those technologies for future field testing and verification.[5]

The principal investigator for WRF Project #4693 was Zia Bukhari, PhD, American Water Company, and included WRF Project Subcommittee members from City of Raleigh, North Carolina, Medford Water Commission, Oregon, and Aqua America, Inc.,publishing results on June 8, 2020.

Figure 6. Lead Service Identification Techniques, Project No. 4693



Conducted over nearly a four year period, with significant information known from prior usage in the field by WRF project contributors, a number of technologies were assessed, as listed in Table 2.

Table 2. Technologies Assessed in WRF Report No. 4693

1. Vacuum Excavation
2. CCTV Inspection
3. Metal Detectors
   - 3.1. Very Low Frequency (VLF) Technology
   - 3.2. Terahertz Technology
   - 3.3. Three-Dimensional Electromagnetic Induction
   - 3.4. Pulse Induction
   - 3.5 Multi-mode Electromagnetic Target Discriminators
   - 3.6. Polyharmonic Metal Detectors
4. Desktop Predictive Models
5. Magnetometers and Gradiometers
6. Ground-Penetrating Radar
7. Stress Wave Propagation
8. Acoustic
9. Electrical Conductivity Object Locators
10. Field Portable X-ray Fluorescence Spectrometry

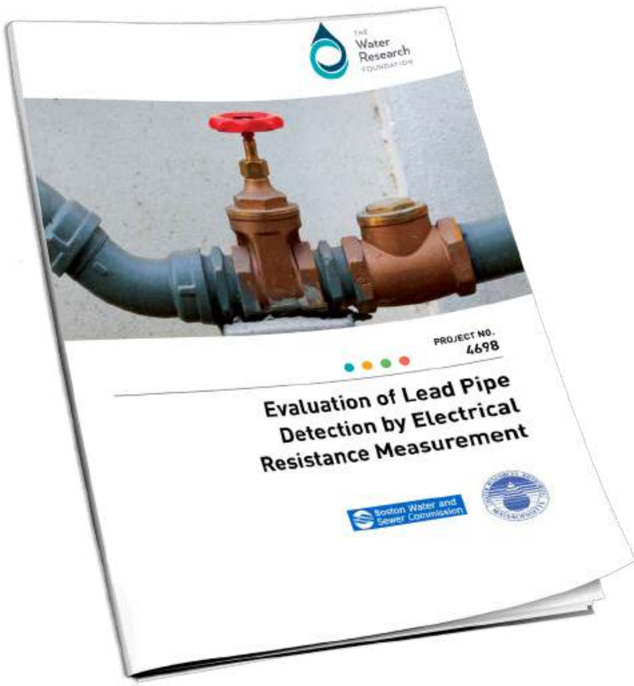
A major conclusion of the study stated that "At this time, there is not a commercially available method to detect the material composition of buried service lines, except for physical excavation and verification." Since many of the techniques were deemed likely to be cost-prohibitive, WRF recommended that utilities focus on supplemental information gathered through indirect methods such as tap cards, service/repair tickets, construction records, plumbing permits, and water quality data.

3.3 Evaluation of Lead Pipe Detection by Electrical Resistance Measurement, WRF Report #4698

Also in 2016, WRF released a Request for Proposal for a project entitled "Evaluation of Lead Pipe Detection by Electrical Resistance Measurement" (#4698). The purpose of this project was to evaluate the possibility of detecting the presence of lead pipe by measuring the electrical resistance of the water service line.[6]

The report was prepared by Agnes Jallouli, Imperia Engineering Partners, and co-sponsored by Boston Water and Sewer Commission and Massachusetts Water Resources Authority, with additional WRF Project Advisory Committee members from Northern Kentucky Water and Corona Environmental Consulting.

Figure 7. Lead Service Identification Techniques, Project No. 4698



Project No. 4693 released January 22, 2022, focused on electrical resistance testing, finding it could tell the difference between copper and lead pipes.

Major findings and conclusions included the following:

- 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.

Choosing not to participate in the original study due to competing patent filings, Electro Scan's engineering team noted a number of shortcomings that had been previously overcome using the Company's machine-intelligent electrical resistance measurement technologies, capable of measuring the change in resistivity of pipe materials by passing a low voltage probe through the interior of any pipe.

Working with existing clients under Non-Disclosure Agreements, Electro Scan began full-scale service line testing after previously finding lead in larger diameter Asbestos Cement pipes in 2015. The challenge was never locating different pipe materials. Rather, the major challenge was getting into and out of smaller diameter service lines, and with minimum disturbance.

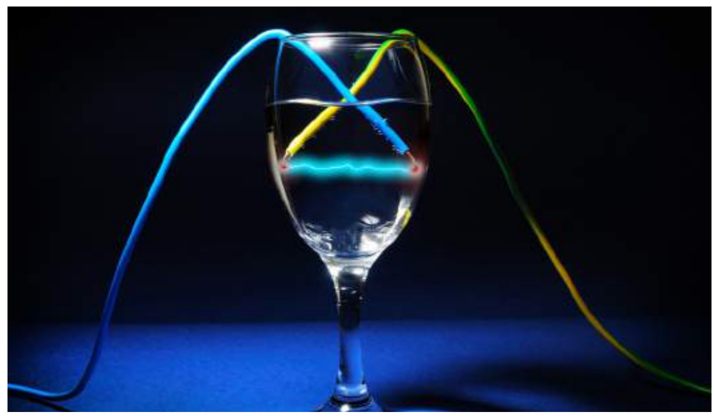
4.0 THE SCIENCE OF ELECTRICAL RESISTANCE

In 2010, after a number of unexplained Cured-In-Place Pipe liner failures occurred after the liner's warranty period had expired, technical solutions were sought to create an accurate, cost-effective, and repeatable way to reliably certify the water tightness of repaired and relined pipelines. Complicating matters were the seemingly endless combinations of pipe materials, diameters, shapes, depths, lengths, gradients, soil types, and age of pipes.

The science of using low voltage conductivity is straightforward as shown in Figure 8, where two ends of the same circuit are able to use water as the conductor to still complete a circuit; often referred to as Focused Electrode Leak Location (FELL).

A similar application, known as holiday testing, was already in use to evaluate protective coatings for exposed pipes, rooftops, and reservoir linings. The technology need was for a low voltage equivalent to assess full-length 360-degree pipe wall integrity while allowing existing flow conditions during inspection.

Figure 8. Using Water as a Conductor



Most pipe materials such as brick, clay, plastic, concrete, and resin-based liners, are poor conductors of electrical current. As a result, if a defect exists in the wall of a pipe, leakage of electrical current will indicate the location and size of the defect. The measured intensity and duration of the electrical signal emanating from the pipe can be correlated to a flow rate in GPM, whether or not water infiltration or exfiltration actually occurs during the survey. Pipe wall corrosion and thickness can also be measured.

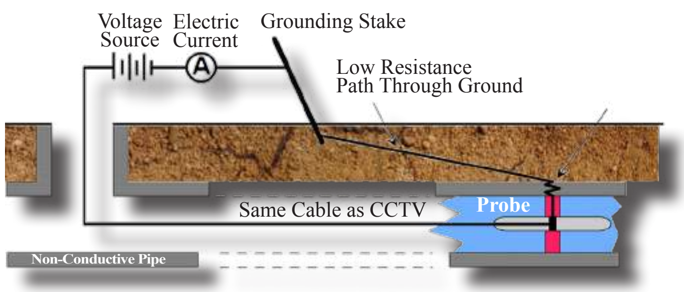
An approach was developed by establishing a (low) 12-volt electrical circuit with a 40 milliamp (mA) signal, using water as a conductor. This allowed two ends of the circuit to connect and close the loop, as depicted in Figure 9. Applied to an underground pipe, one side of the circuit would remain inside a non-conductive pipe (e.g., asbestos cement, brick, epoxy-coated ductile iron, high density polyethylene, plastic, resin-based liner, vitrified clay pipe, etc.). Connected to a grounding stake, any defect current would need to travel to the surface to confirm a corresponding pipe wall defect or leak.

If the loop remains 'open,' whereby changes in resistivity is flat or unchanged, the pipe would have no defects. Conversely, if the loop is 'closed,' whereby an electrical connection is made, then a leak or defect undeniably exists in the pipe wall, allowing a pathway from inside of the pipe to ground.

Since water leakage and electric current are highly correlated, the intensity and duration of measured current can provide a specific defect size and corresponding flow rate in gallons per minute.

In 2010, desktop pipe simulation tools reliably modeled variable impedance of electric circuits in pipes. Additional testing confirmed required probe dimensions, power settings, grounding sources, data capture, repeatability of results, and precision of leak location, by pipe diameter. Important also to defect location was quantifying a leakage rate in GPM.

Figure 9. Principle of Electrical Resistance Testing



Source: ASTM F2550 (2006, 2013, and 2018).

Basic assumptions related to hydraulic conditions on a defect and surrounding buried pipe soil conditions. This allowed leakage rates to be reliably computed in gravity pipes and accurate estimated size of each 'hole' determined by the volume of electric current.

Following the principle operation of AC circuits, a grounding source was needed which was created when a conductive rod driven into the ground near the operation of the device. When the probe approaches a pipe defect as illustrated in Figure 10, current will escape through a leak, hole or orifice and create a measured reading.

AC current levels on the electrode increases with spatial dependence inside a pipe, comprising the most important conduction characteristics that make the device perform.

In other words, pipe defects are identified by the probe's measured current levels. The measured area beneath the current spike curve can be used to compute the flow rate of the defect.

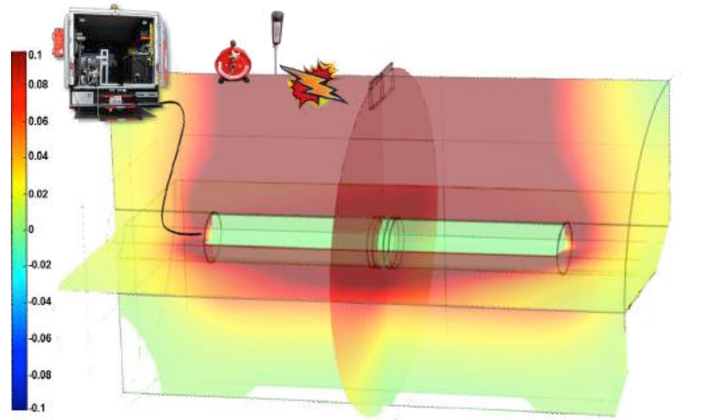
Flow rates can be provided in any customary unit of measure, such as gallons per minute,[7] with data for each defect, including:

- Starting Point, Ending Point, and Maximum Defect Current.
- Defect Classification as Large, Medium, or Small.
- Flow Classification as Sever, Moderate, or Minor Defect Readings.
- Total Estimated Defect Flow in units of volume over time.
- Total Pipe Segment Defect Flow in units of volume over time, by pipe diameter & length.

A benefit of using COMSOL® Multiphysics® was the ability to model, test, and confirm single and multiple pipe defects, in minutes across multiple pipe materials.[8]

While COMSOL® easily accommodates multiple pipe materials, internal pipe pressures, gradients, and water conductivity, desktop results needed to be field validated to account for environmental constraints and demands of working in residential, commercial, and open areas.

Figure 10. COMSOL® Multiphysics® Depiction of Electro Scan



4.1 FELL Technology in the Field

By 2011, FELL technology was undergoing refinements in field testing, based on results from the Kansas City, MO, EPA Study and involvement of Ken Kerri, PE, Ph.D., Office of Water Program Director, California State University, Sacramento.[9]

By passing a tethered probe through a utility's pipe network, connected to a deployment support vehicle using a cable from 300-1000 feet in length, the probe emitted a 40-milliamp current into the water inside a pipe, producing a one kilohertz signal distinct from that emitted by anything else in the ground, eliminating false positives.

To summarize the use of low voltage conductivity and its application to field testing of pipes, key elements include:

(a) If a crack or break occurs in a pipe wall, a tethered probe emitting electric current will complete the circuit above ground to map the precise location and severity of each leak in both gravity & pressurized pipes,
(b) That the technology could be easily retrofit to a standard TV truck or van,
(c) That FELL had the capability of measuring leaking joints missed by CCTV cameras that cannot see into bell & spigots, and
(d) That FELL was able to test full-length 360-degree surfaces for plastic pipes, including HDPE, CIPP, and spiral wound pipe for water permeability, leaks, and pinholes. Pipe materials are listed in Table 3 with set-up illustrated in Figures 11 and 12.

Table 3. Selected FELL Tested Materials, Shapes, Sizes.

Pre-Rehabilitation Pipe Materials		**Pipe Types**
ABS	Acrylonitrile-Butadiene-Styrene Pipe	Gravity Sewers
ACP	Asbestos Cement Pipe	Rising (Force) Mains
BRK	Brick Pipe	Pressurised Water Mains
CON	Concrete Pipe	Private Sewer Laterals
DIP	Ductile Iron, with coating	Service Laterals
ORP	Orangeburg Pipe	Stormwater
PB	Lead	Open Channels
PCCP	Pre-stressed Concrete Cylinder Pipe	Home Plumbing Pipes
PVC	Polyvinyl Chloride Pipe	Large Diameter
RCP	Reinforced Concrete Pipe	Sewer Interceptros
VCP	Vitrified Clay Pipe	Manhole Chambers
Post-Rehabilitation Pipe Materials		**Pipe Shape**
CMLSP	Cement Mortar Lined Steel Pipe	Box
CIPP	Cured-In-Place Pipe	Circular
FF	Fold & Form	Oval
FRP	Fiberglass Reinforced Pipe	Trapezoidal
FRPM	Fiberglass Reinforced Polymer Mortar	**Pipe Diameter & Length**
GRP	Glass Reinforced Pipe	
GROUT	Grouted Joints and Laterals	Smallest
HDPE	High Density Polyethylene Pipe	76mm (3 inches)
PE	Polyethylene Pipe	
RTR	Reinforced Thermosetting Resin Pipe	Largest
SIPP	Spray-in-Place Pipe	2000mm (70 inches)
SPR	Spiral Wound Pipe	Up to 300m (1,000 feet)
Cost	Similar to CCTV Cost, but production rate up to 1km /day.	

4.2 The Role of Electrical Resistance Testing for Assessing Cured-In-Place Pipe (CIPP)

Many cities and utilities have long adopted Closed-Circuit Television (CCTV) to inspect and accept CIPP liners and repairs. But, most pipeline professionals know that CCTV has no ability to test newly installed liners. Unable to locate leaks in liners or pinholes, electrical resistance testing has emerged as the new standard for accepting CIPP liners and repairs as watertight. Spearheaded by the Institut für Unterirdische Infrastruktur (IKT), Gelsenkirchen, Germany, in 2016, IKT invited British-based WRc Plc and Electro Scan to participate on IKT's short-liner CIPP study. Conducting field and laboratory testing, including hydrostatic pressure testing and FELL testing using Electro Scan certified equipment, initial results were published in October 2019, with final results published with approval by the German government.[10]

A key finding of IKT's work was the consistent, repeatable test results of FELL, which it had assessed as part of earlier versions in 2001.

While key readings demonstrated remarkable repeatability, IKT further recommended that additional software developments be undertaken, completed in 2018, to quantify rates of pinhole leakage (less than 0.1 gallon per minute), as shown in Figures 12, 13, and 14.

Figure 11. IKT Eye-dropper CIPP Leak Testing

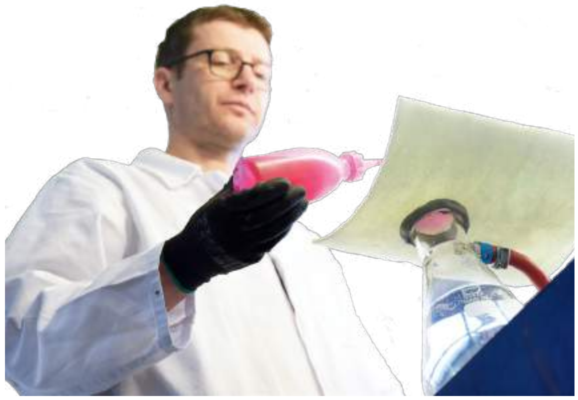


Figure 13. IKT Eye-dropper CIPP Leak Testing

Figure 12. Repeatability Testing

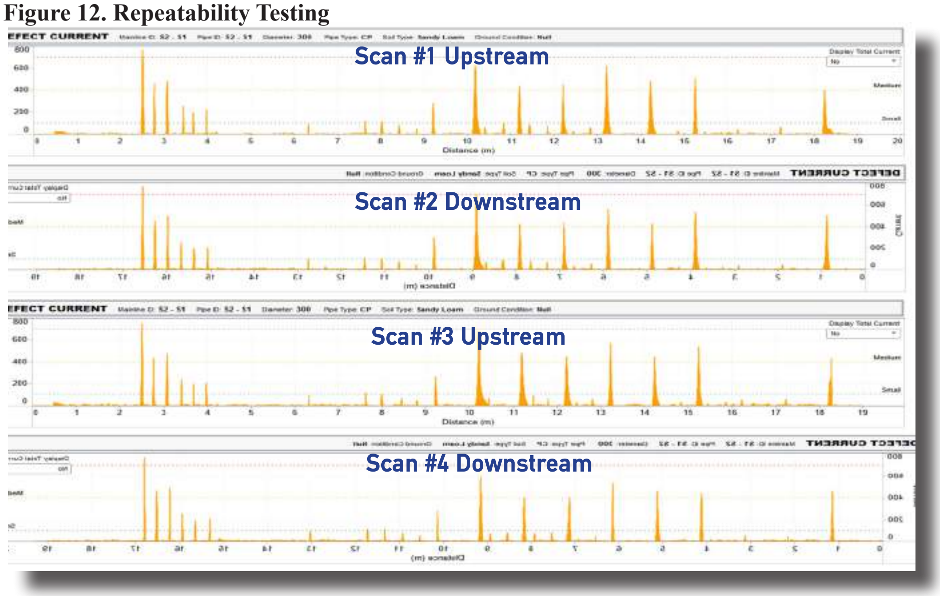
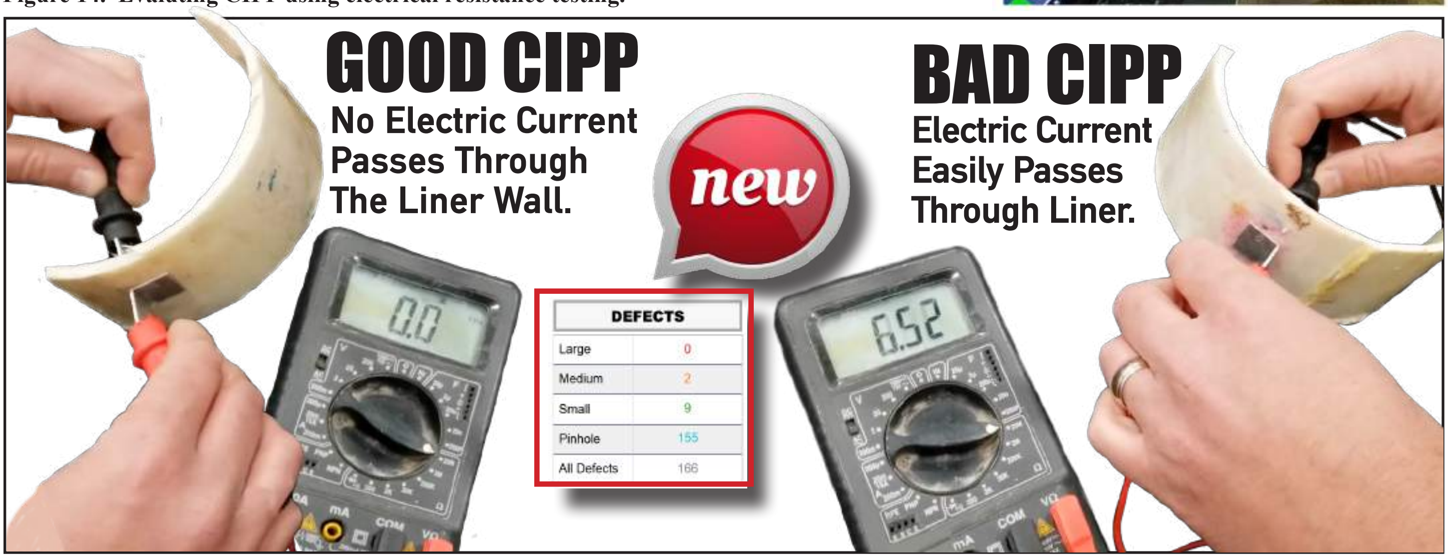


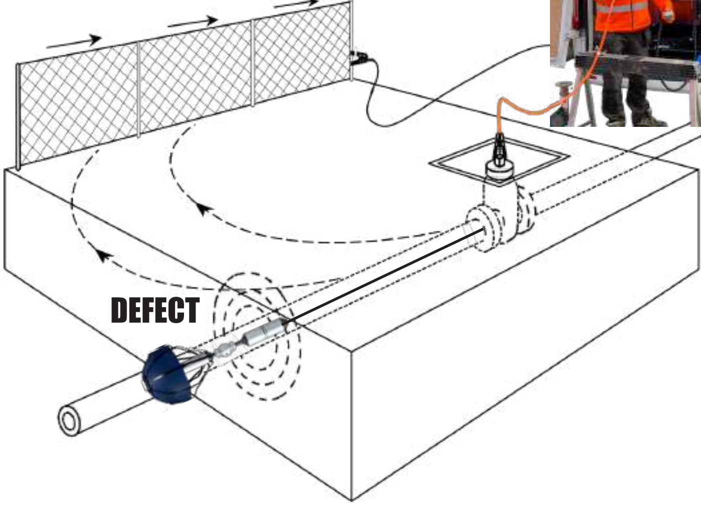
Figure 14. Evaluting CIPP using electrical resistance testing.



4.3 FELL Identification of Lead Soldered Joints

By 2014, Electro Scan had started the assessment of pressurized water pipes integrating its electrical resistance testing probes in combination with an acoustic sensor to immediately compare results with tethered-based competitive solutions and high resolution CCTV cameras to begin observing exit locations and tracing of water particulates. Initial work focused on Asbestos Cement Pipes.

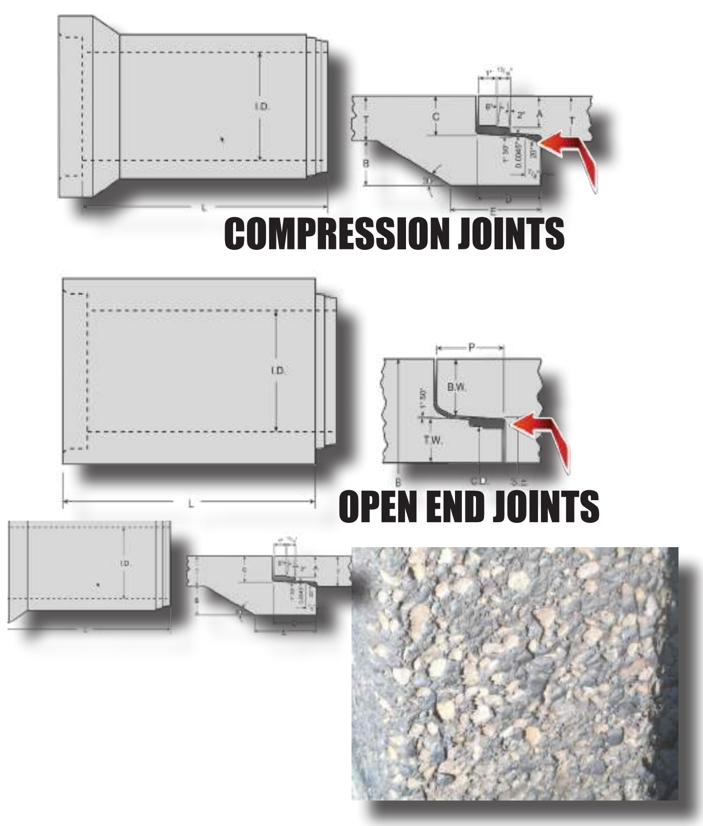
Figure 15. Internal Water Pipeline Assessment Using Electrical Resistance Testing by Electro Scan



In contrast to gravity pipes that support sanitary sewer and stormwater pipes, Electro Scan's water-based solutions were able to enter pressurized or non-pressurized water mains, as shown in Figure 15.

Many utilities began trialing the solution to assess (1) HDPE & Plastic pipes, difficult if not impossible to get reasonable signals from acoustic sensors, (2) Prestressed Concrete Cylinder Pipes (PCCP), highly prone to corrosion and often mis-judged by

Figure 16. Identification of Lead Soldered Joints by Electro Scan (2015).

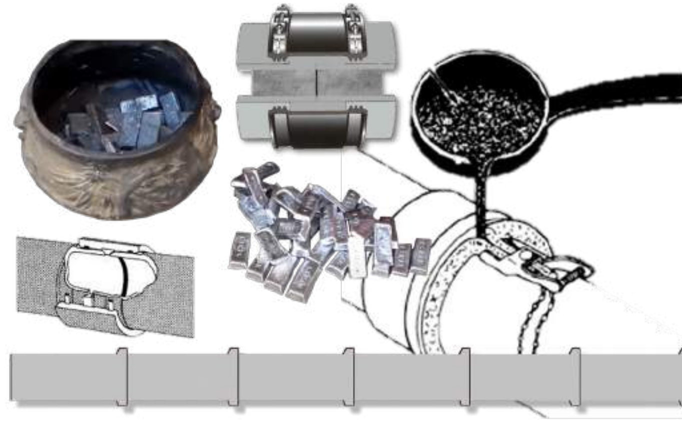


electro-magnetic sensors designed to detect wire breaks inside the pipe wall, and (3) Asbestos Cement (AC) Pipes, having pipe wall thickness issues that are typically undetected by acoustic sensors or electro-magnetic imaging.

As shown in Figure 16, the use of AC pipes were largely discontinued in North America in the late 1970s due to health concerns associated with the manufacturing process, especially related to the possible release of asbestos fibers into drinking water from deteriorated pipes.

But, the risk of AC pipes doesn't stop with asbestos fibers, as melted lead ingots were often poured into joints as shown in Figure 17 to seal individual joint and service connections. As many plumbers know, the melting point of lead — at 327.5 °C (621.5 °F) — is very low compared to other metals.

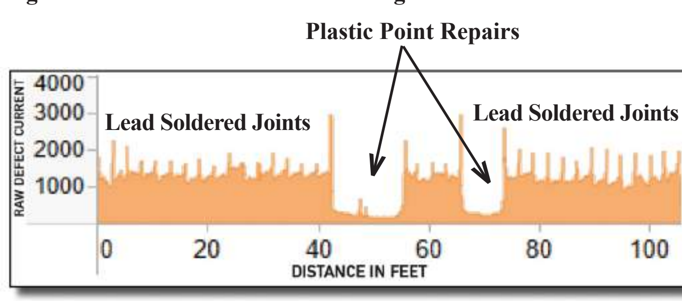
Figure 17. Identification of Lead Soldered Joints by Electro Scan (2015).



A key advantage to measuring the change in electrical resistance, inside a pipe, is the ability to have a real-time display of changes in pipe material. And, where lead soldered joints have been used at individual joints.

As shown in Figure 18 below, Electro Scan's electrical resistance testing can display changes in resistivity that can show both material changes and lead soldered joints in the same pipe

Figure 18. Electrical Resistance Readings of Lead Soldered Joints



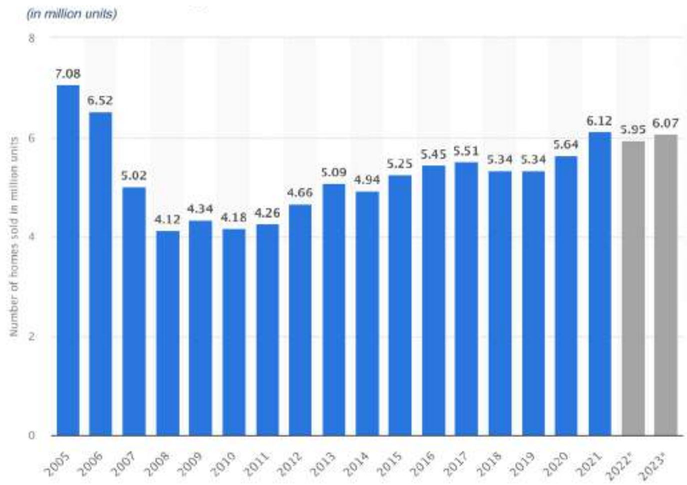
Electro Scan's ability to accurately identify lead soldered joints and lead pipe sections, allowed the Company to focus on the more daunting challenge; the entry, navigatoin, and exit of water service lines.

Already completing hundreds of worldwide leak detection projects with electrical resistance testing in larger diameter pipes (i.e. 3-inch to 72-inch diameter pipes), it was a straightforward development to reduce the size of its probes and insertion tubes, to assess service lines ranging from 1/2-inch to 3-inch diameter pipes, unaffected by flow velocity or pressure.

5.0 TESTING OF BURIED LEAD SERVICES

In 2021, home sales in the United States surged, reaching the highest number of unit sales since 2006. A total of 6.12 million housing transactions were completed in that year, up from 5.64 million in 2020. According to the forecast, sales activity is expected to slow down slightly in 2022 and increase again in 2023.

Figure 18. Number of Existing Homes Sold In the U.S. from 2005-2023



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Why are housing sales important to the 50,765 water utilities that must complete service line inventories by October 16, 2024?

The fact that all 'unknown' service addresses, whether located on the utility-side of the meter or private property-side of the meter, must be considered as LEAD and be displayed online and available to the general public represents a major concern for future real estate disclosure requirements between sellers and buyers.

State Disclosure Policies for Lead Pipes

When purchasing a home, buyers expect to be informed about deficiencies, defects, or environmental hazards on the property. Since 1996, they have been told about lead in paint. However, the likelihood that a buyer will be told their prospective home has lead pipes, including an LSL, depends on what state they live.

In the 1980s, many states began requiring sellers to proactively disclose to buyers information about known property defects. Requirements differ by state, and some states do not have disclosure requirements at all. Disclosure laws are intended to protect buyers from purchasing a property without full knowledge of potential defects. They also help protect sellers from legal liability.

While the only federal housing disclosure requirement for environmental hazards is for lead-based paint, many states have requirements or policies that would trigger disclosure for LSLs.

The Lead Service Line Replacement Collaborative, a diverse group of 25 organizations that aims to accelerate full LSL replacement, identified expanding federal, state, and voluntary disclosure policies to include LSLs as an opportunity to help consumers make informed decisions.

To support and expand this work the Environmental Defense Fund (EDF) created a scorecard of states and their disclosure or lack of disclosure on lead pipes[11]. EDF is a U.S.-based nonprofit environmental advocacy group best known for its work on global warming, ecosystem restoration, oceans, and human health. Its key objective is to advocate the use of sound science, economics and law to find environmental solutions that work.

Believing that home buyers deserve to know about the presence of environmental hazards, including the presence of an LSL, on property they are considering buying, EDF created a scoring system to rank state policies for lead pipes, publishing their results in 2017.

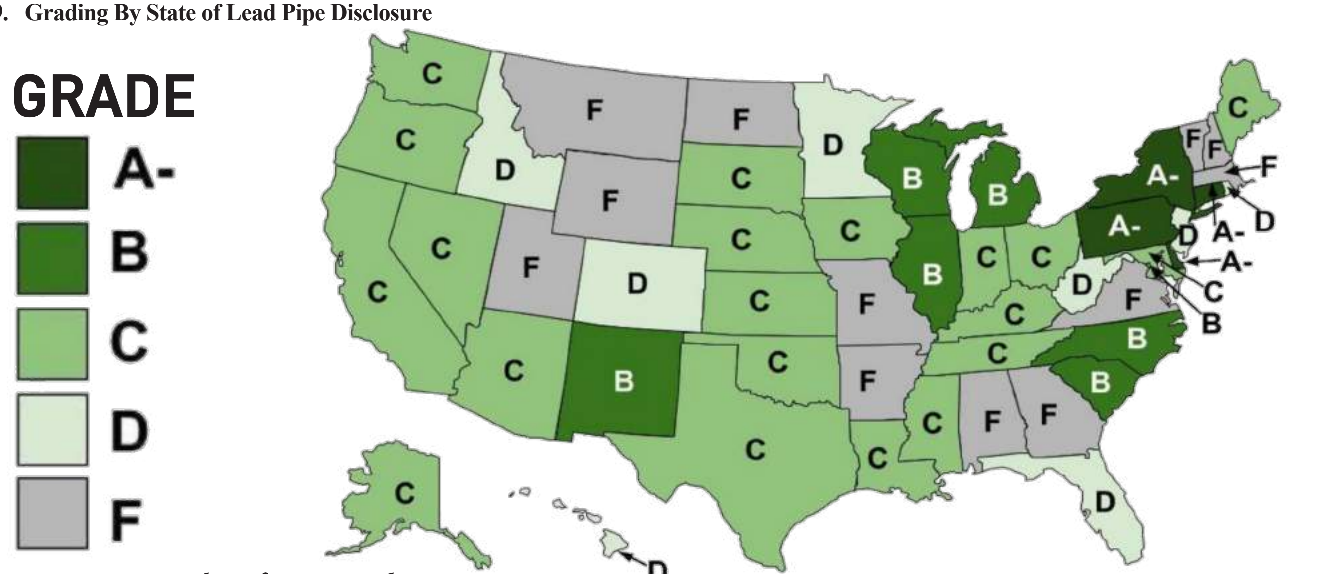
How Are States Graded on Disclosing Lead Pipes?

As shown in Figure 19, EDF graded the housing disclosure policies of all states and D.C. according to their ability to help homebuyers make informed decisions about LSLs before they sign a sales contract. EDF's research on state disclosures used legal articles at www.Nolo.com with results shown on the following page in Table 4.

EDF assessed the following aspects of the seller disclosure policies, for each state, including:

1. Does the state law require any disclosures of deficiencies, defects or environmental hazards at sale?
2. Is there a required or voluntary form for disclosure?
3. Does a seller need to disclose knowledge of lead pipes or pipe material?
4. Does a seller need to disclose knowledge of environmental hazards?

Figure 19. Grading By State of Lead Pipe Disclosure



Source: Environmental Defense Fund.

Table 4. Grading States By Their Requirements for Lead Pipe Disclosures?

Grade	Description	No. of States	States
A-	**Mandatory disclosure of lead pipes.** ***Example:*** State-required form asks, "Is lead plumbing present? If yes, state location or locations.")	4	Connecticut Delaware Pennsylvania New York
B	**Mandatory disclosure (M) of pipe material (lead not specifically addressed) or lead pipes if seller determines conditions unsafe.** ***Example***: State-required form asks, "Type of plumbing system: Copper/ Galvanized/Plastic/ Polybutylene./Unknown/ Other" **Voluntary disclosure (V) of lead pipes.** ***Example***: Voluntary form asks, "Type of water supply pipes: Lead/ Galvanized Copper/ Polybutylene/ Other/ Don't know"	7	District of Columbia (M) Illinois (M)* Michigan (M) New Mexico (V) + North Carolina (M) South Carolina (M) Wisconsin (M)*
C	**Mandatory disclosure (M) of general environmental hazards.** ***Example:*** State required form asks, "Have there been or are there any hazardous conditions on the property, such as methane gas, lead paint, radon…" **Voluntary disclosure (V) of pipe material (lead not specifically addressed)** ***Example:*** Voluntary form asks, "Are you aware of the type of water pipes, such as galvanized, copper, PVC, CPVC, or polybutylene?"	20	Alaska (M) Arizona (V) California (M) Indiana (M) Iowa (M) Kansas (M) Kentucky (M) Louisiana (M) Maine (M) Maryland (M) Mississippi (M) Nebraska (M) Nevada (M) Ohio (M) Oklahoma (M) Oregon (M) South Dakota (M) Tennessee (M) Texas (M) Washington (M)
D	**Mandatory disclosure (M) of defects and deficiencies but not specifically environmental hazards.** **Voluntary disclosure (V) of general environmental hazards** ***Example***: Voluntary form asks, "Have there ever been substances, materials, or products which may be an environmental hazard…"	8	Colorado (V) Florida (M) ♦ Hawaii (M) ♦ Idaho (M) ♦ Minnesota (V)(M) New Jersey (V) Rhode Island (M)♦ West Virginia (V)
F	**Limited or no disclosure requirements.** ***Example:*** Disclosure only required if seller "knows the home may pose a health or safety risk to the buyer…"	12	Alabama Arkansas ♦ Georgia ♦ New Hampshire ♦ North Dakota Massachusetts ♦ Missouri ♦ Montana ♦ Utah ♦ Vermont ♦ Virginia Wyoming ♦

* Disclosure if unsafe concentrations or unsafe conditions related to lead in water pipes
\+ State also has less detailed mandatory requirements
♦ Voluntary state realtor association disclosure form does address lead pipes or environmental hazards generally, but is not made public by the association

New York: A- *(mandatory disclosure of lead pipes)*
Mandatory form asks, "Is lead plumbing present? If yes, state location or locations below."

New Mexico: B *(voluntary disclosure of lead pipes)*
Voluntary form asks, "Water pipes are: Lead/ Galvanized/ Copper/ Polybutylene/ Other/ Don't Know."

California: C *(Mandatory disclosure of env. hazards)*
Mandatory form asks, "Are you…aware…of any of the following substances, materials, or products which may be an environmental hazards such as, but not limited to, asbestos, formaldehyde, radon gas, lead-based paint, fuel or chemical storage tanks, and contaminated soil or water on the subject property?"

Colorado: D *(Voluntary disclosure of env. hazards)*
Voluntary form asks if there are/is, "Hazardous materials on the Property, such as radioactive, toxic, or biohazardous materials, asbestos, pesticides, herbicides, wastewater sludge, radon, methane, mill tailings, solvents, or petroleum products?"

North Dakota: F *(Limited disclosure requirements)*
Buyer Beware: The responsibility is on the buyer to investigate hazards.

"Water utilities will be responsible for publishing an online map that discloses what is known and unknown about LSLs for each property."

- Chuck Hansen, CEO, Electro Scan Inc.

Grading the States on Lead Pipe Disclosures

Four states, Connecticut, Delaware, New York and Pennsylvania, scored an 'A-' because they each have a state-required disclosure form that specifically asks if the home has lead plumbing.

Six states and D.C. received a 'B.' Of these, three states and D.C. require disclosure of pipe material (lead not explicitly addressed), two states require disclosure of unsafe conditions or unsafe concentrations related to lead in water pipes, and the remaining state has a voluntary disclosure form that specifically asks about lead pipes.

Twenty states scored a 'C' because they require disclosure of environmental hazards generally but do not address lead pipes specifically. One state, Arizona, scored a C because the voluntary disclosure used by realtors requires identification of pipe material.

Eight states scored a 'D' because they have mandatory disclosure requirements that do not broadly address environmental hazards and/or they have a voluntary disclosure form that asks about environmental hazards generally.

Twelve states failed because they lacked or had extremely limited disclosure requirements.

Variation and Limitations of State Requirements

There is a remarkable amount of variance in state disclosure laws regarding LSLs – from states that require sellers to fill out detailed 10+ page disclosure forms to "buyer beware" states where the responsibility is on the buyer, not the owner, to investigate hazards.

A buyer's likelihood of being informed of whether a home has an LSL before signing a sales contract depends entirely on the state. However, it is important to note that there are limitations to the effectiveness of disclosure even in those states where it is required by law.

A seller only needs to disclose information they know, and sellers are usually given the option to select "unknown" on forms. States generally do not require the seller to examine the property for hazards, and a real estate agent may discourage a seller from performing testing to avoid disclosing negative information to buyers.

Presumably, if a utility notifies a property owner that there is an LSL or makes maps of LSL locations available online, it should result in a more effective disclosure.

Why Complete Your Inventory by October 16, 2024?

Since all real estate transactions must reveal 'defects' to prospective home buyers, water utilities are expected to play a key role in every real estate transaction that is conducted after October 16, 2024.

While some states allow water utilities to use 'probabilities' of service lines being lead, most understand that probabilities or estimates of service line materials will not allow utilities to adequately develop reliable inventories of lead pipes for buyers or sellers to confirm if there is an environmental risk due to LSLs.

In completing an "Independent Verification and Validation of DC Water's Lead Free DC Lead Service Line Removal Plan," dated September 22, 2022, Safe Water Engineering, LLC, concluded that:

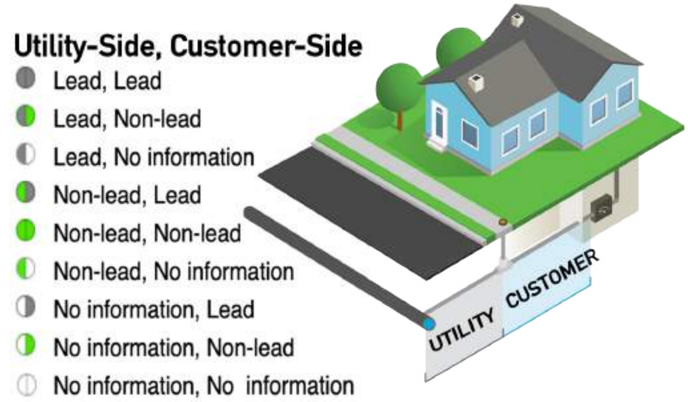
> **"While data modeling techniques for identifying probabilities of Lead Service Lines (LSLs) exist and have been useful in some cities, these techniques only identify probabilities of LSLs that can be used to prioritize work; they do not generate a verified service line inventory."**

Key Requirement for Success

Many utilities are confident they know the pipe material that connects curbstops or meters to their distribution mains. Development of Geographic Information Systems (GIS), initially improved installation and maintenance records, but homeowner and new home construction rarely contributed reliable information about the service line located on public-side of a property.

As property owners provided little if any information to city planning or water departments, Figure 20 shows why nearly 50% of the country's service lines are UNKNOWN.

Figure 20. Utility-Side and Customer-Side of Curbstop or Meter



The US EPA's 7th Drinking Water Infrastructure Needs Survey and Assessment (April 2023) estimates 9.2 million water services are presumed to be lead.[12] Based on surveys from 3,526 water utilities that responded, representing a 97% response rate, the number of lead service lines may be substantially higher than the 9.2 million surveyed as it does not appear that private property service lines were included in the most recent US EPA survey.

Based on a combined estimate of Utility-side and Private Property-side services, it can be estimated that **the U.S. may have as many as 26.7 million lead services lines that may be on one or both sides of a meter**, as shown in Tables 5 & 6.

Table 5. AS REPORTED - By the Latest US EPA Survey

Service Line Material	Utility-Side	
Lead Count	**9,223,745**	**9%**
Stand-Alone Galvanized	2,800,839	3%
No Lead Contect	87,929,975	88%
Total Utility Services	**99,954,559**	**100%**

Table 6 AS ESTIMATED - Based on Age of Housing in the U.S.

Service Line Material	Private Property-Side	
Lead Count (ESTIMATE)	**17,492,048**	**35%**
Stand-Alone Galvanized	19,990,912	40%
No Lead Contect	12,494,320	25%
Total Private Services	**49,977,280**	**50%**

Due to the risk of potential disruption to the U.S. real estate market, and a substantially higher number of lead pipes, water utilities should use the most efficient tools available, i.e. electrical resistance testing, to accurately locate all lead services by October 16, 2024.

6.0 ELECTRO SCAN SWORDFISH

SWORDFISH represents the industry's first machine-intelligent solution that can accurately and reliably detect, store, and document locations of buried lead water service lines based on electrical resistance testing.

Using measurements in conformity with the periodic table, each element has its own unique and measurable level of resistivity. In other words, how strongly each element resists electric current.

As shown in Figure 21 & 22, Copper and Lead both have different resistance levels to electric current, allowing Electro Scan's SWORDFISH to measure and record the changes as its probe passes through different pipe materials.

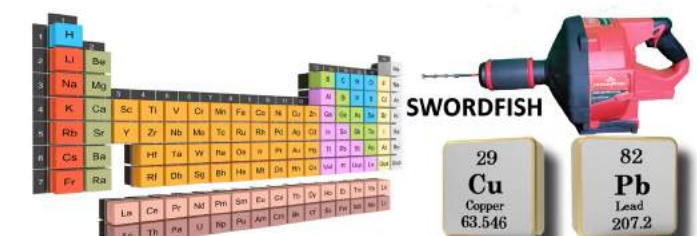
Figure 21. Elements.

A key advantage is the lack of external factors that might change, alter, or affect readings derived by SWORDFISH.

For instance, while acoustic-based sensors may be negatively impacted by ambient noise, flow velocities, traffic sounds, customer usage, pressure, pipe material, repairs, and other factors, electrical resistance is unaffected by all of these factors.

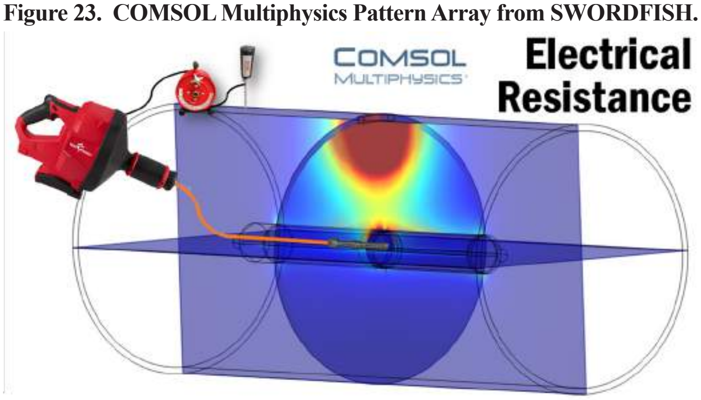
Additionally, electrical resistance operates at a low voltage (40 mAmps) and high frequency that is neither impacted by surrounding soil resistivities or random metallic objects that may be below the surface as shown in Figure 23.

Figure 22. Periodic Table Highlighting Copper and Lead Elements



International Annealed Copper Standard (IACS)	100%	7%
Electric Conductivity (10.E6 Siemens/m)	58,7	4,7
Electric Resistivity (nano-ohm meter)	16.8	208
Thermal Conductivity (W/m.K)	386	35

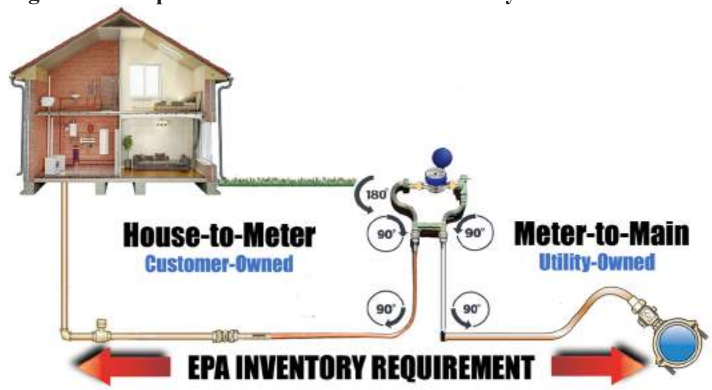
Figure 23. COMSOL Multiphysics Pattern Array from SWORDFISH.



6.1 SWORDFISH Service Line Entry and Testing

SWORDFISH is purpose-built for assessing pipematerials. Unlike other assessment techniques, such as acoustic, CCTV cameras, electro-magnetic, ground penetrating radar, helium tracers, or LIDR, SWORDFISH is unique in its ability to provide accurate, repeatable, and substantive information on full-length pipe materials. A fundamental difference is its ability to navigate pipeline configurations whether entering from the sidewalk or customer's basement, shown in Figure 24.

Figure 24. Simplified Illustration of Curbside Entry



A key factor in SWORDFISH's success has been its numerous field tests by some of the nation's largest and smallest utilities. Both aboveground and below ground tests, as illustrated in Figure 25, demonstrated how SWORDFISH can navigate the most challenging underground pipe material changes, in many cases, not known by the utility.

Figure 25. SWORDFISH Benchmark Evaluations

6.2 SWORDFISH Basement Entry

While most new meters are (now) located outside an owner's premise in a right-of-way where private meter readers or automated meter reading devices may be installed, it is estimated that almost 15% of all domestic water meters are located inside a downstairs basement.

Basement meter locations may have numerous challenges.

Water meters located in basements are typically placed near the wall that is closest to the street at the front of a home because this may be where the water pipe comes into a house.

In cold climates, building codes often brought water to a home at 5-7 feet deep so that it is well below the frost line. The pipe may then run it up into a valve that is often called a street-side valve.

Typically water meters could be installed after that valve. After the meter, another valve called the house-side valve might be installed.

Figure 26. A Typical Basement Entry for SWORDFISH Survey.

Generally, two valves make it easier for a city's water department to change out the meter, if needed. As shown in Figure 26, once pressures are measured, valves can be shut off so meters can be temporarily removed to allow SWORDFISH insertion.

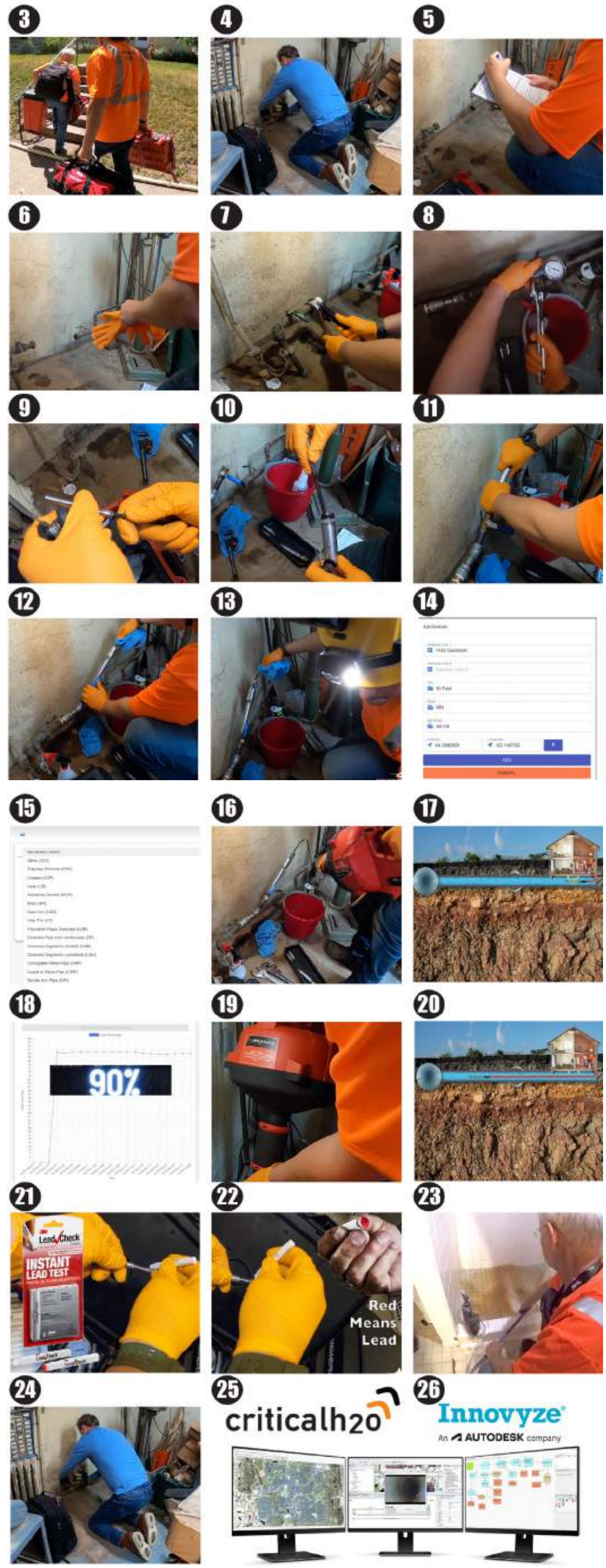
If starting from inside a customer's basement, it is recommended that a city approved plumber removed and reinstalls the meter after SWORDFISH inspection. It is also important that the water company or city water department communicate the nature of the water service line inspection and schedule a 1-2 hour service appointment window to complete the inspection.

SWORDFISH field procedures as illustrated in Figure 27 should be updated in accordance with local standards and practices.

Whether work is completed by an Electro Scan Service representa-

Figure 27. SWORDFISH Basement Inspection.

Figure 26. SWORDFISH Basement Inspetion *(Continued)*.



tive, certified Authorized Service Provider, or trained & certified Utility Service personnel, each survey follows a proven field guide to complete each survey on a timely and accurate basis.

Customer information may either be pre-loaded into SWORDFISH field software, prior to customer arrival, or entered at each home.

A Microsoft® Surface® tablet computer is included with each SWORDFISH purchase. Equipped with Electro Scan developed data capture software, the Microsoft Surface tablet computer also includes an integrated camera to take numerous photos to document conditions at the homeowner's meter, including needed parts repairs, replacements, and evidence of leaks before or after completing each survey.[13]

Electro Scan recommends that all service providers and utilities use a minimum two-person crew to assist in meter location, removal, survey, and clean-up activities, as shown in Figures 28-31.

Figure 28. A Basement Entry in Massachusetts.

Figure 30. Electro Scan's Patent-Pending SWORDFISH - Basement.

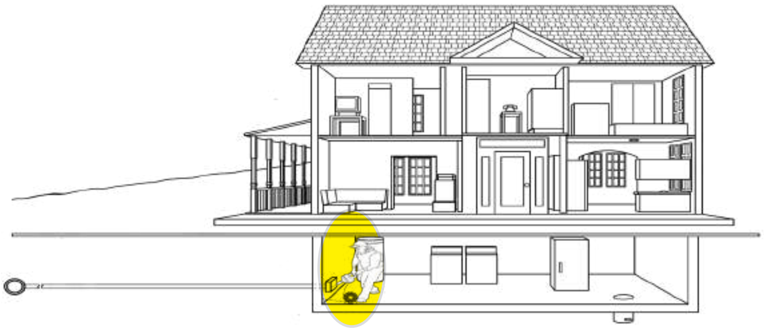


Figure 31. Taking a Photograph to Document Site Specific Conditions.

Figure 29. Various Basement Meters and Service Configurations.

6.3 SWORDFISH Curb Entry

The majority of water utilities utilize meters, valves, curb stops, and service valves, to deliver water from distribution water mains to private properties. As a result, determining which approach is needed to inspect the water service line, may vary for each location.

Unfortunately, even the most advanced GIS solutions do not reflect actual piping. As shown in Figures 32 and 33, GIS depicted services may not be helpful in planning service line inspections.

Figure 32. Typical GIS Representation of Water Service Lines.

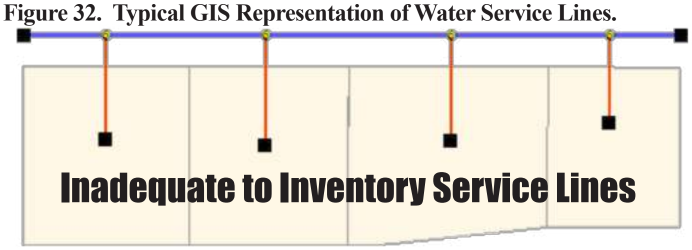


Figure 33. A Typical Curbside Entry for SWORDFISH Survey.

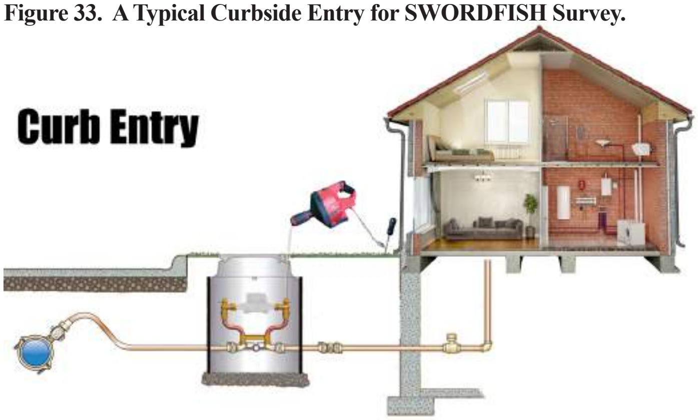
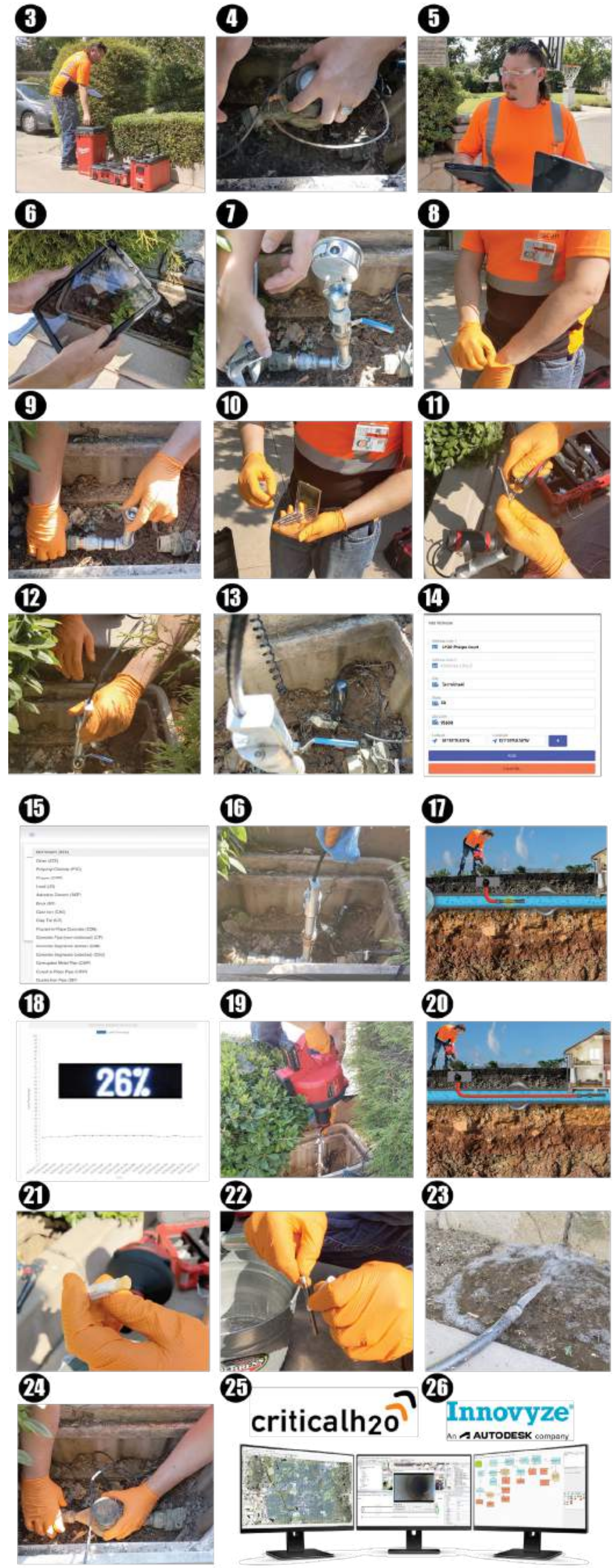


Figure 33. SWORDFISH Curbside Inspection.

Figure 33. SWORDFISH Curbside Inspection *(Continued)*.



While cities and utilities expended great sums of public funds to digitize water mains, valves, hydrants, and appurtenances, many times each asset was stored on different GIS layers. Unfortunately, the failure to cross-reference each layer became a major roadblock in helping field staff know which valves or hydrants were related to specific water main.

For instance, by having valves physically stored on different layers than water mains, maintenance crews are unable to know which valves are required to shut-off (direction of turns and number of turns) to shut down water mains when needed.

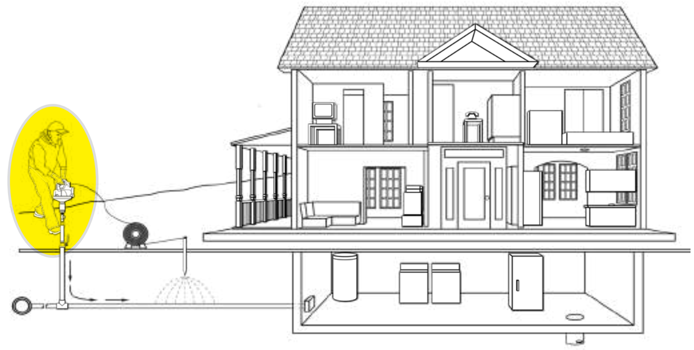
GIS driven impediments to field work continued as service lines were deemed too costly to individually digitize, causing many utilities to simply draw (electronically) a line from the center point of a parcel linked to the closest water main. Completed for expediency and to reduce the cost of building GIS solutions, many digital lines or services failed to confirm if that was the correct water main delivering water to the parcel or private property. Furthermore, actual curb box locations, meters, service valves, and appurtenances were not digitally recorded, while actual pipe bends and turns (installed on the utility-side and private property-side of the meter) were never recorded, making most GIS solutions problematic or useful for completing a comprehensive service line inventory.

Despite the shortcomings of GIS and lack of manual records, the first question utilities must answer is whether a service line inspection is needed from the curb box to the water main (or gooseneck), curb box to customer's home, or both.

The answer to that question tells field crews and supervisors whether pipe entries will need to be made into pressurized pipes (i.e. from meter to main) or unpressurized pipes (i.e. from meter to house, once meters are removed and service valves temporarily shut-off).

As shown in Figure 34, there are a variety of meter settings used in the water industry. Representing the pipe that supports the meter

Figure 35. Electro Scan's Patent-Pending SWORDFISH -- Curbside.



that measures the water delivered to the homeowner, the meter setting may be a typical entry point[13] as shown in Figure 35.

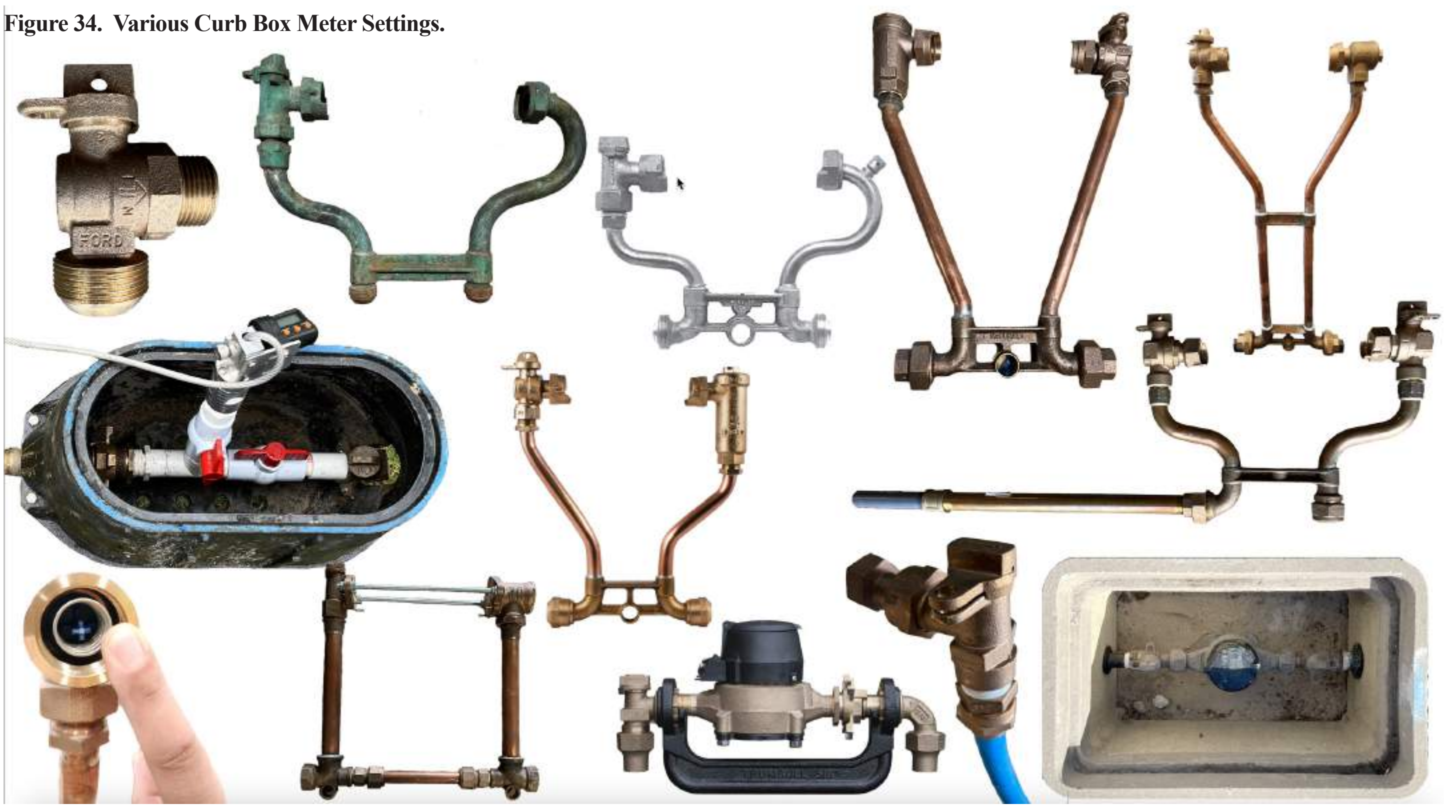
Using SWORDFISH, digging or excavating on private property can be eliminated allowing for aboveground access through meter, valve, or other appurtenance. The SWORDFISH probe then measures the service line's resistivity as it moves through the pipe.

Because potholing or hydro-excavation is often limited to one or two holes that are dug down to the service line piping, many state drinking water officials are finding this process may miss diagnose key sections that may be lead and may cause internal pipe disruption of biofilms, debris, lead soldered joints, and tuberculation, that may discolor water or intensify the presence of lead where none had existed before.

The California State Water Resources Control Board has notified water utilities that any proposed excavation will require separate environmental justification before any State Drinking Water Revolving Funds will be approved.

Separately, the Massachusetts Department of Environmental Protection (Mass DEP)[14] has issued rulings that potholing would no longer be funded by its State Drinking Water Revolving Funds.

Figure 34. Various Curb Box Meter Settings.



6.4 SWORDFISH Insertion Tube & Chlorination Chamber

If a water utility cannot confirm or verify the pipe material from water main to meter, then field work may require the insertion of the SWORDFISH probe into a pressurized pipe.

As mentioned previously, a key strength of SWORDFISH is its ability to automatically identify pipe materials based on their electrical resistance. Copper, Galvanized Steel, Lead, Plastic, and other pipe materials each have unique properties so it makes sense that measuring the change through a full length pipe will identify one or more pipe materials in a service line.

The challenge has always been the entry, navigation, and retrieval of the probe given the pipe configuration of the utility's and customer's service line.

Adapting its insertion devices approved for larger pipe diameters from 3 inches to 72 inches, included as part of AWWA M77 Standard for Condition Assessment of Water Main,[15] shown in Figure 36, Electro Scan has created a line of insertion tubes for small diameter pipes from 1/2 inch to 3 inches in diameter, shown in Figure 37.

Figure 36. Example Electro Scan Pressurized Pipe Insertions into Live Drinking Water Pipes in Accordance with AWWA M77 Standard (2019).

Figure 37. Electro Scan's Combination Pressurized Insertion Tube, Chlorination Chamber and Footage Encoder.

6.5 Pipe Disturbances

There has not been any significant research conducted on the impact of various inspection technologies and resulting water quality changes that might occur before and after in-pipe testing. While the US EPA has organized several preliminary discussions, attended by professional engineers of Electro Scan Inc., little progress has been made as of June 2023 to determine benchmark conditions, by inspection technique.

In the meantime, water utilities have relied on other industry-accepted techniques that have allowed for the temporary insertion of devices into clean water pipes.

In addition to insertion techniques highlighted as part of AWWA M77, several other techniques, as shown in Figure 38, are similar to Electro Scan's SWORDFISH.

Figure 38. Common Methods That May Disturb Service Lines.

6.6 SWORDFISH Configurations

It is a well-established fact that not all water utilities have used the same meters, valves, service lines, and appurtenance, to convey water to private property owners. And, there is even more variations how building contractors and plumbers have configured parts and piping to internal drinking water systems.

As a result, Electro Scan has developed a line of SWORDFISH hand tools to facilitate the entry, navigation, and retrieval of its machine-intelligent probes.

As show in Figure 39, the SWORDFISH, SWORDFISH Special Edition (SE), and SWORDFISH Flow Express (FX), were designed, developed, and deployed to allow water utilities and authorized service providers the widest possible options to assess service lines and locate lead pipe materials.

Figure 39. SWORDFISH, SWORDFISH SE, and SWORDFISH FX Comparison.

Electro Scan SWORDFISH Comparison

Feature Comparison			
Product	SWORDFISH	SWORDFISH SE Special Edition	SWORDFISH FX Flow Express
Target Service Line Entry	For utilities with meter setting entries with limited 90-degree bends and straight entries.	For utilities that have valves with extreme internal geometry, change in pipe diameter, and multiple 90-degree bends.	Designed for multiple bends in non-pressurized (gravity) pipes, primarily for meter-to-house customer service lines.
Cable Length	80 ft	100 ft	500 ft
Cable Diameter	1/4"	3/16"	3/16"
Pipe Diameter	1/2" - 3"	1/2" - 3"	1/2" - 3"
Probe	Spring/Beveled	Purpose Built	Meter-to-House Only
Real-Time Display	✓	✓	✓
Bluetooth Enabled	✓	✓	✓
Insertion Tube	✓	✓	✓
Pressurized Entry	✓	✓	⊘
Non-Pressurized Entry	✓	✓	✓
Power Forward	⊘	✓	✓
Power Retraction	⊘	✓	Powered by Hydraulic Pump
Power Rotation	✓	⊘	⊘
MSRP	$70,000	$74,500	$65,000

U.S. Patents and Patent-Pending.

Electro Scan's award-winning SWORDFISH has undergone major testing in the U.S. and United Kingdom. With experience developing inspection products for larger diameter pressure and gravity water and sewer mains, and successfully locating leaks to the closest 1/4 inch (1cm) measuring leak severities in gallons per minute (litres per second), the Electro Scan engineering & operations team has made entries in hundreds of smaller diameter pressurized and unpressurized service lines to allow rapid access and testing of pipe materials.

Key differences for each SWORDFISH have been designed to address different pipe lengths, pipe bends, and pressures. For example, the SWORDFISH FX can only be used in non-pressurized pipes. In contrast to SWORDFISH and SWORDFISH SX that employ a manual push-through tactic to transit through the inside of a pipe, the SWORDFISH FX uses a flow-based tactic that pushes a lightweight tethered ball through the pipe, usually from meter to houses.

6.7 SWORDFISH Cloud Reporting and Data Management

Developed and successfully implemented worldwide, Electro Scan's data management and reporting allows field data capture and office reporting within minutes of completing each SWORDFISH survey. Data from all SWORDFISH handtools is transmitted to a Microsoft Surface Tablet, included with all sales and to all authorized service providers. Data is displayed in real-time for the operator to see readings as each survey takes place.

Figure 40 Microsoft Surface Tablet-Based Data Capture with BlueTooth® Communication to SWORDFISH.

Intial address data entry, GPS location, photographs, and condition assessment are recorded and transmitted, directly to the Electro Scan Cloud as shown in Figure 40 & 41, with reports generated as shown in Figure 42.

Figure 41. Electro Scan's AWS CriticalH2O Cloud Configuration.

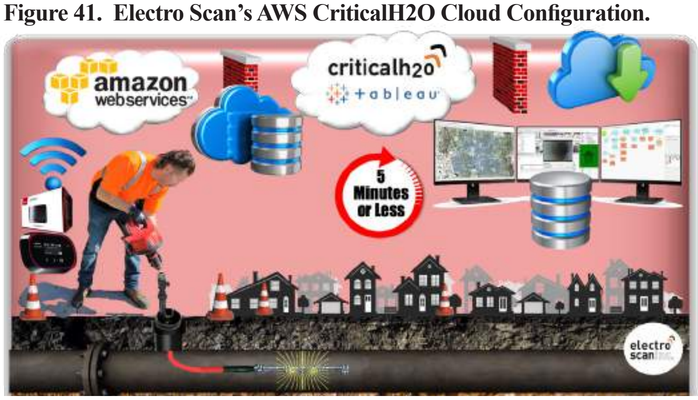
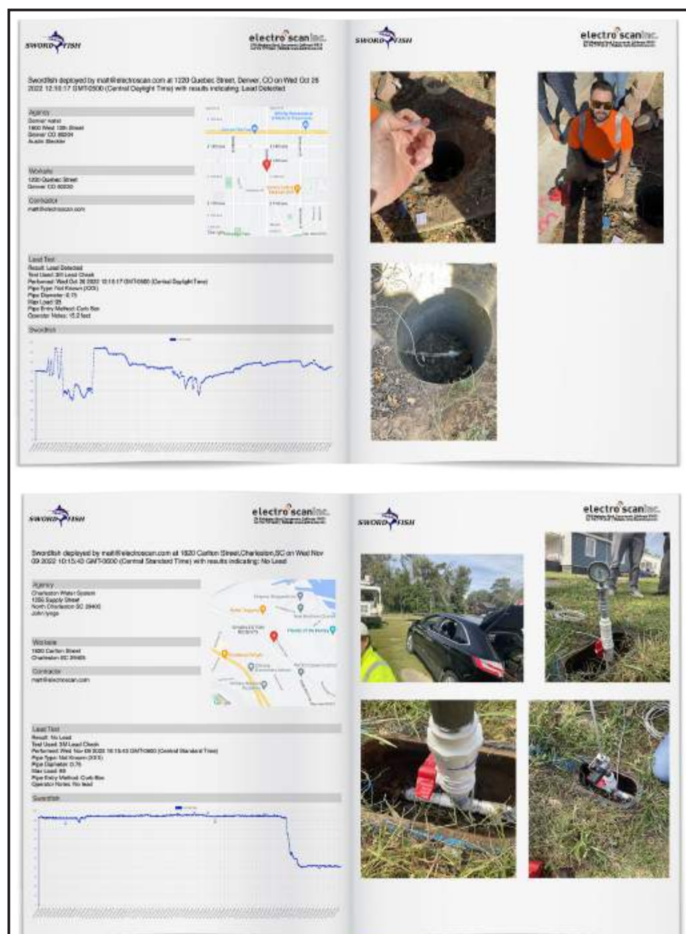


Figure 42. Example Reports Produced in the Field, in Minutes.

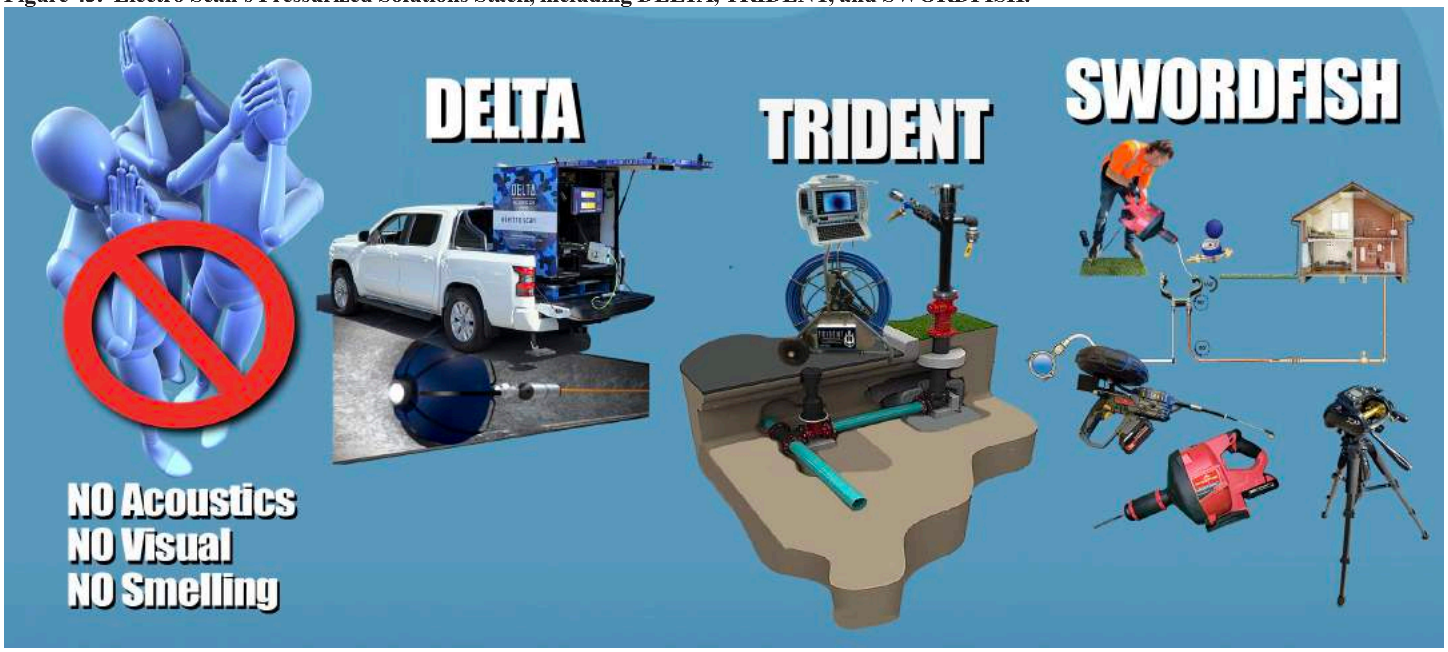


7.0 ELECTRO SCAN SOLUTIONS STACK

Founded in 2011, Electro Scan has been the leading company worldwide to adapt electrical resistance testing to the pipe condition assessment market. Operating in both gravity and pressurized water and sewer pipes, Electro Scan's award winning portfolio of machine-intelligent solutions shown in Figure 43 locates, confirms, and measures defects and pipe conditions not found by other techniques.

Headquartered in Northern California, several of the company's principals have over 40 years of experience (each) in the water business, allowing unprecedented access to the world's leading water utilities to sandbox its solutions. In many cases on a confidential basis. Electro Scan's significant and substantive approach has allowed the Company to help address climate change and adhere to emerging cleantech sustainability and resiliency standards

Figure 43. Electro Scan's Pressurized Solutions Stack, including DELTA, TRIDENT, and SWORDFISH.[16]



8.0 SUMMARY

Electrical resistance testing[17] in detecting buried pipe materials without digging provides an economical and sustainable approach to identifying toxic lead pipes in service lines.

Representing a transformational solution that replaces potholing or excavating, electrical resistance testing is expected to play a major role in the inventory of both Public Side and Homeowner Side water services as listed in Figure 45. In addition, its award winning solutions, winning the Best of Sensors Award for 2023 shown in Figure 46, is expected to streamline home sales by assuring buyers that harmful lead pipes have been eliminated from private properties and utility lines.

Figure 45. Required Service Line Inventory Categories to be Publicly Identifed After October 16, 2024, Impacting All Future Home Sales.

Figure 46. Recent Electro Scan SWORDFISH Award.

Dedicated to ongoing stewardship, governance, and resiliency of underground pipeline networks, customer satisfaction, and financial return.

About the Authors

Chuck Hansen, Chairman & CEO, Hansen Analytics & Electro Scan Inc.
Email: chuck.hansen@hansen.com | Mobile: 916-275-2921

BUILTWORLDS 2022 Top 50 Maverick and Environment & Energy 2021 Top 100 Leaders, Hansen is a pioneer in the field of public sector enterprise asset management, cloud computing, and pipeline condition assessment. Prior to founding Electro Scan Inc. in 2011, Hansen was Chairman & CEO, Hansen Information Technologies, which he founded in 1983 and sold in 2007 for $100 million to Golden Gate Capital. Former Chair, F36.20 ASTM Committee, Water and Sewer Inspection and Rehabilitation, Hansen is a current member AWWA Water Main Condition Assessment Committee. Holder of eighteen (18) patents in pipeline condition assessment, Hansen earned his BS, UC Berkeley, and MBA, UCLA, and is currently enrolled in Stanford University's Innovation and Entrepreneurship Program. Hansen is also an instrument-rated aircraft pilot and certified drone pilot. Appearing on the last two music CDs of Tower of Power, Hansen plays Baritone & Bass Sax with the band, when available.

Mike App, Executive Vice President
Email: mike@electroscan.com | Mobile: 917-817-0090

App is responsible for coordinating and managing all worldwide projects for Electro Scan Inc., including work with public sector, industrial, and oil & gas pipeline customers. App was responsible for the successful start-up and growth of London-based Electro Scan (UK) Ltd., expanding project implementation in the European Union, Qatar, United Arab Emirates, and the Kingdom of Saudi Arabia. Prior to joining Electro Scan in 2018, App was a Senior Project Manager with Precision Trenchless LLC where he was responsible for the largest UV Fiberglass installation in the U.S. and installed liners as large as 63" which was a North American record in 2016 and the World's first UV Cured NSF 61 liner, that same year. App earned his BS from St. John Fisher University and MA, International Business, University at Albany, SUNY.

Paul J. Pasko, III P.E., VIce President, International Business Development
Email: paul@electroscan.com | Mobile: 612-201-1867

Prior to joining Electro Scan in 2020, Pasko enjoyed a 24-year career with Short Elliott Hendrickson, Inc. (SEH) as a professional engineer, where he specialized in rehabilitation projects, including trenchless pipe repair and replacement of pressurized and gravity pipes. Pasko managed several early Electro Scan projects throughout the Midwest, including several large diameter inspection projects. Responsible for international Electro Scan projects, Pasko also assists large profile water and sewer Electro Scan projects requiring his specialized skills. Pasko earned his B.S. Civil Engineering, University of Illinois, Urbana-Champaign.

Basari Doshi, Manager, AI, Cloud, and Data Architecture
Email: bansari@electroscan.com | Mobile: 408-981-7066

Doshi is responsible for all aspects of Electro Scan's IT, including ASP.Net, ASP.Net Core, SQL Server, and JavaScript frameworks, and supplementing the team with outsourced program development located in India. Most recently, Doshi managed a software team that designed and developed the SWORDFISH field application and Critical H2O cloud application. Doshi received her BS, Computer Engineering, C.U. Shah College of Engineering and Technology, Wadwan City, India.

Matt Campos, Vice President, Pressurized Pipelines
Email: matt@electroscan.com | Mobile: 916-879-0686

Joining Electro Scan in 2014, Campos has completed more Electro Scan mileage than all other staff, combined. Completing worldwide projects, including work with water utilities in Australia, European Union, and United Arab Emirates, Campos spearheaded development of Electro Scan's SWORDFISH product. In addition to key benchmark testing, Campos also helped design the Company's pressurized insertion devices, including Electro Scan's small diameter pressure insertion tubes used to evaluate buried lead pipes. An avid Corvette automobile enthusiast, Campos has been responsible for designing and fabricating a number of specialty after-market projects. A named inventor for the patent-pending SWORDFISH, Campos continues to attract and implement new SWORDFISH customers throughout the U.S.

United States Environmental Protection Agency

Guidance for Developing and Maintaining a Service Line Inventory[16]

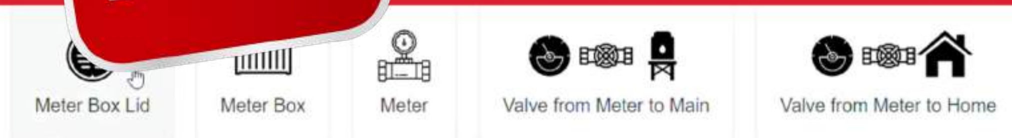
Inventory Requirement	40 CFR Citation	Information Provided in:
WATER SYSTEM REQUIREMENTS		
Inventory Specifications		
Material Classification: Classify each service line or portion of the service line where ownership is split as lead, galvanized requiring replacement, non-lead, or lead status unknown.	§141.84(a)(4)	Section 2.1
All service lines and ownership: Prepare an inventory that includes the system- and customer-owned portions of all service lines in the system's distribution system.	§141.84(a), (a)(2)	Section 2.2
Information to Identify Material: Use previous materials evaluation, construction and plumbing codes/records, water system records, distribution system inspections and records, information obtained through normal operations, and state-specified information.	§141.84(a)(3), (a)(5)	Sections 3.4 & Chapter 4
Deadlines for Submission		
Initial Inventory: Submit an initial inventory or demonstrate the absence of LSLs by October 16, 2024.	§141.80(a)(3)[1]	Section 1.3.2 & Section 6.4
Updates to Primacy Agency: Submit updated inventories to the primacy agencies annually or triennially based on lead tap sampling frequency, but not more frequently than annually Water systems that have demonstrated the absence of LSLs by October 16, 2024 are not required to provide an update. However, if these systems subsequently find any LSL or galvanized requiring replacement service line, they have 30 days to notify the state and prepare an updated inventory on a schedule established by the state.	§141.90(e)(3), §141.90(e)(3)(ii)	Sections 6.3 & 6.6
STATE REPORTING		
Reporting to EPA: For each water system, the number of lead, galvanized requiring replacement, and lead status unknown service lines in its distribution system, reported separately.	§142.15(c)(4)(iii)(D)	EPA will include additional details in the data entry instructions guidance for the LCRR.

Office of Water (4606M)
EPA 816-B-22-001
August 2022

electro scan

NEW

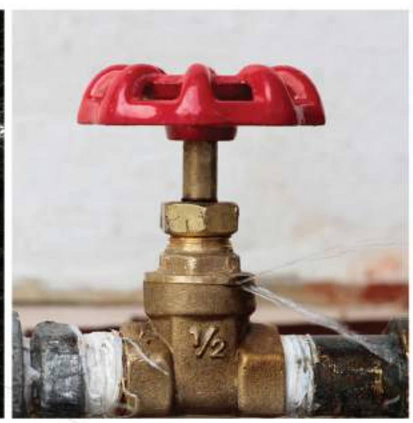
Condition Assessment and Leak Detection Module



Condition Assessment & Leak Detection Module

- Inventory Water Fixtures & Plumbing Components.
- Rate the Condition and Recommend Repairs or Replacements.
- Identify Existing Leaks to Solve Non-Revenue Water Equation.
- Automatically Generate Order Entry and Extended Invoice.
- Schedule Parts Delivery Associated with Specific Property Address.
- Upgrade Plumbing Fixtures to Increase Asset Life.

Available as an Optional Module to the Electro SWORDFISH Field Application.
Integrated to Amazon Web Service Critical H20 Application. powered by aws



Requires SWORDFISH Field Application and Critical H20 Cloud Application Licensing, including Microsoft® Surface® Tablet.

amazon web services

1745 Markston Road | Sacramento, California USA 95825 | Tel: +1 916.779.0660 | Email: info@electroscan.com | Web: www.ElectroScan.com
U.S. Patents and Patents Pending: 9143740, 9304055, 9933329, 10451515, 10557772, 10816431

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electroscan inc.

HANSEN

Hansen Analytics, LLC

1745 Markston Road, Sacramento, California 95825-4026
Tel: +1 916 779 0660 | Email: info@electroscan.com | Website: www.ElectroScan.com
Email: info@hansenanalytics.com | Website: www.HansenAnalytics.com