Tools for Lead Service Line Identification

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REVIEW ARTICLE

AWWA WATER SCIENCE

Lead service line identification: A review of strategies and approaches

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Abstract
Lead service lines (LSLs) represent the greatest source of lead in drinking water. Identifying the locations of LSLs can be challenging, and recent service line (SL) material surveys in Michigan, Illinois, Wisconsin, and Indiana found that on average the materials making up 16% of SLs in these states are unknown and may be lead. Given the large number of possible LSLs in the United States, new and pending regulatory requirements, LSL replacement costs, associated lead exposure risks, and the public's desire to reduce lead exposure, there is a need to rapidly and cost-effectively identify where LSLs are located, on public and private property. This review summarizes current industry LSL identification methods, including records screening, basic visual examination of indoor plumbing, water sampling, excavation, and predictive data analyses. A qualitative comparison of method cost, accuracy, disturbance, and other impacts is provided as a starting point for utilities that are developing a feasible approach for their specific needs/constraints. Lastly, an example stepwise approach to identify unknown SL materials is proposed.

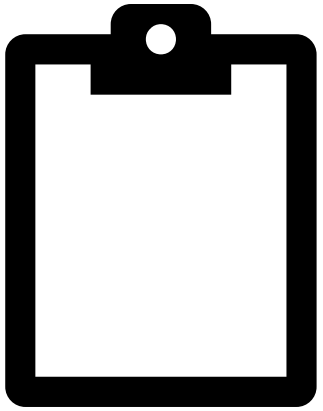
KEYWORDS
drinking water, identification, lead, pipe material, service line

https://awwa.onlinelibrary.wiley.com/doi/abs/10.1002/aws2.1226

LSL Estimates - National

National Surveys

- 3.3 million LSLs & 6.4 million lead gooseneck connections (Weston and EES 1990 based on 1988 AWWA survey)
- 6.1 million partial or full LSLs (Cornwell et al. 2016 based on AWWA 2011 & 2013 surveys)



Challenges

- Level of detail

  -- Smaller area analysis (i.e., # LSLs by US State or by US EPA Region) not possible (Cornwell et al., 2019)

  -- Discrepancies between recent national survey and individual state survey results (Perry et al., 2018)
- Low response rates in surveys, utility records (absent/ incomplete/ inaccurate), documentation of private LSL # (Wasserstrom et al., 2014)
- May not be statistically representative & responses difficult to verify (GAO, 2018)

LSL Estimates - States

Inventories range in format (3 general categories) and specifics within each category

- total number by material type
- interactive databases
- interactive maps showing LSL locations

State LSL inventories (ASDWA, 2019)

- 4 states (CA, IL, MI, and WI) require CWSs to provide summaries of service line materials
- 2 states (CA and OH) require CWSs to submit maps with likely LSL locations
- Voluntary surveys in other states

(e.g., IN, MA, NC, and WA)

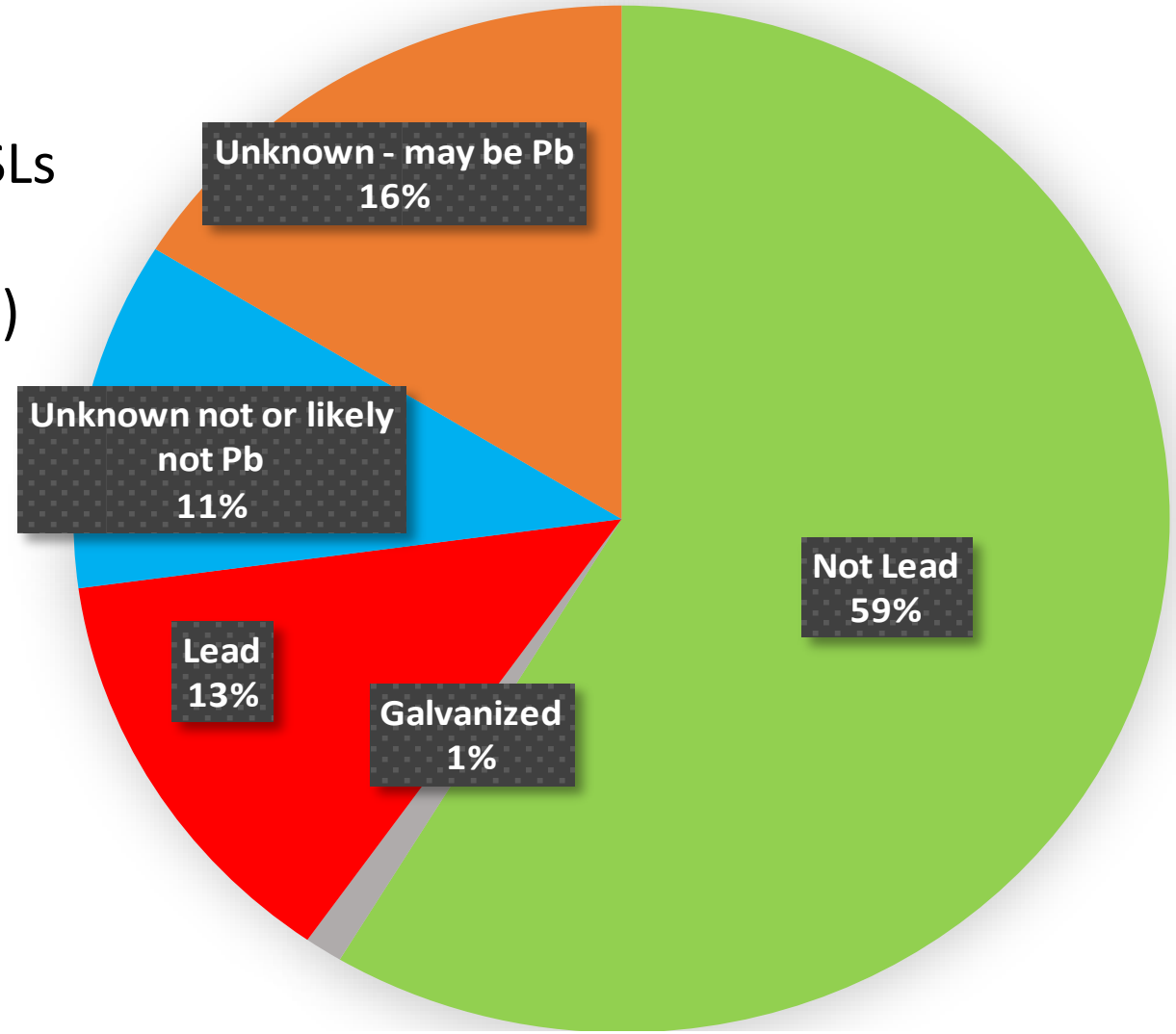
Material	WI (2014-19)	IL (2018-19)	CA (2018)	MI (2020)
Pb (any portion)	X	X	X	X
Pb fitting NOT on Pb pipe			X	
Pb fitting ON Pb pipe			X	
Galvanized	X	X	X	
Galvanized (previously connected to Pb)				X

ASDWA, 2019

ASDWA 2019. Developing lead service line inventories. Association of State Drinking Water Administrators. https://www.asdwa. org/wp-content/uploads/2019/08/ASDWA_Developing-LeadService-Line-Inventories.pdf

LSL Estimates - 4 States

- 13% LSLs
- 16% unknown SLs that may be Pb (> 1.58 million SLs)



Hensley, Bosscher, Triantafyllidou , Lytle, 2021, AWWA Water Science
"Lead Service Line Identification: A Review of Strategies and Approaches"

Publicly available data:

- Michigan EGLE (2020)
- Illinois EPA (2020)
- Wisconsin PSC (2020)
- Indiana, including lead goosenecks (via EDF, 2018)

LSL Identification tools

Preliminary Records Screening - phase out dates after 1986 SDWA lead ban, local/state plumbing codes, construction specifications

Community Records - SL installation records, Inspection and maintenance records, plumbing permits, meter installation records, others

Basic/Visual – visual scratch/magnet test or lead test kit

Tap Sampling - flushed, sequential, targeted

Excavation - traditional, vacuum

Predictive - geospatial, machine learning

Alternative Methods - electrical resistance, acoustic wave, eddy current, others

What the code language meant	Municipal code language
The entire service line was required to be made of lead.	WATER SERVICE…Sec. 23. All water pipes laid underground whether outside or inside the building and of a diameter less than two (2) inches shall be "extra strong" lead pipe.
Lead pipe was only required between the water main and the property line.	Pipe Material. Sec. 17. All service pipe, from the point of union with the main to the service stop inside of curb line shall be of lead, known and designated as "Extra Strong," weighing as follows per lineal foot:
The service line could be lead pipe, galvanized iron pipe or enameled iron pipe. However, a short lead pipe at least 18 inches long (commonly called a 'lead gooseneck') was required at the connection with the water main.	Sec. 14. PIPE, KIND USED, WATER COMMISSIONER TO PURCHASE.–Either lead, galvanized or enameled iron service pipes may be used at the option of the applicant. All lead and iron pipes must have sufficient strength to sustain a pressure of not less than two hundred (200) pounds to the square inch, and at the point of connection with the street main between the corporation cock and the coupling in the iron service pipe there must be at least eighteen (18) inches of lead pipe to retain rigidity of the iron pipe.
Lead was not required but was one of the types of pipes allowed.	Section 995. WATER CONNECTIONS FOR BUILDINGS: All pipes leaving the curb cock and used for connecting buildings with the City water system, shall be laid under ground, and at least eighteen (18) inches below the established grade, and shall be of lead or galvanized wrought iron or steel.
Lead was not required but was one of the types of pipes allowed.	Section 660 A. MATERIALS OF WATER PIPE AND FITTINGS. All water service and distribution pipes shall be of lead, galvanized wrought iron, galvanized steel, brass, copper, or cast iron with brass, copper, galvanized iron or galvanized or malleable iron fittings.

Miguel Del Toral, 2018

Phase Out Dates after 1986 SDWA Lead Ban

Region	State	Implemented Lead Ban	Method	Date Effective	Certification Signature	Requires Solder	Use of Flux	Lead Pipe	Notes
	Virginia	Yes	Uniform Statewide Plumbing code P-501.7.3, P-501.8.4 and P-2101.4	04/01/86	Governor	X	X	X	Adopted BOCA 04/15/87
	West Virginia	Yes	Legislative Rules, Dept. of Health, Plumbing Requirements 64 CSR 57	06/19/88	Governor	X	X	X	Requires PN
IV	Alabama	Yes	State Lead Ban Act, ADEM Admin. Code R.335-7-11-05	05/10/88 01/89	Governor/ADEM Director	X	X	X	
	Florida	Yes	Florida Statues, Subsection 553.11 and 553.06	06/30/88 12/88	Governor/DER Secretary	X	X	X	Dept. of Community Affairs to adopt amended State Plumbing Codes
	Georgia	Yes	State Plumbing Code, Section 402.1 Section 114.5 and Section 1109.1; State Regs.	03/87 01/89		X	X	X	
	Kentucky	Yes	State Plumbing Code, Section 17, PC-60-3	01/04/88	Commissioner of Bd. of Housing Mgt. D.w. Branch	X	X	X	Formalization of enforcement procedures with the Div. of Plumbing with the next few months. (11/90)
	Mississippi	Yes	Board of Health, Havir. Regs. Division 300 Water Supply, Part 301 Section 301.5(c)	04/13/88 05/88	Exec. Secy. Bd. of Health/Asst. Dir. Div. Water Supply	X	X	X	Requires PN
	North Carolina	Yes	State Plumbing Code Volume II, Section 602.4 (solder & Flux) Section 1008 (solder, pipe, flux)	03/87	Comm. of Insurance/head Public Water Supply Branch	X	X	X	Requires PN
	South Carolina	Yes	State SDWA, 61-58.4(1)	11/88	Chief Bureau DW Program	X	X	X	Requires PN; State Plumbing Codes expected to be amended during next legislative session.
	Tennessee	Yes	Tennessee Code Annotated, Title 68, Chapter 13, Part 7	03/18/88	Governor/Dir. Div. Water Supply	X	X	X	
V	Illinois	Yes	Illinois Administrative Code, Chapter 1, Section 890.620d	04/86	Dir. of IL EPA & Dir. of Dept. of Health, 09/13/88	X	X	X	
	Indiana	Yes	IN Plumbing Code, title 675, Sec 7 Subsec. 113g and Sec. 602, Subsec d	03/01/87	NA	X	X	X	
	Michigan	Yes	MI Construction Code Act	06/30/88	Governor 11/21/88	X	X	X	
	Minnesota	Yes	Minnesota Statues, Chapter 326, Section 326.371, MN Plumbing Code	06/01/85	Comm. of Health 09/27/88	X	X	X	Sellers of lead solder must display warning sign.
	Ohio	Yes	OH Basic Building Code	09/12/88	OH EPA & Governor 09/26/88	X	X	X	

EPA Region 4 States: 1987-1989

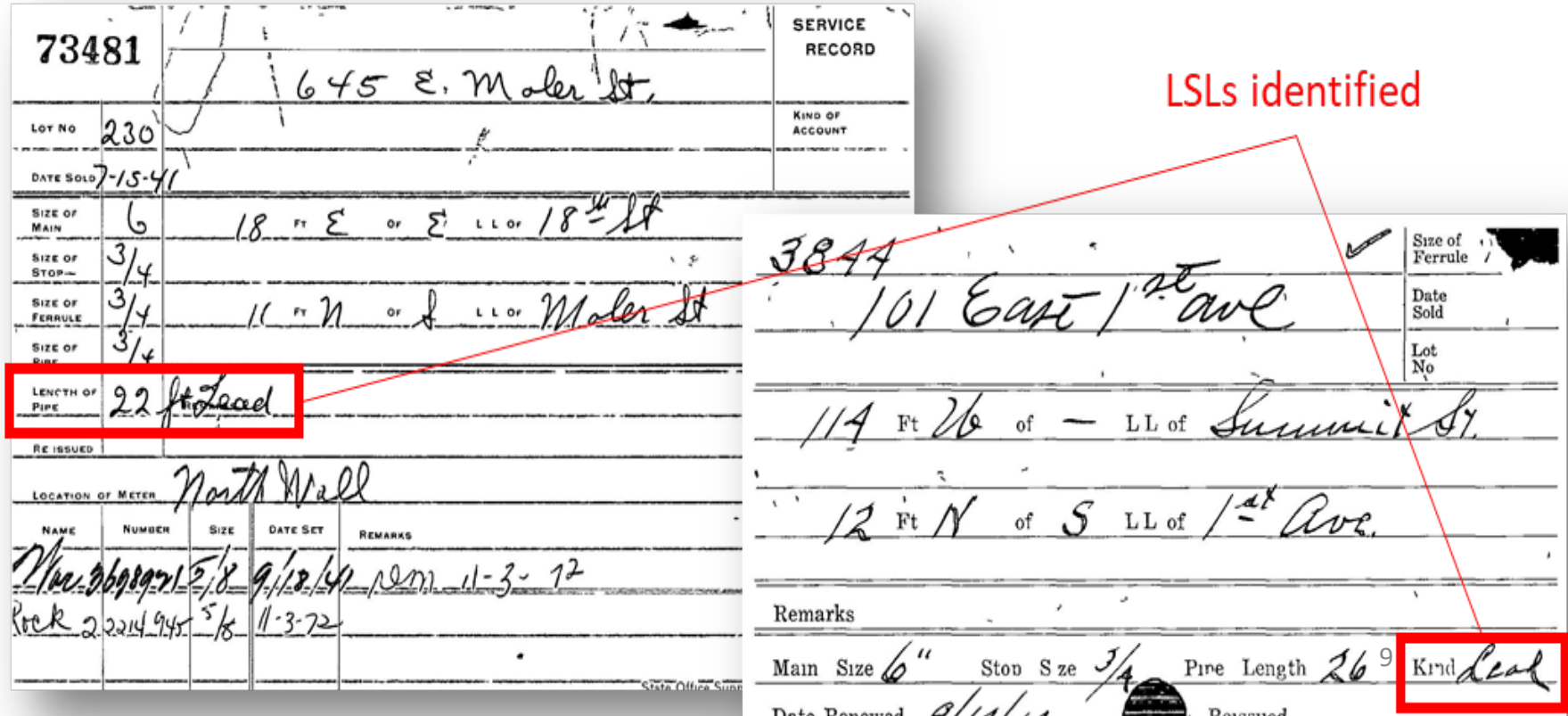
EPA 1991 LCR Guidance Manual Vol. 1 - Monitoring Lead ban provisions by state
Table 3-1 Summary of Lead Ban Provisions by State

Records Review

- SL installation records
- Inspection and maintenance records, including replacement or repairs of specific SLs and larger water main replacement projects
- Plumbing permits
- Meter installation records
- Property tax records
- Distribution system maps & drawings

Caution:

- Available?
- Legible?
- Complete?
- Accurate? Up-to-Date?



Basic/Visual

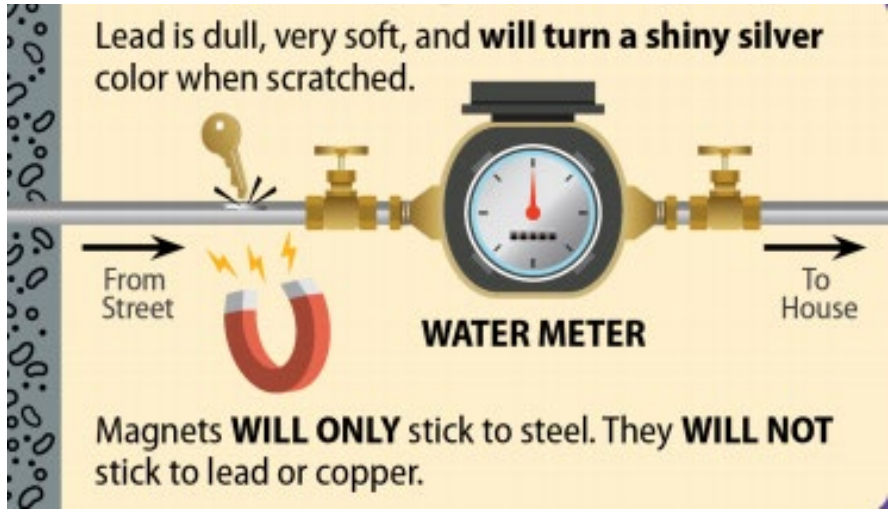
Scratch/Magnet Test

- Easy for residents if service line is accessible
- When scratched (coin, key, etc), the exposed outside pipe surface area will be shiny silver and flake off
- Magnet will not stick to Pb
- Can identify solid lead service lines but not lead-lined iron pipe

Lead Test kit

- Surface swab kits approved for lead paint change color after contacting lead surface

https://www.epa.gov/il/advice-chicago-residents-about-lead-drinking-water

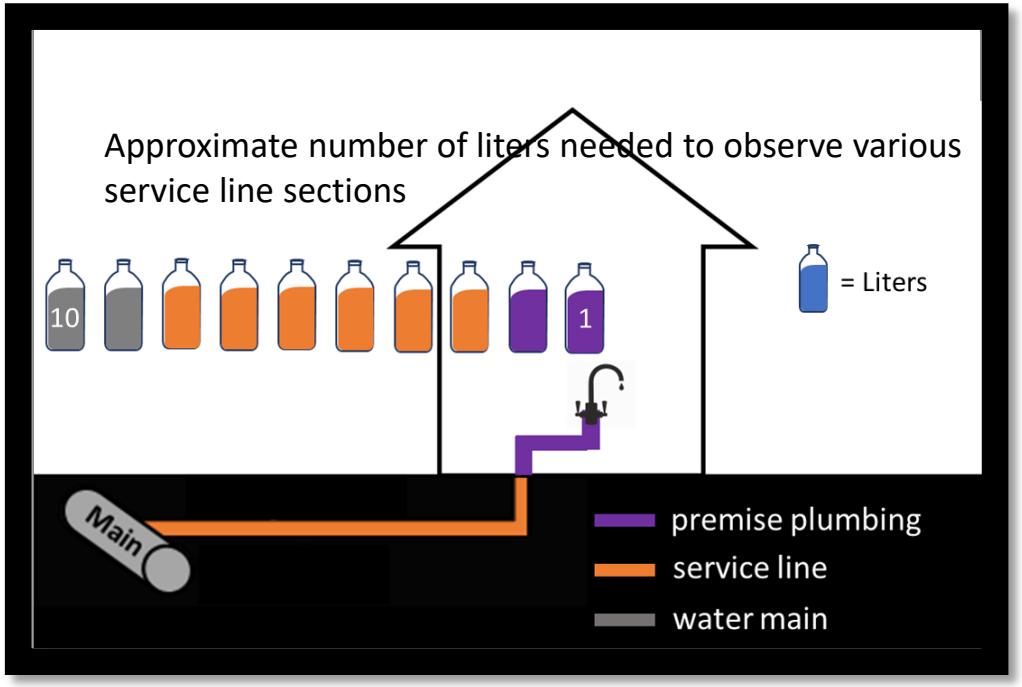


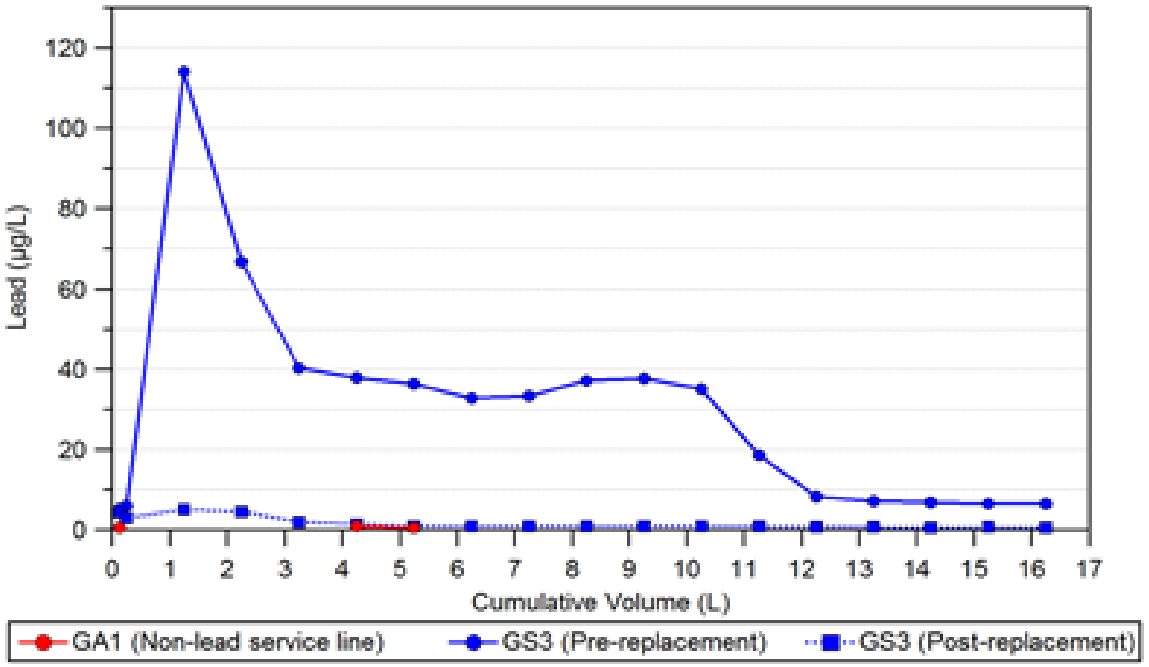
https://www.trentonnj.org/DocumentCenter/View/406/How-to-Find-Out-if-You-Have-a-Lead-Service-Line-PDF

EPA, 2021. Protect Your Tap: A Quick Check for Lead. Guide to help people identify LSLs in their homes: https://www.epa.gov/ground-water-and-drinking-water/protect-your-tap-quick-check-lead-0
National Public Radio., 2016. Do you have lead pipes in your home? https://apps.npr.org/find-lead-pipes-in-your-home/en/#intro

Tap sampling - Sequential (profile)

- Community-specific LSL ID water concentration thresholds needed
- High Pb "peaks" indicate likely LSL; Multi-metal analysis (e.g., Cu, Zn, Fe, Sn, Cd) helpful





Denver Water 2019 – 6 h stagnation profiles
- LSL indicated by maximum Pb ≥ 5 µg/L (lower Pb in water samples from homes with copper & Pb solder)
- 1/16 false negative. Confirmed LSL had Pb <1 µg/L in all samples (suspected lack of stagnation)

DC Water 2019 - 6 h stagnation profiles 10x1L
- LSL indicated by total Pb mass ≥ 5 µg and shape of profiles
- 2/30 false negatives

Tap sampling-Flushed or Targeted

Flushed: Sampling after a standardized time of flushing to distinguish LSL sites from non-lead

Canadian water systems without CCT: Cartier et al 2012 – 5min flush samples in Montreal

- ≥2 µg/L Pb high probability of LSL; confirmed if 2nd liter after 15min stagnation exceeded 3 µg/L and/or any >3µg/L for 3rd-6th liter 15MS profile
- ≤1 µg/L Pb very low probability of LSL

Denver Water 2019. If built <1952

- Average 5 µg/L Pb in 3-bottle set (1st draw, then 30 sec flush, and then another 30 sec flush) iconsidered LSL.

Targeted: Flush out the volume of water contained within premise plumbing, to collect liter of water contained within SL

Cartier et al 2012 – 2nd liter after 15min stagnation in Montreal

- 2nd liter chosen based on typical premise plumbing volumes in community
- ≥ 3 µg/L Pb was indicative of an LSL
- False negatives attributed to temperature effects, short LSLs, or larger premise plumbing volumes

Caution:

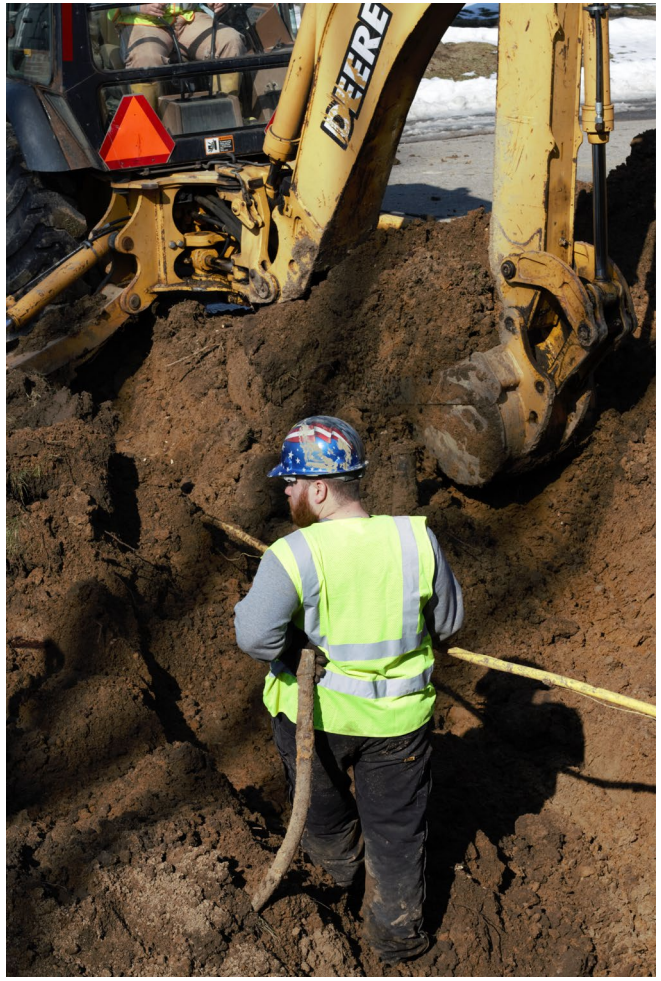
- Community-specific LSL ID water lead thresholds needed
- Community-specific SL volumes needed
- If Pb(IV) is controlling, or CCT truly optimized, LSL sites harder to differentiate through water sampling

Mechanical Excavation

- Backhoe or another mechanical excavator to dig a test pit down to the SL to expose it
- Reliable
- Costly
- Disturbance due to removal of topsoil, sidewalk, or other obstacles
- Higher accuracy rate than other excavation methods because a longer length of SL is exposed for observation, up to 10 ft in some instances

Caution:

- Cost, time and disturbance to dig SLs that are not lead



Vacuum Excavation

- Hydro-vacuum truck consists of a high-pressure water jet and industrial vacuum
- Jet loosens soil, vacuum removes it into a holding tank until the SL is exposed
- Smaller hole, less expensive, less disturbance

Caution:

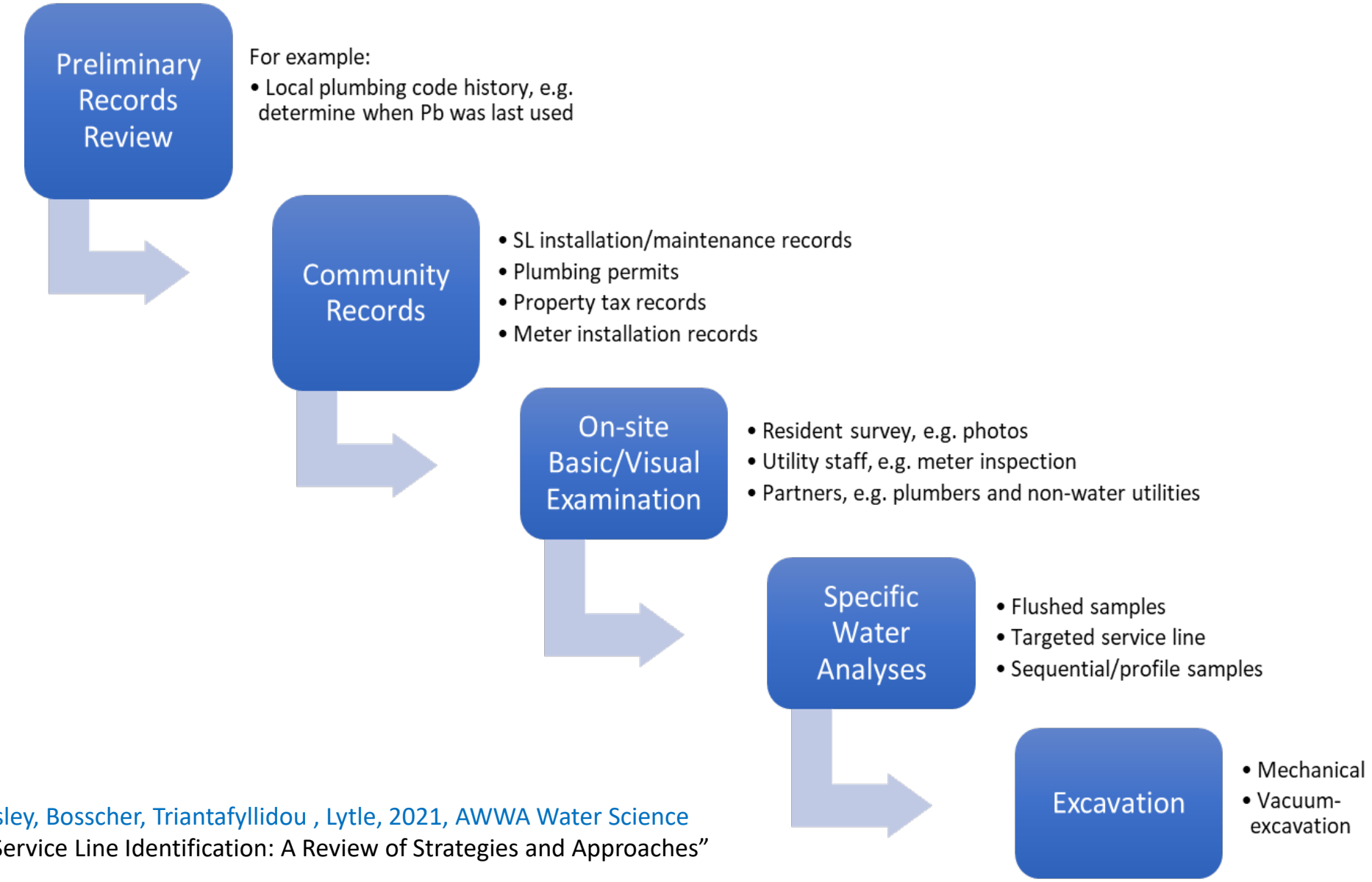
- Heterogeneous SL may have lead segments that could be missed by single hole

Relative pros/cons of LSL identification methods

LSL ID Method	Utility Cost			Disturbance		Impact to Homeowner			Utility Skills Required		Overall	
	Financial	Onsite time	Pre-/Post-time	Service line	Traffic flow	Water service disruption	Property damage	Homeowner involvement (includes pre-/post-time)	Technical interpretation	Labor	Time	Accuracy
Community Records Review	L or M (if digitized)	NA	M to H (L if digitized)	None	None	None	None	None	L to M	None	M	L to H
Basic/Visual Observations (on private-side)	L	L	L to M	None	None	None	None	L	L	L	L	M to H
Water Quality Sampling-Flushed	L	L	M to H	None	None	None	None	L	M	L	M	L to M
Water Quality Sampling-Sequential	M	L	M to H	None	None	M	None	M to H	M	L to M	M	L to H
Water Quality Sampling-Targeted	L	L	M to H	None	None	M	None	M to H	M	L to M	M	M
Excavation-Mechanical	H	H	M to H	H	M to H	H	H	L	L to M	H	H	H
Excavation-Vacuum	M to H	L to M	M to H	M	L to M	M to H	M to H	L	M	M to H	M	M to H

Hensley, Bosscher, Triantafyllidou , Lytle, 2021, AWWA Water Science
"Lead Service Line Identification: A Review of Strategies and Approaches"

Suggested stepwise SL identification approach



Hensley, Bosscher, Triantafyllidou , Lytle, 2021, AWWA Water Science
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Predictive

Geospatial

- spatial patterns and proximity to **known LSLs**
- predictions can be made for unsampled sites

Machine Learning

- uses a predictive self-learning algorithm with a geospatial model

Caution

- Relies on data inputs (e.g., LSL ID approaches on previous slides)
- Data quality and confidence?

Abernathy et al 2018. ActiveRemediation: The Search for Lead Pipes in Flint, Michigan (see also BlueConduit.com) https://arxiv.org/abs/1806.10692

ASDWA 2020. Predictive Tools for Lead Service Line Inventories webinar https://www.asdwa.org/past-events-webinarrecordings/?mgi_158=19130/predictive-tools-for-lead-service-line-inventories

Alternative Methods

Some lab/field evaluation

- Electrical resistance
- Acoustic Wave
- Eddy current

Conceptual

- Metal detectors
- Magnetometers/Gradiometers –locate iron, not lead/copper
- Ground penetrating radar
- Electrical conductivity

Arnette, V. (2020). Lead service line identification, inventories, and replacement. *Water Research Foundation*. Webcast at https://www.waterrf.org/sites/default/files/file/2020-06/WRF%20LSL%20Inventory%20Webcast_FINAL.pdf

Ballinger, R., Coates, D., Jallouli, A., Lu, H., & Roy, V. (2020). *Evaluation of lead pipe detection by electrical resistance measurement.* Water Research Foundation, Project No. 4698.Webcast at https://www.waterrf.org/sites/default/files/file/2020-06/WRF%20LSL%20Inventory%20Webcast_FINAL.pdf

Bukhari, Z., Ge, S., Chiavari, S., & Keenan, P. (2020). *Lead service line identification techniques.* Water Research Foundation, Project No. 4693. Report for members https://www.waterrf.org/resource/lead-service-line-identification-techniques

Deb, A., Hasit, Y., & Grablutz, F. (1995). *Innovative techniques for locating lead service lines.* American Water Works Research Foundation. Report for members https://www.waterrf.org/resource/innovative-techniques-lead-service-line-location

Alternative Methods – Cumulative (Passive) Sampler

Lead Evaluation and Assessment Device (LEAD) →**EPA research in-progress**
– Install POU filter at kitchen tap, use per manufacturer, return cartridge for analysis
– Extract total lead mass (µg) accumulated on the POU filter
– Hypothesis: Average lead mass in home with LSL>> home that never had a LSL

Caution:
- Relies on ability to extract the lead mass
- Community-specific threshold to be developed based on POUs from known LSL and known non-LSL

Summary

- Uncertainty in the estimates of LSLs present
- Increased need for LSL inventories
- Larger drinking water utilities and/or utilities with State requirements have developed inventories
- Variety of LSL ID tools available, combination of tools is typically recommended
- Selection criteria may include cost, skill (labor, technical interpretation), disruption to homeowner (water service interruption, property damage, involvement), disturbance (service line, traffic flow), overall time and accuracy
- As more utilities share their experiences, the pros/cons will be better defined in practice
- Solutions driven research opportunity

National Problem of Lead Service Line Identification Deserves Large Effort

How can we work together?

- Solutions-driven research (SDR) is a specific ORD research approach that emphasizes stakeholder engagement to develop research that is directly along the path to a solution or decision
- Stakeholder engagement is critical throughout the research process, informing problem formulation, research planning, implementation, dissemination, and evaluation
- The research focuses on solutions-oriented outputs with specific identified stakeholders

SDR to assess LSL identification technologies in collaboration with stakeholders & communities:

Goal*: Evaluate the use of accurate, non-invasive and cost-effective LSL identification technologies in laboratory and field conditions in collaboration with stakeholders and communities

- EPA OW
- EPA Regions
- AWWA
- ASDWA
- WRF

Possibly

- Tech developers
- Communities
- Nonprofits
- Others

EPA ORD Core Teams

Coordinator: Simoni Triantafyllidou

Science: Darren Lytle
Robert Janke
Regan Murray

Translational Science: Megan Christian

Communications: Lahne Mattas Curry
Michelle Latham

How we communicate our lead research & technical support

Peer-review journal articles:

Our journal articles now become freely accessible after about a year of publication in a journal!

- Hensley, K., Bosscher, V., Triantafyllidou, S., Lytle, D. Lead Service Line Identification: A Review of Strategies and Approaches. AWWA Water Science, 2021 https://awwa.onlinelibrary.wiley.com/doi/abs/10.1002/aws2.1226
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- Triantafyllidou, S., Burkhardt, J., Tully, J., Cahalan, K., DeSantis, M., Lytle, D., Schock, M. Variability and Sampling of Lead (Pb) in Drinking Water: Assessing Potential Human Exposure Depends on the Sampling Protocol. Environment International, 2021. https://doi.org/10.1016/j.envint.2020.106259 **[JOURNAL OPEN ACCESS]**
- Doré, E., Lytle, D.A., Wasserstrom, L., Swertfeger, J., Triantafyllidou, S. Field Analyzers for Lead Quantification in Drinking Water Samples. Critical Reviews in Environmental Science and Technology, 2020. https://doi.org/10.1080/10643389.2020.1782654
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- DeSantis, M.K., Schock, M. R. Tully, J., Bennett-Stamper, C. Orthophosphate Interactions with Destabilized PbO2 Scales. Environmental Science and Technology, 2020. https://pubs.acs.org/doi/abs/10.1021/acs.est.0c03027
- Lytle, D.A., Schock, M. R., Formal, C., Bennett-Stamper, C., Harmon, S., Nadagouda, M.N., Williams, D., DeSantis, M. K., Tully, J., Pham, M. Lead Particle Size Fractionation and Identification in Newark, New Jersey's Drinking Water. Environmental Science and Technology, 2020 https://pubs.acs.org/doi/10.1021/acs.est.0c03797
- Tully, J.; DeSantis, M. K.; Schock, M. R. Water Quality–Pipe Deposit Relationships in Midwestern Lead Pipes. AWWA Water Science 2019, 1 (2), e1127. https://doi.org/10.1002/aws2.1127**[JOURNAL OPEN ACCESS in March 2019],** https://www.ncbi.nlm.nih.gov/pmc/articles/PMC7336533/ **[EPA PUBLIC ACCESS in July 2020]**

How we communicate our lead research & technical support

EPA Science Matters Newsletters (Freely accessible at https://www.epa.gov/sciencematters)

- Scaling Back: EPA Researchers Help Communities Protect Drinking Water Systems from Lead, *April 8, 2019*
- Revealing the Complicated Nature of Tap Water Lead Contamination: A Madison, Wisconsin, Case Study, *July 30, 2018*
- Identifying the Best Lead Sampling Techniques to Protect Public Health, *October 22, 2018*

Fact Sheets (Freely accessible)

- How to Identify Lead Free Certification Marks for Drinking Water System and Plumbing Products
- Consumer Tool for Identifying POU Drinking Water Filters Certified to Reduce Lead

Workshops

- EPA 18th Small Drinking Water Systems Annual Workshop virtually August 30-September 2, 2021

  -SESSION T1: Corrosion on August 30, 2021 (4 contact hours)

  -SESSION 3A on August 31—MONITORING & DISTRIBUTION II: Corrosion and Lead (1.75 Contact Hours)

Technical Support Summaries, including lead (Freely accessible)

Technical Support Summary, Water Infrastructure Division, Fiscal Year 2019

Webinars

- ORD/OW Small Systems Monthly Webinar Series

  Lead Management in Homes and Buildings, DeSantis, Tully, and Latham, March 26, 2019

Thank you

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