Sampling drinking water for lead- How the protocol used impacts results

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General occupation?

A. Student
B. Public Health Professional
C. Consultant
D. Health Care Professional
E. Researcher
F. Environmental Protection
G. Academic
H. None of the above

I am aware of drinking water lead contamination risks:

A. As part of my job training/experience
B. As a tenant/homeowner aware of plumbing materials
C. As a water consumer/parent with personal experience
D. As a water consumer/parent reading news about other communities
E. No, I am not particularly aware/familiar
F. Other

Lead

- Naturally occuring element
- Toxic to humans and animals
- Used extensively in the USA prior to various regulations outlawing its use
  - Phase out of leaded gasoline began in 1970
  - Ban on lead in residential paint in 1978
  - Ban on lead in plumbing in 1986
  - Ban of lead solder in food cans 1995

Elevated Blood Lead Levels in Chil With the Flint Drinking Water Cris Analysis of Risk and Public Health

Mona Hanna-Attisha, MD, MPH, Jenny LaChance, MS, Richard Casey Sadler, PhD, and Allison C

Objectives. We analyzed differences in pediatric elevated blood lead level incidence before and after Flint, Michigan, introduced a more corrosive water source into an aging water system without adequate corrosion control.

Methods. We reviewed blood lead levels for children younger than 5 years before (2013) and after (2015) water source change in Greater Flint, Michigan. We assessed the percentage of elevated blood lead levels in both time periods, and identified geographical locations through spatial analysis.

Results. Incidence of elevated blood lead levels increased from 2.4% to 4.9% ($P<.05$) after water source change, and neighborhoods with the highest water lead levels experienced a 6.6% increase. No significant change was seen outside the city. Geospatial analysis identified disadvantaged neighborhoods as having the greatest elevated blood lead level increases and informed response prioritization during the now-declared public health emergency.

Conclusions. The percentage of children with elevated blood lead levels increased after water source change, particularly in socioeconomically disadvantaged neighborhoods. Water is a growing source of childhood lead exposure because of aging infrastructure. (*Am J Public Health.* Published online ahead of print December 21, 2015: e1–e8. doi:10.2105/AJPH.2015.303003)

Elevated Blood Lead in Young Children Due to Lead-Contaminated Drinking Water: Washington, DC, 2001–2004

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Received October 2, 2008. Revised manuscript received January 13, 2009. Accepted January 16, 2009.

Incidence of EBL (blood lead ≥ 10 μg/dL) for children aged ≤ 1.3 years in Washington, DC increased more than 4 times comparing 2001–2003 when lead in water was high versus 2000 when lead in water was low. The incidence of EBL was highly correlated (R^2 = 0.81) to 90th percentile lead in water lead levels (WLLs) from 2000 to 2007 for children aged ≤ 1.3 years. The risk of exposure to high water lead levels varied markedly in different neighborhoods of the city. For children aged ≤ 30 months there were not strong correlations between WLLs and EBL, when analyzed for the city as a whole. However, the incidence of EBL increased 2.4 times in high-risk neighborhoods, increased 1.12 times in moderate-risk neighborhoods, and decreased in low-risk neighborhoods comparing 2003 to 2000. The incidence of EBL for children aged ≤ 30 months also deviated from national trends in a manner that was highly correlated with 90th percentile lead in water levels from 2000 to 2007 (R^2 = 0.83) in the high-risk neighborhoods. These effects are consistent with predictions based on biokinetic models and prior research.

Lead In the News

In Echo of Flint, Mich., Water Crisis Now Hits Newark

HEALTH & FITNESS

University Park residents express anger, fear over lead-contaminated water

Georgia to Test 800 Schools for Lead in Drinking Water

ROWAN COUNTY

3 more samples of drinking water from homes in part of Rowan contain elevated levels of lead

County leaders urging residents to participate in testing

Tests find potentially toxic levels of lead in some Steamboat drinking water

Deceptively Simple Citizen Question…

Am I being exposed to lead in my drinking water?

Is lead present at the point of consumption?

Water leaves the treatment plant with no Pb

However, the water must travel through the distribution system and premise plumbing before making it to a kitchen tap

Ban on Lead Plumbing

Reduction of Lead in Drinking Water Act (RLDWA)/Use of Lead Free Pipes, Fittings, Fixtures, Solder, and Flux for Drinking Water

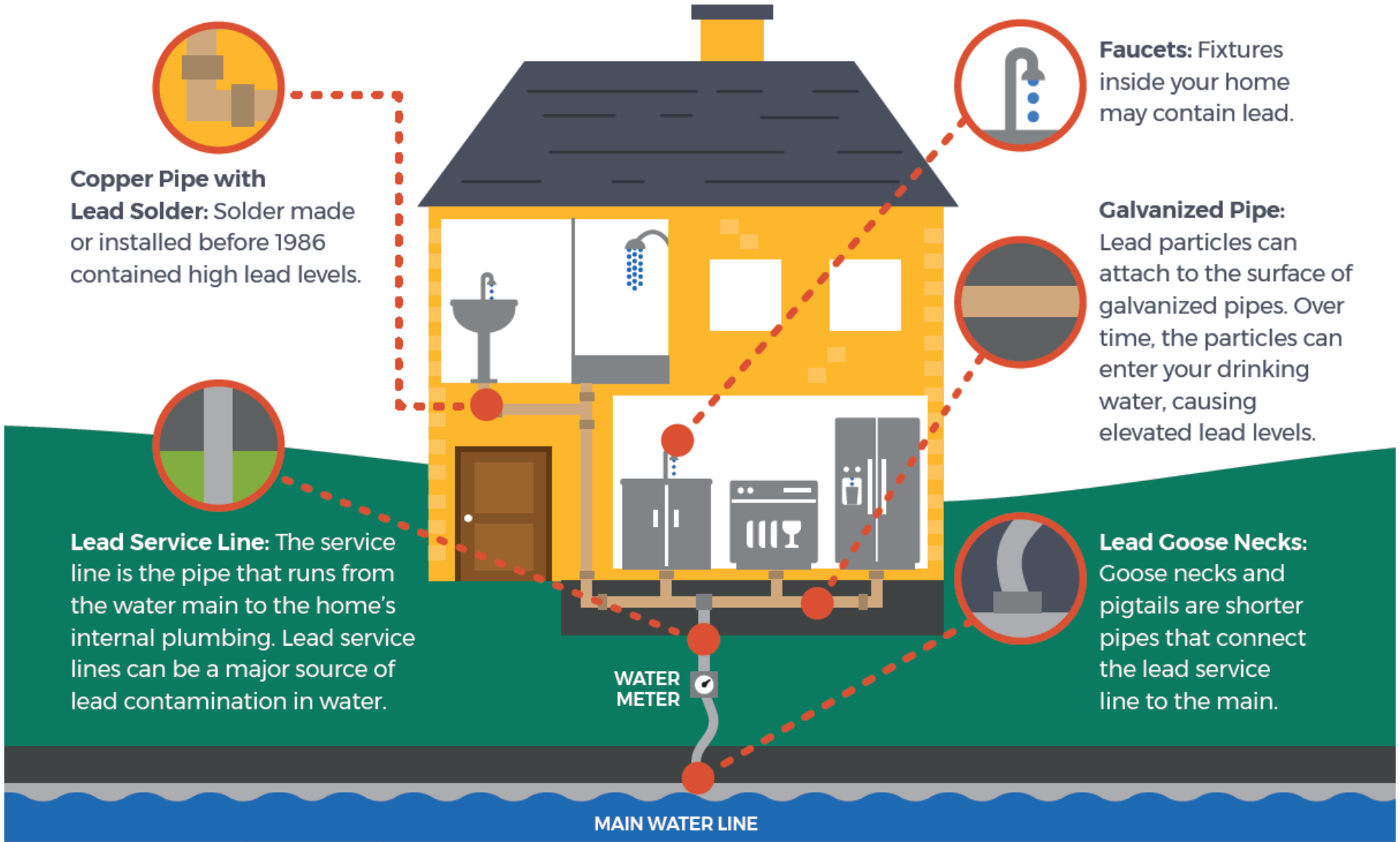
- The Act prohibits the “use of any pipe, any pipe or plumbing fitting or fixture, any solder, or any flux, after June 1986, in the installation or repair of (i) any public water system; or (ii) any plumbing in a residential or non-residential facility providing water for human consumption, that is not lead free.”

However, “lead free” has had various definitions

- **1986**: defined as solder and flux with no more than 0.2% lead and pipes with no more than 8%
- **2011**: defined as an average lead content of 0.25% across the wetted surfaces of plumbing products (ie. Pipes, fittings and fixtures), but did not require product testing or third-party verification.
- **2020**: defined as a weighted average of 0.25% lead calculated across the wetted surfaces of a pipe, pipe fitting, plumbing fitting, and fixture and 0.2% lead for solder and flux. Manufacturers and importers must certify that their products meet this requirement through third-party verification.

Sources of **LEAD** in Drinking Water

Taken from: https://www.epa.gov/ground-water-and-drinking-water/infographic-lead-drinking-water



Approximately how many lead service lines are left in the United States?

A. <300,000
B. 300,000-1 million
C. 3-5 million
D. 6-10 million

Leaded Plumbing Today

An estimated 6.1-10 million LSLs remain in the U.S.

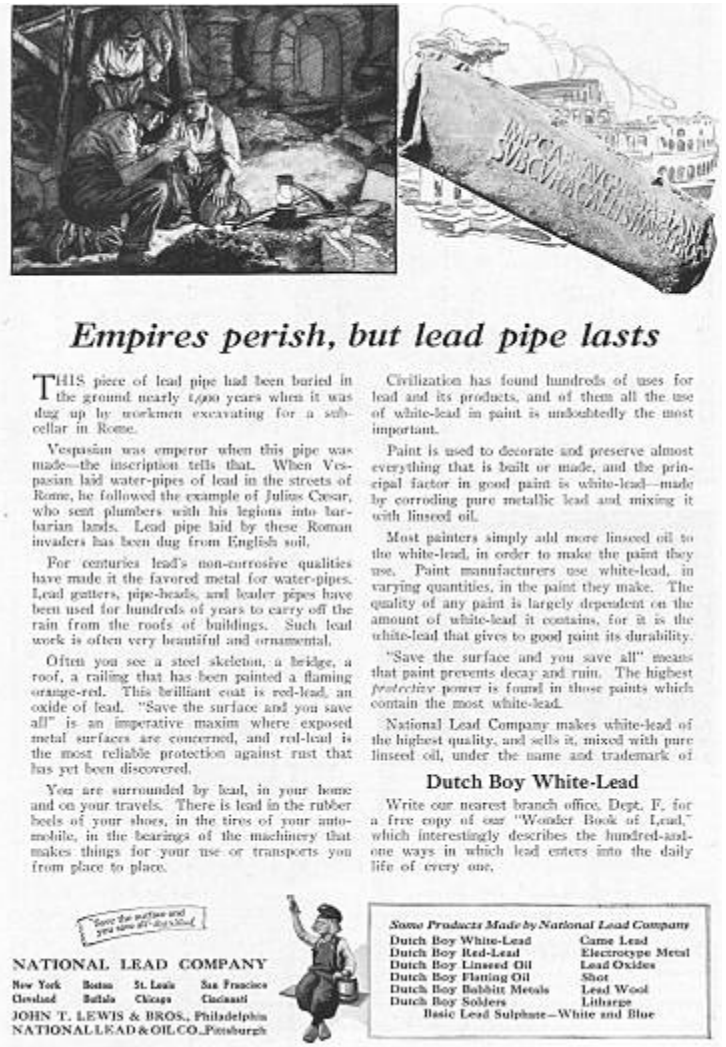
City	Estimated Number of LSLs
Chicago, IL[1]	385,000
Detroit, MI[2]	80,000
Cincinnati, OH[3]	55,000
South Bend, IN[4]	24,000
St. Paul, MN[5]	14,000
Racine, WI[6]	11,000

2.63 million[7] LSLs estimated in EPA Region 5

1920s: LSLs were being phased out in many cities

1938: the Lead Industries Association promoted leaded plumbing in Region 5 states and hosted classes to re-train plumbers to work with lead [8]

In Region 5 LSLs were still being installed as late as 1986



Empires perish, but lead pipe lasts

THIS piece of lead pipe had been buried in the ground nearly 1,900 years when it was dug up by workmen excavating for a sub-cellar in Rome.

Vespasian was emperor when this pipe was made—the inscription tells that. When Vespasian laid water-pipes of lead in the streets of Rome, he followed the example of Julius Cæsar, who sent plumbers with his legions into barbarian lands. Lead pipe laid by these Roman invaders has been dug from English soil.

For centuries lead's non-corrosive qualities have made it the favored metal for water-pipes. Lead gutters, pipe-heads, and leader pipes have been used for hundreds of years to carry off the rain from the roofs of buildings. Such lead work is often very beautiful and ornamental.

Often you see a steel skeleton, a bridge, a roof, a railing that has been painted a flaming orange-red. This brilliant coat is red-lead, an oxide of lead. "Save the surface and you save all" is an imperative maxim where exposed metal surfaces are concerned, and red-lead is the most reliable protection against rust that has yet been discovered.

You are surrounded by lead, in your home and on your travels. There is lead in the rubber heels of your shoes, in the tires of your automobile, in the bearings of the machinery that makes things for your use or transports you from place to place.

Civilization has found hundreds of uses for lead and its products, and of them all the use of white-lead in paint is undoubtedly the most important.

Paint is used to decorate and preserve almost everything that is built or made, and the principal factor in good paint is white-lead—made by corroding pure metallic lead and mixing it with linseed oil.

Most painters simply add more linseed oil to the white-lead, in order to make the paint they use. Paint manufacturers use white-lead, in varying quantities, in the paint they make. The quality of any paint is largely dependent on the amount of white-lead it contains, for it is the white-lead that gives to good paint its durability.

"Save the surface and you save all" means that paint prevents decay and ruin. The highest *protective* power is found in those paints which contain the most white-lead.

National Lead Company makes white-lead of the highest quality, and sells it, mixed with pure linseed oil, under the name and trademark of

Dutch Boy White-Lead

Write our nearest branch office, Dept. F, for a free copy of our "Wonder Book of Lead," which interestingly describes the hundred-and-one ways in which lead enters into the daily life of every one.

NATIONAL LEAD COMPANY

New York Boston St. Louis San Francisco
Cleveland Buffalo Chicago Cincinnati

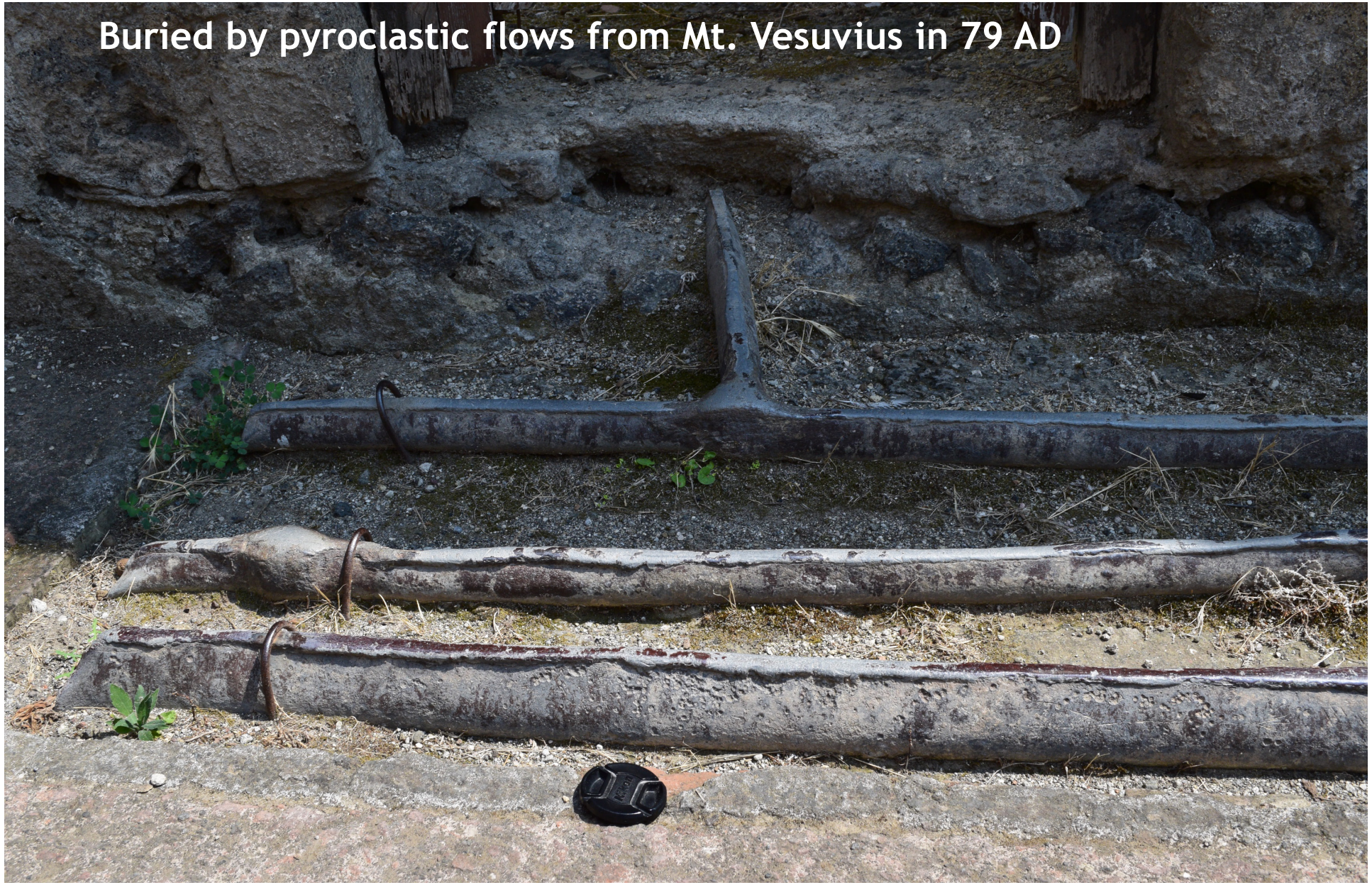
JOHN T. LEWIS & BROS., Philadelphia
NATIONAL LEAD & OIL CO., Pittsburgh

Some Products Made by National Lead Company

Dutch Boy White-Lead	Came Lead
Dutch Boy Red-Lead	Electrotype Metal
Dutch Boy Linseed Oil	Lead Oxides
Dutch Boy Flating Oil	Shot
Dutch Boy Babbit Metals	Lead Wool
Dutch Boy Solders	Litharge

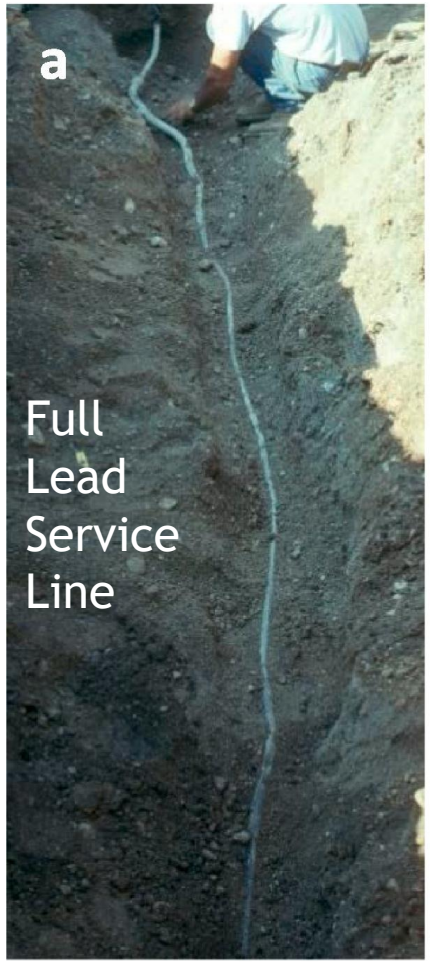
Basic Lead Sulphate—White and Blue

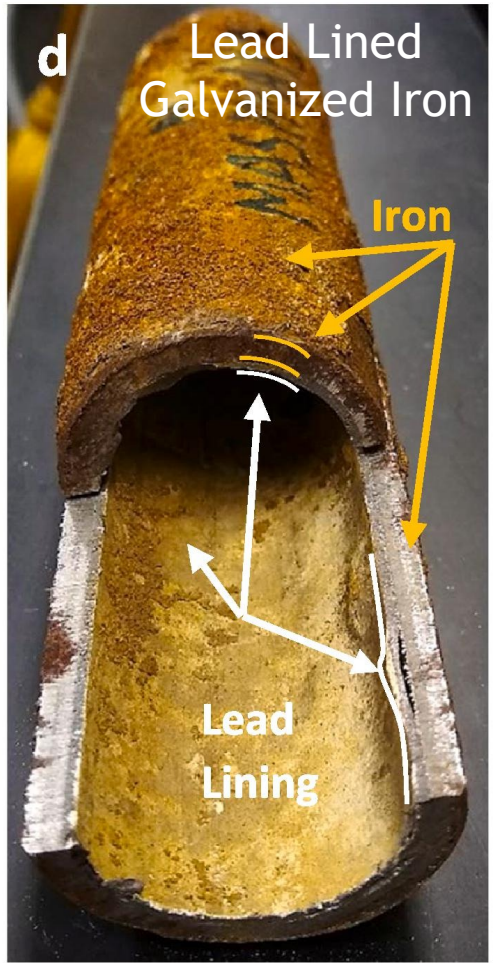
[1](Hawthorne & Matuszak, 2016) [2](Detroit Water and Sewerage Department, 2021) [3](City of Cincinnati, 2021) [4](Indiana Active CWS LSL Survey, 2018) [5](Benson, 2016) [6](Racine Water Utility, 2021) [7](Cornwell et al, 2016) [8](Rabin, 2008)



City of Herculaneum (Ercolano, Campania, Italy)

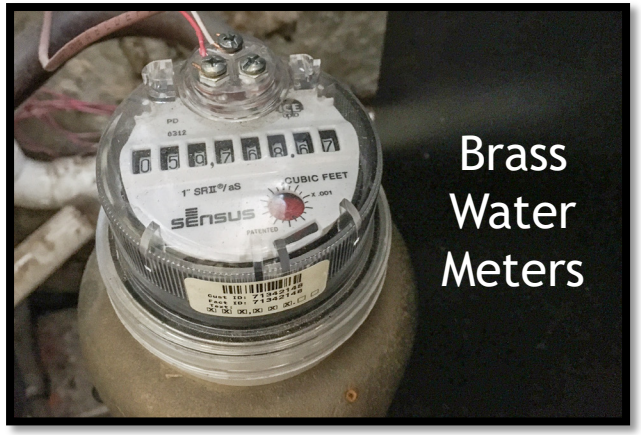
Sources of Pb in Drinking Water

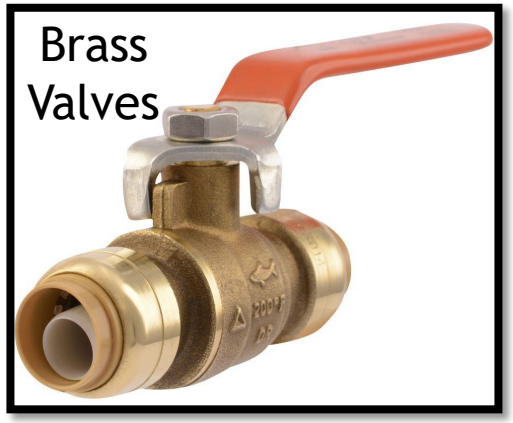




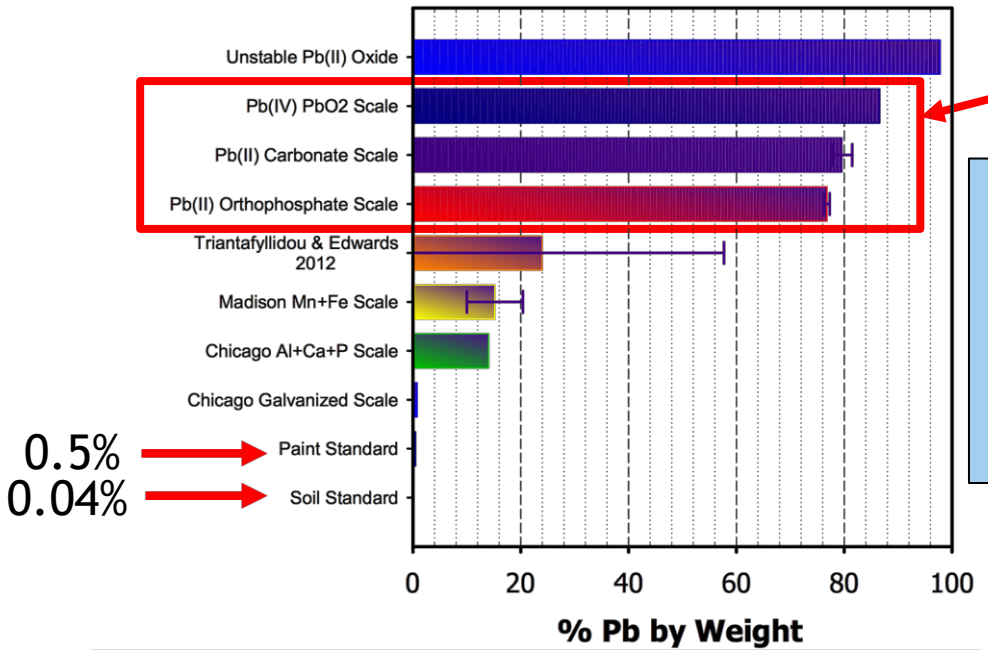
Triantafyllidou et al., 2021

Sources of Pb in Drinking Water





Some Pipe Scale Particles Have More Lead Than Pb in Paint, Soil, or Hazardous Waste



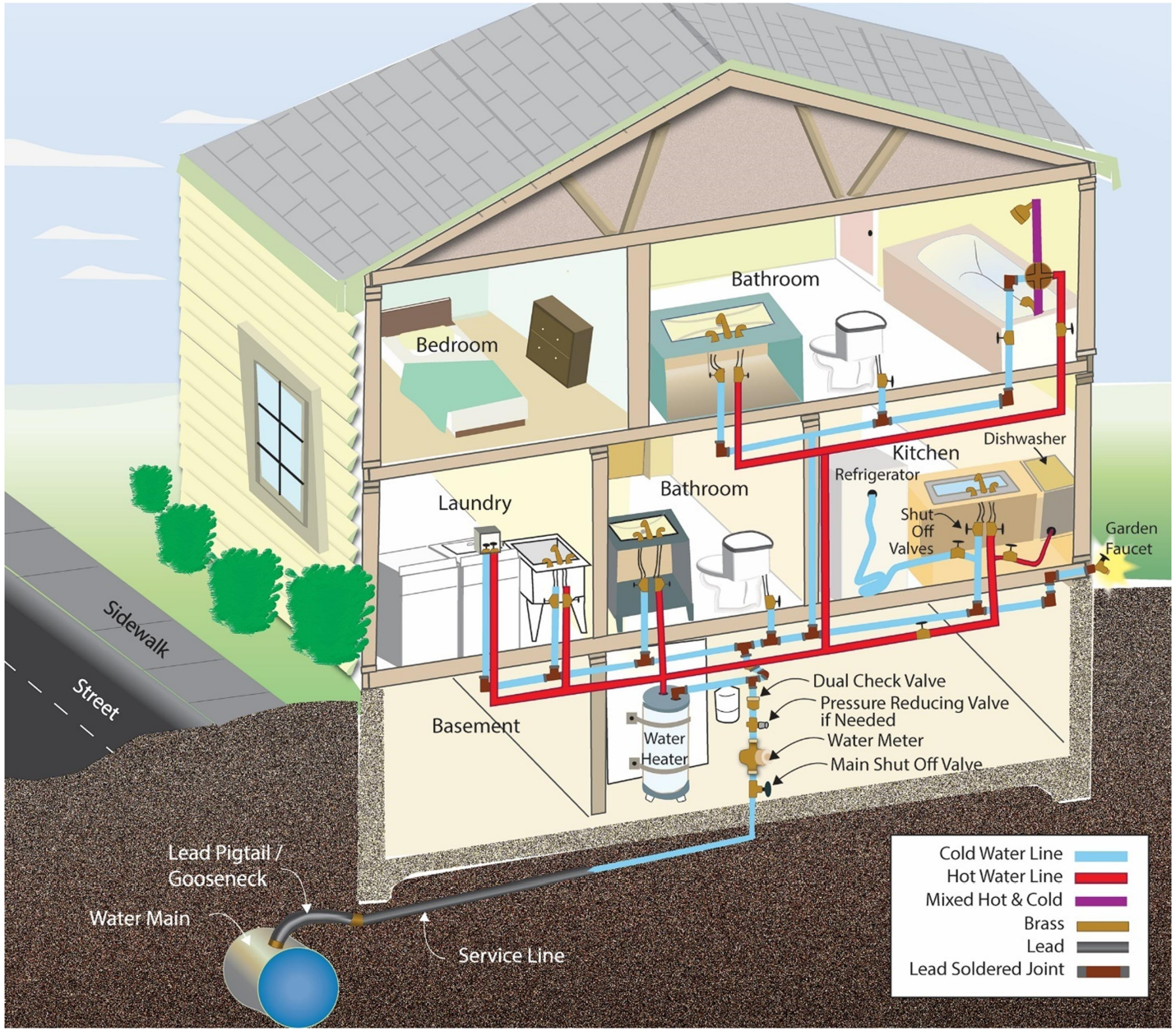
GOOD CORROSION CONTROL

Erosion of particles from pipe scales is inevitable.

Release of small particles can potentially result in greater relative exposure from drinking water than paint or soils

Resource Conservation and Recovery Act (RCRA) deems a waste “hazardous” if it leaches ≥ 5 mg/L Pb (or 0.0005 wt %)

Lead sources are not uniformly distributed throughout a residence



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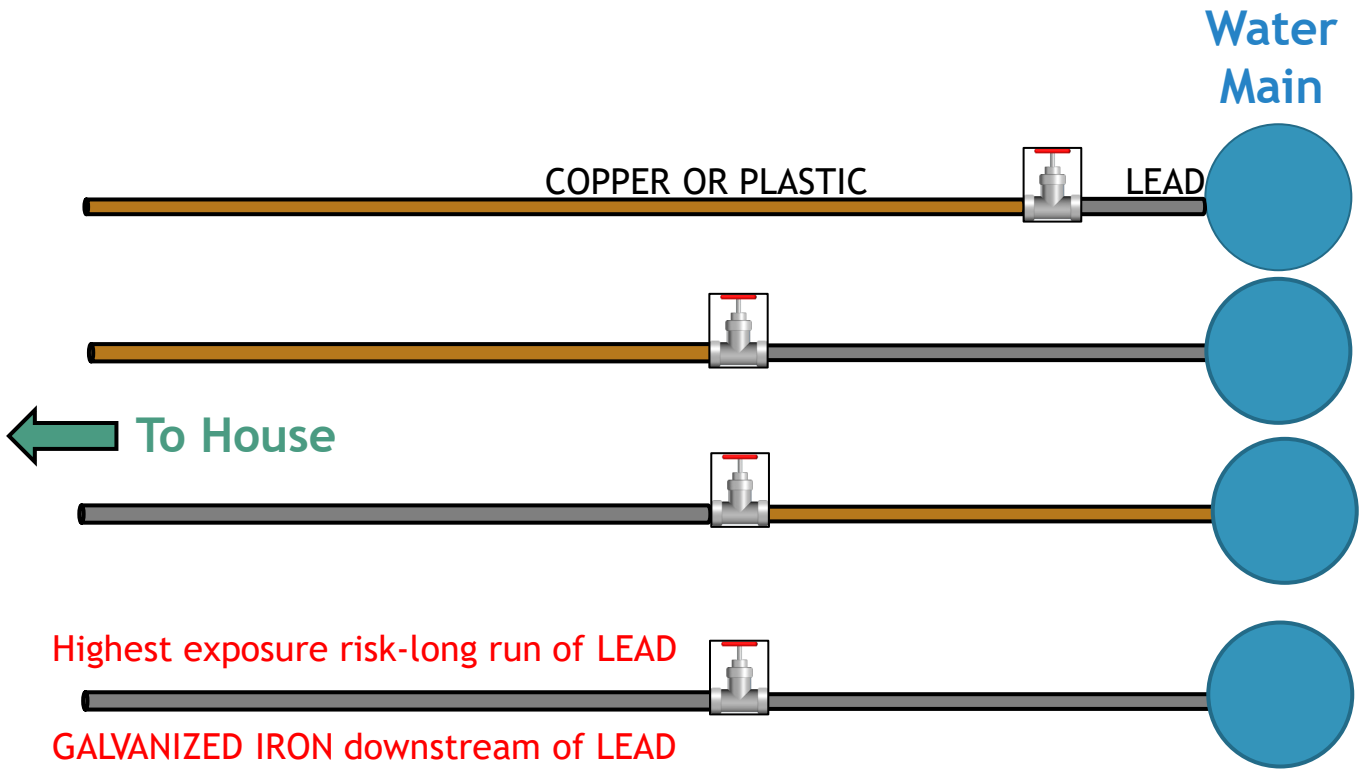
Risk defined by sources present and exposure

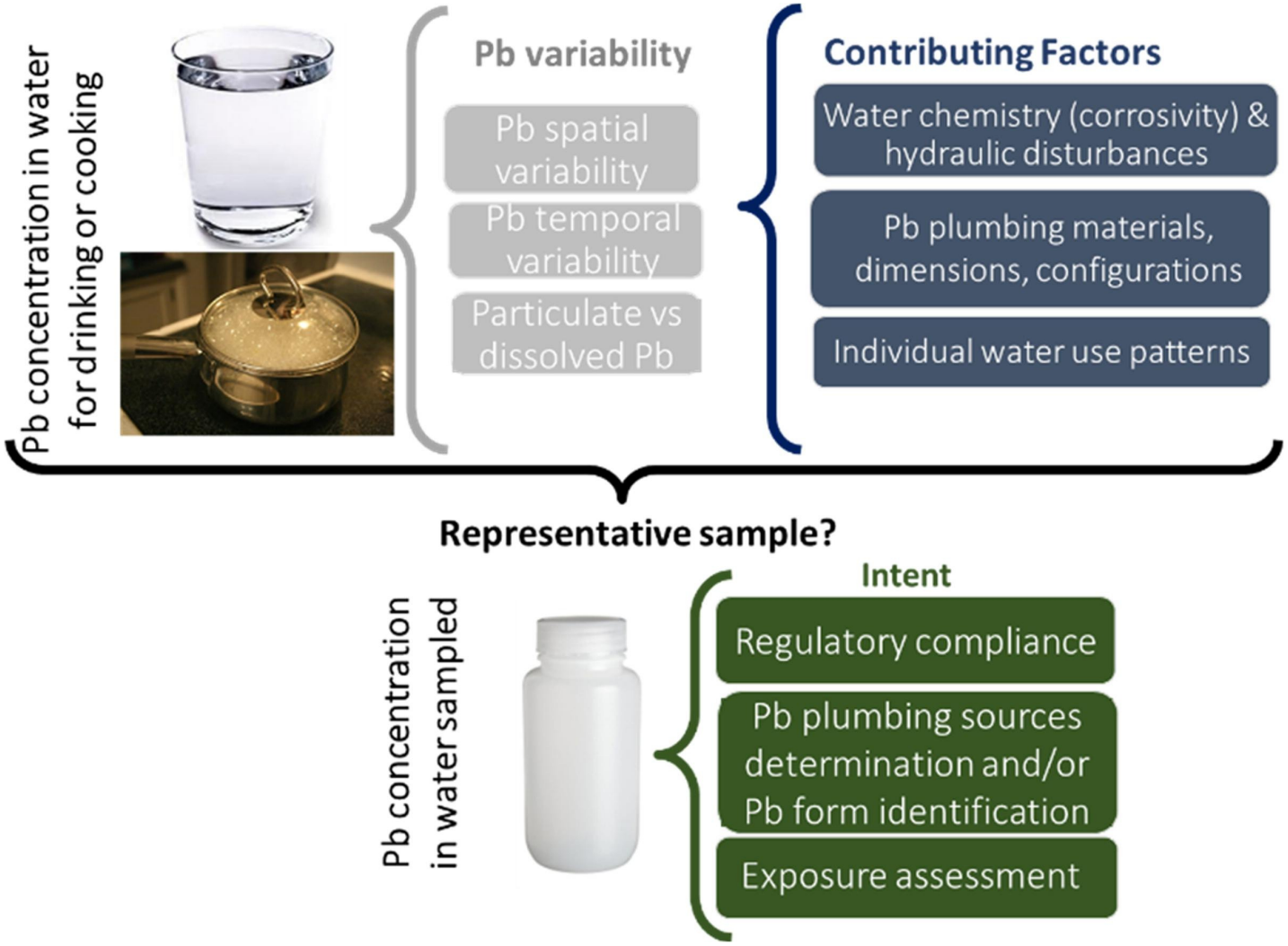


LSL Risk = Pb Amount x Exposure Chance

There are a lot of variables when it comes to sampling drinking water for lead

- Sampling site?
- Number of sites?
- Number of samples per site?
- Sampling frequency?
- Sample volume?
- Stagnation time?
- First draw or flush?
- Pre-flushing, aerator removal?
- Sampling flow rate?
- Sample hot or cold water?

Unfortunately, Pb in drinking water can vary widely in space and time



Triantafyllidou et al., 2021

Sampling is a TOOLBOX with Many Purposes

- **Regulatory/Compliance/Treatment Sampling**
  - Does the water meet regulatory standards for lead?
  - How effective is the current corrosion control treatment for interior plumbing?
- **Exposure Assessment Sampling**
  - What is the general public's exposure to lead in water in this residence/neighborhood/town/distribution system?
- **Diagnostic Sampling for Lead (or copper) Sources**
  - Where is the lead coming from?
  - What type of lead is present (dissolved vs particulate)?

Once you define your question(s), you can choose from appropriate sampling options

No single universally applicable sampling approach for lead in drinking water exists

There are many protocols, but each has a *specific use* in answering one or more of those many questions

Deceptively Simple Citizen Question…

Q: Am I being exposed to lead in my drinking water?

A (most of the time): Here is a sample bottle and instructions for taking a sample with a protocol for community-based regulatory monitoring.

Regulatory/Compliance/Treatment Sampling

OBJECTIVE & QUESTION(S)	SAMPLE TYPE EXAMPLES	PROTOCOL SUMMARY
Lead regulatory compliance in a certain jurisdiction: • **Does the water meet the regulatory standard for Pb?** • **How effective is the current corrosion control treatment for interior plumbing?**	First Draw, US - 90^{th} percentile Pb < 15 µg/L	- Collect after overnight water stagnation (6+ hr) - Collect first 1 L
	Random Daytime (RDT), UK - 95^{th} percentile Pb < 10 µg/L	- Collect during random work hours (i.e., variable stagnation) - Collect first 1 L
	30 Min. Stagnation (30MS), Ontario Canada - 90^{th} percentile Pb <10 µg/L - Stricter criterion of <5 µg/L considered	- Flush ≥ 5 min. - 30 min. stagnation - Collect first two liters

Is the EPA's 15 µg/L 90th percentile action level for lead in drinking water a health-based value?

A. Yes
B. No
C. Unsure

Regulatory/Compliance/Treatment Sampling

OBJECTIVE & QUESTION(S)	SAMPLE TYPE EXAMPLES	PROTOCOL SUMMARY
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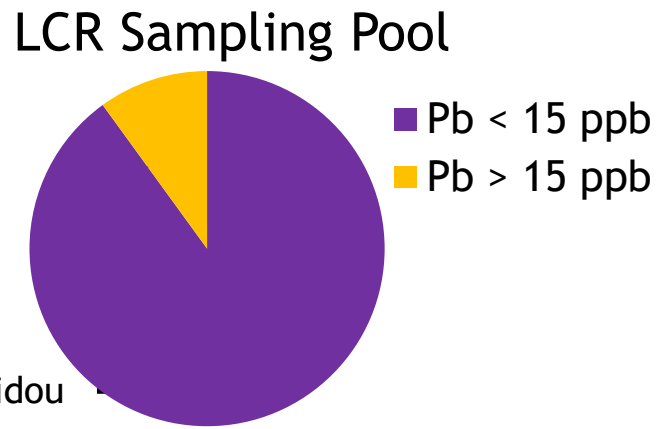
NOT a Health Based Value

Maximum Contaminant Level Goal for Lead in Drinking Water is ZERO

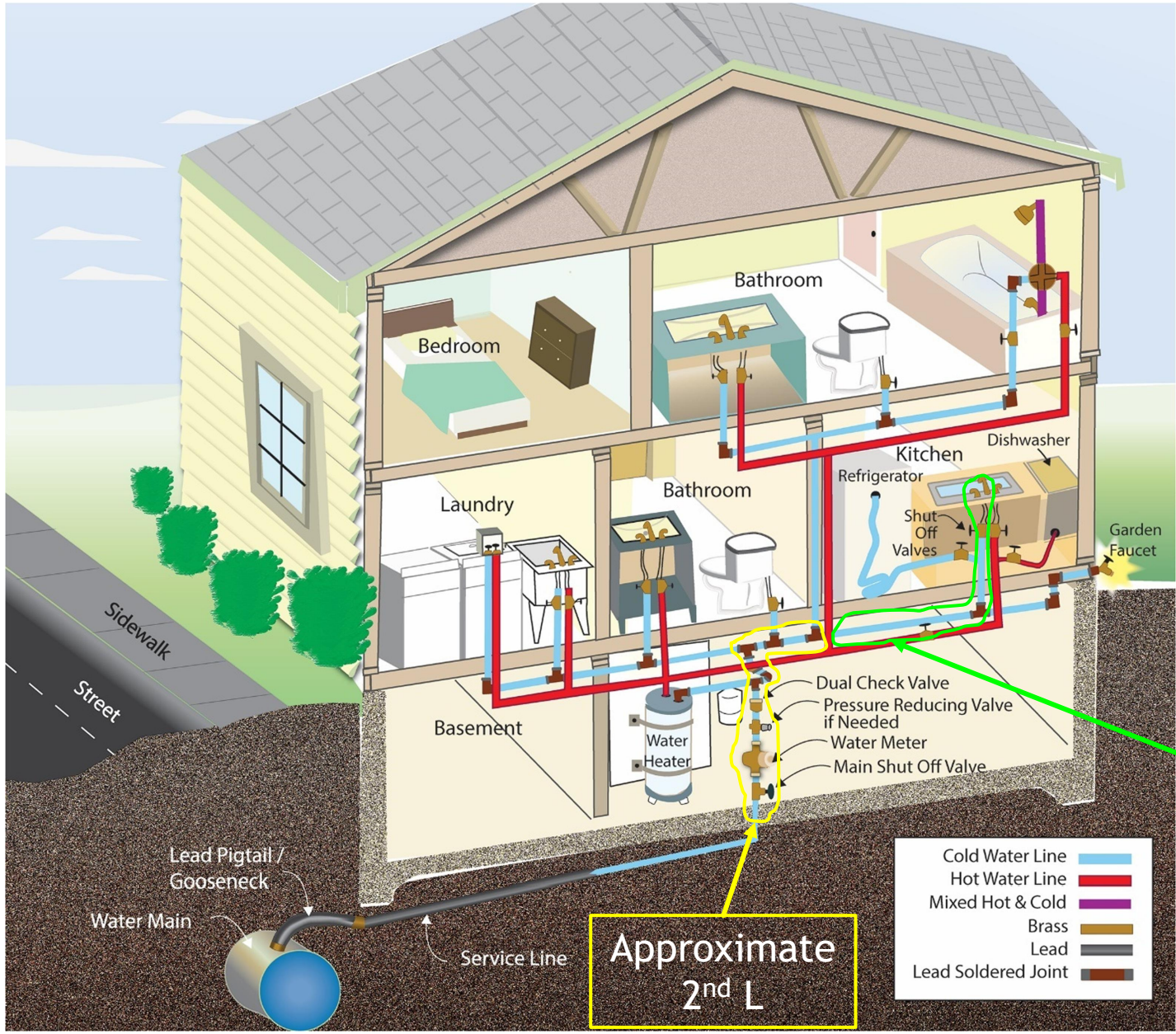
Corrosion Control Assessment

Lead and Copper Rule (LCR), 1991

- LCR sampling pool consists of homes believed to contain major lead plumbing sources
- Homeowners collect 1 L of water from kitchen tap after overnight water stagnation (6+ hr)
- 90th percentile lead results compared to Lead Action Level of 0.015 mg/L
- 90th percentile action level is a trigger for corrosion control treatment rather than an exposure level
- Rule identifies system-wide problems rather than problems at individual buildings

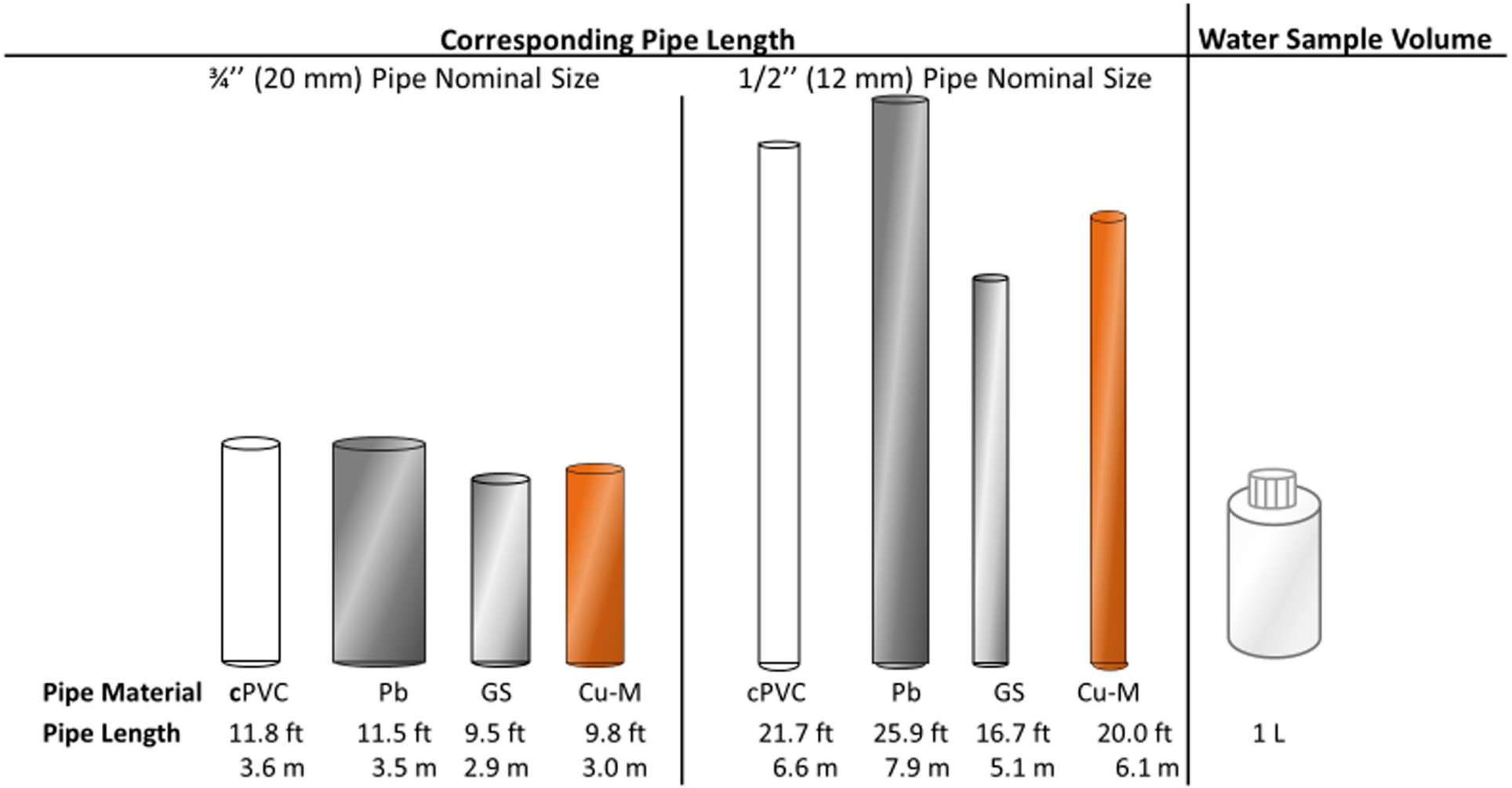


Pie chart idea from Y. Lambrinidou



Triantafyllidou et al., 2021

Sample Volumes Represent Source Position in Plumbing



Triantafyllidou et al., 2021

cPVC: Chlorinated Polyvinylchloride
Pb: Lead
GS: Galvanized Steel
Cu-M: Copper Type M

Wide-mouth bottles preferable to allow higher flow rate more typical of “normal” use

VS

Narrow-mouth bottles

Diagnostic Sampling for Lead Sources

OBJECTIVE & QUESTION(S)	SAMPLE TYPE EXAMPLES	PROTOCOL SUMMARY
Lead plumbing sources determination: • **Where is the Pb coming from?**	Profile (or sequential)	- Defined stagnation time - Collect 10 to 20 sequential samples of defined volume (125 mL, 250 mL, 500 mL 1 L, etc.)
	School guidance (3Ts), US	- Overnight stagnation - Step 1: Collect first 250 mL from all taps and fountains - Step 2: Flush tap for 30 seconds and collect a second 250 mL sample
Lead type identification: • **What type of Pb is present (dissolved/ particulate)?** ***Any sample collected can also be analyzed to determine dissolved vs particulate***		Profile sampling repeated at increasingly higher water flow rate: low, medium, and high flow rate
		- 5 min stagnation first liter and maximum flow rate, d close tap five times, fill rest of bottle at normal flow rate. - Collect second liter at a normal flow rate - Collect third liter the same way as the first

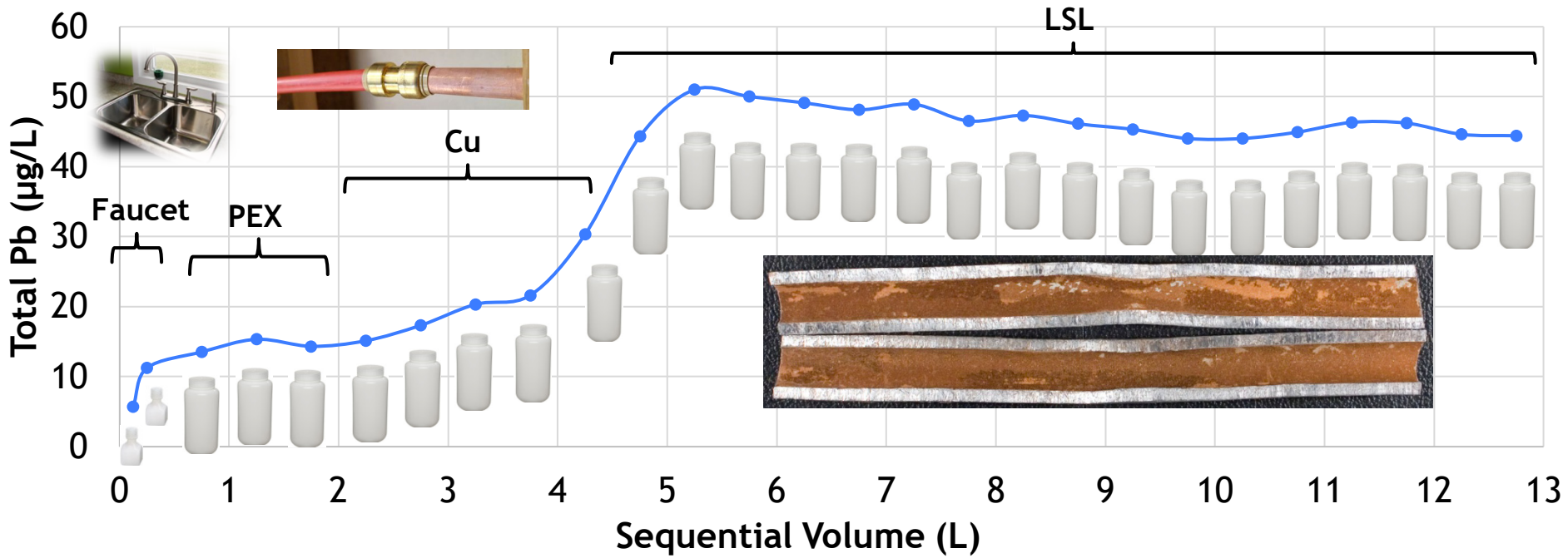
Prior to the 2018 revision, 20 ppb was the "action level"

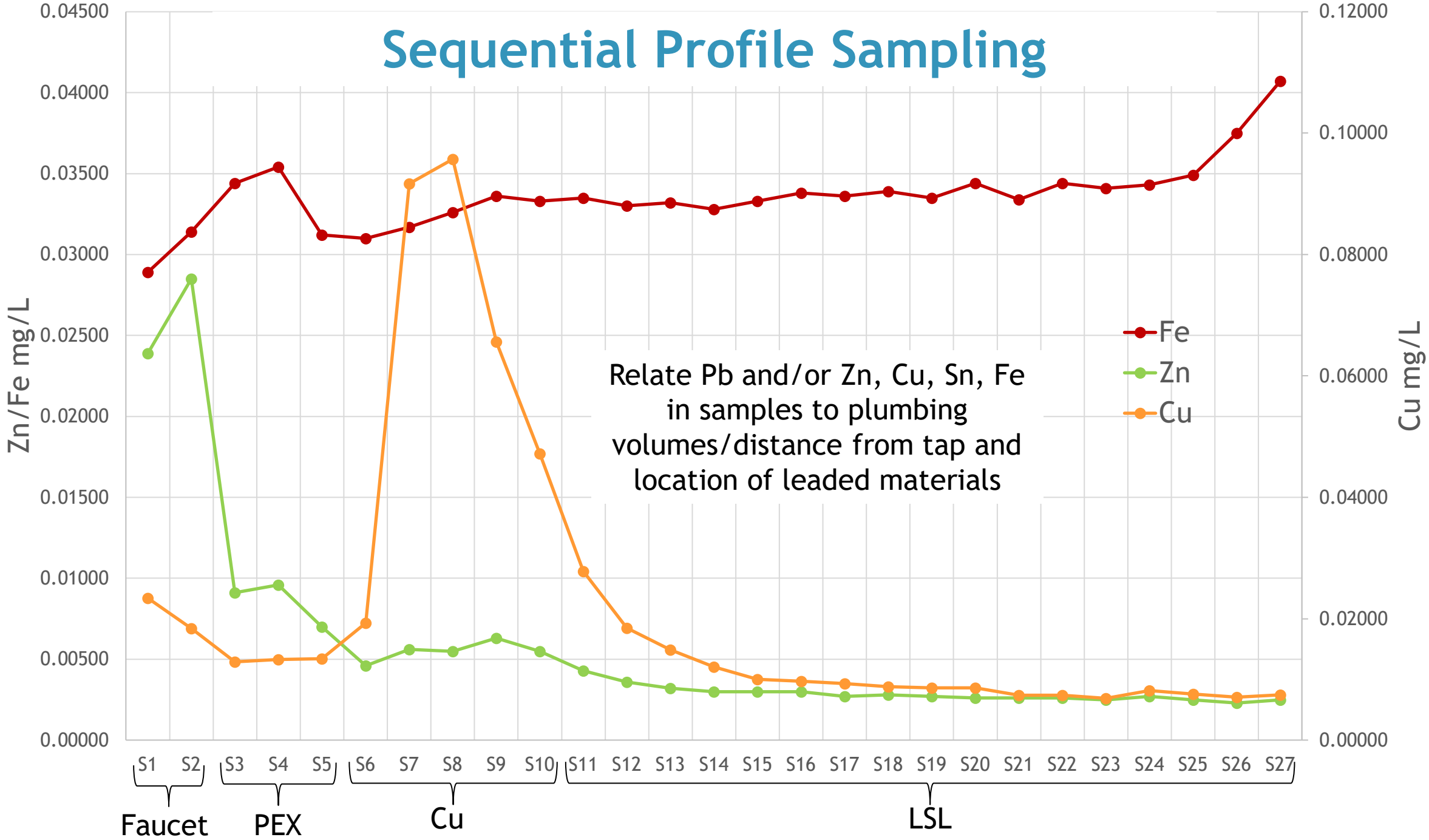
NOT a Health Based Value

Sampling for Lead Sources, where is the lead coming from?

Sequential Sampling ("Profiling")

- Map interior plumbing and approximate exterior route to main in terms of lengths, ID and visible materials
- Allow water to sit motionless for 30 minutes to overnight
- Take successive samples of variable volumes, as desired
- Can somewhat differentiate bubbler, faucet, valve, tubing, inside-wall plumbing by different sample volumes




Sequential Profile Sampling
Zn/Fe mg/L
Cu mg/L
0.04500
0.04000
0.03500
0.03000
0.02500
0.02000
0.01500
0.01000
0.00500
0.00000
0.12000
0.10000
0.08000
0.06000
0.04000
0.02000
0.00000
Fe
Zn
Cu
Relate Pb and/or Zn, Cu, Sn, Fe in samples to plumbing volumes/distance from tap and location of leaded materials
S1 S2 S3 S4 S5 S6 S7 S8 S9 S10 S11 S12 S13 S14 S15 S16 S17 S18 S19 S20 S21 S22 S23 S24 S25 S26 S27
Faucet
PEX
Cu
LSL

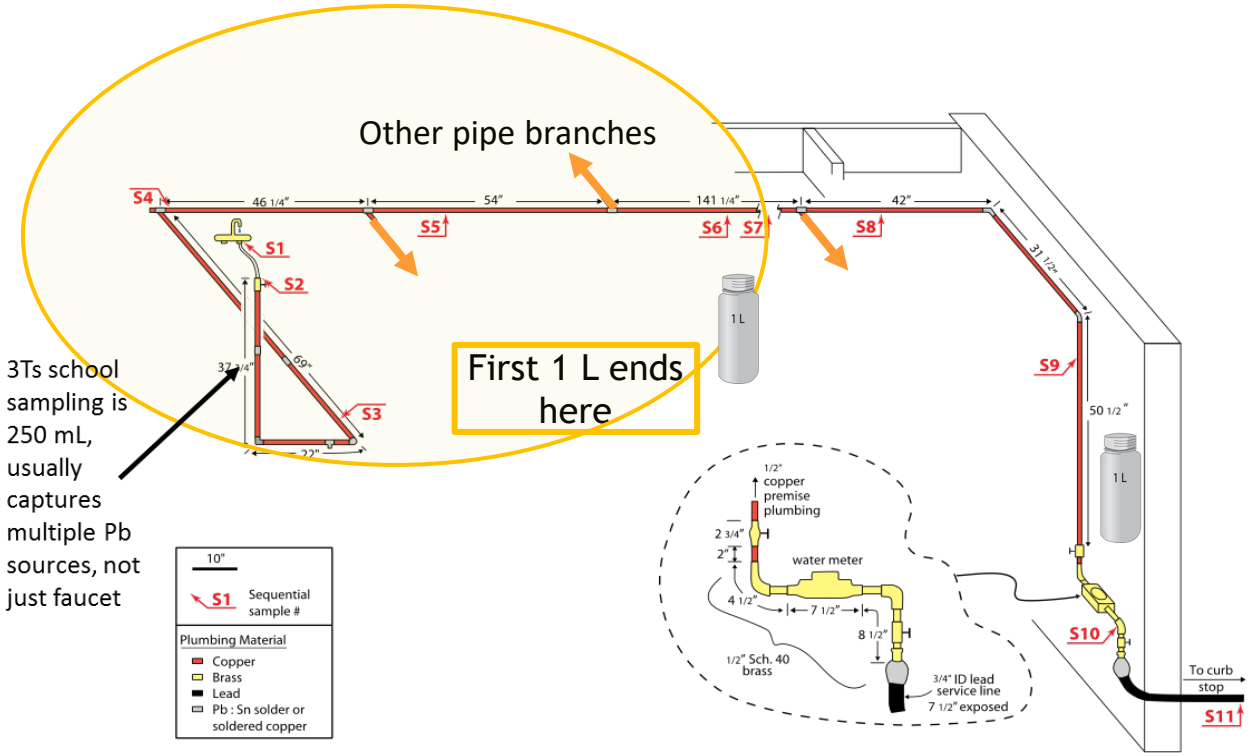
Sequential Profile Sampling

System ID	Corrosion control treatment	LCR action level[1]	PO_4 Residual (mg/L)[2]	Length of phosphate treatment[1]	Average first liter lead (µg/L)	LSL average maximum lead (µg/L)	LSL maximum lead (µg/L)
13-IL	40% ortho/ 60% poly	Met	0.51 (0.48 - 0.55)	18 years	**5** (n=57)	**16**[4] (n=57)	**37**
22-WI	100 % ortho	Met	0.50 - 0.55	21 years	**7** (n=4)	**23**[4] (n=4)	**43**
20-WI	40% ortho/ 60% poly	Met	0.191	18 years	**8**[3] (n=5)	**19**[4,5] (n=5)	**51**
8-WI	pH/alk	Exceeded	N/A	N/A	**7** (n=17)	**26**[5] (n=17)	**61**

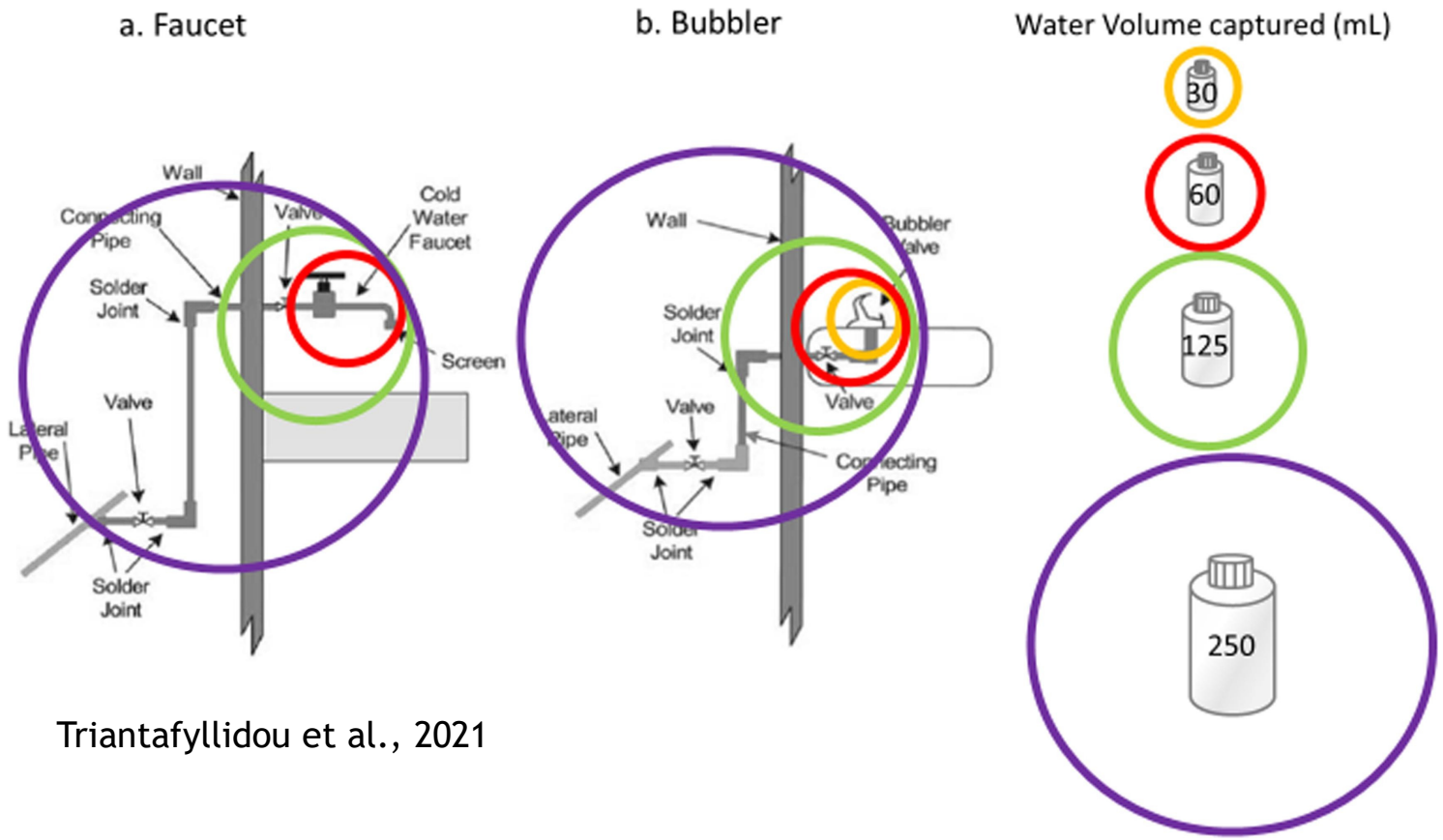
From Tully et al. 2019

1 Around time of profile sample
2 Average value and range (within parentheses) are reported when available
3 One calculated first liter
4 Unknown LSL location (estimate)
5 Known LSL location

LCR 1st Liter Sampling Usually Misses the LSL



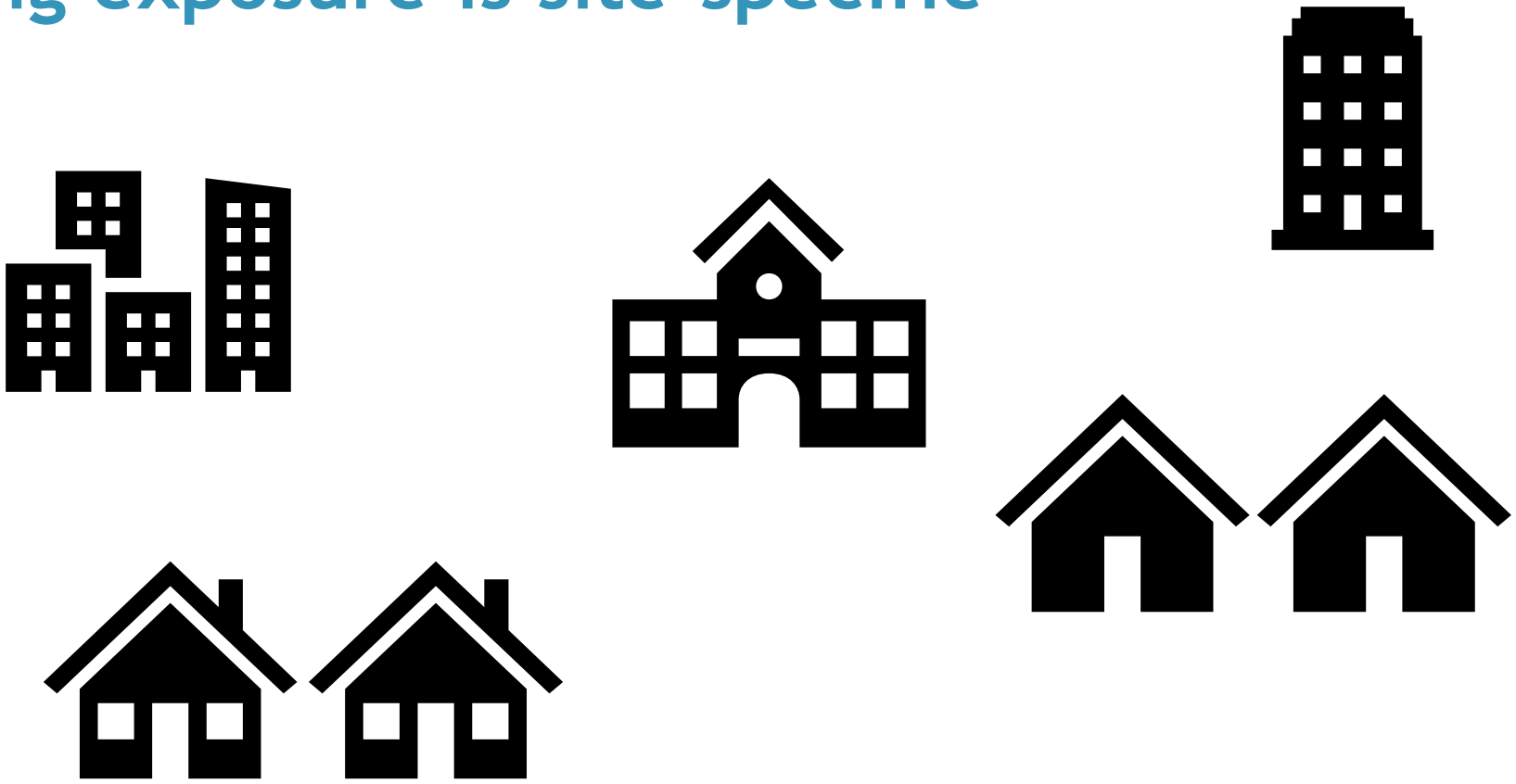
Volume of the sample matters: Faucet sampling can catch valves



Triantafyllidou et al., 2021

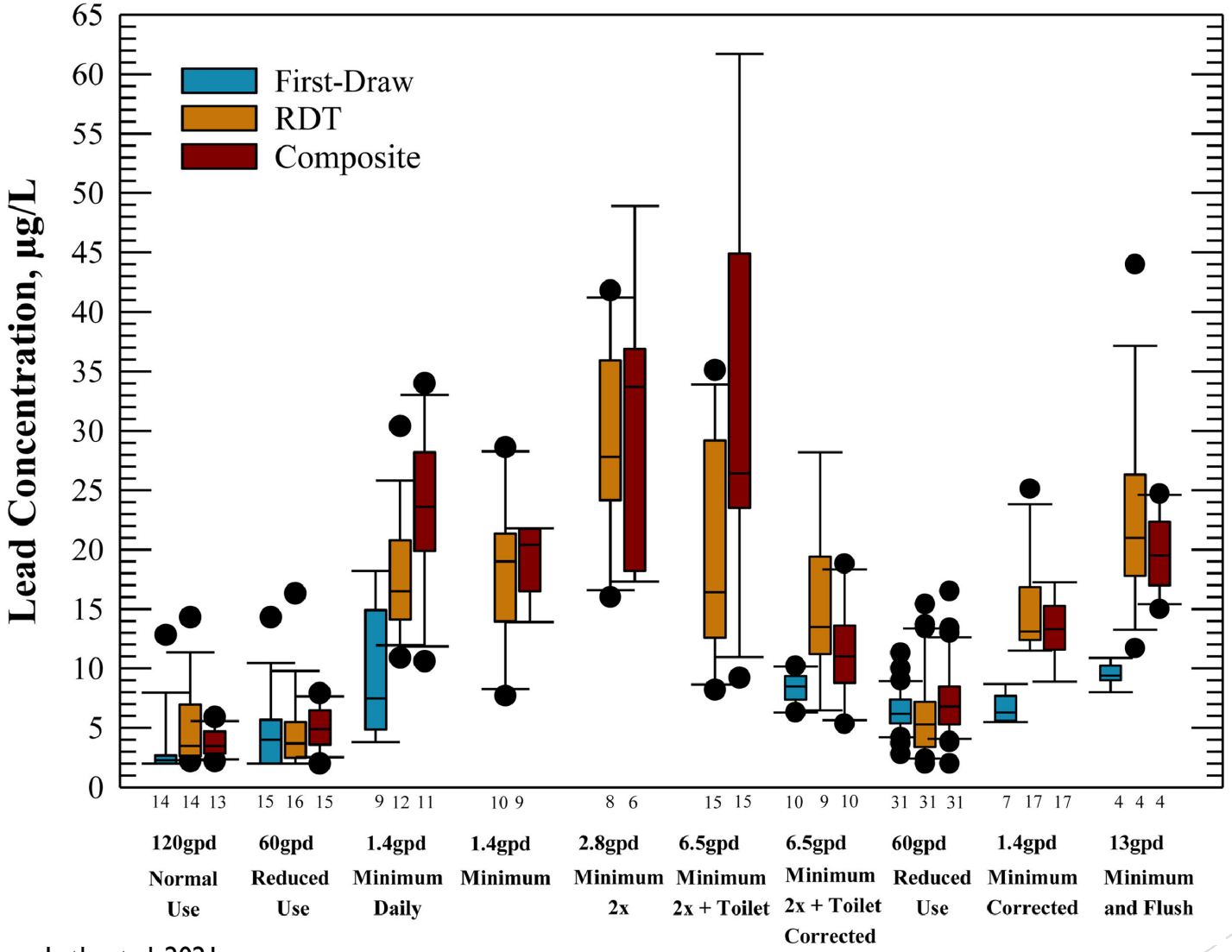
Many plumbing fixtures can be included in larger volume samples- this can dilute the amount of Pb measured and muddle sources

Assessing exposure is site-specific



- Multiple houses, side-by-side with same plumbing configuration can all have very different Pb in water exposure risks, depending *solely on amount and pattern of water usage*.

- Even in the exact same “residence” Pb in water varies depending on the amount of water used and the sampling method.



Lytle et al, 2021

Site-specific variables to extrapolate profiles to "exposure"

- When do you use your water each day?
- How many people, and of what ages, use the water?
- Which faucet or outlet is used EACH time, and by whom?
- Which activities are done, and in what order?
- What is the water pathway through the plumbing, each time a faucet or appliance is turned on?
- What kind of pipes are there, in what order are they arranged, how old and how long are they?
- How long did the water stand in *which part(s) of the* piping?

Site-specific variables to extrapolate profiles to "exposure"

- How much does the pattern of use vary from day to day, week to week?
- Does the background water chemistry change during the day?
- Are school or work-related activities the same or different from the prior day/week/month?
- Are there visitors that change the water use pattern?
- Is work being done to the plumbing, to the water mains in the street, hydrant repairs, or other construction work that can physically disturb (vibration, air, flow direction) pipe scales?

Exposure assessment

Environmental assessments of lead-exposed children by Health Departments:

- “Ad hoc” sampling protocol
- At the discretion of Health Department, since guidance does not exist
- Generally, a single sample method is used

Exposure Assessment Sampling

OBJECTIVE & QUESTION(S)	SAMPLE TYPE EXAMPLES	PROTOCOL SUMMARY
Exposure Assessment: • **What is the public's exposure to Pb in water in this town, neighborhood, or home?**	Composite proportional: - Automatic	- Device splits fixed proportion (e.g., 5%) of water from every draw intended for consumption
	Composite proportional: - Manual	- Collect cumulative water sample (typically no more than 3 L) over extended period of time (e.g., 1 week)

Exposure Assessment Sampling: Single Site

Is my water safe to drink?

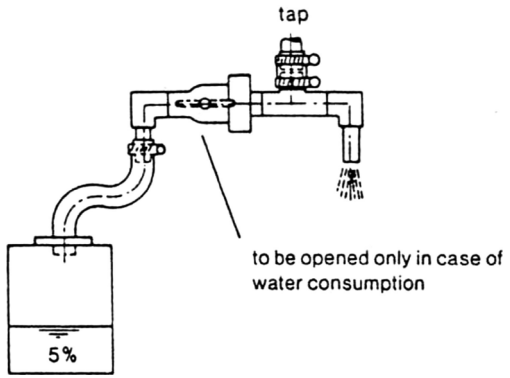
- Side Stream Composite Sampler
  - Automatically diverts fixed fraction of water to container
  - Collect composite and analyze after known time
- "Manual" Proportional Composite Sampling
  - Customers take sample each time of water actually used for consumption
  - Deposit in collection vessel
  - Collect composite and analyze after known time
- Integrated Composite Sampling Devices (slightly theoretical)
  - Similar to existing faucet-mounted POU devices, but amount of Pb accumulated is measured
  - Collects proportion of all lead or copper consumed per unit time or volume used

Automatic vs Manual Composite Sampling

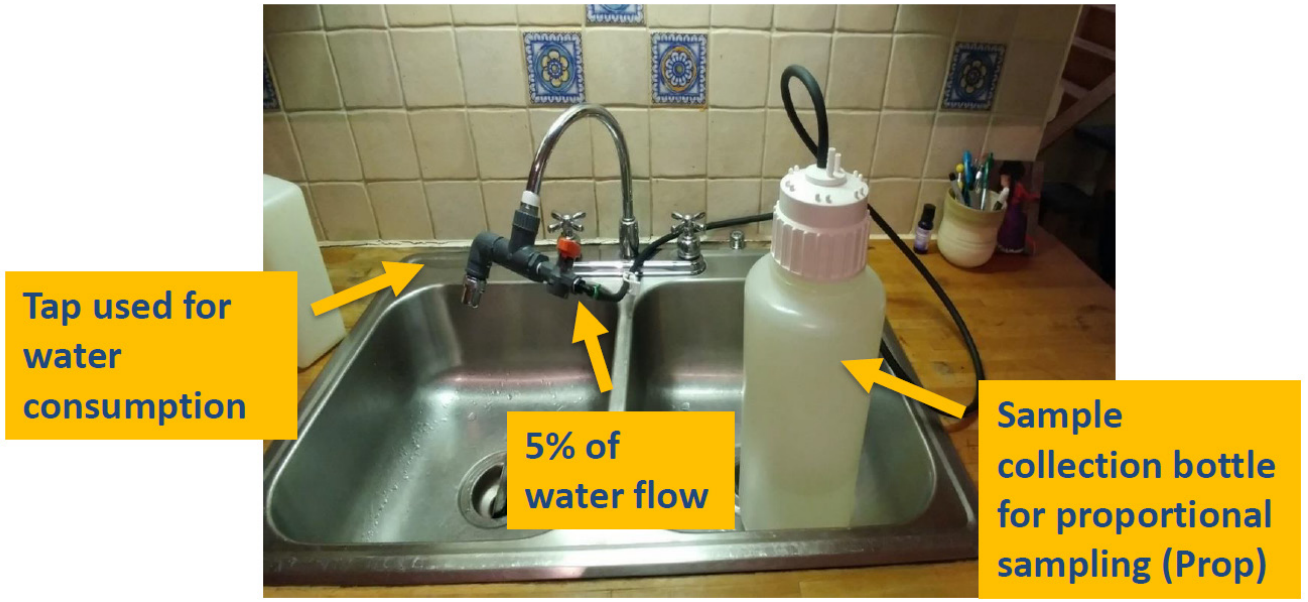
- Collects lead under normal use conditions, capturing a range of flow rates, stagnation times, flow durations, and temperatures

Automatic Composite Sampling

- Device is affixed to the tap & consumer operated
- 5% of every draw meant for consumption is routed into holding tank



Triantafyllidou et al. 2021 reprint from van den Hoven, 1987



Deshommes et al, 2017

- Inconvenient and cumbersome to residents

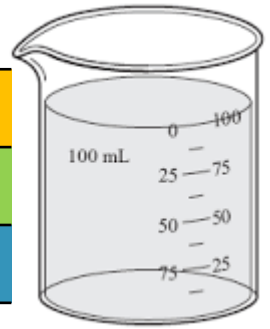
Manual Composite Sampling

- Of all water drawn for consumption the consumer pours a small volume into a collecting vessel
- Creates a composite sample over a day's use, few days, week…

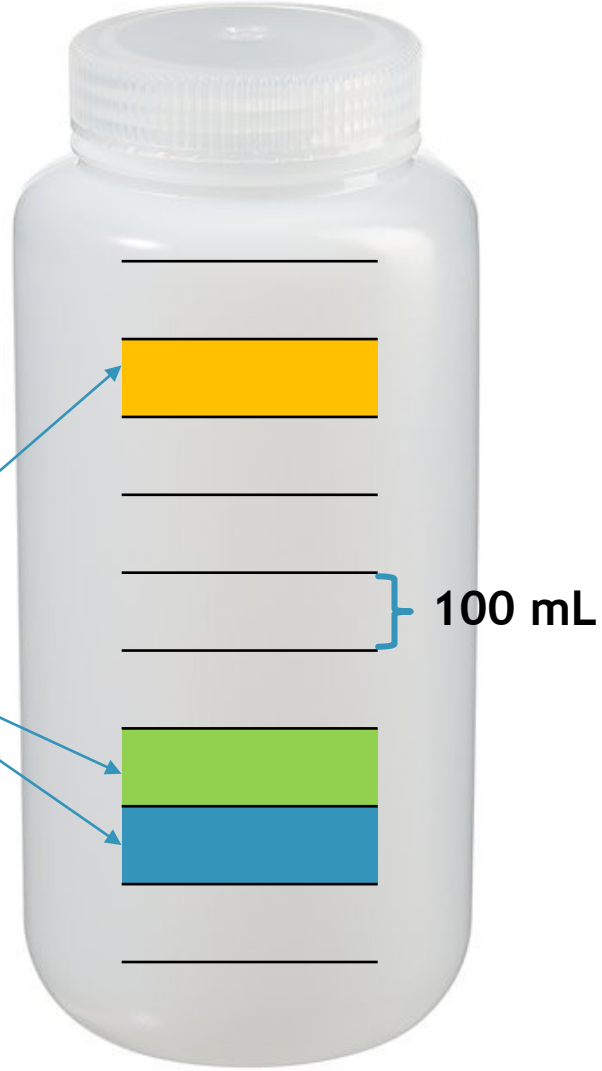
Tuesday 5:45pm- Glass of water

Tuesday 8:15am- Water for oatmeal

Tuesday 7:30am- Water for coffee



Composite Sample Collecting Vessel



Can provide a measuring vessel for the consumer to use or mark the collecting vessel with volume increments

After a period of time the composite sample analyzed for lead → <u>average lead concentration</u>

Drawback

- Requires more cooperation of the public- more intrusive and involved sampling method
  - Integrated composite sampling devices (once developed) have the potential to alleviate much of the burden on the consumer
- Provides an indication of average lead for a household, individual exposures may vary
- A balance needs to be found between the logistics of data collection and the benefits/limitations of different sampling protocols

Food for Thought

- What about exposure of small children when visiting grandparents with lead pipes?
  - Water usage may be low, hence, not as protective pipe scales
  - They may not be concerned about their own Pb exposure
- What about buying foreclosed or unoccupied homes?
  - Scales can deteriorate over extended periods of time
  - Could happen in months to years, depending on pipe scale
  - Typically no assessment of water risk when reoccupying a house
- Purchasing a regular market home?
  - Lead pipes are often not disclosed
  - Fix and flips
  - Even if a lead service line has been “replaced”, need to clarify that the entire service line has been removed and not only partially replaced

Choosing the correct protocol for the question being asked is extremely important

- **Protocol Considerations:**
  - Sample volume
  - Number of samples per site
  - Number of sites
  - Stagnation time
  - First draw, flush, sequential..
  - Site choice
  - Frequency of sampling
- **Sampling Variabilities:**
  - Flow rate
  - Water temperature
  - Time of year
  - Pre-flushing
  - Aerator removal
  - Particulate release
  - Stagnation time differences

Risk = Hazard x Exposure

Reminder: LCR sampling does not assess exposure

Going back to that Deceptively Simple Citizen Question…

Q: Am I being exposed to lead in my drinking water?

A: In short there's no simple answer. Instead let's take meaningful samples, identify sources, and provide data that can be used to evaluate the risk of lead exposure from drinking water.

Conclusions

- Lead in water can be highly variable (spatially and temporally)
- Sampling is EVERYTHING in figuring out if there is a lead problem
- Choosing the appropriate protocol for the sampling intent is crucial to producing meaningful data (and being able to interpret that data)
- Different sampling protocols may yield different lead concentrations and sample different sources/forms of lead
- The efficacy of a given protocol in capturing water lead risks varies from building to building due to plumbing differences and other site variabilities
- House configuration and family demographics create widely different lead risks from water

Conclusions

- No regulatory compliance sampling gives information for risk assessment or exposure at the dwelling
- Many health department lead contamination assessment forms nationally don't even have a checkbox for lead from water
- Understanding differences in sampling protocols is important when attempting to compare lead results from different studies
- The cost, logistics, timeliness, and consumer participation are all practical considerations that need to be made when conducting a sampling event, however, so is the protocol used to collect the sample

Questions?

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