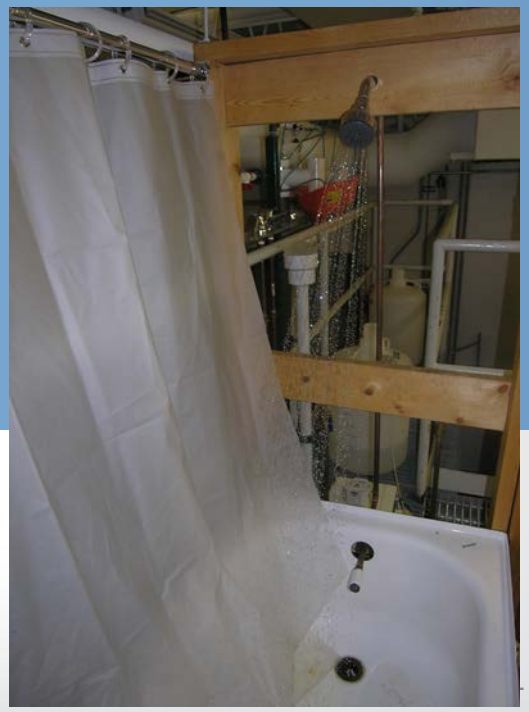
AWWA ACE 17
June 14th 2017

A Simulated Household Plumbing System to Understand Water Quality and Corrosion

Kelly Cahalan
ORAU
Darren Lytle
USEPA



Premise Plumbing Issues

- Metals Release (Pb, Cu, Fe)
- Copper Pitting
- Blue Water
- Biofilm Growth
- Dezincification
- Disinfectant Residual Depletion

Factors such as water quality, plumbing materials, water use patterns, and plumbing configuration contribute to the likelihood of these issues

Goal: Determine how water usage and temperature impact lead, copper, and chlorine levels

Built a model home plumbing system based on a household of 4, followed a regimented flushing schedule, and monitored daily for 5 years to capture the aging and corrosion processes

Home Plumbing System (HPS) Components

Faucet 1:

Brass Utility Faucet

Faucets 2-4:

American Standard Chrome Faucet

Faucet 2-4 interior

- Copper (½" Type M) connected by Sn-Cu solder, except a portion of Faucet 3 line has 60:40 Sn:Pb solder
- Faucets have brass and plastic wetted surfaces
  - Purchased at same time
  - Faucets 2-4 certified to meet NSF/ANSI 61 section 9
- Brass and Pb-Sn solder are the only lead sources during the first 1800 days
- Plumbing length of a typical 4-person house

Toilet and Shower

Glacier Bay toilet and shower head

Other Features

- Hot Water Heater
- Flow Totalizer
- Acid Feed Pump

Copper Plumbing

Inches of copper pipe from flow meter to fixture

	Cold Water Line	Hot Water Line
Faucet 1	586”	568”
Faucet 2	518”	477”
Faucet 3	406”	361”
Faucet 4	292”	243”
Shower	546”	486”

- 214” from recirculating pump at Faucet 1 back to hot water heater
- Recirculates if temperature falls below 33° C

Flushing Regimen

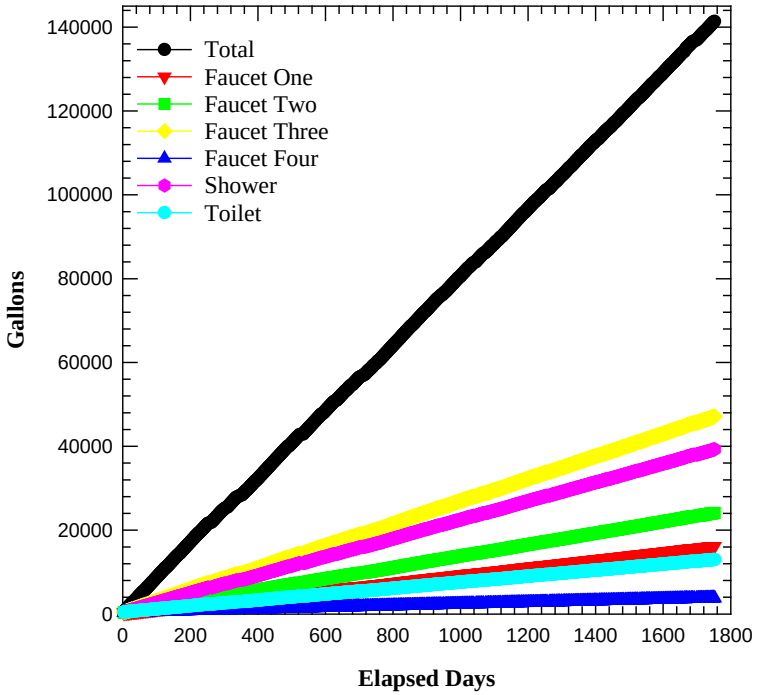
All fixtures flushed 3x per weekday at maximum flow rate (0.8-1.2 gal/min) at :

- 8 AM (cold)
- 12 PM (50/50 hot & cold)
- 3 PM (cold)

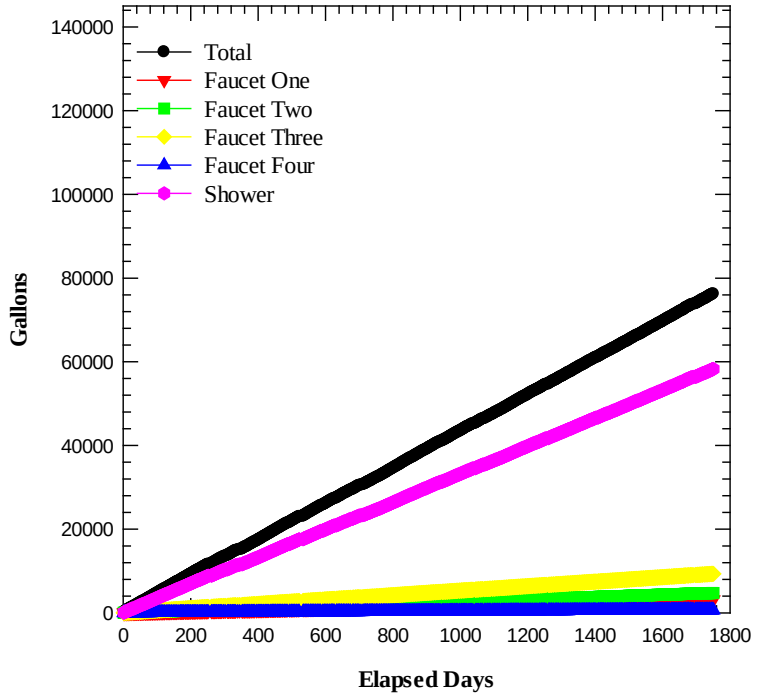
Fixture	Time per Flush	Time per Day
Faucet 1	7 minutes	21 minutes
Faucet 2	7 minutes	21 minutes
Faucet 3	15 minutes	45 minutes
Faucet 4	1 minute	3 minutes
Shower	15 minutes	45 minutes
Toilet	3 flushes	9 flushes

- Based on the typical use of a family of 4 reported by AWWA/WRF's survey (1999)
- Does not include water use from outdoors or a clothes washer

Water Use by Fixture



Cold Water Line



Hot Water Line

- 188 gallons total per each day ran
- Ran 1157 days

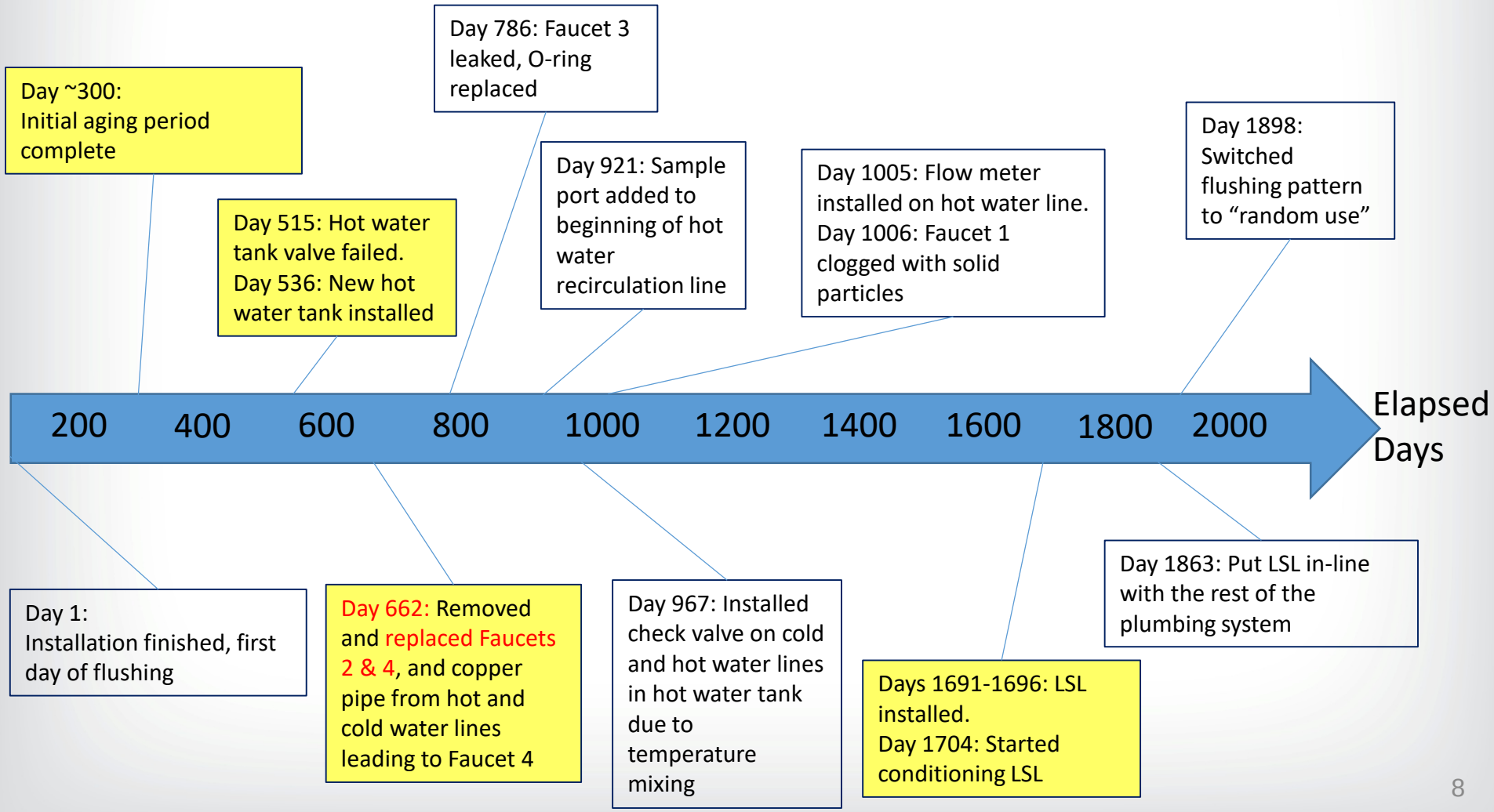
Sampling Schedule

- 250 mL samples
- Stagnant sampling includes first and second draw (two 250 mL samples)
  - First draw covers faucet and 1.3 m copper pipe
  - Second draw covers 1.5 m copper pipe

- Analyzed for metals by ICP-MS and ICP-AES
- Water Quality samples analyzed for inorganics

	Monday	Tuesday	Wednesday	Thursday	Friday
8 AM	Cold 3-Day Stagnation			Cold 1-Day Stagnation	Hot 1-Day Stagnation
3 PM	Water Quality		Cold Flushed	Hot Flushed	Cold Flushed

Model System Required Regular Plumbing Work

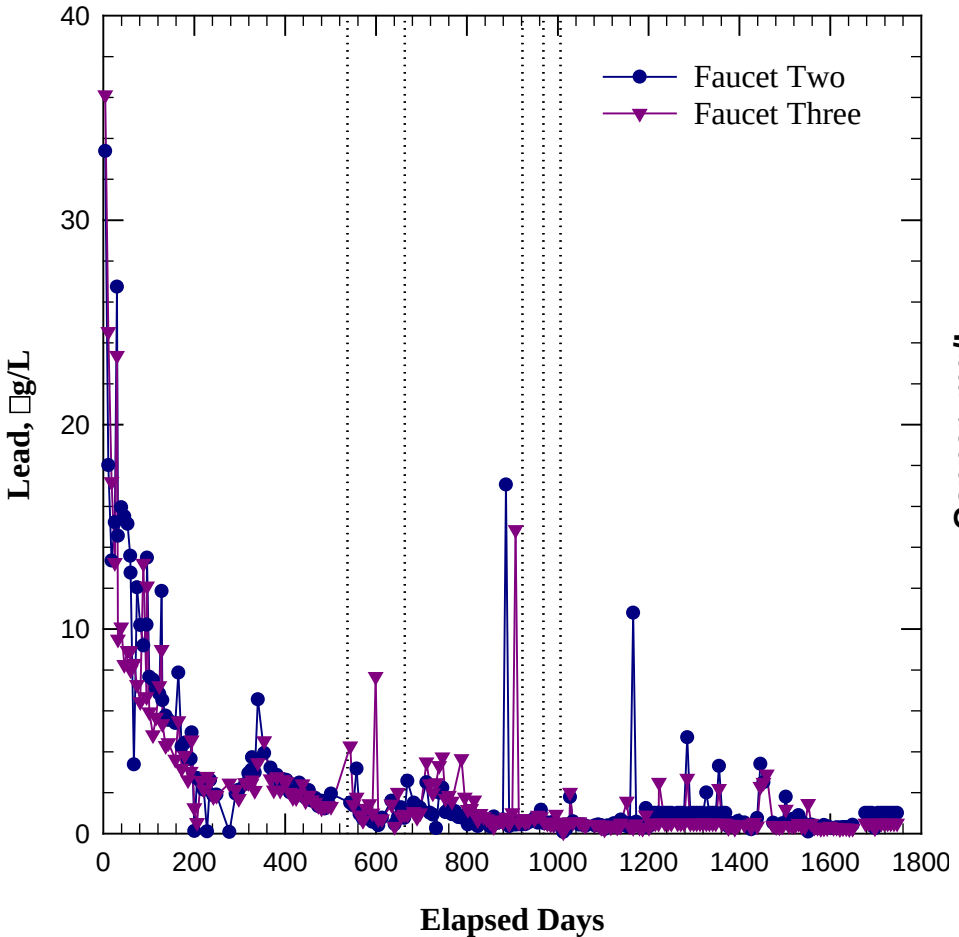


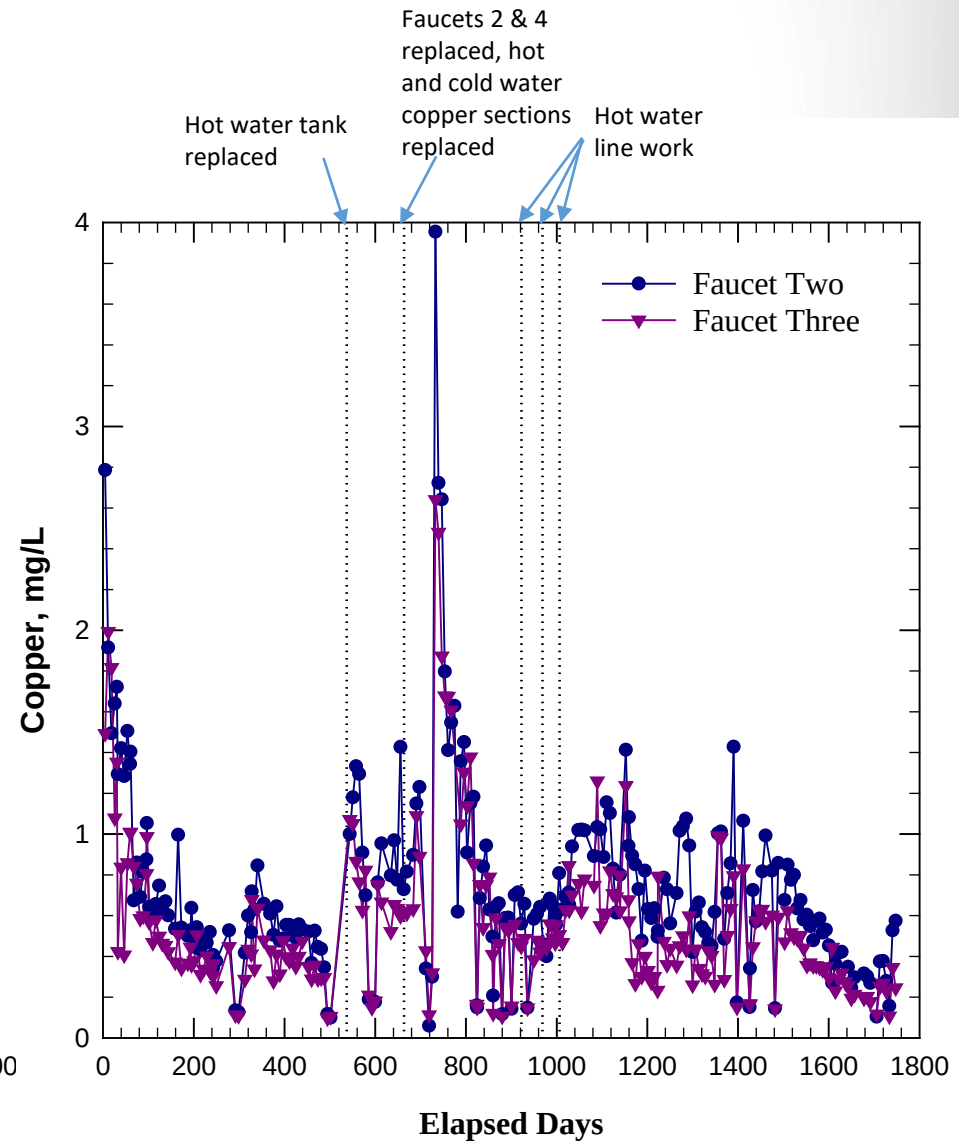
Water Quality

Water Line	pH	Temperature (deg. C)	DO (mg/L)	Free Chlorine (mg/L)	Chloride (mg/L)	Phosphate (mg/L)	Nitrate (mg/L as N)	Total Alkalinity (mg/L as $CaCO_3$)
Cold	7.2 ± 0.43 (189)	21.4 ± 4.20 (190)	8.5 ± 1.6 (190)	0.71 ± 0.28 (192)	39.5 ± 9.3 (199)	0.14 ± 0.07 (192)	0.83 ± 0.20 (199)	58.5 ± 11.4 (199)
Hot	7.3 ± 0.54 (188)	28.5 ±6.82 (189)	7.5 ± 1.6 (189)	0.27 ± 0.19 (191)	42.6 ± 42.1 (197)	0.20 ± 0.11 (192)	0.83 ± 0.19 (197)	62.1 ± 11.1 (197)

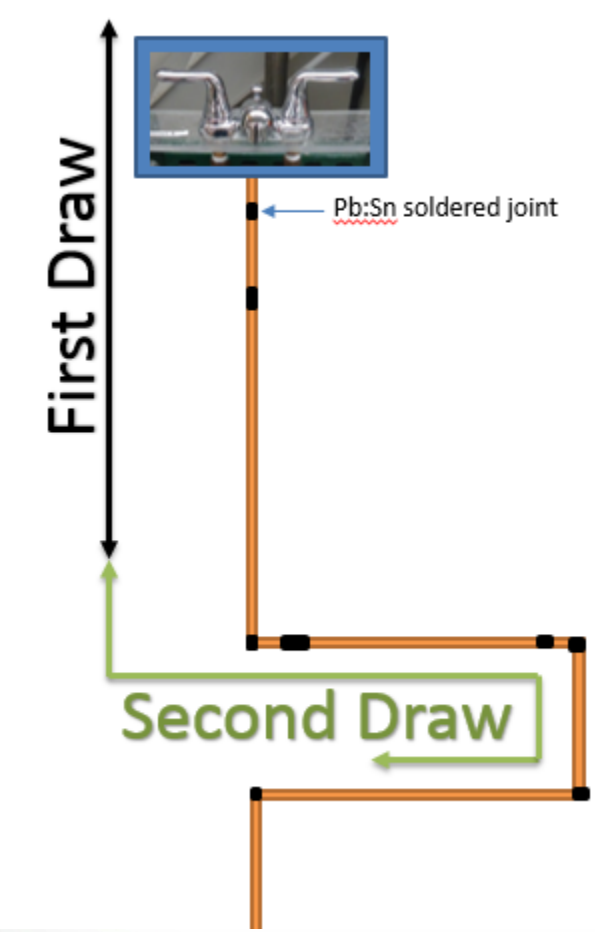
*Adjusted pH from 8.5 to make water more corrosive

Cold Water 17 h Stagnation





Faucet 3: Pb-Sn Solder



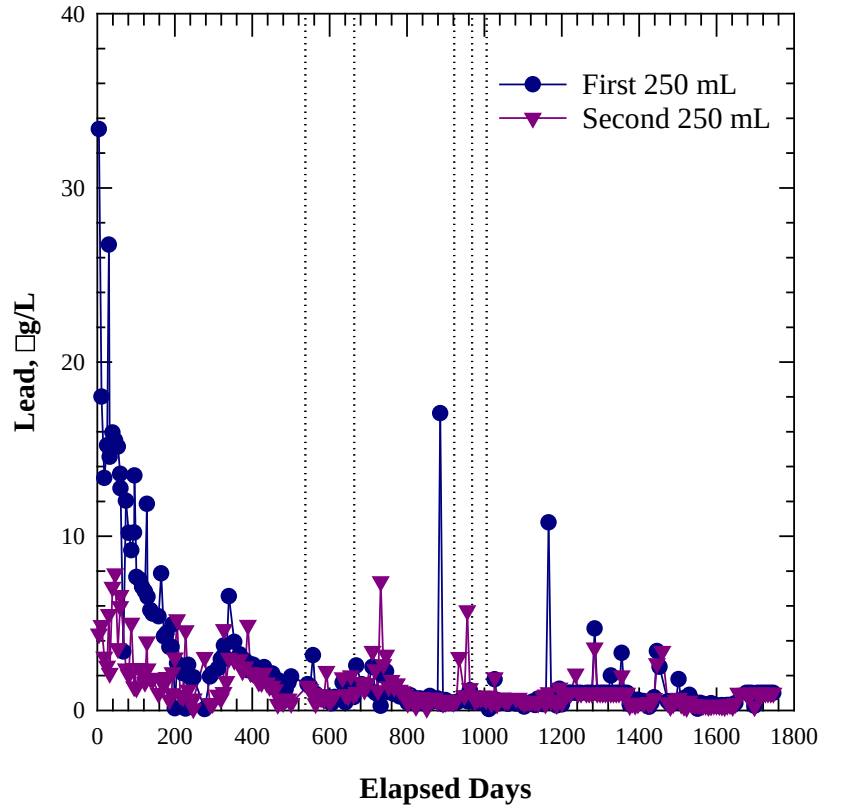
The first draw (black line) covers the faucet and 1.3 meters of pipe. It covers 2 Pb:Sn soldered joints.

The second draw (green line) covers the next 1.5 meters of pipe. It covers 5 Pb:Sn soldered joints.

Cold Tap: First 250 mL vs. Second 250 mL

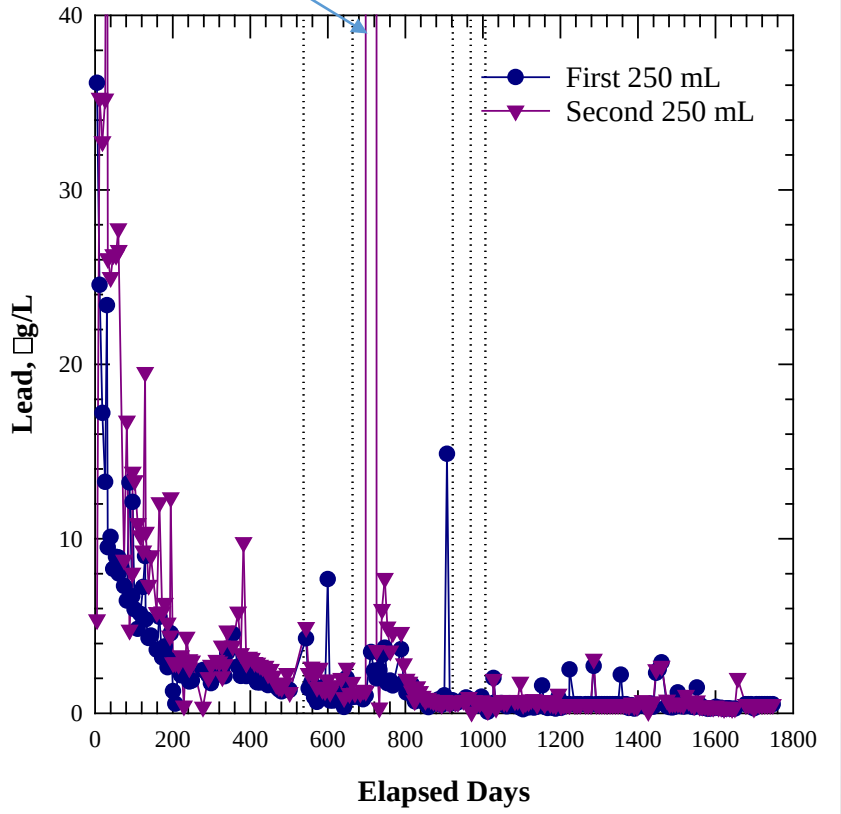
- Pb-Sn soldered joints in Faucet 3 cause high lead release in the second draw

Faucet 2: No Pb Solder



11550 ppb

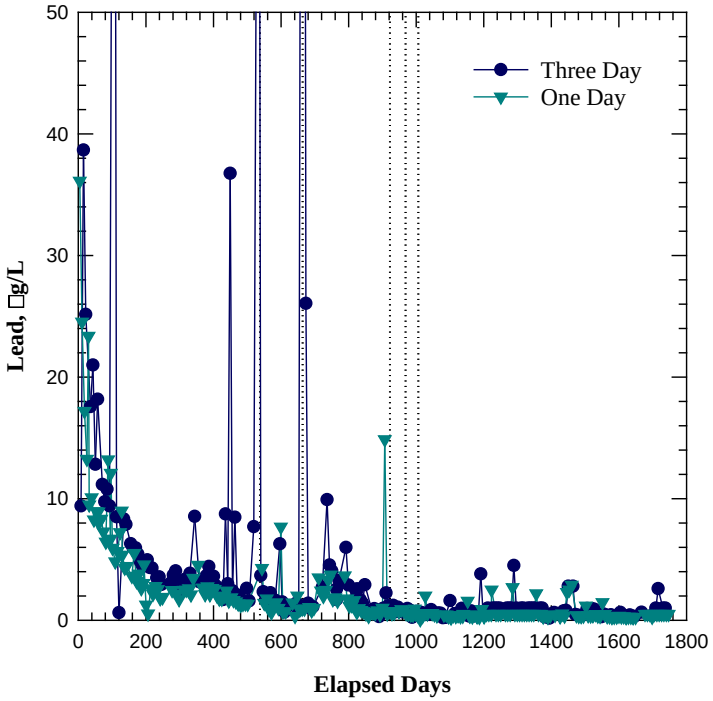
Faucet 3: Pb Solder

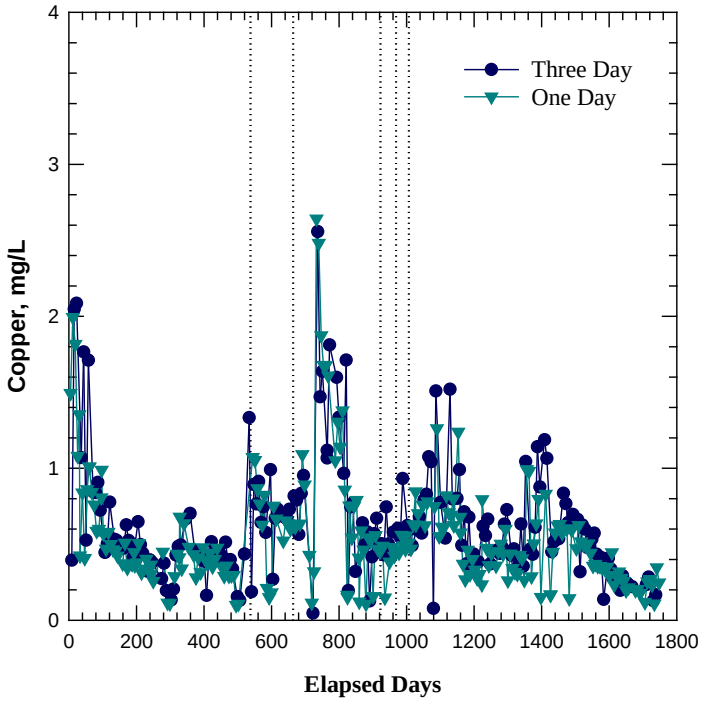


17 h Stagnation samples

Cold 1 Day vs. 3 Day Stagnation

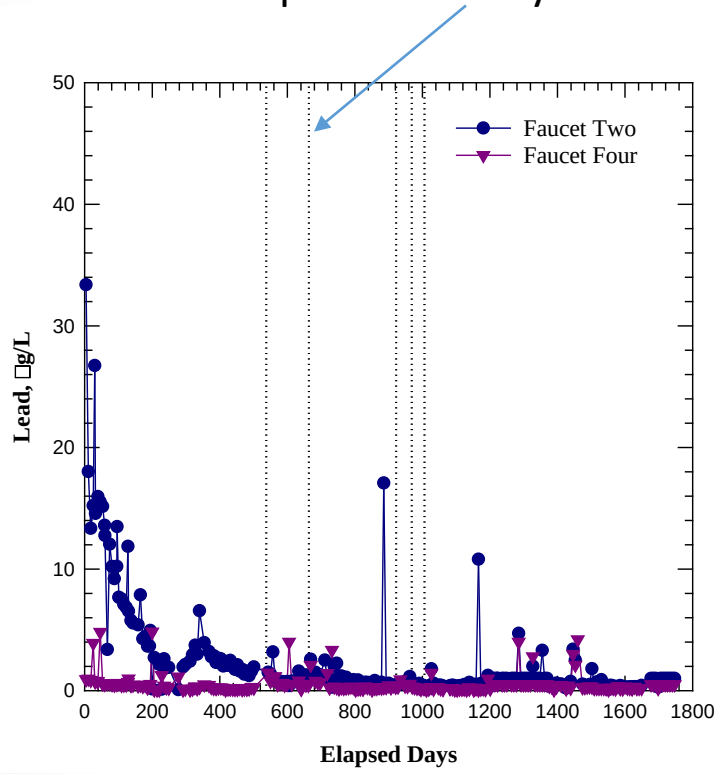
Faucet 3



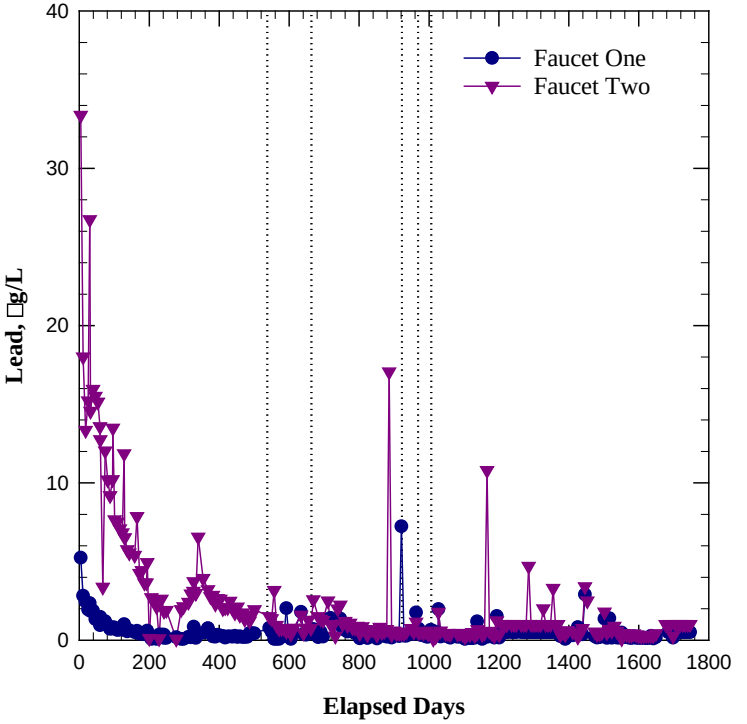


Faucet Type

- Faucet 2:Faucet 4 water use ratio of 7:1
- Same faucet type
- Both faucets replaced on day 662



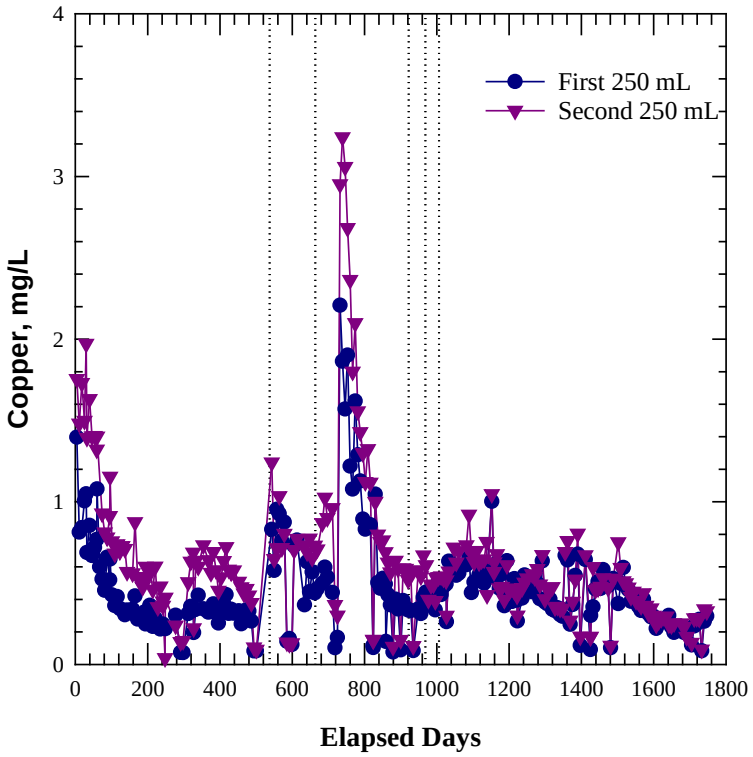
- Faucet 1 is a brass utility faucet
- Faucet 2 is certified as complying with NSF/ANSI 61
- Identical water use



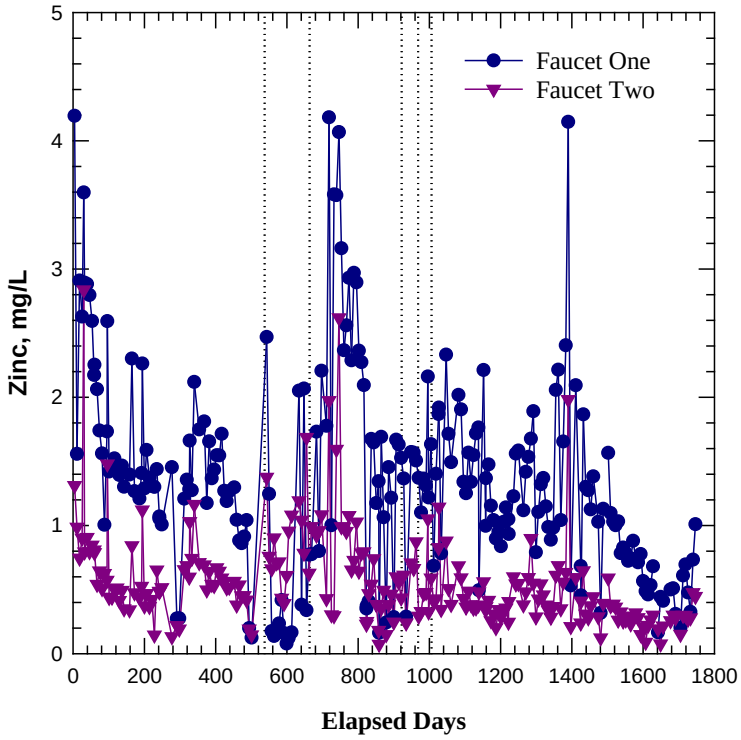
Cold water line
1 day stagnation

Faucet 1 Cold 17 h Stagnation

Copper



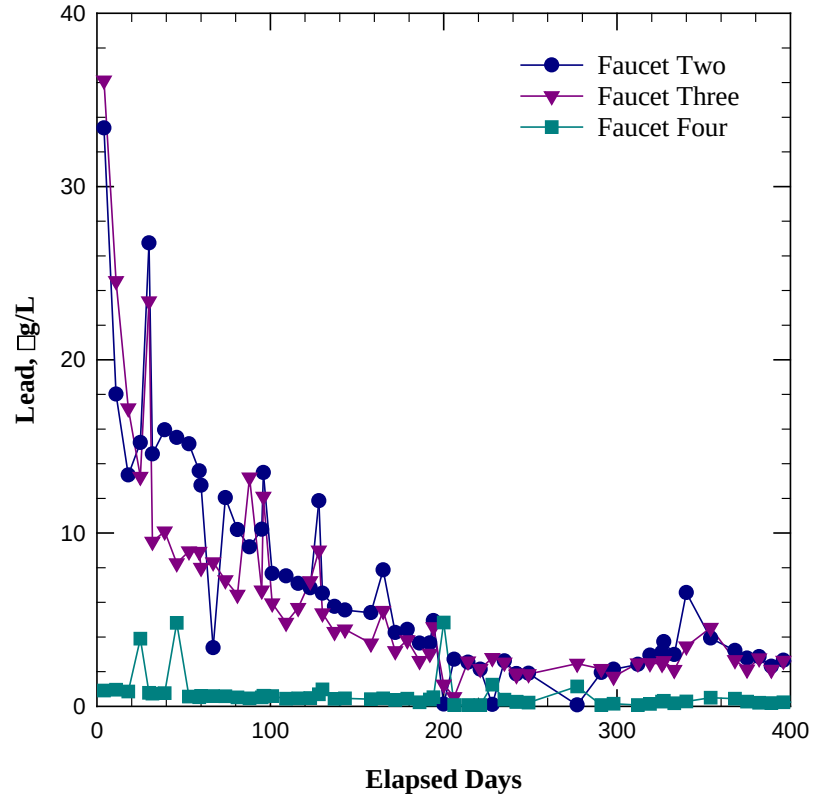
Zinc

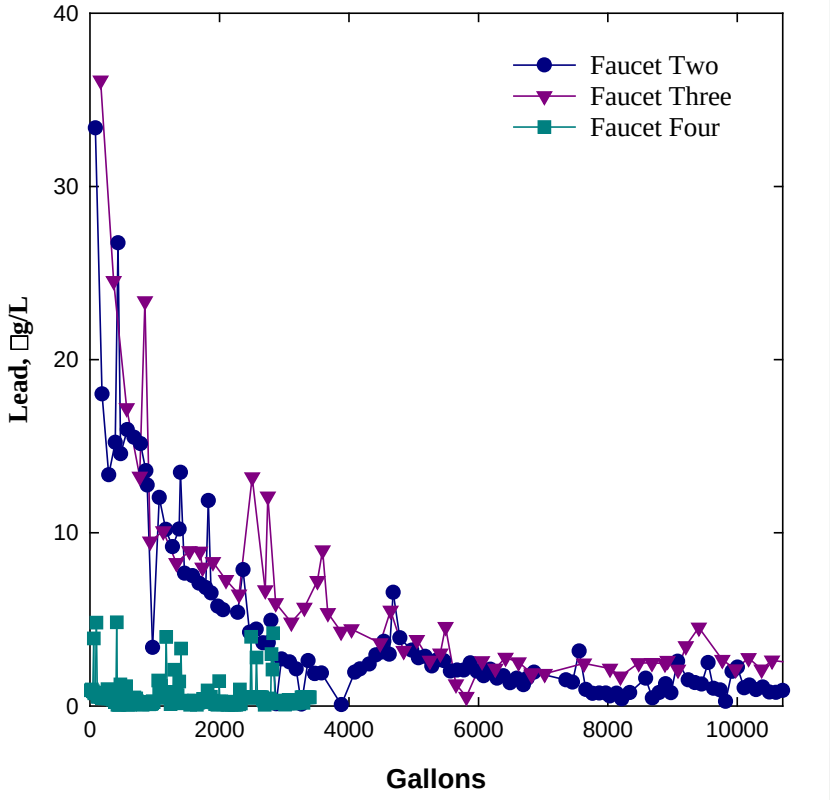


Faucet 1: 1.35 ± 0.80 mg/L

Faucet 2: 0.56 ± 0.37 mg/L

Aging by Gallons and Days



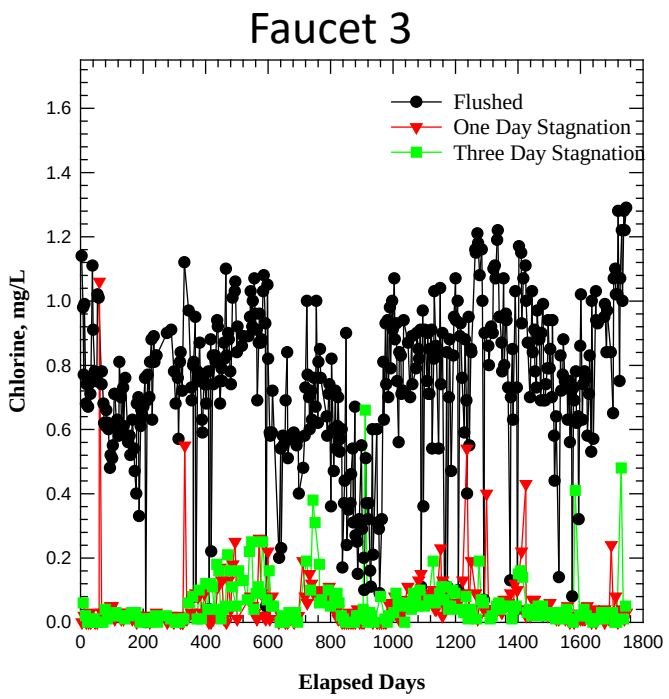


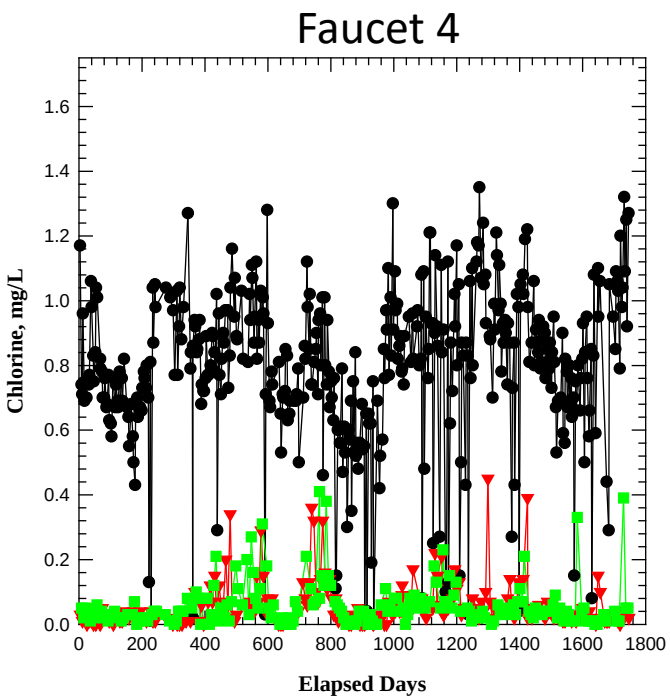
Cold 17 h stagnation

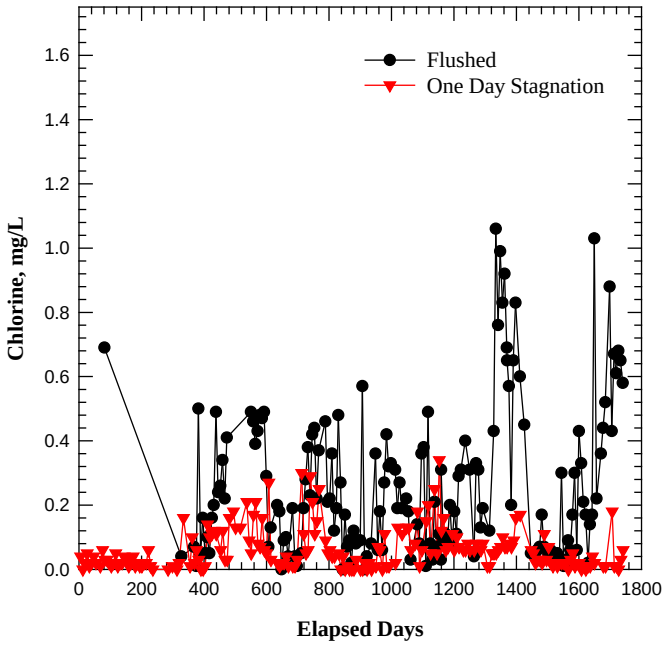
Free Chlorine Depletion

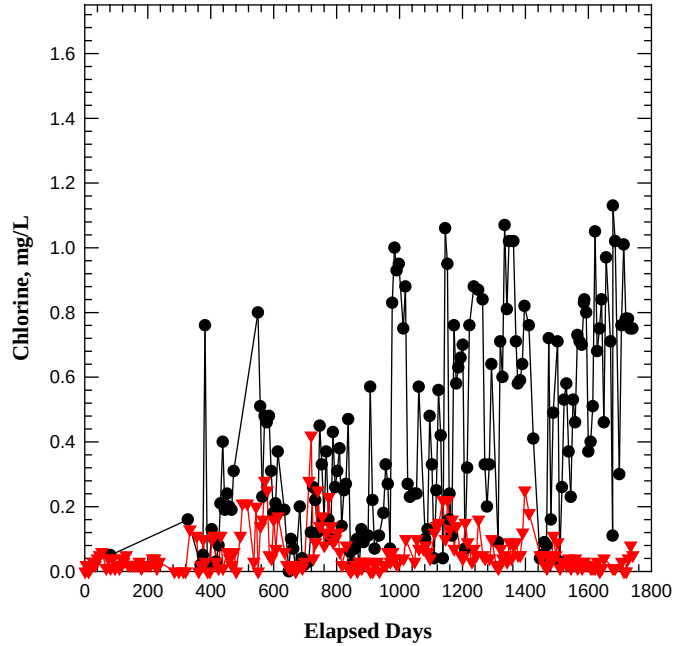
Cold Water

Hot Water







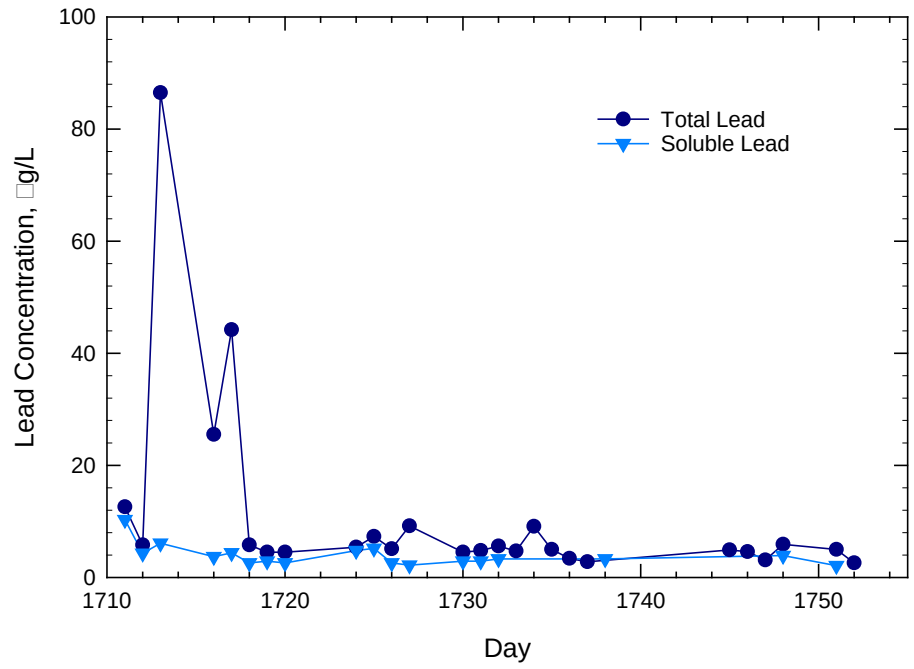


Day 1696: Installed Lead Service Line

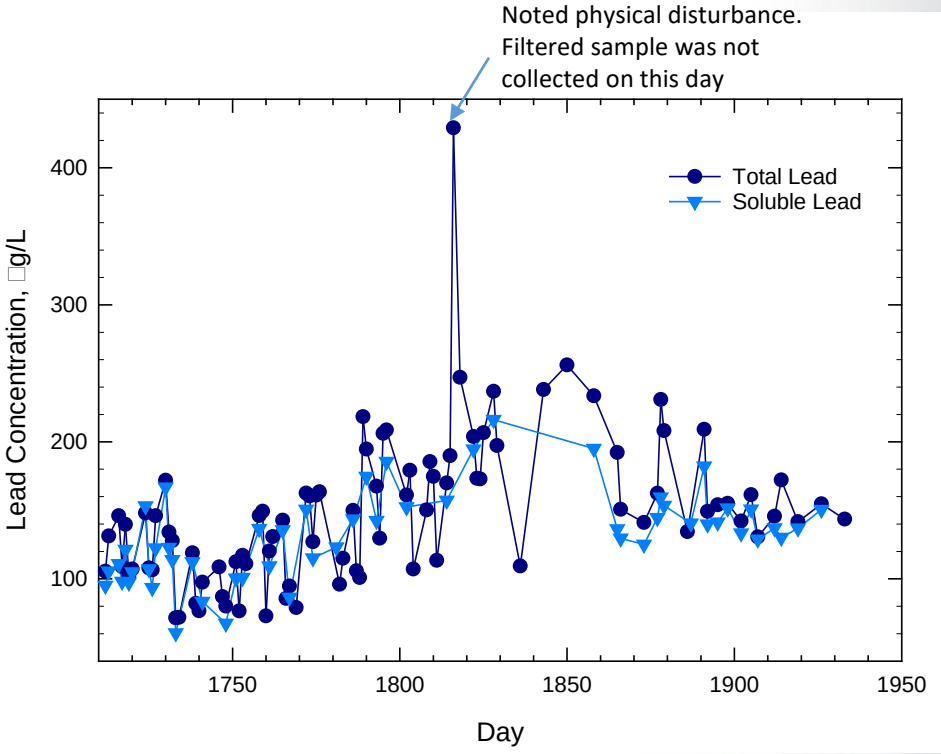
- Excavated from Cincinnati property
- 6’8” length, 0.5” ID
- Began conditioning pipe separately from premise plumbing
  - ~250 gal/day, 1 gal/min
  - pH 7.50

Lead Service Line Conditioning

Flushed

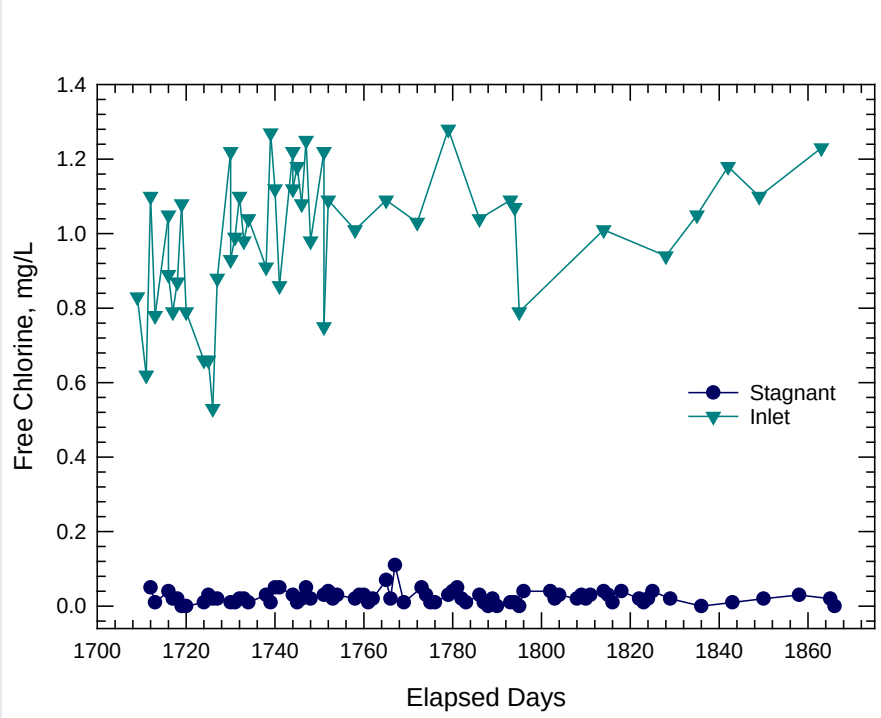


17+ h Stagnation

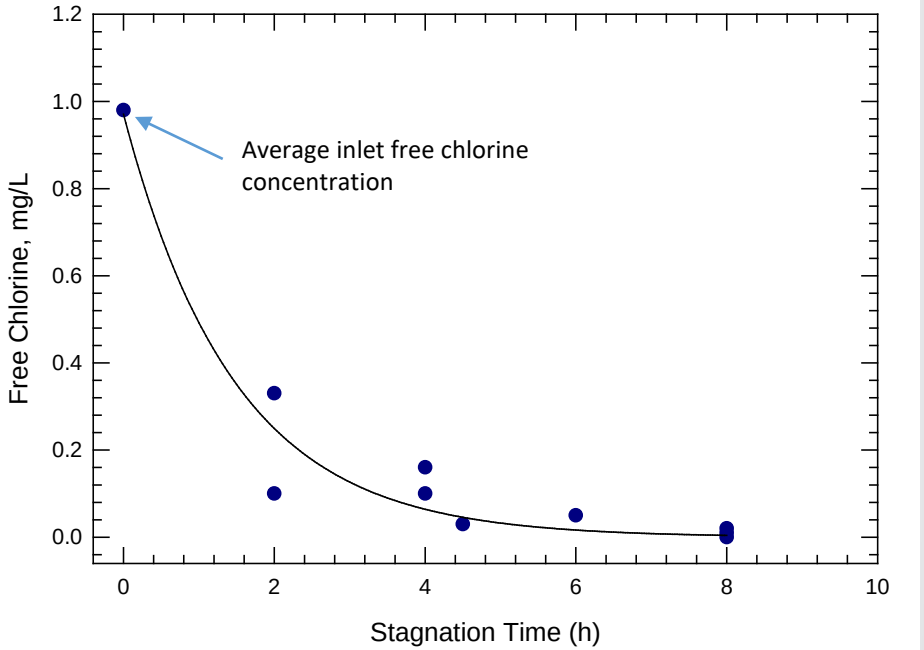


Average particulate percentage for stagnant= 10.6% (0.7-31%)

Chlorine Demand

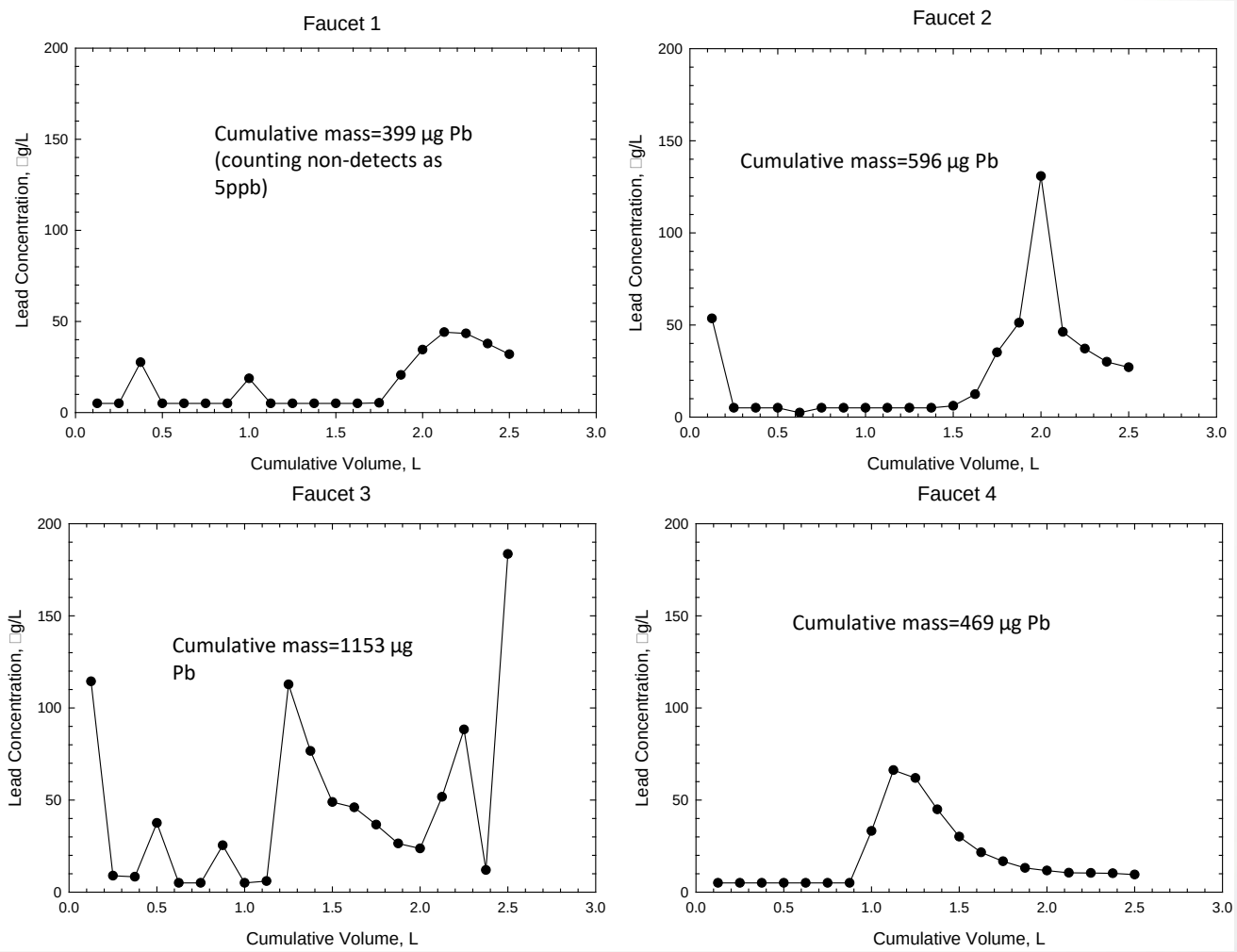


Collected on days
1802-1853



Day 1863: LSL put In-line with downstream premise plumbing

Total lead only



Day 1898:"Typical" Use Patterns

Switched water usage from regimented flushing to random use to observe how water use patterns and typical sampling protocols reflect a system's plumbosolvency

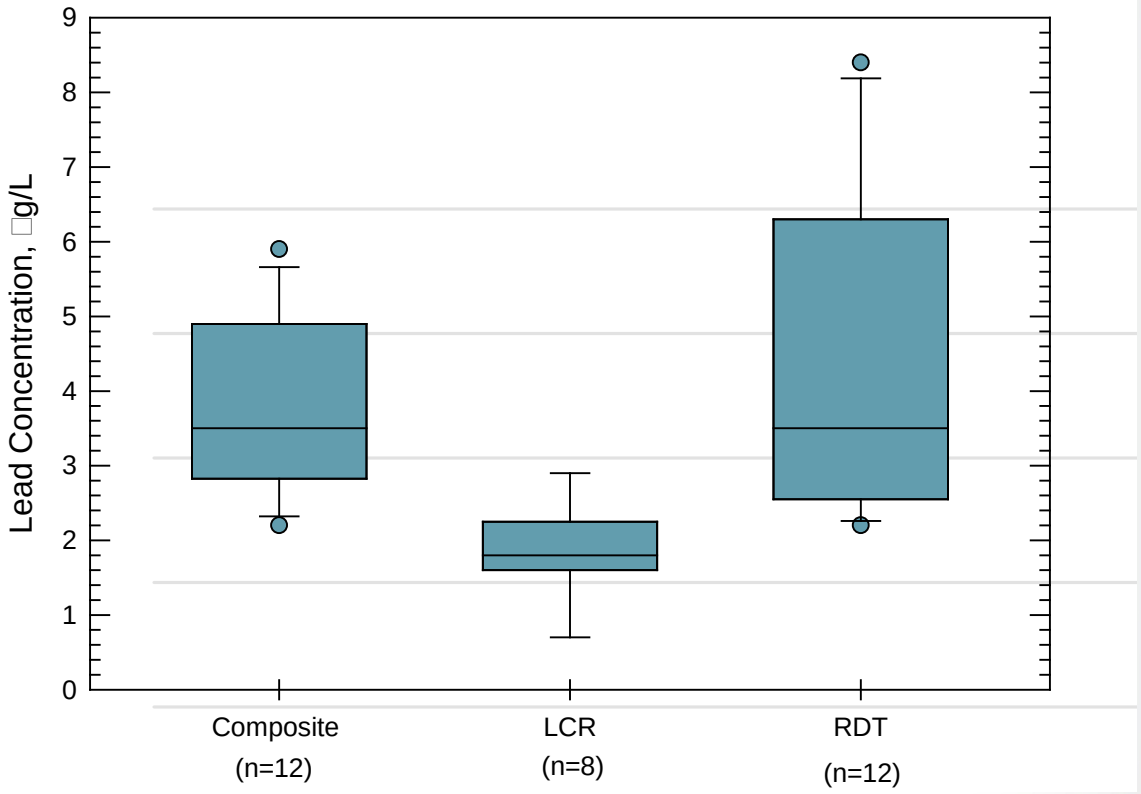
- Faucet 3 is the simulated "kitchen tap" because it has the most water use
  - Pb-Sn solder
- Outlined typical use patterns based on 2016 WRF survey
  - Average number of water uses (pulses)
  - Average draw per use
  - Faucet 1 simulated as appliances (washing machine & dishwasher) that each have a defined water draw
- Recorded time and volume of each draw
  - Different members of the lab chose time, volume, flow rate, temperature, and fixture for each draw

Sampling Protocols

- Random Daytime (RDT)
  - Protocol: 1 L sample collected at a random time during workday hours
  - ❖ Captures wide range of exposure scenarios
- Lead and Copper Rule (LCR)
  - Protocol: 1 L first draw after at least 6 hours of no use
    - Stagnation time was 17 h in this system
  - ❖ Lack of pre-flush preserves varying contact times with the LSL, dependent on water use patterns
- Composite Sampling
  - Protocol: 60 mL into a 1 L container whenever a glass of water or cooking water is drawn over the course of 1 day
  - ❖ Combination of many small samples at time of consumption approximates true exposure

Sampling Results

- Frequent water use can severely dilute samples compared to the stagnant LSL concentration (~150 µg/L)
- LSL is only 6% of total plumbing length (typical LSL is ~60 ft)
- 1.3 L from Faucet 3 to LSL



Continuing Work

Microbiological Work

- Legionella bacteria detected in the four faucets and shower head
- Ongoing work monitors growth and response to normal hot water maintenance work and preventative practices

Lead Transport Modeling

- The model system's plumbosolvency has been characterized through sampling
- A range of lead exposure scenarios can be modeled based on different water use patterns

Summary

- Significant amounts of lead can leach from new brass, solder, and faucets, even those complying with NSF standards
- Identical faucets can initially release drastically different amounts of lead and copper
- Lead and copper levels both plateaued after ~300 days and aging is dependent on both time and volume of water used
- Plumbing work including faucet, pipe, and/or hot water heater replacement causes extended and variable lead and copper release, and levels can be higher than those after first installation
- High plumbosolvency is not accurately reflected by conventional sampling protocols

Contact Information

Kelly Cahalan

cahalan.kelly@epa.gov

Darren Lytle

lytle.darren@epa.gov

Special thanks to Christy Muhlen, Matt Staudinger, and Dan Williams for assistance with building and operating the Home Plumbing System

Notice

The findings and conclusions in this presentation have not been formally disseminated by the U.S. Environmental Protection Agency and should not be construed to represent any Agency determination or policy. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.