APPLICATION OF EPANET TO UNDERSTAND LEAD RELEASE IN PREMISE PLUMBING

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AWWA ACE

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Presentation outline

- Motivation & background
- Approach
- Factors affecting lead concentration at tap
- Application of model to understand exposure
- Validation of model with experimental data

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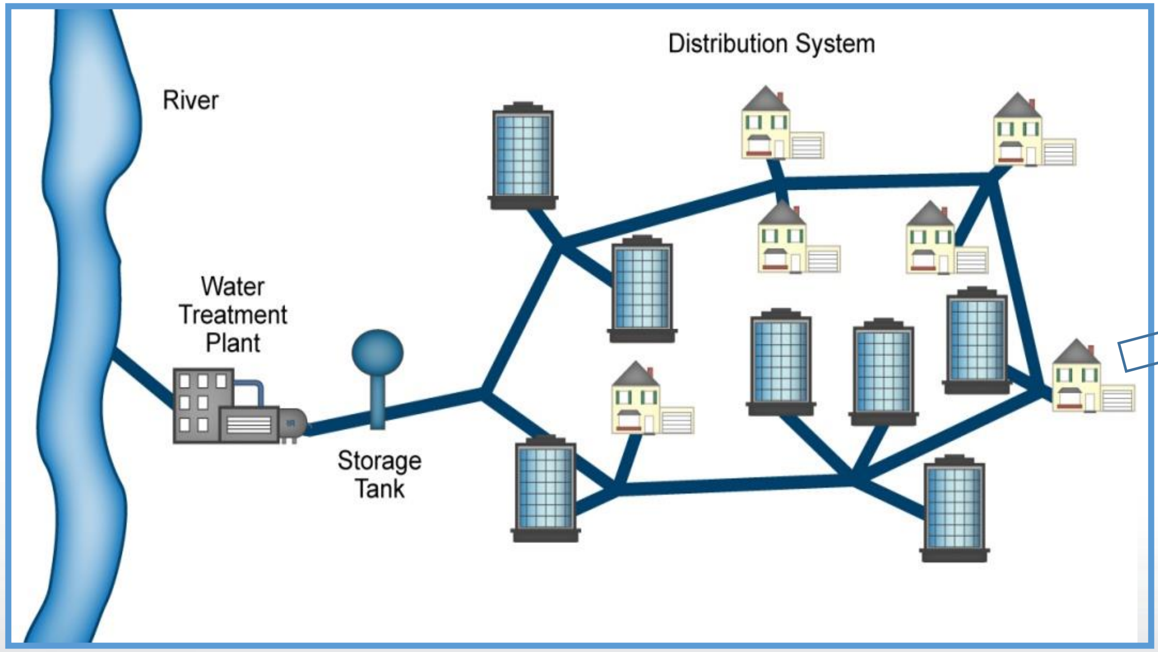
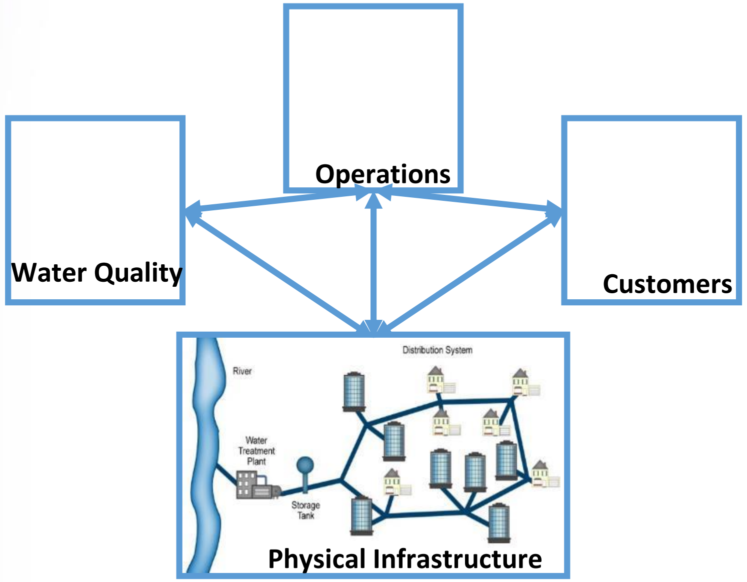
Motivation

- Millions of U.S. homes have lead service lines & other sources of lead in the home
- What factors affect *how much* lead is in the water at the tap?
- If a water sample is taken at the tap, what does the resulting lead concentration mean?

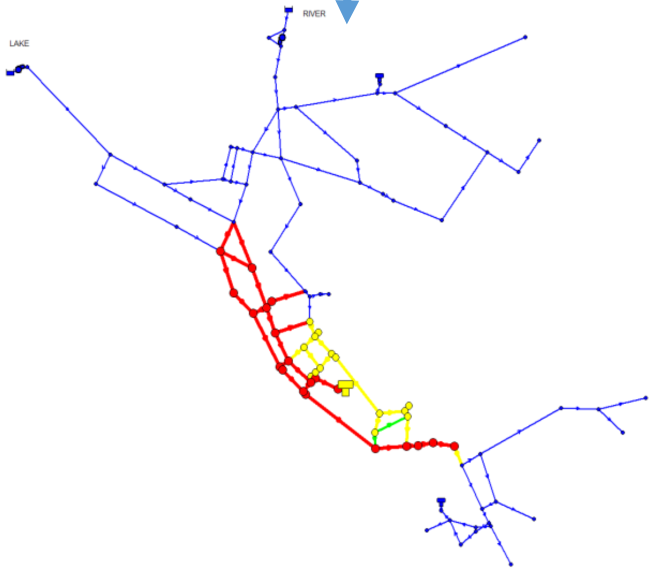


Approach - EPANET Modeling



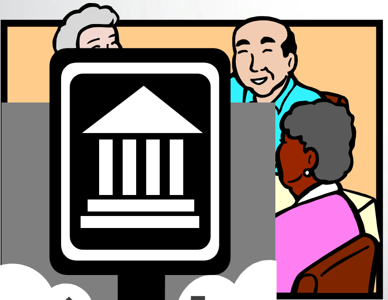
Input data

EPANET: first principles physics-based equations for flow, pressure and water quality



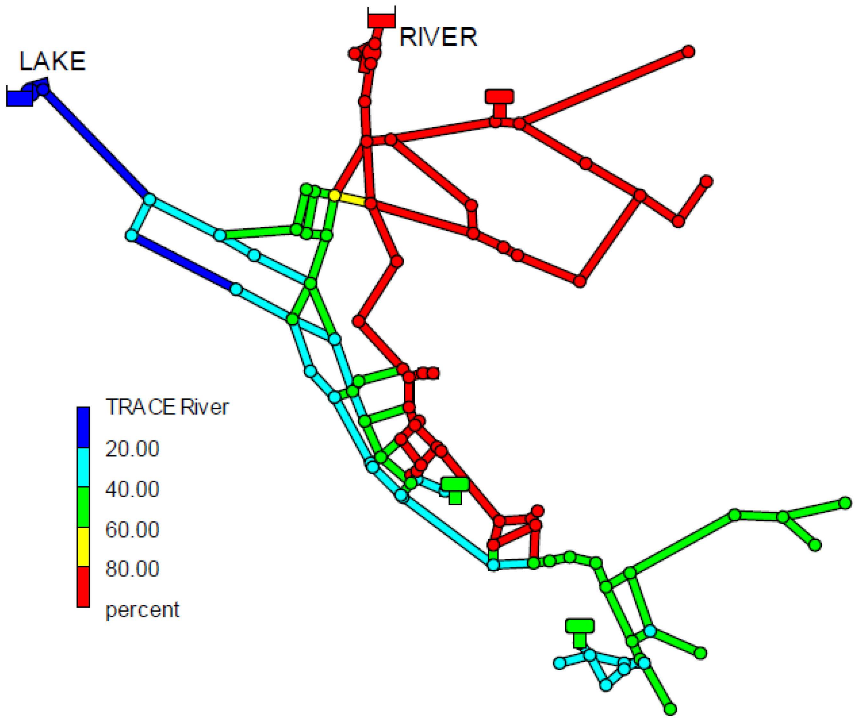
Pressure
Head
Flow
Tank Levels
Concentration

Output data



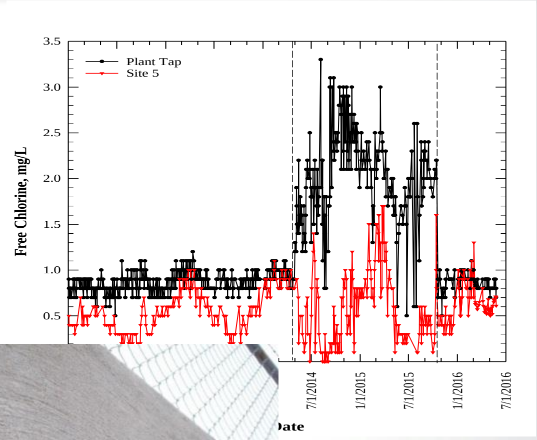
EPANET Software

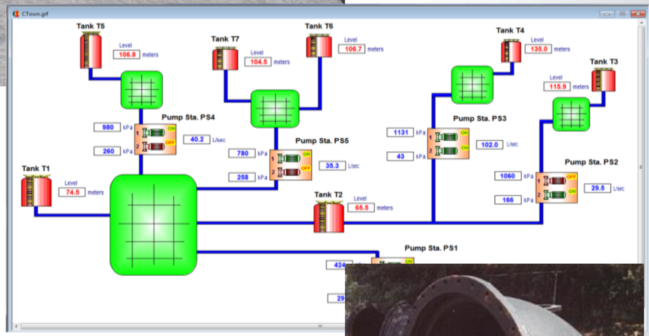
- Models and simulates hydraulics within water distribution network
- Models and simulates simple decay/growth of a single substance
- Available for free on EPA's website
- Developed in 1990
- Provides basis for multiple commercial software packages



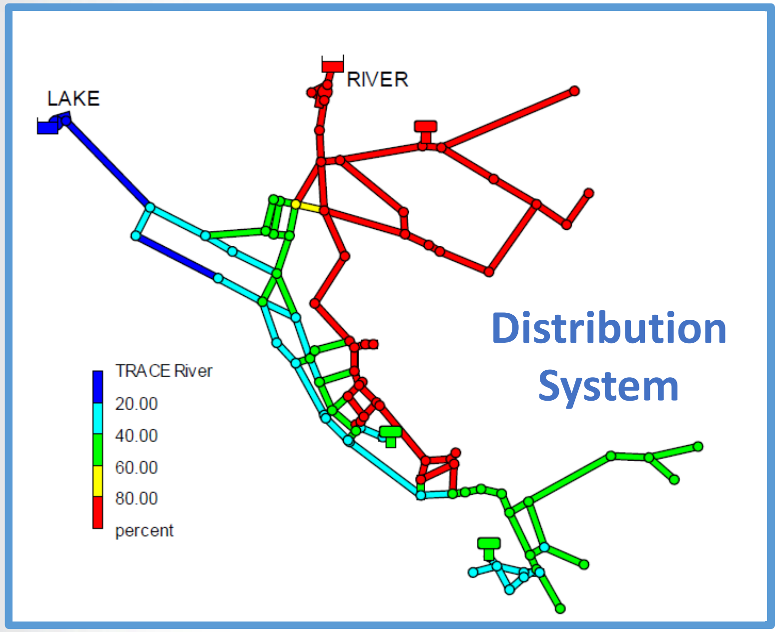
WDS Modeling Can Address

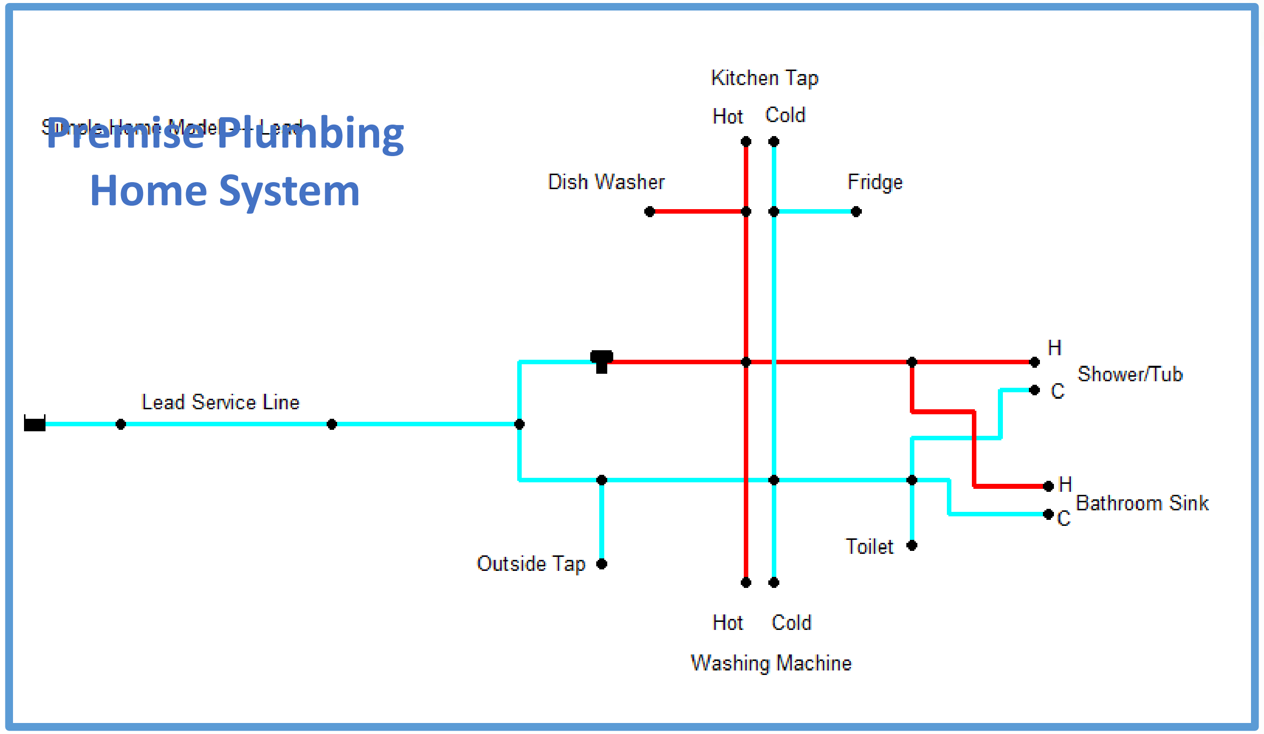
- Replacing Aging Infrastructure
  - Main breaks, damaged hydrants and valves, water loss
- Optimizing Operations
  - Pump schedules, tank cycling, pressure management, chlorine dosing, energy reduction
- Planning
  - Future demands, sizing new pipes & facilities, evaluating supplies, growth and decline
- Solving Water Quality Problems
  - Violations, customer complaints, low disinfectant residuals, disinfection byproducts

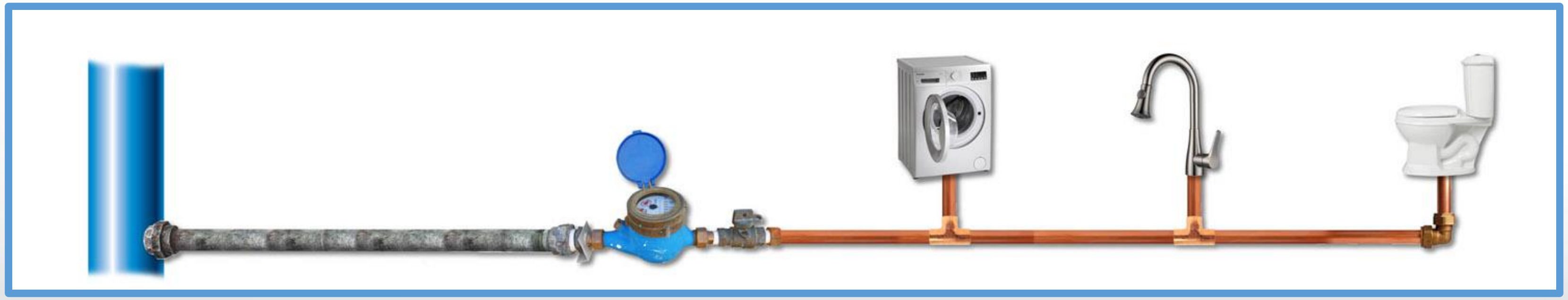




EPANET to Model Premise Plumbing







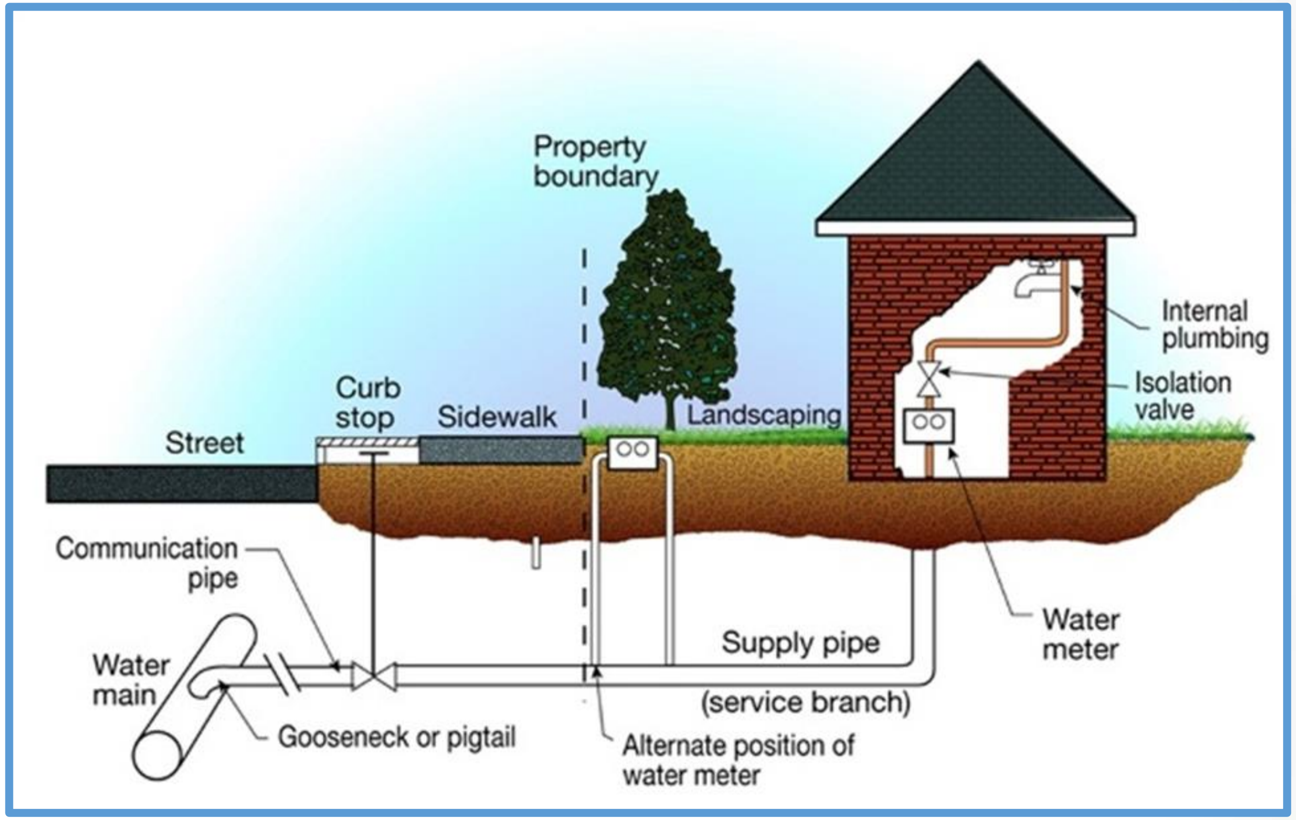
Factors Affecting Lead Concentration

- Hydraulic
  - Pipe lengths & diameter
  - Fixtures & appliances (where)
  - Customer usage patterns (when)
  - Flow rates (how much)

- Water quality
  - Lead sources (pipe & plumbing materials)
  - Lead dissolution (corrosivity of water)
  - Lead particulate release

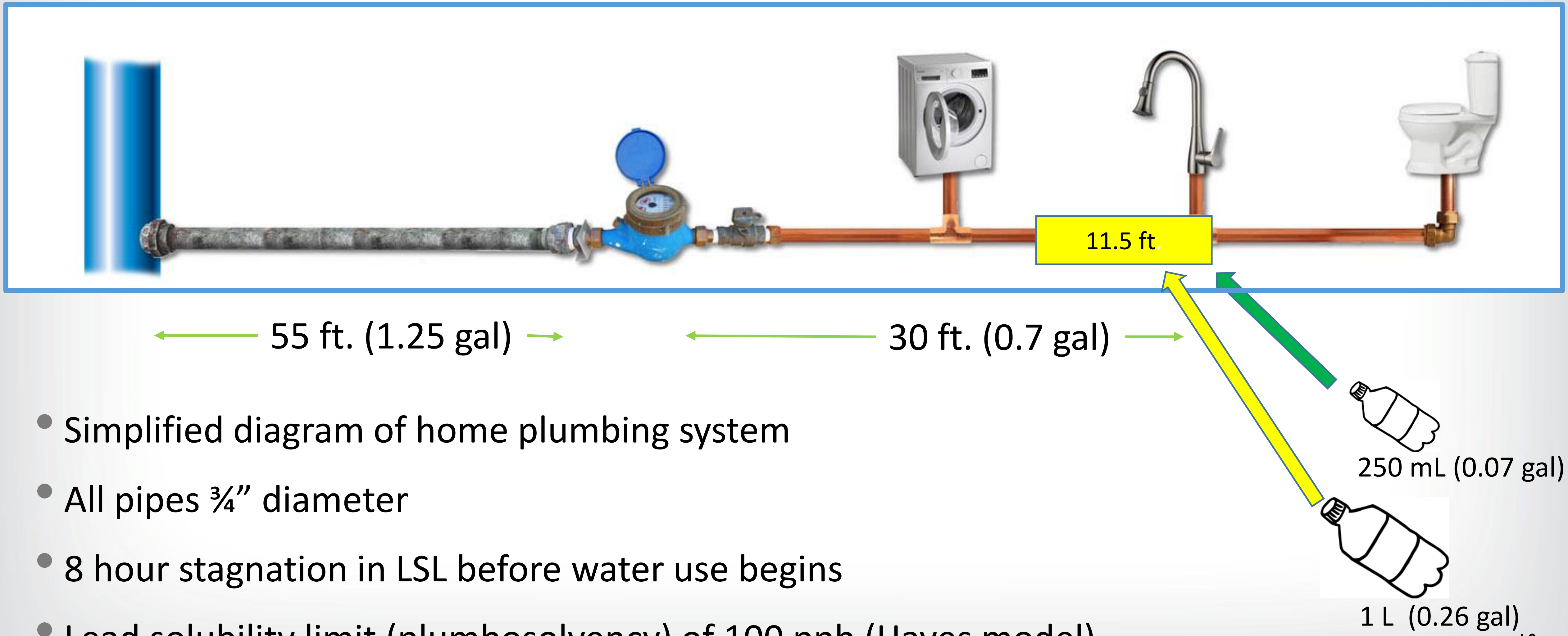
Sources of Lead

- Lead service line (50-75%)
- Other materials such as galvanized pipes, lead solder, fittings, etc. (20-35%)
- Faucets (1-3%)



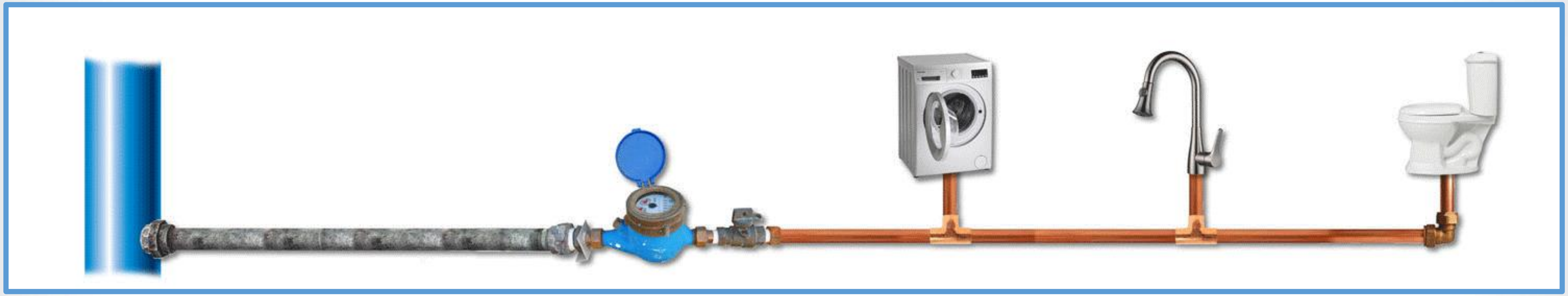
From AWWARF 2008 Contribution of Service Line and Plumbing Fixtures to LCR Compliance

Simple Home Model



- Simplified diagram of home plumbing system
- All pipes ¾” diameter
- 8 hour stagnation in LSL before water use begins
- Lead solubility limit (plumbosolvency) of 100 ppb (Hayes model)

Corrosion & Lead Dissolution



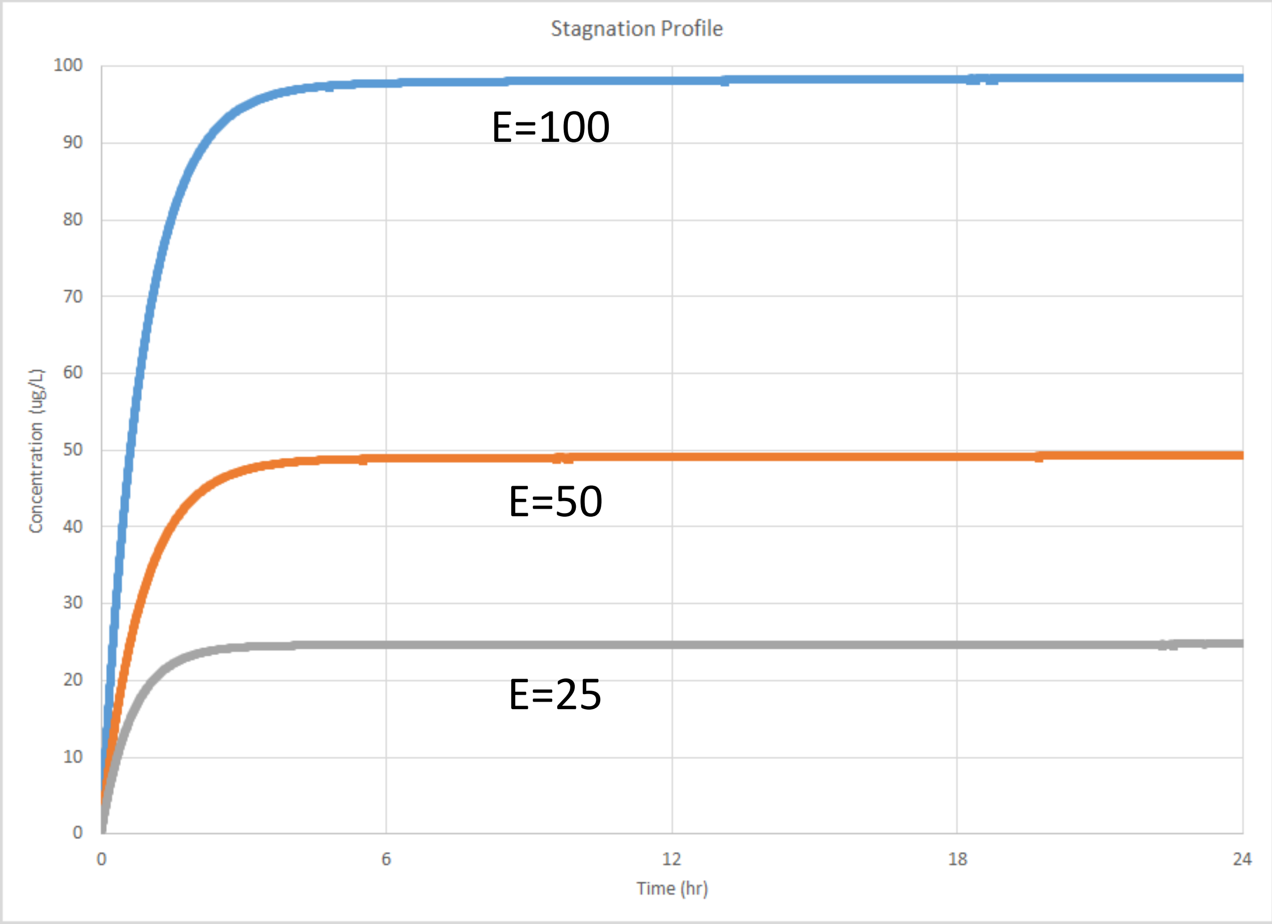
- Why does soluble lead release into water from lead sources?
- Chemical reaction between water and plumbing causes dissolving or wearing away of lead in pipe
- Affected by use of water treatment chemicals, presence of protective scales or coatings inside pipes, condition of pipes, amount of disinfectant, and background water chemistry (e.g., alkalinity, pH, temperature)

Lead Equilibrium Model

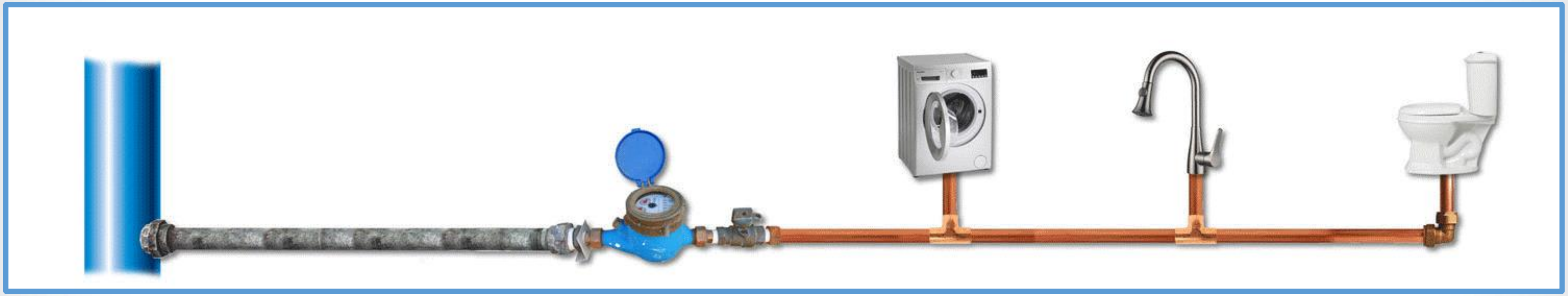
$$\frac{dC}{dt} = \frac{AM}{V}\frac{E - C}{E}$$

- C is the lead concentration in the LSL (mg/L)
- A is pipe surface area (m^2)
- V is pipe volume (L)
- E is the maximum lead capacity of a water (mg/L)
- M is the dissolution rate ($mg/m^2/s$)

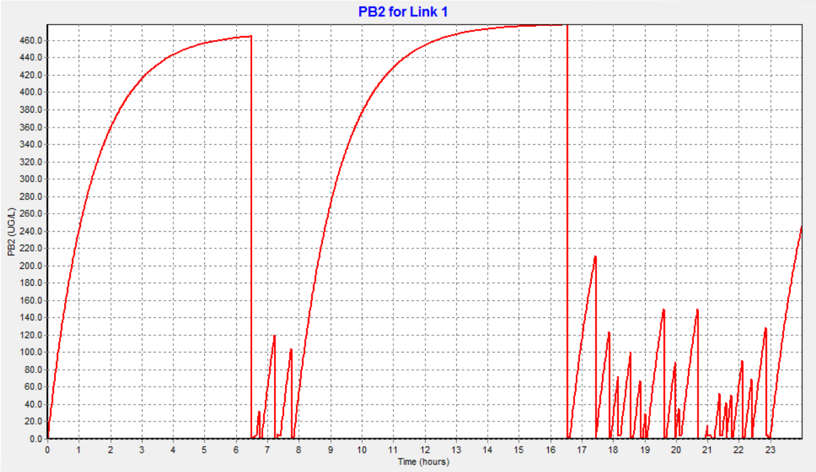
Hayes et al. (2009)



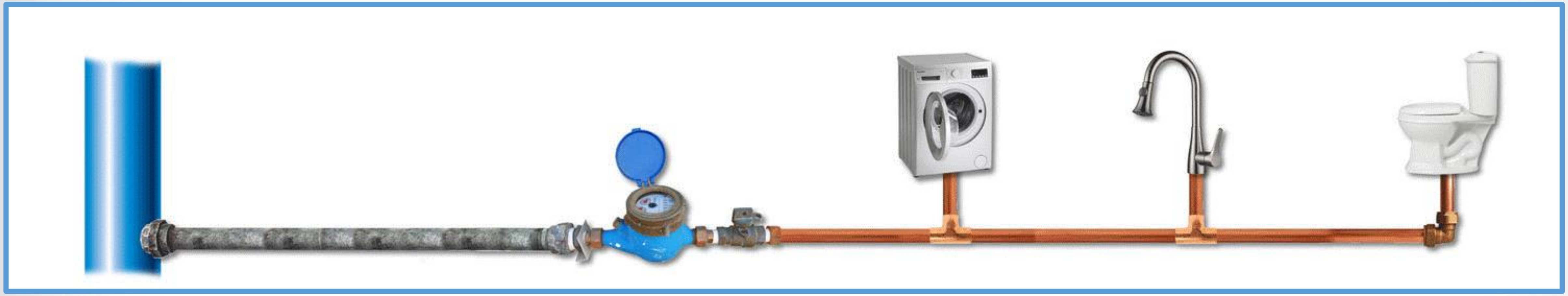
Water Usage - Stagnation



- As water sits in pipe, the concentration of lead increases in the water within the LSL until it reaches its solubility limit
- When water is used within the home, the slug of lead in the LSL moves into the other pipes and enters the home through the faucets/fixtures
- Lead increases in the LSL water again



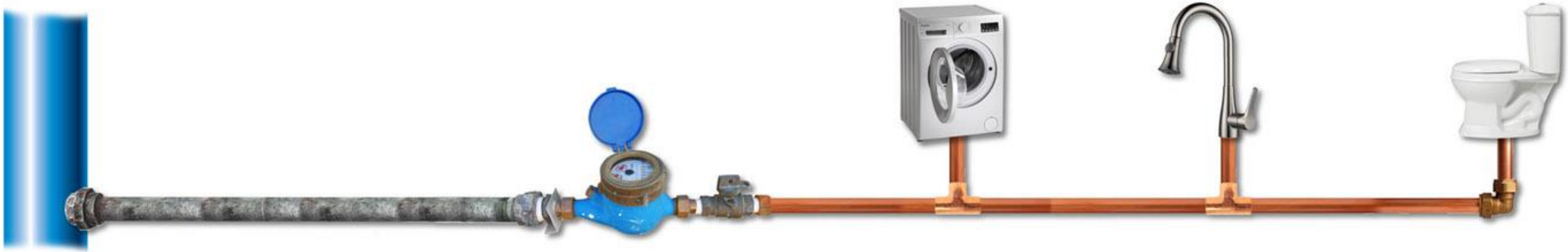
Water Usage – Large Volumes



- Large water usage flushes out soluble lead
- If someone takes a drink of water from the kitchen faucet after large water usage, the concentration at tap varies
- Concentration depends on flow rate

	% LSL removed	Conc. in next glass
Shower (17.2 gal @ 2 gpm)	100%	4 ppb
Toilet (3.6 gal @ 2 gpm)	100%	4 ppb
Toilet (1.3 gal @ 2 gpm)	50%	100 ppb

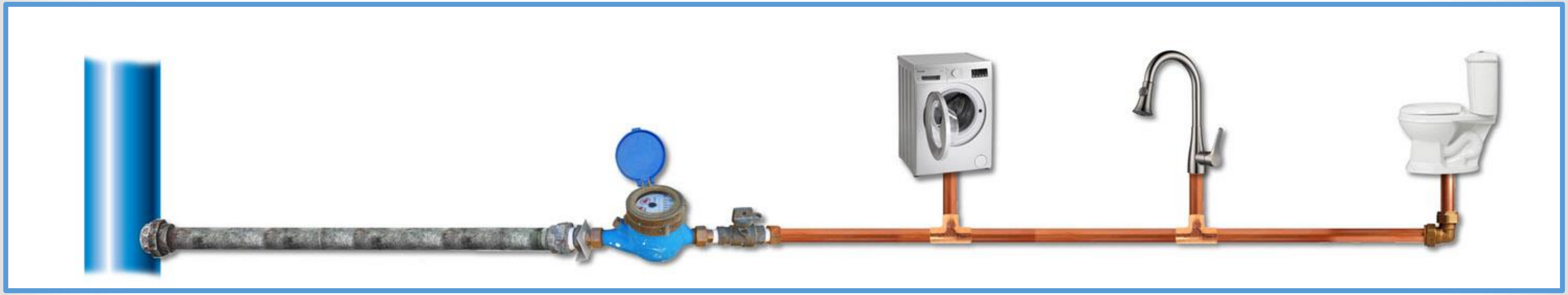
Water Usage – Small Volumes



- Small water usages move lead from LSL into home plumbing pipes
- Concentration at tap stays at 0 until more water is used

	% LSL removed	
8 oz glass of water	0% - slug moved 2.7 ft.	0 ppb
Coffee pot (32 oz)	0% - slug moved 11 ft.	0 ppb
Brushing teeth (1 gal)	20% - slug moved 43.5 ft.	100 ppb

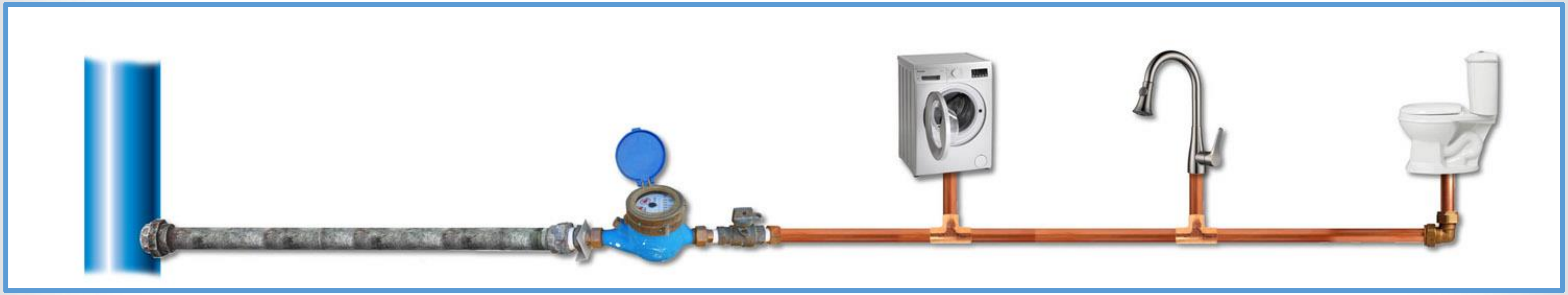
Pipe Diameter



- Assume 1.5 gpm flow at faucet until lead slug removed, then glass of water is filled
- As diameter increases,
  - Lead arrives later at the tap
  - Slug duration at tap increases
  - After slug conc. in glass increases

	Arrival time at tap	Duration	Conc. in next glass
D=0.5 in	12 sec	22 sec	3 ppb
D=0.75 in	28 sec	50 sec	5 ppb
D=1 in	49 sec	90 sec	7 ppb

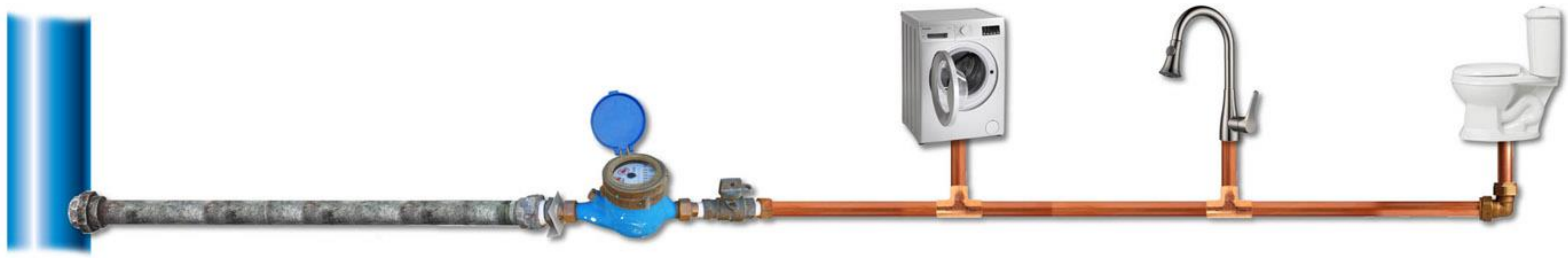
Premise Pipe Length



- Assume 1.5 gpm flow at faucet until lead slug removed, then glass of water is filled
- As home plumbing pipe length increases,
  - Lead arrives later at the tap
  - Slug duration stays the same
  - After-slug conc remains constant

	Arrival time at tap	Duration	Conc. in next glass
L = 10 ft.	9 sec	50 sec	5 ppb
L = 30 ft.	28 sec	50 sec	5 ppb
L = 50 ft.	46 sec	50 sec	5 ppb

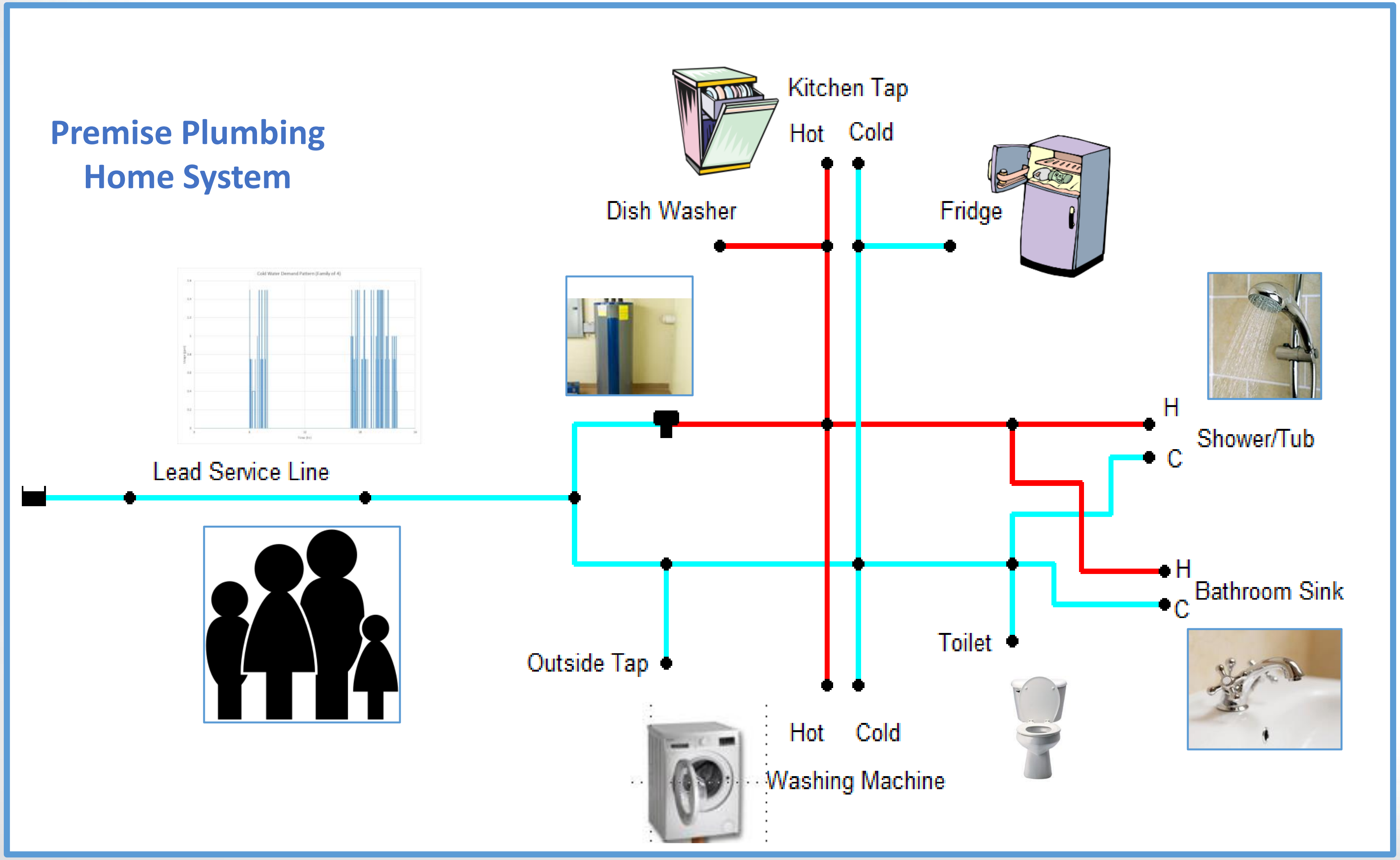
LSL Pipe Length



- Assume 1.5 gpm flow at faucet until lead slug removed, then glass of water filled
- As LSL pipe length increases,
  - Arrival time is the same
  - Slug duration increases
  - After-slug conc in glass increases

	Arrival time at tap	Duration	Conc. in next glass
L = 35 ft.	28 sec	32 sec	3 ppb
L = 55 ft.	28 sec	50 sec	5 ppb
L = 75 ft.	28 sec	69 sec	7 ppb

Summary of Factors Affecting Lead



- Pipe lengths & diameter
- Fixtures & appliances
- Flow rates
- Customer usage patterns
- Lead sources
- Water quality & treatment
- Particulate release

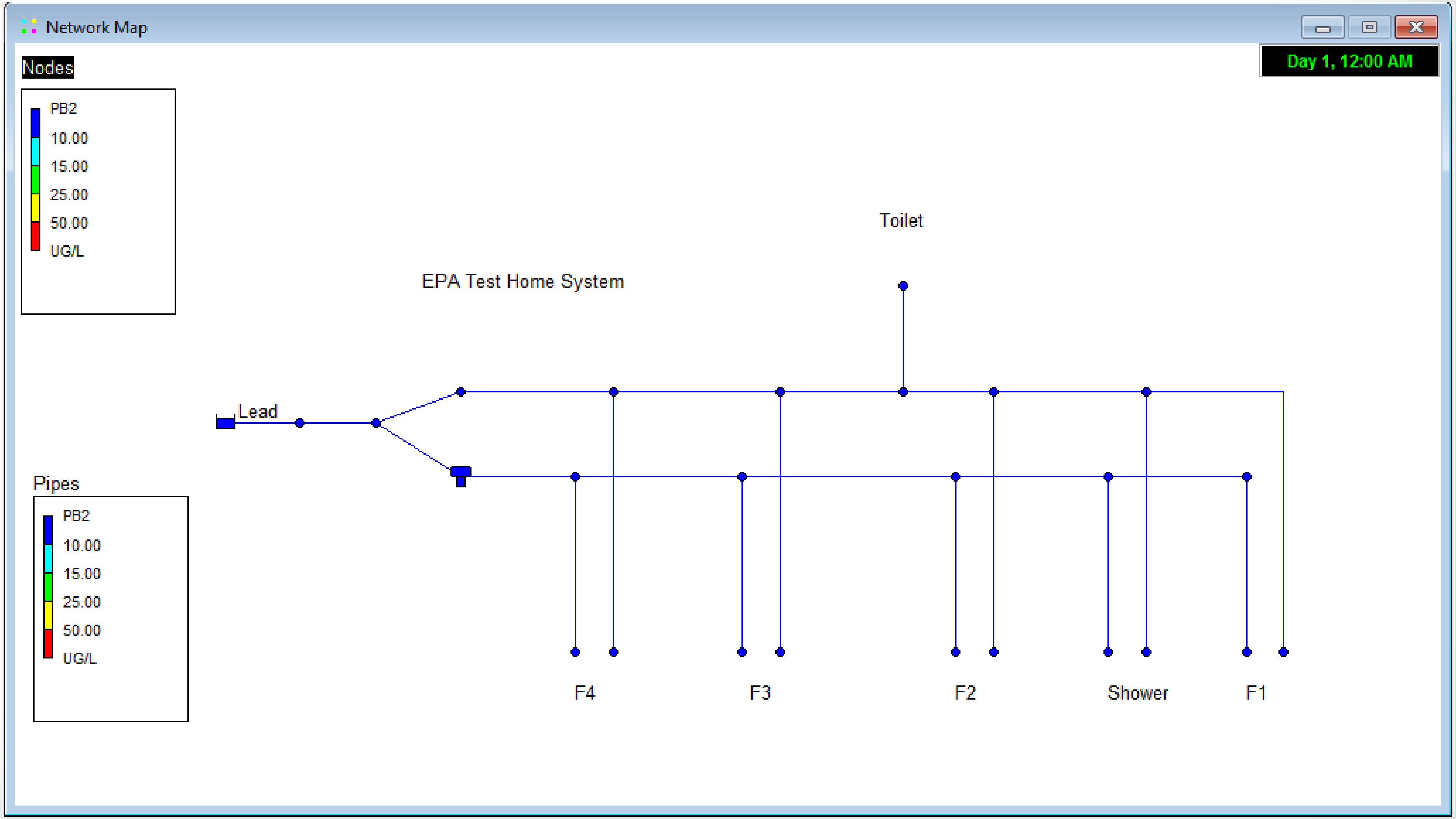
Modeling Exposure in Homes

- Data on variability in hydraulic and water quality factors across communities with remaining lead service lines
- Models
  - EPANET model of premise plumbing including multiple lead sources
    - potentially modified for low flow and stagnant conditions
  - Lead fate & transport model (Hayes model)
  - Models of water usage (family size, appliance type)
- Monte Carlo probabilistic simulations

Data → Models → Exposure Estimates

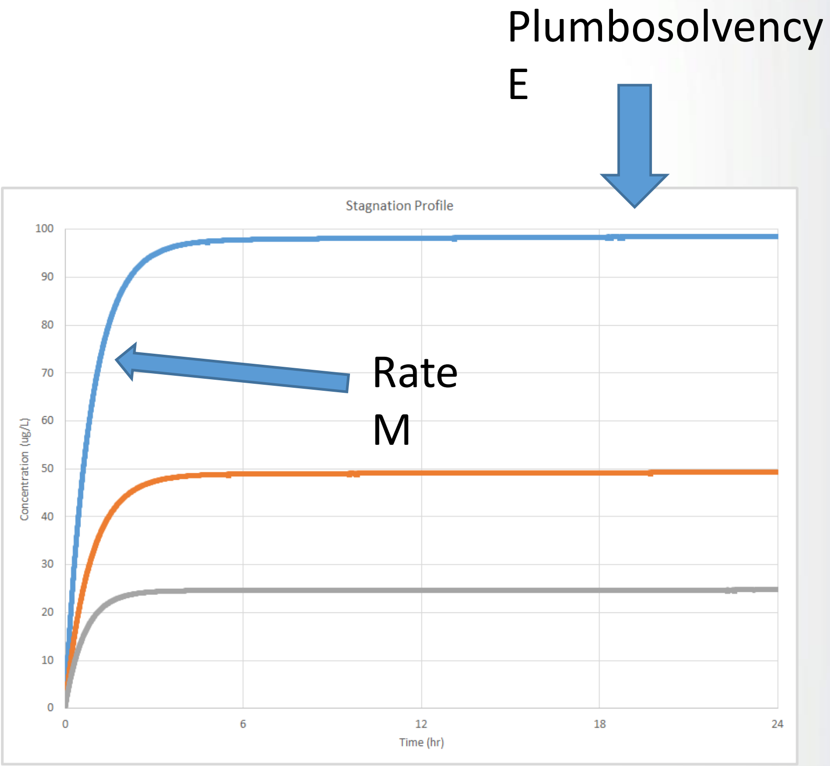
Model Validation with EPA HPS

- LSL
- Pipes
- Appliances
- Usage patterns for family of 4
- Sampling strategies
- Goal: use experimental data to validate model



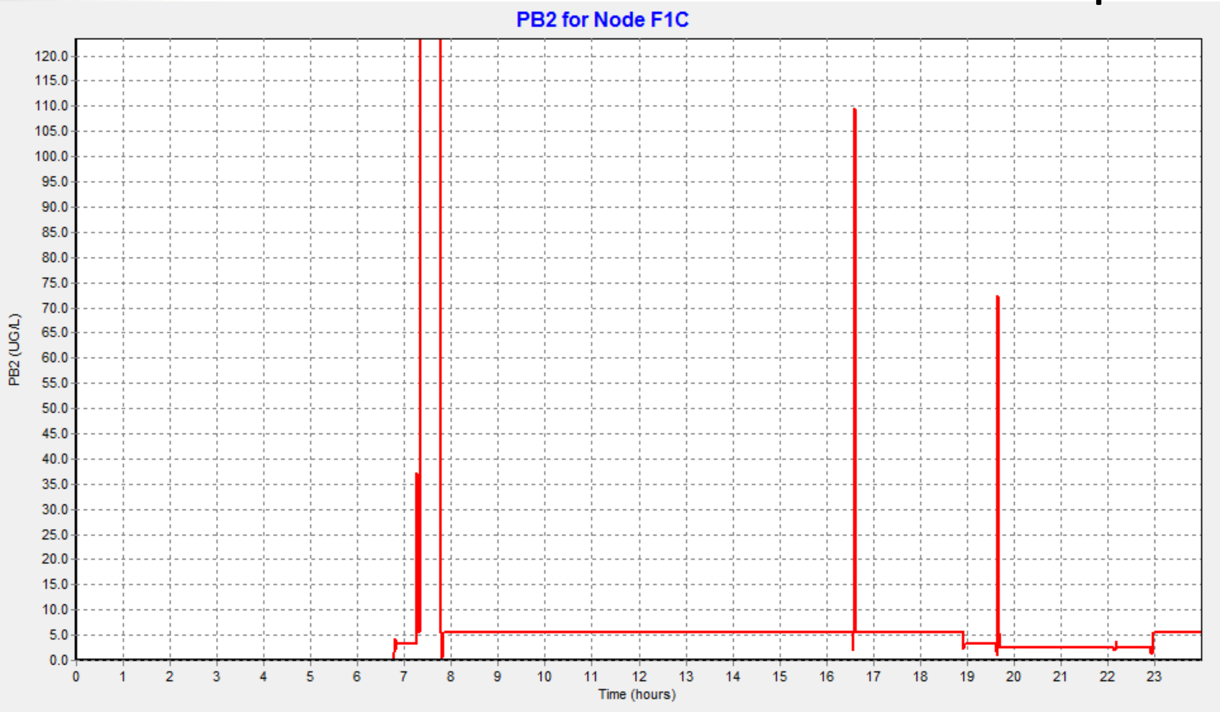
Model Validation with EPA HPS

- Validation of Hayes Model in HPS
  - Experiments to determine plumbosolvency (E) and reaction rate (M)
    - Fixed Length Stagnation – 1, 2, 4 and 16 hours
    - Sampling under constant flow conditions – 8 flowrates ranging from 0.1 to 12 L/min
- Validation of EPANET system model
  - System size/volume
  - Sequential sampling w/ 125mL vials from 4 cold faucets
  - Various actual usage patterns for multi-week period

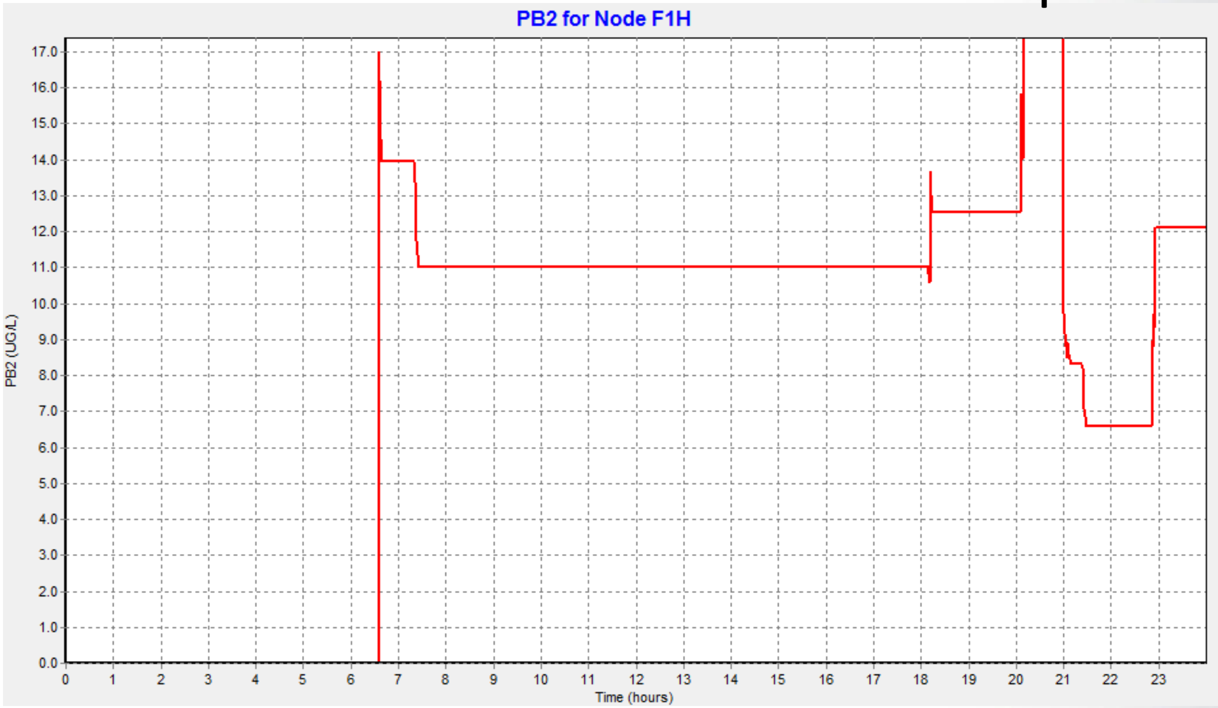


EPA HPS Lead Concentration

Lead Concentration - Cold Water Tap



Lead Concentration - Hot Water Tap



Lower concentrations due to dilution in hot water heater

Conclusions

- Concentration of lead at the tap is affected by
  - Water quality factors (lead sources, water treatment, water chemistry, pipe condition)
  - Hydraulic factors (usage patterns, pipe diameter & length, flow rates, configuration of fixtures & appliances)
- A single sample of tap water cannot represent individual exposure profiles
- A probabilistic modeling study is underway to better estimate exposure in the home and understand the relative importance of each of these factors

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