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Modeling Drinking Water Lead Exposure from Premise Plumbing

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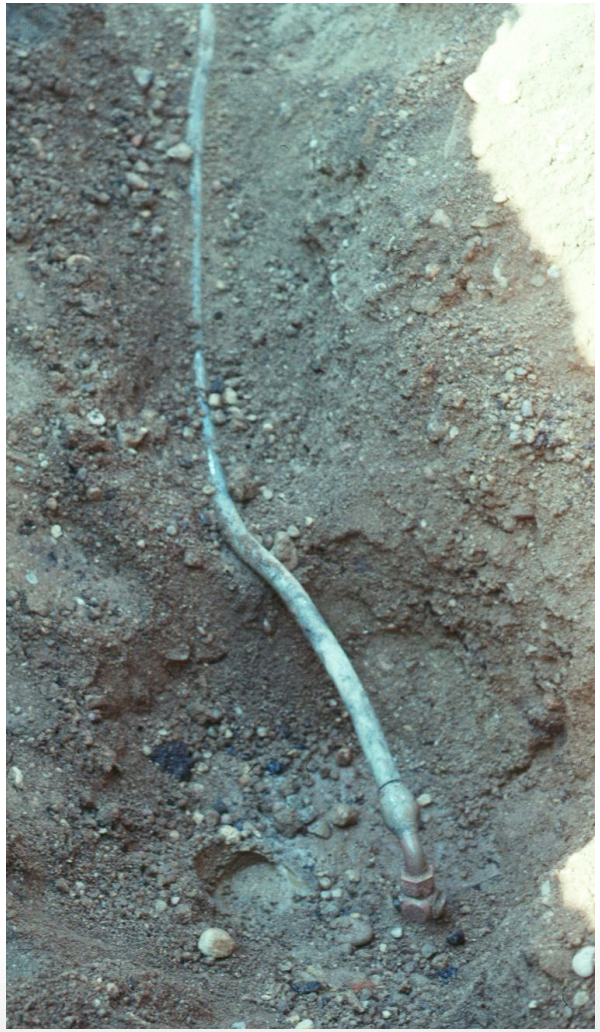
Outline

- Introduction
- Home Plumbing System Simulator (HPSS)
- Updates to EPANET/Dispersion Modeling
- Python Model Framework/Data Analysis
- Validation with HPSS data
- Mini Case Study: Effect of Lead Service Line Length
- Conclusions

Introduction

- Lead is a neurotoxin
- Exposure to lead from water in homes or buildings can occur
  - Depends on the sources in the building (service line material, presence of lead solder, galvanized materials or faucet materials)
- Amount of lead in the water and the possible exposure is a complex mixture of sources, plumbing size, water chemistry, and usage patterns
- Lead can be present as dissolved lead or particulate lead



Challenge

- No good way to predict lead exposure
- Sampling methods do not capture water consumption patterns under typical household use
- Extrapolating knowledge from one home, with its unique usage patterns, to a different home is not trivial
- Each use throughout a day is not getting the same quality of water

Home Plumbing System Simulator

- Installed in 2012
- Has been used in ongoing study of metal corrosion and *Legionella* occurrence
- Designed to replicate a small home
  - 4 faucets, 1 bath/shower, 1 toilet
  - Lead solder used on one branch
  - 40 gallon hot water heater
- **Lead Service Line installed in 2016**
- Random daytime use pattern implemented in 2016
  - Daily use goals established, and simulated users recorded uses in log
  - Logged activities were converted into EPANET pattern

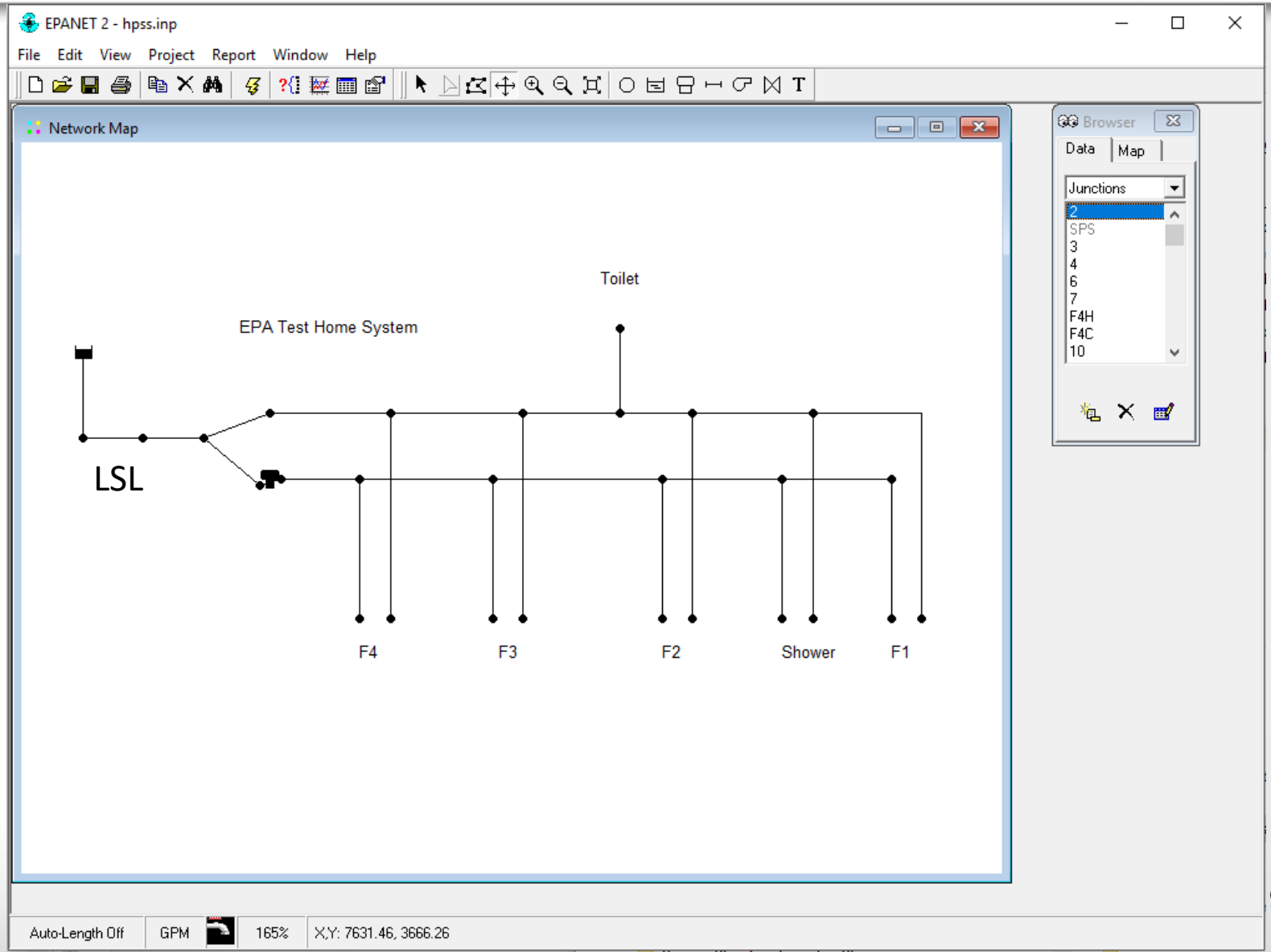
Home Plumbing System Simulator

- Ongoing Samples Collected
  - Lead & Copper Rule samples
    – 1st draw, 1L, twice weekly
  - Random Daytime
    – 1L drawn randomly, twice weekly
  - Composite Samples
    – 60mL collected after Faucet#3 use, analyzed composite for two days per week
  - Lead Service Line
    – sample collected from tap directly after LSL
- Additional Samples
  - Fixed Length Stagnation, Continuously Flowing, and Sequential Samples per Faucet

EPANET Model HPSS Model

- Pipe lengths were measured for each section
- Hot Water Heater is simulated as a single pipe with dimensions to match the volume
- Maximum demand was measured for each faucet
- Patterns are generated for each faucet
  - *Hot and cold were separated, but with a measured maximum for the faucet*

- *No pressure dependent demand was considered*
- *Lead source in current model is only LSL*



Modeling Questions

Can EPANET be used to accurately model exposure to dissolved lead within a home?

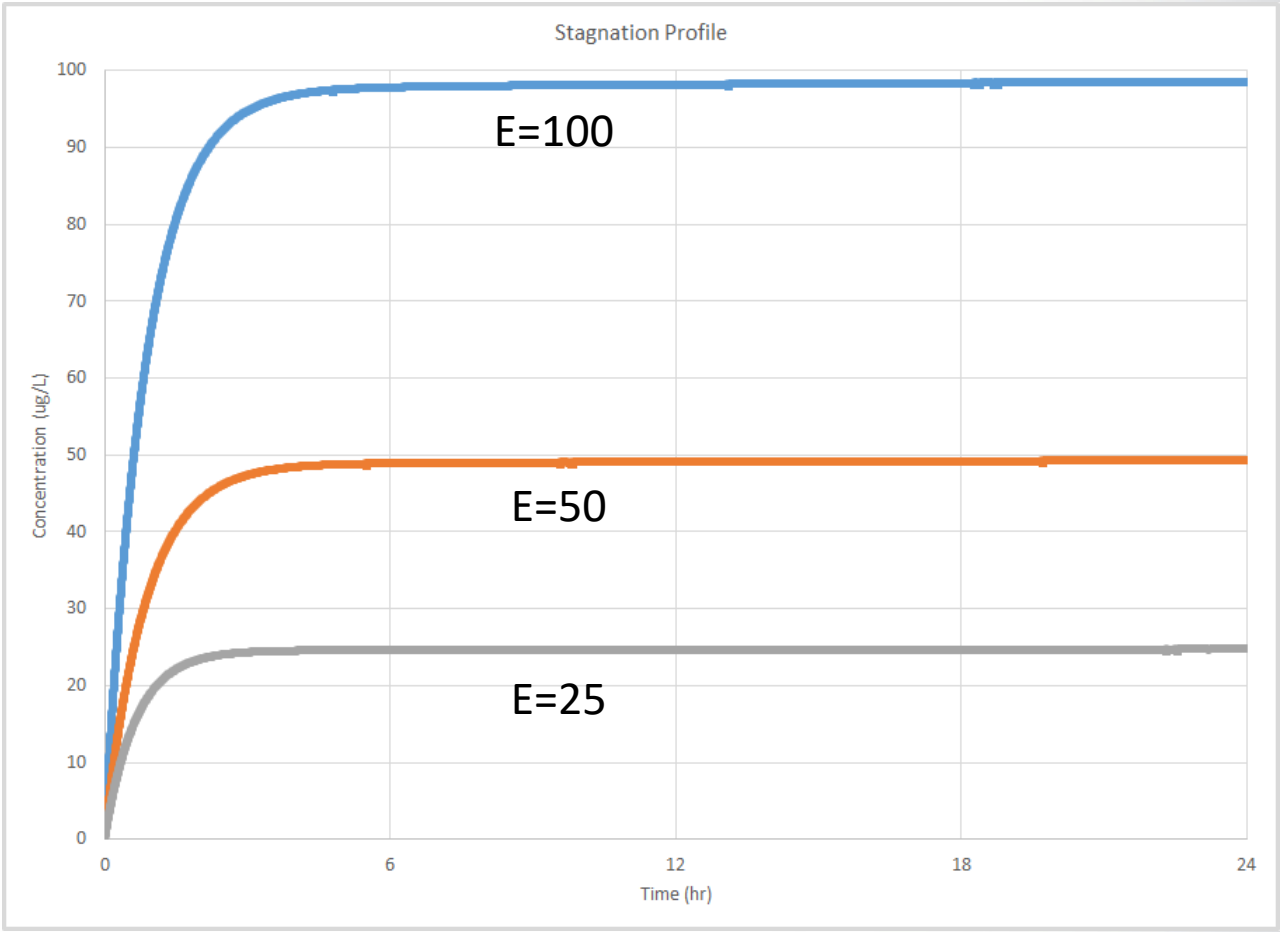
What needs to be done to improve EPANET?

Approach – develop EPANET model of HPSS, include dissolved lead modeling, water use patterns, simulate flow. Compare to experimentally collected lead values

Lead Equilibrium Model

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

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



Hayes et al. (2009)

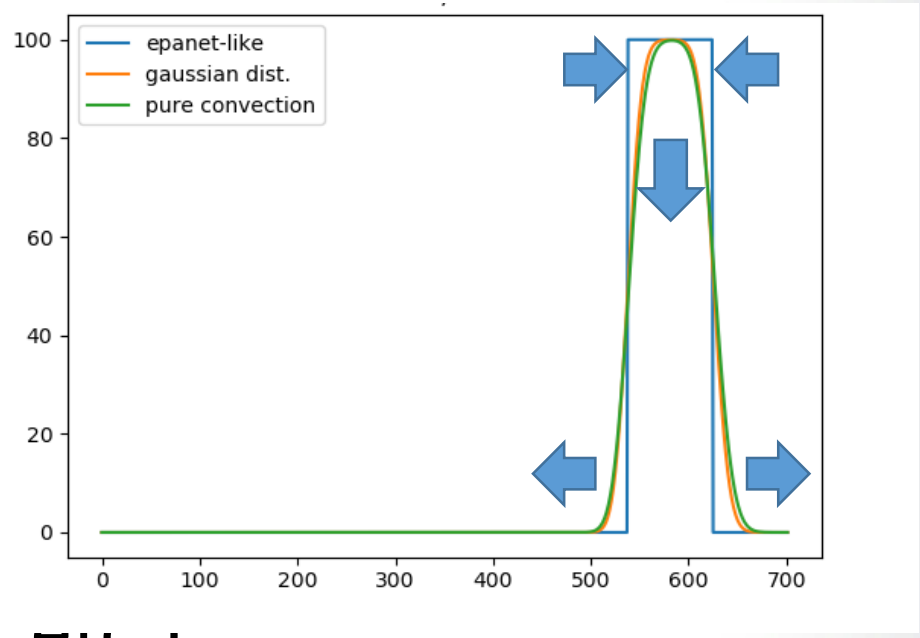
$$\frac{dC}{dt} = \frac{AM}{V}\frac{E-C}{E} \Rightarrow dC = k_1(E - C)$$

$$k_1 = \frac{AM}{VE}$$

EPANET 1st order decay with limiting potential

Sources of Uncertainty in HPSS Model

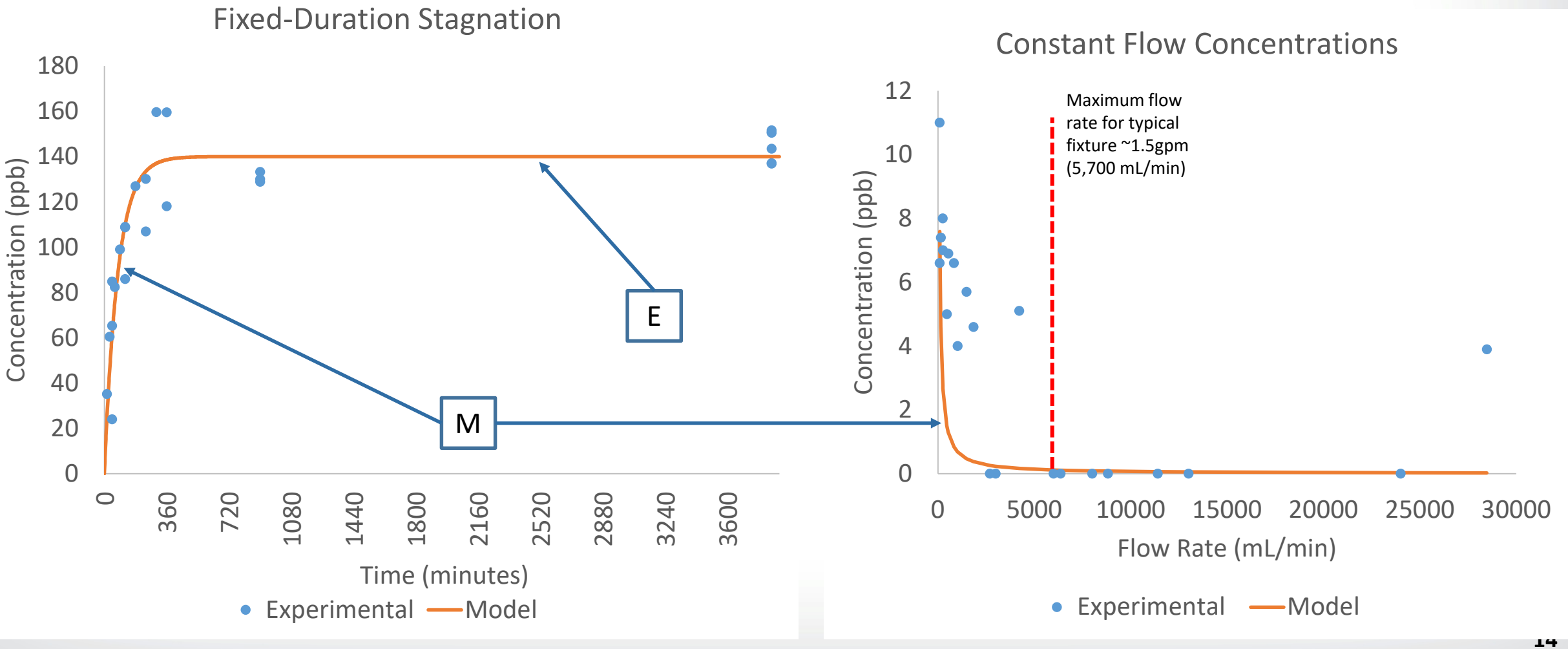
- Water quality variability (plumbosolvency, rate)
- Water use variability
  - How much or How long
  - Flowrate
  - Which fixture
  - Who used the water
- Effect of dispersion
- Particulate lead (source, deposition, scale, etc.)
- How accurate was the usage log
- Additional lead sources (faucet, solder, etc)



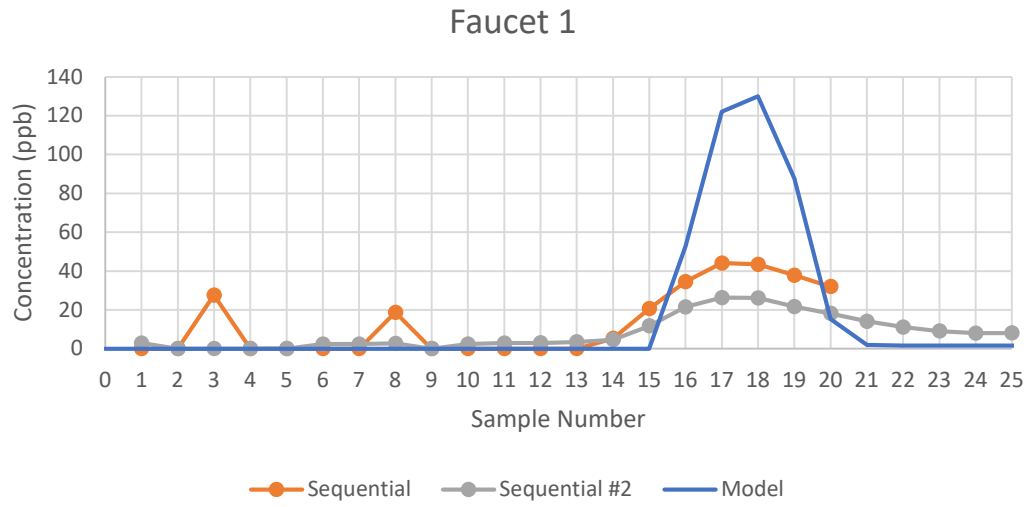
Modification to EPANET

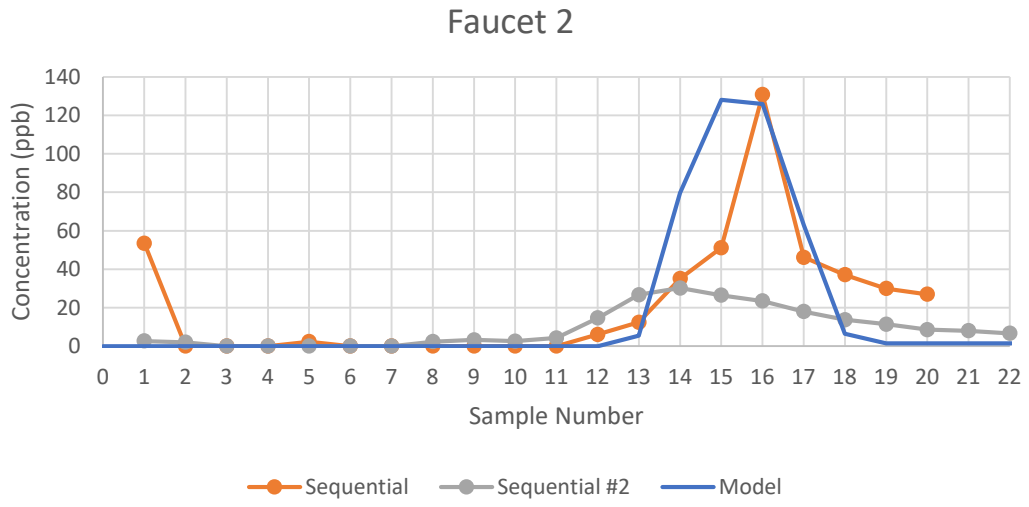
- Stagnant flow
  - Prevent advection of mass if flow rate is below a fixed threshold
- Artificial advection
  - Prevent concentration difference between two pipes from causing an artificial movement of mass
  - Secondary benefit related to overall performance was gained, because fewer segments were produced

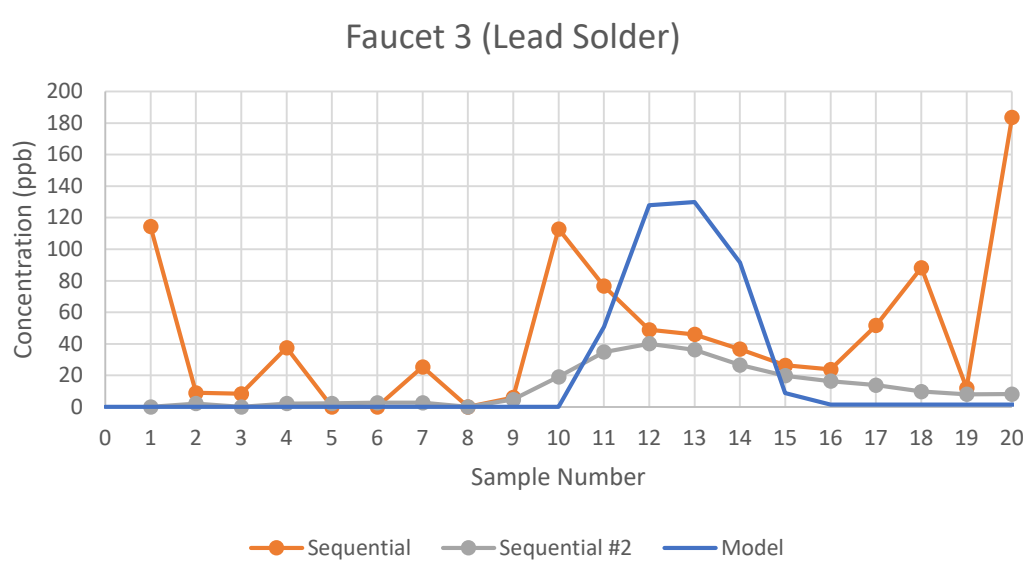
Parameter Determination

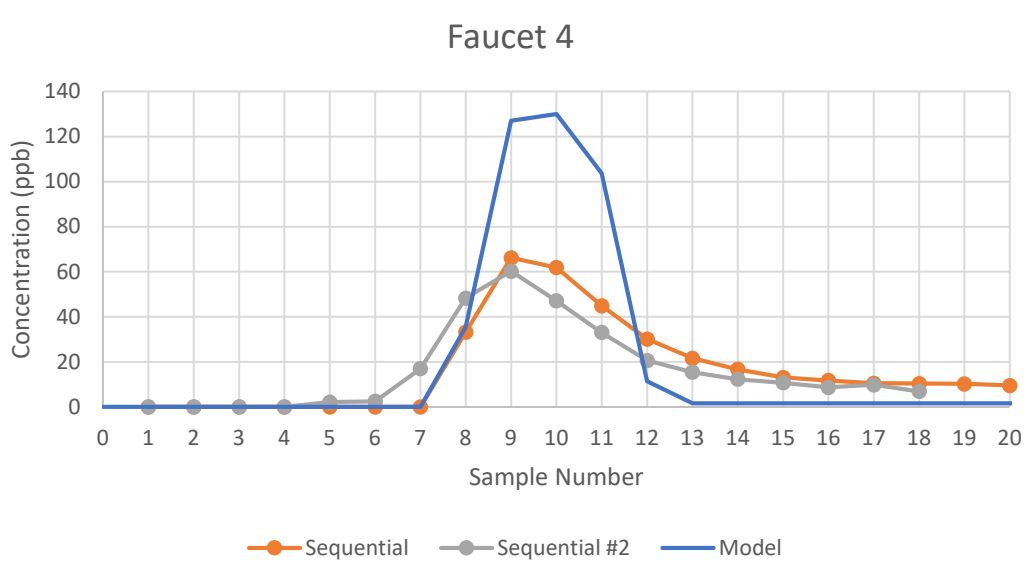


Sequential Sampling Results

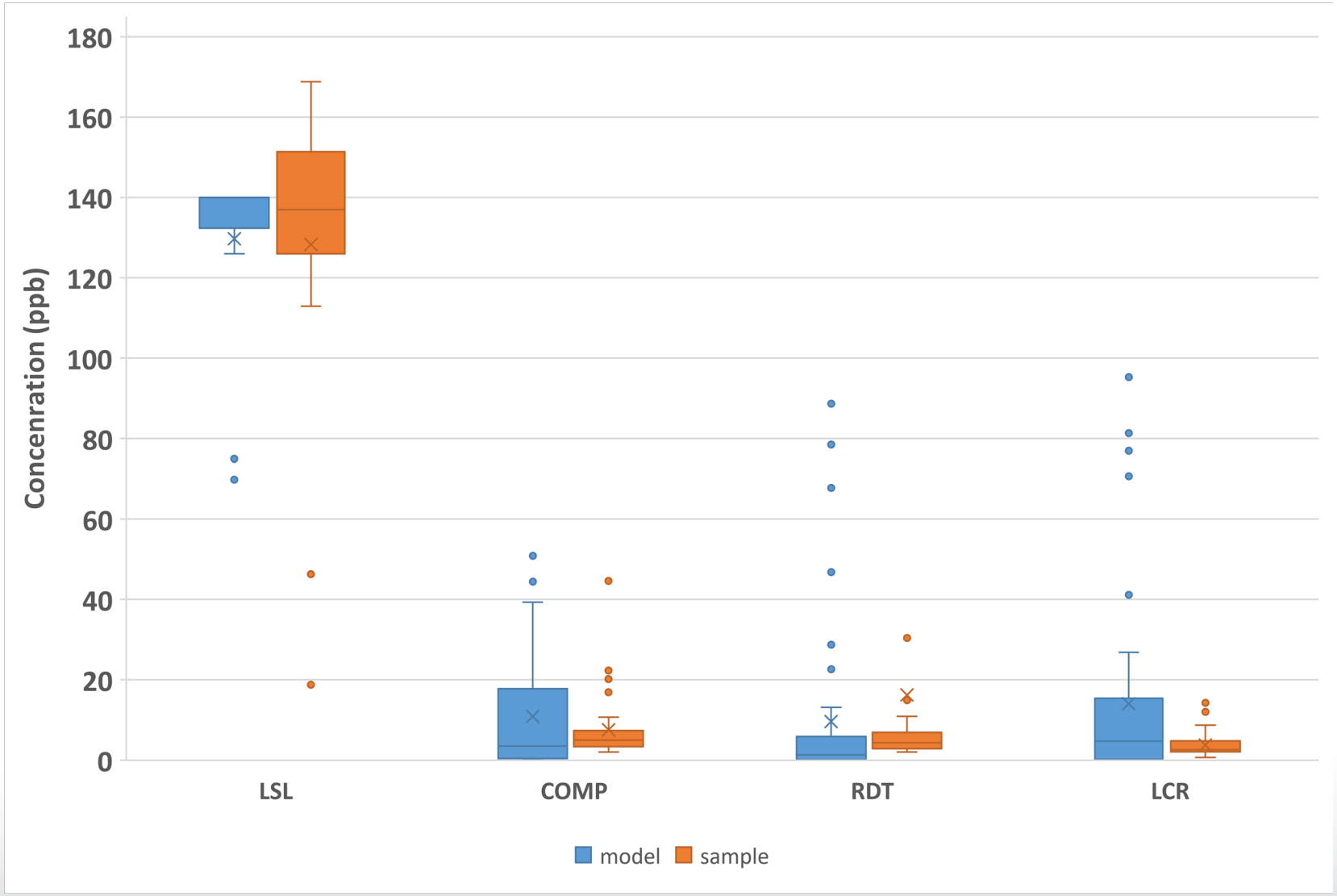








Sampling Comparison



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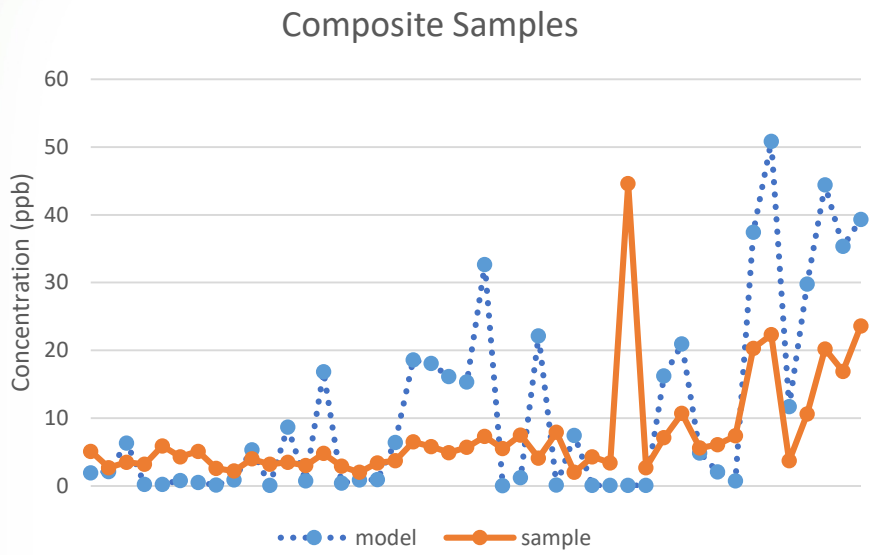
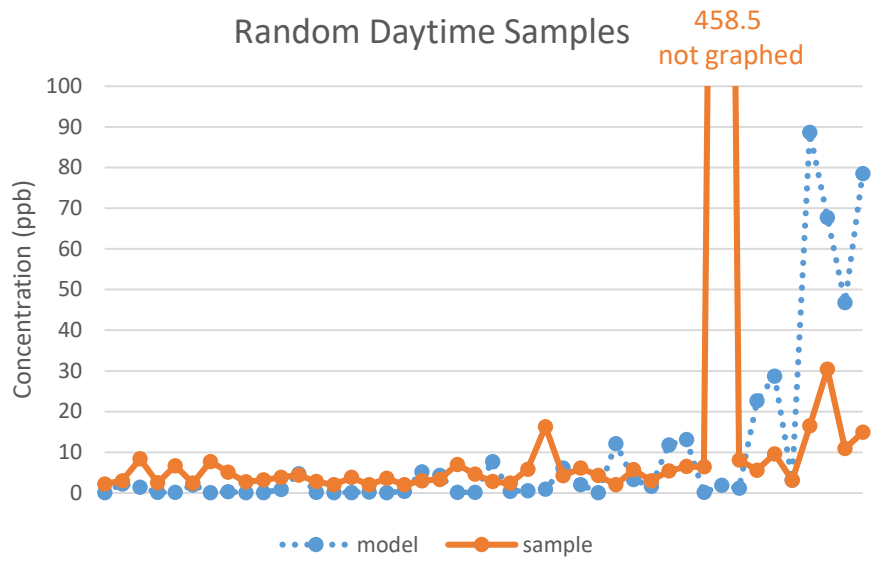
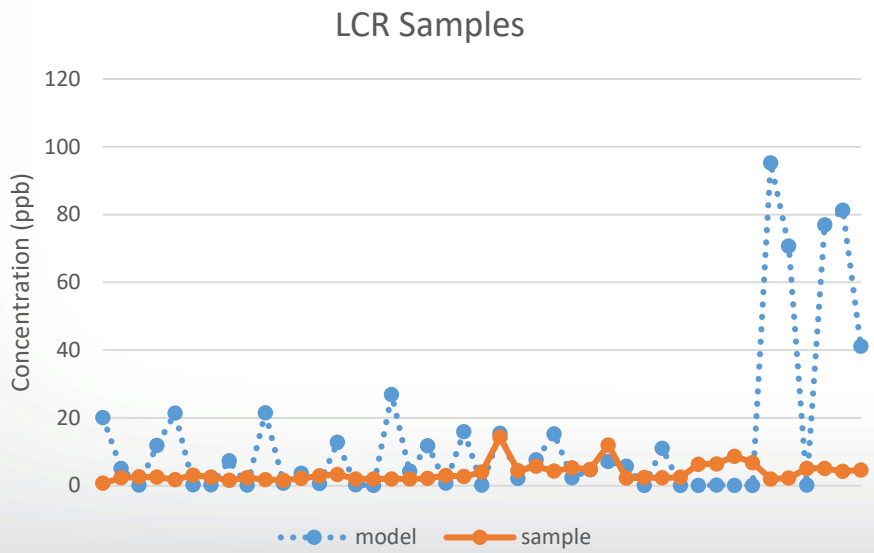
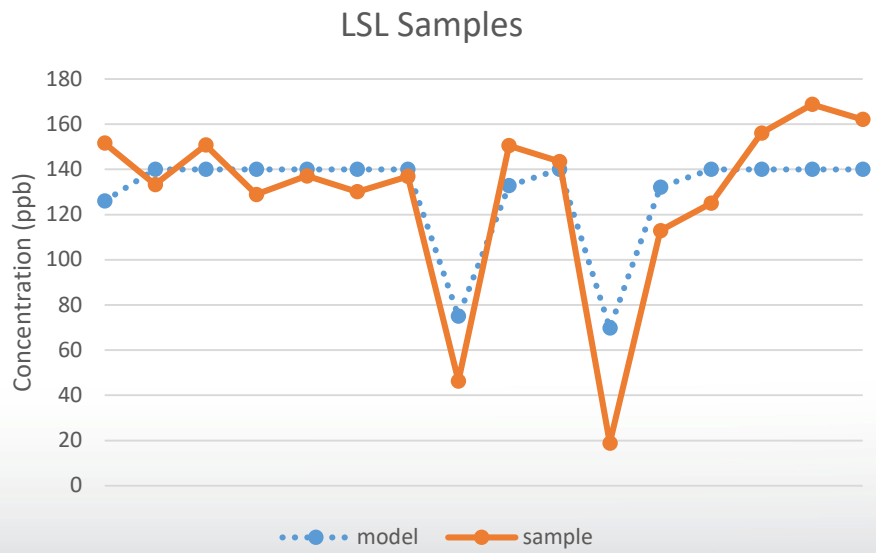








Model Conclusions

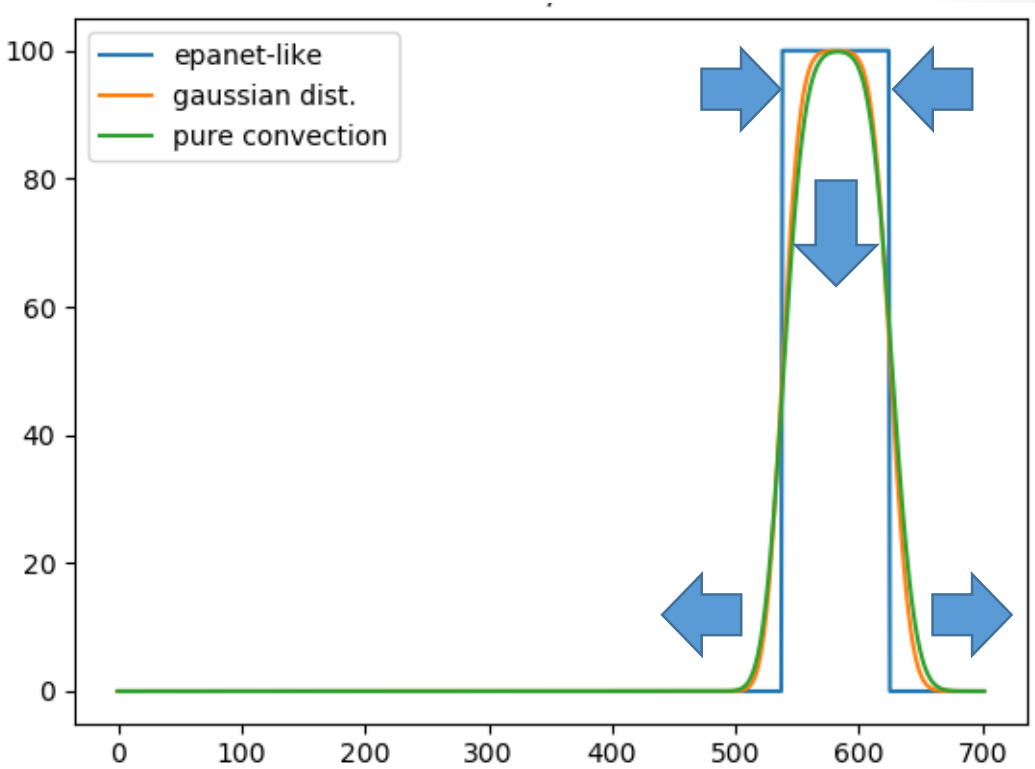
Sample Type (N)	Sample	Model
LSL (16)	128.29 ± 40.39	129.73 ± 22.78
LCR (43)	3.78 ± 2.71	14.03 ± 23.63
RDT (44)	5.95 ± 5.27*	9.59 ± 20.89
COMP (44)	7.54 ± 7.94	10.90 ± 14.10

* Excludes 458.5 ppb sampled value

- Generally good agreement for sequential and fixed length stagnation samples
- Dispersion observed, but not captured in model
- Particulate values not captured in model, but possibly present in samples
- Modeled concentrations under flowing conditions were generally lower than observed at low flow rates
- EPANET model resulted in more scatter in predicted values

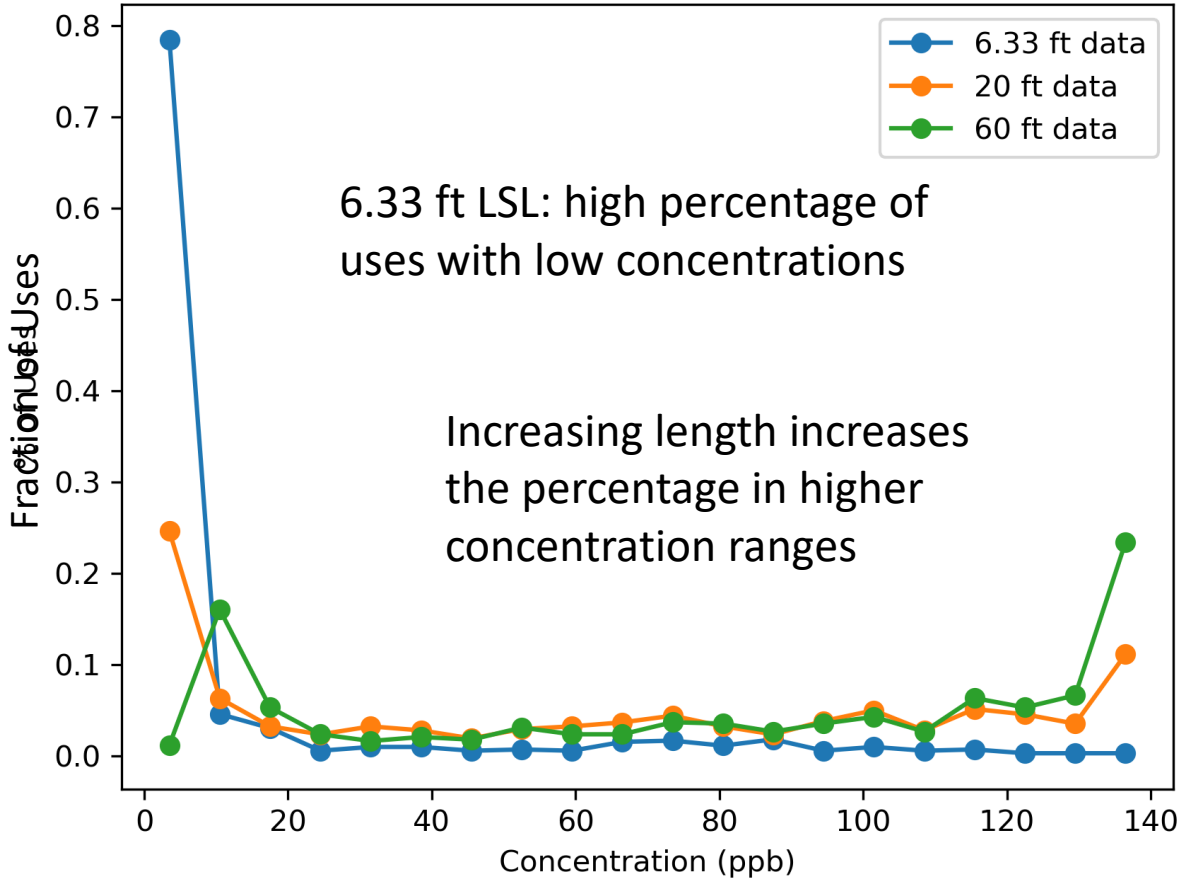
Impact of Dispersion (Ongoing Work)

- Dispersion is not currently modeled in EPANET
- The mass within a slug is transported at different rates
  - Water near edges moves slower
  - Water near central axis of pipe moves faster
- Dispersion lengthens or broadens the slug
- Peak concentration can be reduced



Impact of Lead Service Line Length

- All uses were the same during 30-week model
- Only changed the lead service line lengt
  - 6.33, 20 & 60 feet
- 6.33 foot LSL system had ~85% of uses modeled in 0-20 ppb range
- Increasing LSL length resulted in a highe percentage of uses modeled in higher concentrations



Ongoing Work

- Update code to incorporate effects of dispersion
- Add particulate lead modeling capability
- Expand to include Monte Carlo study to allow for prediction of individual exposure to lead

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Questions?