Development of effective dispersion coefficients for premise plumbing systems

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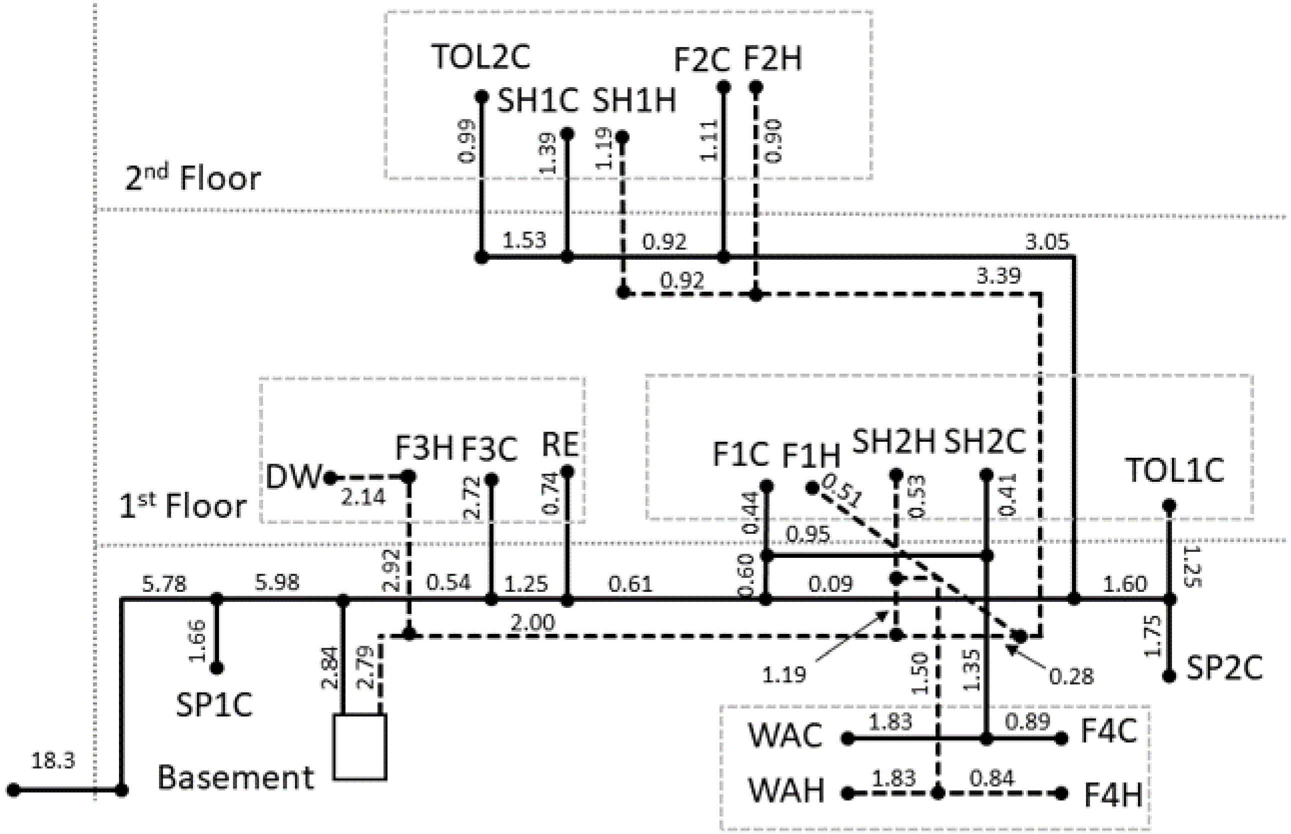
Motivation

- Needed to model premise plumbing systems
- Many uses result in flow rates in laminar to low turbulent (Re<20K) conditions that might experience dispersion
- Wanted a model that could predict water quality transport



Motivation (Questions)

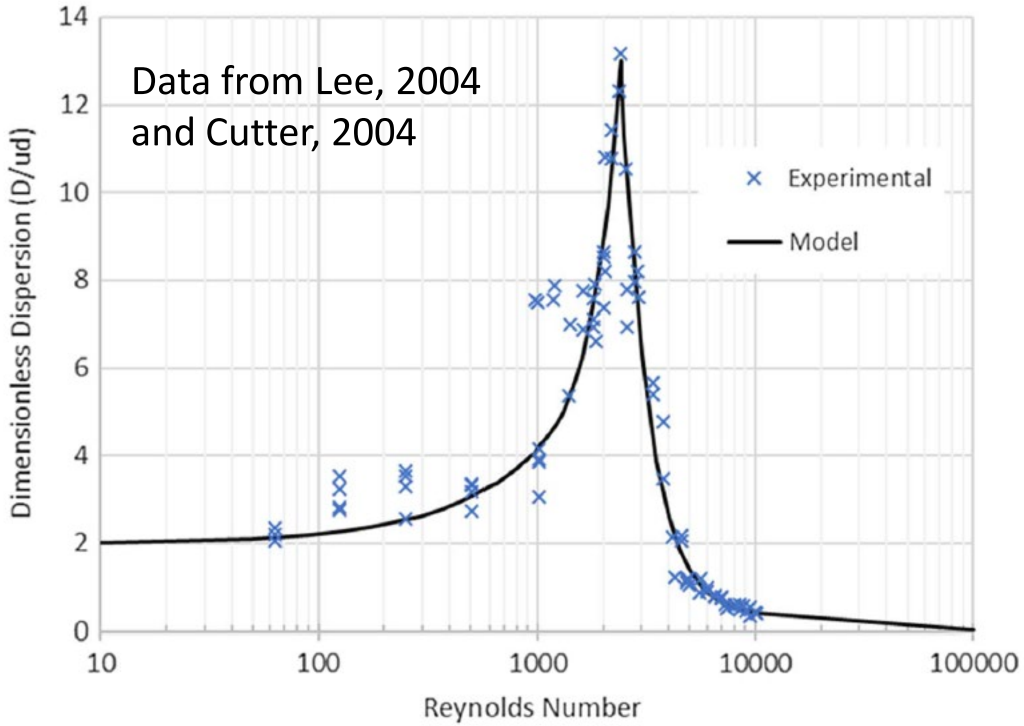
- Fully developed vs. Partially developed dispersion profile
  What is the effective dispersion coefficient for premise plumbing systems?

- How big of an impact will dispersion have in premise plumbing systems?

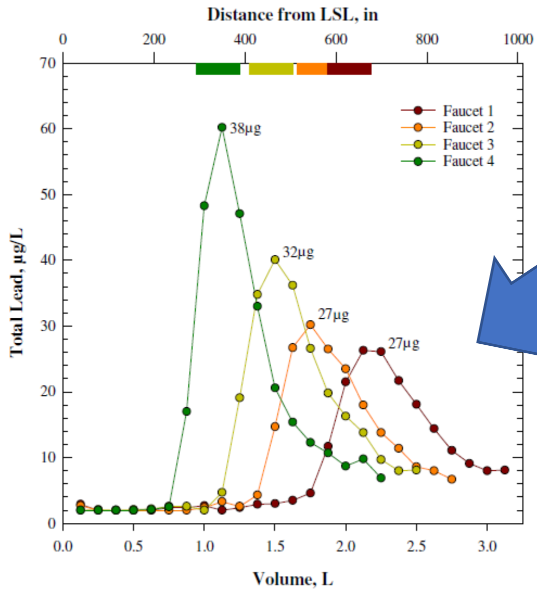
- **Can we ignore it?**

Previous Work

Sampling results didn't match simple advection only modeling (EPANET)

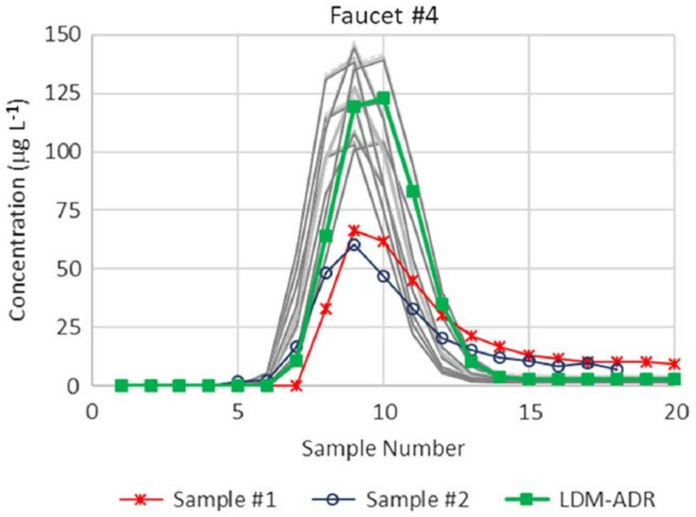


$$\frac{D}{ud} = \begin{cases} (2.1 \pm 1.1 \times 10^{-3})R + (2 \pm 0.3) & R \leq 1{,}000 \ (N = 17) \\ (6.79 \pm 0.68 \times 10^{-10})R^3 + (3.5 \pm 0.48) & 1{,}000 < R \leq 2{,}400 \ (N = 24) \\ (2.4 \pm 0.1) \times 10^{12} R^{-3.337} + (0.31 \pm 0.17) & 2{,}400 < R \leq 10{,}000 \ (N = 39) \\ 5.05\sqrt{f/8} & R > 10{,}000 \ \text{(Taylor's Equation)} \end{cases}$$



Observed dispersion during sampling

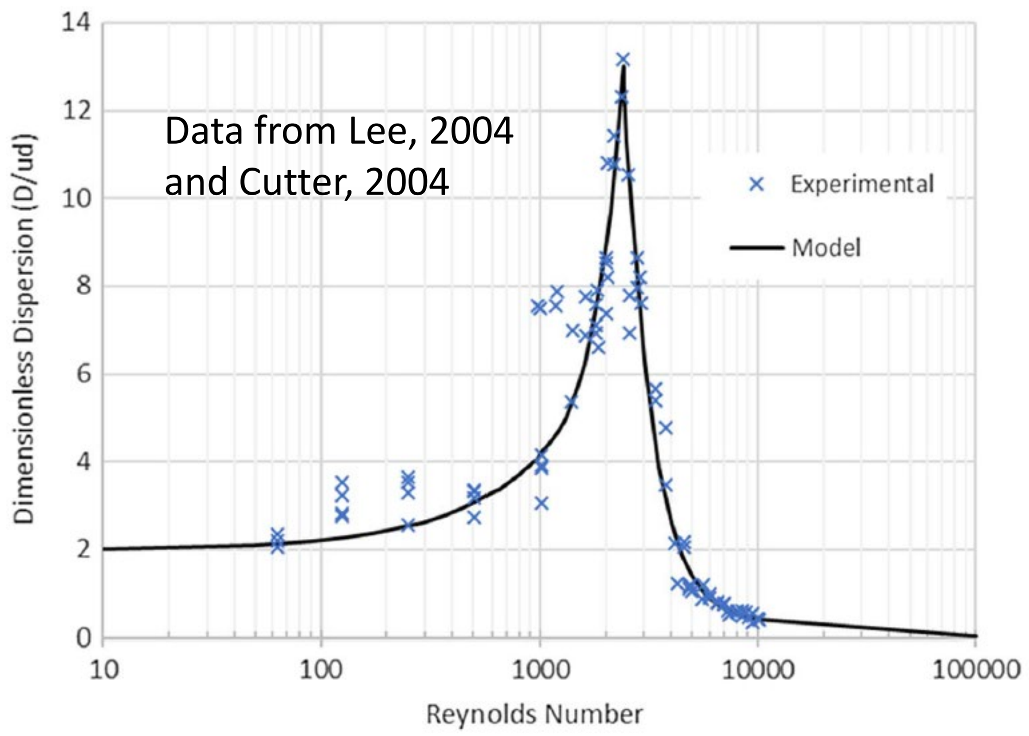
Lytle, et al. (2021) Water Research 197, 117071



Uncertainty in flow rate with advection-dispersion-reaction model

Burkhardt, et al. (2020) JWRPM 146(12): 04020094.

Assuming Re < 20,000 might require dispersion calc.



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Burkhardt, et al. (2020) JWRPM 146(12): 04020094.

Most fixtures in homes are only allowing ~1 – 2 gpm (3.8 – 7.6 Lpm) through

Flow Rates for Re=2,500

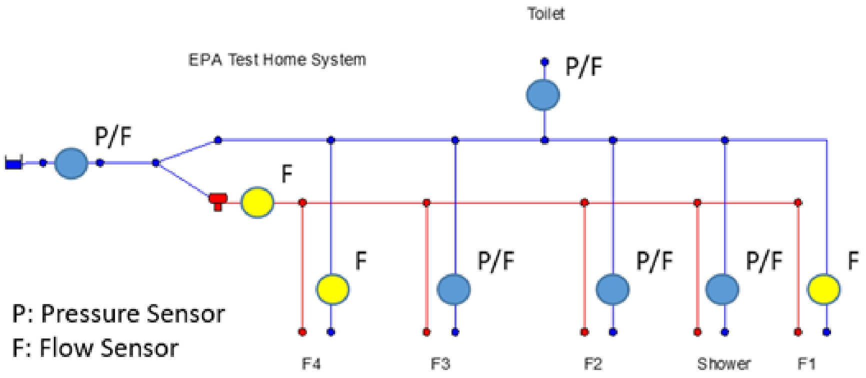
Pipe Size	GPM	LPM
½” (12.7 mm)	0.4	1.5
¾” (19 mm)	0.6	2.3

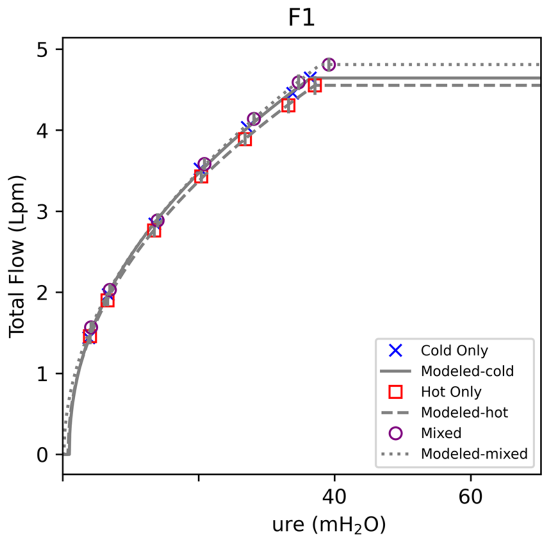
Flow Rates for Re=20,000

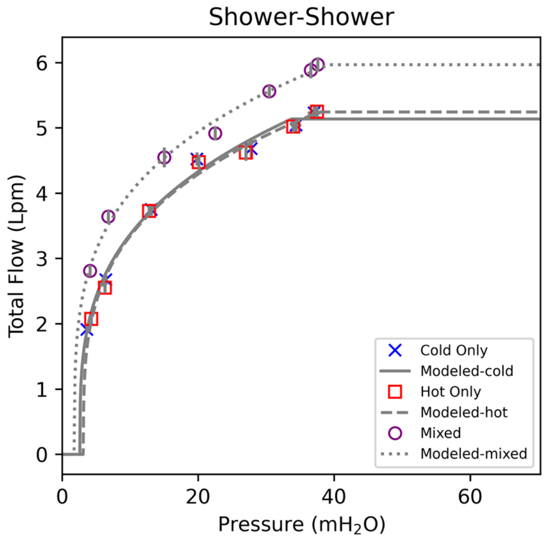
Pipe Size	GPM	LPM
½” (12.7 mm)	3.2	12
¾” (19 mm)	4.7	18

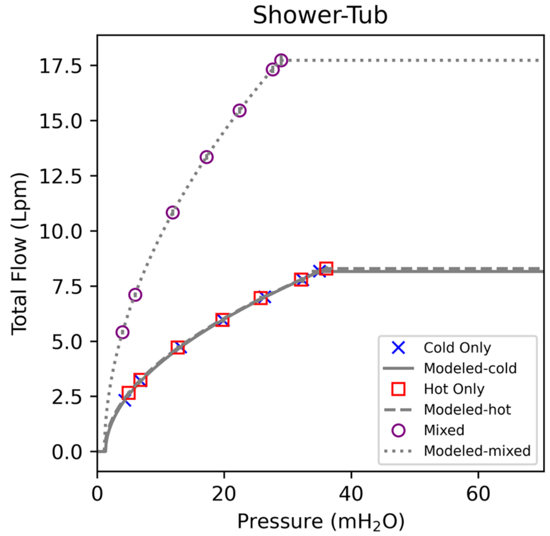
Pressure’s Impact on Flow

What is the actual flow rate in PPSs? What is pressure’s impact?









Burkhardt, et al. (2023a) Submitted AWWA Water Science

EPANET Compatible Approach

Developed EPANET compatible Lagrangian approach

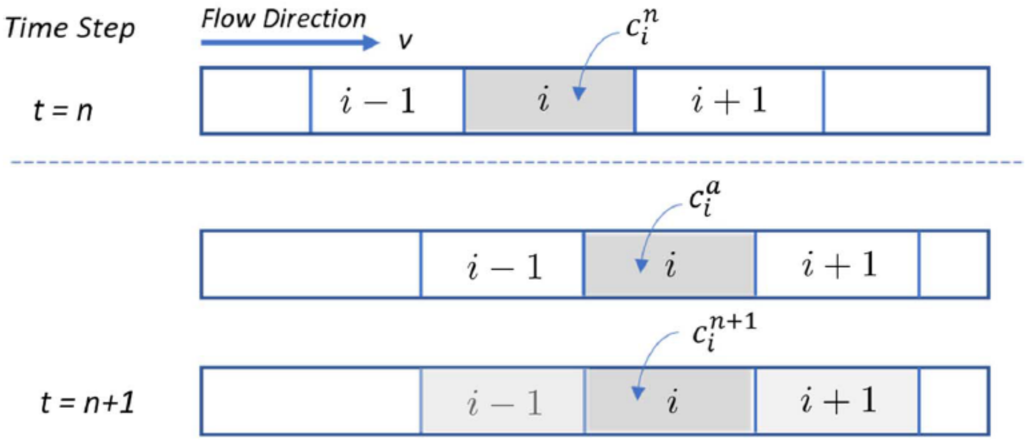


Fig. 1. Nonuniform pipe discretization and Lagrangian transport.

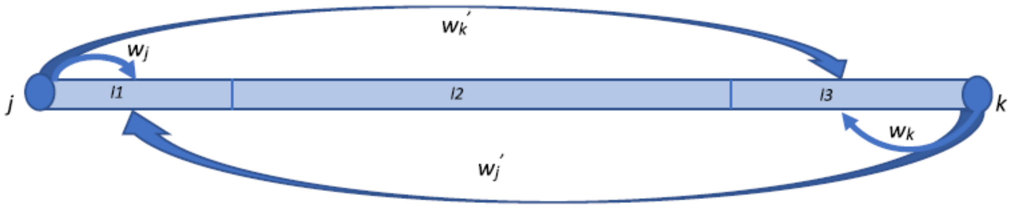


Fig. 3. Impact of a pipe's junction concentrations on its segment concentrations.

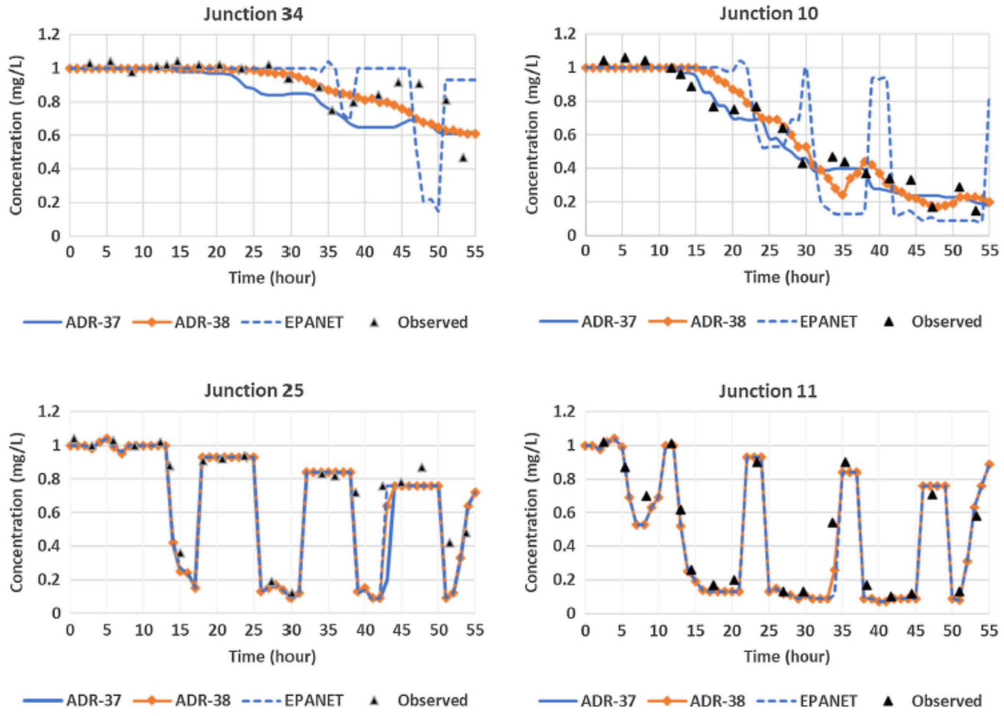


Fig. 8. Simulated fluoride tracer concentrations against field measurements at four junctions within Cherry Hill/Brushy Plains network.

Can run entire network, rather than segmenting only dead-end sections

Shang et al. (2021), JWRPM 147(9): 04021057.

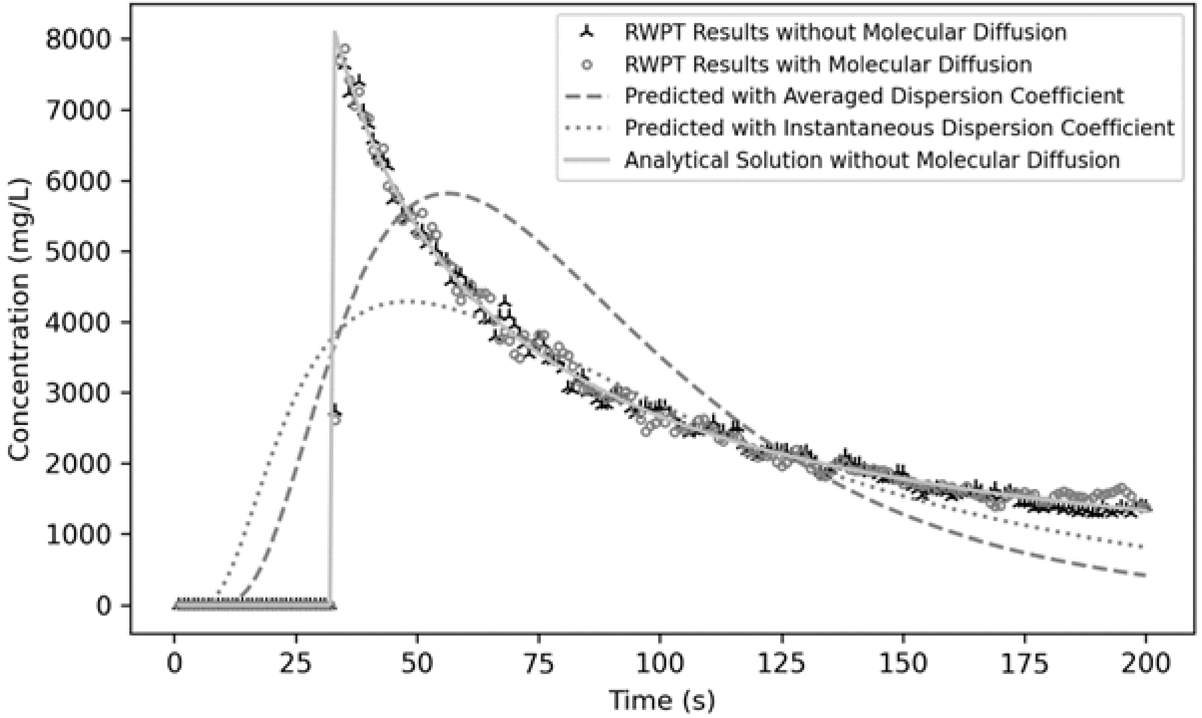
2D Random Walk Particle Tracking

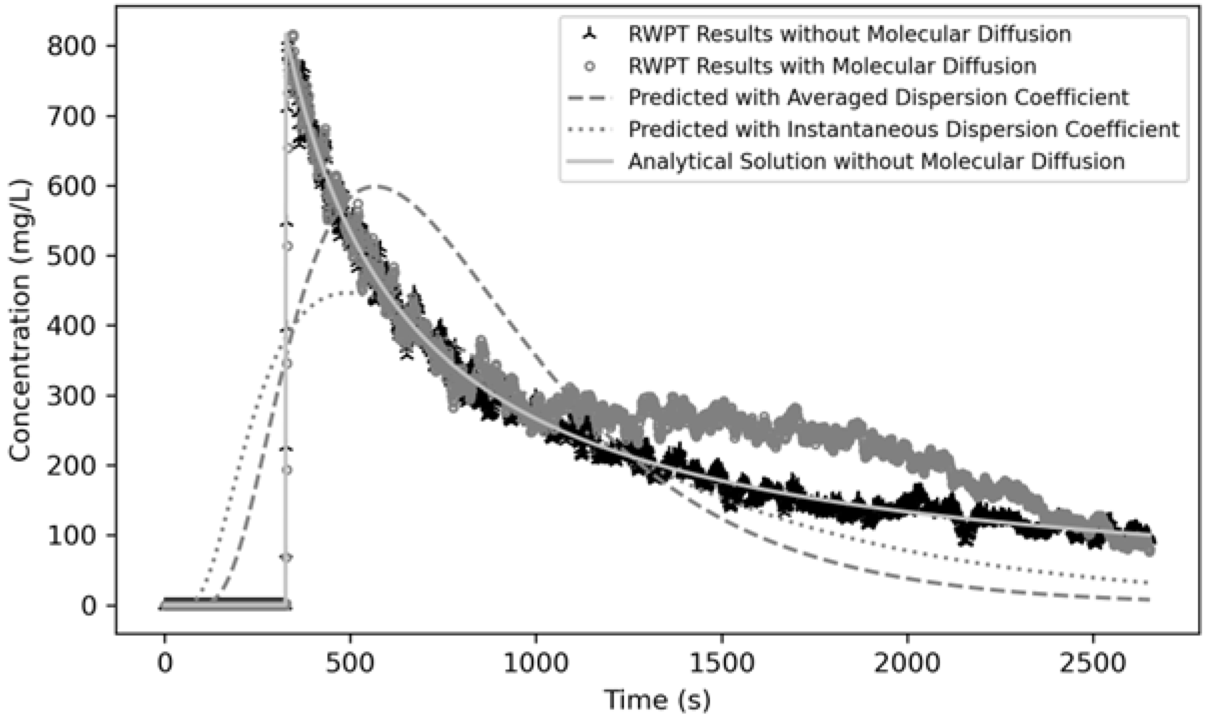
Wanted faster model than 3D CFD, that was more accurate than 1D advection-dispersion in EPANET-MSX

L = 6.5 m, R = 0.02 m, U = 0.098 m/s

Re = 363

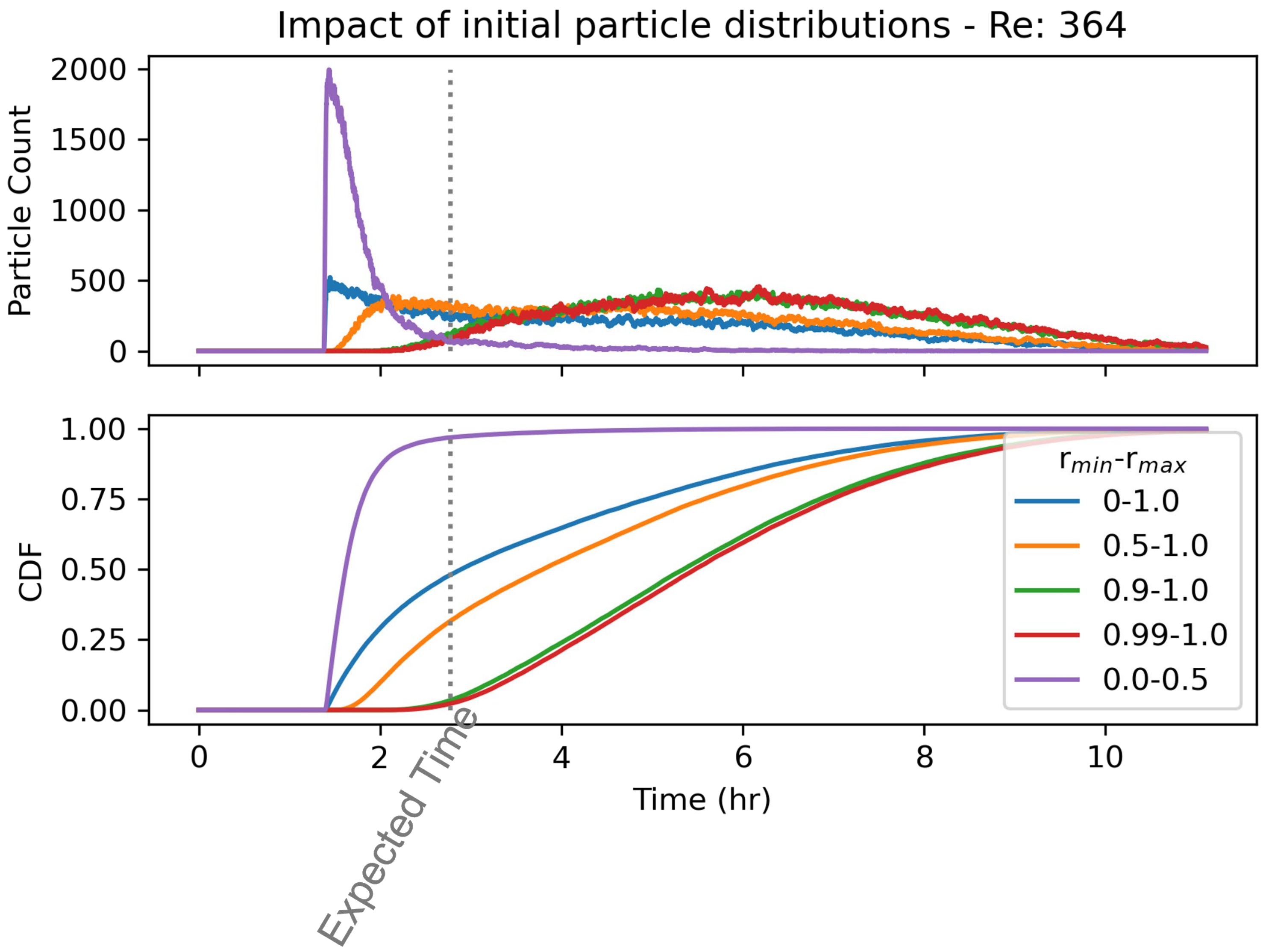
L = 65 m, R=0.02 m, U = 0.098 m/s





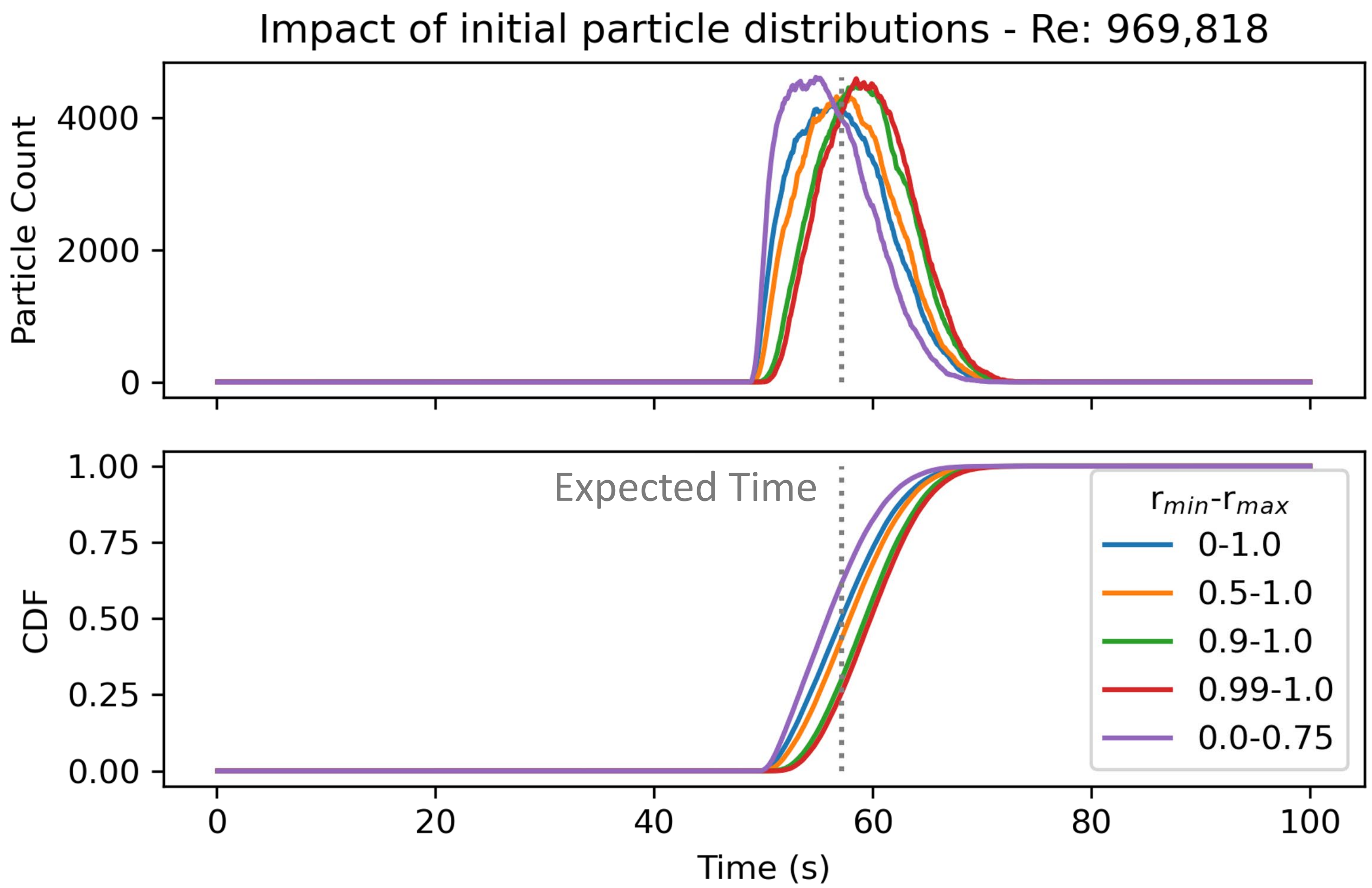
Shang, et al. (2023), Journal of Hydraulic Engineering

Impact of Initial Distribution: Laminar



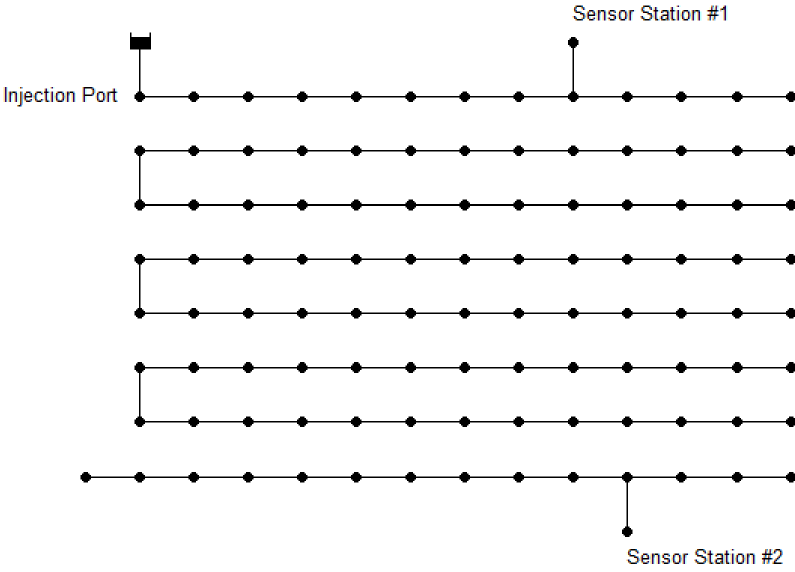
- Uniform
- Outer 50%
- Outer 10%
- Outer 1%
- Inner 50%

Impact of Initial Distribution: Turbulent



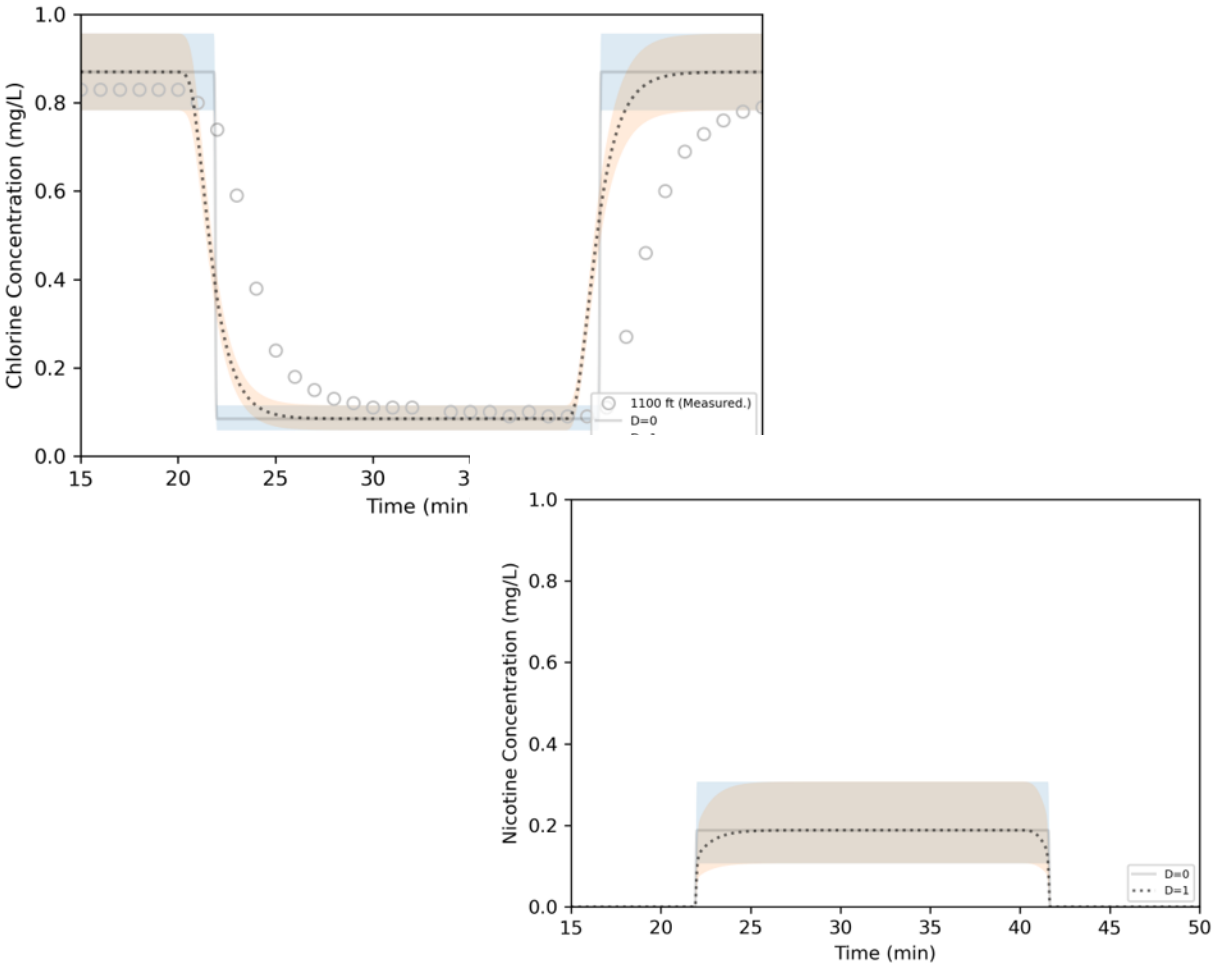
- Uniform
- Outer 50%
- Outer 10%
- Outer 1%
- Inner 25%

Lagrangian approach integrated into EPANET-MSX 2.0



1,200 ft pipe, 3” diameter, 22 gpm

Model with and without dispersion, with associated reaction



Burkhardt, et al. (2023b) Submitted J. Env. Mod. & Soft.

Planned Future Work

- Flushing Study
  - Contaminate and flush out the single-family home simulator
  - Model system to test effectiveness of flushing protocols and compare with experimental data
- Effective 1D Dispersion Study
  - Monitor conductivity sensor response associated with a contaminated slug under various PPS relevant flow rates
  - Introduce tees and elbows to assess their impact on effective 1D dispersion in PPSs, focusing on relevant lengths and flow rates
  - Goal is to provide better dispersion coefficients for PPS modeling

Questions

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Models Used

https://github.com/USEPA/EPANETMSX
https://github.com/USEPA/EPANET2.2
https://github.com/USEPA/msx_tools
https://github.com/USEPA/WNTR