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Evaluation of Complete and Incomplete Mixing Models in Water Distribution Pipe Network Simulations

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Overview

- Introduction
- Experimental Approach
- Modeling Approach
- Results
- Conclusions

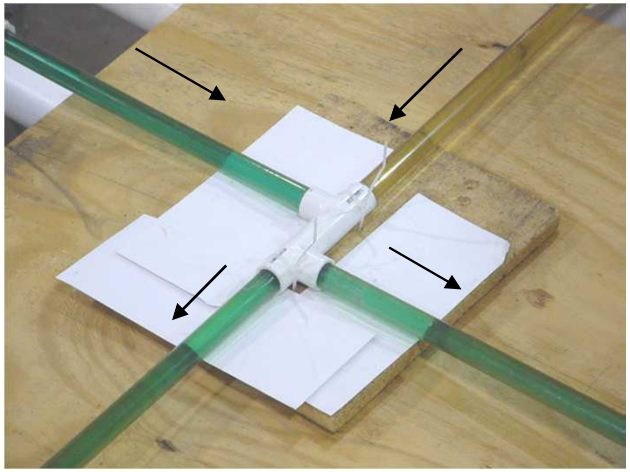
Introduction

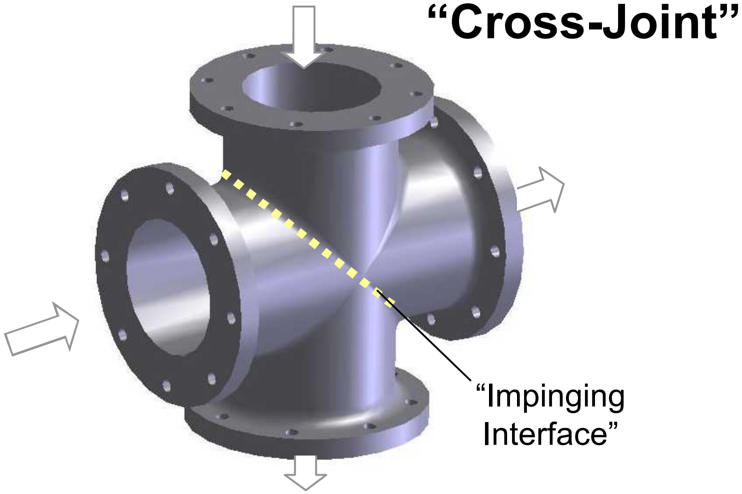
- **Contaminant transport in water-distribution pipe networks is a growing concern**
  - **Need to understand and predict contaminant movement and mixing in junctions**
  - **Many network models assume complete mixing at junctions**
- **Previous studies have shown incomplete mixing in pipe junctions (experimental and computational)**
  - **van Bloemen Waanders et al. (2005)**
  - **O'rear et al. (2005)**
  - **Ho et al. (2006)**
  - **Romero-Gomez et al. (2006)**
  - **Webb and van Bloemen Waanders (2006)**

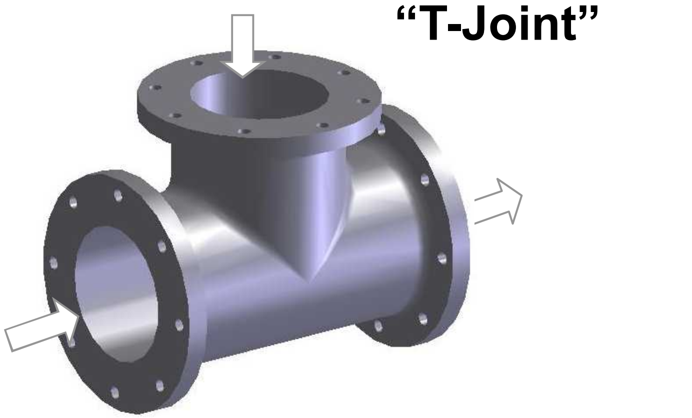
Objective

- **Determine impact of incomplete mixing at individual junctions on network of junctions**

- **Determine conditions when complete mixing is valid**







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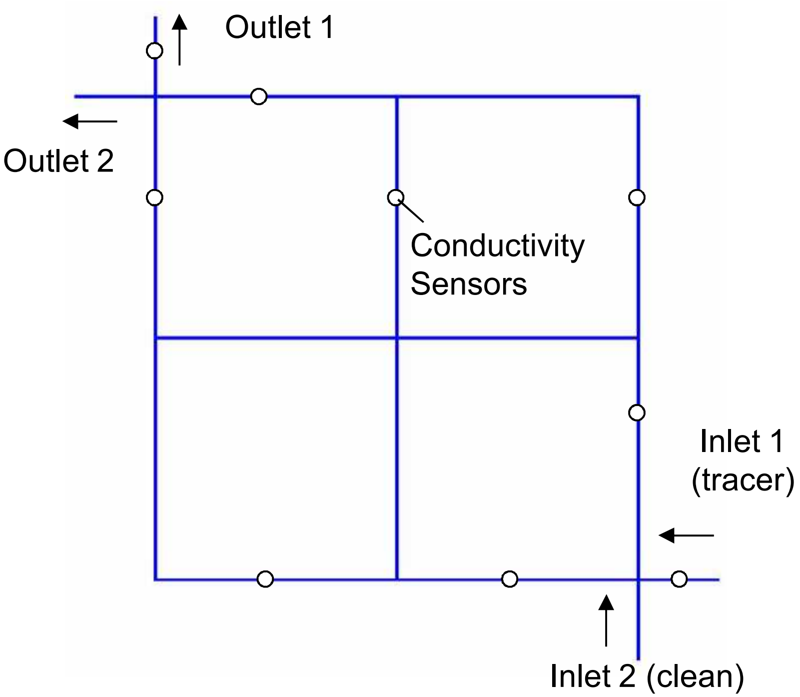
Small-Scale Network Tests
(O'rear et al., 2005)



- **3x3 array of cross joints with 3-foot pipe lengths**
- **Flow rates at inlets and outlets controlled**
- **Pipe diameter: 0.5"**

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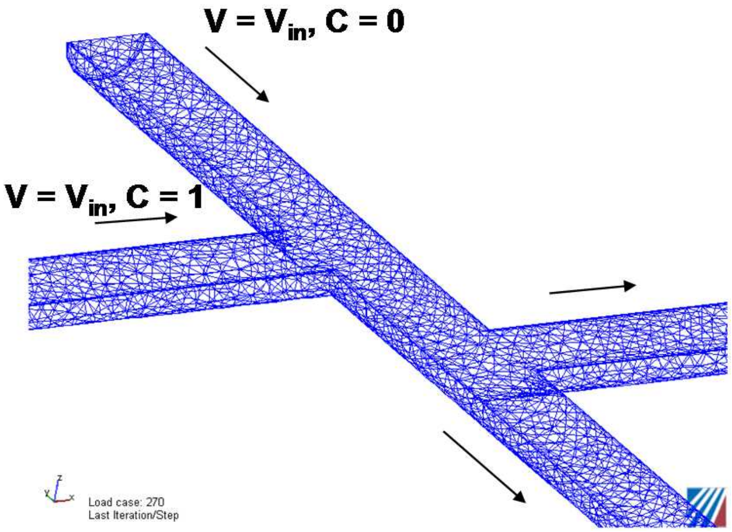
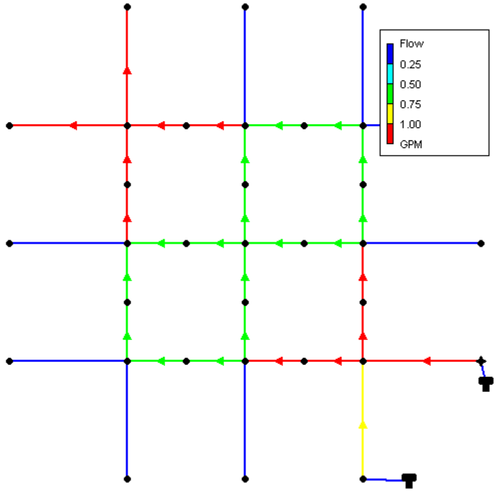
Modeling Approach

- **Simulate network experiments using different models**
  - **Finite-element computational fluid dynamics simulations**
    - **K-ε turbulence model**
    - **Allows incomplete mixing in junctions**
  - **EPANET**
    - **Assumes complete mixing at junctions**
    - **Modified version developed to allow incomplete mixing based on empirical correlations**





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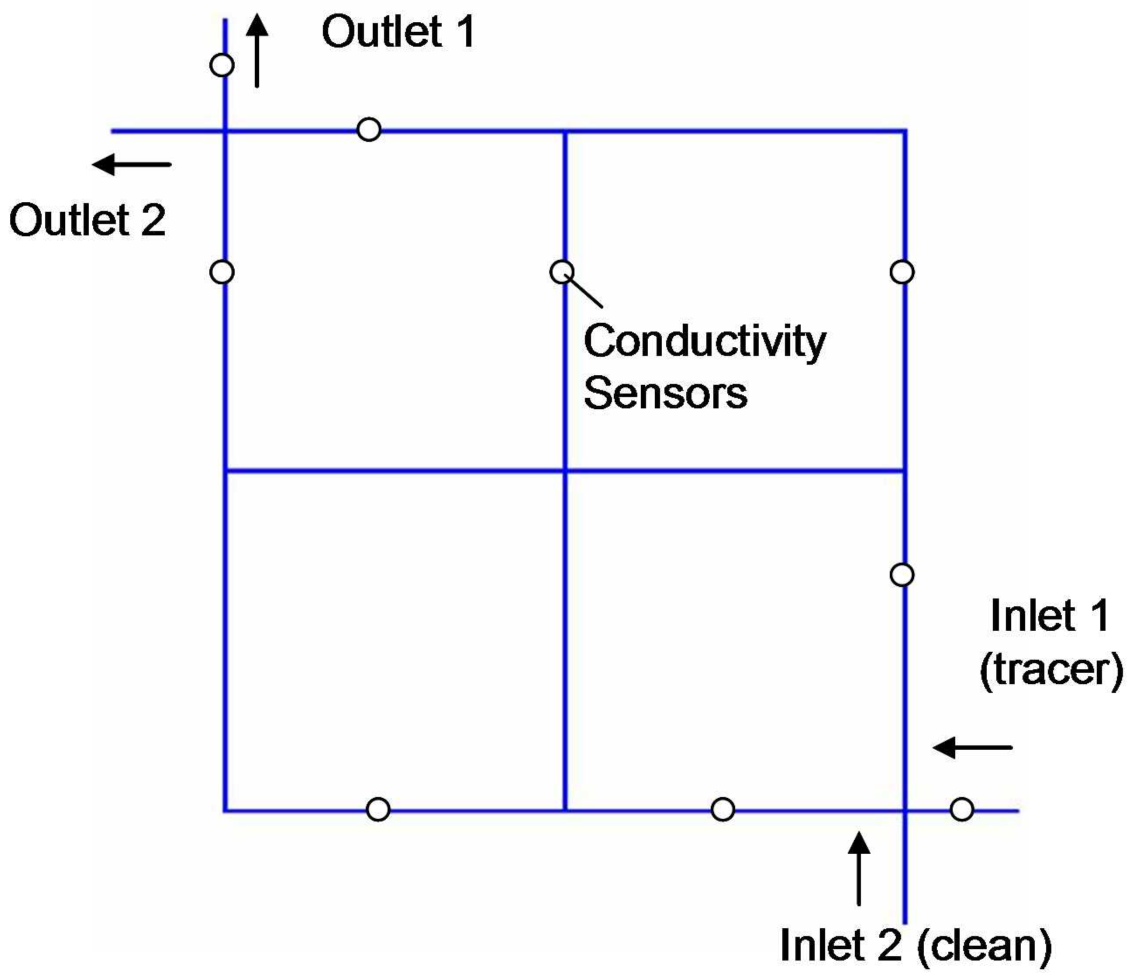
Model Geometry



Network Simulations

- **Two simulations**
  - **Tracer inlet flow > clean-water inlet flow**
  - **Tracer inlet flow < clean-water inlet flow**

Boundary Conditions (flow rates half actual values due to symmetry employed)				**Reynolds Number**	**Turbulent Schmidt Number**
Tracer Inlet Flow (Q_{tracer})	**Clean Water Inlet Flow (Q_{clean})**	**Outlet 1 Flow ($Q_{out,1}$)**	**Outlet 2 Flow ($Q_{out,2}$)**		
38 mL/s* (0.61 gpm)	31 mL/s (0.49 gpm) (P = 0 gage used as B.C.)	33 mL/s (0.52 gpm)	37 mL/s (0.58 gpm)	4,000 – 9,000	0.01, 0.001
28 mL/s** (0.44 gpm) (P = 0 gage used as B.C.)	50 mL/s (0.79 gpm)	32 mL/s (0.50 gpm)	46 mL/s (0.73 gpm)	7,000 – 11,000	0.01, 0.001

*Test period from 19-20 minutes in Orear et al. (2005)
**Test period from 8-9 minutes in Orear et al. (2005)

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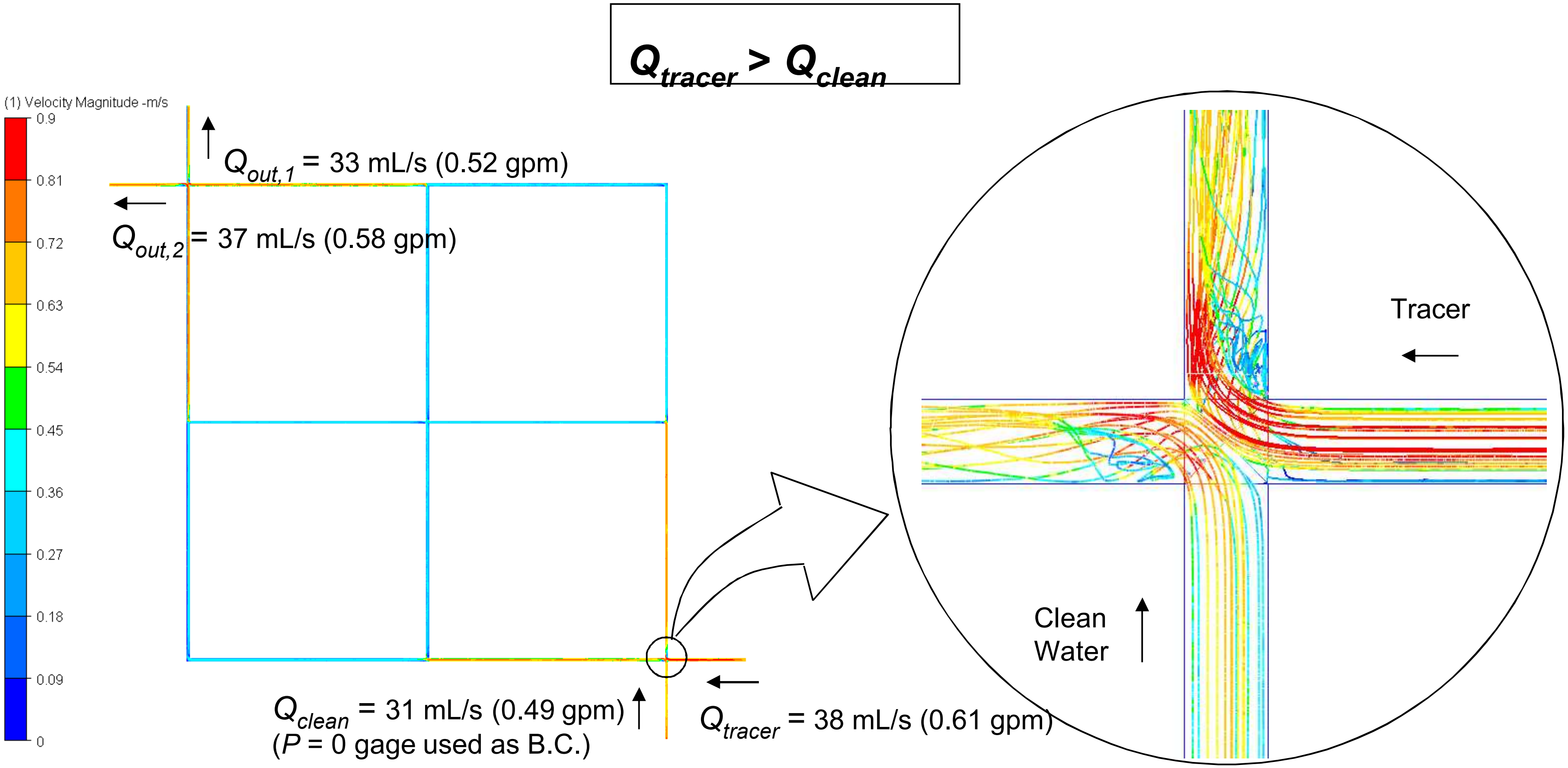
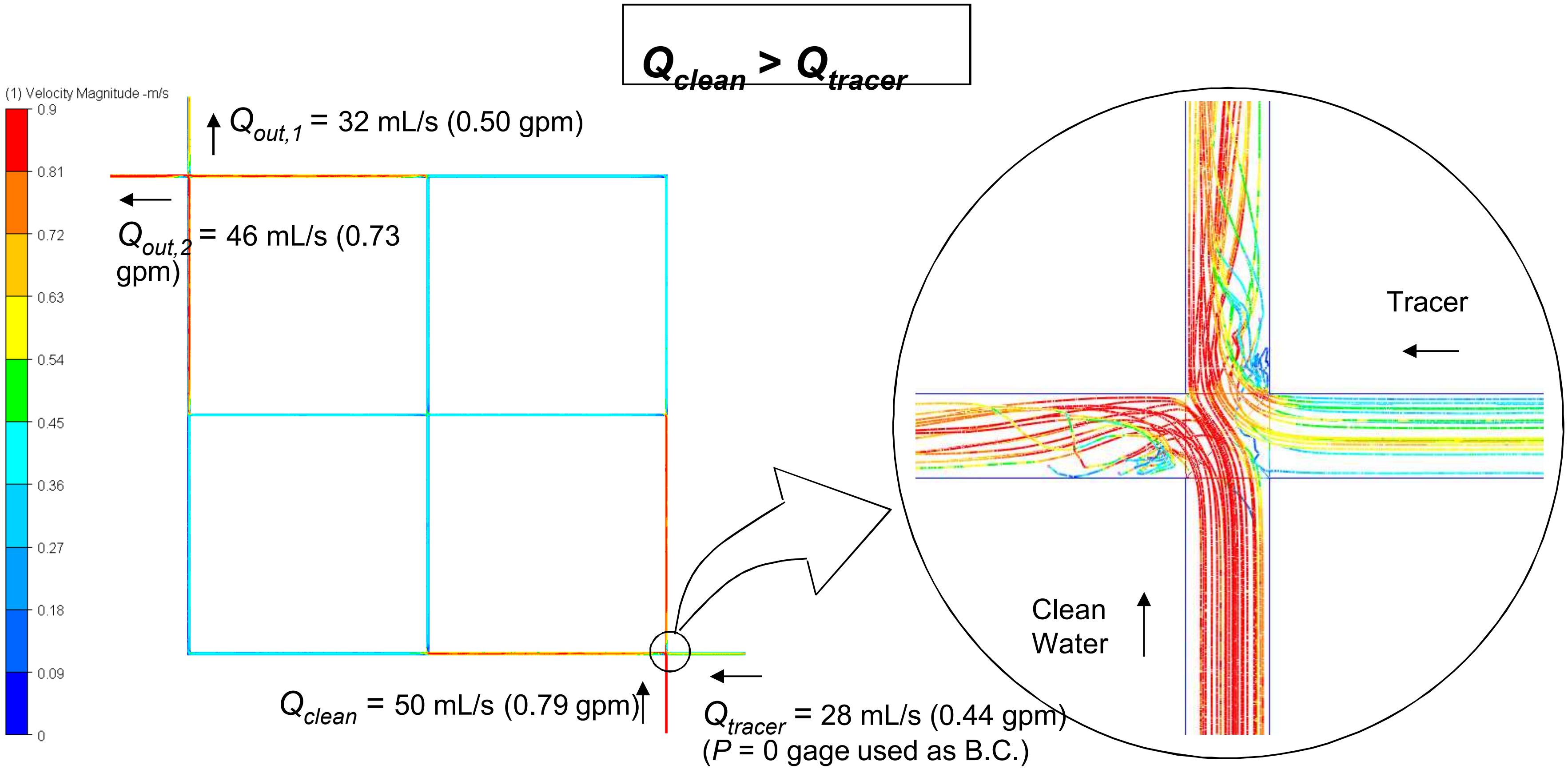
CFD Hydraulic Results

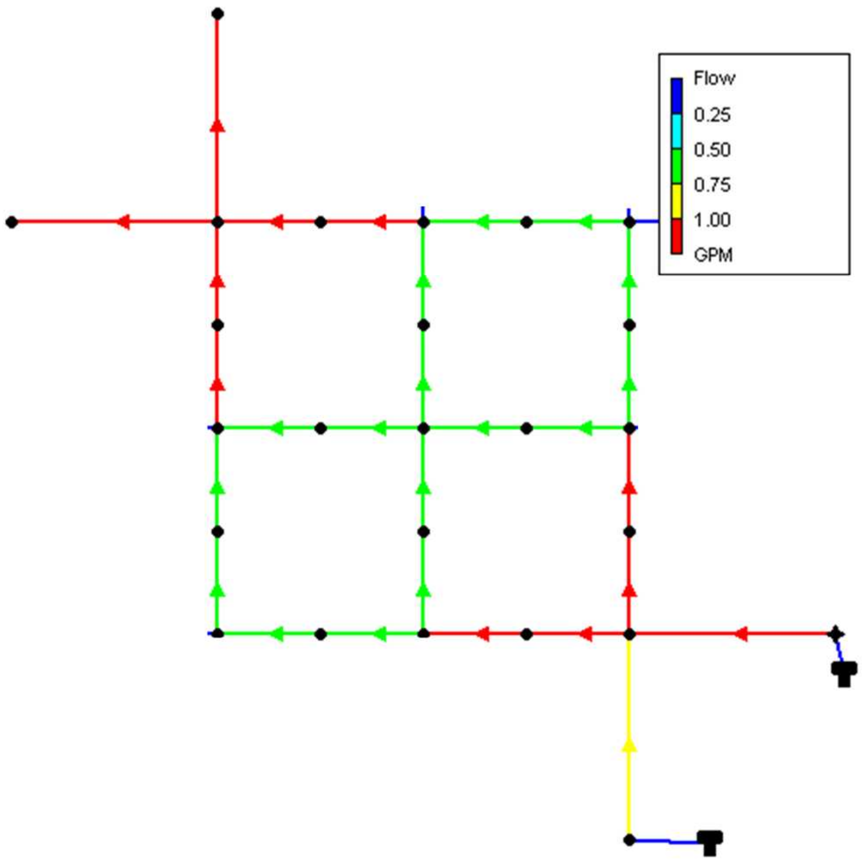


CFD Hydraulic Results

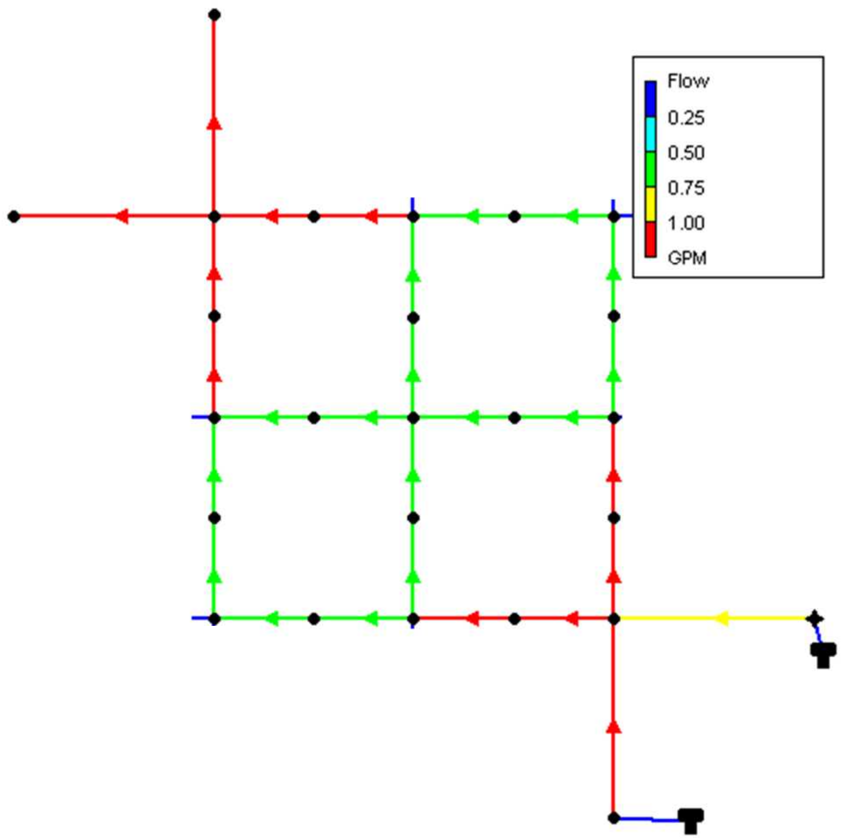


EPANET Hydraulic Results

$Q_{tracer} > Q_{clean}$

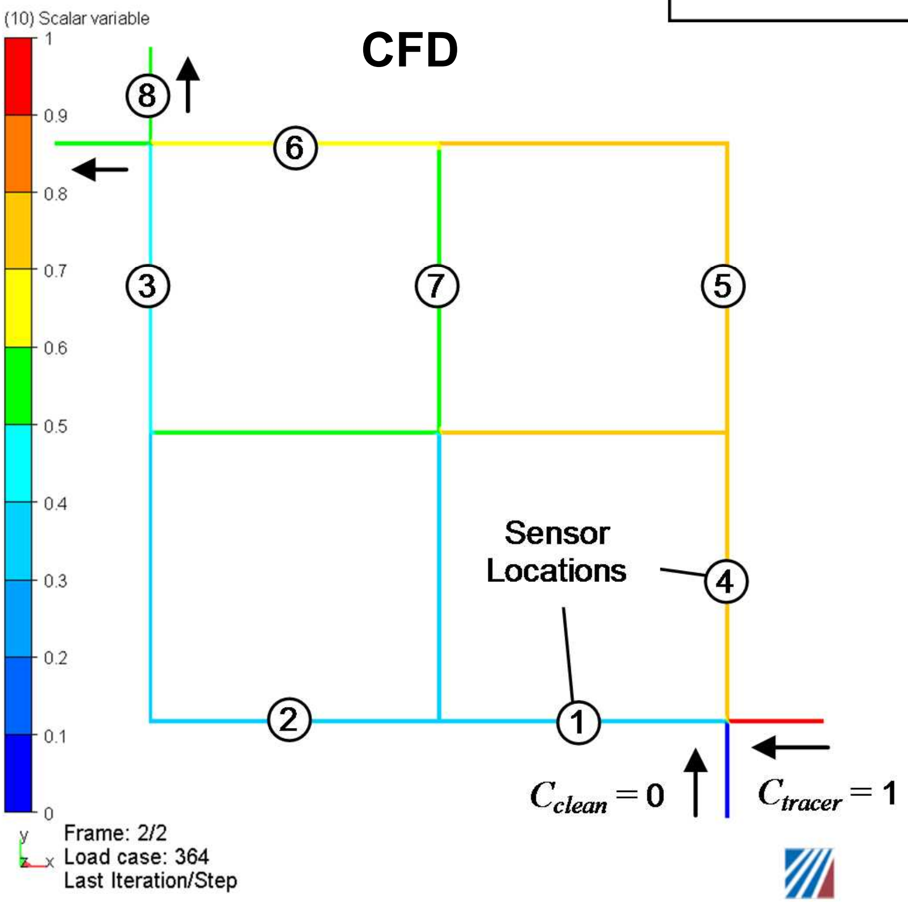


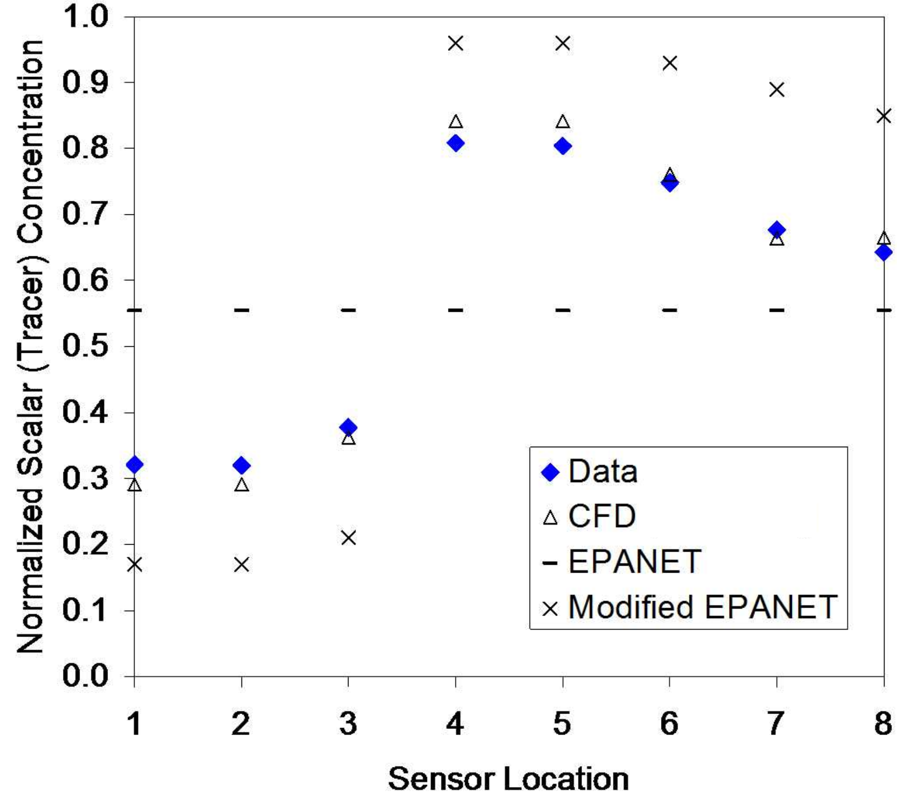
$Q_{clean} > Q_{tracer}$



Solute Transport Results

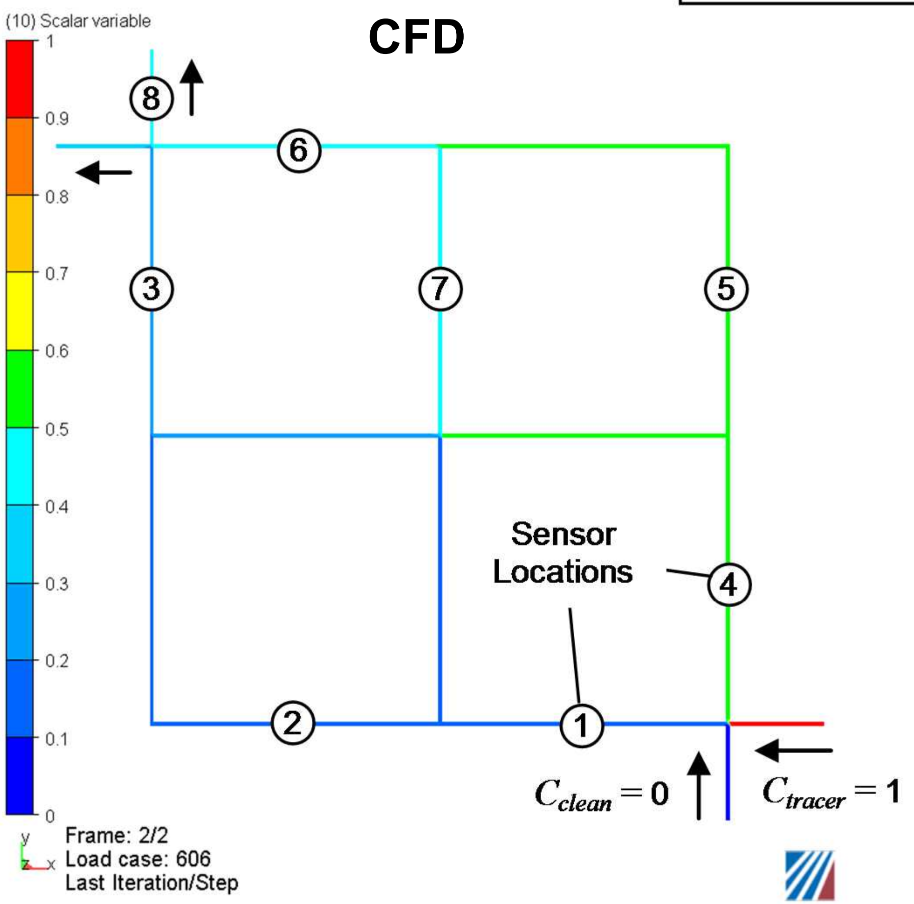
$$Q_{tracer} > Q_{clean}$$

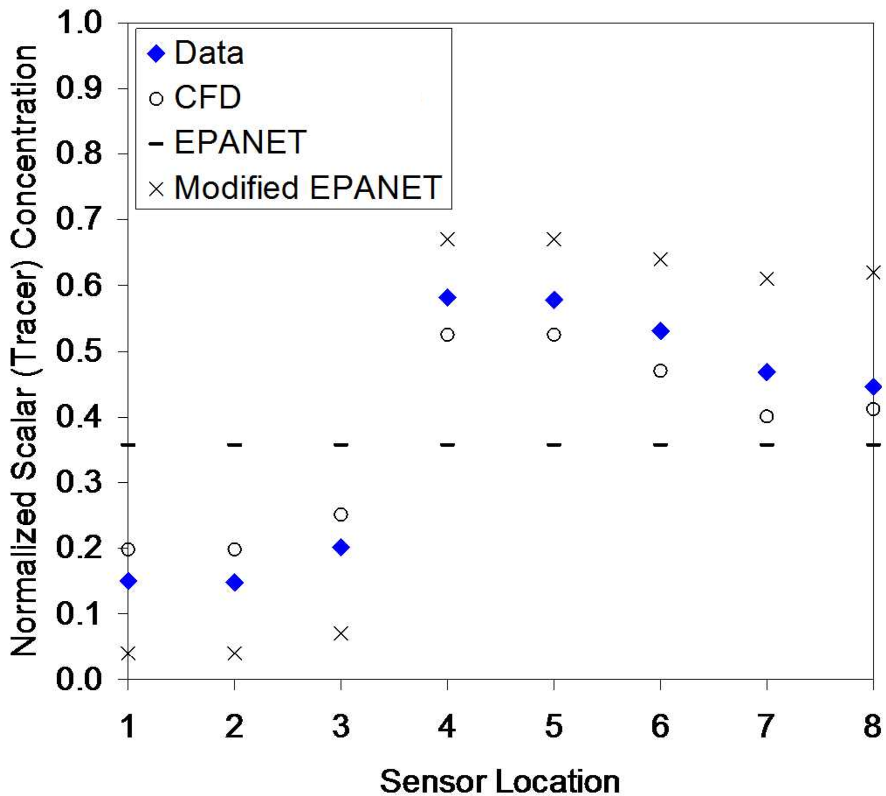




Solute Transport Results

$Q_{clean} > Q_{tracer}$





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Is Complete Mixing Ever Valid?

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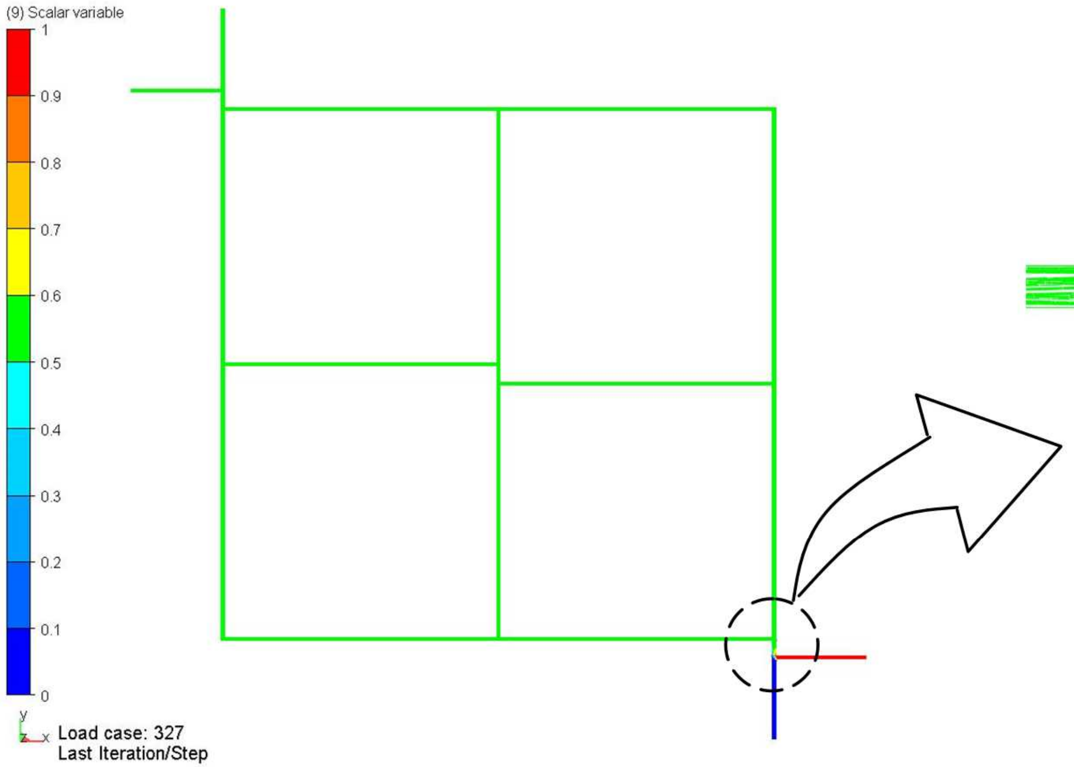
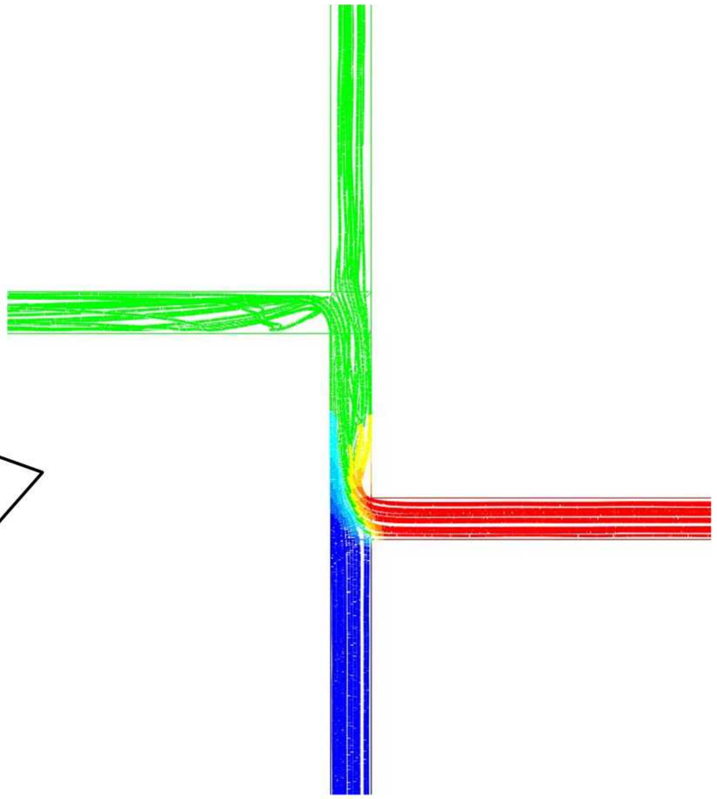
Double-T Junctions

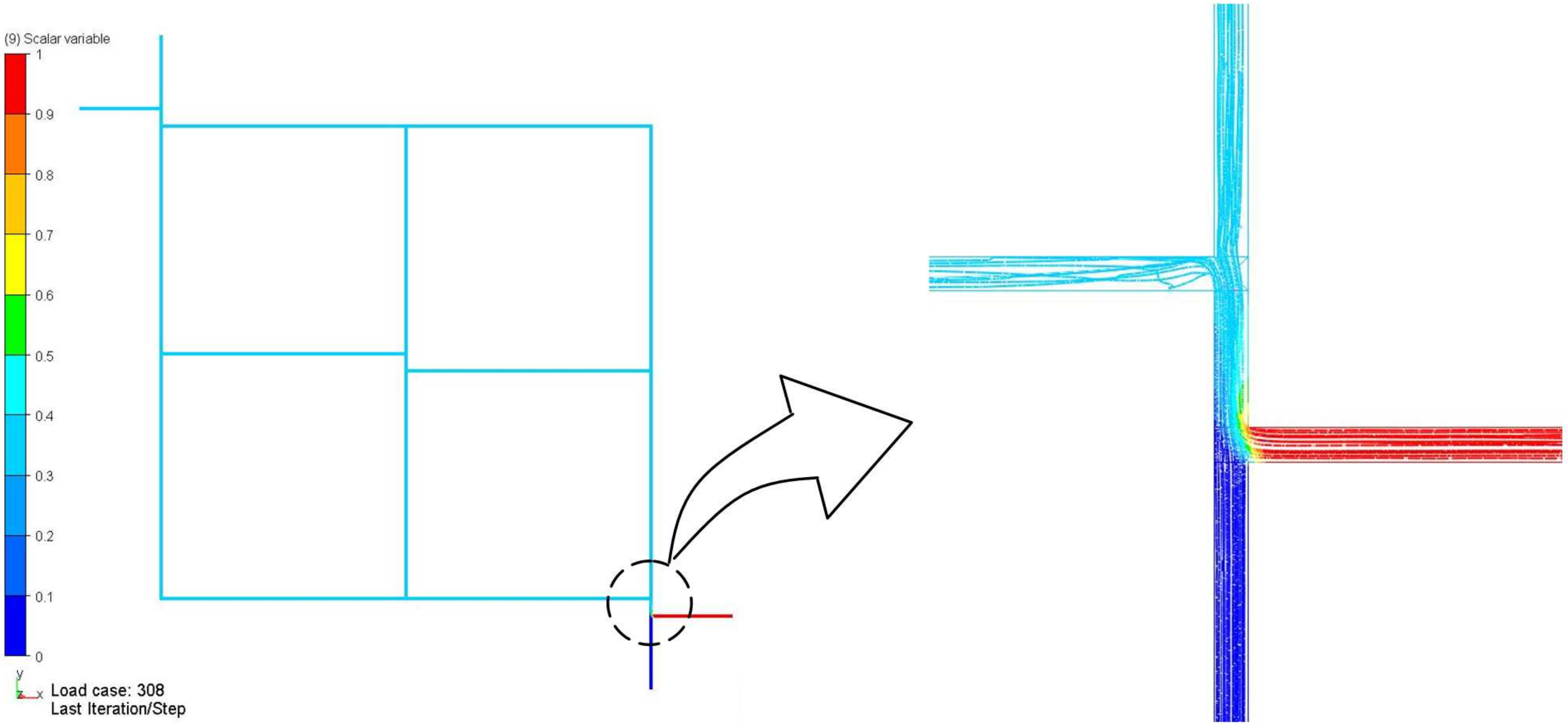
$$Q_{tracer} > Q_{clean}$$





Double-T Junctions

$$Q_{clean} > Q_{tracer}$$



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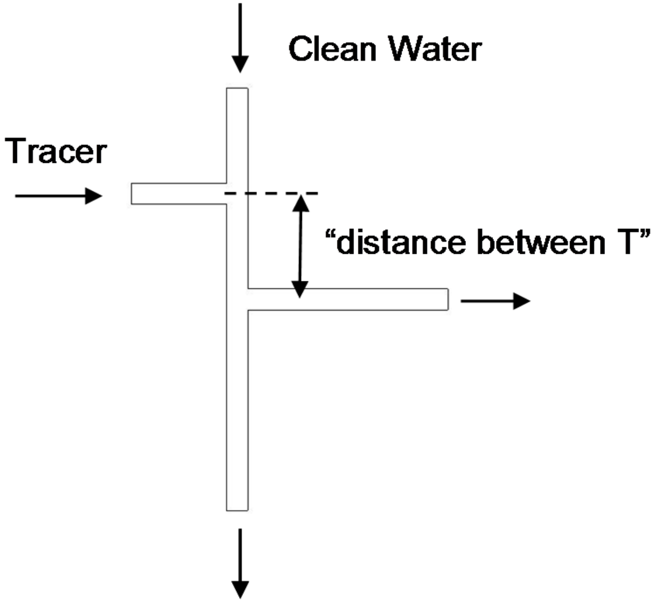
Conclusions

- Water flow and solute transport in a small-scale network were evaluated experimentally and computationally
  - CFD (allows incomplete mixing at junctions)
  - EPANET (assumes complete mixing at junctions)
  - Modified EPANET (incomplete mixing based on correlations)
- Results with cross junctions resulted in incomplete mixing, even after several consecutive junctions
  - EPANET produced inaccurate results
  - Modified EPANET captured trends in mixing and solute concentration
  - CFD provided good matches with data

Conclusions (cont.)

- **Simulations with double-T junctions resulted in completely mixed concentrations in the network**
  - **Complete mixing is likely to occur in double-T junctions when separated by > 5-10 pipe diameters**



Next Steps

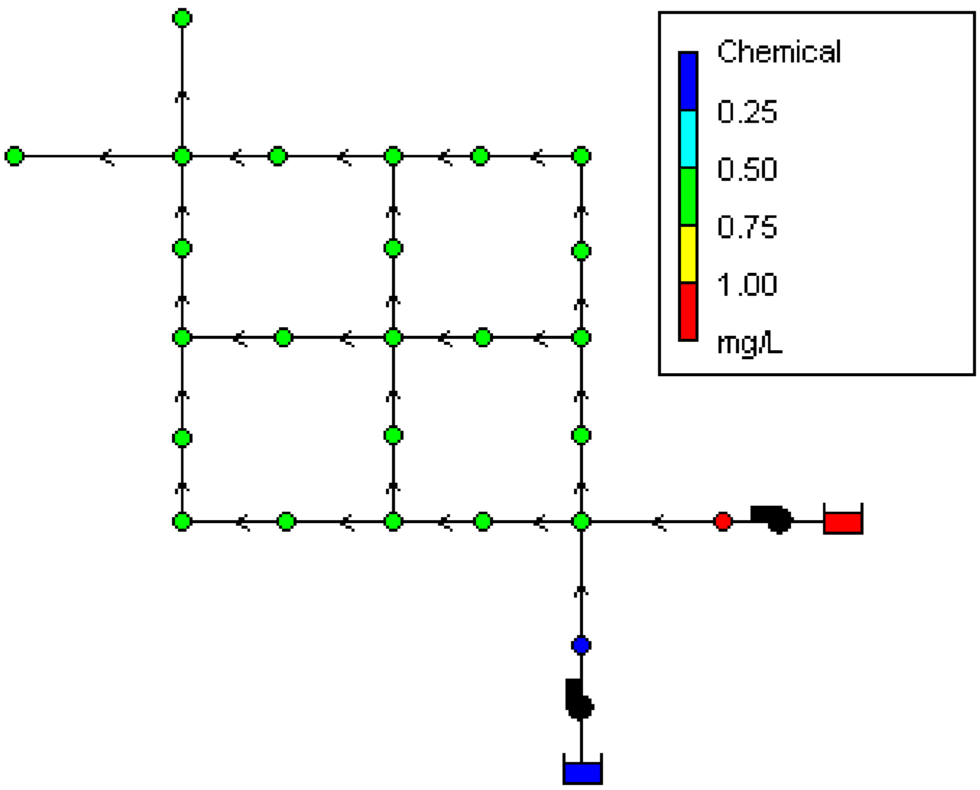
- Continue physical and numerical simulations
  - Evaluate mixing in more complex configurations and networks
  - Evaluate the effects of transient oscillations and storage on mixing in pipe networks
- Incorporate improved models of mixing into EPANET

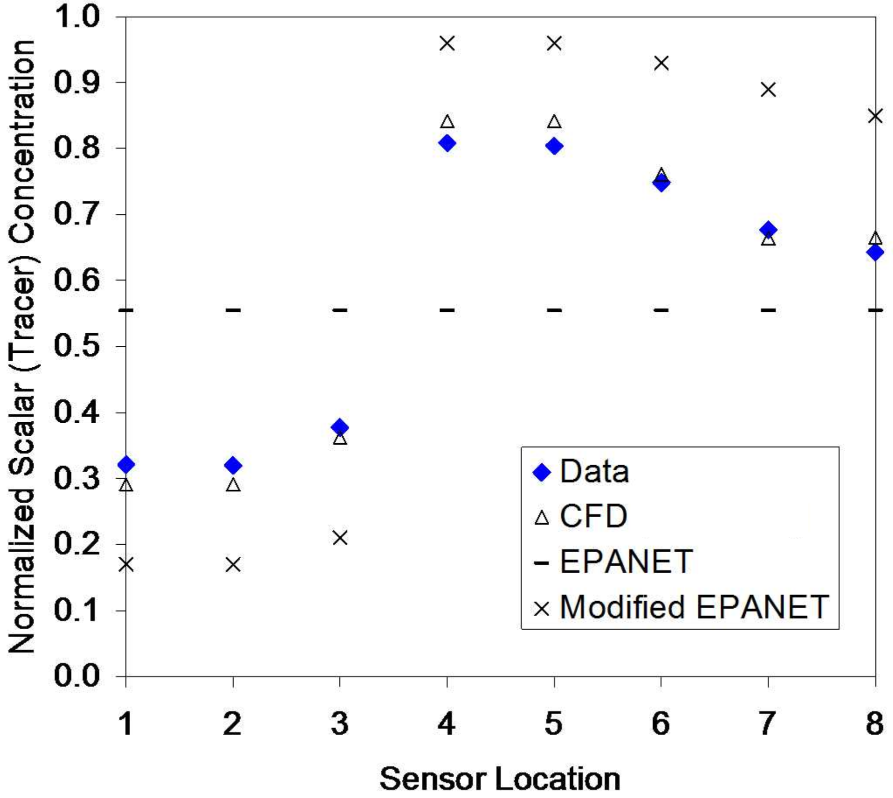
Backup Slides

Solute Transport Results

$Q_{tracer} > Q_{clean}$

EPANET





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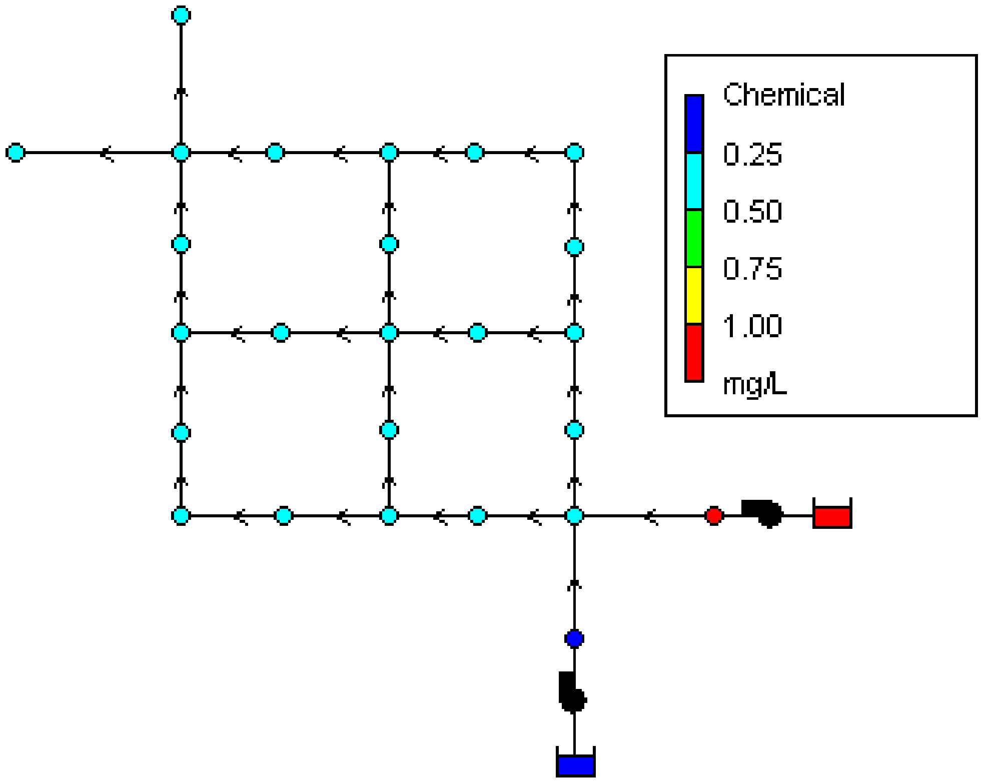
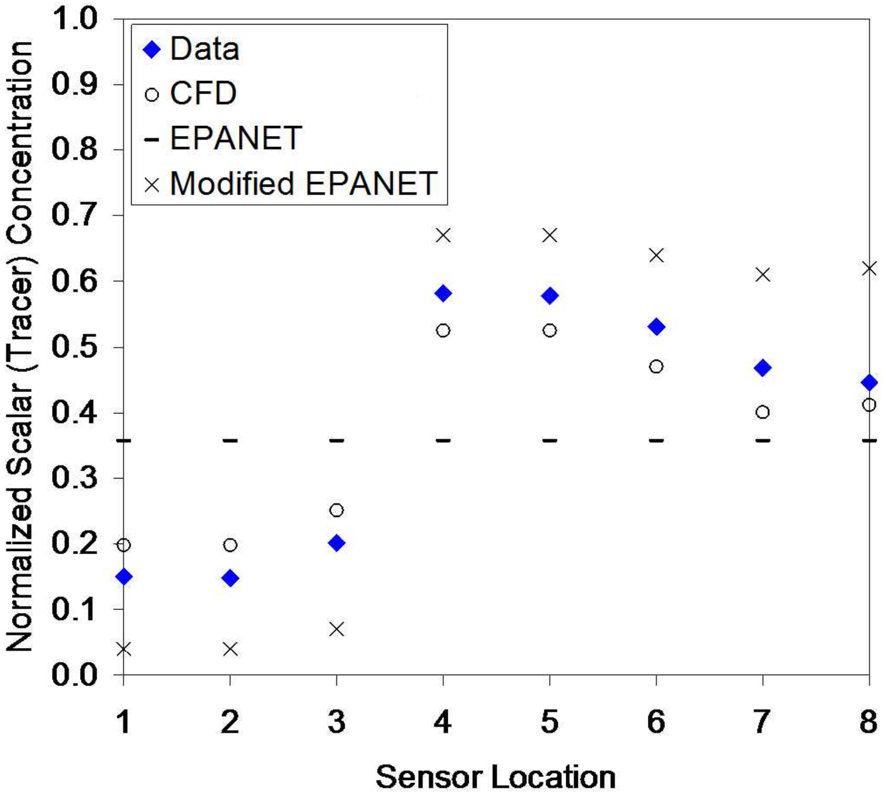
Solute Transport Results

$Q_{clean} > Q_{tracer}$

EPANET





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