CAMRA
Center for Advancing Microbial Risk Assessment

Improvement of Water Quality Modeling for Microbial Risk Assessment: Recent Advances

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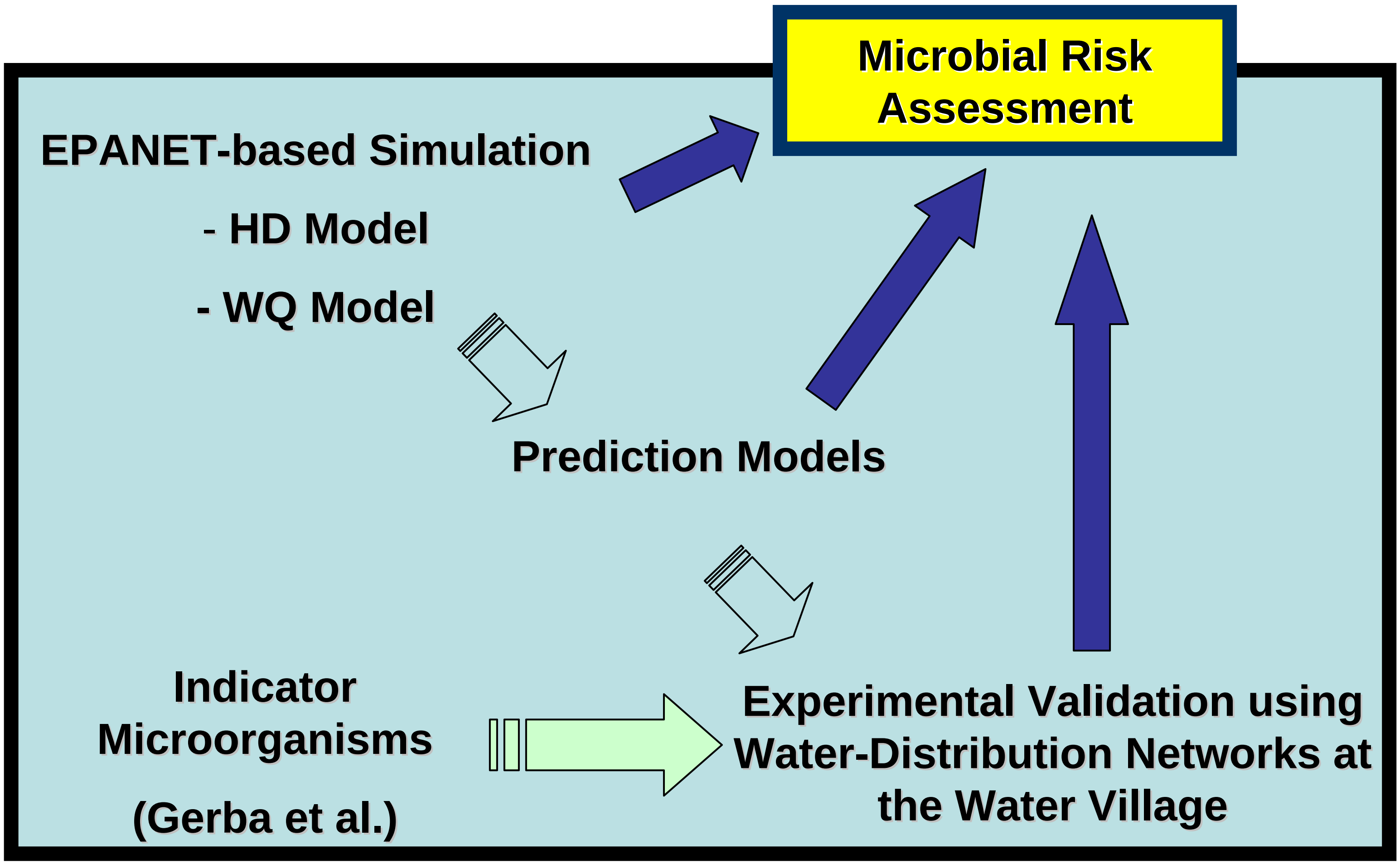
CAMRA/The University of Arizona

CAMRA – National Homeland Security Center

The Center for Advancing Microbial Risk Assessment

Main Research Focus of Choi's Group: Water Distribution Systems

Research Plan



CAMRA Center for Advancing Microbial Risk Assessment

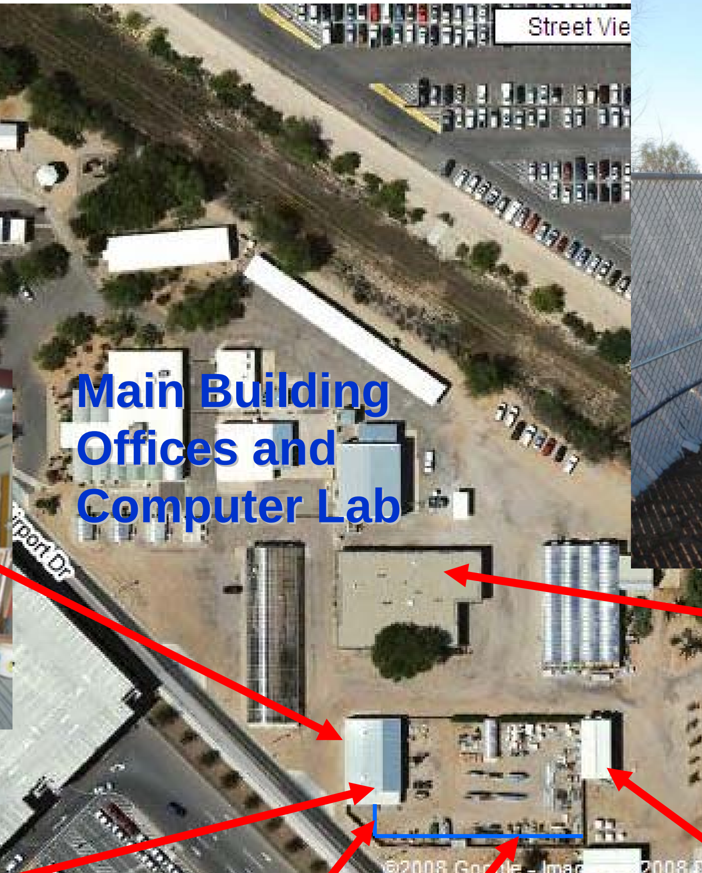
Point of Use & Microbiology Laboratory

Water Village

Water Distribution Systems Laboratory

Pilot Scale Experiments

Current Laboratories



Real-time
Water
Quality
Monitoring
Lab

Water
Chemistry
Lab

Water
Treatment
Laboratory

Pumpin
Station

Trench

50 m line for dispersion experiments

Research Plan

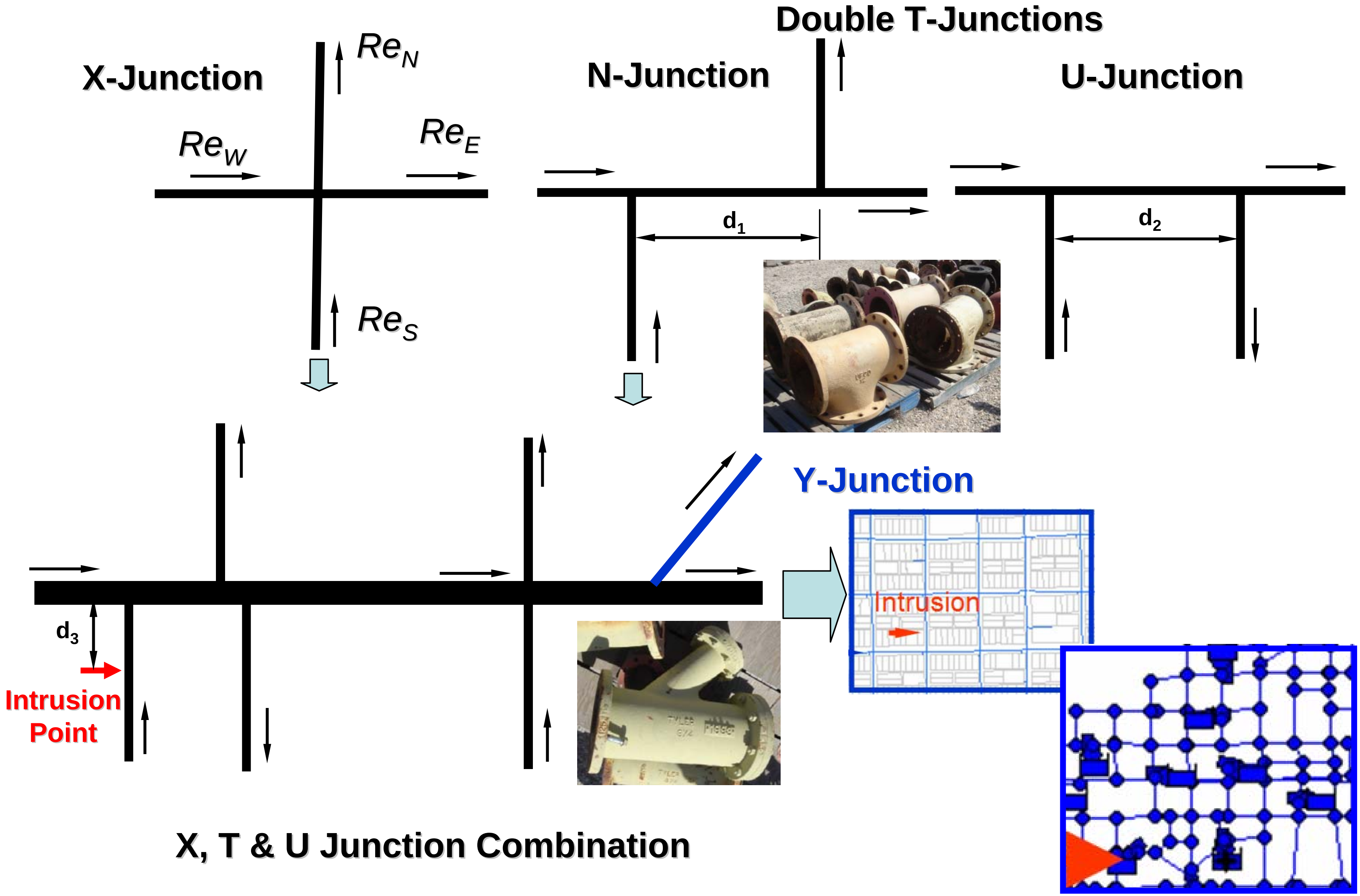
Step 1. Accurate Water Quality Modeling

Step 2. Accurate Prediction of Dispersion of Microorganisms

Step 3. Use of Prediction Tools such as ANNs

Step 4. Accurate Quantitative Microbial Risk Assessment

Building a Real-World Network Model



Two Significant Assumptions for EPANET Water Quality Model

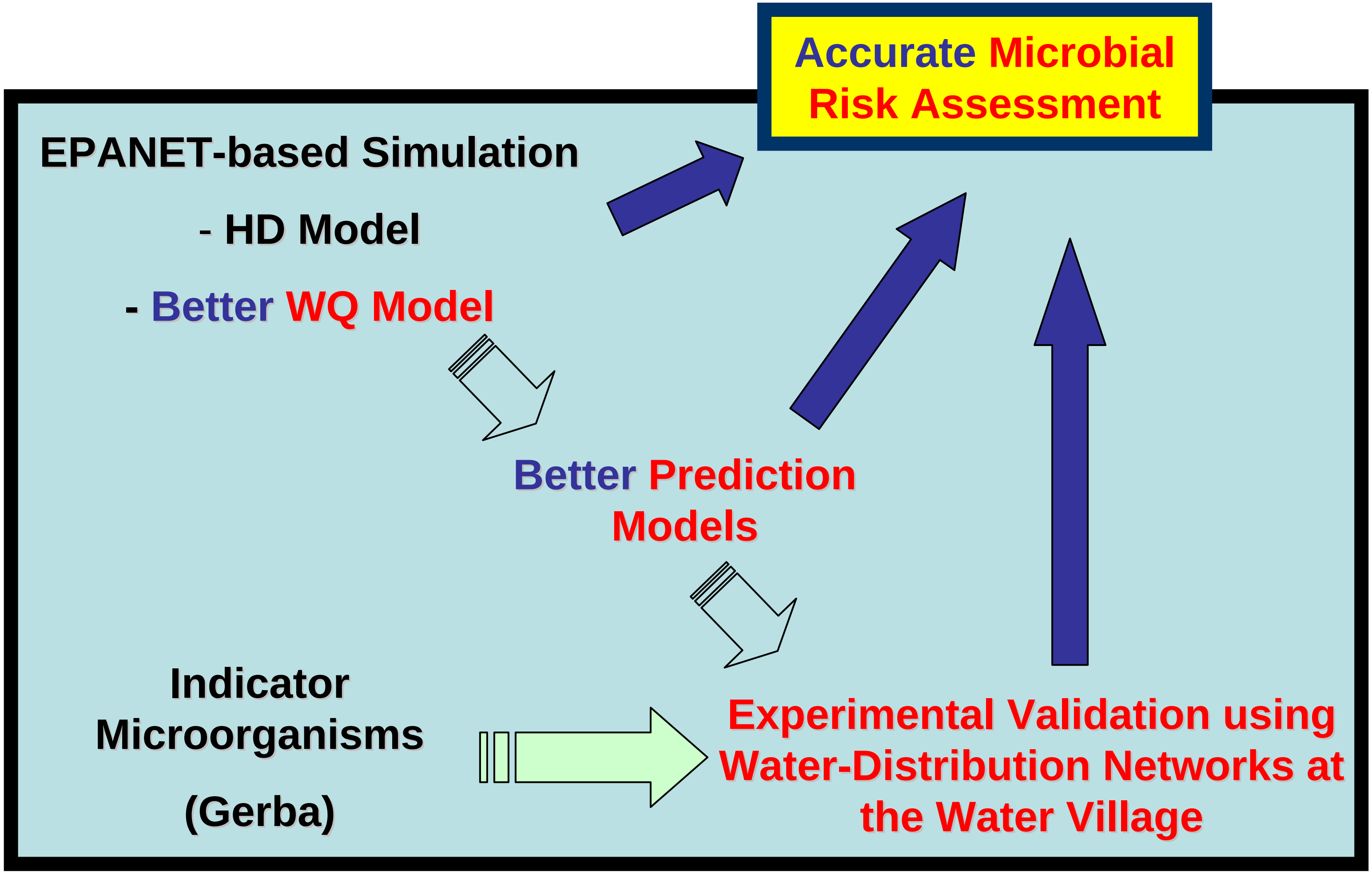
At present, prevailing network water quality models are based on two major simplifications.

First, longitudinal dispersion of the solute mass along the pipe axis is ignored, and "plug flow" is assumed to prevail.

Second, solute mixing is assumed to be "complete and instantaneous" at the pipe junctions.

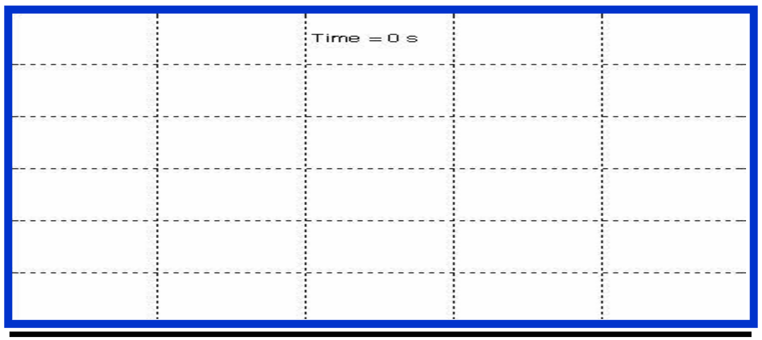
Recent investigations suggest that these assumptions may NOT be valid in real pipe networks.

Potential Improvement

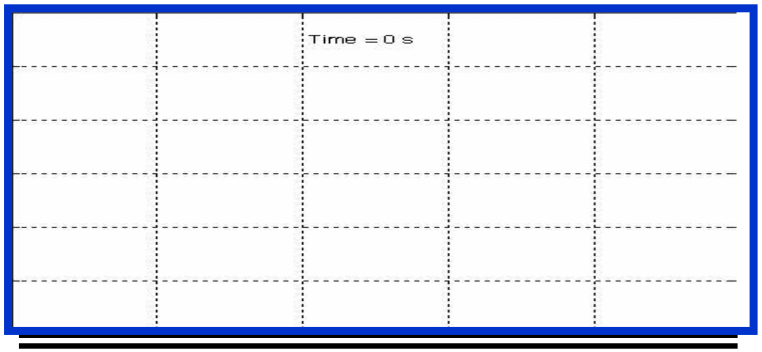


CFD Simulation for Pipe length = 6.35 m, D = ½ in.

U = 0.635 m/s   Re = 8,000



U = 1.27 m/s   Re = 16,000



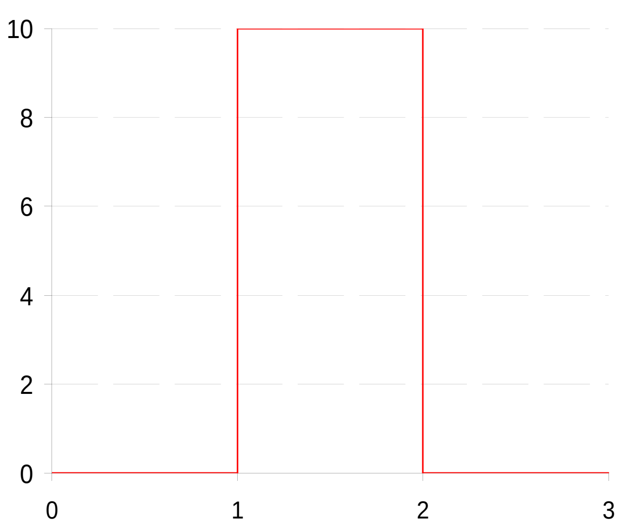
Re = 8,000 , Tmax = 6.5 s

Re = 16,000 , Tmax = 4.05 s

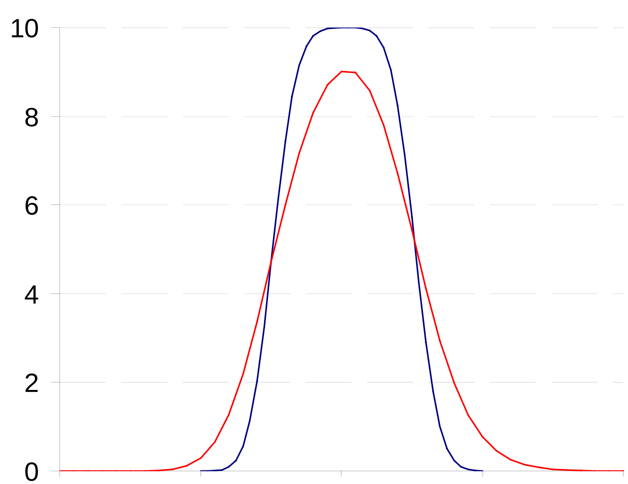
Re = 8,000 , Tmax = 11.6 s

Re = 16,000 , Tmax = 6.55 s

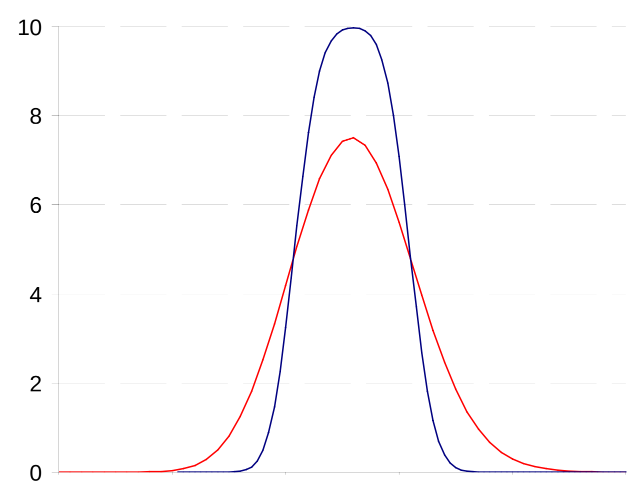
X = 0



X = 250 D

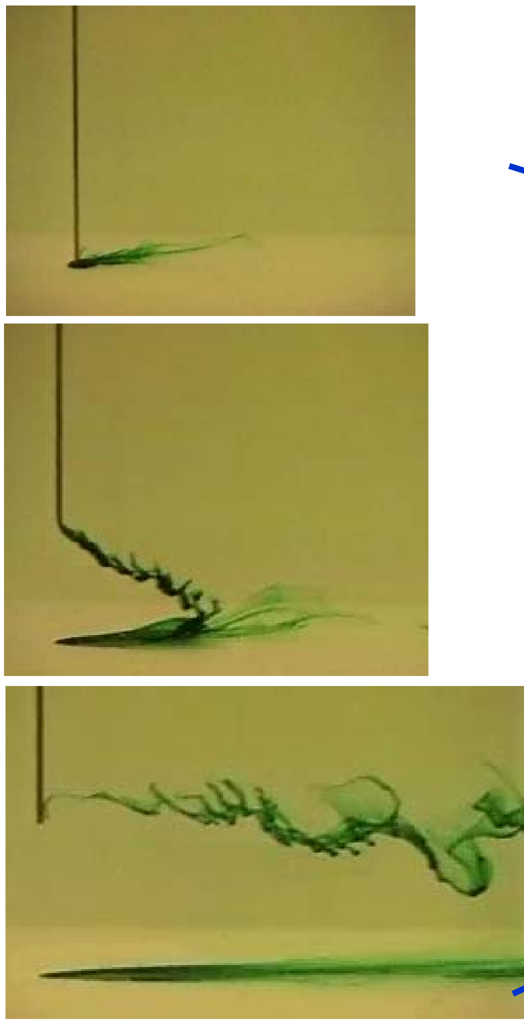


X = 500 D

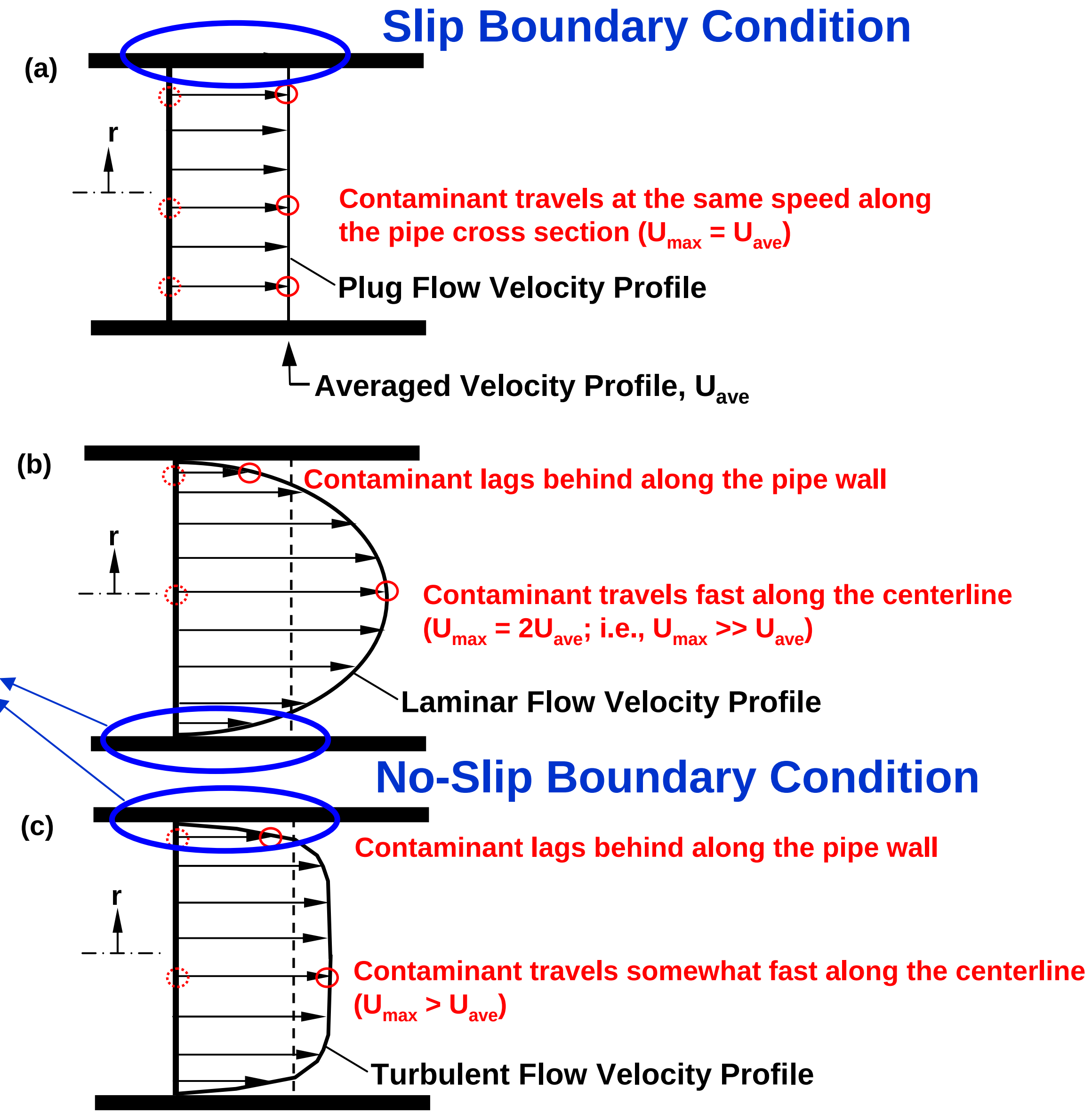


Why Axial Dispersion?

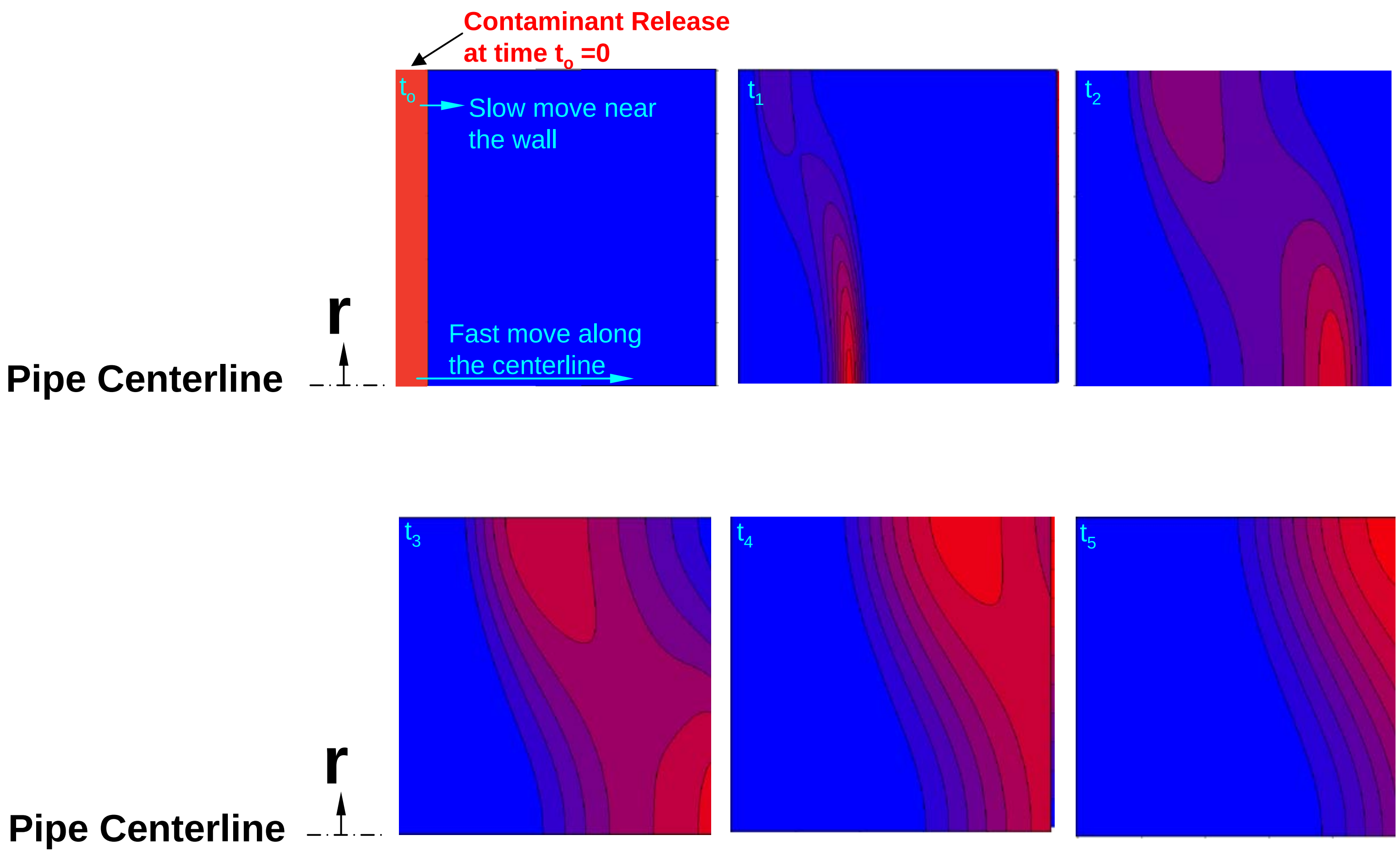
Typical tracer dispersion along the pipe wall



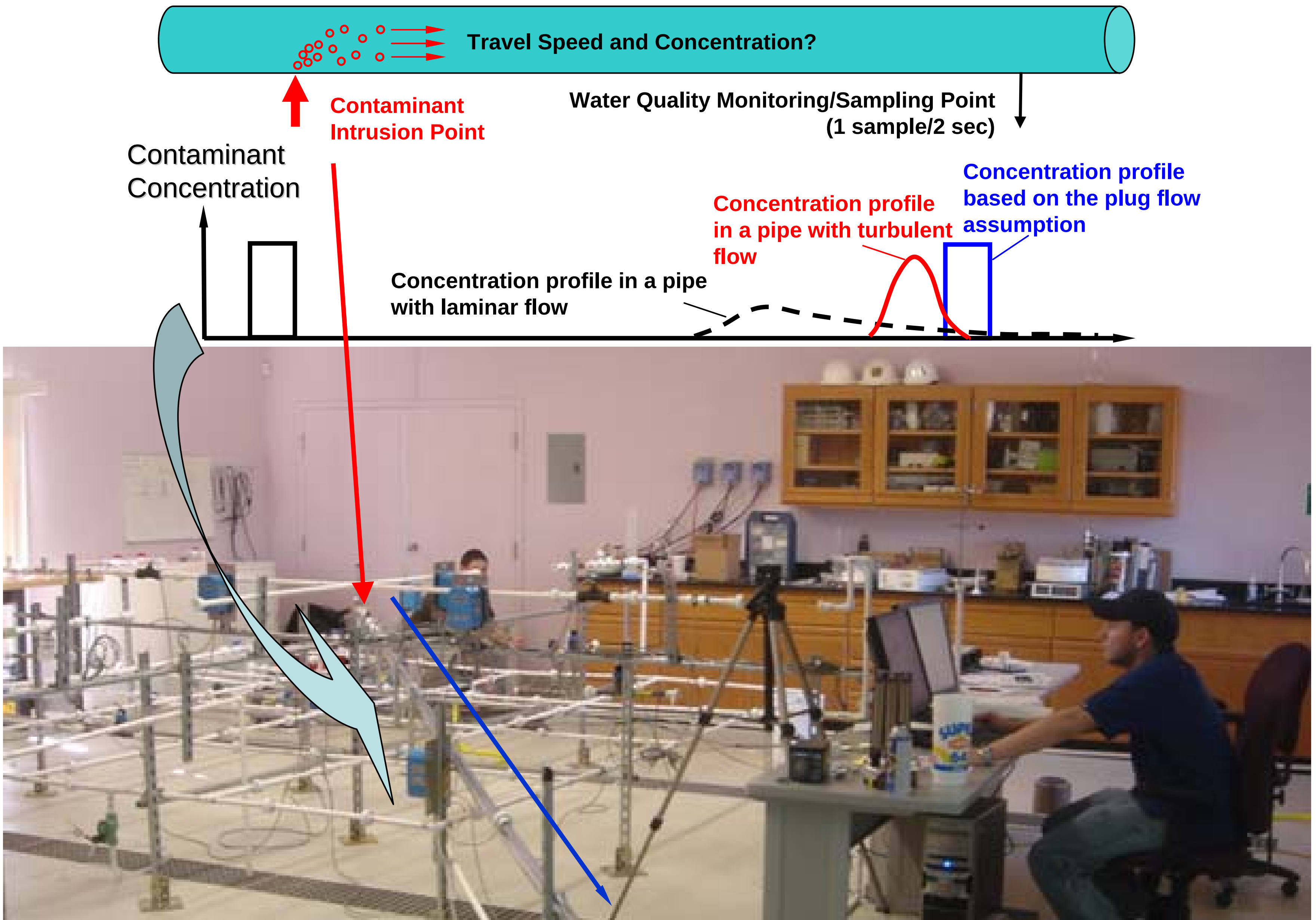
(Moran et al. 2003)



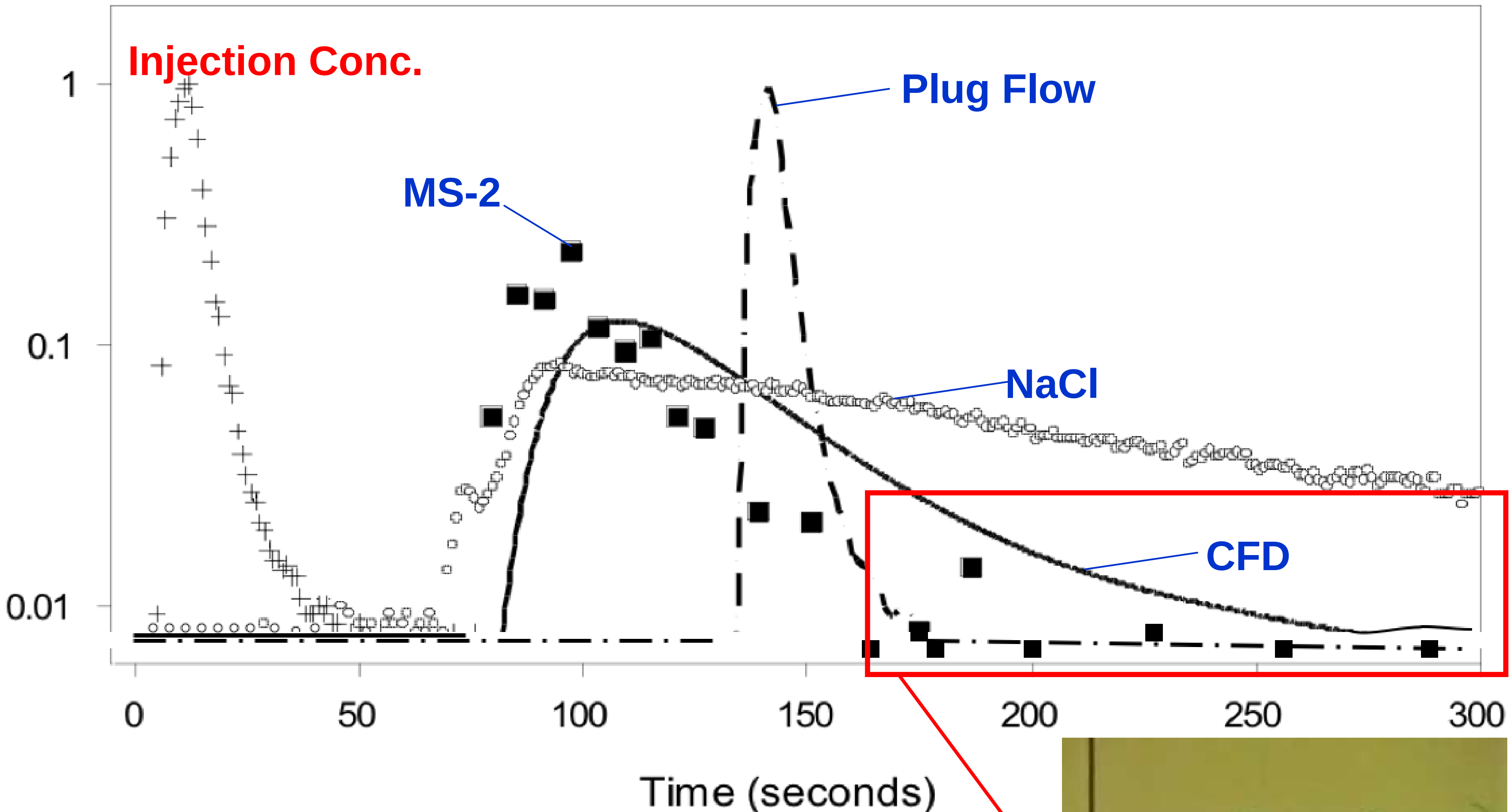
Computational Fluid Dynamics Simulations

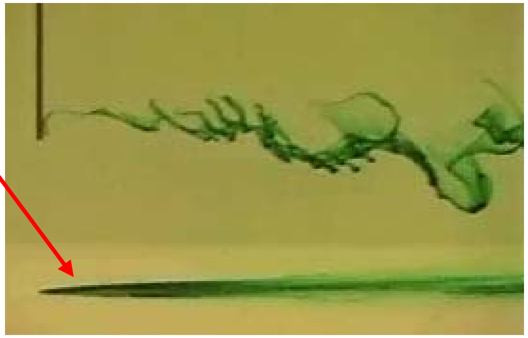


Experimental Setup



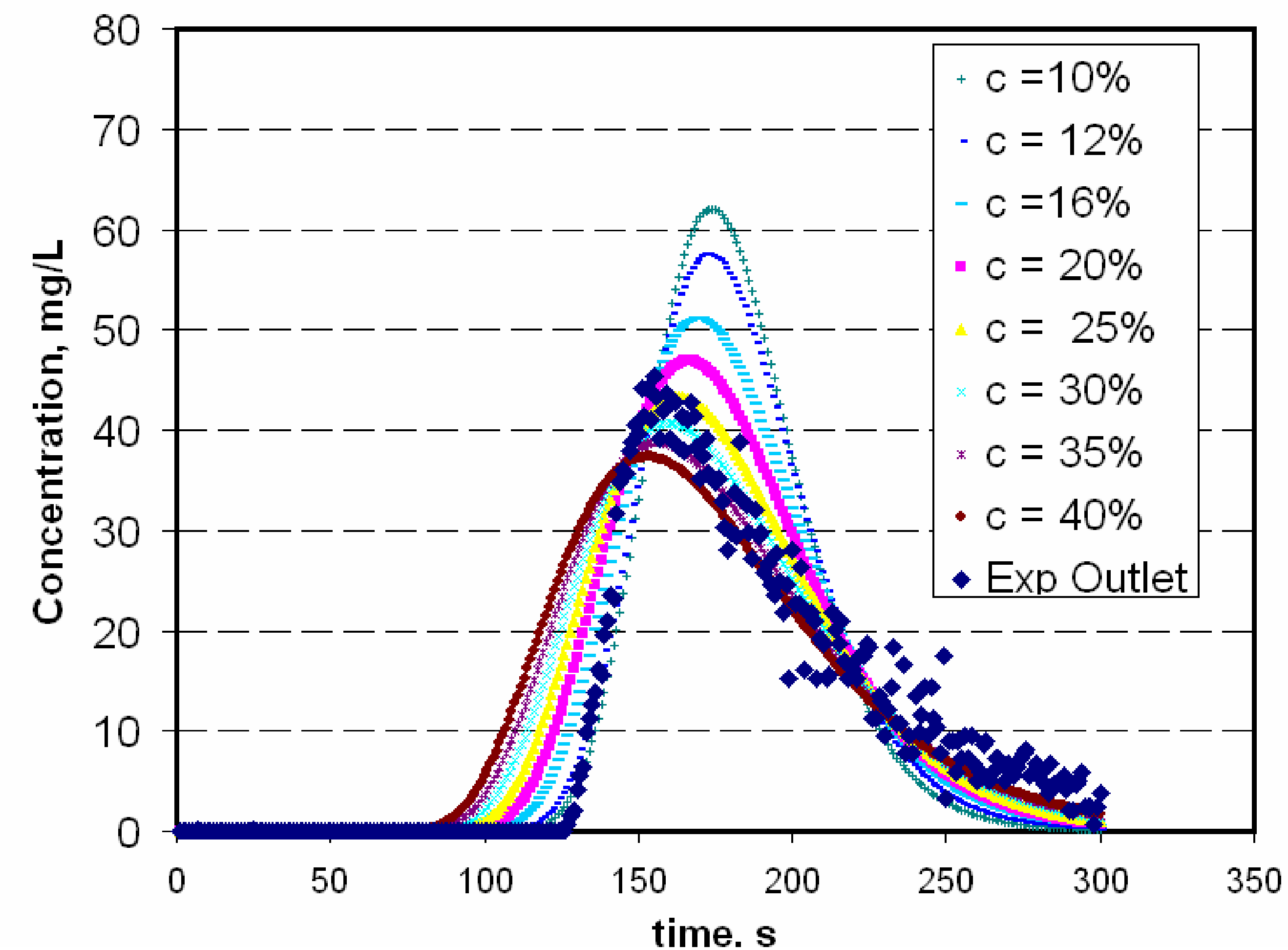
Injection of tracers
Laminar flow





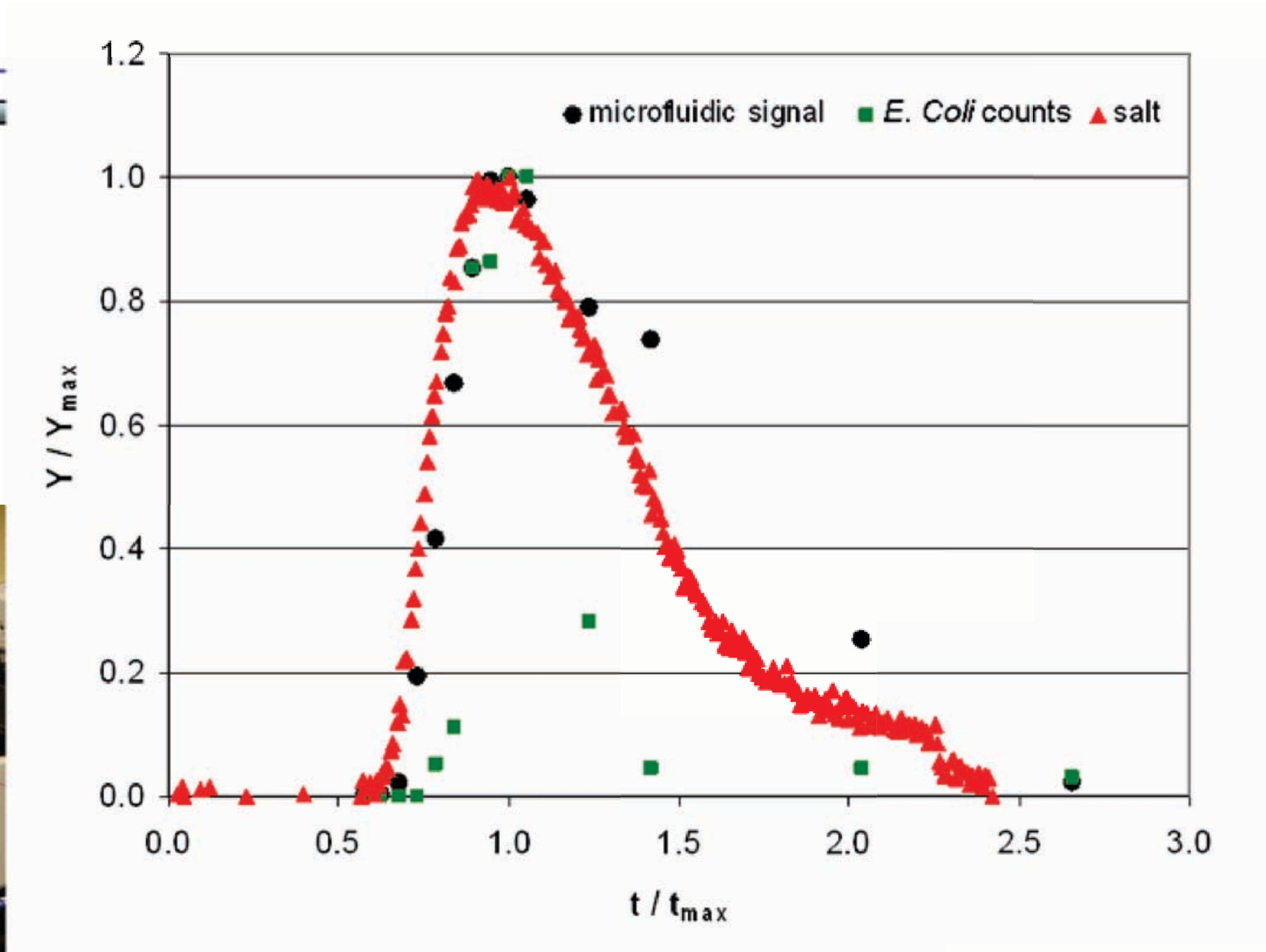
Axial dispersion & tailing of microorganisms:
Detection limits, sampling frequency, sensor locations

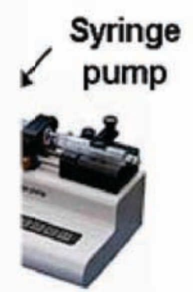
Examination of Existing Models



ADRNET (Buchberger and Li)/IMTARED (Tzatchkov)/In-House Code (Kang and Lansey)/Experimental Data (Choi)

Real Time Biosensor Research

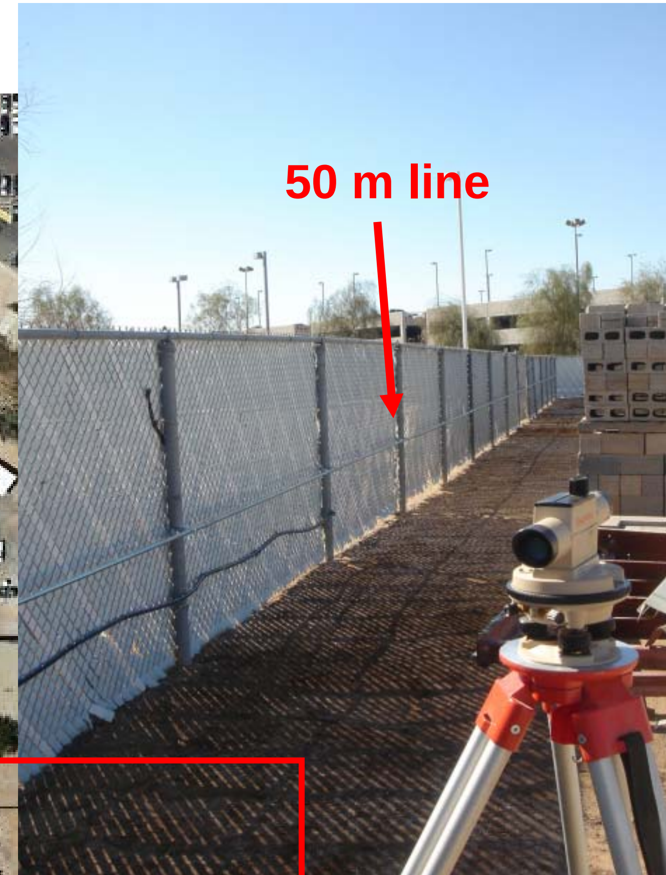




Courtesy of Professor Yoon
The Univ. of Arizona

Lab Scale ⇨ Pilot Scale Experiments

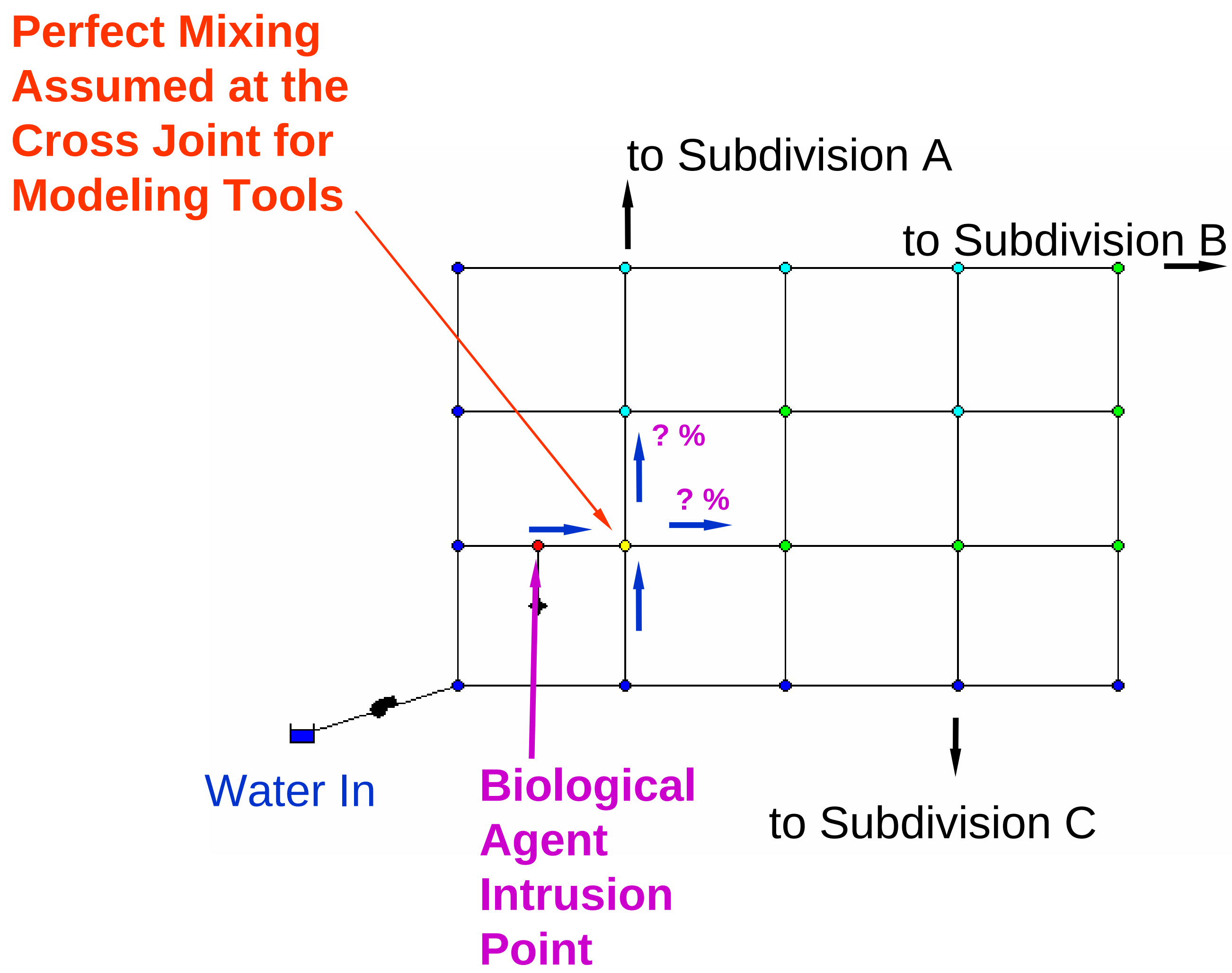
Pumping Station



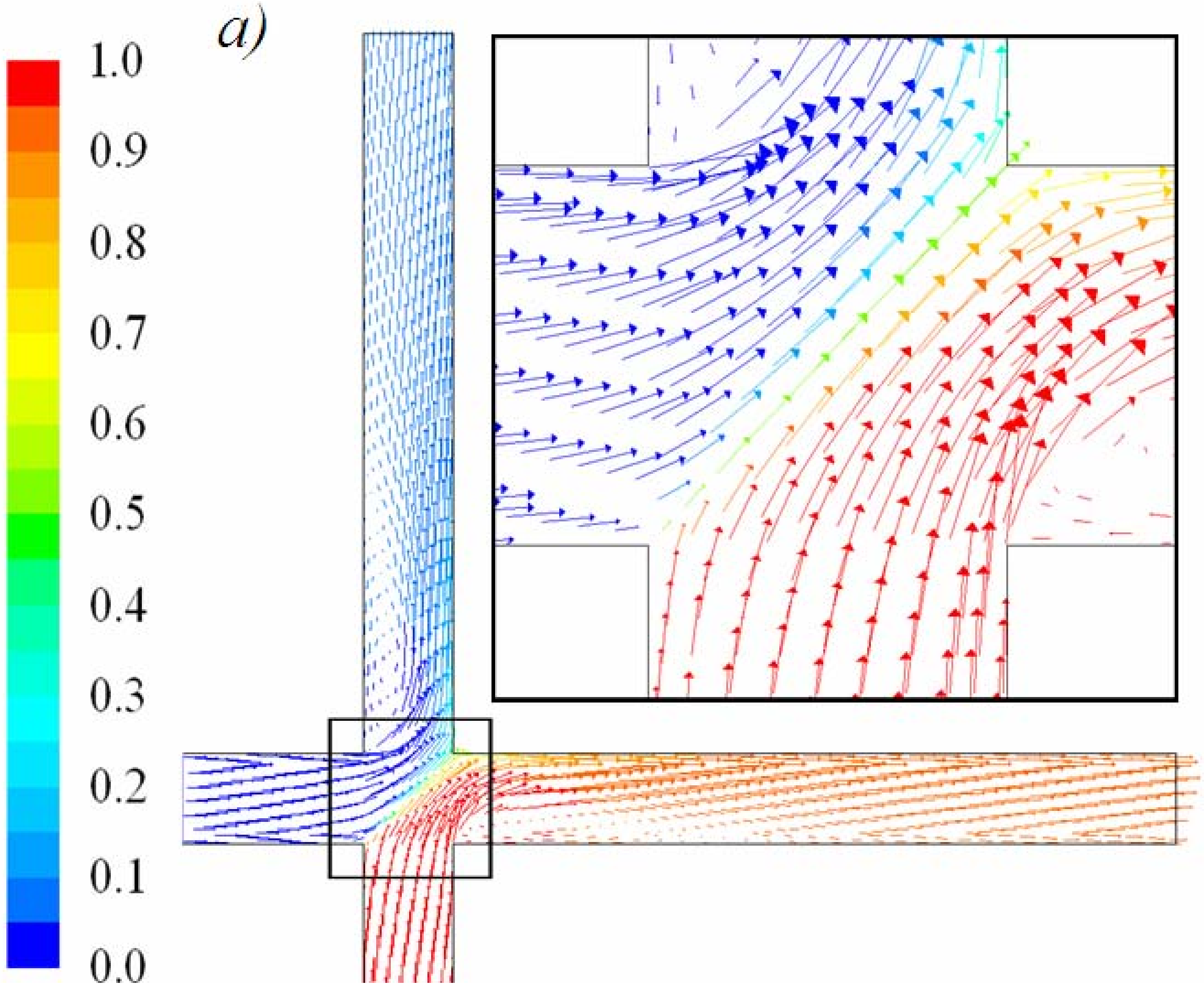
Trench

50 m line for dispersion experiments

Mixing at Junctions

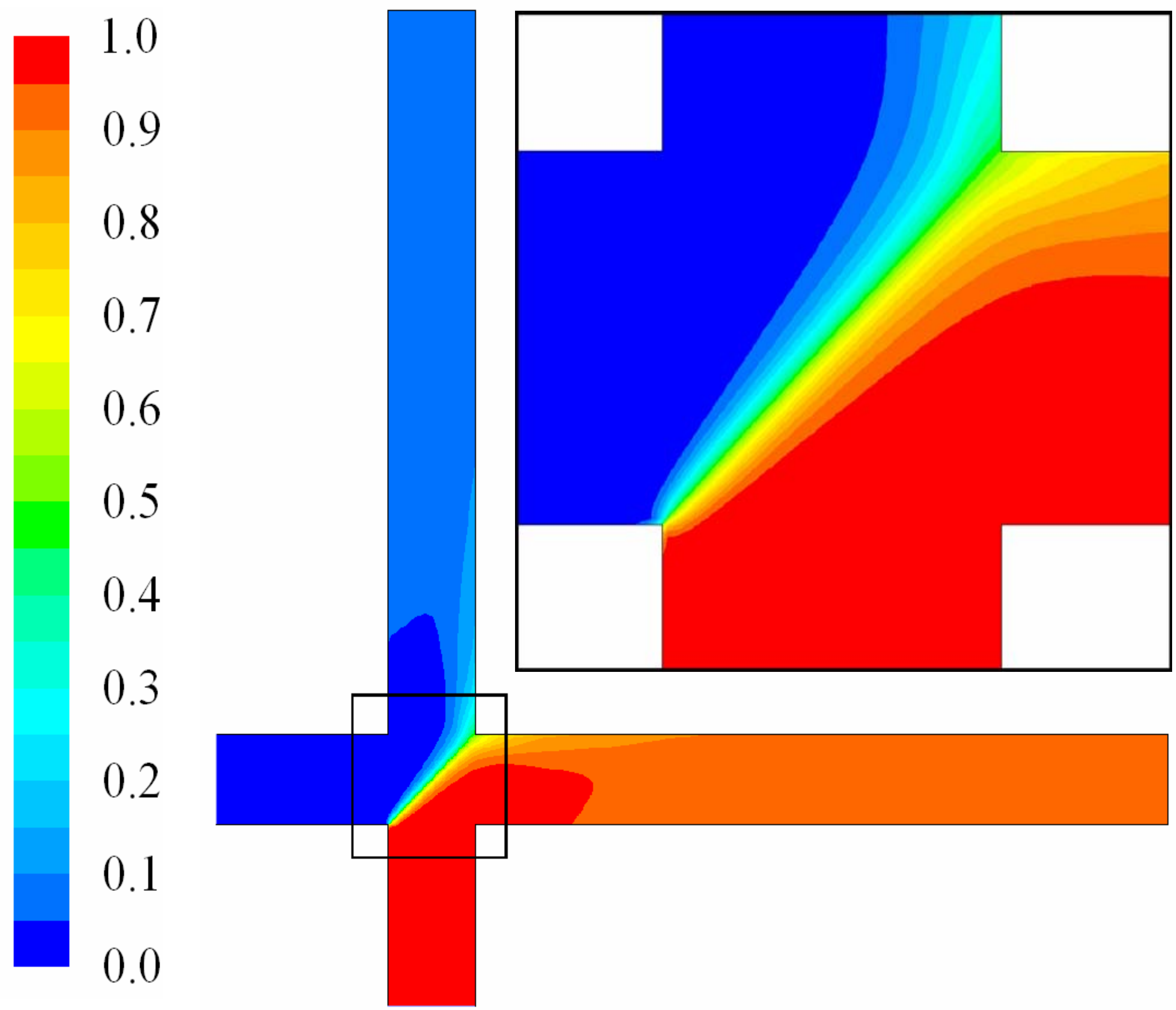


Mixing patterns along the interface



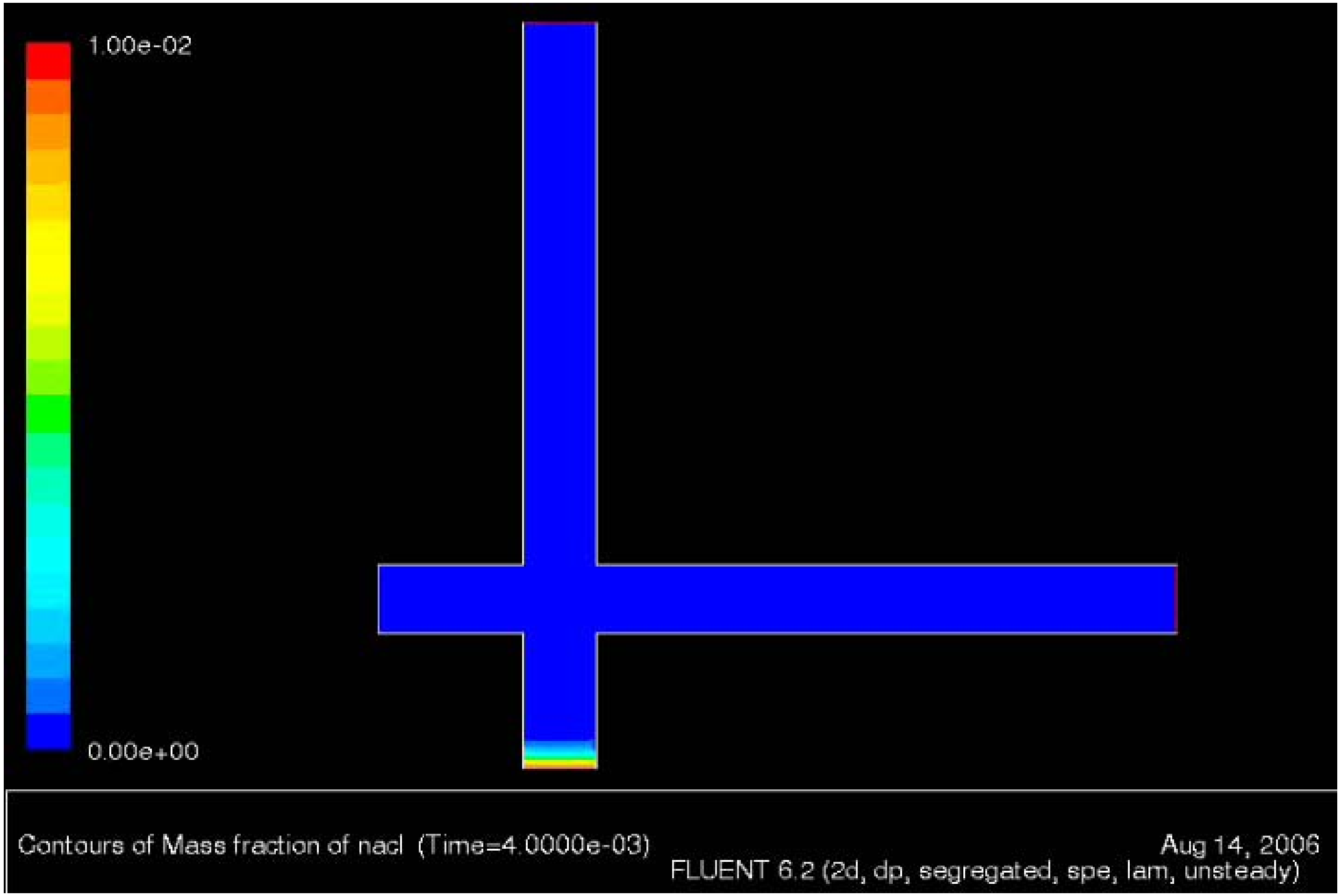
Velocity vectors at a cross junction, when $Re_S = Re_W = Re_E = Re_N = 44{,}000$ ($Re_{S/W} = 1$, $Re_{E/N}=1$), and $Sc_t = 0.1875$

Mixing patterns along the interface



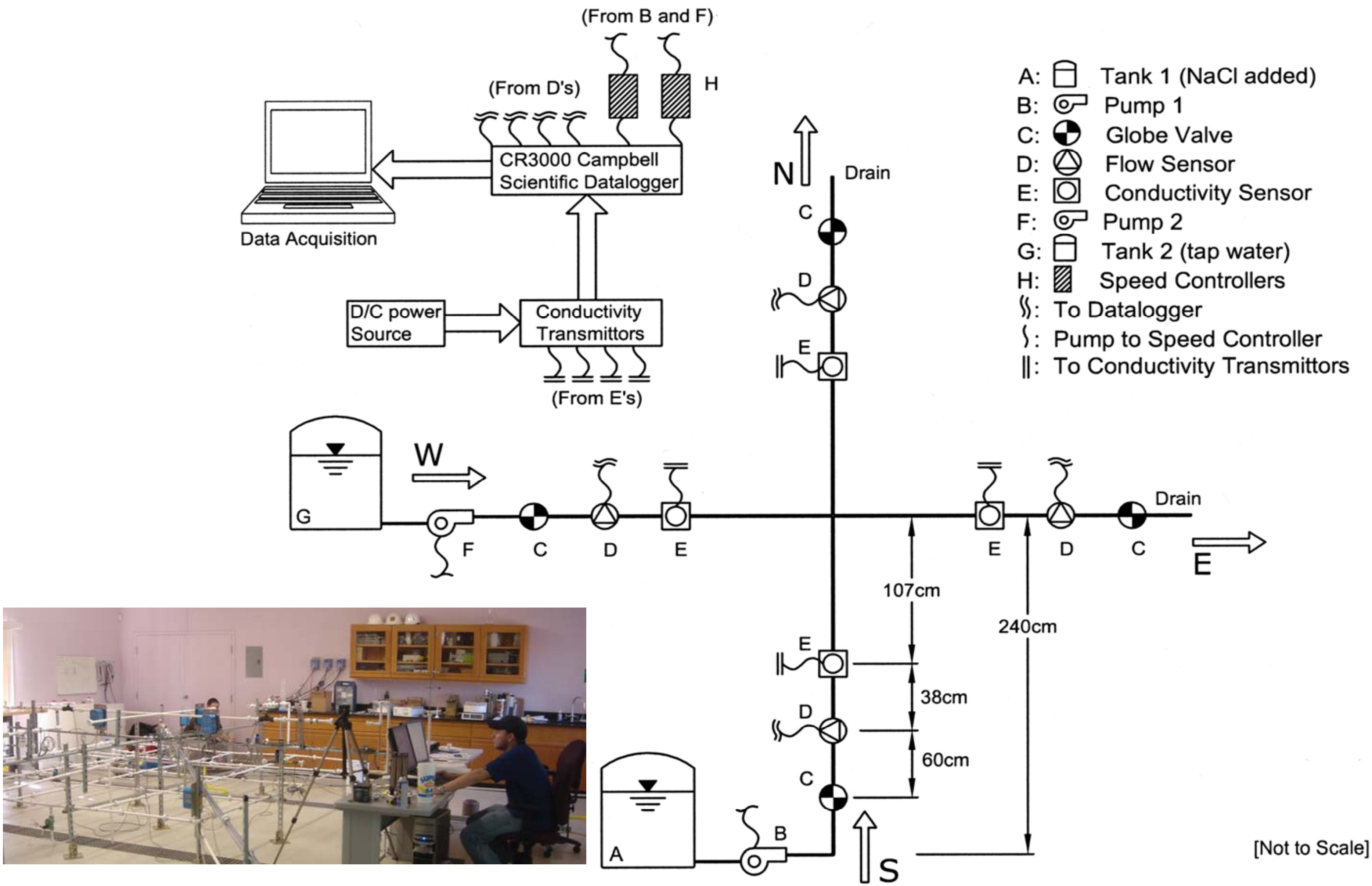
Dimensionless NaCl Concentration contours at a cross junction, when ReS = ReW = ReE = ReN = 44,000 (ReS/W = 1, ReE/N=1), and Sct = 0.1875

Mixing patterns along the interface

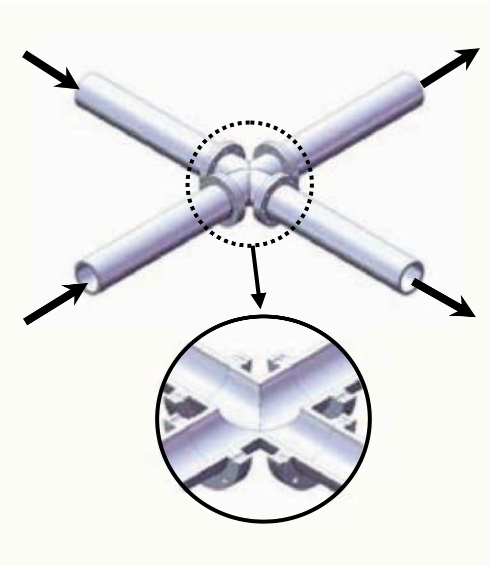


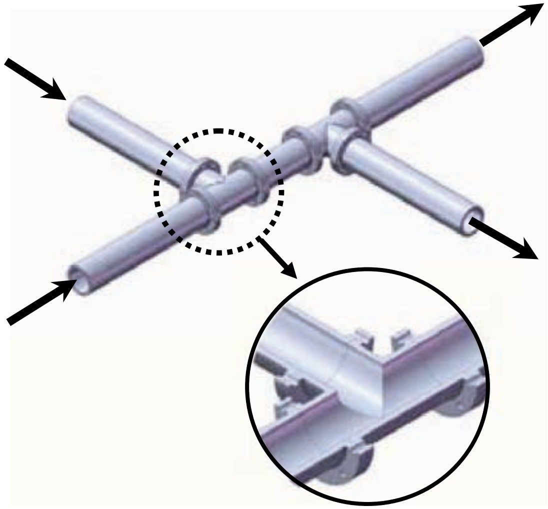
Simulation Video Clip

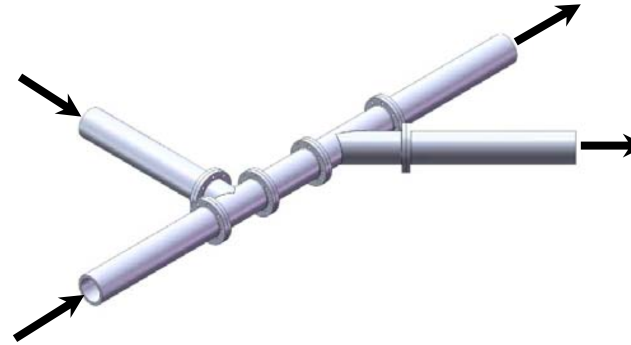
A schematic of the experimental setup

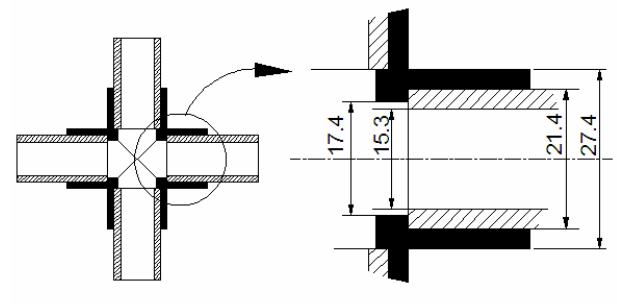


Representative Junction Types

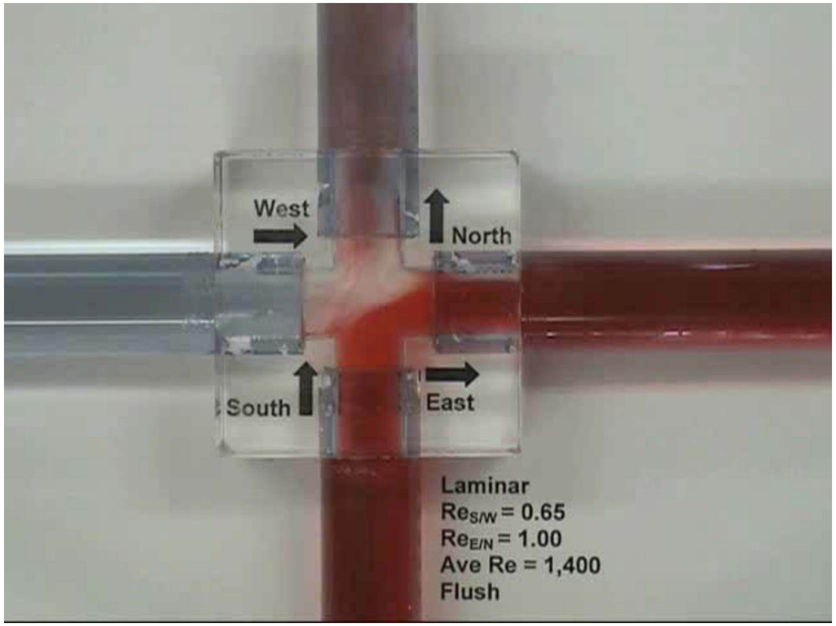


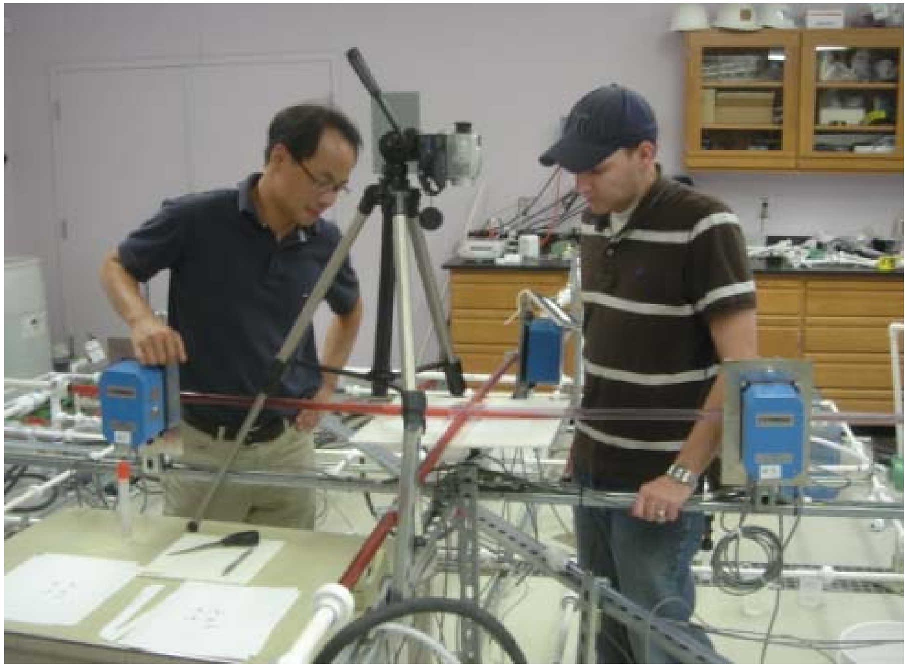




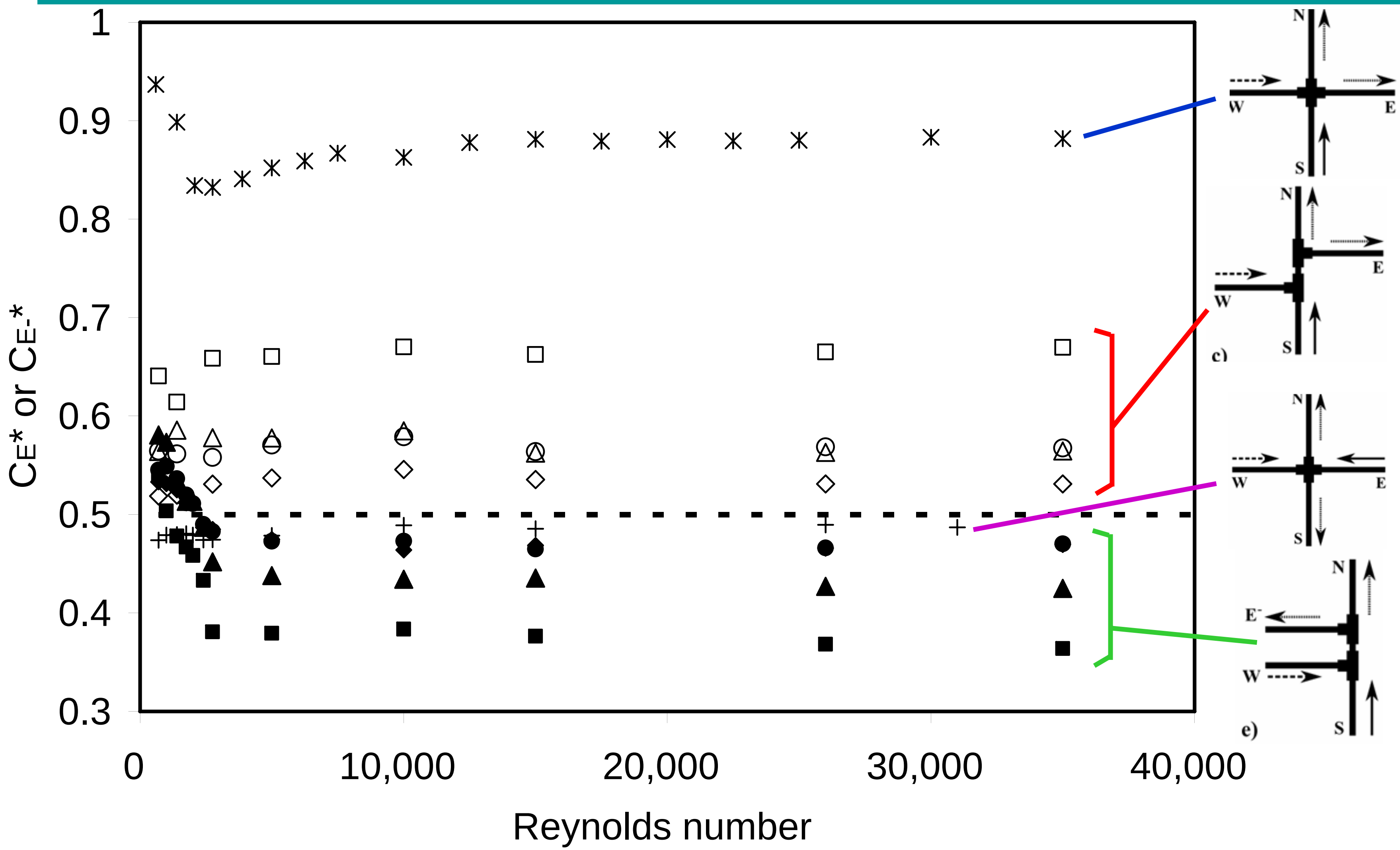


Flow Visualization



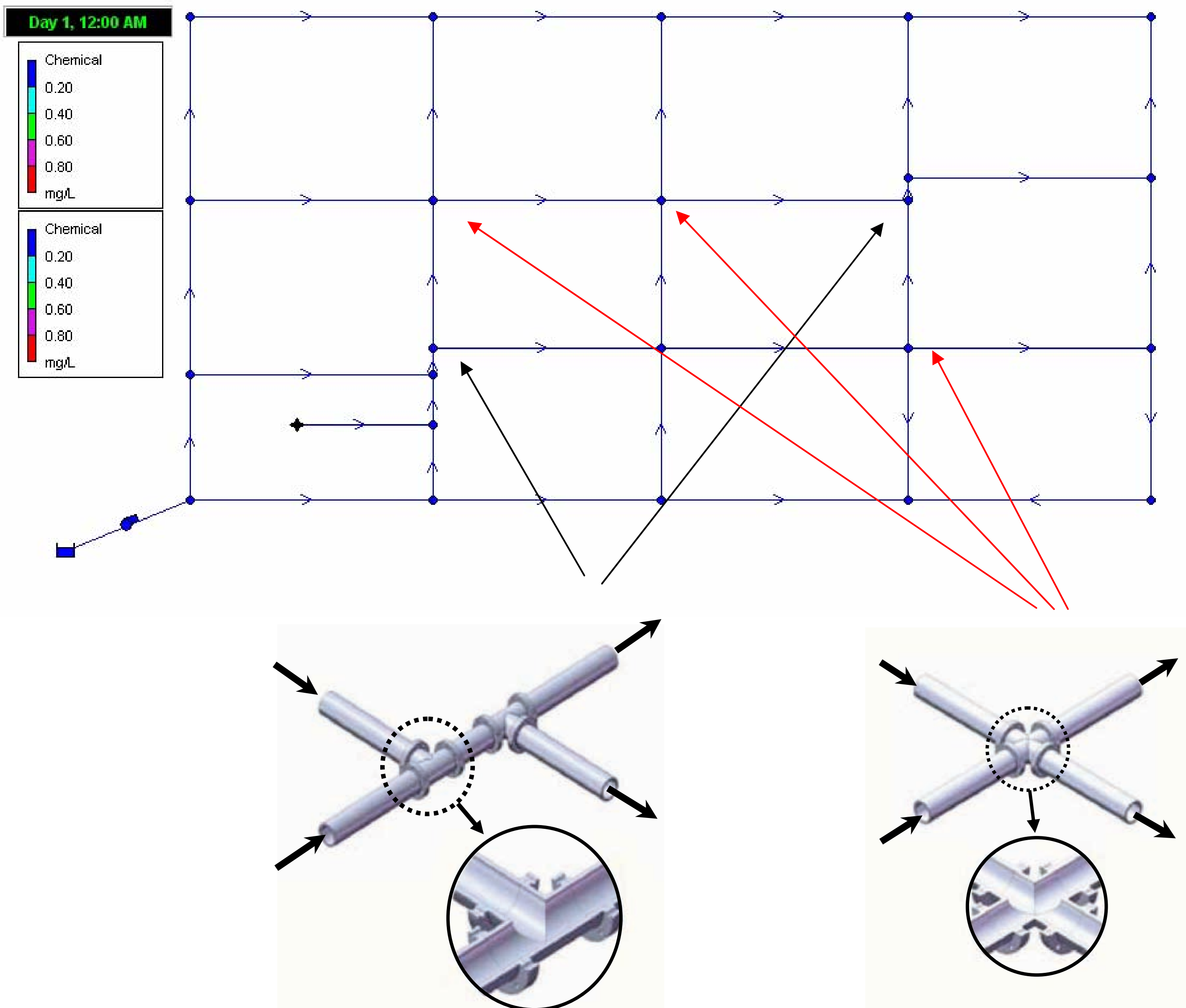


X, T, Y junctions for Scenario 1
$Re_E = Re_W = Re_S = Re_N$

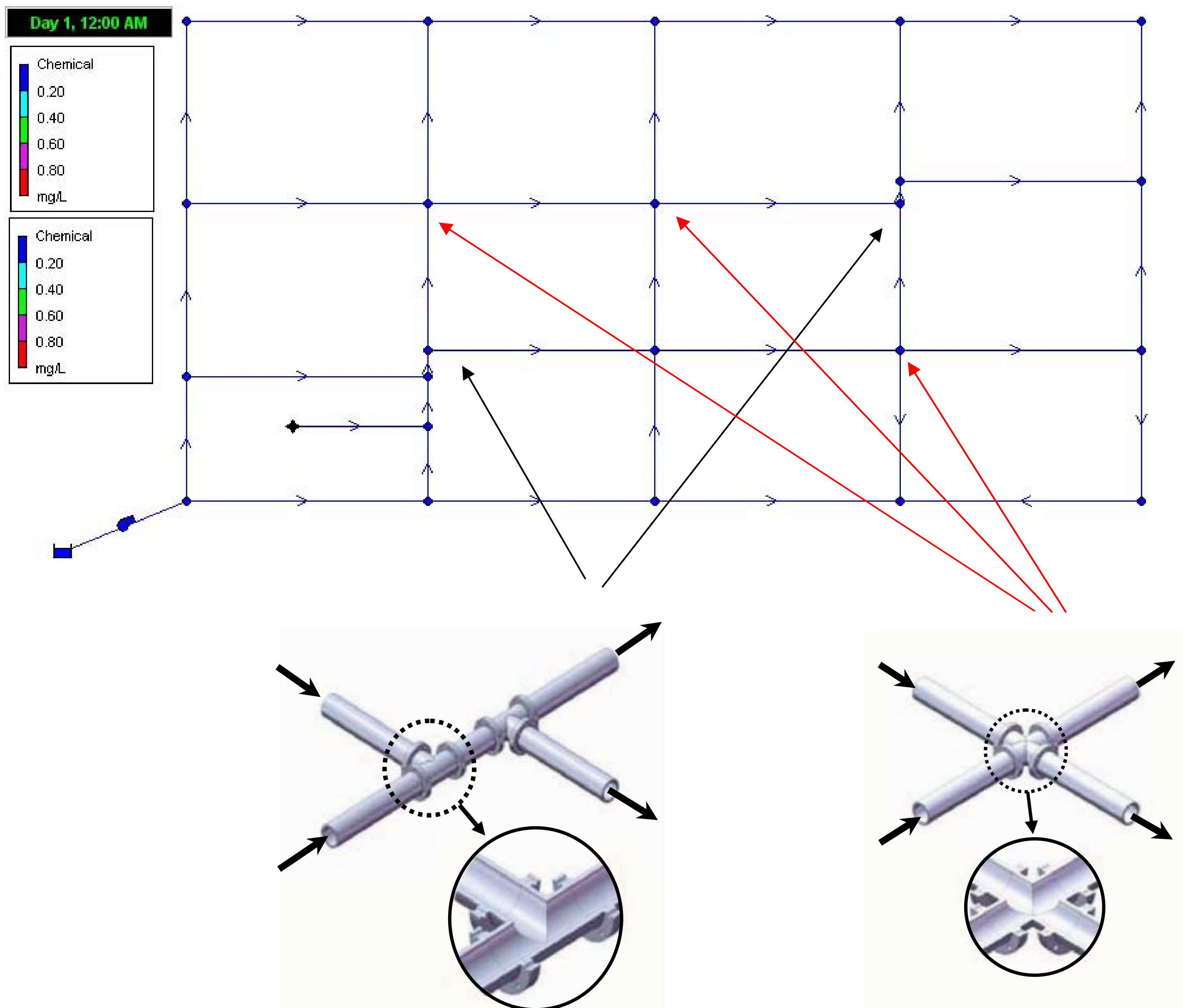


D=0, Cross, X1	D=0, Cross, X2	D=2.5, N1	D=5.0, N1
D=7.5, N1	D=10, N1	D=2.5, U1	D=5.0, U1
D=7.5, U1	D=10, U1	Complete Mixing	

Development of AZRED (with Perfect Mixing Model)

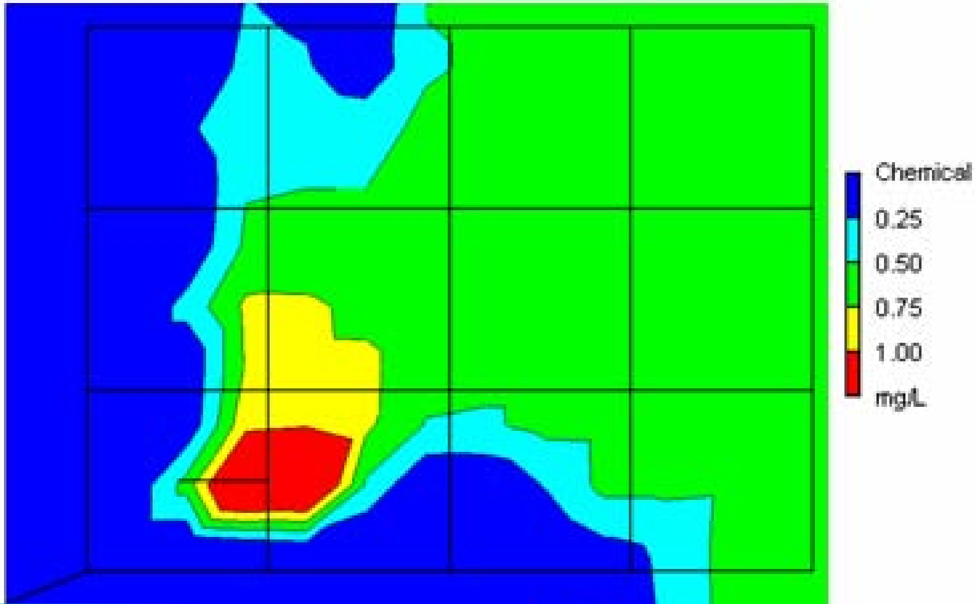


Development of AZRED (Improved Water Quality Model)

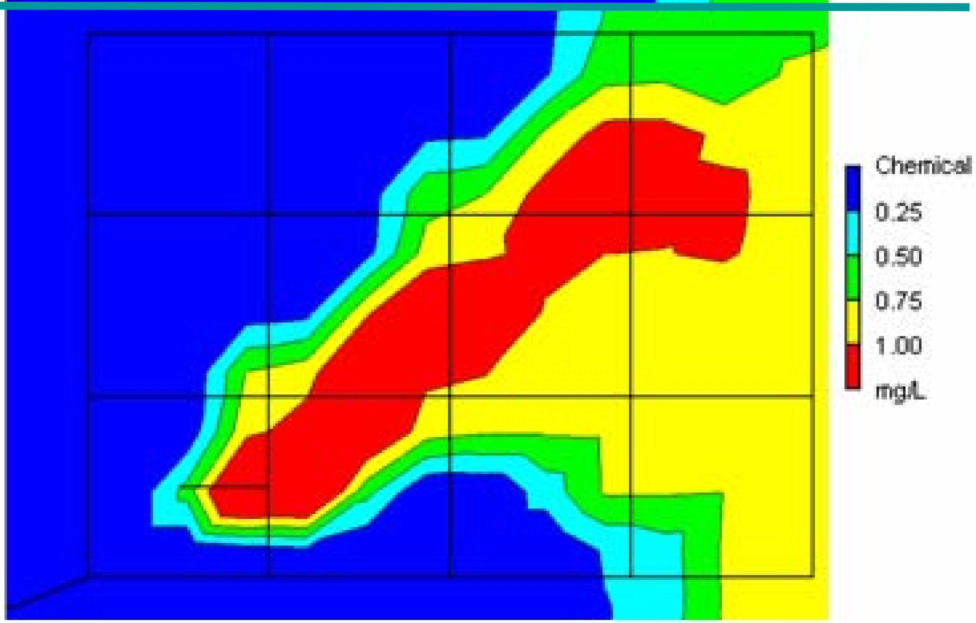


Comparison

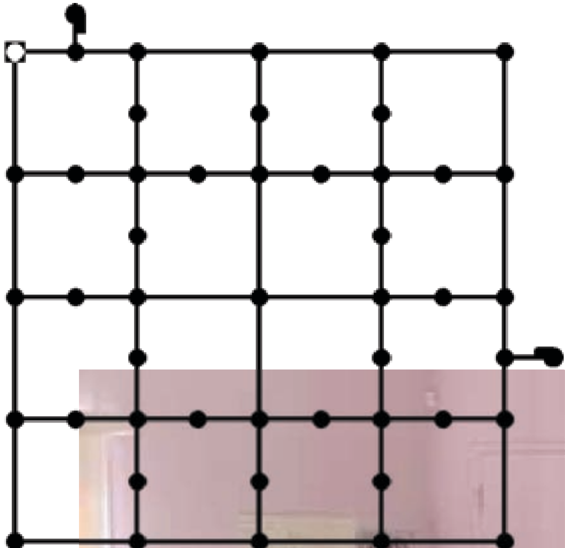
Existing Model based on Perfect Mixing

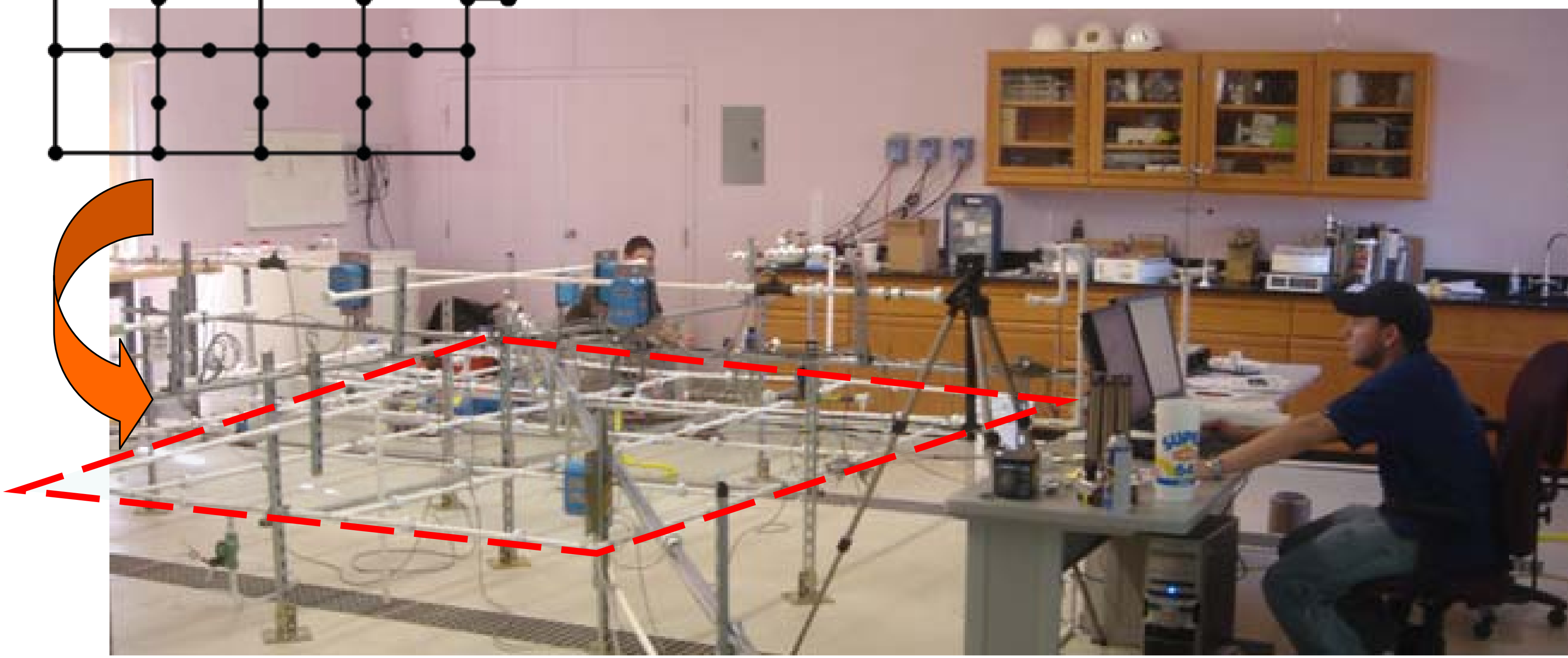


AZRED

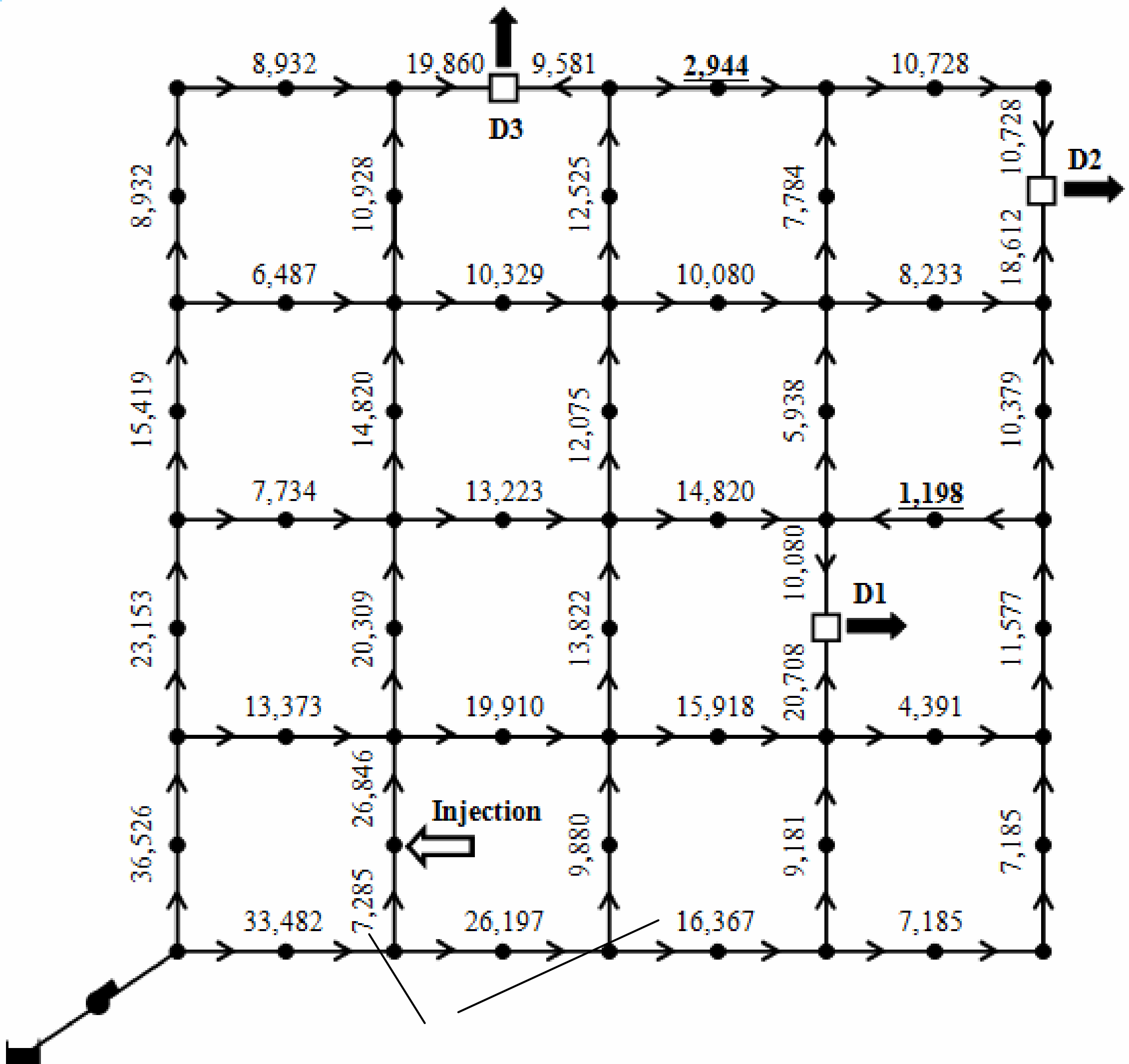


5x5 Network Establishment





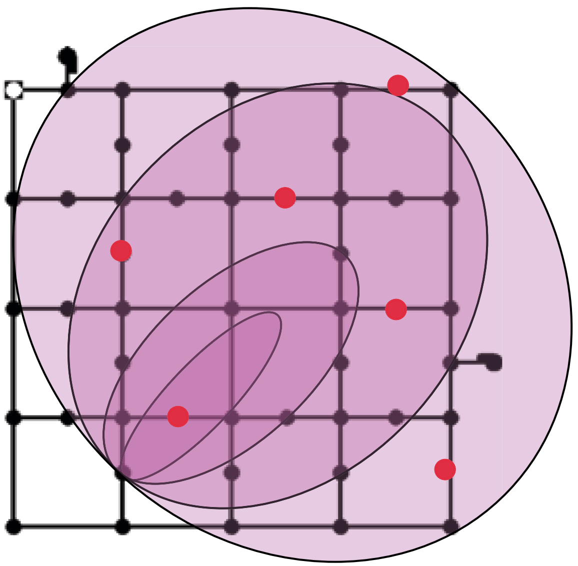
EPANET Hydraulic Model (Experimentally Validated)

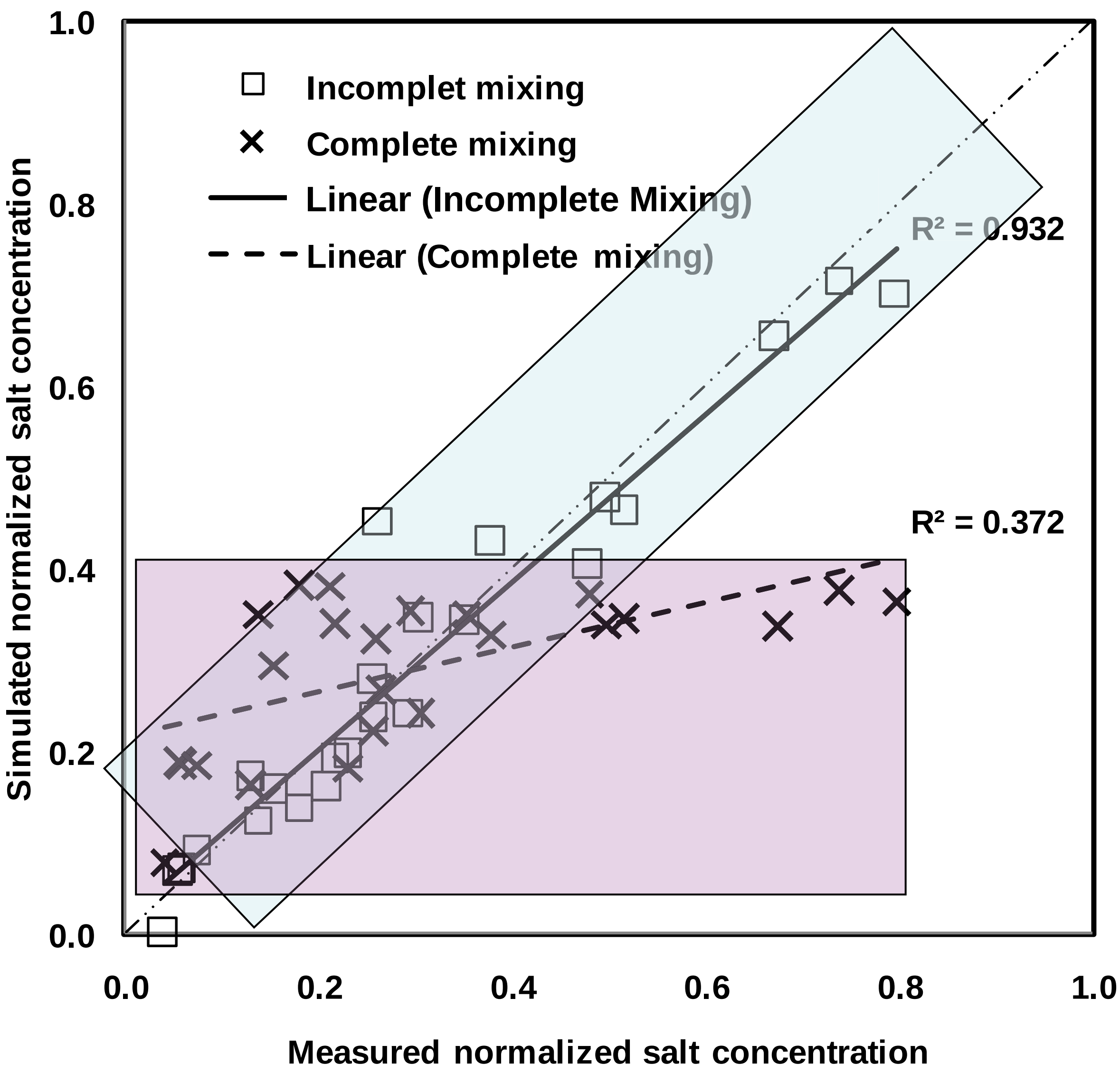


Reynolds Numbers

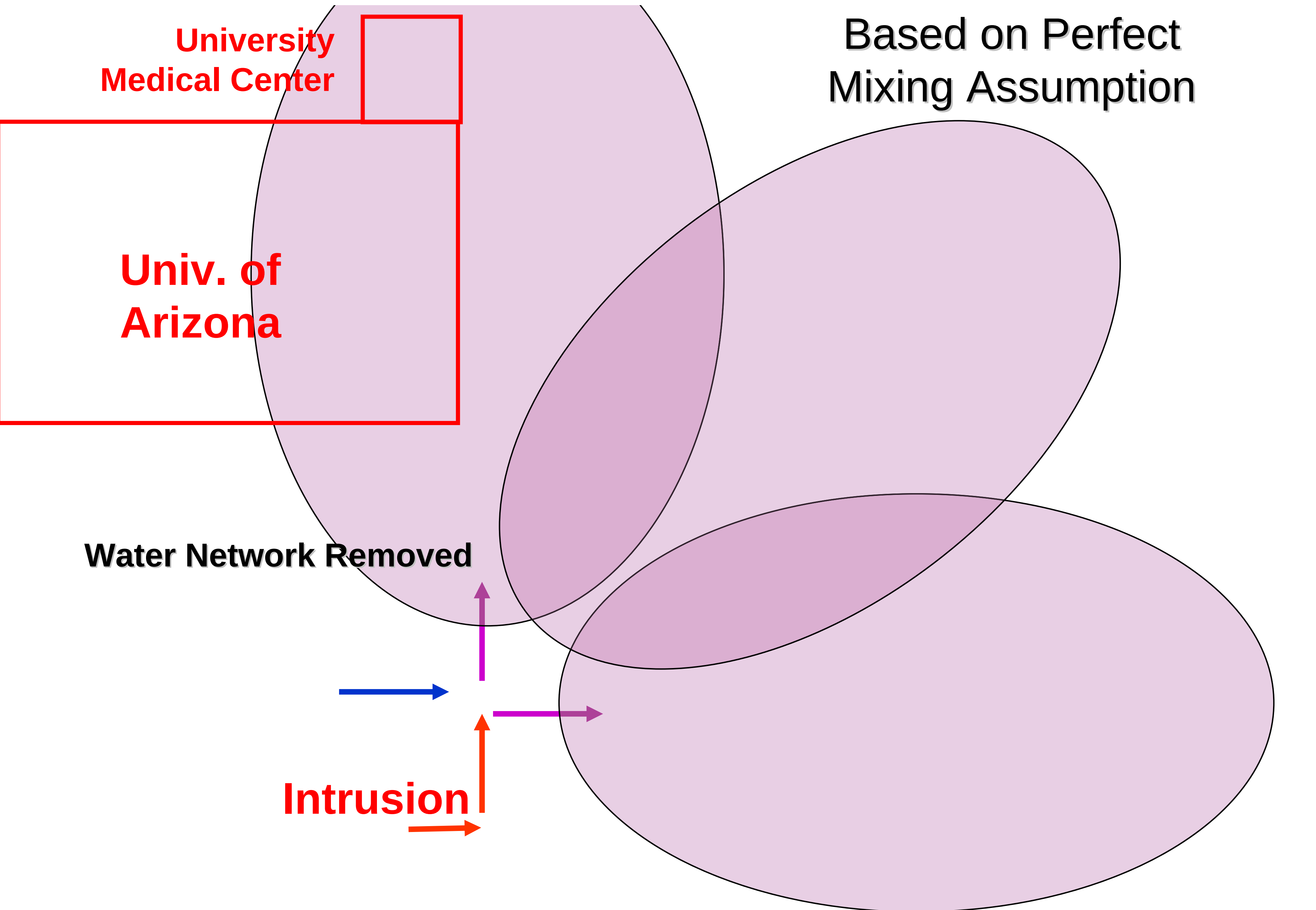
AZRED Water Quality Model vs. Experimental Results

● Sensor Locations

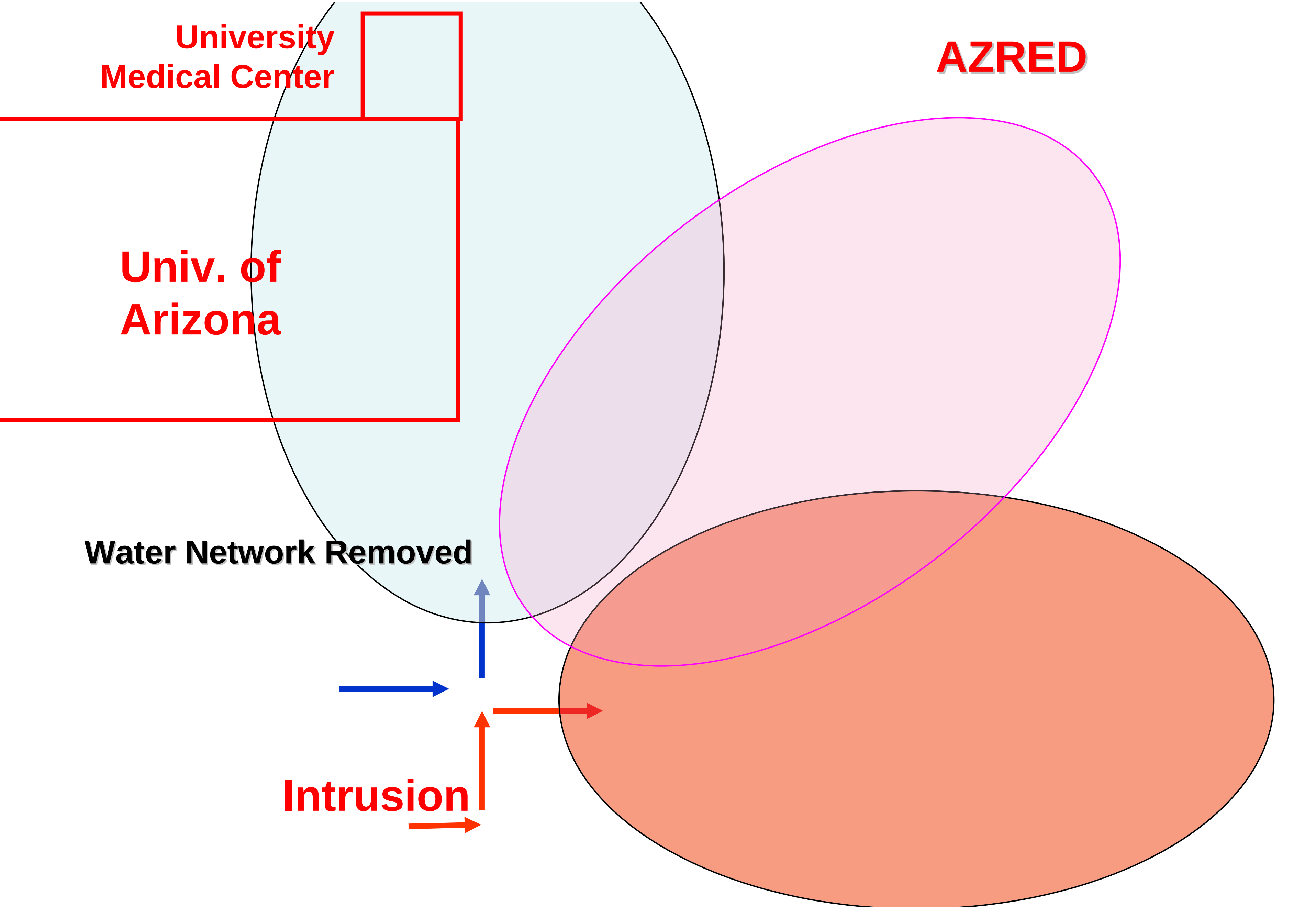




Corresponding Risk Microbial Risk Assessment & Consequences



Corresponding Risk Microbial Risk Assessment & Consequences

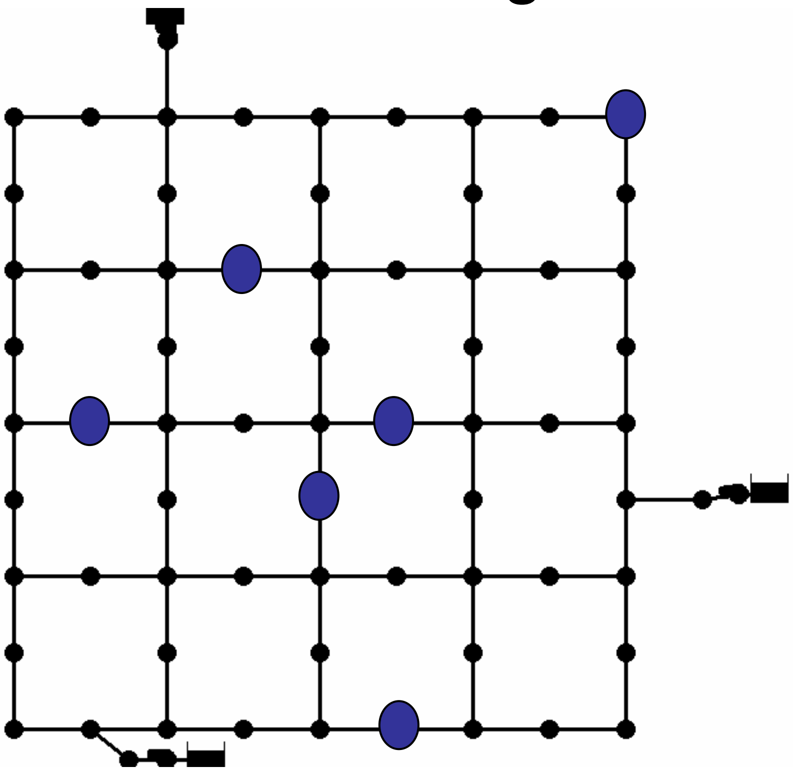


Optimal Sensor Placement

Minimum Hazard Levels (MHL) = 1 mg/L
Level of Services (LOS) = 25 m^3

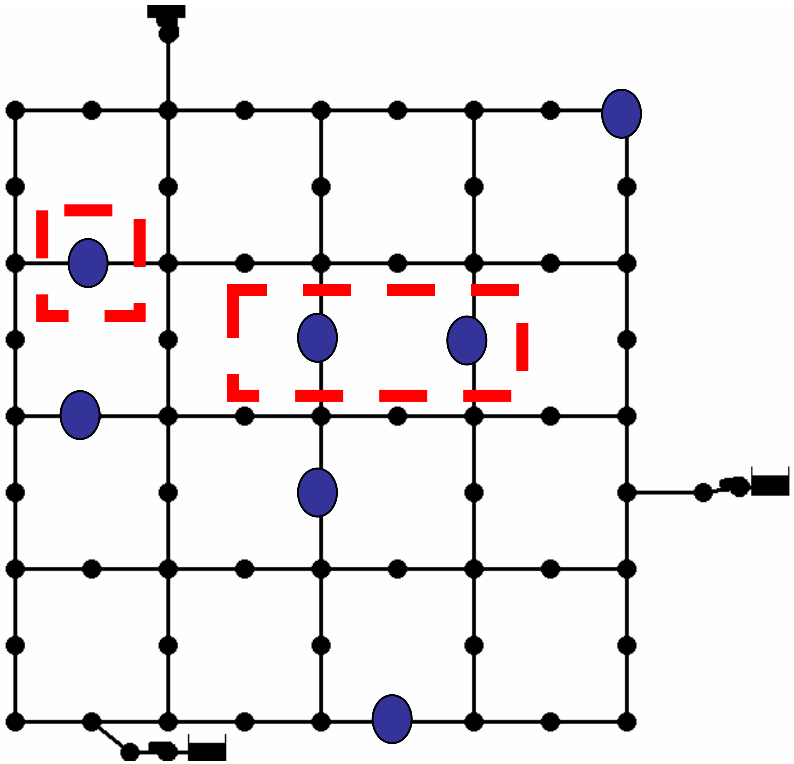
The total number of sensors and their locations change based on AZRED water quality data.

Perfect Mixing



6 sensors

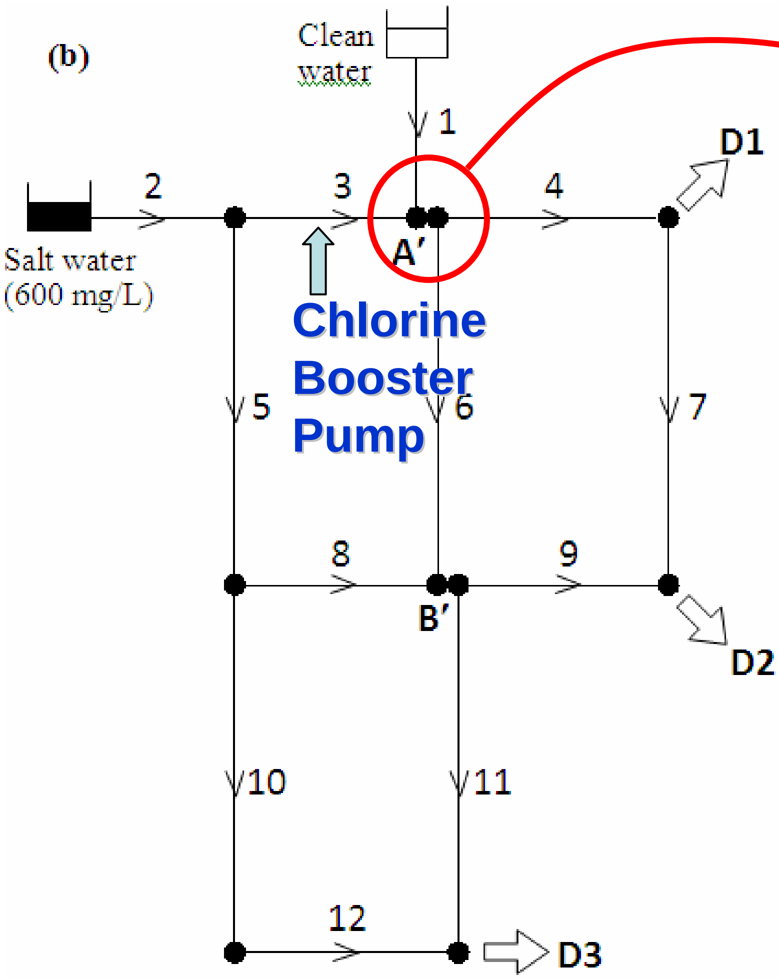
AZRED

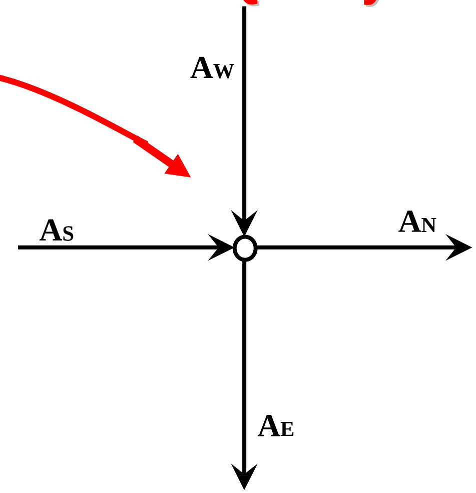


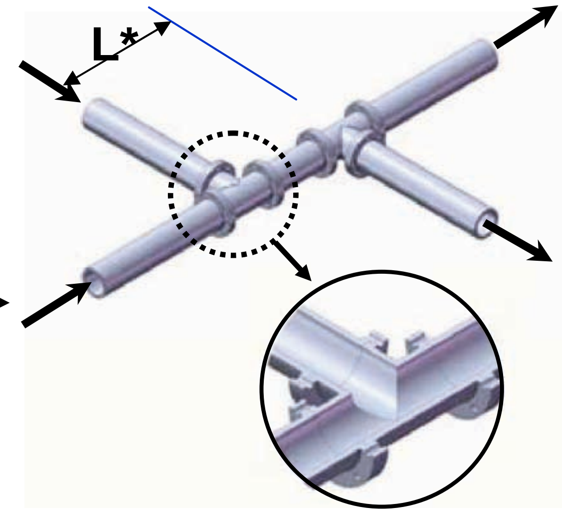
7 sensors

Beyond Water Security: Water Safety and System Design

Water Age = Reliable Surrogate for Water Quality

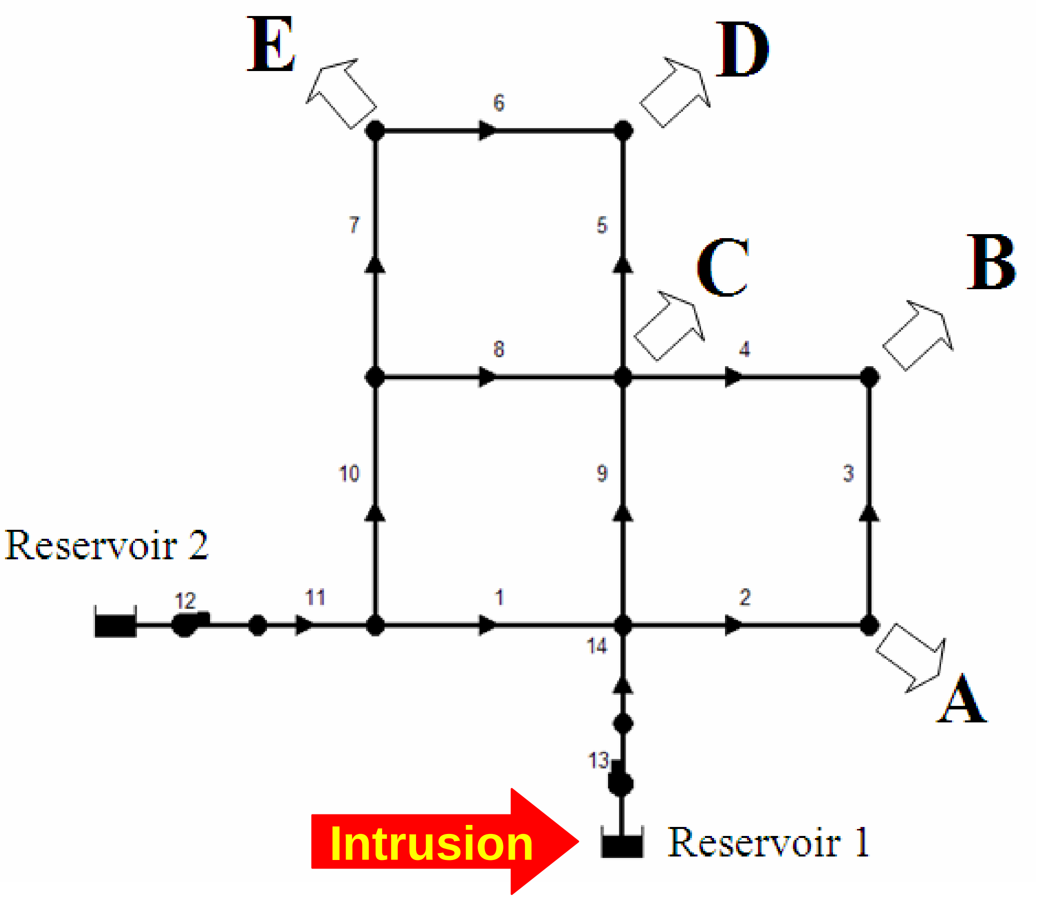


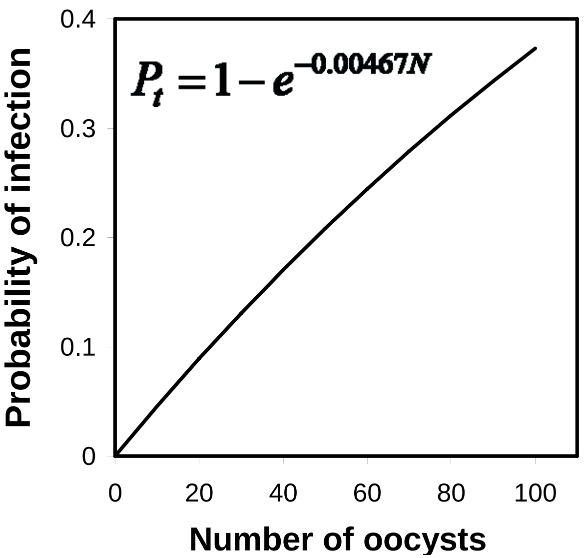




<table>
<tr><th rowspan="2">Assumption</th><th rowspan="2">L*</th><th colspan="4">Water age (hr)</th></tr>
<tr><th>A_S</th><th>A_W</th><th>A_N</th><th>A_E</th></tr>
<tr><td>Complete mixing (A0)</td><td>-</td><td rowspan="5">1.56</td><td rowspan="5">2.97</td><td>2.27</td><td>2.27</td></tr>
<tr><td rowspan="4">Incomplete mixing (A1)</td><td>0.0</td><td>2.76</td><td>1.62</td></tr>
<tr><td>2.5</td><td>2.47</td><td>2.00</td></tr>
<tr><td>5.0</td><td>2.35</td><td>2.15</td></tr>
<tr><td>10.0</td><td>2.30</td><td>2.22</td></tr>
</table>

Microbial Risk Assessment

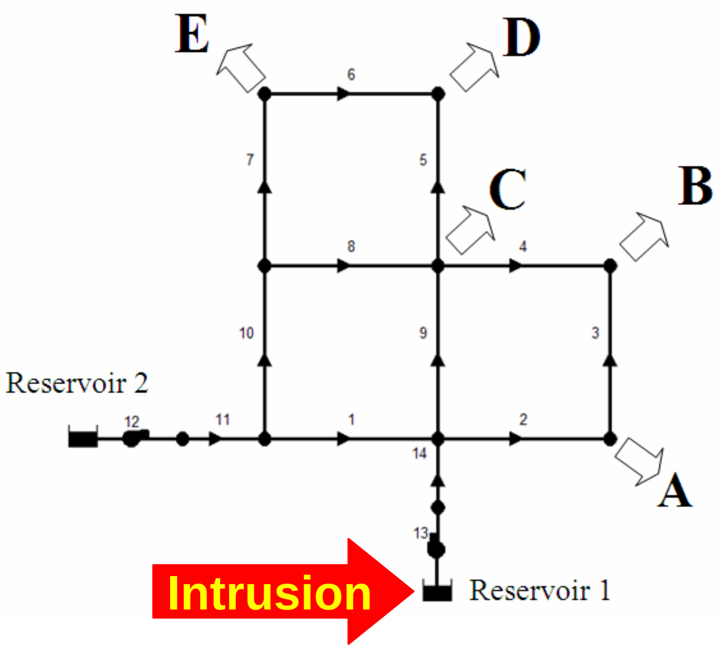


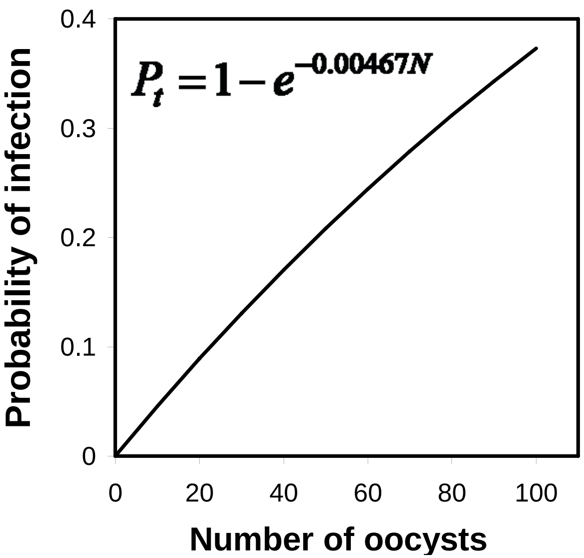


Dose-Response curve, Cryptosporidium (Haas *et al*., 1996)

Based on **'complete' and 'incomplete'** mixing assumptions, **calculate the number of infected people during this event**, when the water consumption of tap water is assumed equal to 2 liters per person per day, and an exposure time of one day.

Significance of Modeling for QMRA

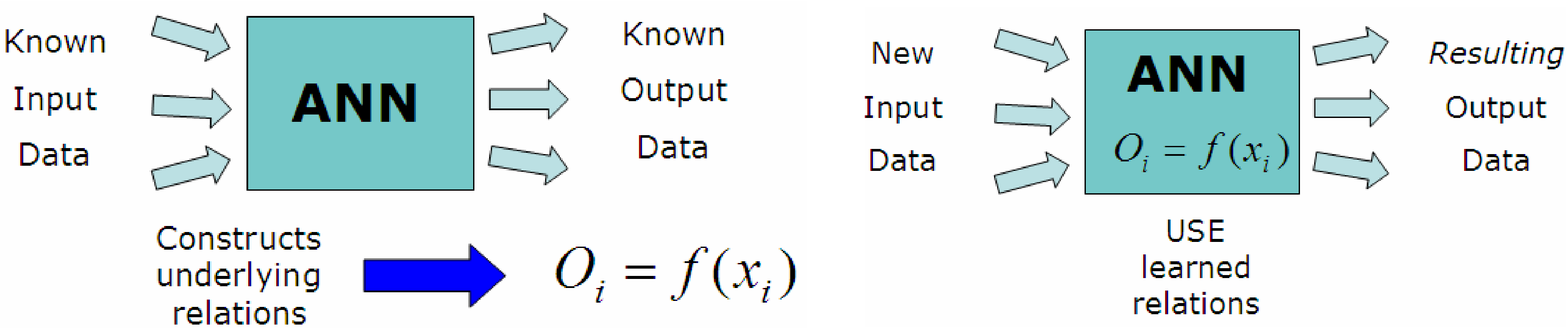




Dose-Response curve, Cryptosporidium (Haas *et al*., 1996)

Neighborhood	Assumption	Oocyst concentration (oocyst/L)	Ingested oocyst per person (dose)	Probability of infection (exponential model)	Infected population
A	Complete Mixing	21.83	44	0.186	186
	Incomplete Mixing	37.35	75	0.294	294
D	Complete Mixing	7.14	14	0.063	158
	Incomplete Mixing	0.50	1	0.005	13

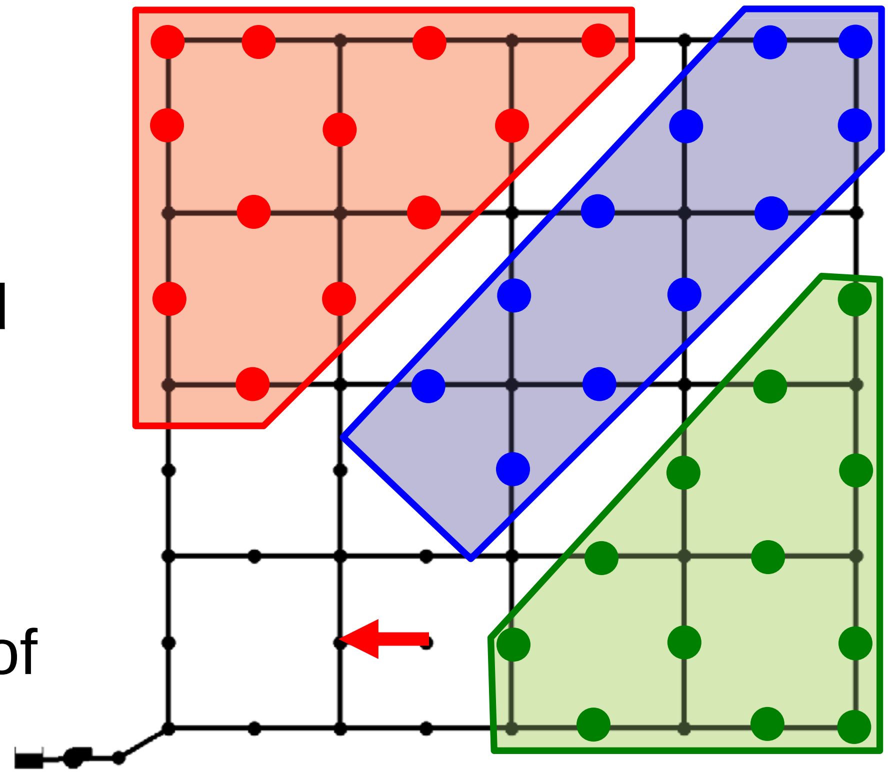
Artificial Neural Networks with AZRED



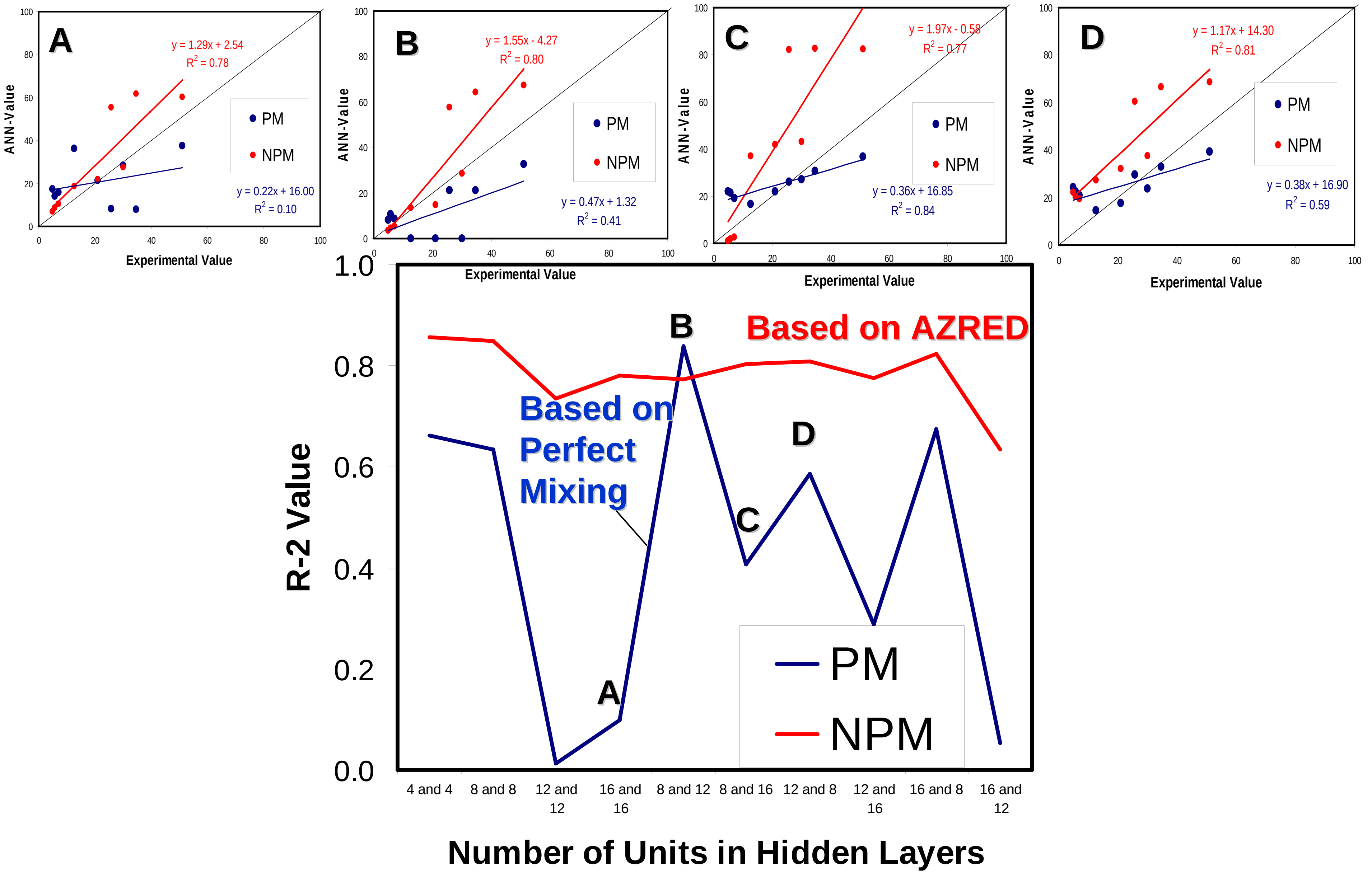
-Three random demands were set, one on each “region”

- AZRED simulations generated input data for ANN training and testing

- ANNs were trained on WQ models with both assumptions of mixing at junctions



ANN vs Experimental Results



The Center for Advancing Microbial Risk Assessment

Research Sponsors and Major Collaborators

Homeland Security

United States Environmental Protection Agency

National Science Foundation
WHERE DISCOVERIES BEGIN

Tucson Water

Sandia National Laboratories