Advances in Microbial Risks Toward Enhancing Water Supply Security

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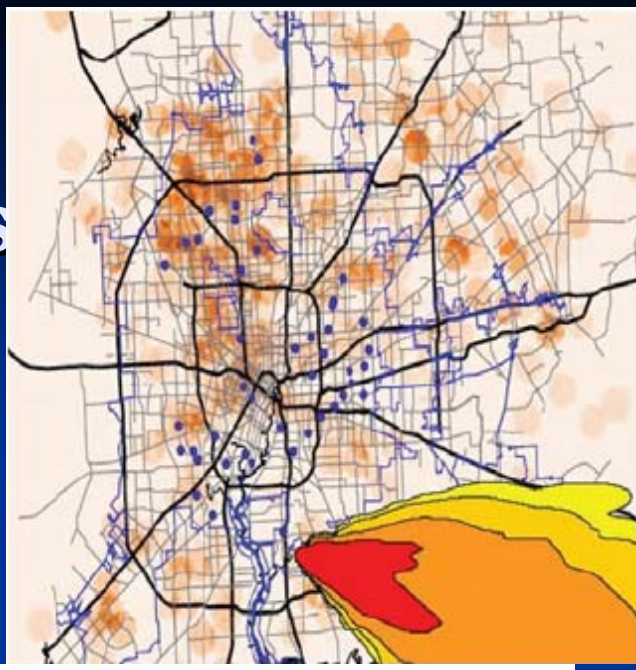
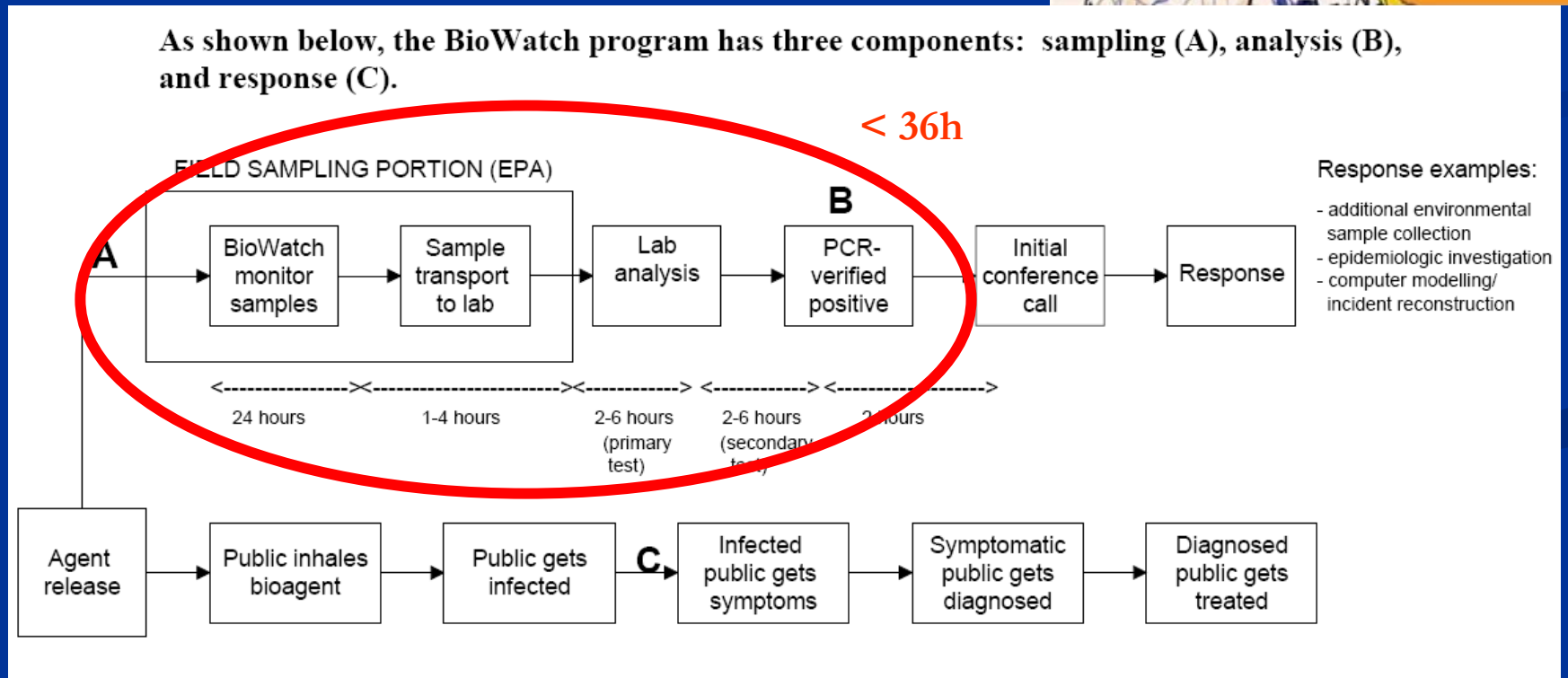
CAMRA
Center for Advancing Microbial Risk Assessment

MICHIGAN STATE UNIVERSITY

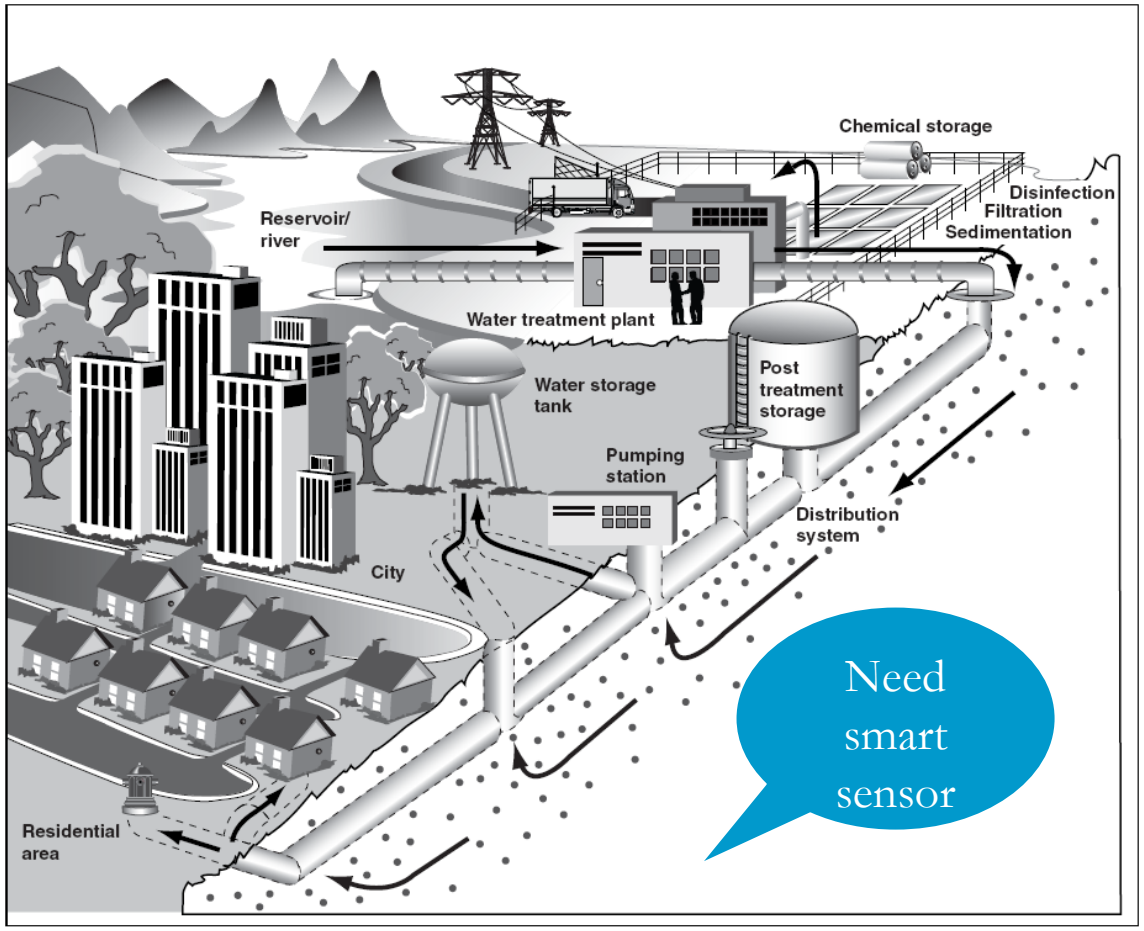
Home Land Security Issues



- BioWatch
  - Outdoor air
  - Indoor air



Home Land Security Issues



Source: GAO.

Structural Security

Home Land Security Issues

- Water Quality:
  - Biological agents
  - Harmful concentrations
  - Real-time monitoring
- Response Plans:
  - Testing → Communication → Remediation.

What is Risk in Water Security

- Risk is the likelihood of (identified?) hazards causing harm in exposed populations in a specified time frame including the severity of the consequences.
  - exposure* hazard
    chance*hazard*exposure*consequence

- EPA has suggested that 1/10,000 infection annually is an appropriate level of safety for drinking water.
  - What is an acceptable risk of fatality caused by a bioterrorism attack?

Contents: Methodology for Risk Assessment (NAS)

- Quantitative Microbial Risk Assessment (QMRA)
- Hazard Identification
  - Biological Agent Concern (BAC)
- Dose-Response Assessment
  - Species
  - Age
- Exposure Assessment
  - New Monitoring Tools
  - Water Distribution Transportation Model
- Risk Characterization & Management
- Summary

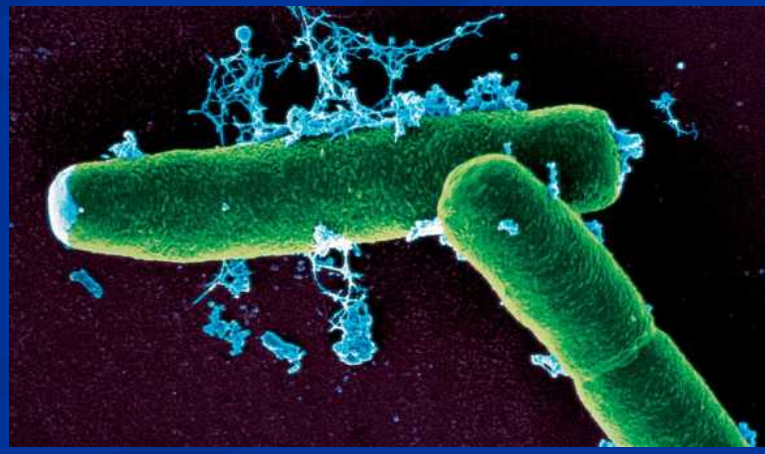
Hazard Identification

What is Bioterrorism?

- A bioterrorism attack is the intentional release of viruses, bacteria, or other germs (agents) used to cause illness or death in people
- Biological agents can be spread through the air, through water, or in food. Terrorists may use biological agents because they can be extremely difficult to detect and do not cause illness for several hours to several days.
  - Some bioterrorism agents, e.g. smallpox virus, can be spread from person to person
  - Some, e.g. anthrax, can not.

Bioterrorism Agent Category A

- Easily spread or transmitted from person to person
- High death rates
- Public panic and social disruption
- Special action for public health preparedness
  - Anthrax (*Bacillus anthracis*)
  - Botulism (*Clostridium botulinum* toxin)
  - Plague (*Yersinia pestis*)
  - Smallpox (Variola major)
  - Tularemia (*Francisella tularensis*)
  - Viral hemorrhagic fevers,
    - e.g. Lassa, Dengue, Ebola



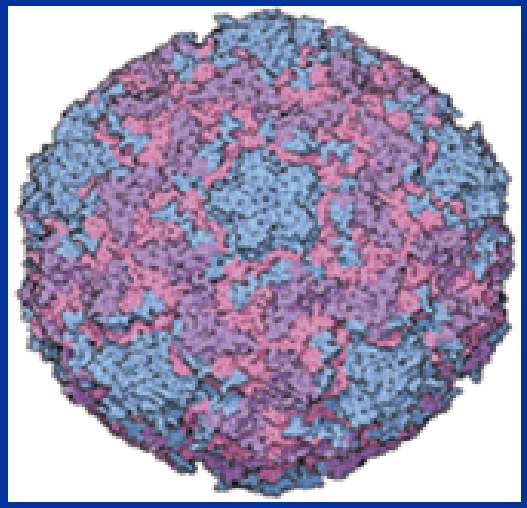
B. anthracis

Bioterrorism Agent Category B

- Moderately easy to spread
- Moderate illness rates and low death dates
- Enhancements of CDC's lab capacity and disease monitoring
  - Brucellosis (*Brucella* species)
  - Epsilon toxin of *Clostridium perfringens*
  - Glanders (*Burkholderia mallei*)
  - Melioidosis (*Burkholderia pseudomallei*)
  - Psittacosis (*Chlamydia psittaci*)
  - Q fever (*Coxiella burnetii*)
  - Ricin toxin from *Ricinus communis* (castor beans)
  - Staphylococcal enterotoxin B
  - Typhus fever (*Rickettsia prowazekii*)
  - Viral encephalitis (alphaviruses [e.g., Venezuelan equine encephalitis, eastern equine encephalitis, western equine encephalitis])

Bioterrorism Agent Category B

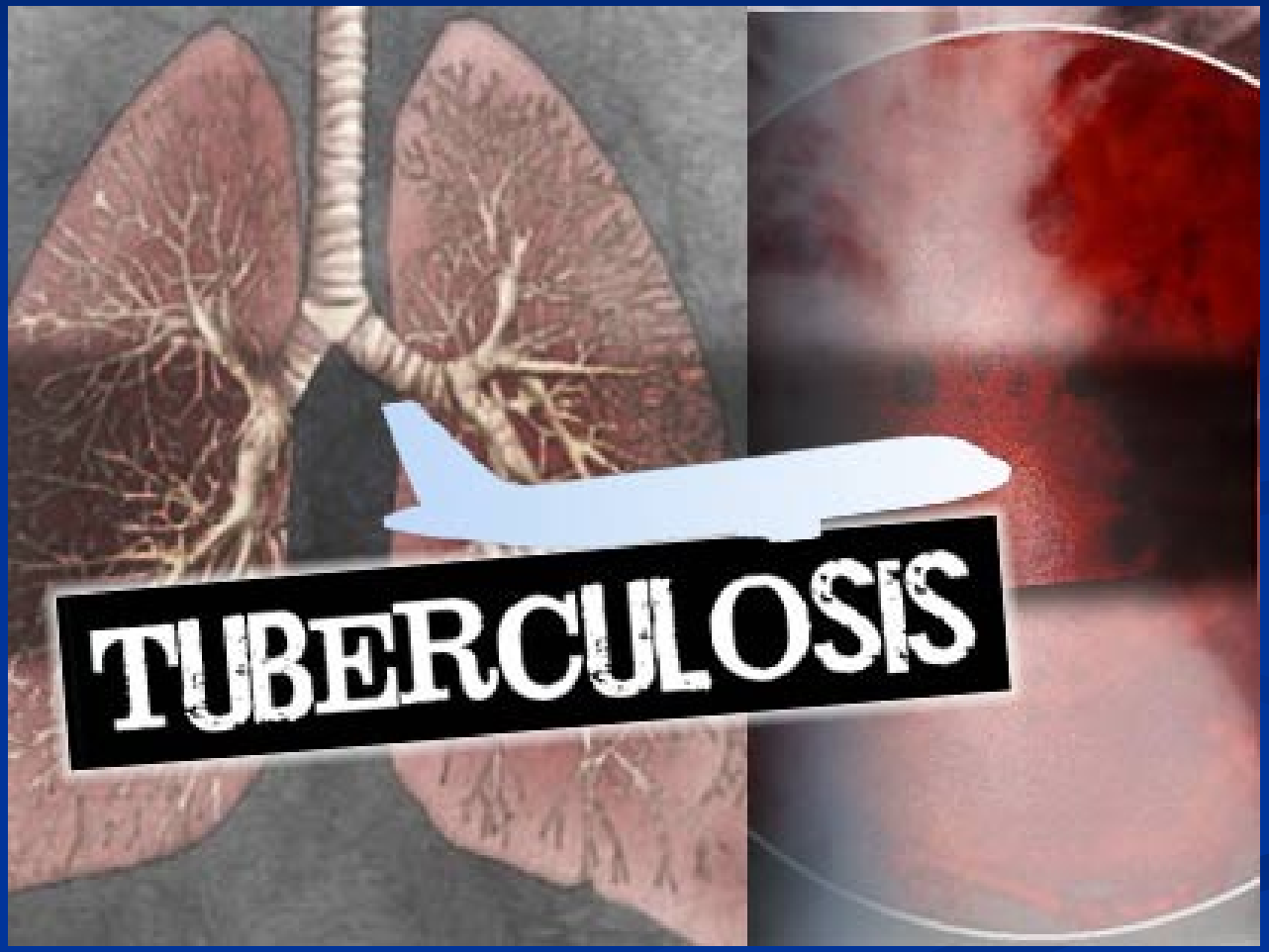
- Food safety threats
  - e.g., *Salmonella* species, *Escherichia coli* O157:H7, *Shigella*)
- Water safety threats
  - e.g., *Vibrio cholerae*, *Cryptosporidium parvum*)



Bioterrorism Agent Category C

- Emerging pathogens that could be engineered for mass spread in the future
- Easily available
- Easily produced and spread
- Potential for high mobility and mortality
  - Nipah virus
  - Hantavirus
  - Severe acute respiratory syndrome-associated coronavirus (SARS-CoV)
  - Influenza
  - Multi-drug resistant TB

Bioterrorism Agent
Category C



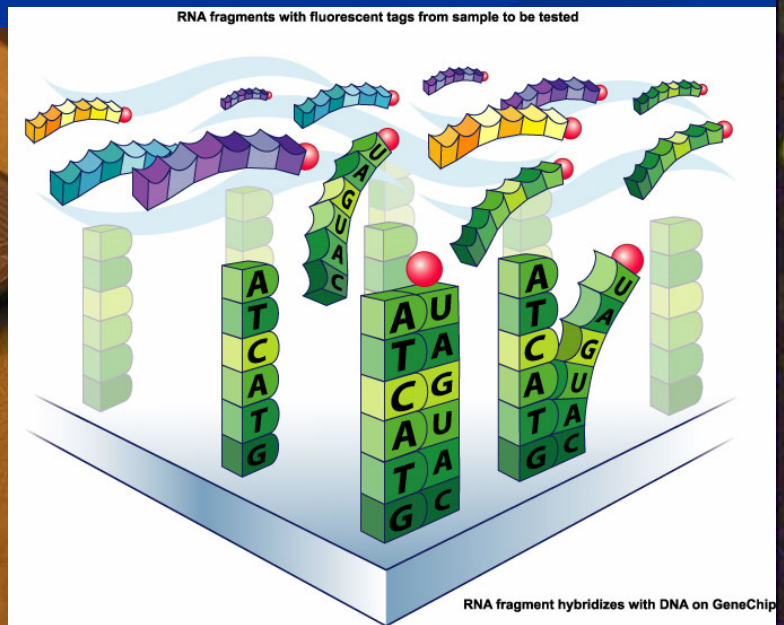
Tools for Hazard ID for Water

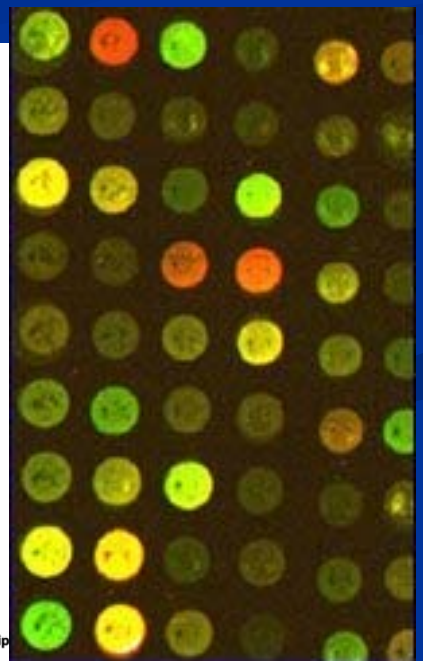
- New microbial contaminants in water have been identified as a risk for waterborne disease. Known as the Contaminant Candidate List (CCL), these microorganisms will be addressed based on health impacts and occurrence in water.
- Molecular tools are providing insight into characterization and detection of both new pathogens (CCL e.g. *Helicobacter*) and our classical pathogens (e.g. *Cryptosporidium*).

Microarrays

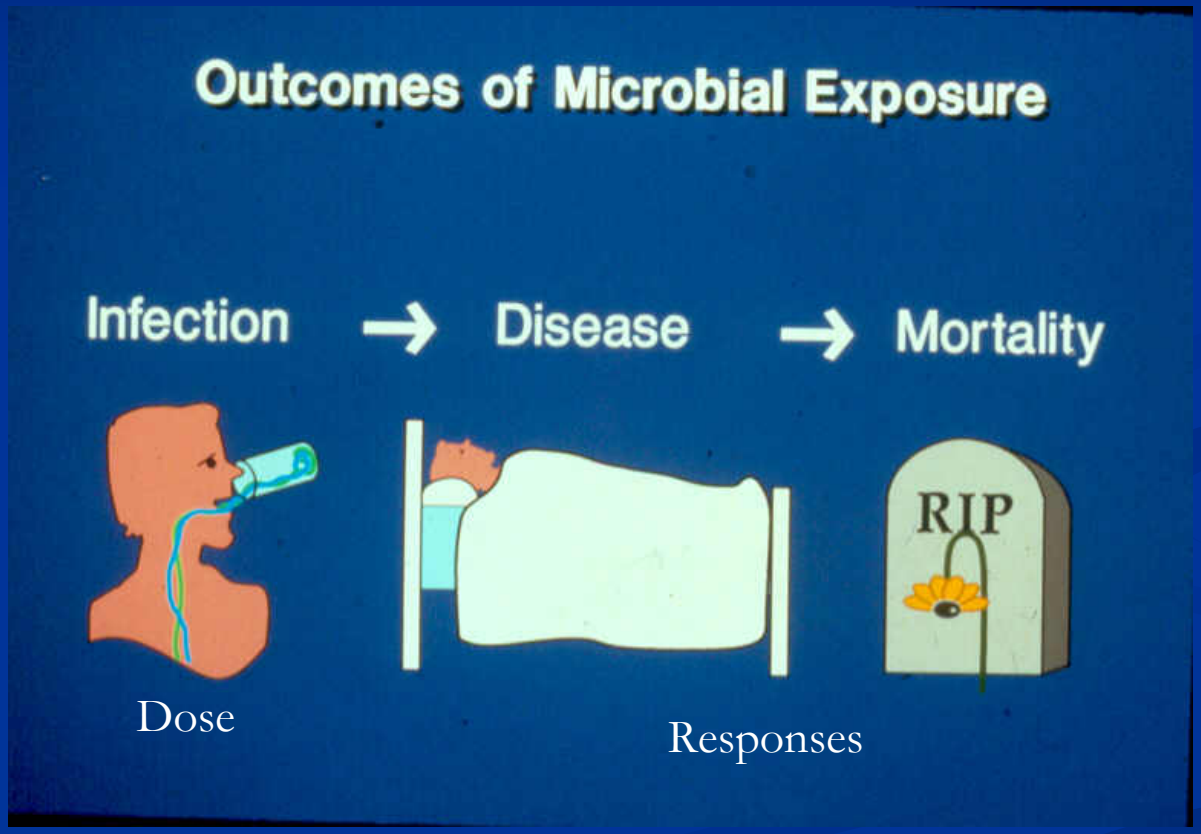
- Chip platform with synthesized genetic sequences
- Hybridization detection
- Multiple pathogens

Dr. Syed Hashsham
Michigan State University





Dose-Response Assessment



$Pi = 1 - \exp(-r \times dose)$

Probability of Infection
Best Fit Models

- Exponential Model

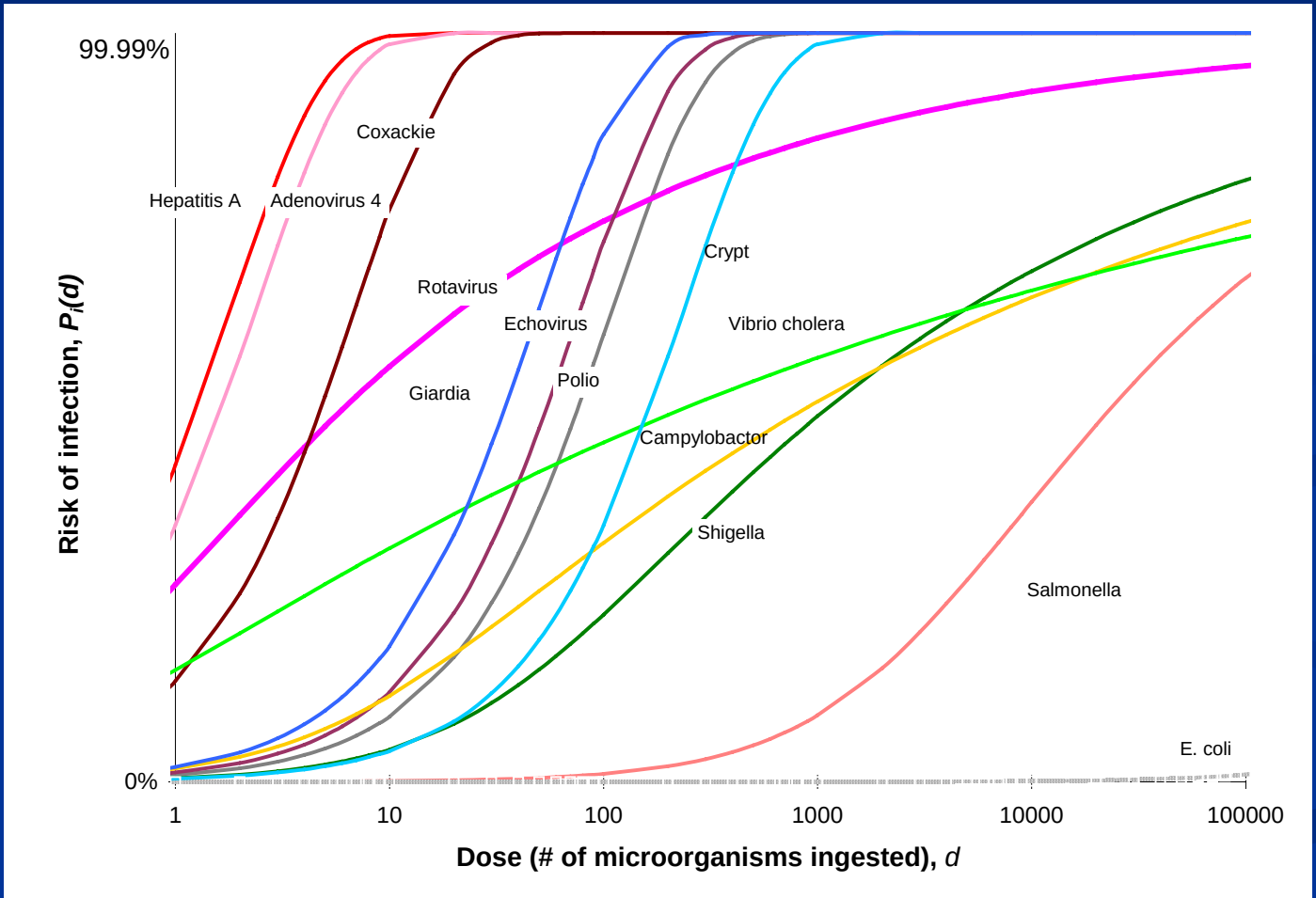
$$Pi = 1 - \exp(-r \times dose)$$

- Beta-Poisson Model

$$Pi = 1 - \left[1 + \frac{dose}{N_{50}}\left(2^{1/\alpha} - 1\right)\right]^{-\alpha}$$

- Major Waterborne Pathogens
  - Haas et al. 1999. Quantitative Microbial Risk Assessment

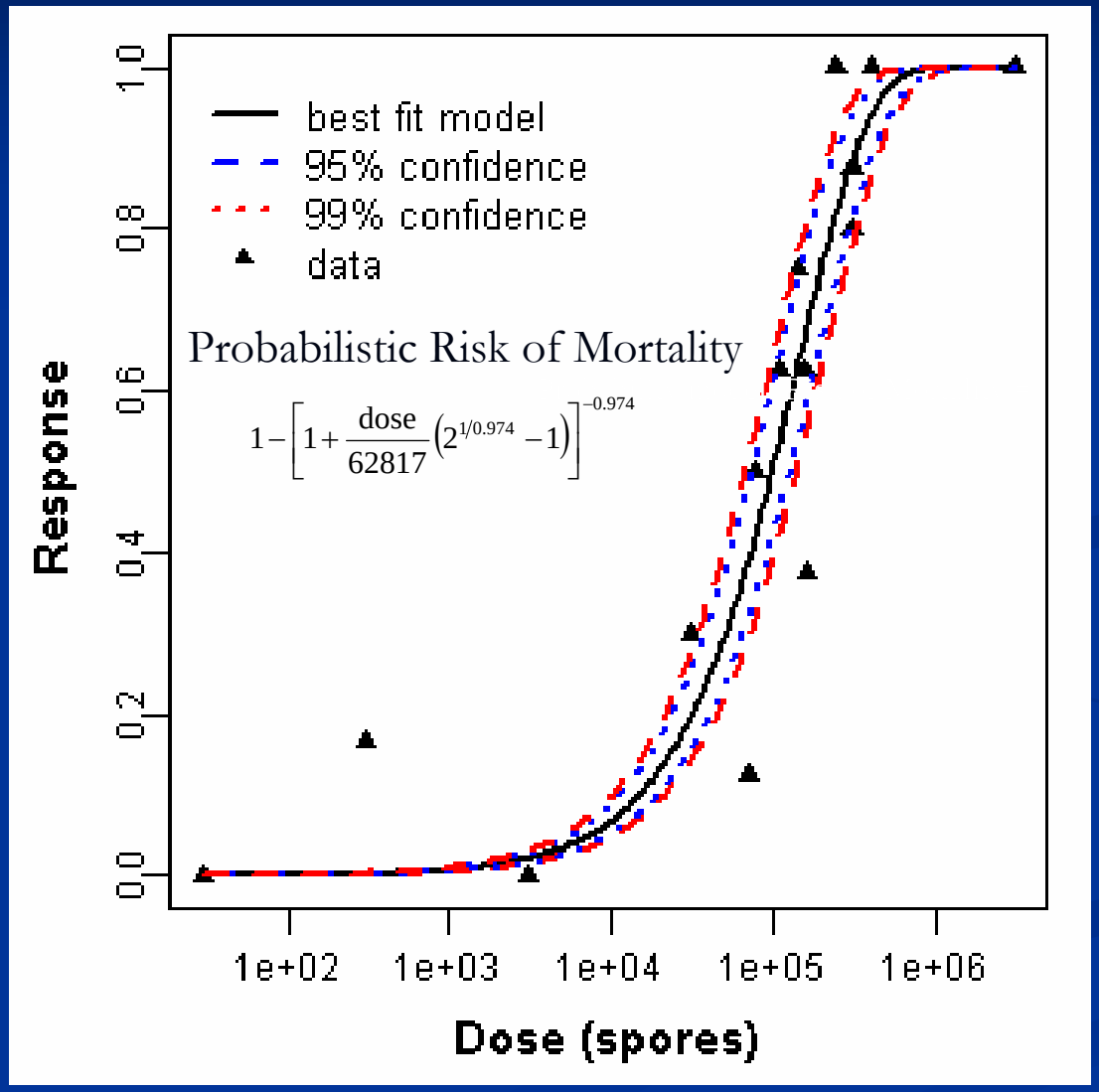
Waterborne Pathogens



Building Dose-Response Models

- Determining the applicability of previously used dose-response models to the Category A bioterrorist agents via the oral, inhalation and dermal routes.
- Assessing the validity of animal to human extrapolation of dose-response.
- Assessing the influence of modifying factors (e.g., host age) on dose-response.

Anthrax: Dose-Response (fatal)

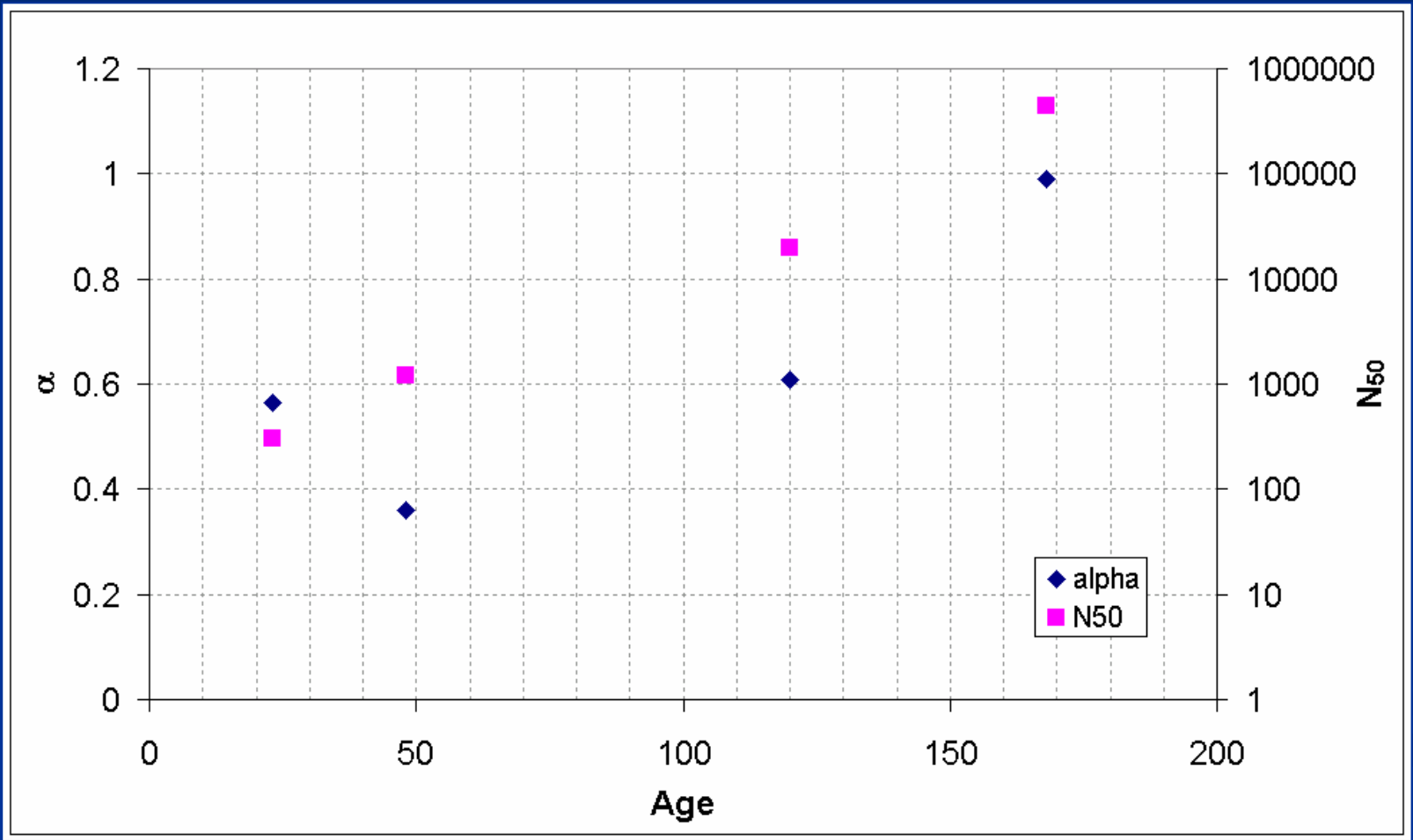


Variety of animal data sets can be combined

Rhesus Monkeys Pooled with Guinea Pigs

Dr. Charles Haas, Drexel University

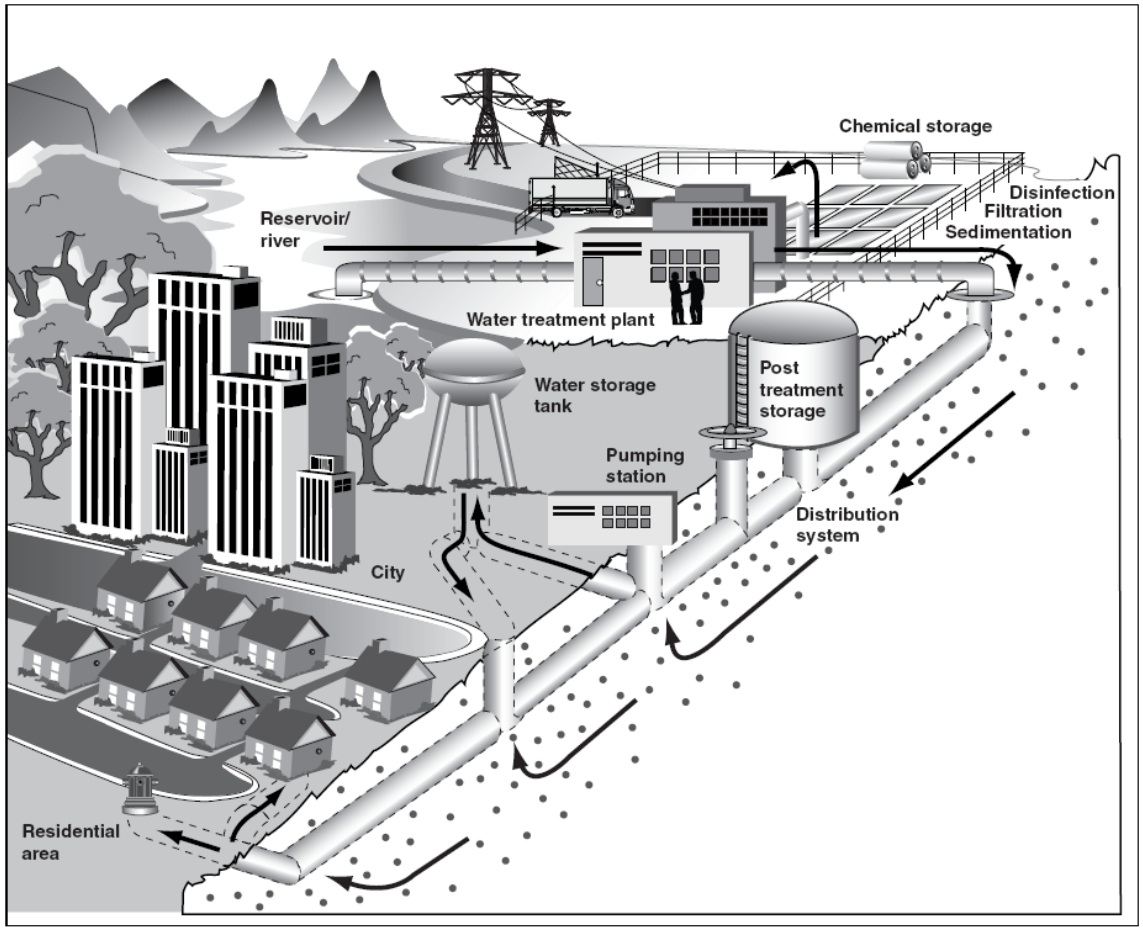
Smallpox: Dose-Response



Lower Median infectivity
For the Young

Dr. Charles Haas,
Drexel University

Exposure Assessment



Source: GAO.

Factors Important in Assessing Exposure

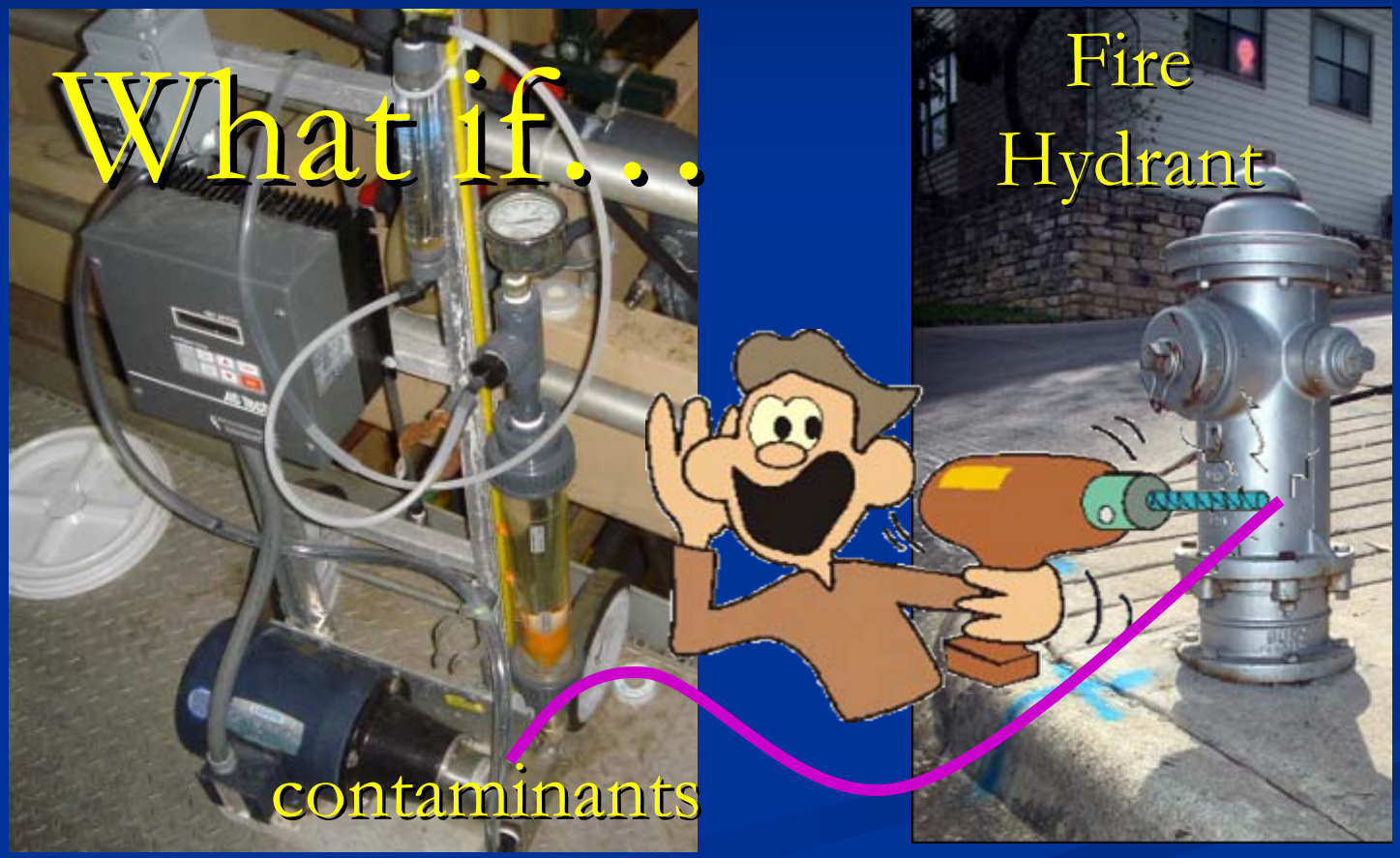
- Route of Exposures
  - Oral, Inhalation, Dermal
- Degree of exposures
  - Liters of water ingested
- Number of exposures
  - How many times in a day, month, year
- Concentrations
  - Spatial and Temporal Variations
  - Fate & Transport

Exposure Assessment and Risk Characterization

- Exposure and levels of contamination are the most important aspect for providing input to risk characterization.
- Need new methods for better assessment of non-cultivatible viruses, parasites and bacteria.
- Need better monitoring data, better transport models.

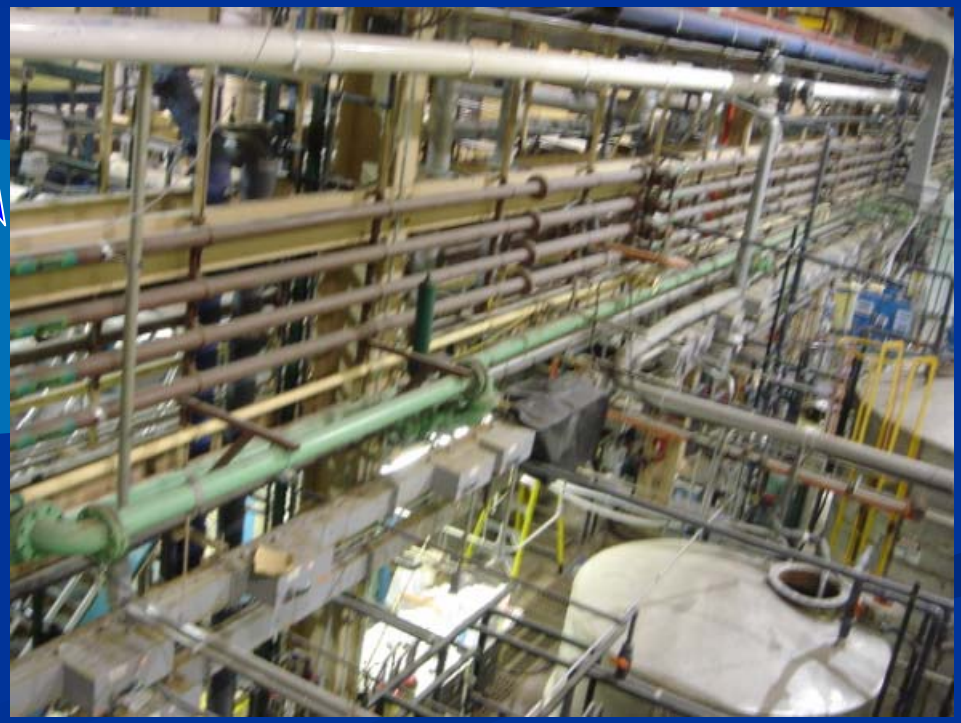
- Essential for Good Risk Management Decisions

Water Distribution Transportation Model

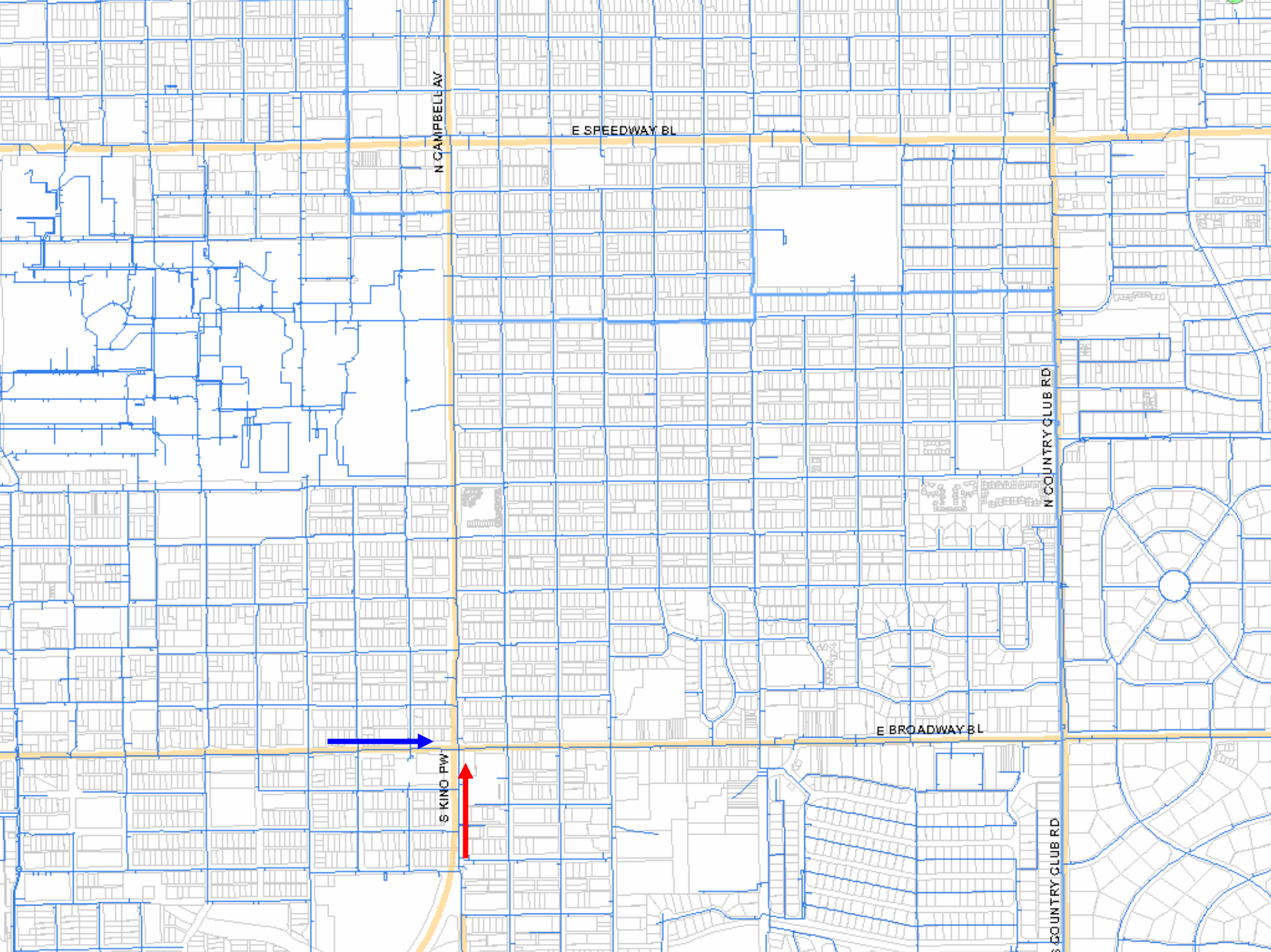


without backflow prevention devices

Serious Engineering and Sensor Research

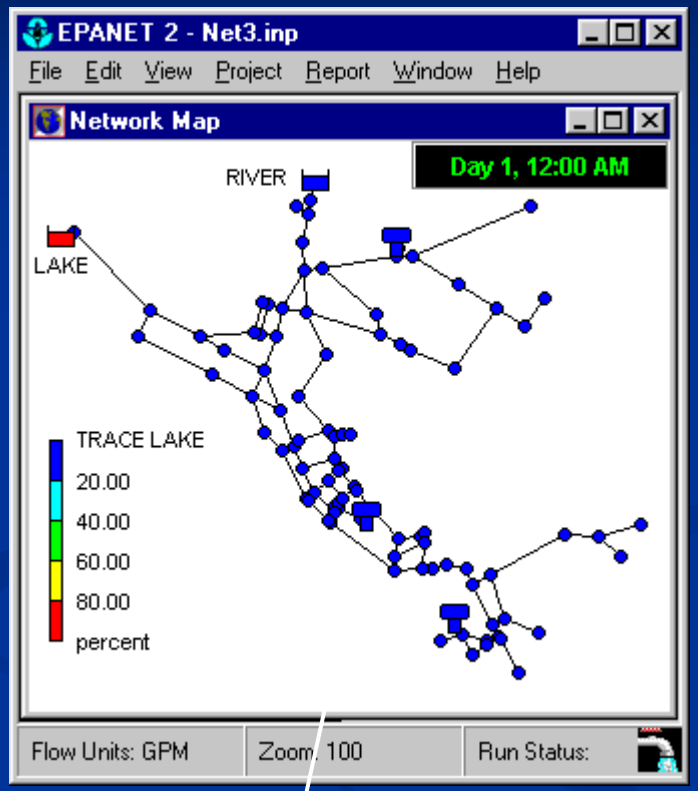


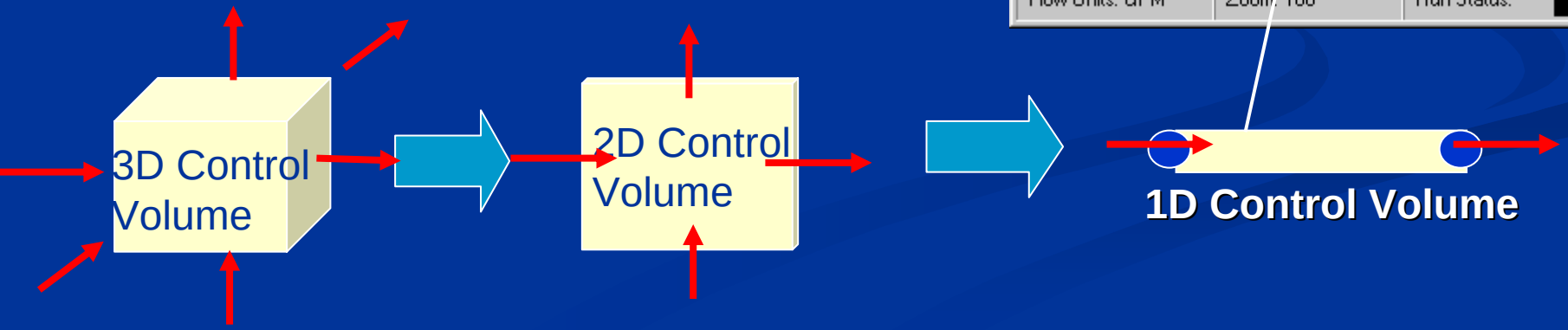
EPA Lab in Cincinnati


N CAMPBELL AV
E SPEEDWAY BL
N COUNTRY CLUB RD
E BROADWAY BL
S KINO PW
S COUNTRY CLUB RD

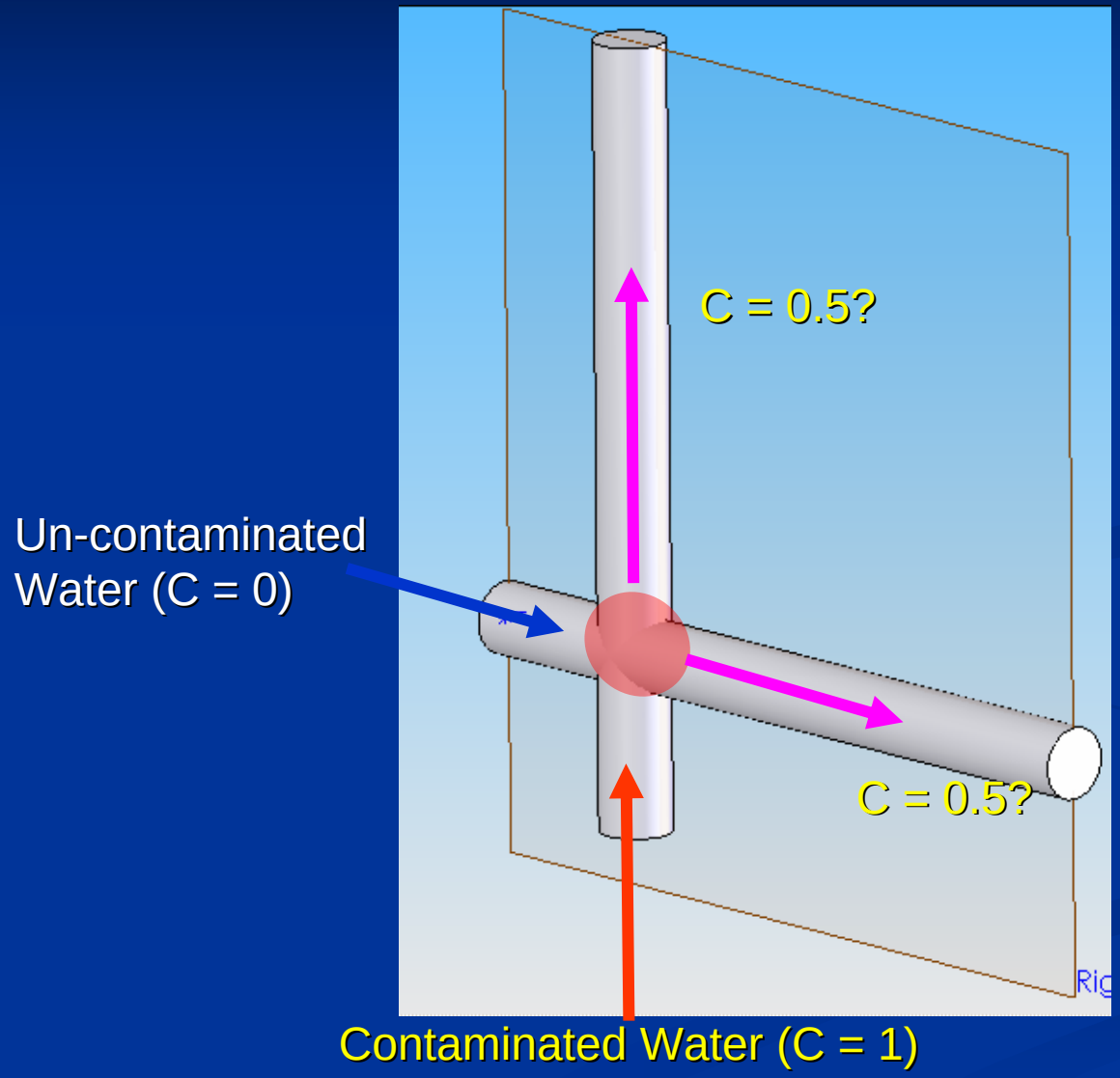
EPANET

EPANET models the hydraulic and water quality behavior of water distribution piping systems. EPANET is a 'free & open source' Windows program written in C & Delphi programming languages that performs extended period simulation of hydraulic and water-quality behavior within pressurized pipe networks. A network can consist of pipes, nodes (pipe junctions), pumps, valves and storage tanks or reservoirs.

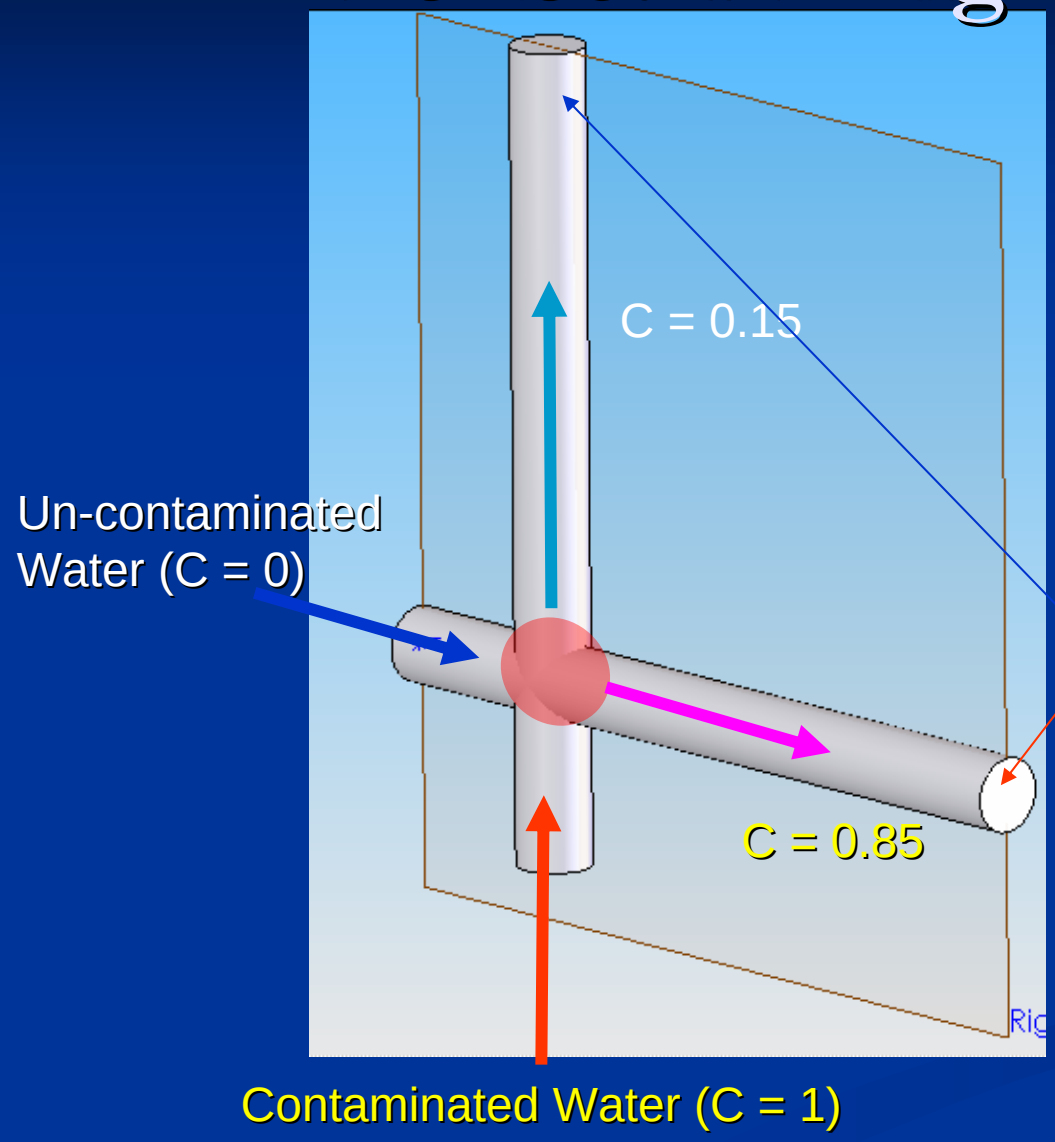


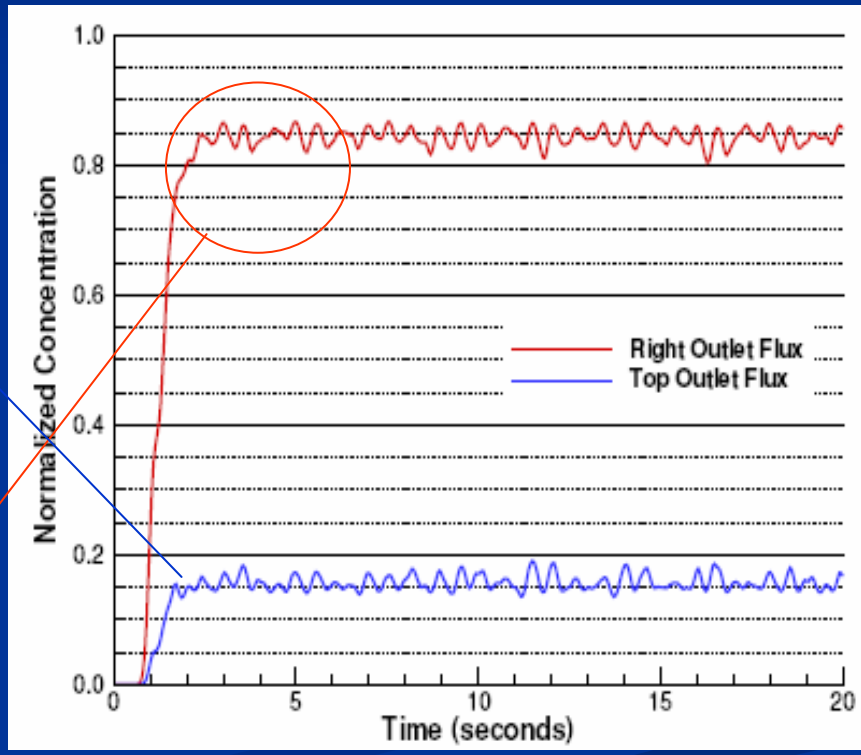


Perfect Mixing Assumption



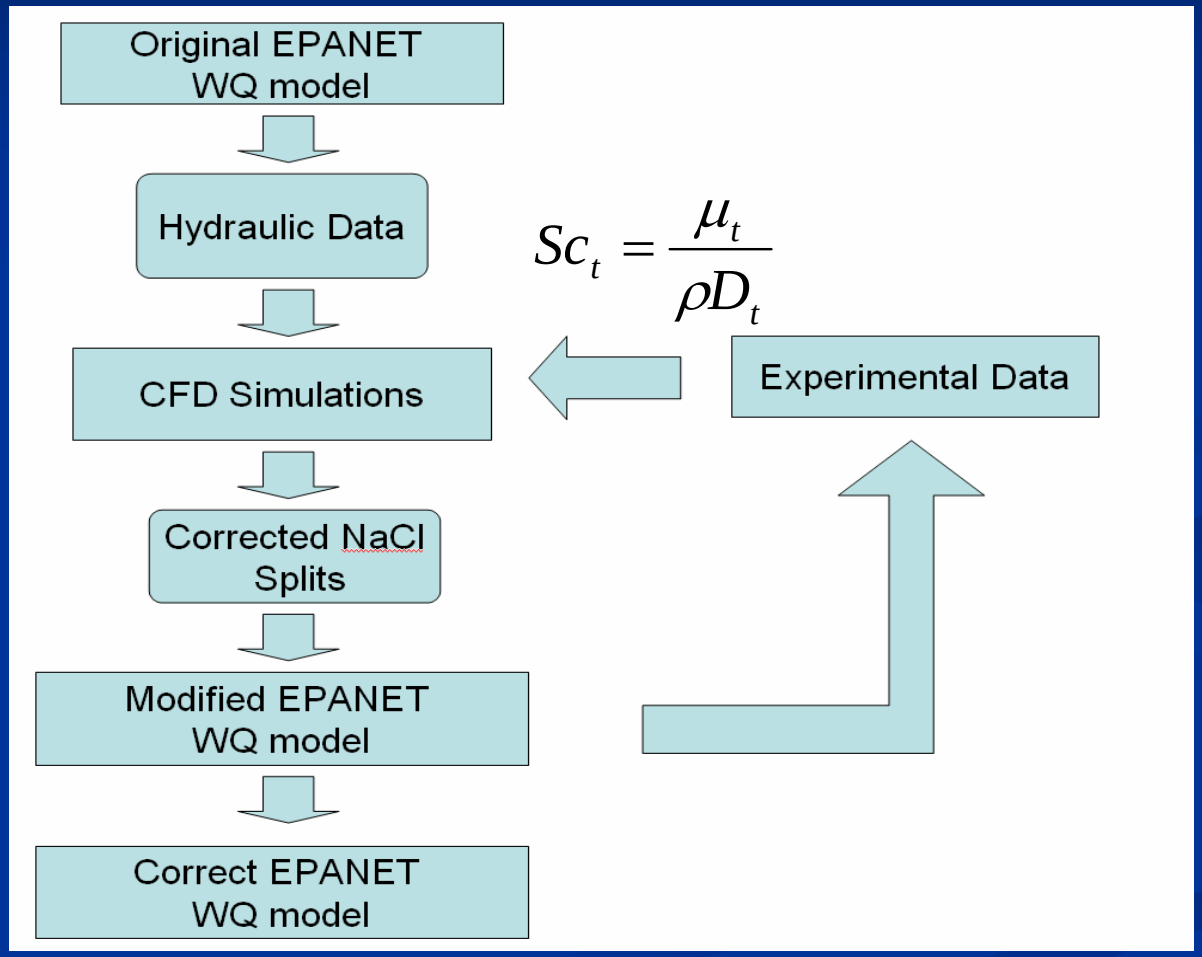
Perfect Mixing Assumption





Courtesy of Sandia National Laboratories

Improving Transport Model (EPANET)

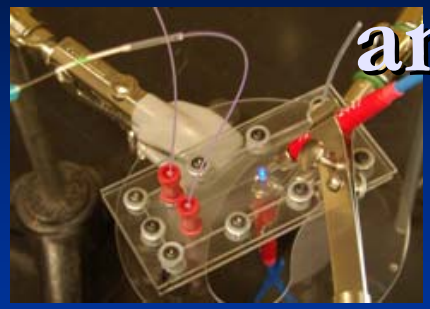


$$Sc_t = \frac{\mu_t}{\rho D_t}$$

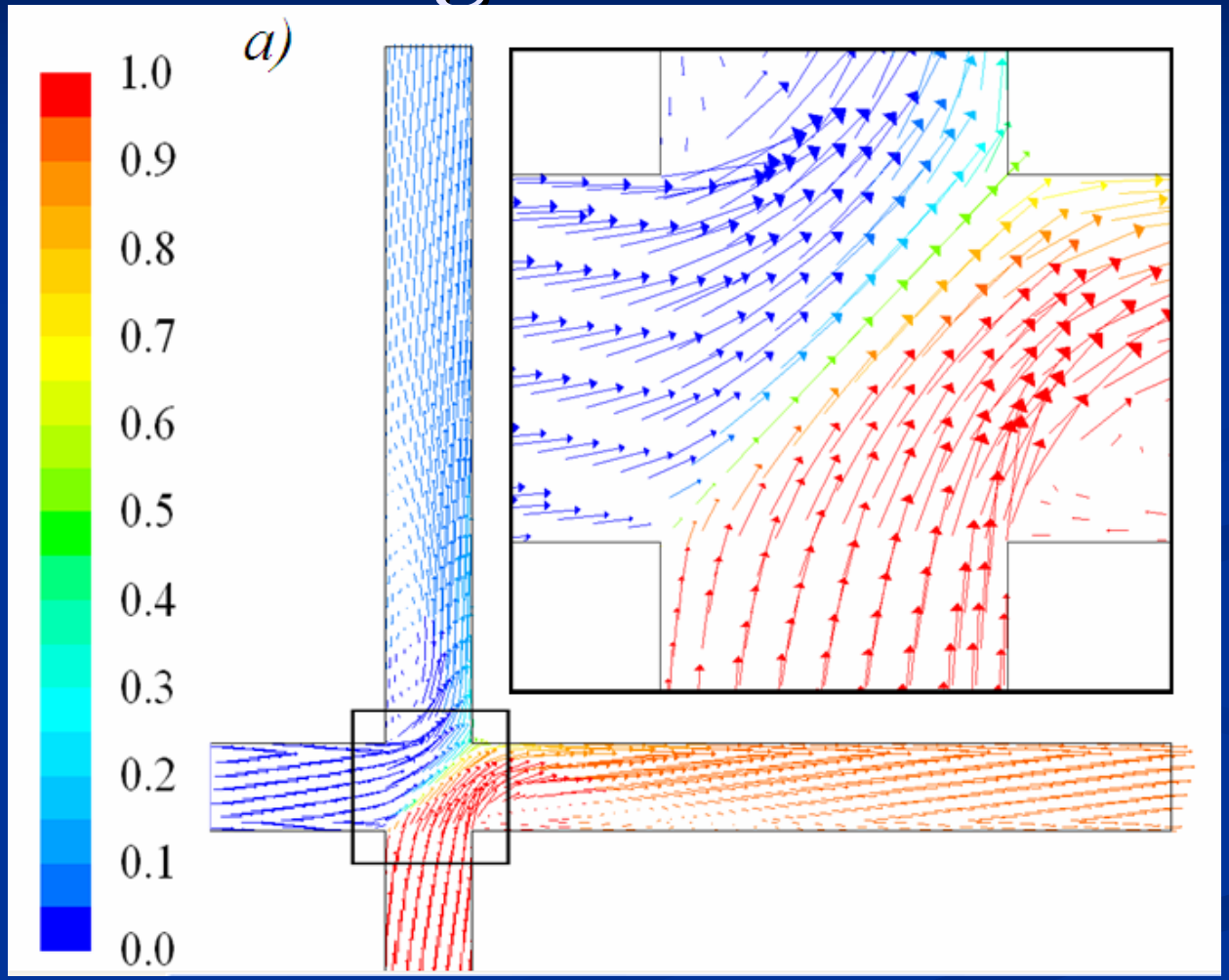
Dr. Christopher Choi
University of Arizona

Water Distribution Systems Laboratory

Test bed for Bio-Sensors and Event Monitors



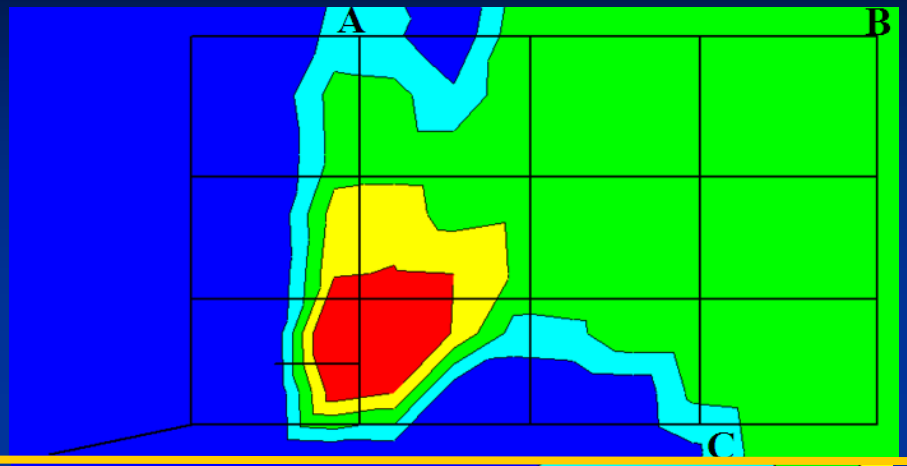
Mixing patterns along the interface



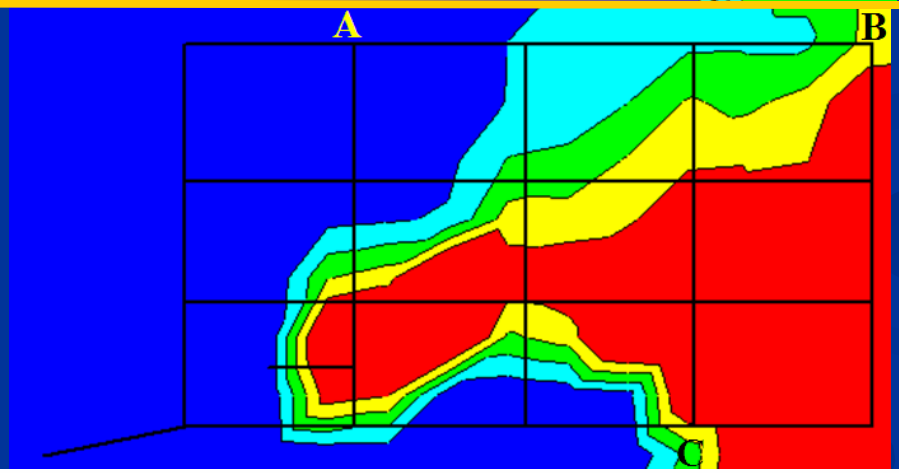
a) Velocity vectors and b) Dimensionless NaCl Concentration contours at a cross junction, when ReS = ReW = ReE = ReN = 44,000 (ReS/W = 1, ReE/N=1), and Sct = 0.1875

Updating Model

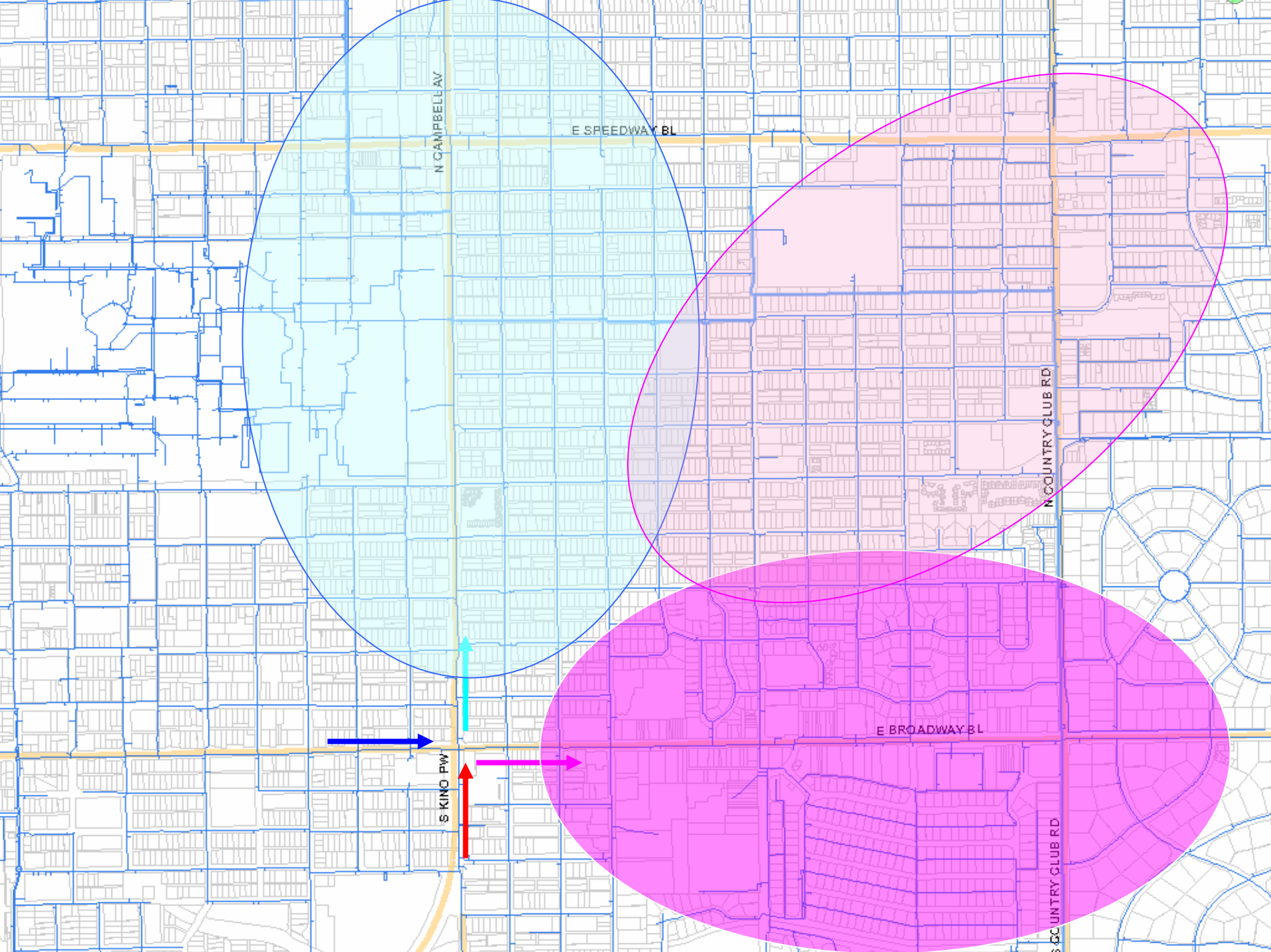
Current WDS Model



Improved WDS Model



		A	B	C
NaCl concentration (mg/L)	Current	0.2699	0.5283	0.1489
	Modified	0.0303	0.6593	0.3598
NaCl mass rate (mg/min)	Current	102.02	199.70	56.28
	Modified	11.45	249.22	136.00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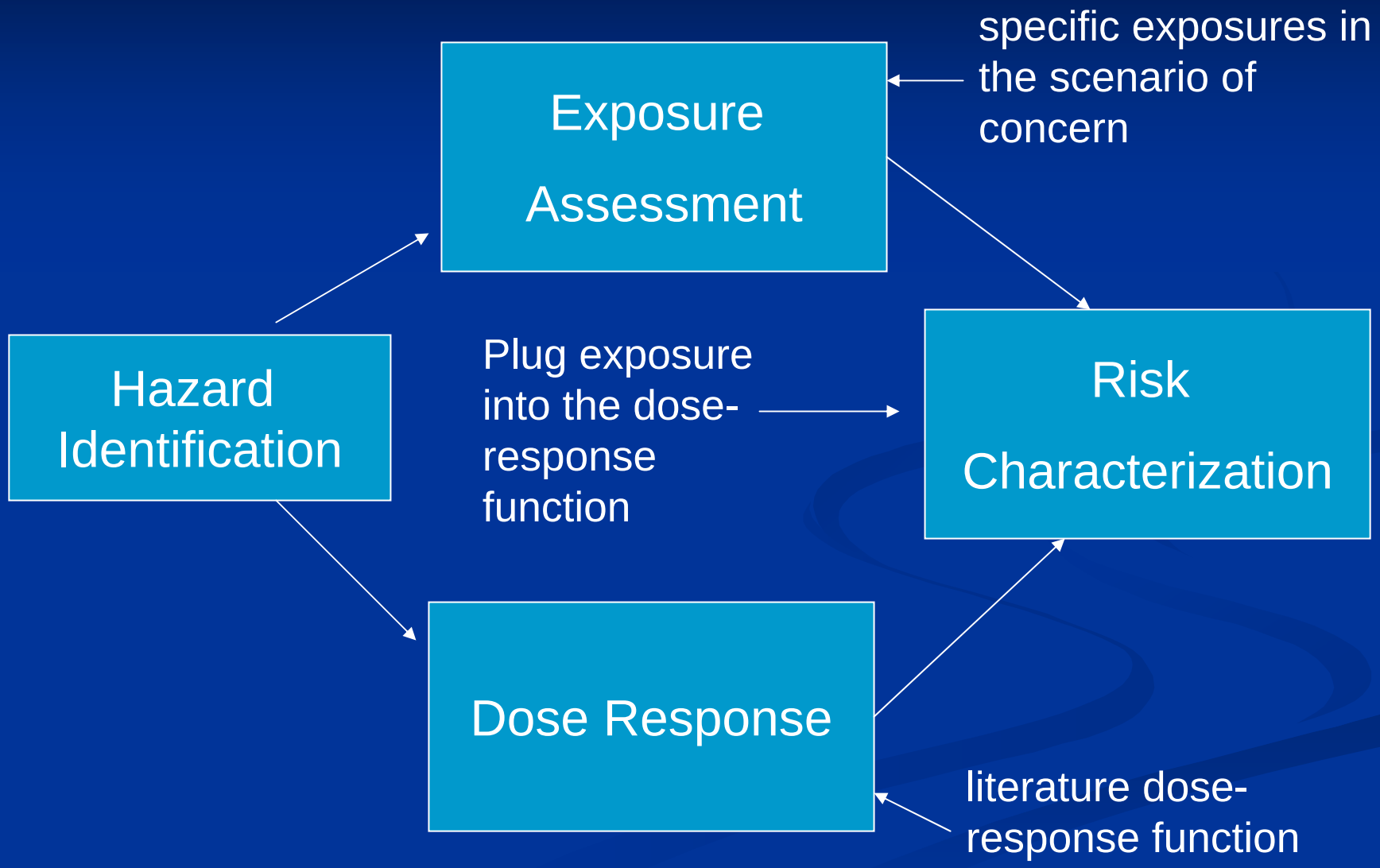
Risk Characterization & Management

Risk Assessment Framework



Point Estimate

- Single numeric value of risk
  - May correspond to best estimate of risk
  - May be maximum reasonable exposure
- Use parameter values of exposure and dose response parameters corresponding to point estimate of interest

Example: Anthrax attack in water

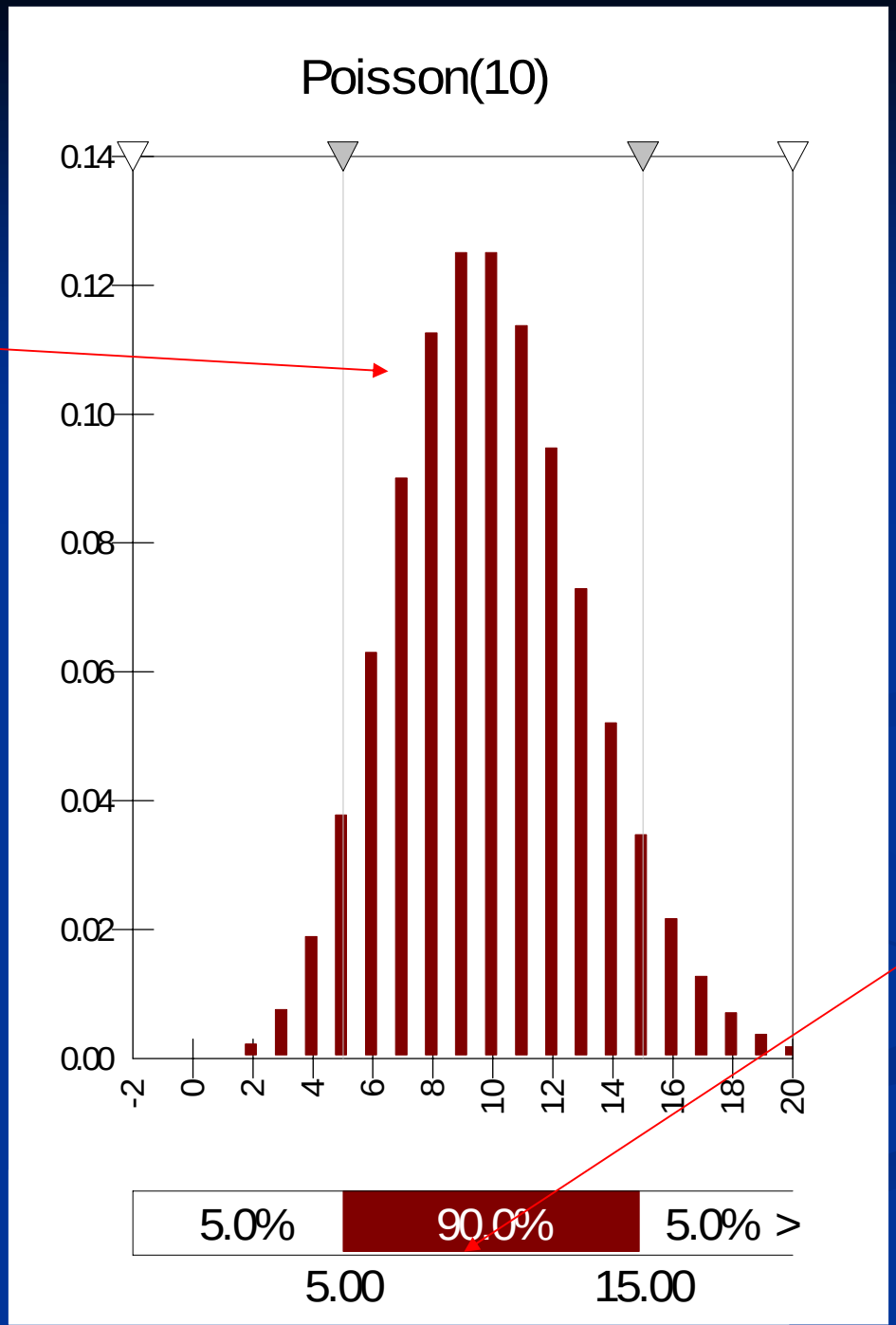
- What is the risk of Anthrax attack?
- Best fit dose-response is Beta-Poisson model

$$P(fatal) = 1 - \left[1 + \frac{\text{dose}}{62817}\left(2^{1/0.974} - 1\right)\right]^{-0.974}$$

- If drinking water contains *B. anthracis* 1 spore/*L*
  - if 1 L of water is ingested, the fatality risk = 1.6×10^{-5}
    - 1 person/population of Lansing (120,000)

Note: this is the fatality risk via inhalation based on animal tests

Now it is our most likely value, but not the only possible value



This was our point estimate

Uncertainty Analysis

- Monte-Carlo Simulation
  - Find range of possible outcomes
  - Determine if the uncertainty matters
  - Determine which inputs contribute the most to output uncertainty
  - Compare range of outcomes under different decisions, policies

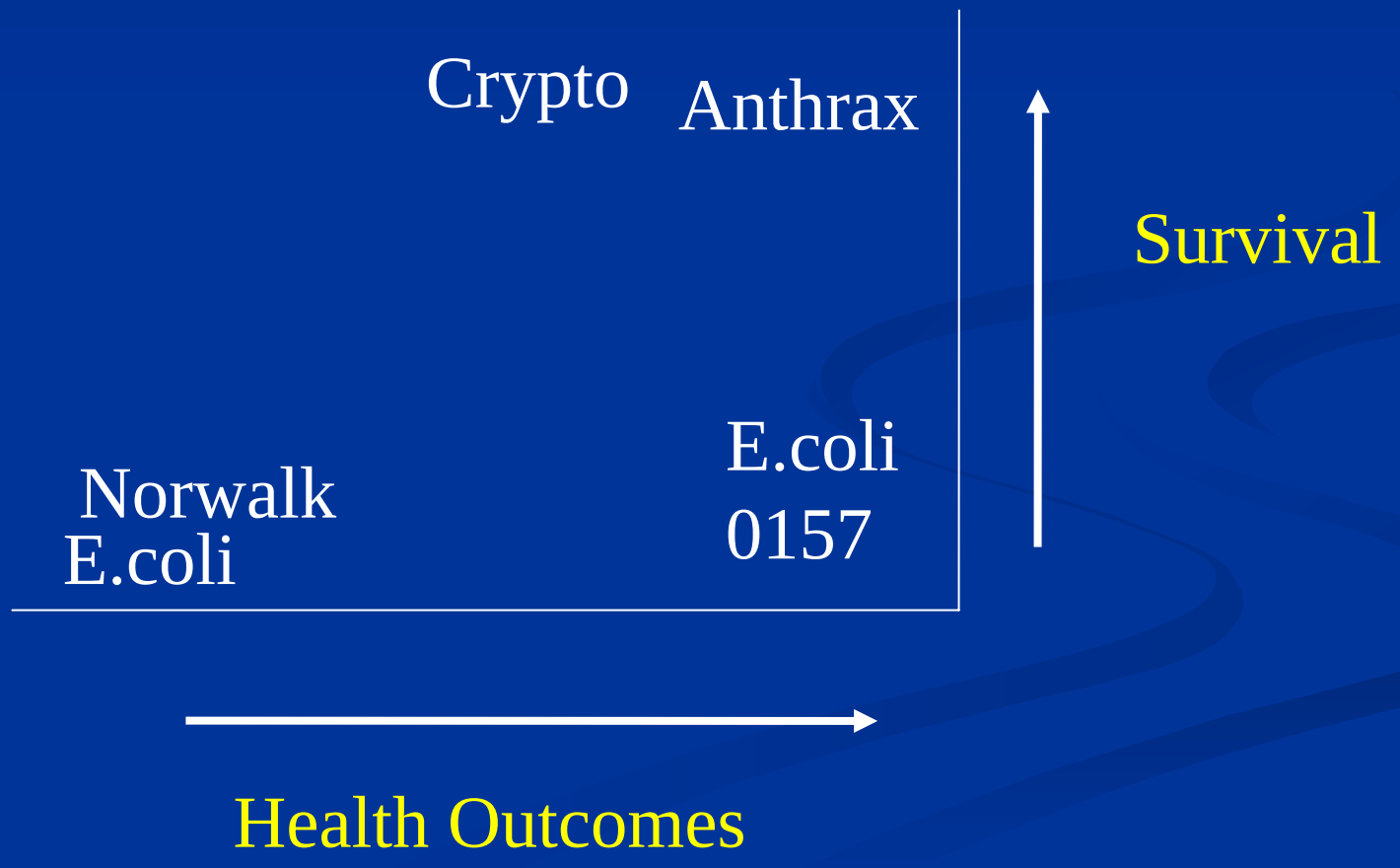
Risk Characterization

- What do we really want to get out of our analysis?
- Not just a number but to inform multiple decisions
  - What is acceptable risk?
    - EPA dirking water 1/10000 infection
    - What is an acceptable risk of fatality caused by a bioterrorism attack?
  - How bad could it be?
  - Can the risk be reduced?
  - What do we need to know to improve management of this risk?
  - Are there subpopulations we should be concerned about?

Informing Risk Management

- What protective action is needed to reduce
  - best estimate of risk to a target value?
  - upper bound of risk to the target value?
- How much will different risk management actions cost and what risk reductions will they achieve?
- How certain are we?

Relative Risks Associated with Chlorinated Water



Current Microbial Drinking Water Standard

- Total coliforms
  - including fecal coliform and *E. coli*
- Heterotrophic plate count
- *Cryptosporidium*
- *Giardia lamblia*
- *Legionella*
- Viruses (enteric)
- Turbidity

EPA's Surface Water Treatment Rules

- *Cryptosporidium*: 99% removal.
- *Giardia lamblia*: 99.9% removal/inactivation
- Viruses: 99.99% removal/inactivation

Geometric Mean of Rotaviruses in Source Water/100 L
10000
1000
100
10.0
1.00
0.10
0.01
Risk Zone
Safety Zone
1
2
3
4
5
6
7
8
9
Log10 Reduction

Summary & Conclusion

- QMRA for decision making
- Better monitoring systems and water distribution model
- Update treatment systems
- Water BioWatch
- Communication

Center for Advancing Microbial Risk Assessment (CAMRA)

- U.S. EPA and Dept of Homeland Security
  - Established in 2005
- 7 Universities
  - Michigan State University, Drexel University, University of Arizona, Northern Arizona University, University of Michigan, Carnegie Mellon University, University of California Berkeley
- Interdisciplinary Researchers
  - Microbiologists, Environmental Engineers, Epidemiologists, Veterinarians, Information Technologists

CAMRA's Missions

- Develop models, tools and information that will be used in a credible risk assessment framework to reduce or eliminate health impacts from deliberate use of biological agents of concern (BAC) in the indoor and outdoor environment
- Build a national network for microbial risk knowledge management, learning and transfer, for the community of scientists, and students via educational programs and community of professionals in the field and in our communities.

Thank you

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CAMRA
Center for Advancing Microbial Risk Assessment

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