Distribution Systems: The Next Frontier

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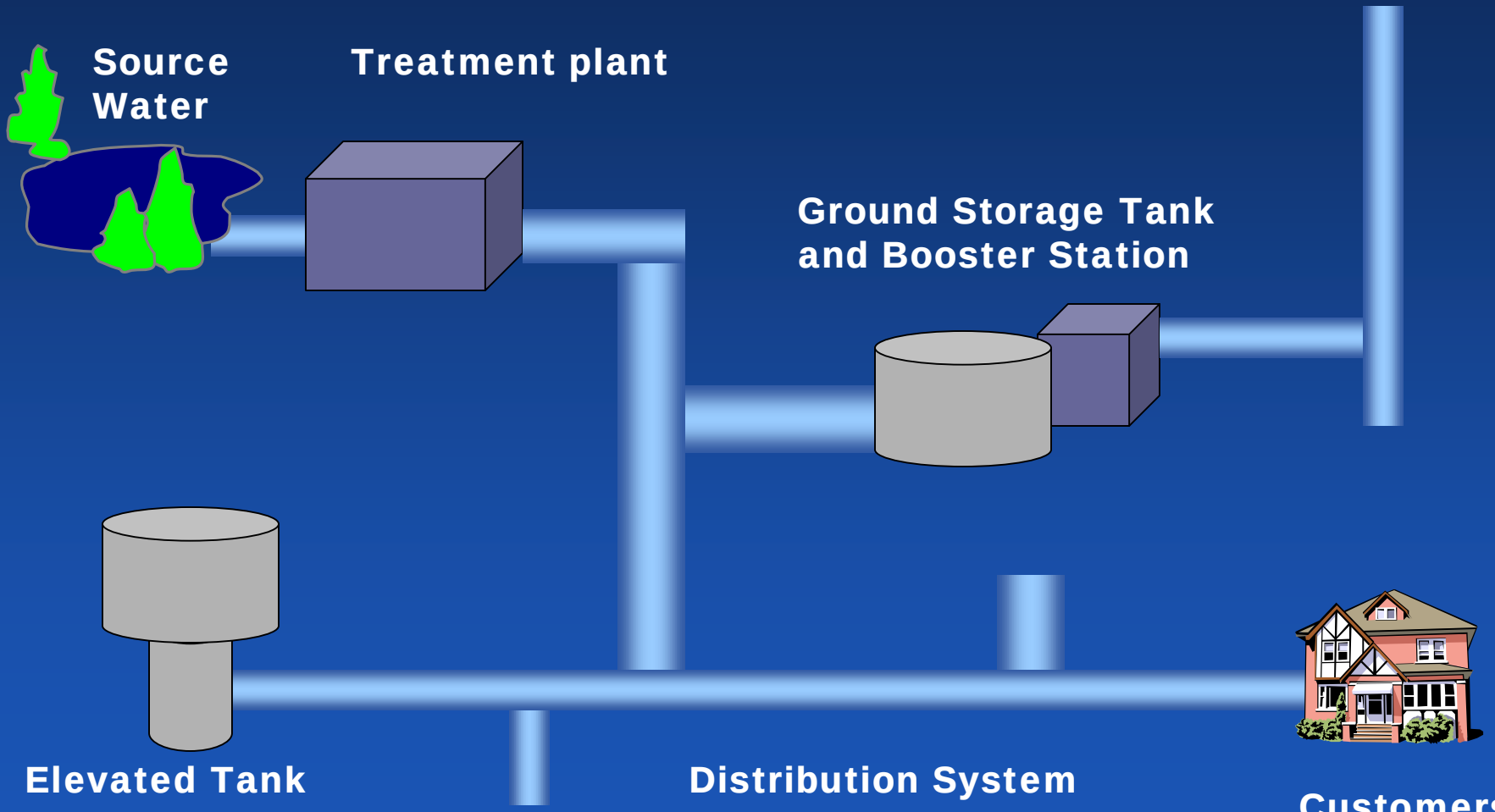
Water Distribution System



Water Distribution Serves a Variety of Purposes

- Drinking water
- Domestic use
- Fire flow
- Industrial use
- Irrigation

Water Distribution Serves a Variety of Purposes

Often with Conflicting Requirements

- Drinking water
- Domestic use
- Fire flow
- Industrial use
- Irrigation

- Uninterrupted service
- Free of pathogens and chemical contaminants
- Adequate pressure and flow
- Maintain disinfectant residual

Estimate of US Distribution Infrastructure

Distribution System Element	Inventory extrapolated to 2004 US population
Miles of pipe	995,644
Storage tanks	24,276
Hydrants	6,772,910
Service connections	69,545,307
Valves	14,604,767
Expansion of systems, miles per year	5,181
Replacement of pipe, miles per year	3,645

US EPA, 2007

Infrastructure Crisis

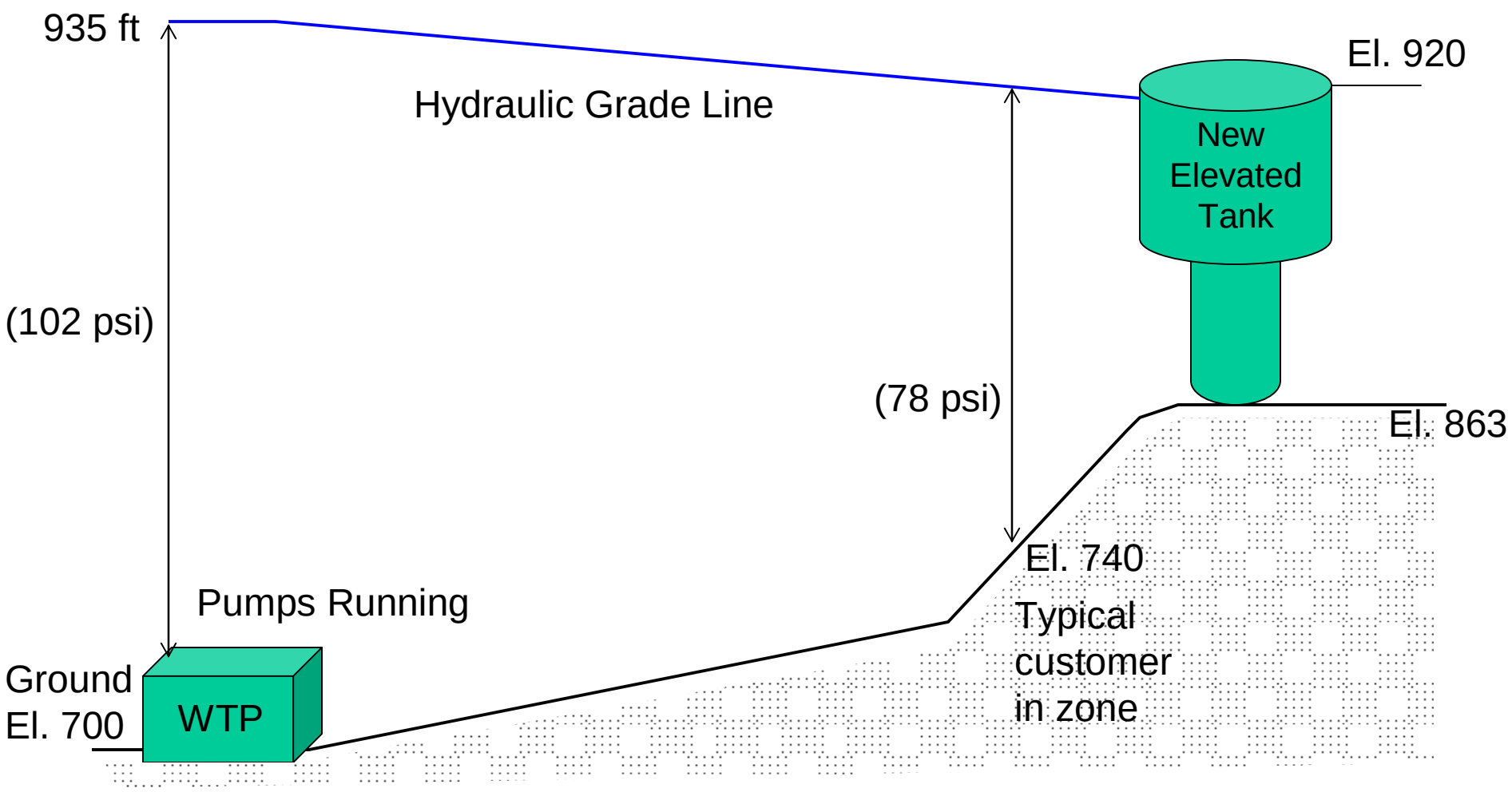
- Estimates to replace infrastructure range from $77 – 325 billion in next 25 years
  - Lead service lines: $10 – 14 billion (1994)
- US distribution system operation and maintenance budget is $4.5 billion/year (1994)
- Water losses range from 10 – 25%
- Infrastructure replacement costs paid primarily by water utility/municipality through customer rates

US EPA, 2007

Hydraulic Challenges

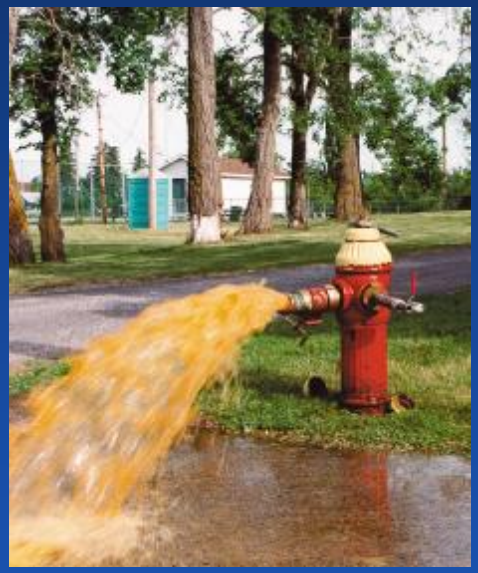
- Maintain pressure
  - Typically minimum of 35 psi is required under normal operation, 20 psi during a fire
- Terrain changes
  - Create zones at similar elevations to regulate pressures
- Storage
  - What is adequate?
- Pressure surge
- Widely variable customer demands
- Emergency situations

Example of Pressure Zone Setup



Potential for Water Quality to Deteriorate

- Long retention times
- Reactions within the pipes
  - Within bulk water
  - At the pipe wall
- Different pipe materials
- Aging infrastructure
- External influences
  - Construction activities
  - Customer usage
  - Household plumbing



Water Quality Parameters of Concern

- Disinfectant residual
  - Chlorine, chloramine
- Disinfection by-products
  - 2 regulated groups of chlorinated by-products
- Pathogens
  - Bacterial indicators
- Lead and copper
- Taste and odor
- Corrosion
- Color

Drinking Water Quality in the Media

"Toxic chlorine pollutants were found at unsafe levels"

New Fears Raised Over Safety of DC Water
Washington Post July 19, 2007

"Water officials say chlorine toxins likely temporary"

DC Officials Say Tap Water is Safe
Washington Post July 20, 2007

www.citizen.org

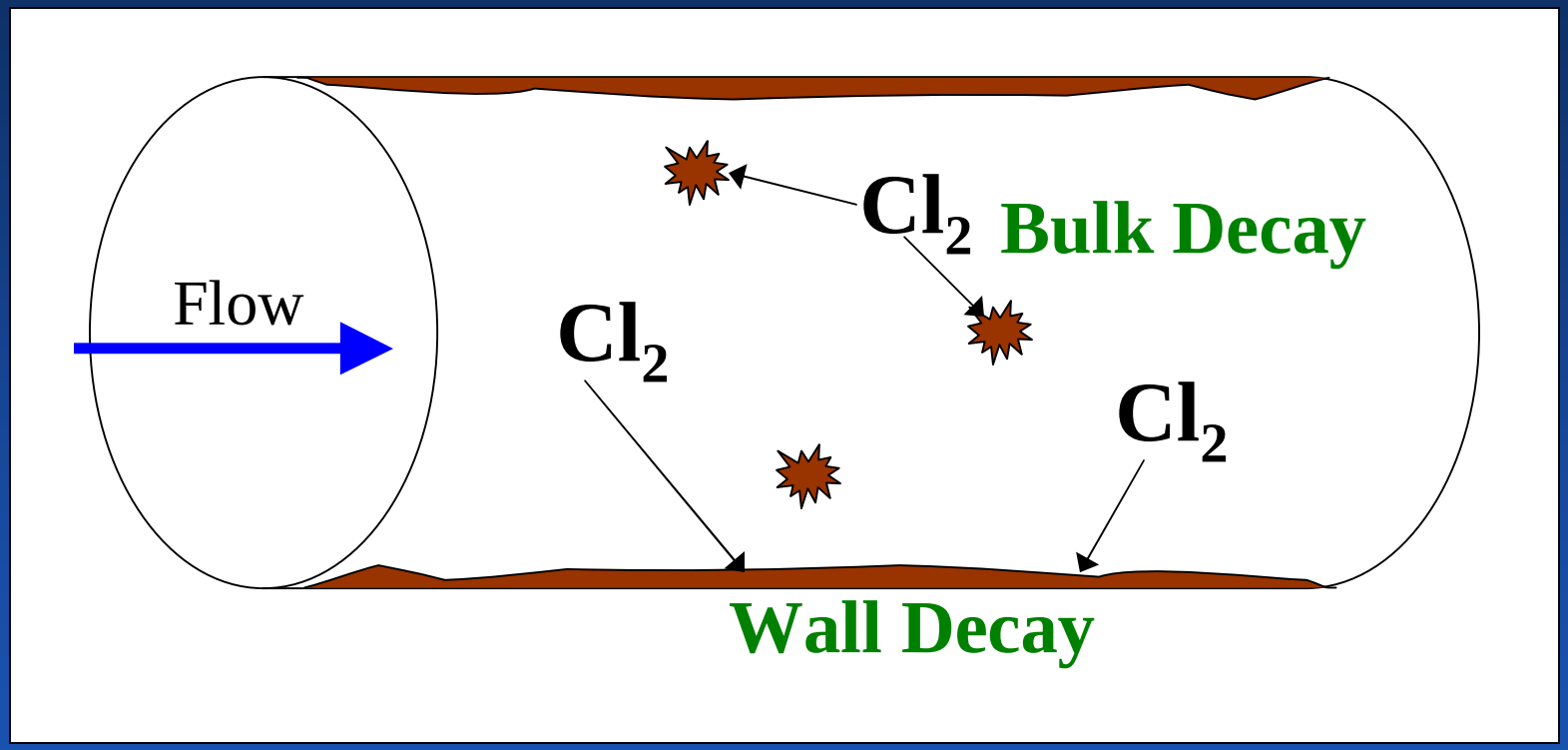
Tools to Address DS Issues

- Modeling
  - Hydraulic
  - Water quality
- Monitoring
  - On-line data collection
  - Grab sampling
- Management
  - Assets
  - Operational data

Distribution System Modeling

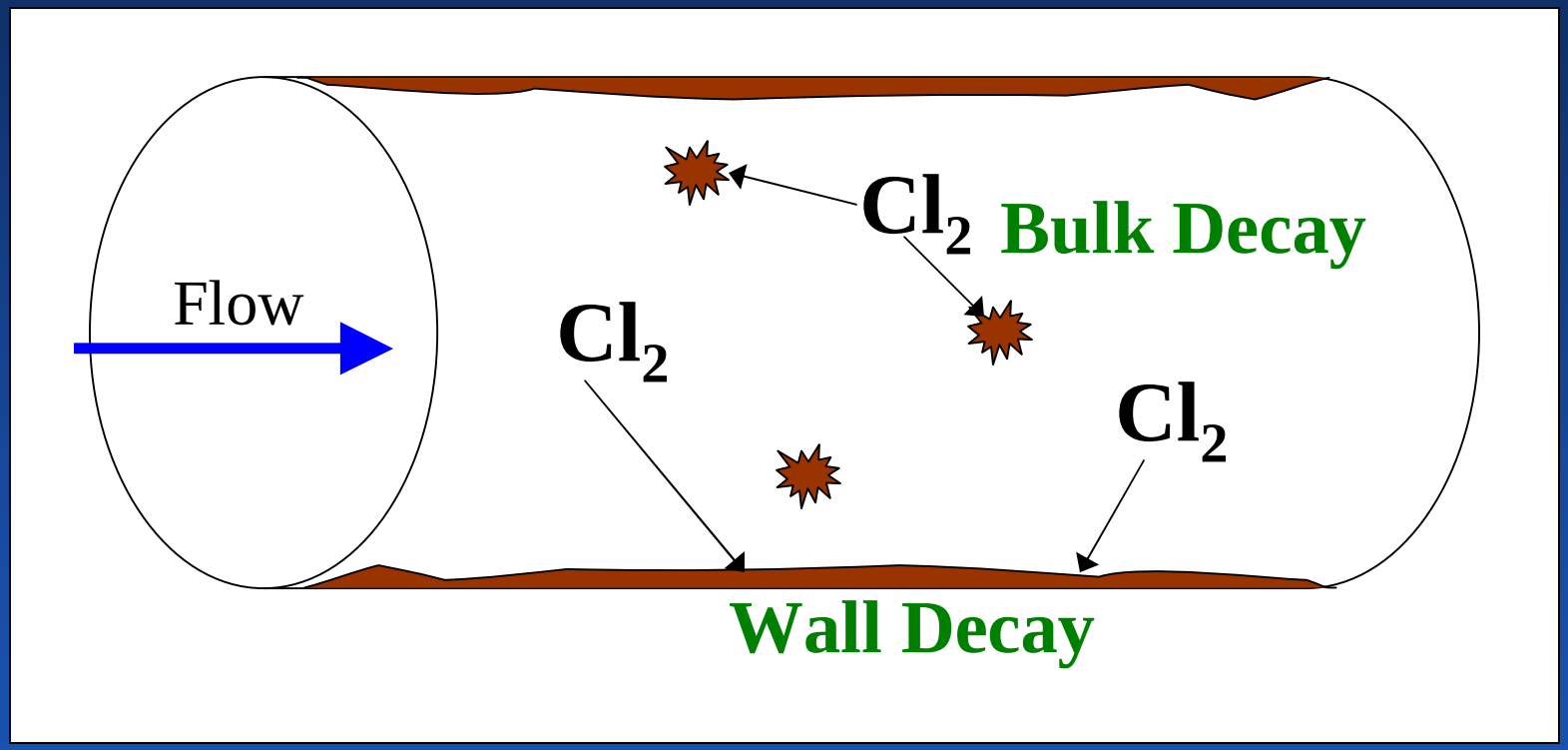
- Simulate flows, pressures, and water quality throughout system
- Becoming more widely used
  - Computational power
  - Data collection efforts (e.g. GIS)
- Challenges include:
  - Accurate data collection for buried infrastructure
  - Estimation of customer demands
  - Collection of operational data for calibration and verification
  - Understanding of fundamental mechanisms for water quality reactions, particularly microbial

Disinfectant Decay Reactions

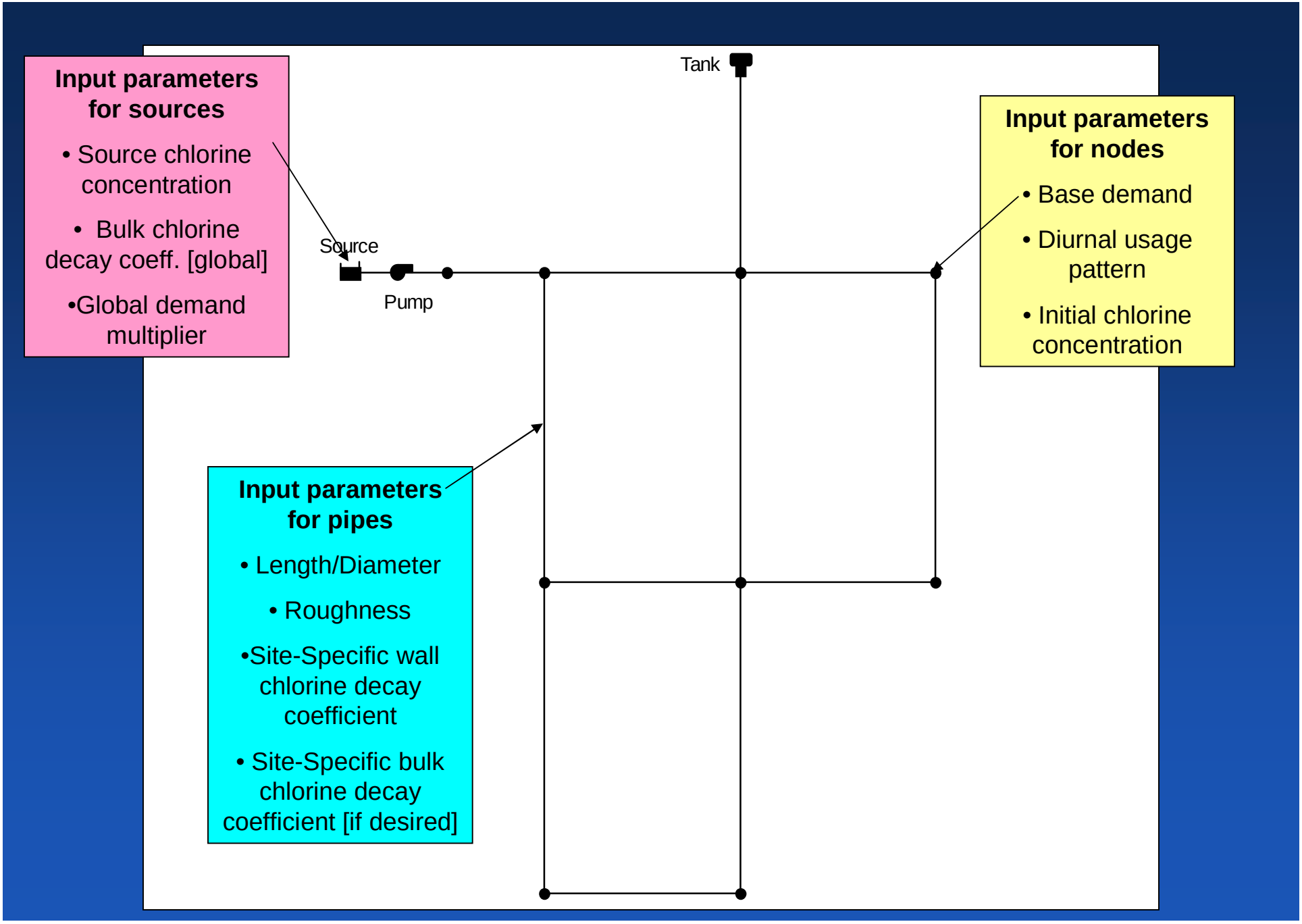


Particle Deposition and Resuspension
Biofilm Attachment, Growth and Detachment
Mass Transfer, Effect of Flow Regime on Reactions

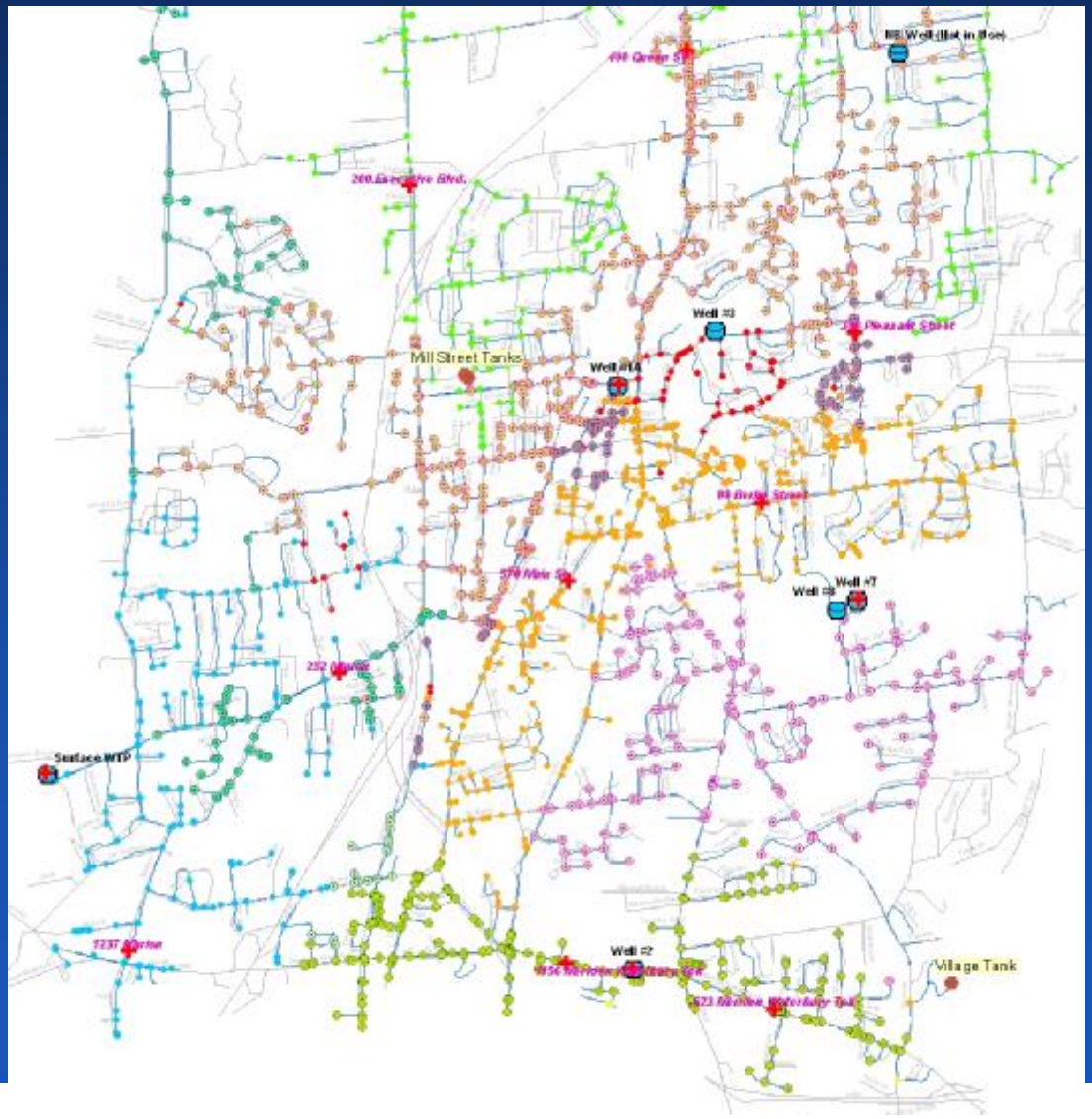
Disinfectant Decay Reactions



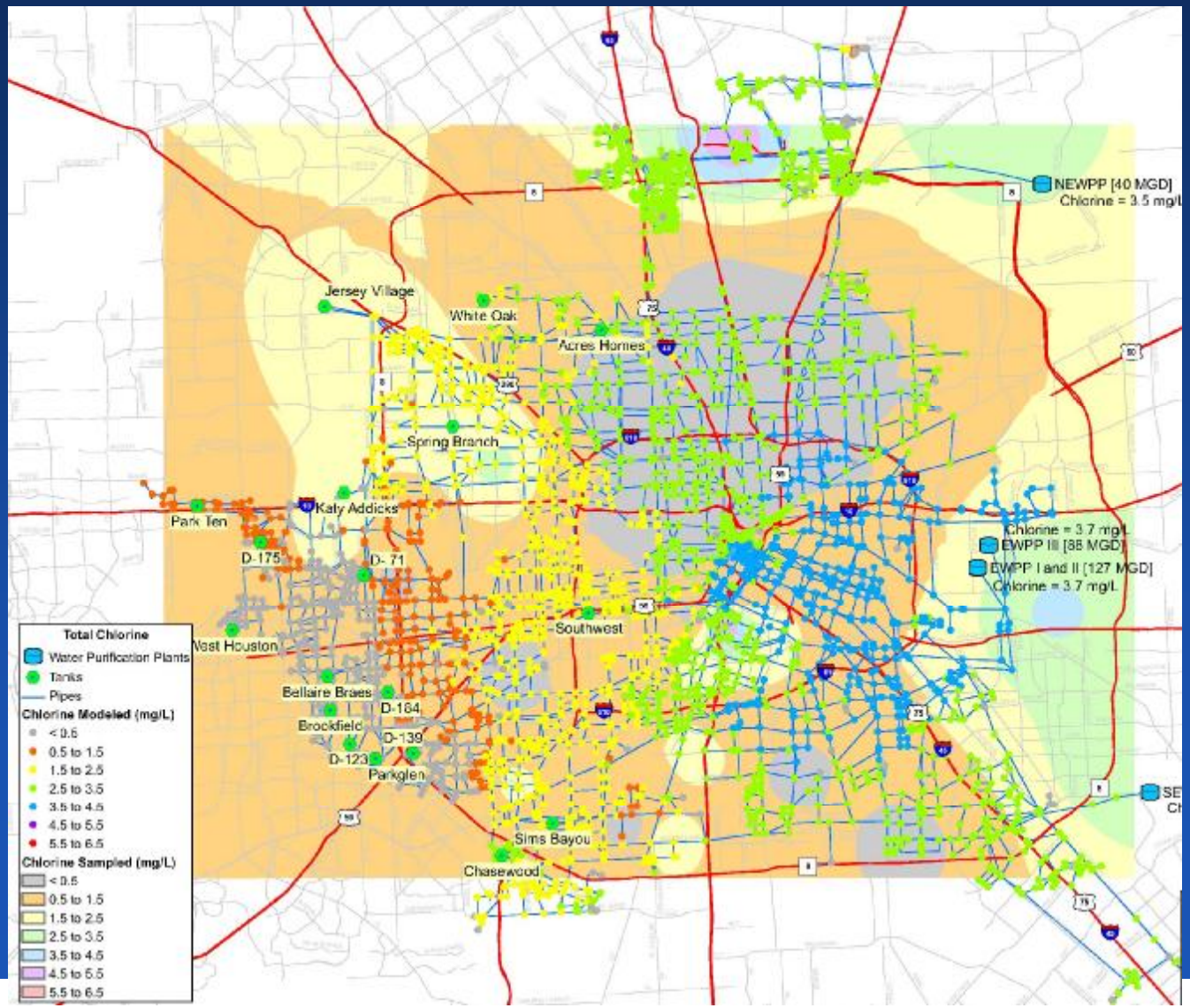
Generally use 1st order reactions


Input parameters for sources
• Source chlorine concentration
• Bulk chlorine decay coeff. [global]
•Global demand multiplier
Tank
Source
Pump
Input parameters for nodes
• Base demand
• Diurnal usage pattern
• Initial chlorine concentration
Input parameters for pipes
• Length/Diameter
• Roughness
•Site-Specific wall chlorine decay coefficient
• Site-Specific bulk chlorine decay coefficient [if desired]

Model Application: Zone of Influence

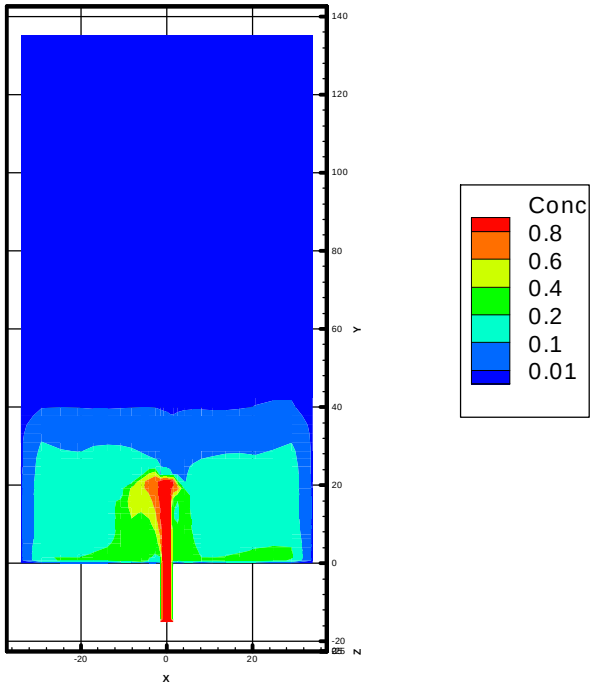


Model Application: Chlorine Residual



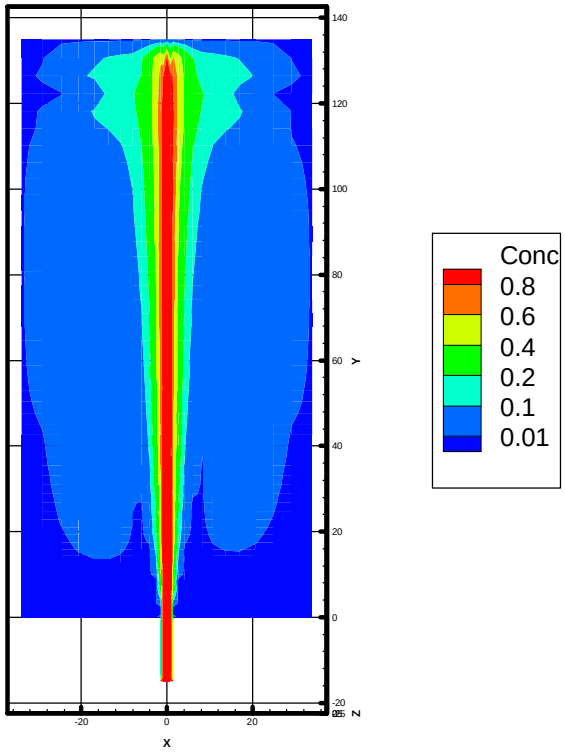
CFD Modeling Application: Tanks

1 mg/L tracer after 60 mins



36” vertical inlet
Tank temp 25 C; Inlet temp 24 C

1 mg/L tracer after 60 mins



36” vertical inlet
Isothermal condition (20 C)

Monitoring

- Hydraulic monitoring (generally continuous):
  - Flows
  - Storage tank levels
  - Pressure
- Water quality sampling for regulatory requirements (generally grab samples):
  - Disinfectant residual
  - Microbial indicators (total coliform)
  - Disinfection by-products
  - Lead and copper

Online Monitoring

- As technologies advance, online monitoring is becoming more common although cost is still a hurdle to implementation
- Most utilities monitor hydraulic parameters
- A few utilities monitor:
  - Disinfectant residual
  - pH, turbidity, conductivity
- Very few utilities monitor:
  - Individual contaminants
  - UV, Total Organic Carbon

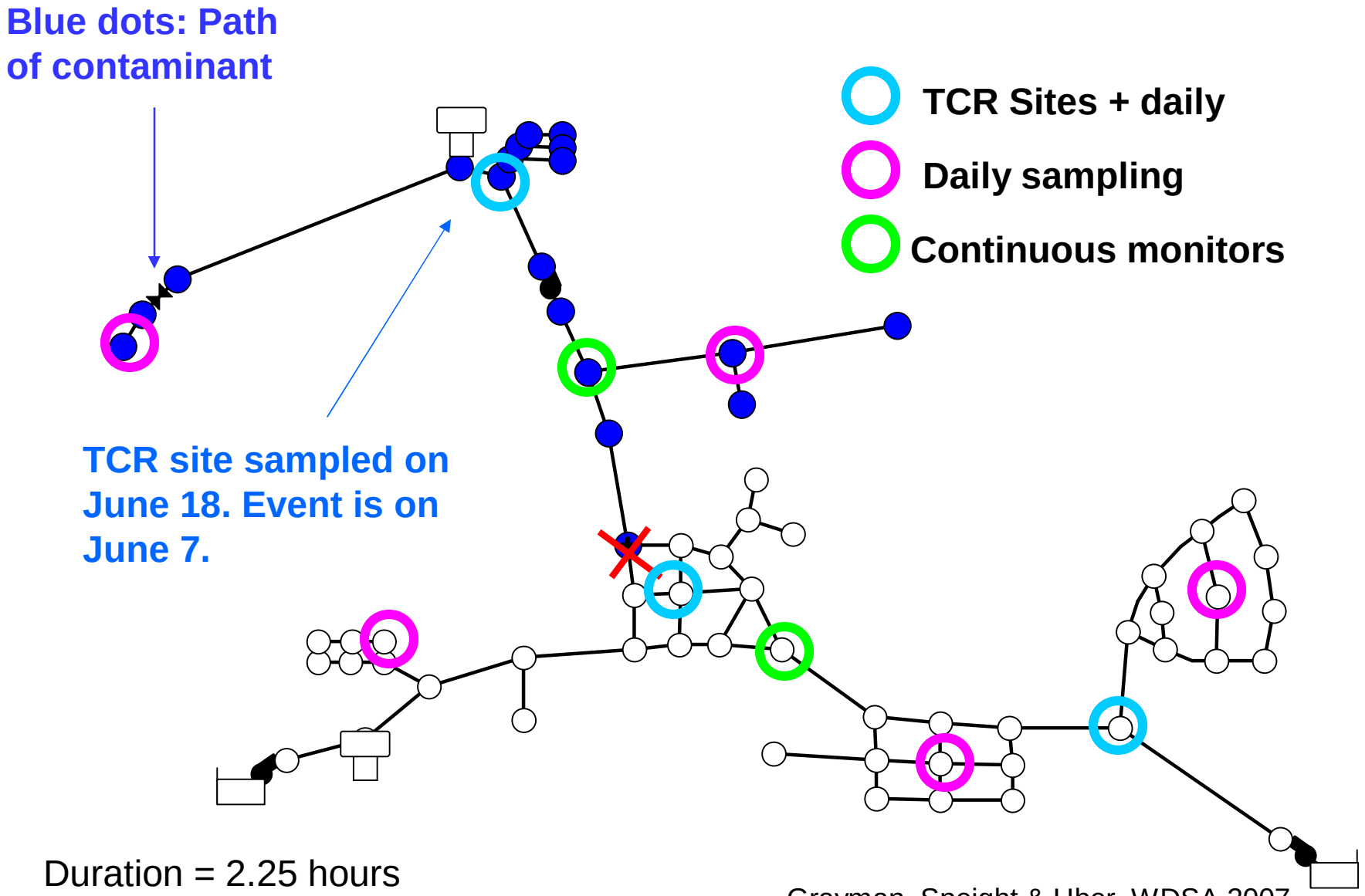
Ongoing Monitoring Research

- Security field has led the way in developing online monitoring technology
- Panels of instruments measuring different indicator parameters
  - Trying to combine the responses from all parameters to identify anomalies
- Data screening and event detection algorithms
- Pilot studies to determine challenges in:
  - Installation (e.g. power requirements)
  - Maintenance (e.g. frequency of service visits)
  - Ability to incorporate non-traditional data streams (e.g. syndromic surveillance)

Ongoing Monitoring Research

- Incorporating model simulations with monitoring data analysis
- Use of models to determine:
  - Optimal design of monitoring programs
  - Movement of contaminants after an event
  - Impact of different contamination events on customers
  - Emergency response protocols

Probabilistic Modeling for Monitoring Plan Evaluation and Design



Duration = 2.25 hours
Magnitude = 16000 mpn/min

Grayman, Speight & Uber, WDSA 2007

Results (100 Simulations)

Monitoring Plan	Detect %
3 TCR sites sampled once a month	0
3 TCR sites sampled weekly	1
8 sites sampled weekly	2
8 sites sampled daily	8
8 sites sampled daily with large sample volumes	33
2 continuous monitors	44

Grayman, Speight & Uber, WDSA 2007

Management Tools

- Emerging field related to management of distribution systems
- Asset management
  - Estimation of remaining service life
  - Tracking of asset status, maintenance history, etc.
  - Development of capital improvement plans
- Data management and analysis
  - Centralizing data streams
  - Providing access to a variety of parties
  - Developing intelligent systems to analyze data and look for events

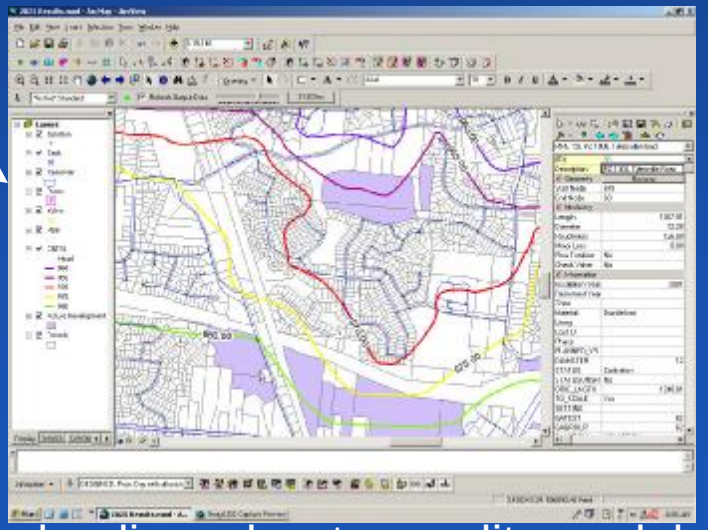
SCADA

LIMS

Customer data

Central integrated platform

GIS and field data



Hydraulic and water quality model

Solving Distribution System Problems

- Will require input from a variety of fields:
  - Materials
  - Water treatment
  - Hydraulics
  - Microbiology
  - Water chemistry
  - Data management / analysis
  - Computational methods
  - Economics
  - Public health and public education
  - Risk assessment and mitigation