Use of Network Models for Estimating Exposure of Consumers to Contaminants in Drinking Water Distribution Systems

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Topics to be Discussed

- What is a water distribution system model?
- How can a model be used in studying contamination of a distribution system?
- Tracer studies
- Case study
- Issues in exposure calculation

What is a Model?

Models are mathematical or physical **approximate representations** of a real world system used to study the behavior of the actual system

Examples of Models

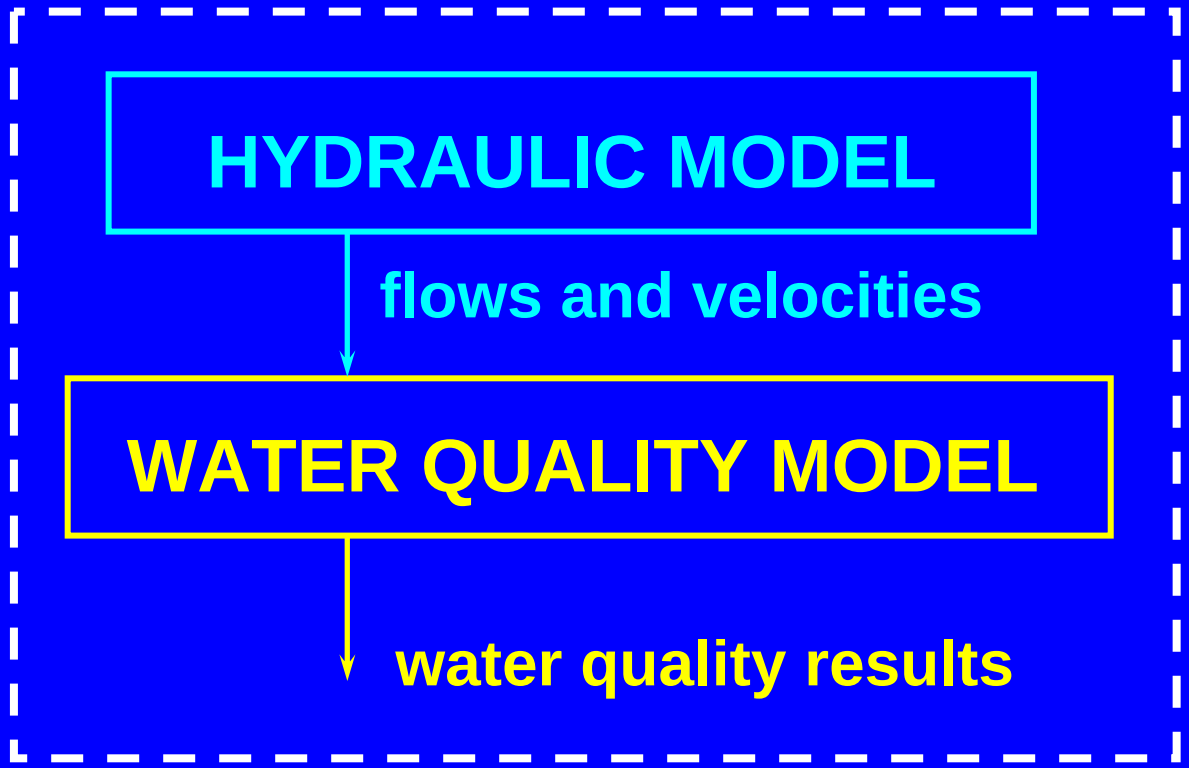
- Hazen-Williams head loss equation

$$h = \frac{kL}{D^{1.16}} \left(\frac{V}{C} \right)^{1.85}$$

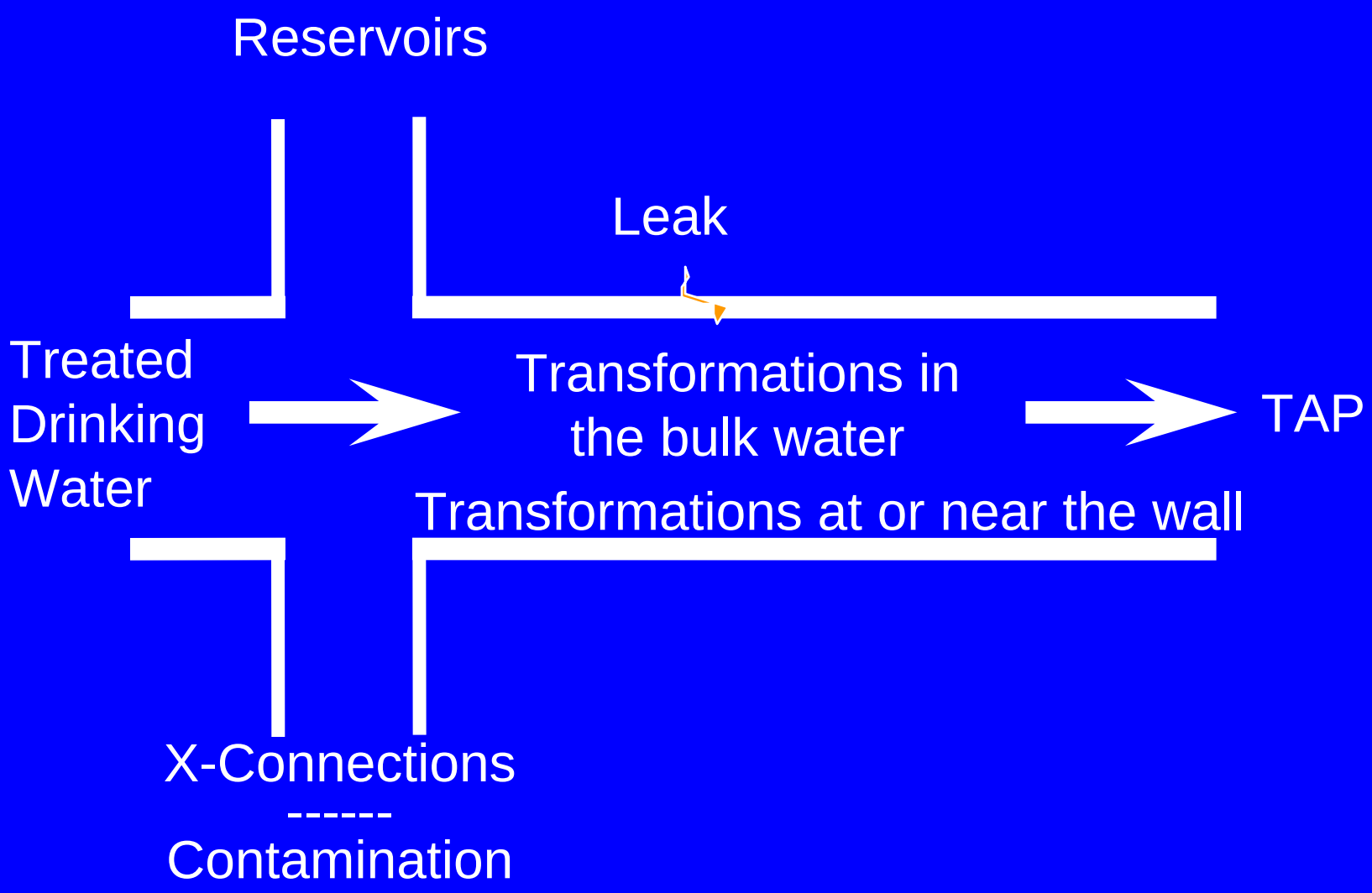
- Mathematical representations of rocket traveling to Jupiter

Select a model that is appropriate for a specific application

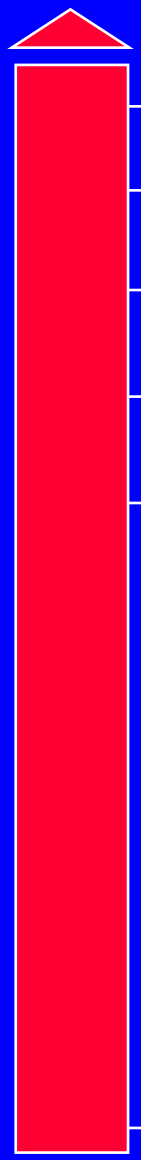
Hydraulic and Water Quality Modeling of Distribution System



Processes Affecting Water Quality



History of Water Quality Modeling



- 2000: User friendly hydraulic & water quality models
- 1990s: Practical applications of water quality models
- 1980s: Early distribution system water quality models
- 1970s: Growing environmental concerns (SDWA, CWA)
- 1960s: Advent of distribution system computer models
- 1930's: Hardy Cross Network Analysis

Modeling Contamination in Distribution System

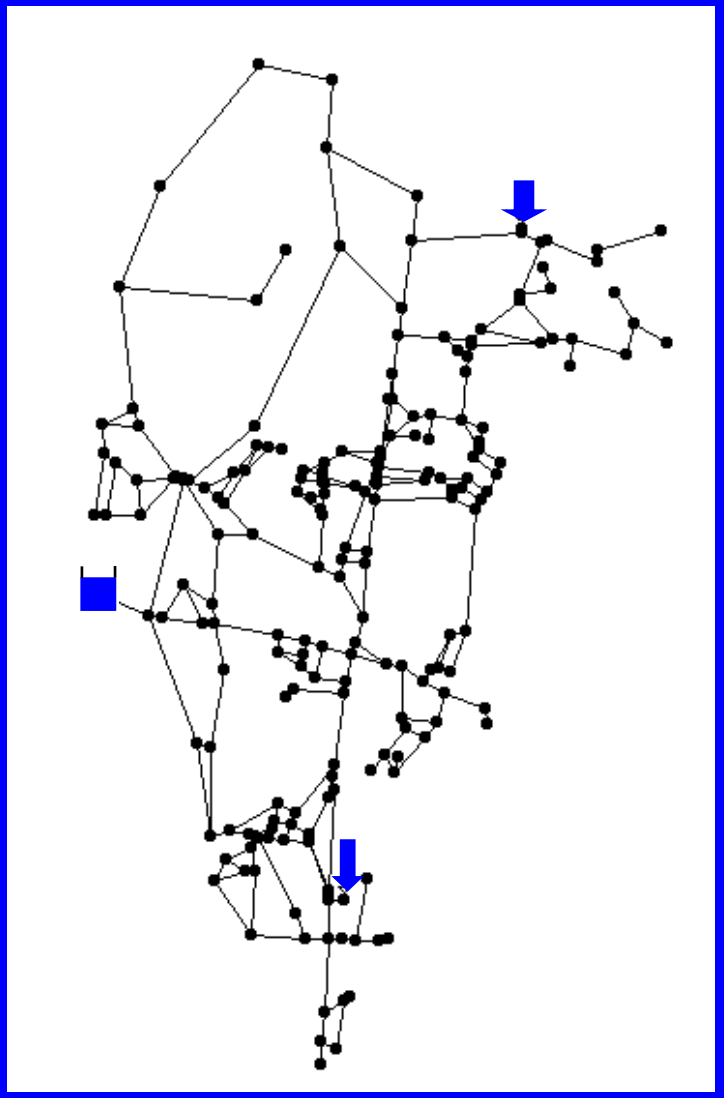
- **Assessing system vulnerability**
- Planning an emergency response
- Responding during an emergency
- Choosing monitor locations
- Retrospective study of waterborne outbreaks

Assessing Vulnerability

- Consequences of contamination event
- Consider:
  - Entry points for contamination
  - Types of contaminants
  - Quantity of contamination
  - Existing response plan
  - Number of customers impacted

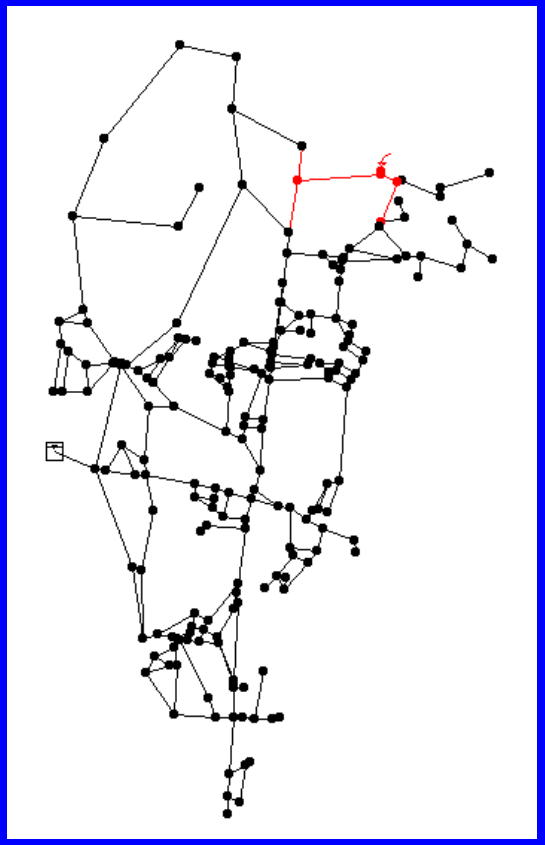
Example System

- In Connecticut
- 2 wellfields
- 1 tank
- Average 2.2 MGD
- Detailed, skeletonized model
- Extended period simulation

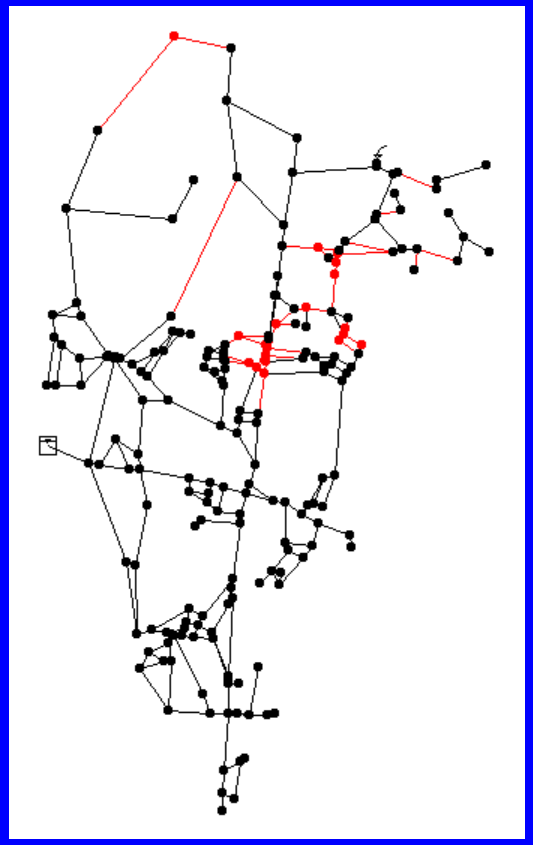


Contaminated Well

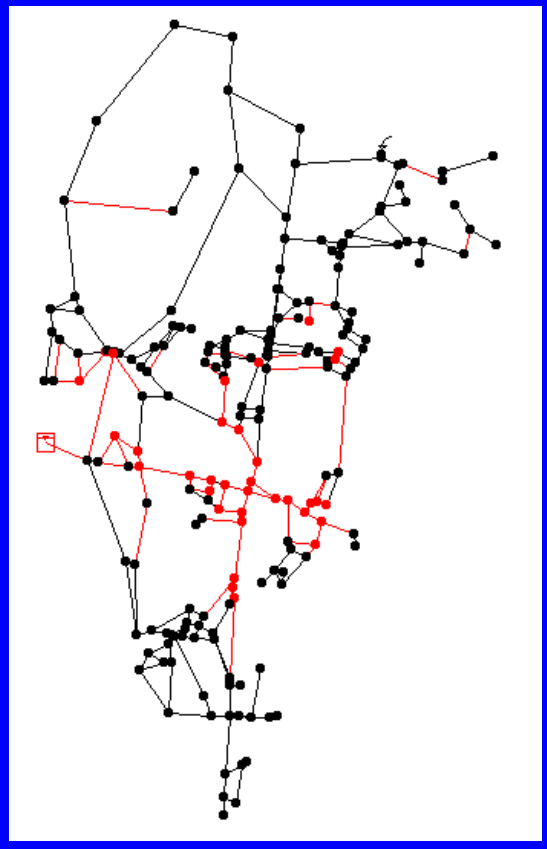
1 hour



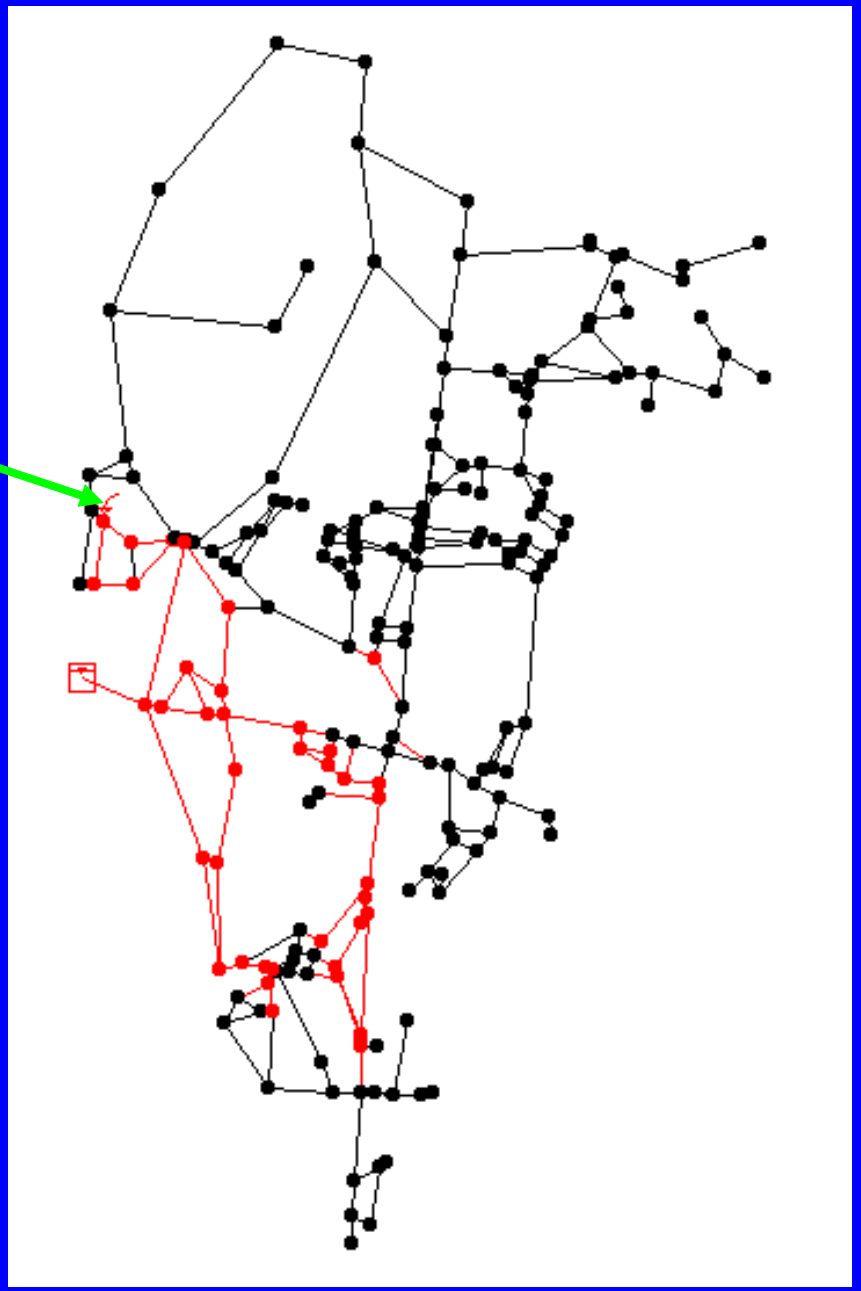
6 hours



24 hours



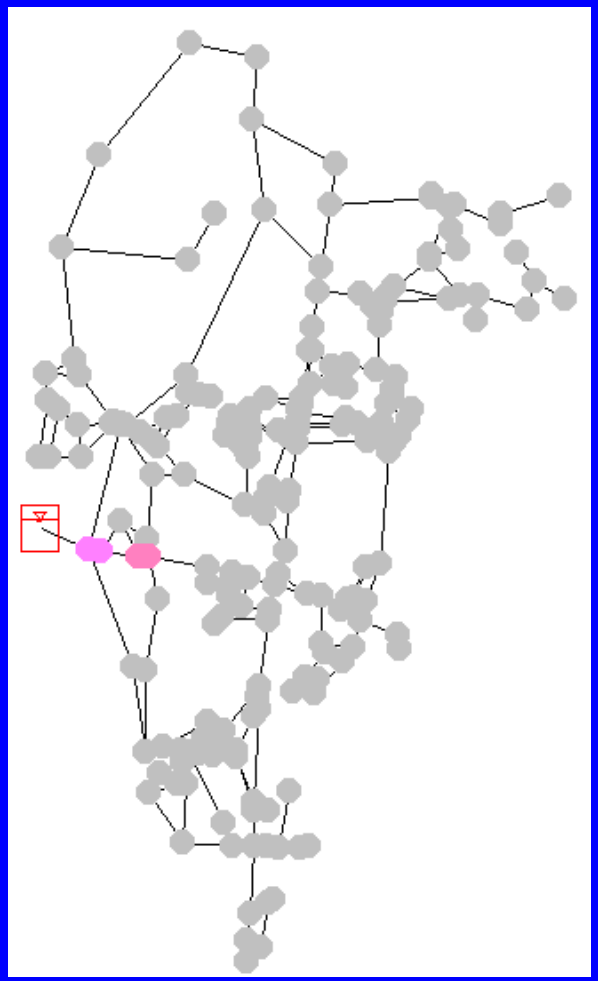
Contamination from Local Connection



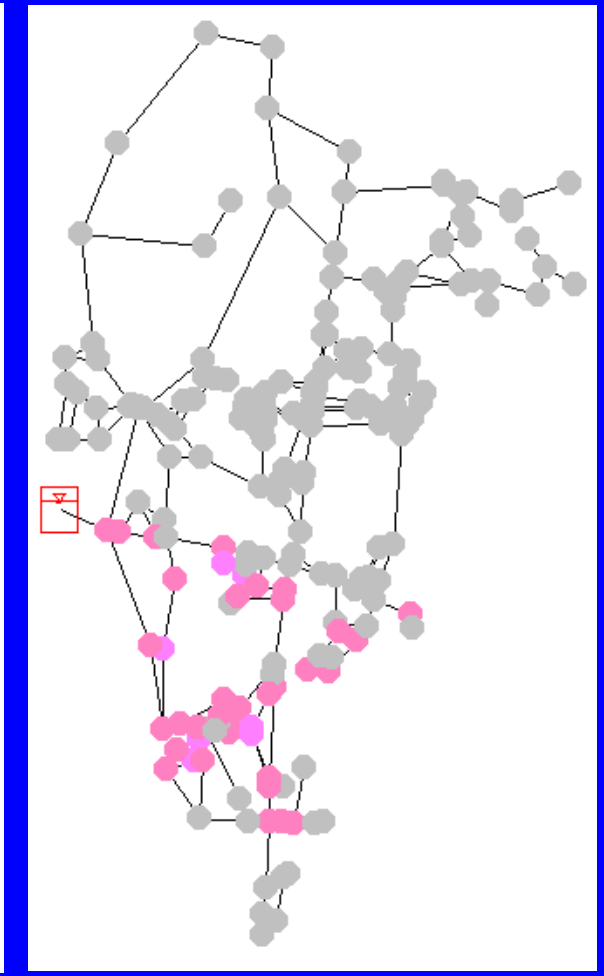
After 24 hours contaminant has reached the tank and a large part of the system

Contaminated Tank

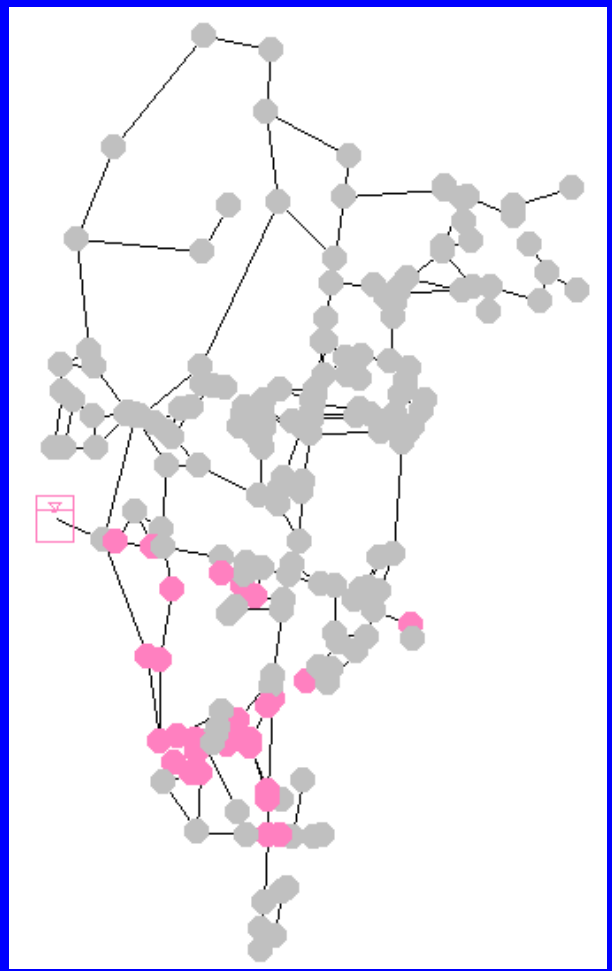
0.5 days



2 days



8 days



Tracer Study

- Purpose:
  - Assess movement of water in distribution system (travel times & blending)
  - Calibrate a hydraulic model
- Options
  - Turn off fluoride feed
  - Inject a chemical (e.g. calcium chloride)
  - Use natural tracer

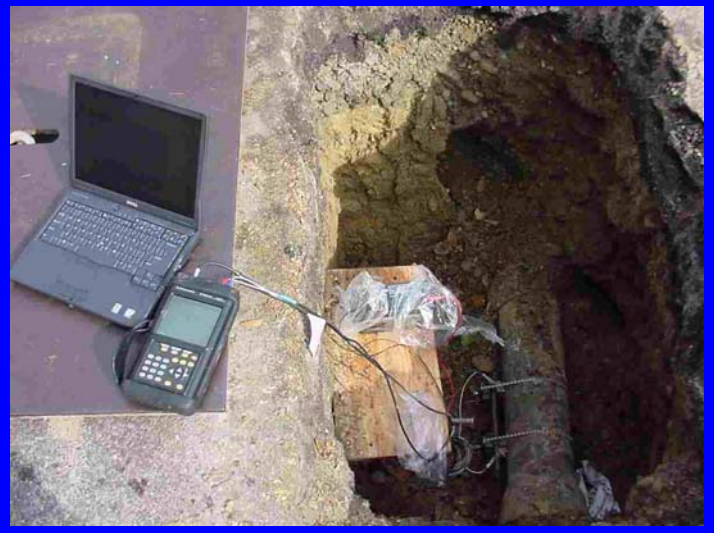
Tracer Study (continued)

- Measure tracer in distribution system
  - Manually
  - On-line monitor
- Also measure
  - Flows
  - Other water quality parameters

Manual vs. Automated Sampling

- Capital costs vs. Labor costs
- Tracer chemical used / Monitor availability
- Tradeoff between number of sampling locations and sampling frequency
- Even with automated sampling do you need manual samples?
  - Backup manual sampling w/ continuous monitors
  - Coincidental sampling for other parameters?
- Both have a role

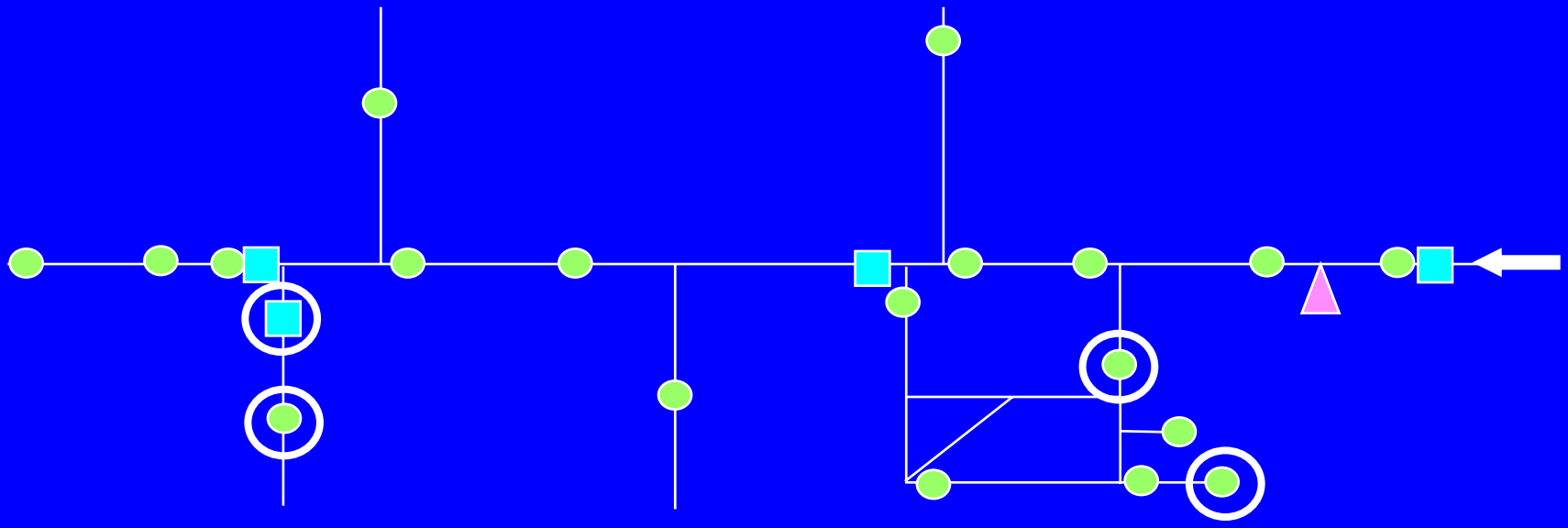
Conducting a Tracer Study



Case Study: Small Dead-end Suburban Area

- Injected two calcium chloride pulses
  - 2 hour pulse, 2.5 hour break, 2 hour pulse
- Monitored chloride per regulations
- 20 continuous conductivity monitors
- 4 ultrasonic flow meters

Schematic of System



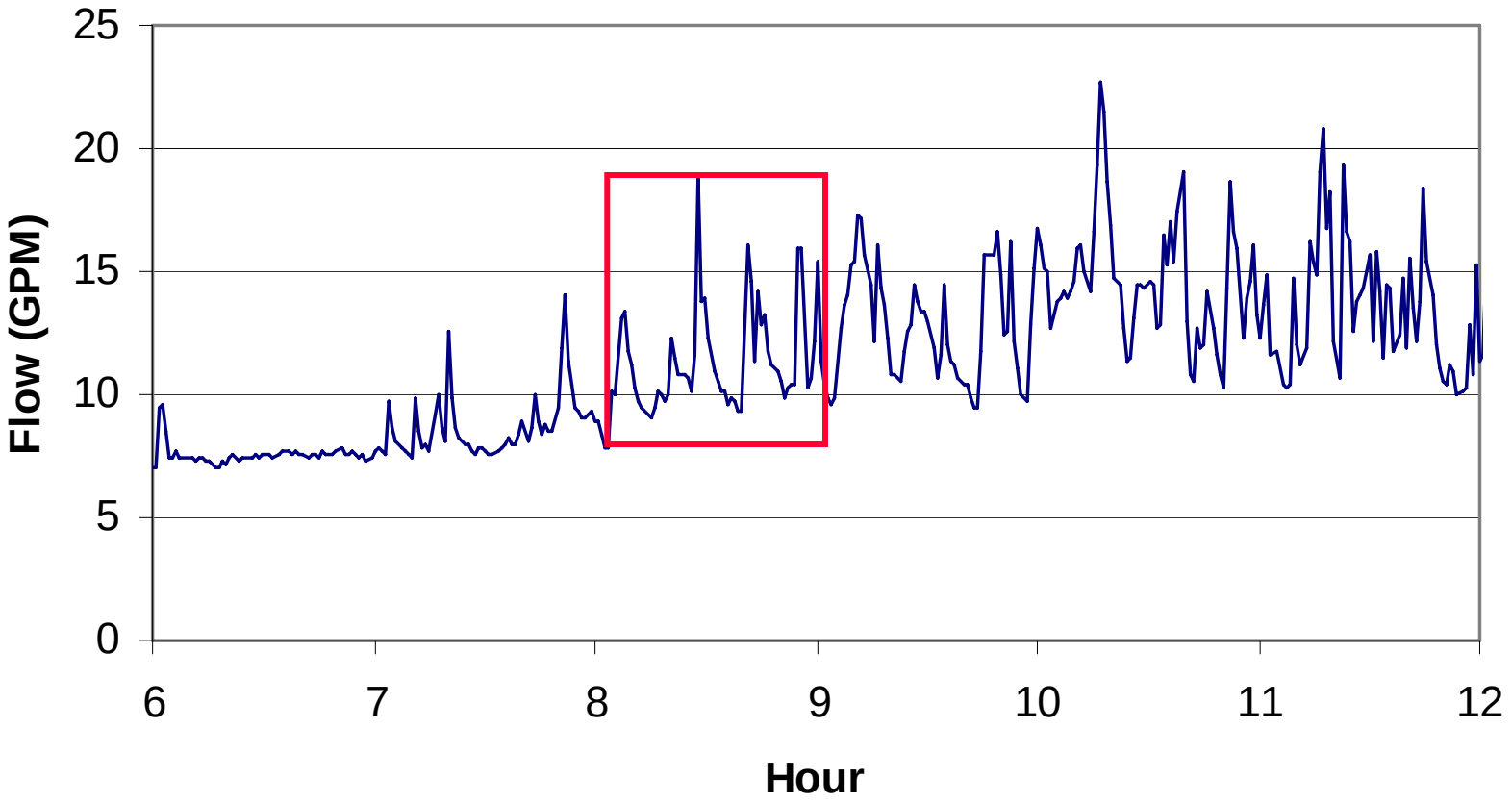
Flow gage

Conductivity meter

Injection point

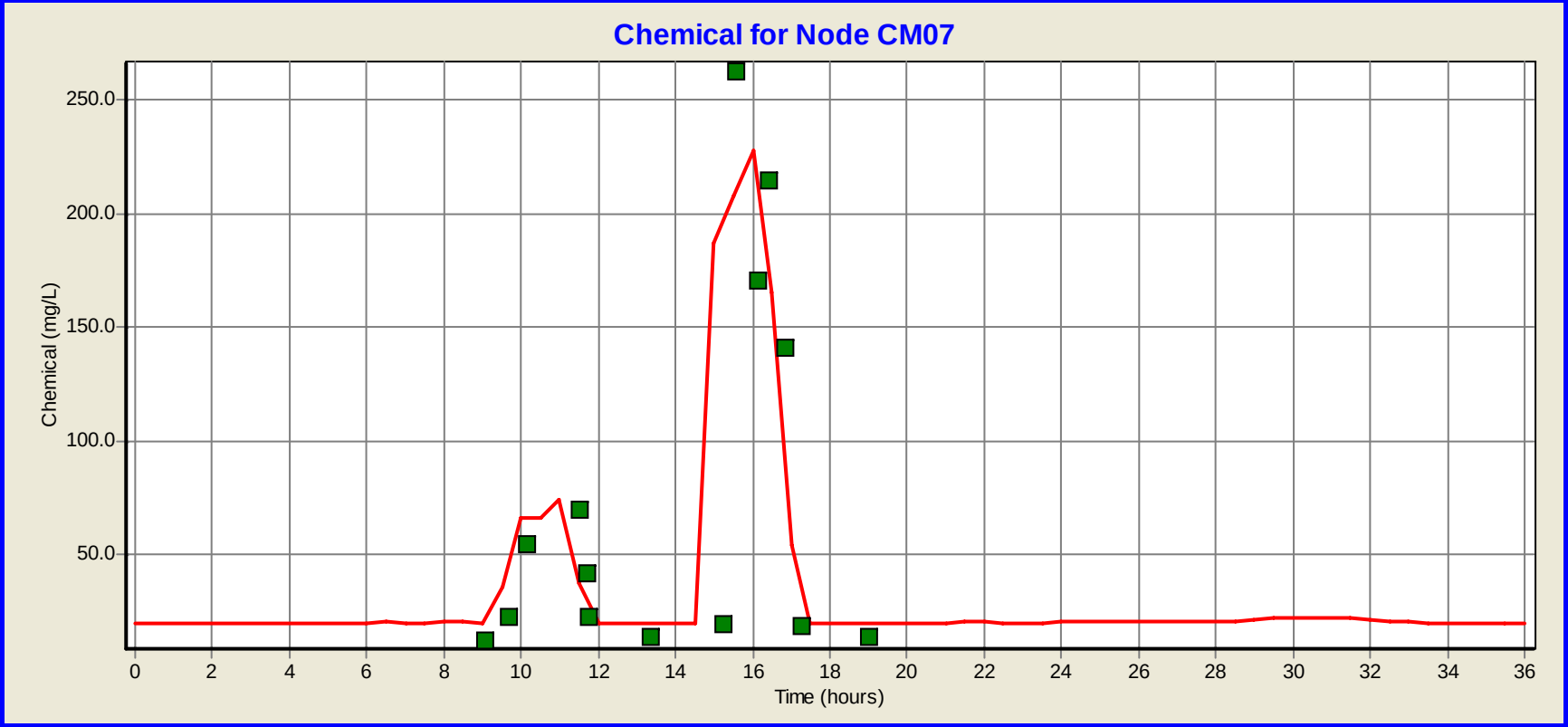
Points of interest

Flow on Dead End Street



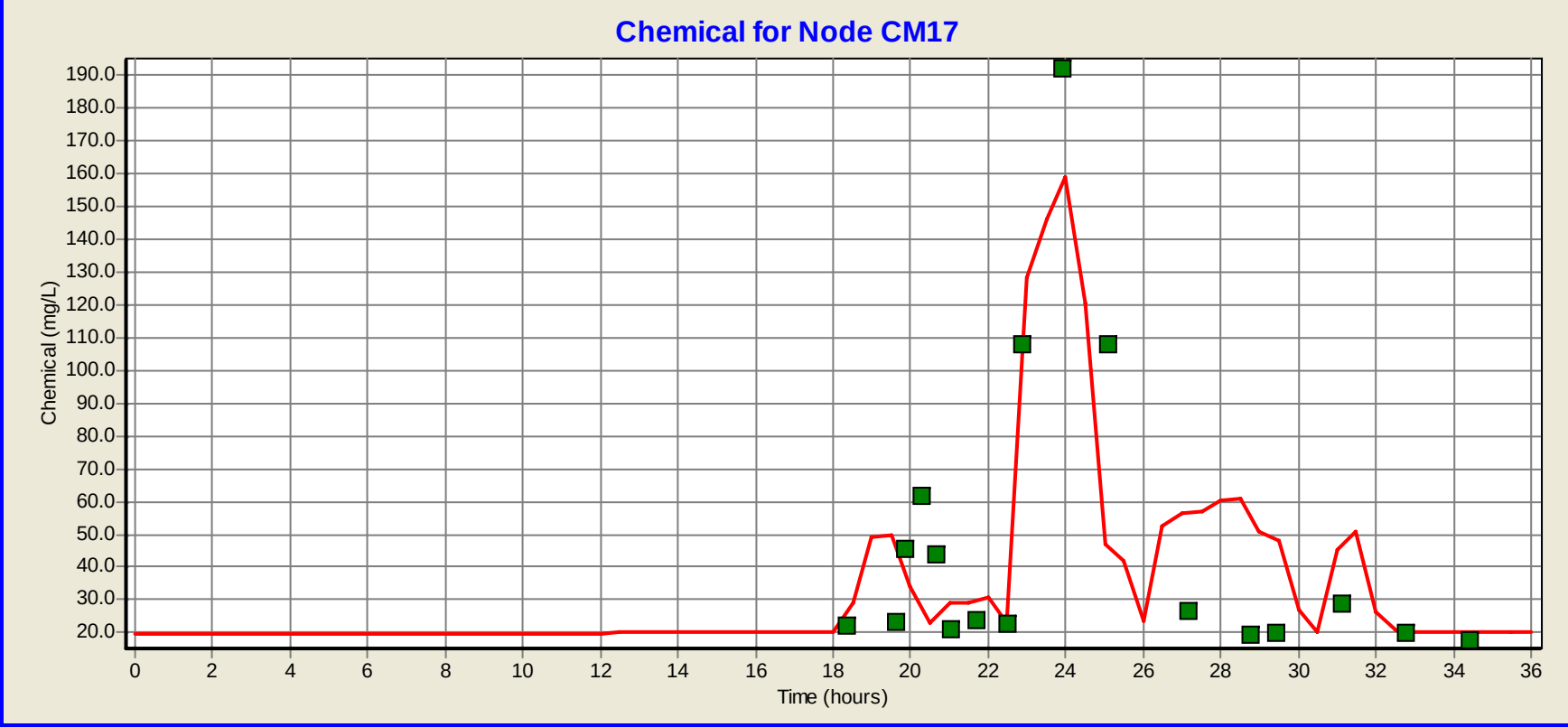
Comparison of Model & Field Data

Before calibration: On main line → good agreement



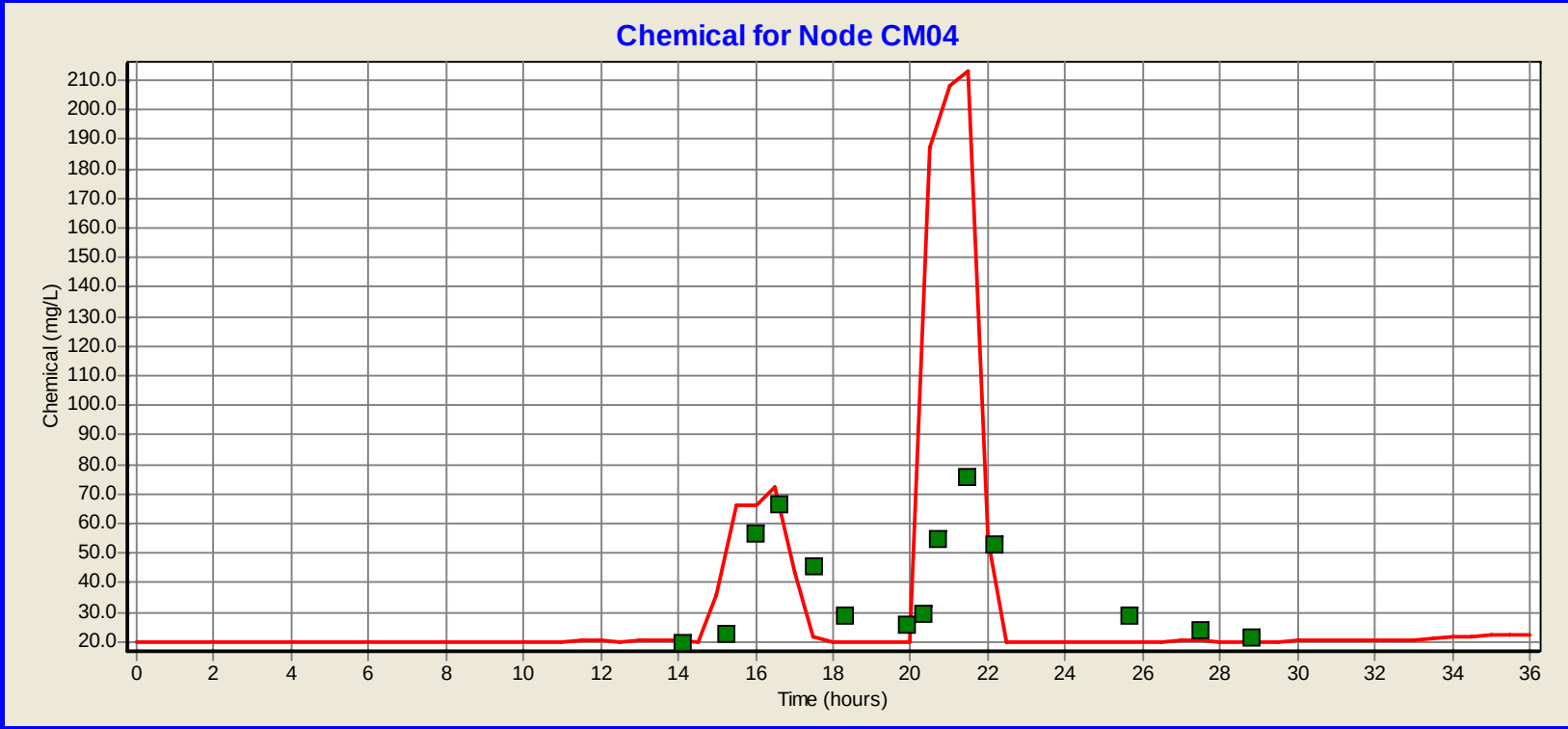
Comparison of Model & Field Data

Before calibration: Midway on dead end line → fair agreement



Comparison of Model & Field Data

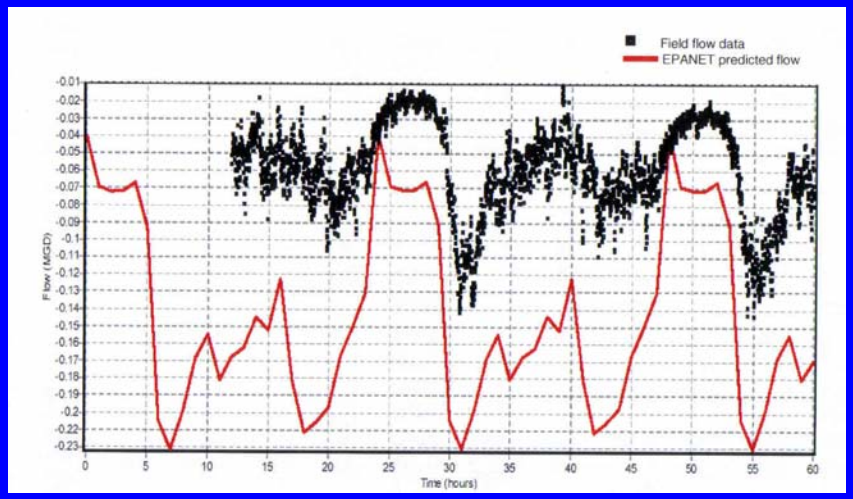
Before calibration: At far end of deadend → poorer agreement



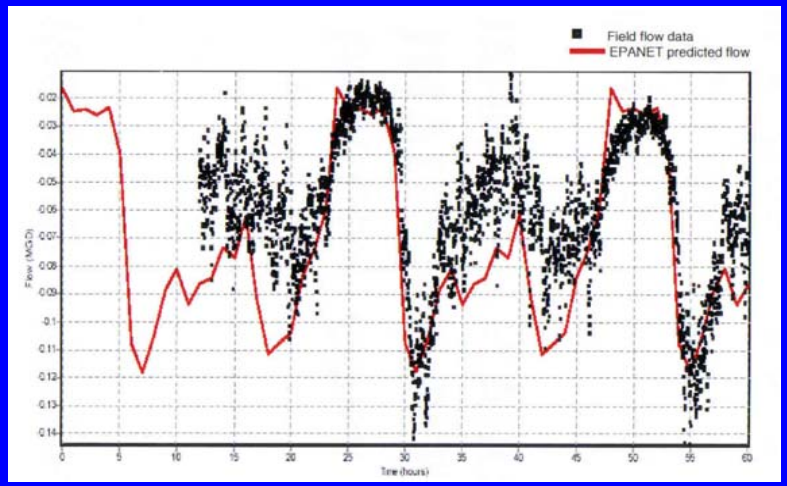
Flow Meters

- Can provide excellent information that is invaluable while calibrating models
- In the U.S. we don't generally do enough flow measurements

Before calibration



After demand adjustments



Tracer Study Evaluation

- Good agreement in travel times and concentrations at most stations after calibration
- More difficult to calibrate for small lines and deadends
- Was dispersion an issue in some of the dead-end pipes due to low velocities?
- Flow meters useful for adjusting demands
- Very useful data for calibrating model

Exposure Analysis

- Calculation of how long and at what concentrations, customers are exposed to contaminant (intensity & duration)
- Contamination pathways:
  - ingestion, inhalation and dermal exposure
- Typically evaluated statistically

Modeling Requirements for Exposure Analysis

- Relatively detailed representation
- Calibrated hydraulic model
- Extended period simulation
- Good demand data

Conclusions

- Model requirements for exposure analysis are more stringent than many modeling applications
- Tracer studies help user better understand distribution system operation & useful in calibration
- Stochastic nature of demand important factor in exposure analysis