Infrastructure Simulation and Analysis

A Brief Introduction

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Infrastructure Systems

- Distributed
- Complex
- Highly Interdependent
- Constantly Changing
- Vital
- At risk:
  - Dilapidation
  - Forces of Nature
  - Supply/Demand
  - Malevolent Threats

Electric Power

Petroleum

Natural Gas

All offshore NG & Petroleum production shut in
Highest probability of damage
Projected surge zone
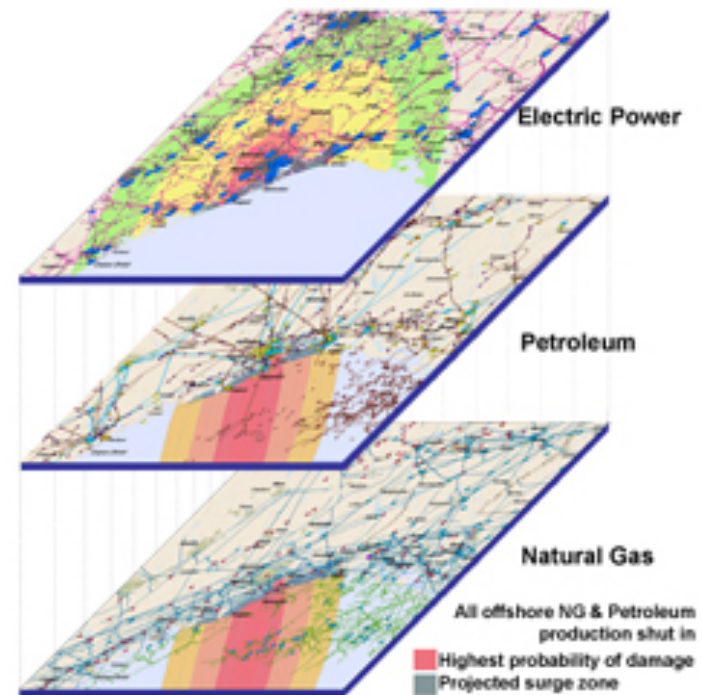
Computational needs

- Population growth model
- Efficient use of resources
- Risk analysis
- Infrastructure modeling
- Analytical studies
- Real-time analysis
- Sensor Placement
- The applications are endless. . .

Fast Analysis

Analytical Studies

Risk Analysis

Applied Capability Development

Infrastructure Model Development
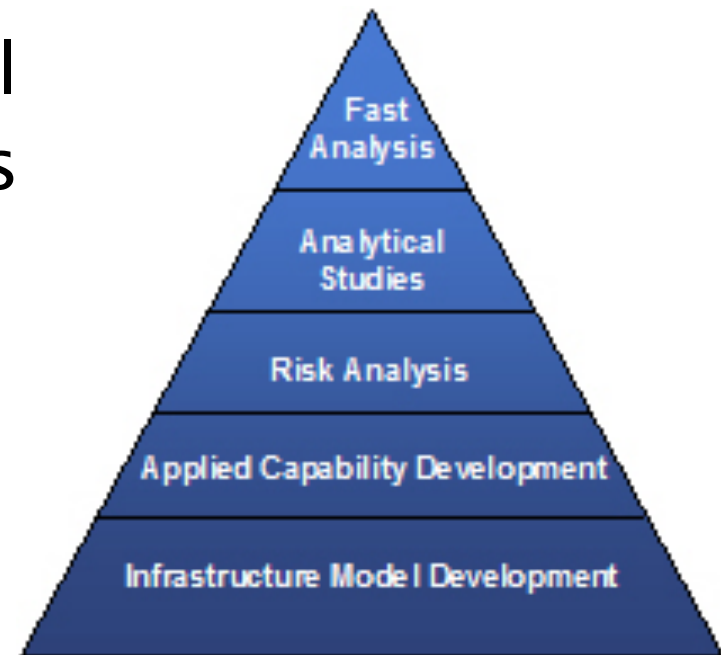
# Accurate models are vital for:

- Economic development
- Energy sustainability
- Cost planning
- Ecology
- Environment
- Quality of life
- Many others. . .
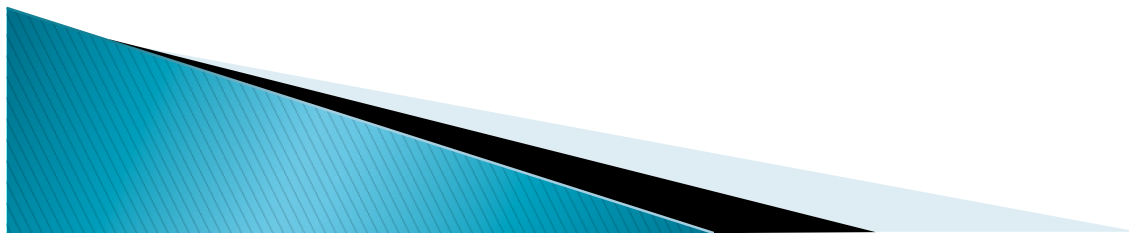
Water Systems

- Are a unique challenge:
  - Availability needs to be high
  - Often built on much older sub-systems
  - Demand is increasing dramatically
    - Population Growth
    - Energy need
  - Resources may be limited
  - Need to be monitored for quality and safety
  - Huge number of possible contaniments/problems in the system
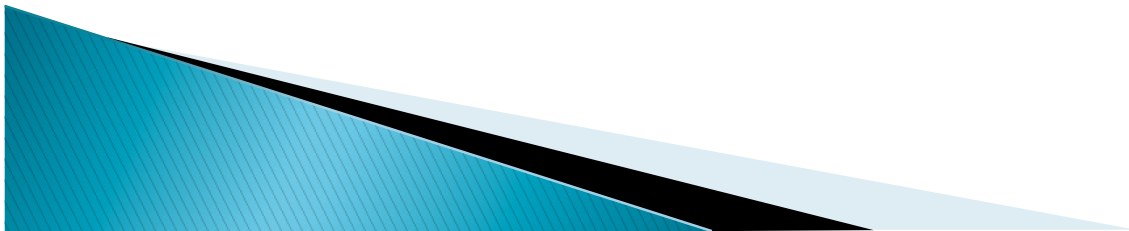
Water Systems (cont.)

- System Problems:
  - Chemical Contaminants
  - Biological Contaminants
  - Physical Damage
  - Source interruption
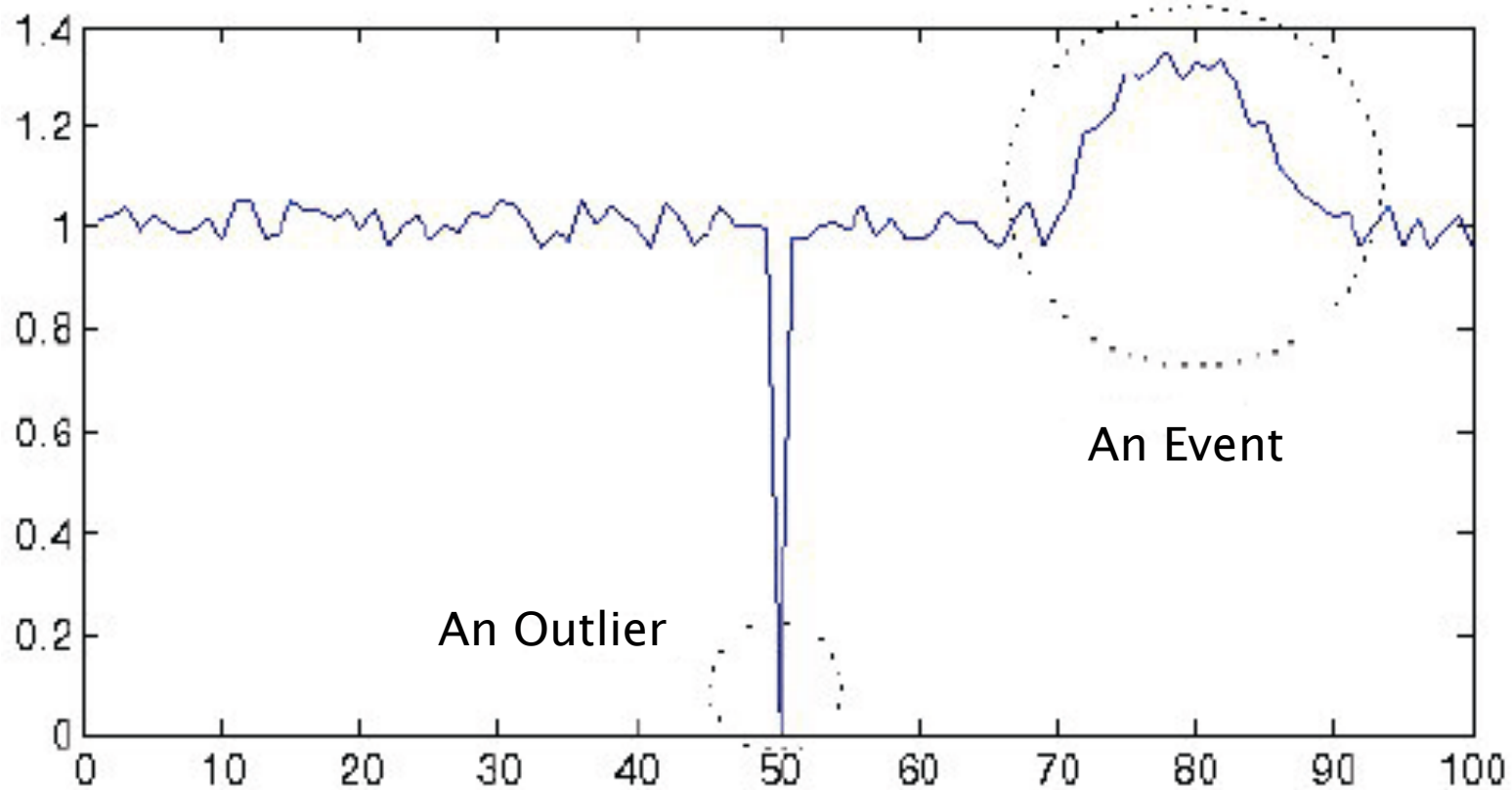 - Unauthorized use
- Sensors
  - Often "secondary" – Ph, Chlorine, Alkalinity, volume, etc.
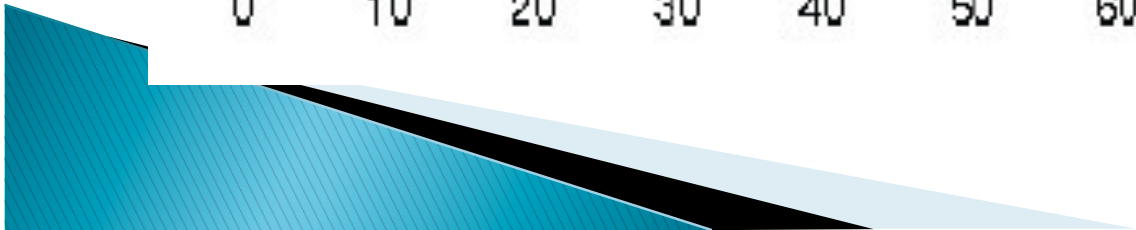 - More advanced (and expensive) sensors may not be feasible, cost prohibitive, etc

Water Systems (cont.)

▸ When is an "event" really an "event"?

Water Systems (cont.)

- When is an "event" really an "event"?

An Event with a baseline change
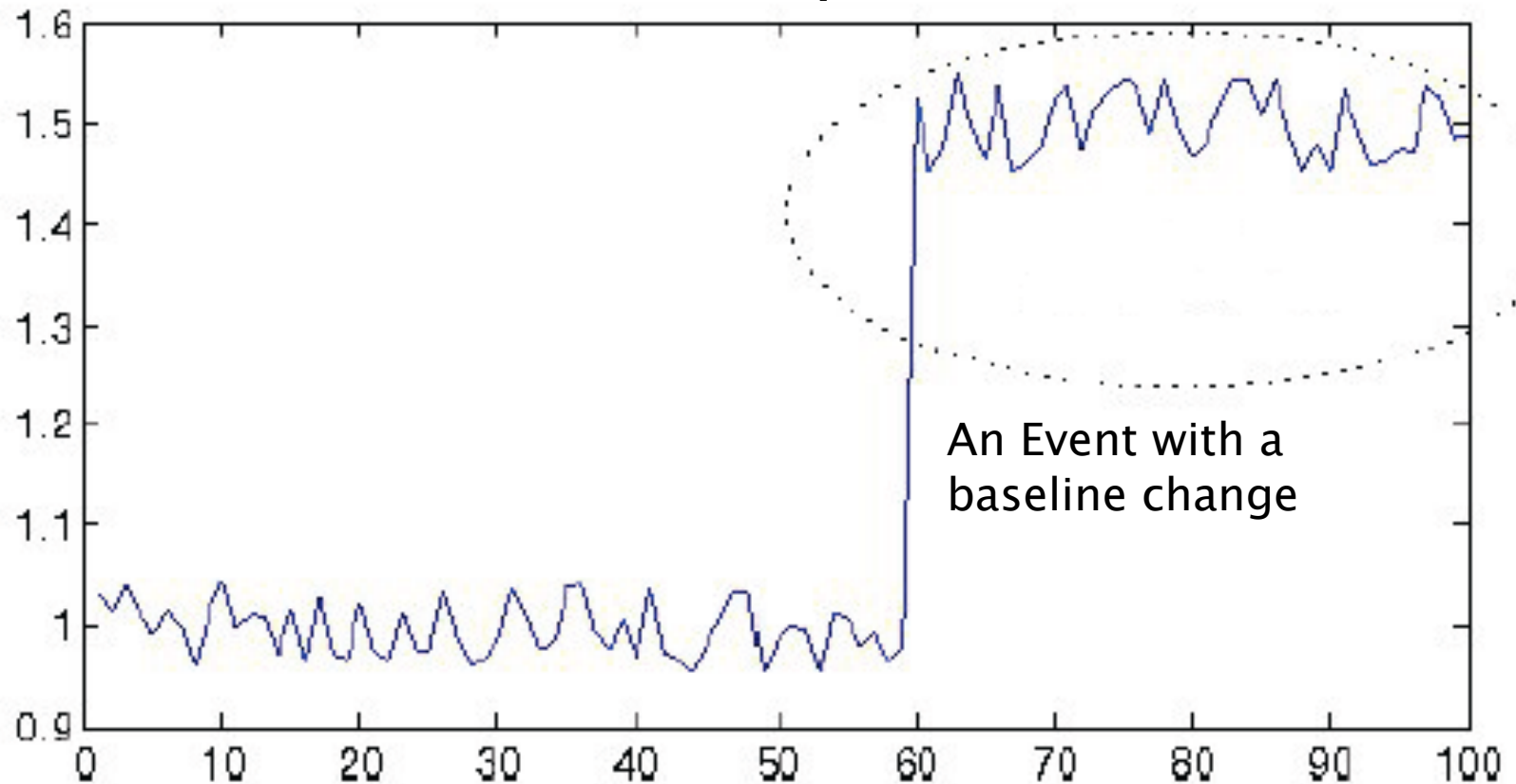
Water Systems (cont.)

Removes "noise" of day-to-day operations
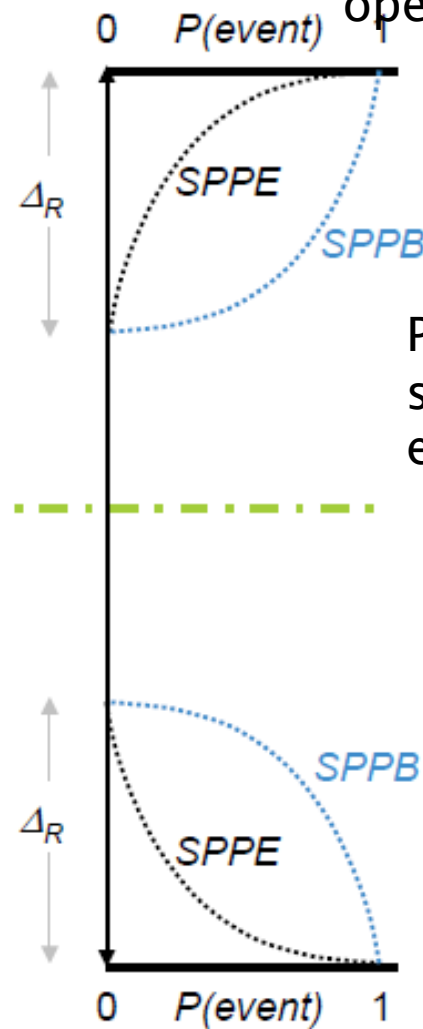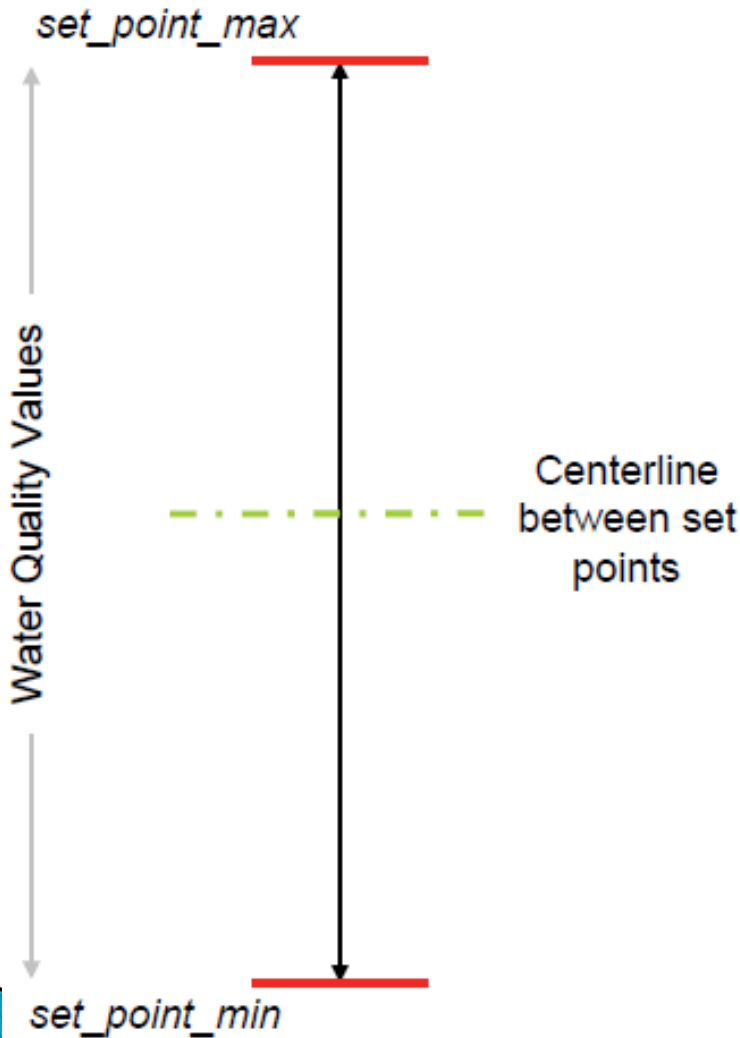
Provides more sensitivity for early warning

Sensor Placement

- Huge systems, limited resources
- Many potential points of failure

Source: EIA, 2003
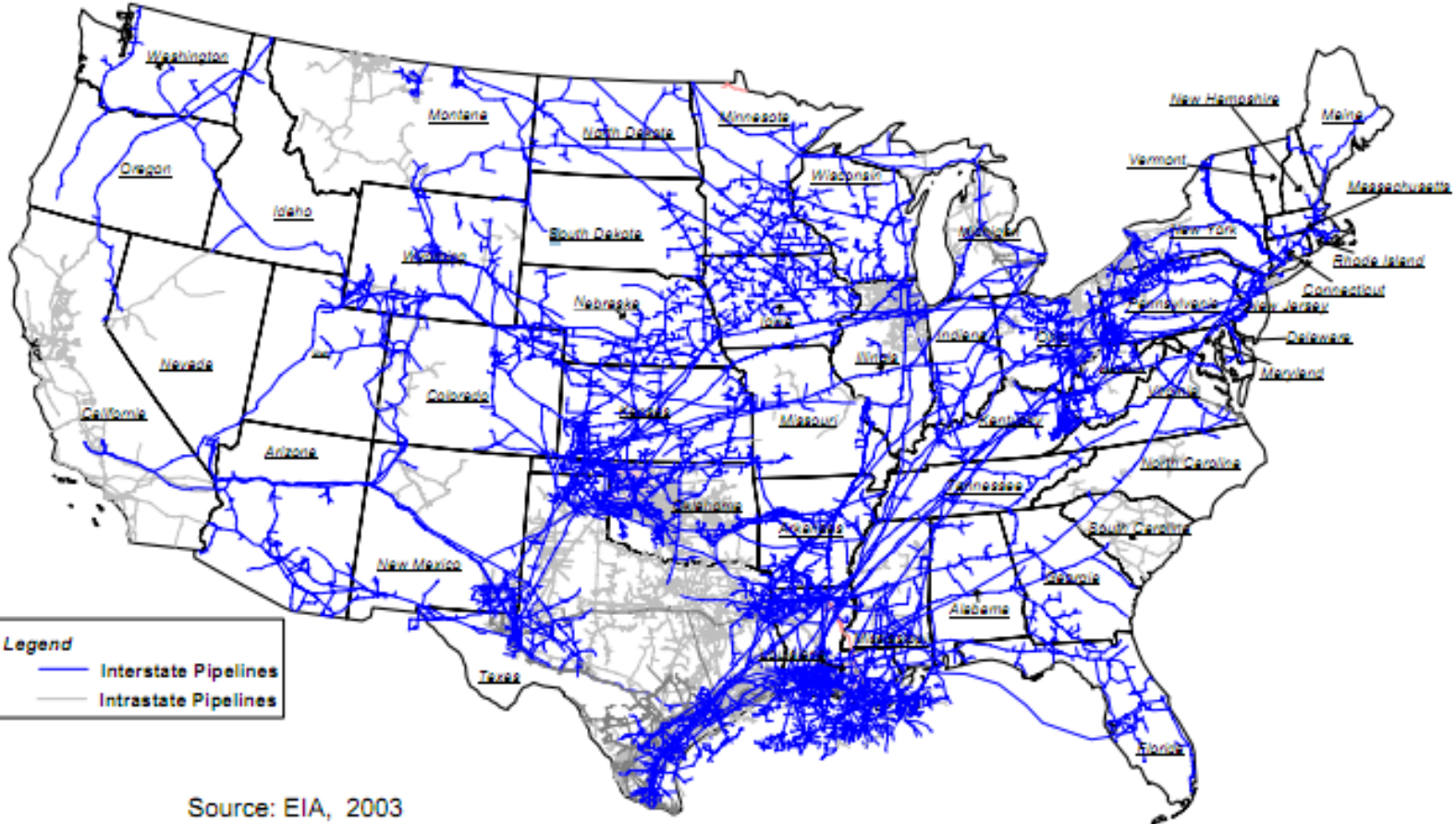
Sensor Placement (cont.)

- Need best coverage for lowest cost
- Parameters change drastically from system to system
- Changes in one system can affect others
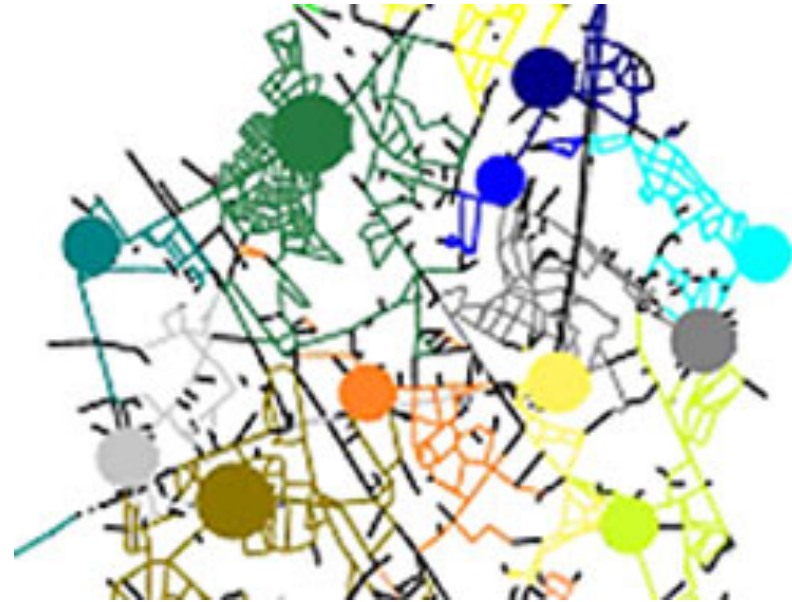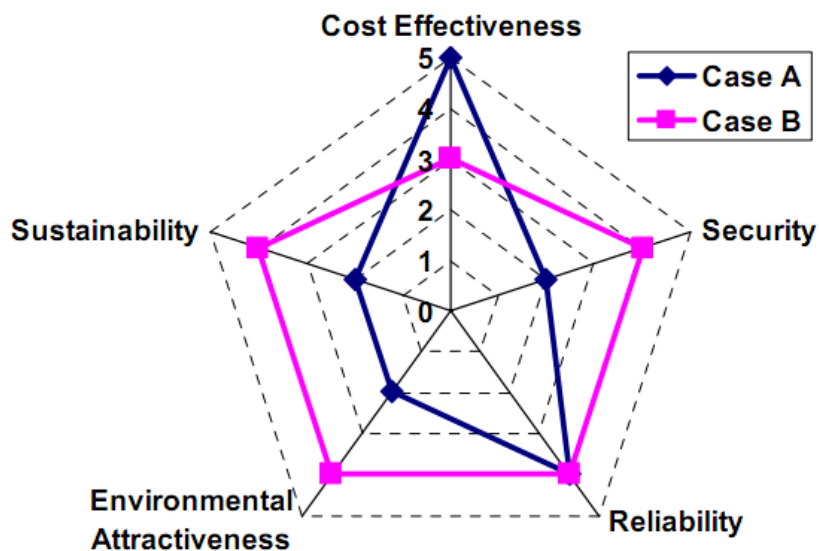
Some solutions

- Contamination warning systems (CWS)
  - EPA:
    - Classification and Analysis of Networked sensor ARraYs for Event Detection Systems (CANARY-EDS)
    - Water Security Initiative (WSI)
    - Vulnerability Self Assessment Tool (VSAT)
    - Water Health and Economic Analysis Tool (WHEAT)
- Sensor Placement
  - Sensor Placement Optimization Tool (SPOT)
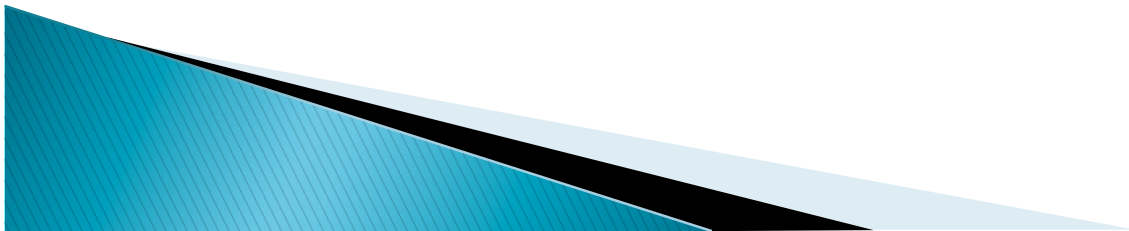
CANARY

- Contamination warning system
- Originally designed to test algorithm feasibility on historical data (offline mode)
- Expanded to include an on-line mode to monitor real-time data provided by SCADA systems
- Analyzes one step of data at a time, compares actual to predicted based on the previous information

Canary (cont.)

SCADA System

SCADA Database

Interface (e.g., EDDIES)

CANARY

Display of real-time results to system operator/analyst
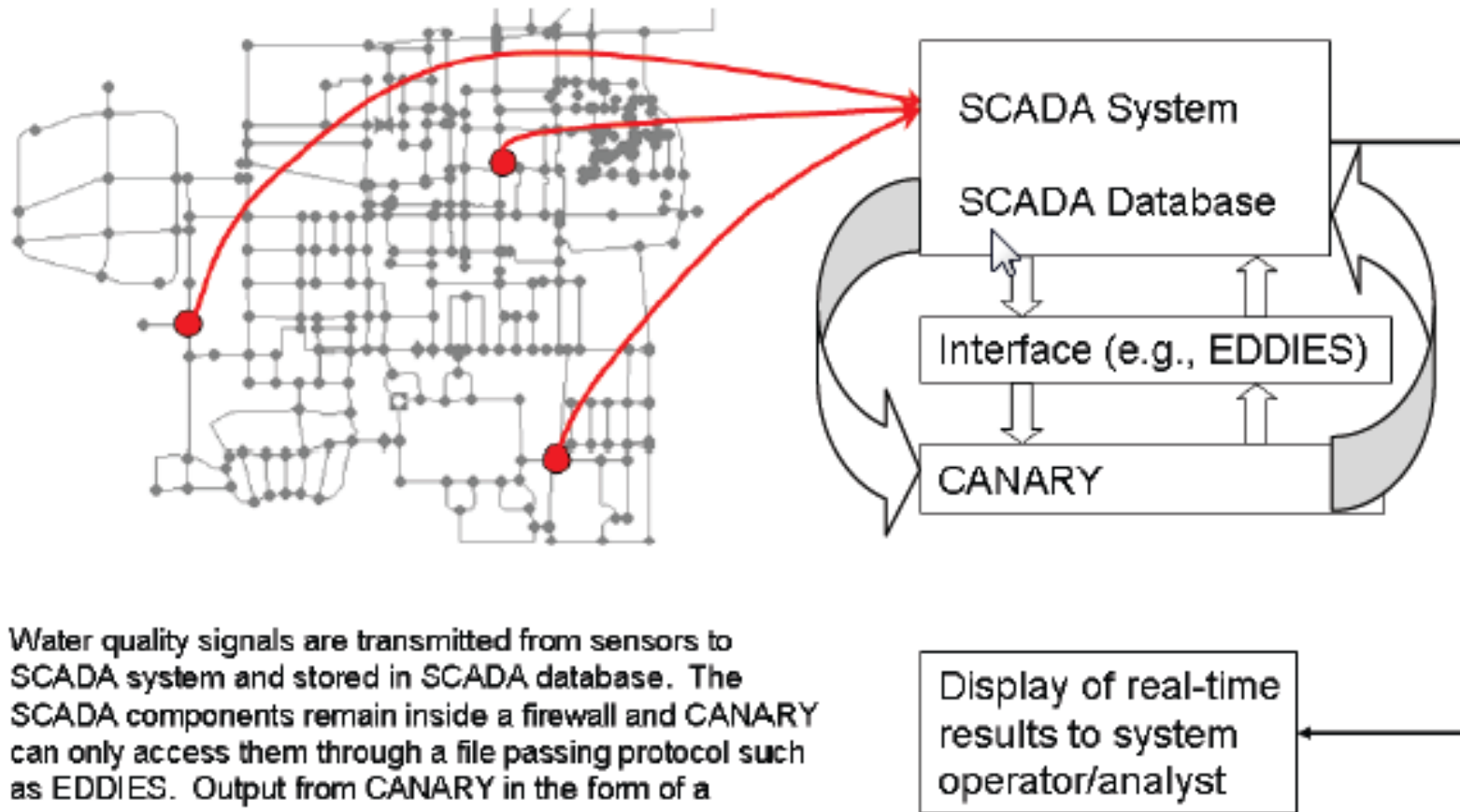
Water quality signals are transmitted from sensors to SCADA system and stored in SCADA database. The SCADA components remain inside a firewall and CANARY can only access them through a file passing protocol such as EDDIES. Output from CANARY in the form of a continuous probability of a water quality event or an alarm is transmitted back to the SCADA system – again through a file passing protocol using EDDIES or a similar system.

Canary (cont.)

ONLINE OPERATION

SCADA Connection

Get next obs.

Enough data to fill *window*? — Yes — Normalize

No

Normalize → Estimation

[INCF, MVNN, LPCF]

Estimation → Residuals

Outlier ← Residual Classification → Backgrd.

BED

P(event) → Probabilities

P(event) < τ_b (backgd.)   P(event) $\geq \tau_b$ (event)

Events & Baseline Changes

Member of pattern library? — Yes $n_o < n_B$

Reset BED   No   Alarm to SCADA System $n_o \geq n_B$ (baseline change – reset window)

Canary (cont.)

$$X_s = \frac{X_h - \bar{x}}{\sigma_x}$$

▶ Data is normalized
▶ Algorithms include:
  ◦ Linear Prediction Filter
  ◦ Multivariate Nearest Neighbor
  ◦ Set-point Proximity Algorithms (SPPB and SPPE)
  ◦ Consensus Algorithms
    • CAVE
    • CMAX
  ◦ Binomial event Discriminator and Event Time-out
  ◦ Pattern Matching based on historical data
  ◦ Home-grown algorithms

SPOT

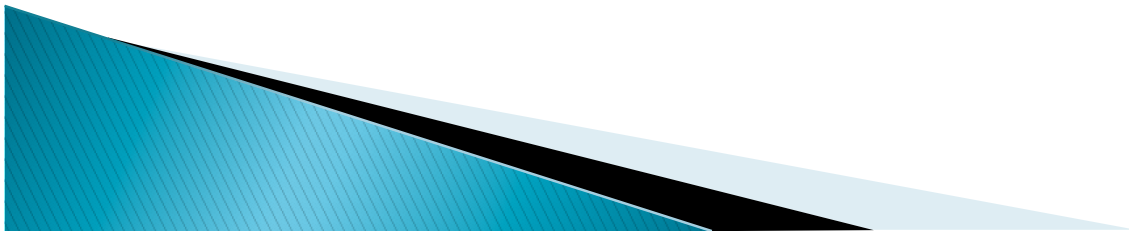- Designed to solve generic placement problems
- Make decisions based on contaminant impact based on external data
- Allows for trade-offs between minimizing exposure, illness, spatial extent, detection time, and cost.
- Designed to solve complex systems (order of 10,000 pipes and junctions) on simple hardware (i.e. a desktop computer)
- Heuristic methods used to calculate mean impact sensor placement formulation

Reference

- Information and graphics from:
  - "Infrastructure Surety and Sustainability", Mike Hightower, Sandia National Labs (http://www3.abe.iastate.edu/biobased/Hightower.pdf)
  - Case Study Application of the CANARY Event Detection Software (Murray et al., 2010)
  - SPOT – A Sensor Placement Optimization Tool for Drinking Water Contamination warning System Design (Hart et al. 2007)
  - CANARY User's Manaual v. 4.3 (Hart et al.)
  - (Hall et al., 2007) Hall, J, Zaffiro, AD, Marx, RB, Kefauver, PC, Krishnan, ER, Haught, RC & Herrmann, JG, "On-line water quality parameters as indicators of distribution system contamination", Journal of the American Water Works Association, vol 99, no. 1, pp. 66–77. 2007.

Reference

- Additional Resources
  - (McKenna et al., 2006) McKenna, SA, Klise, KA & Wilson, MP, "Testing water quality change detection algorithms", Proceedings of the 8th Annual Water Distribution Systems Analysis Symposium (WDSA), ASCE, Cincinnatti OH. 2006.
  - (Klise & McKenna, 2006b) Klise, KA & McKenna, SA, "Water quality change detection: multivariate algorithms", Proceedings of SPIE Defense and Security Symposium 2006, Internation Society for Optical Engineering (SPIE), Orlando FL. 2006
  - (Hart et al., 2007) Hart, DB, McKenna, SA, Klise, KA, Cruz, VA & Wilson, MP, "CANARY: A water quality event detection algorithm development and testing tool", Proceedings of ASCE World Environmental and Water Resources Congress 2007, ASCE, Tampa FL. 2007.

Reference

- Additional Resources
  - https://software.sandia.gov/trac/canary
  - https://software.sandia.gov/trac/spot
  - http://www.sandia.gov/nisac/
  - http://www.epa.gov/nhsrc/news/news112607.html