

Exceptional service in the national interest



Sampling to Increase Certainty About the Extent of the Contaminated Zone

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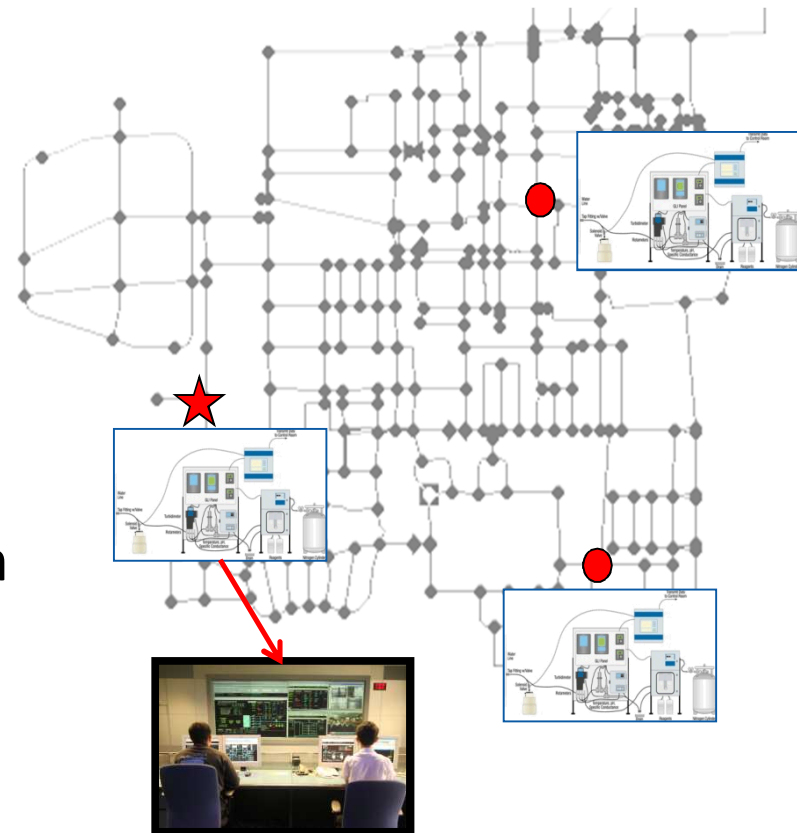
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Background

- Water distribution systems are vulnerable to intentional or accidental contamination through multiple points of access
 - Deliberate: terrorism, criminal activity
 - Mechanical: cross contamination, pipe breaks, backflow
 - Natural disasters: flooding, hurricanes
 - Environmental: algal blooms, chemical spills, treatment failures
- Contamination could cause severe public health consequences and significant economic impacts
- Good decisions are difficult without using well calibrated up-to-date infrastructure models due to complex flow paths
- State of the art tools are needed to help detect and mitigate the consequences of contamination

Contamination Warning Systems

- Water quality monitors are located throughout system
- Anomaly detection systems alert water utility operators of water quality concerns
- Emergency response and consequence management plans need to be initiated after detection



Response Strategy

- When responding to an incident, there are many questions to address

**Where is the source
of the contamination?**

When did the incident
start?

What is the contaminant?

Does it react with anything in the water or pipes?

Where should samples be taken?

How much of the system is affected?

What response action would be most effective?

Sampling

- Focused on sampling as part of response strategy
- Following an alert of anomalous water quality, sampling could help determine
 - Existence of a contamination incident
 - Extent of contaminated area
 - Source of contamination
 - Type of contaminant



Sampling Locations

- Identifying effective sampling locations can be affected by
 - Purpose
 - Confirmatory
 - Extent
 - Uncertainties
 - Hydraulics
 - Infrastructure
 - Contaminant
- Modeling and simulation tools can assist in identification of these locations
 - Evaluate different metrics
 - Extent of contamination
 - Population impacted

Sources of Uncertainty



Customer Water Use

Valve Closures

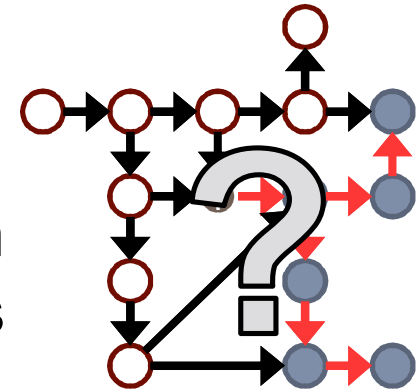


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Reaction Dynamics

Contamination
Characteristics

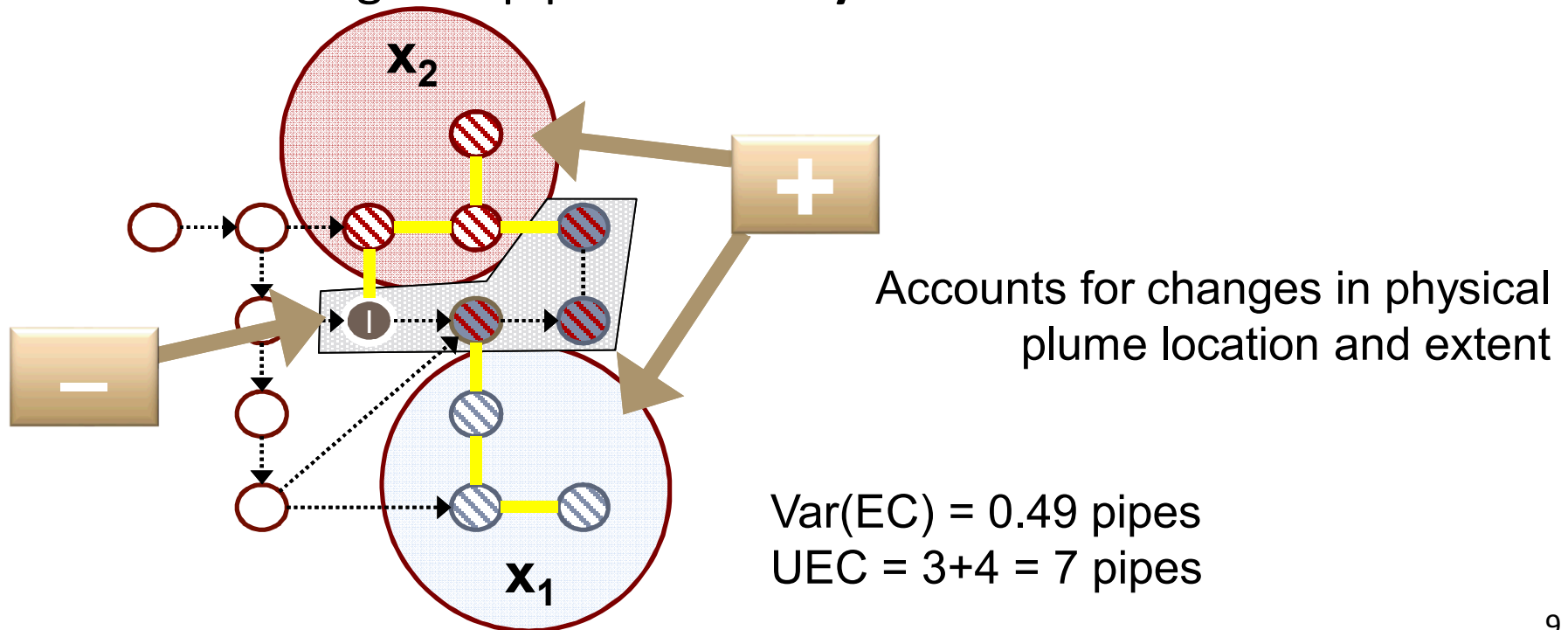


* Photo by Heather Smith (The Alloy Valve Stockist's photo gallery.)
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Unknown EC (UEC)

- Will help identify areas from which to select sampling locations

UEC = length of pipes that **possibly** have been contaminated, **minus** the length of pipes **definitely** contaminated



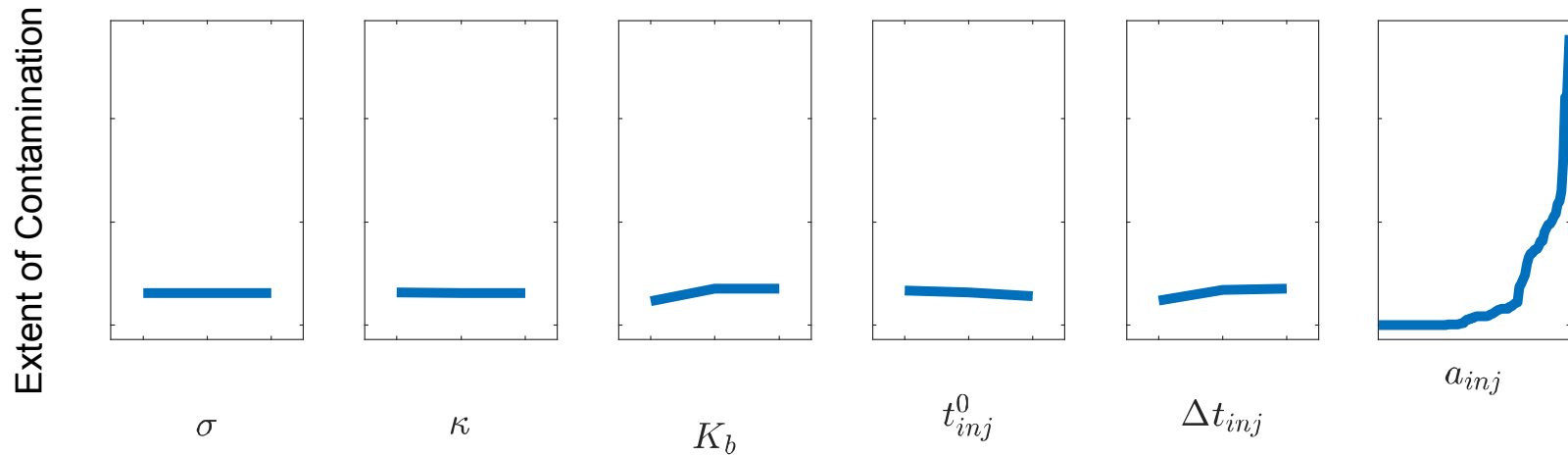
Simulation Studies

- Used a real WDS model for a city of around 300,000 people
- Varied parameters for
 - Nodal demands (σ)
 - Valve status (κ)
 - Bulk reaction coefficient (K_b)
 - Injection start time (t_{inj}^0)
 - Injection duration (Δt_{inj})
 - Injection location (a_{inj})
- Ran simulation for a duration of 40 hours
- Completed over 1 million simulation runs



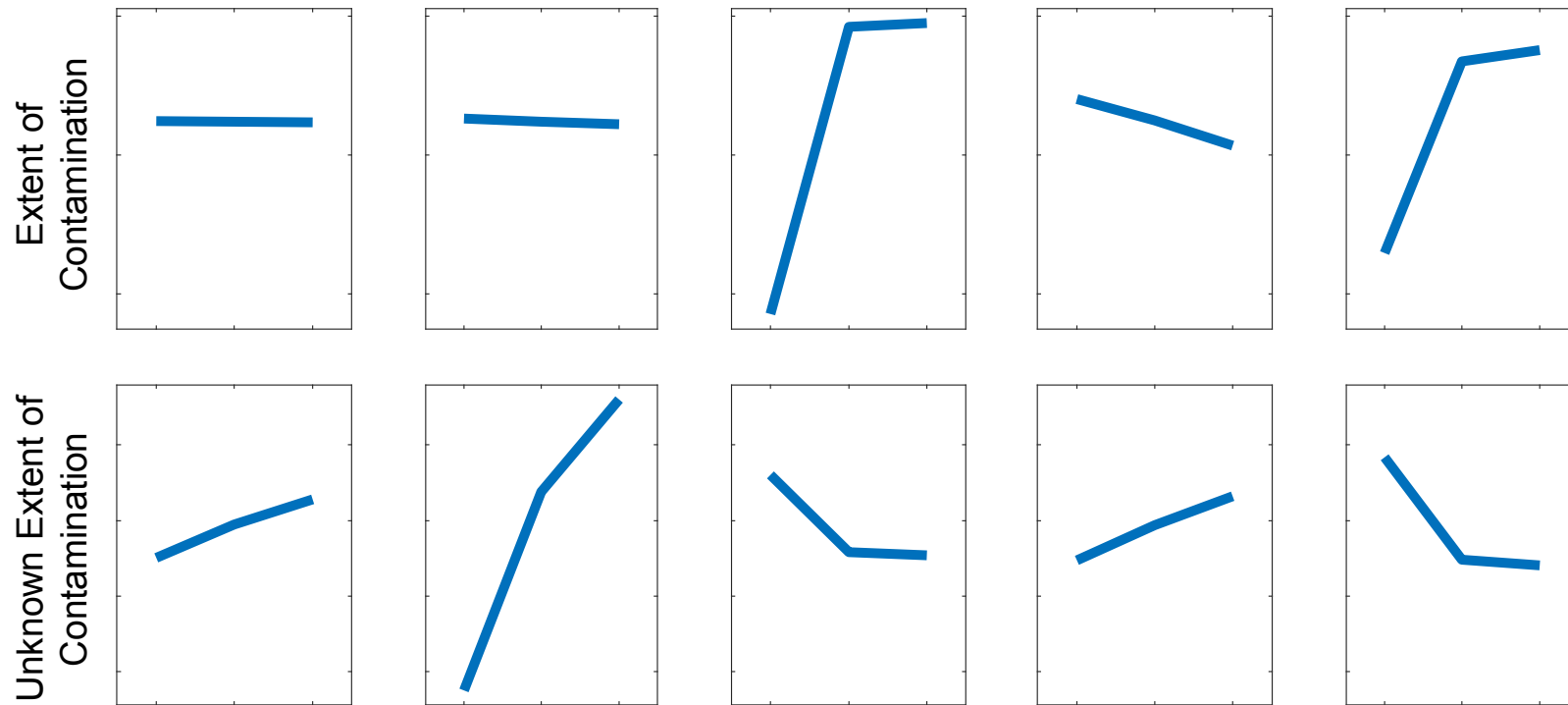
Results (Main Effects)

- Location, location, location ...

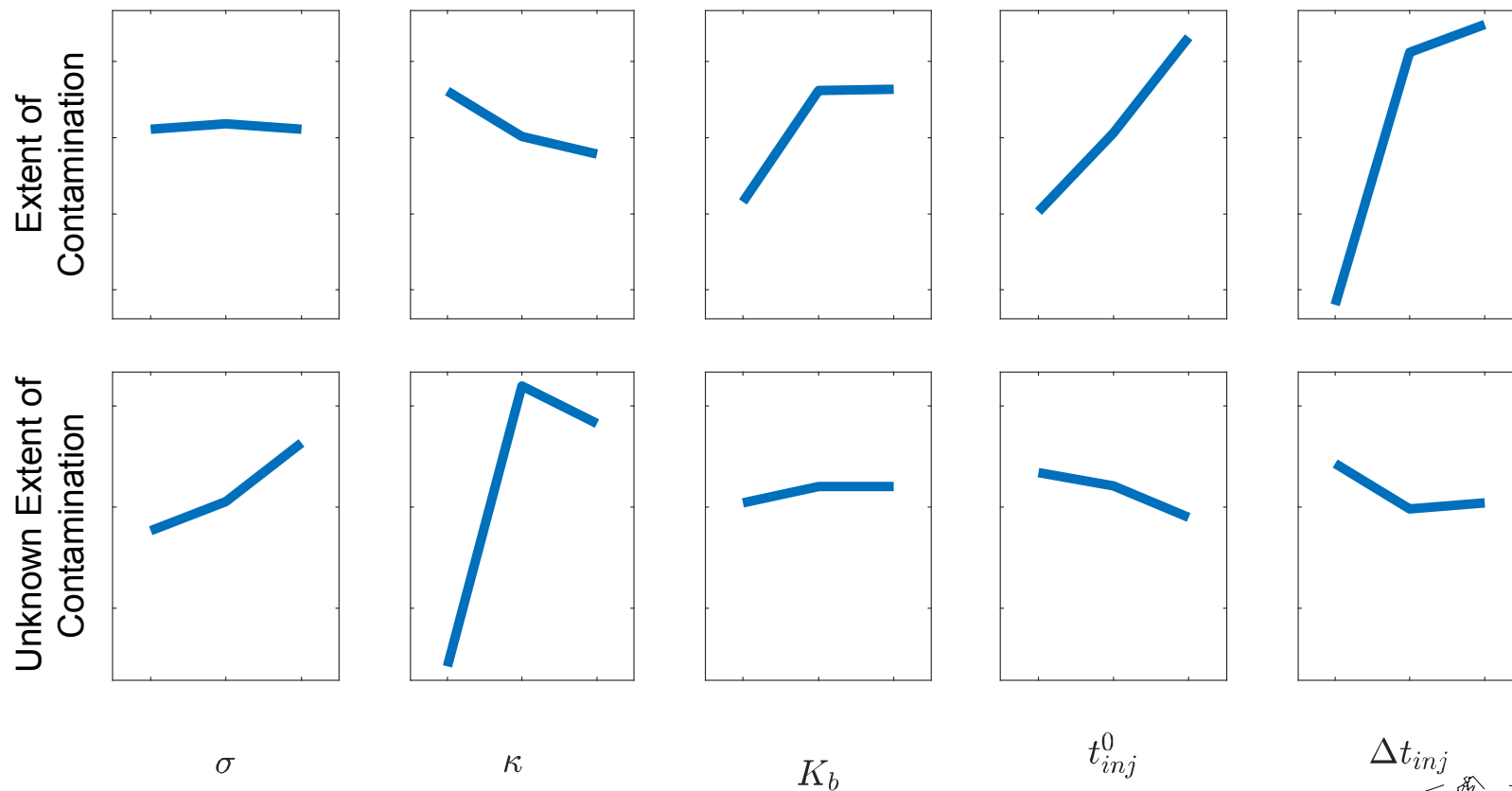


- Injection location overwhelms all other variables ...
this is why source identification is so important

Example: The Reservoir

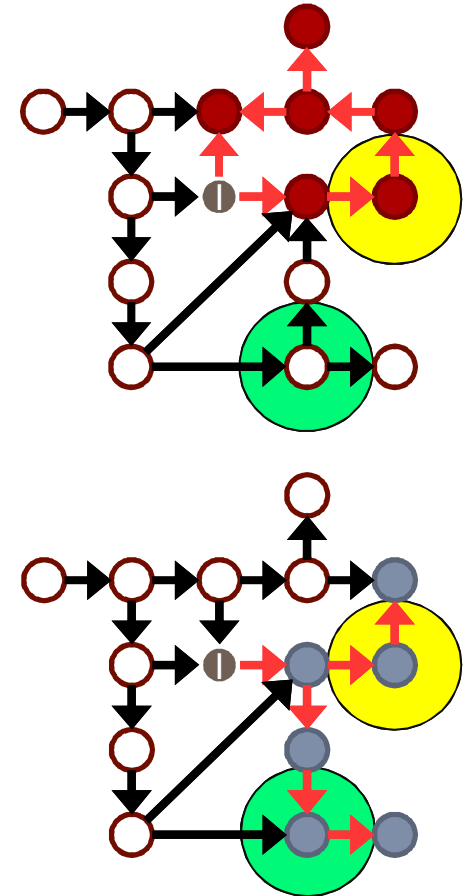


Example: Mid-network Node



How This Helps Sampling ...

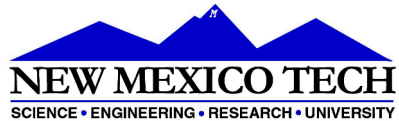
- Direct efficient sampling
 - Green dots help distinguish plume
 - Yellow dots do not help
- By sampling strategic locations, the injection location, plume edge and extent can be identified simultaneously



Conclusions and Future Directions

- Knowing **where** and **when** contamination started are the most important factors to identify
- Once injection location is known, uncertainty in valve settings and demand patterns play major role in finding the edges of the contaminant plume
- Full analysis of trends and uncertainty quantification to be completed
- Integration of this information in source identification and grab sample planning algorithms
- Is it possible to use this information for better every-day sampling plans?

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