Hydrocarbon Groundwater Plume Stability and Persistence: Lessons learned from 32 sites and 5 million data points

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Remediation Technologies Symposium 2025

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01

02

03

Today's Roadmap:

1. GW sampling and variability
2. Autonomous sensors and benzene trends
3. Why GW models disagree and solutions
4. GW Models: LiORA Trends and Insights

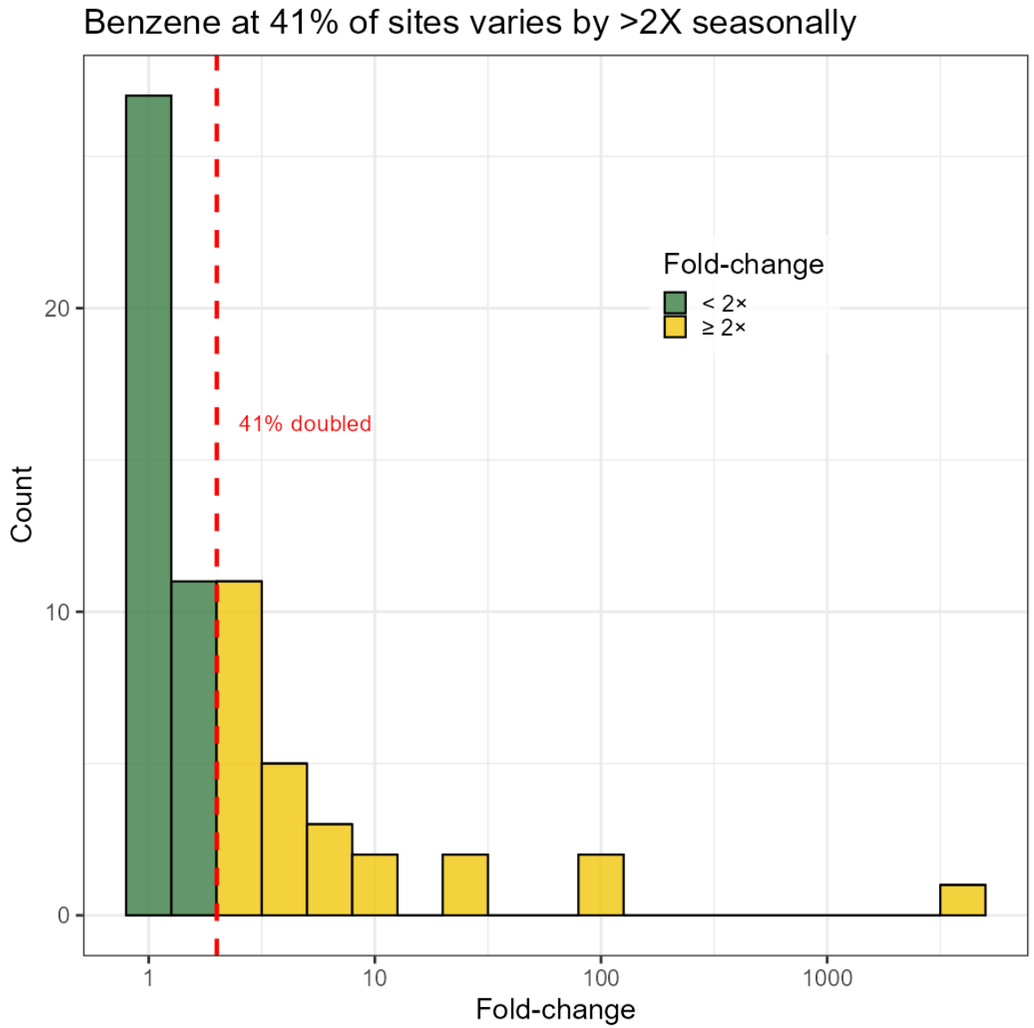
Remediation Technologies Symposium 2025

How do we measure groundwater plumes?

We measure dissolved concentrations once or twice per year.

Is that the best approach?

GW Sampling: Same well, same season, same result?



Benzene across 11 sites with groundwater wells sampled at least twice during a season

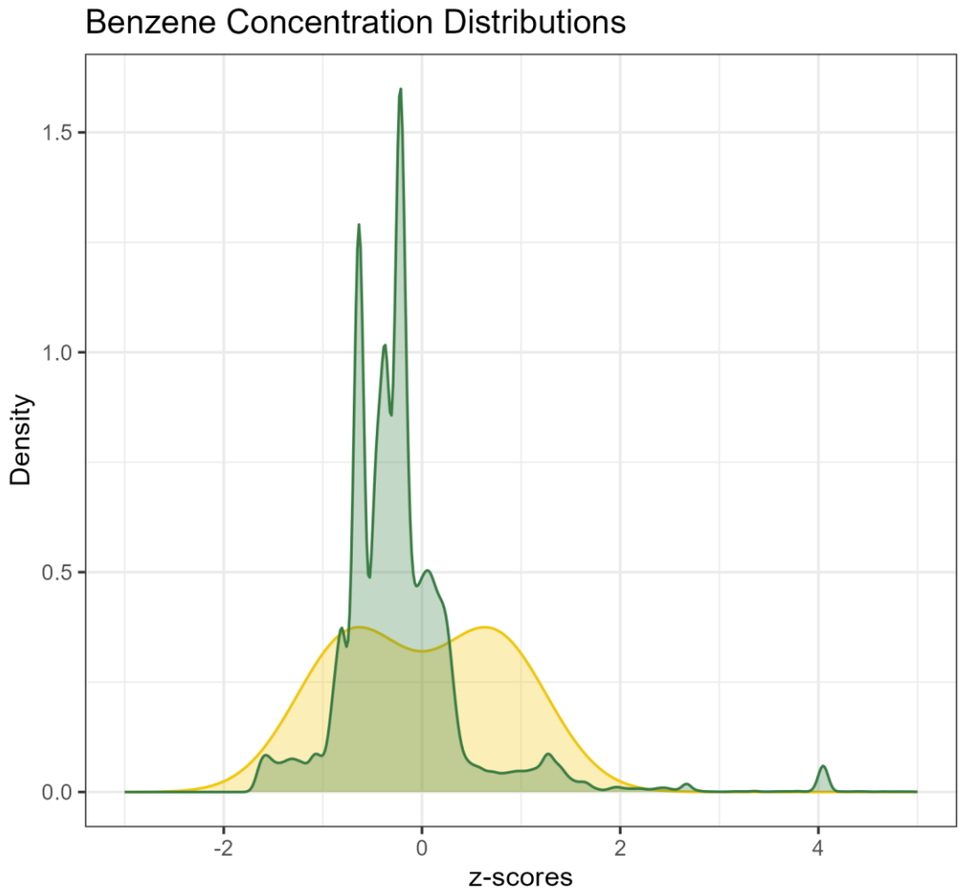
- Across **64 wells** and **138 samples**, only **28% were the same** (no variance)
- Only **half** of subsequent samples were **within 50%** of the previous measurement
- **41% varied by a factor of two or more!**

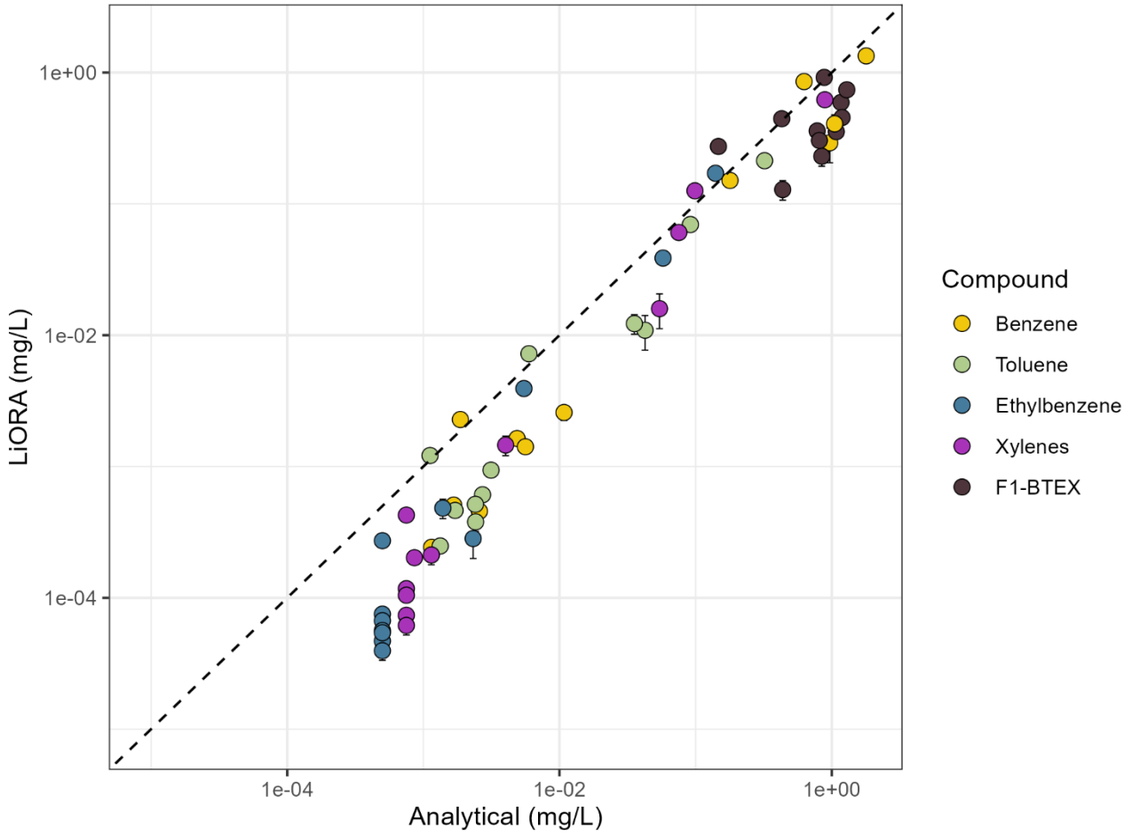
LiORA Water Sensor measures:
Vapour: CO_2, CH_4, total hydrocarbons Other:
Temperature and pressure.

Improving Groundwater Models with Autonomous Sensors

- LiORA’s autonomous sensors continuously measure contamination levels in groundwater.
- Data are measured, transferred, and stored automatically.
- Continuous sensor data updates groundwater models for improved risk assessment.

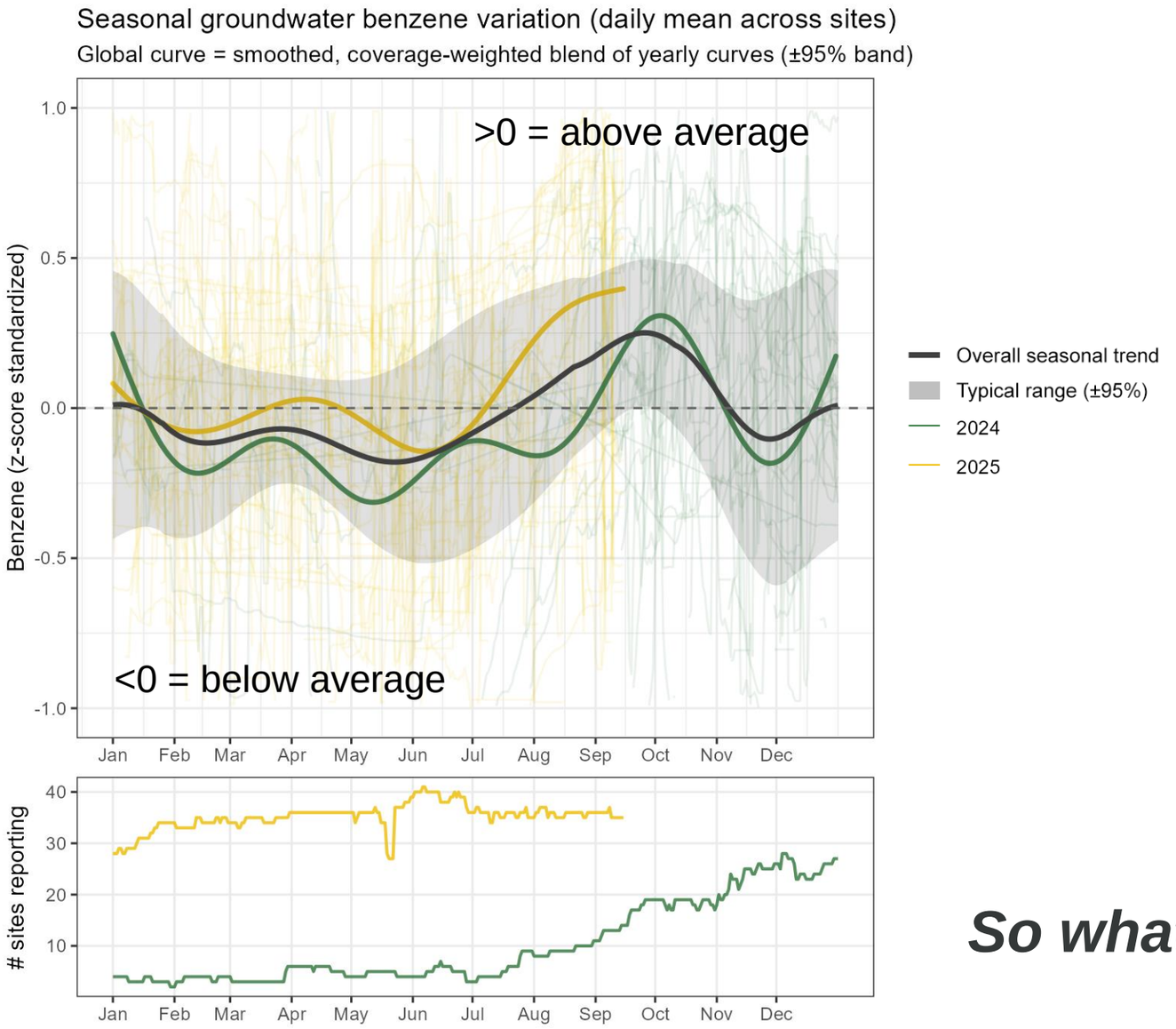
Are sensors and analytical telling the same story?





So what? *Repeated, continuous measurements at each location = increased concentration confidence*

Groundwater benzene varies seasonally



How does groundwater benzene vary seasonally?

- 42 sites (2024 & 2025)
- 5.7M half-hourly data points
- Lowest in spring, greatest in autumn

Implications?

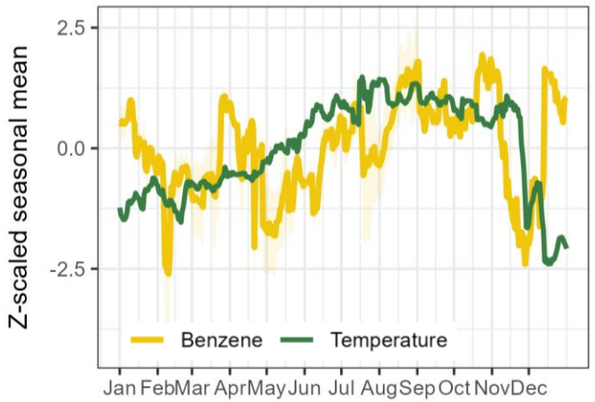
- Depending on when you sample, may not be directly comparable to previous measurements without seasonal context

So what? *Clear seasonal cycle confounds point in time sampling*

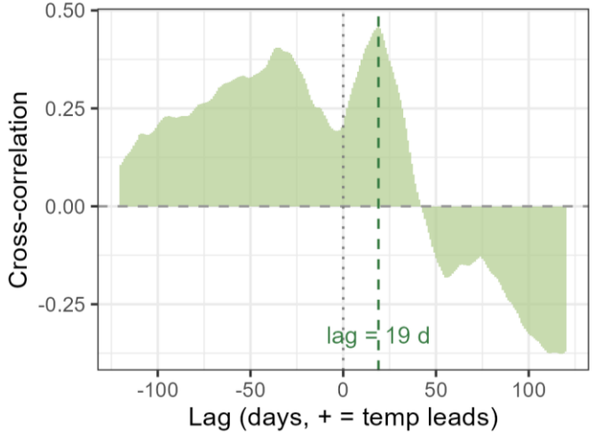
Benzene lags temperature

LiORA GW Sensors

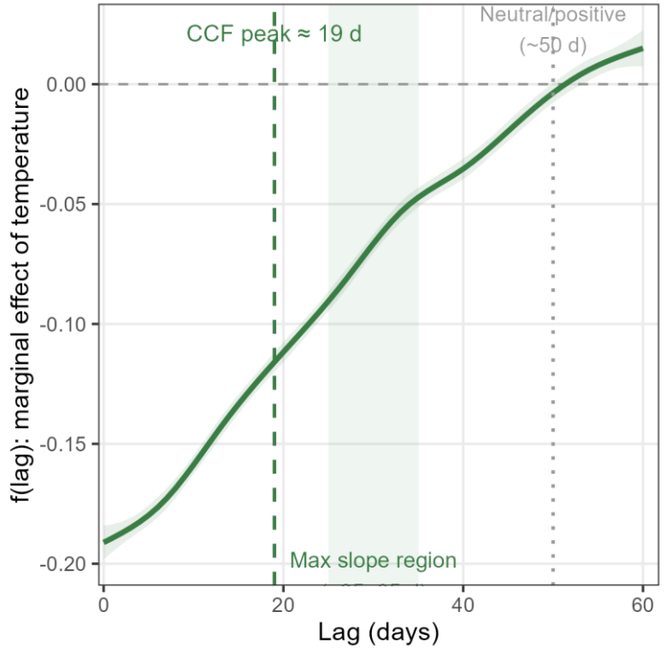
Temperature ↑ first, then benzene vapour due to thermal and diffusive inertia



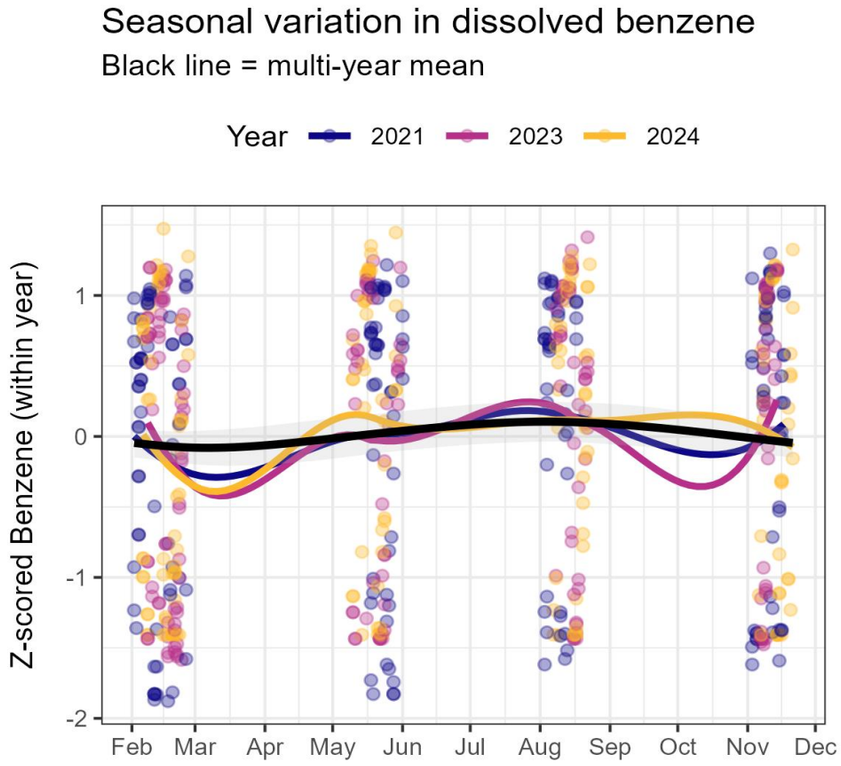
Peak lag ~3 weeks, positive association around 50 days



Lagged temperature effect confirms delayed benzene response



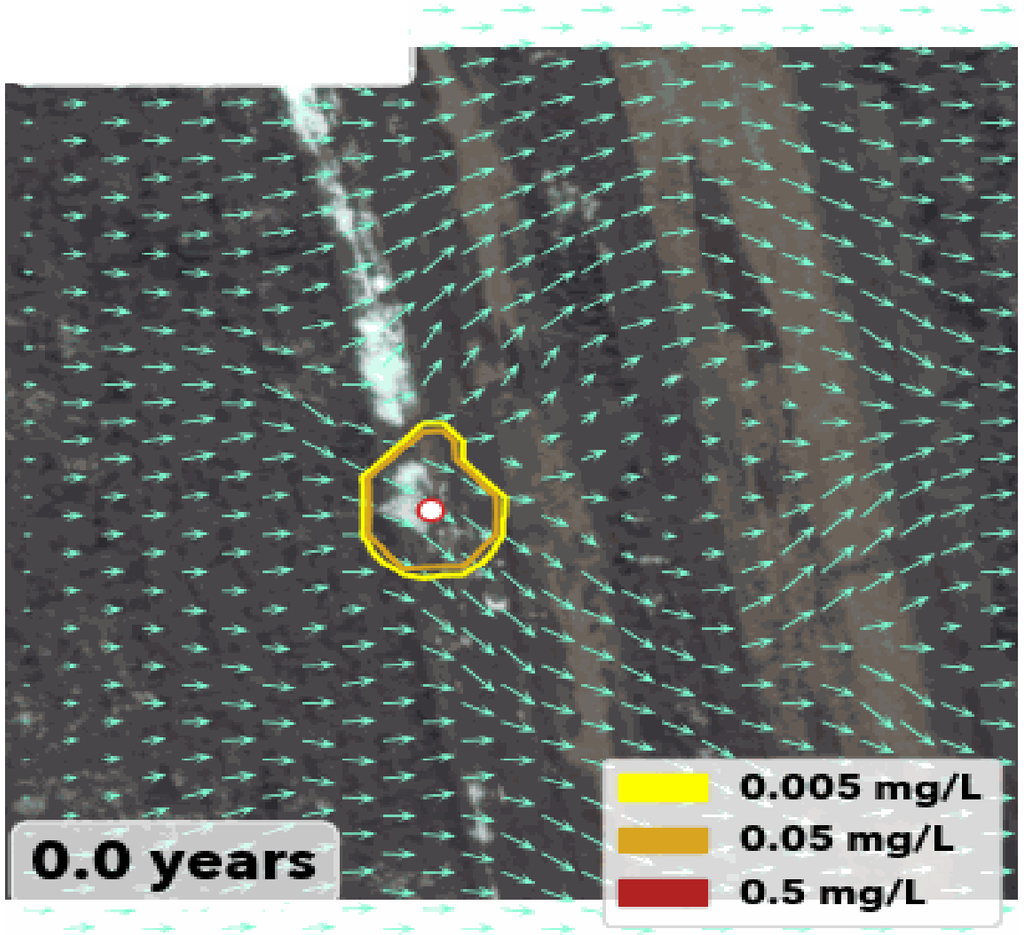
Groundwater PIT Data



Similar pattern in groundwater data – not simply a sensor phenomenon

So what? *Recognizing this lag helps separate true concentration changes from temperature-driven effects, improving how we interpret seasonal data, calibrate models, and schedule sampling.*

Why do we care about plumes?

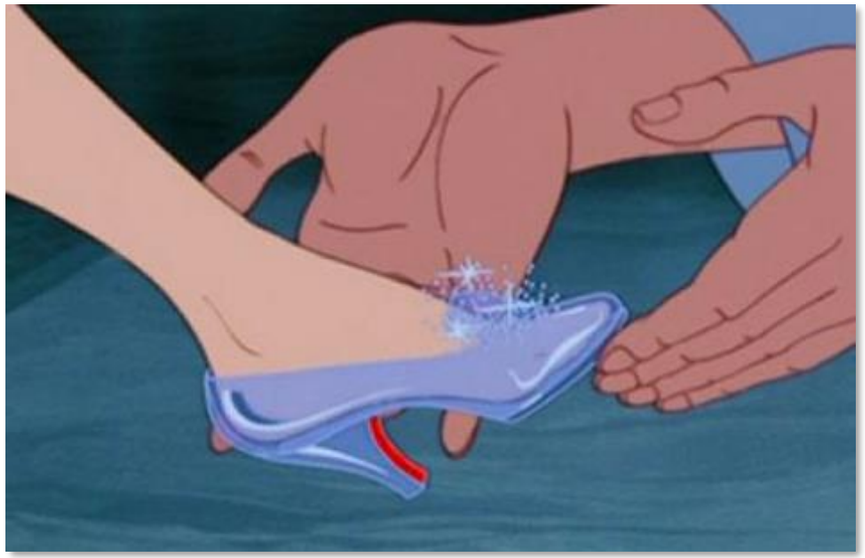


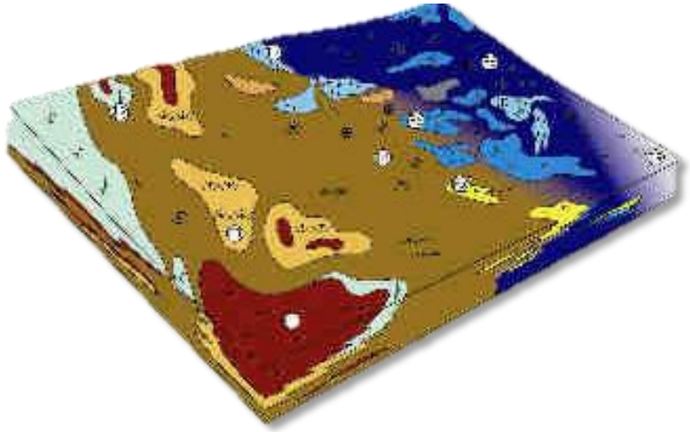
Vapour intrusion: Will humans be poisoned?

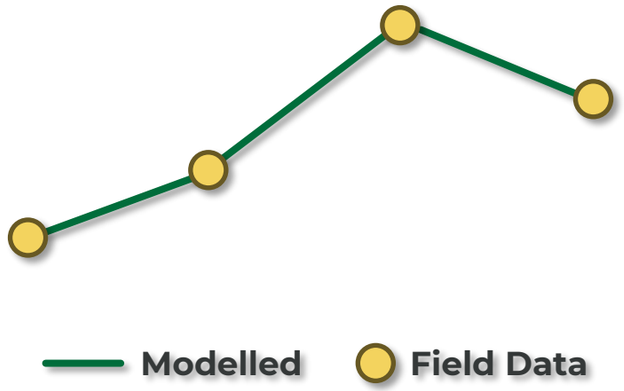
Water Health: Will humans, animals, or fish be poisoned?

Soil Health: Is soil getting healthier?

Cinderella Syndrome







Non-Uniqueness

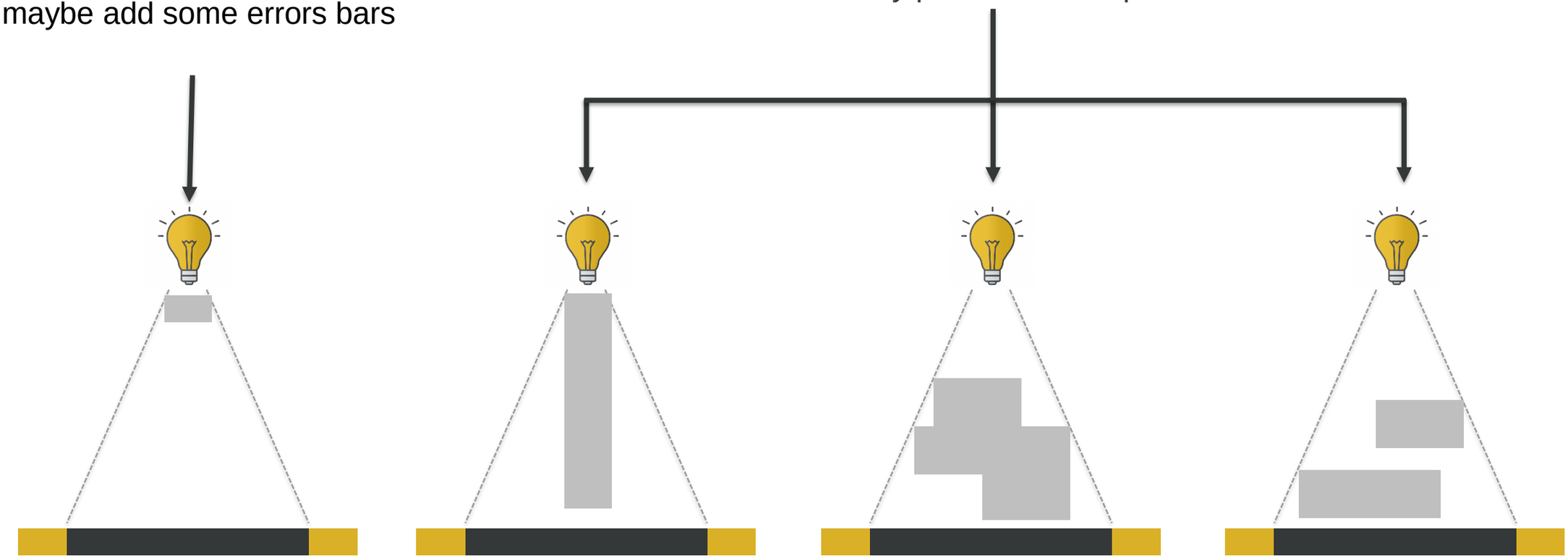
Model Parameters

Measurement Data

Deterministic Approach
Only considers one possibility, maybe add some errors bars

Stochastic Approach

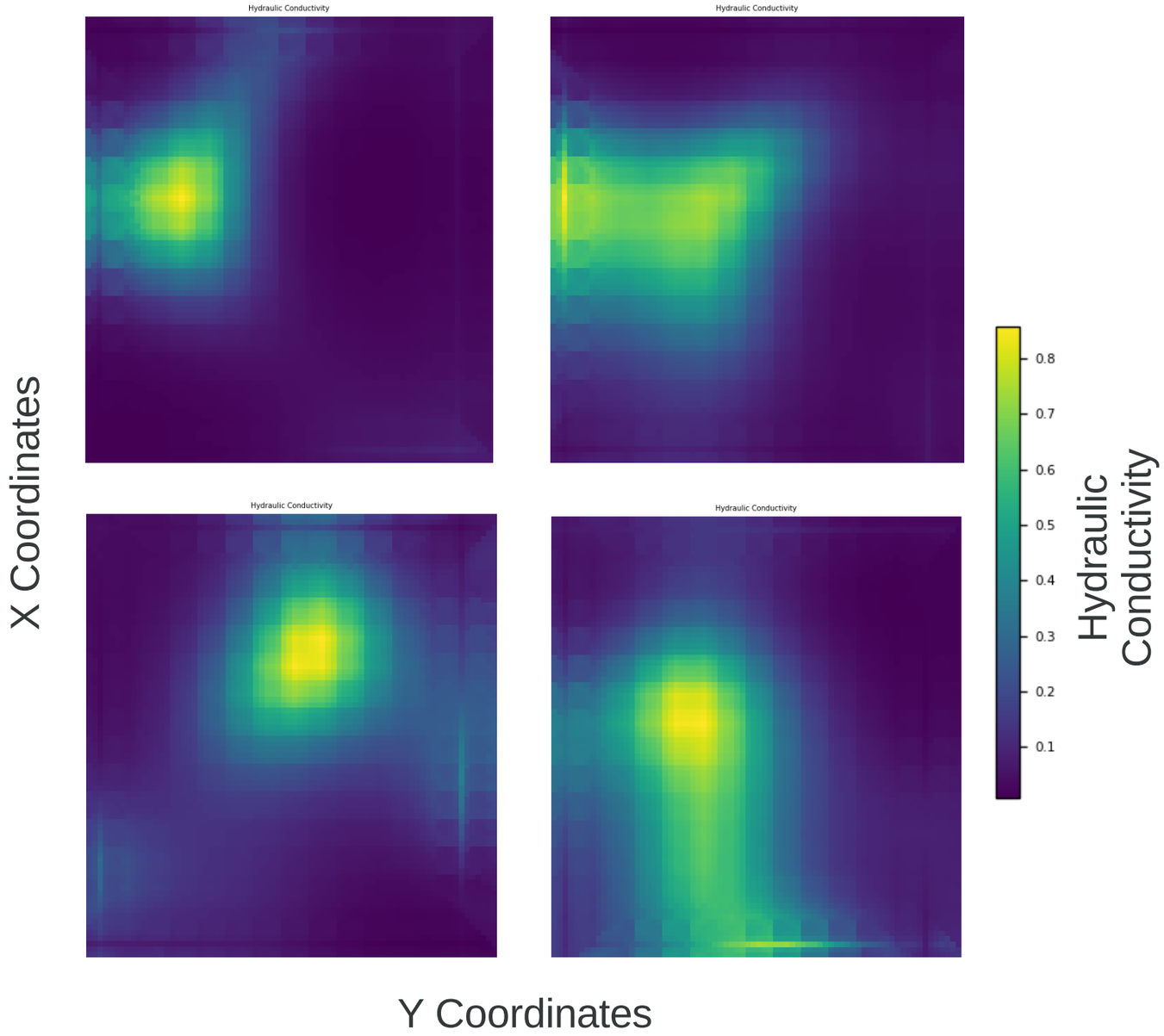
Considers as many possibilities as possible



Non-Uniqueness Means Uncertainty

Same site.
Same data.

Many Models



Uncertainty Means Poor Predictive Power

Age 11….

Age 14….

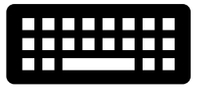
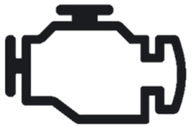
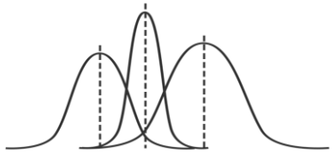
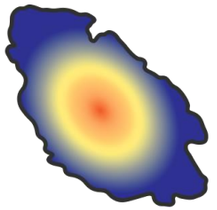
Age 17….

And finally, age 18

MATT GROENING

LiORA Trends

- **Adaptive groundwater models** that evolve with new data.
  - MODFLOW, HYDRUS-1D, & PEST++

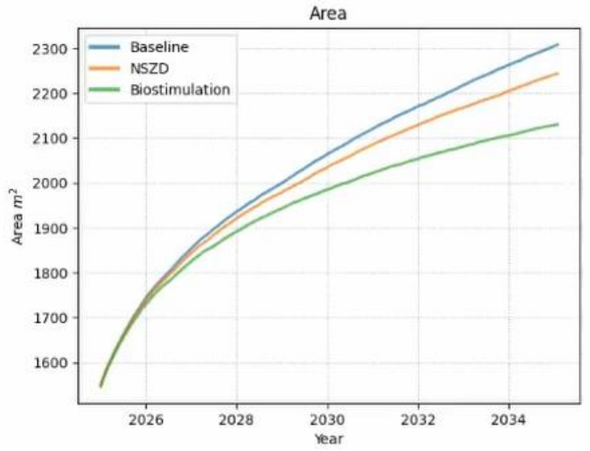
Inputs	Engine	Data Assimilation	Outputs
			
Data: *DEMs* *Hydrostratigraphy* *HYDRUS-1D* *Monitoring data* *LiORA sensor streams*	***MODFLOW:*** *GW/solute flow* ***PEST++:*** *automated calibration and uncertainty reduction*	***Iterative Ensemble Smoother:*** *updates models as sensor data arrive*	***Dynamic Plume extent/Persistence:*** *Risk forecasts*

So what? *Deliver decision-critical, uncertainty-quantified predictions of plume behavior and remediation performance.*

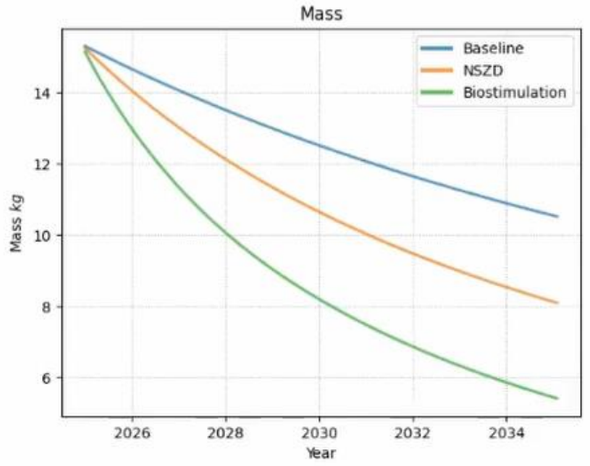
Historical benzene model: Built on PIT data only

Plume by Method of Remediation

Plume Area

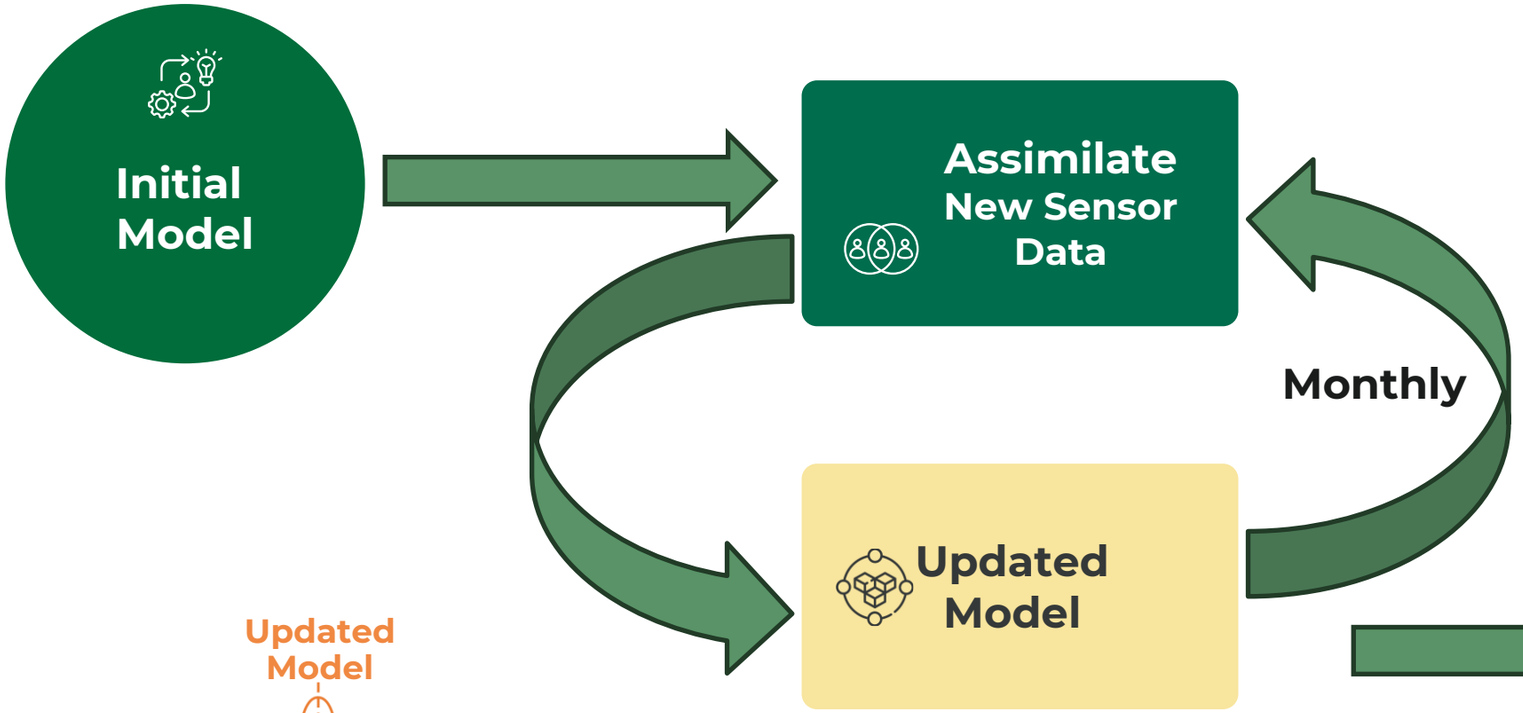


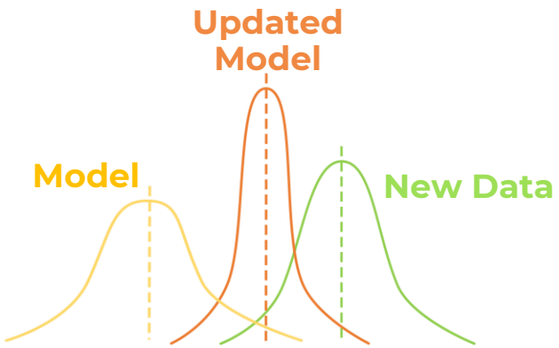
Plume Mass



Plume Risk Assessment

We can now build Machine Learning Bumpers



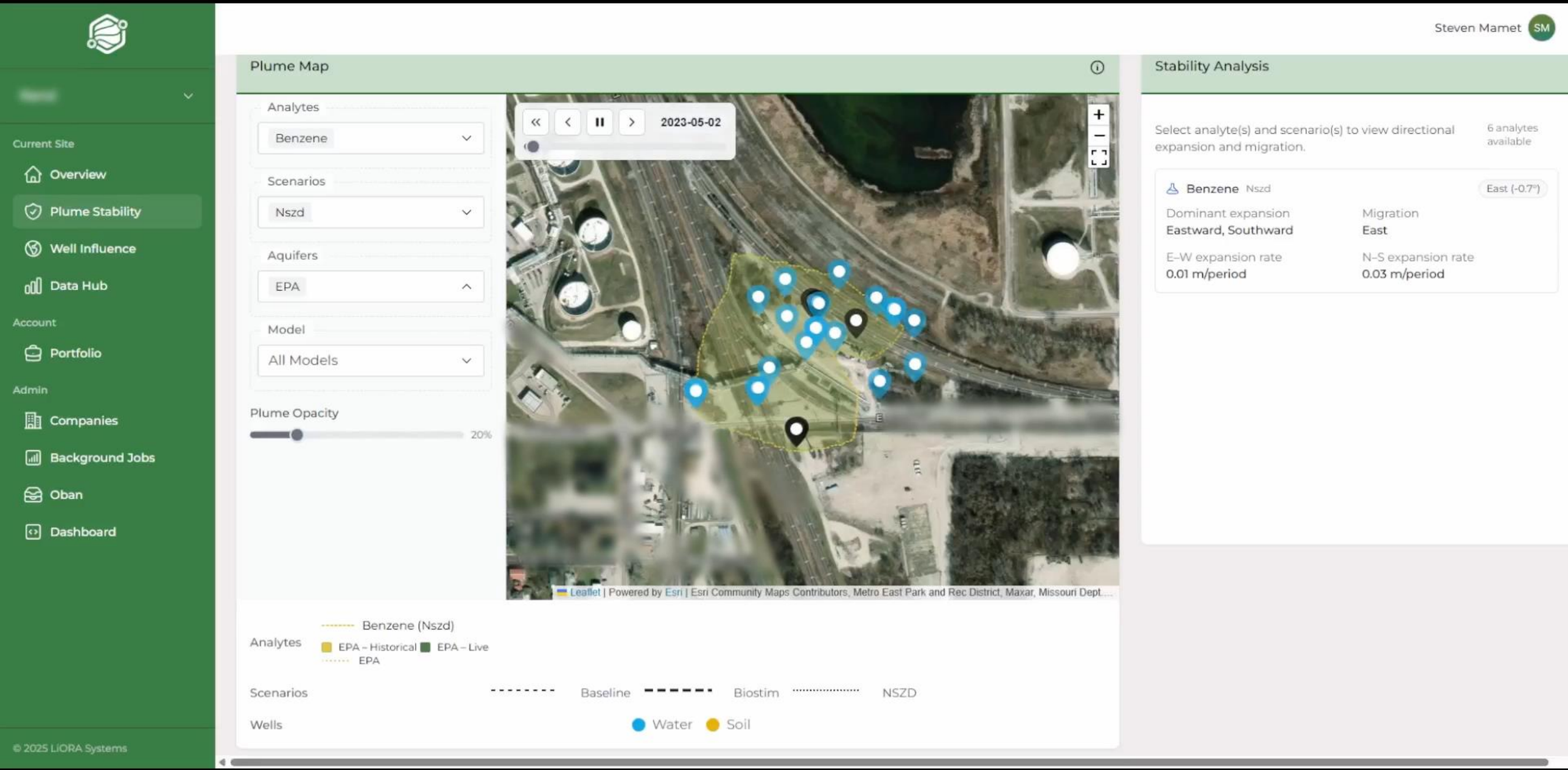


PEST++ and LiORA Data Assimilation into PlumeFutures

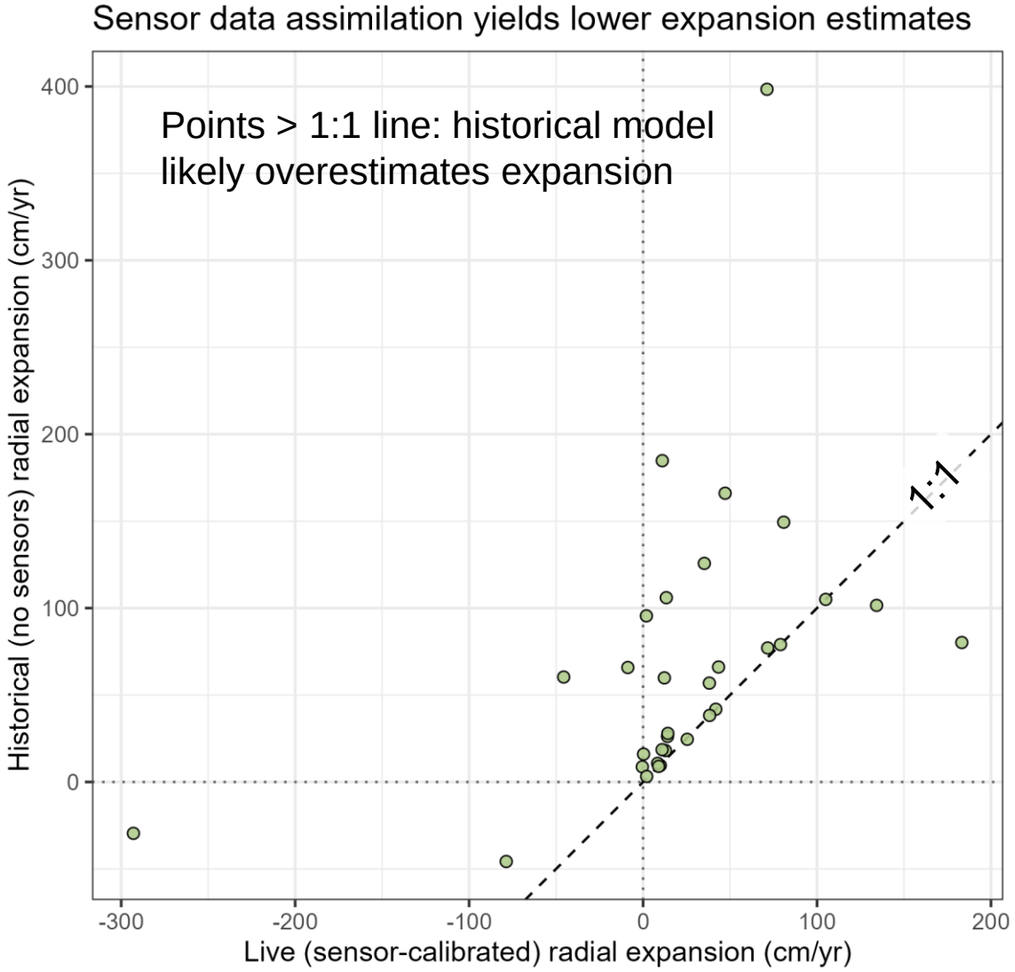
Improve **Decision** Confidence

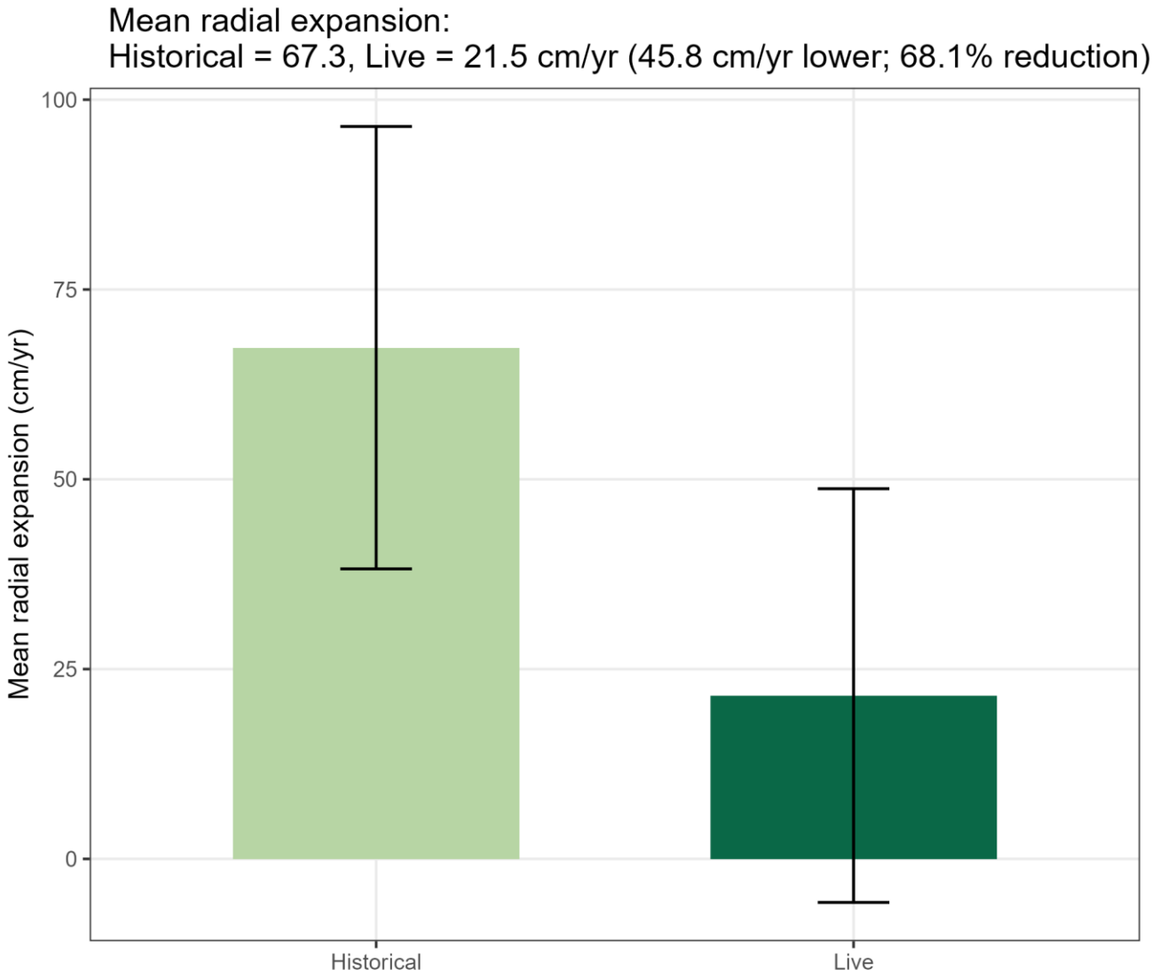
Risk/Liability continuously updated:

- ✓ Vapour Risk
- ✓ Water Risk
- ✓ Pollutant Persistence


Steven Mamet SM
Current Site
Overview
Plume Stability
Well Influence
Data Hub
Account
Portfolio
Admin
Companies
Background Jobs
Oban
Dashboard
© 2025 LiORA Systems
Plume Map
Analytes
Benzene
Scenarios
Nszd
Aquifers
EPA
Model
All Models
Plume Opacity
20%
2023-05-02
Leaflet | Powered by Esri | Esri Community Maps Contributors, Metro East Park and Rec District, Maxar, Missouri Dept....
Analytes
Benzene (Nszd)
EPA – Historical
EPA – Live
EPA
Scenarios
Baseline
Biostim
NSZD
Wells
Water
Soil
Stability Analysis
Select analyte(s) and scenario(s) to view directional expansion and migration.
6 analytes available
Benzene Nszd
East (-0.7°)
Dominant expansion
Eastward, Southward
Migration
East
E–W expansion rate
0.01 m/period
N–S expansion rate
0.03 m/period

Historical data over-estimated plume expansion in 22 of 32 sites





Key Takeaways

Traditional groundwater sampling misses key dynamics

- >40% of repeated samples from the same well, same season varied by >2X.
- Seasonal and thermal cycles can mimic or mask real concentration changes.
- Temperature and recharge drive predictable lags and cycles.

Adaptive modeling (LiORA) turns data into foresight

- Continuous data assimilation improves confidence and reduces overestimation.
- Historical models overpredicted plume growth in 22 of 32 sites.

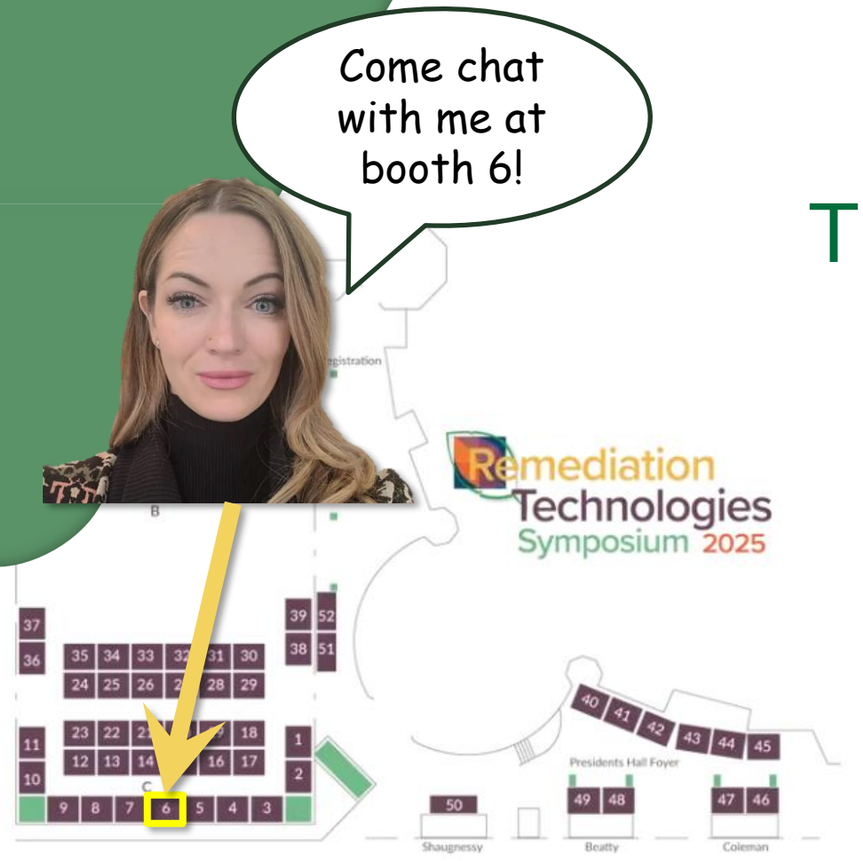
Decision value

- Know what's changing, when, and why.
- Reduce/strategize expenditures.
- Prioritize interventions that matter.

So what? *Continuous sensing and data assimilation turn uncertainty into foresight.*

LiORA

Site insights for
a better world.



Want to take advantage of what you learned today?

But with your historical data?

Talk to me or Carolyn about LiORA Trends?

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Carolyn Inglis
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Benzene lags temperature

Q1: Why this pattern?

- *Driven by groundwater seasonality:*
  - *Spring → recharge and dilution*
  - *Fall → concentration and reduced mixing*

Q2: Is it temperature, and how?

- *Mostly yes. The lag reflects delayed mass transfer:*
  - *GW → membrane → vapour phase*
  - *Thermal and diffusive inertia cause benzene to respond weeks after temperature rises*

Q3: Would we see this same pattern in intensive GW sampling?

- *Yes, but with a shorter since there's no membrane resistance:*
  - *GW → mass transfer*

So what? *Recognizing this lag helps separate true concentration changes from temperature-driven effects, improving how we interpret seasonal data, calibrate models, and schedule sampling.*