ALTEMIS: Next-Generation In Situ Real-time Groundwater Monitoring Strategies (Update)

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science : systems : society

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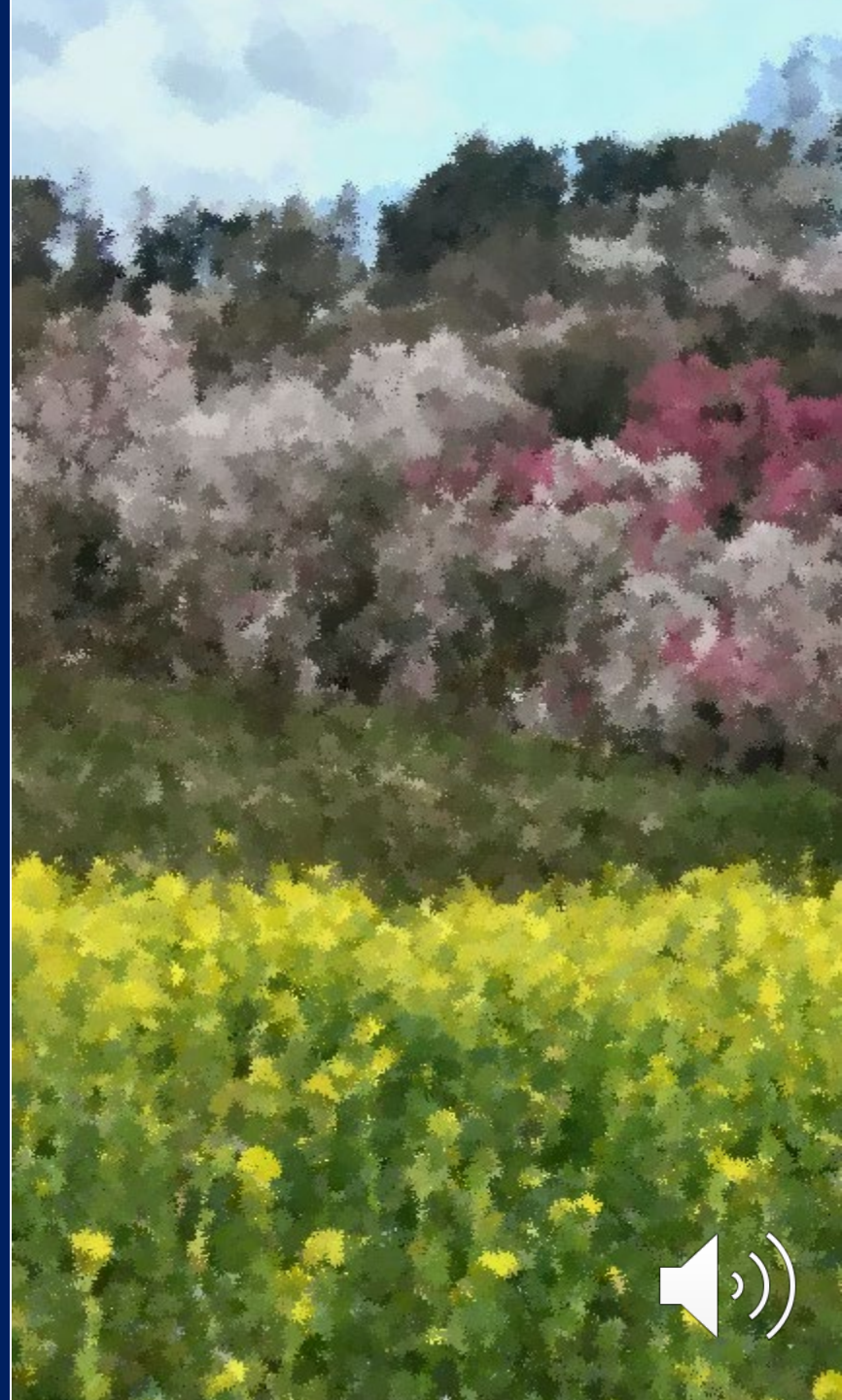

Acknowledgement: ALTEMIS Team

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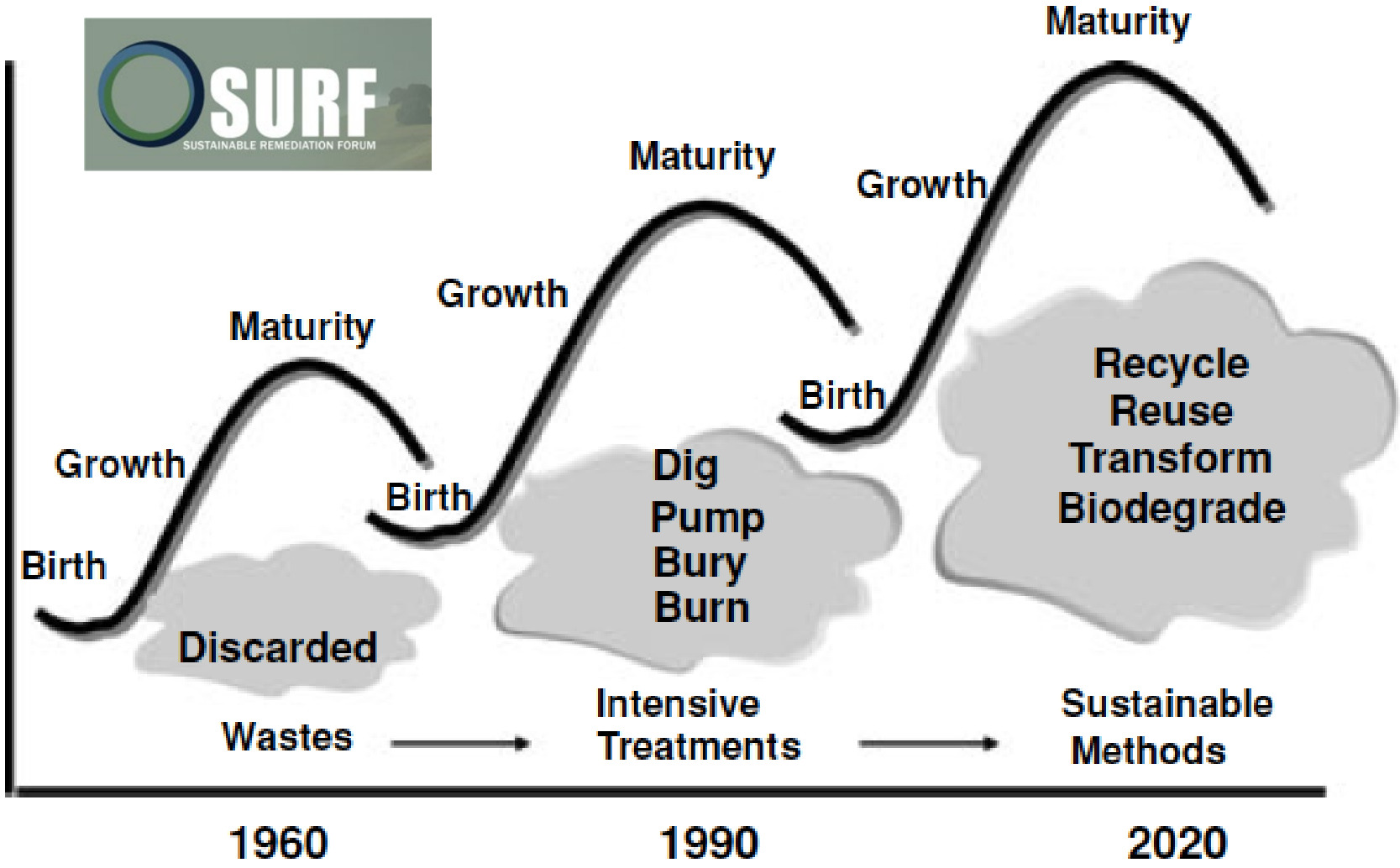
Soil and Groundwater Contamination

- Remediation of DOE's remaining complex groundwater contamination will take decades
- GAO estimates EM's liability for environmental cleanup across the country will exceed $550 billion
- Long-term monitoring of groundwater contamination is a large component of that liability

- DOE-**EM-3.21 Office of Technology Operation** has initiated a SRNL-led program since 2020
- Multi-laboratory/multi-agency team: SRNL, SRS-ACP, MIT, LBNL, PNNL, FIU, EM-MSIPP

Transition to Sustainable Remediation



Trade offs: Contaminant removal vs

- Waste
- CO2 emission
- Energy Use
- Ecological Impacts
- Noise, Air pollution

Sustainable Remediation Forum (SURF), "Integrating sustainable principles, practices, and metrics into remediation projects", Remediation Journal, 19(3), pp 5 - 114, editors P. Hadley and D. Ellis, Summer 2009

Sustainable Remediation

- Minimize waste/pollution/energy-use/water-use/ecological damages
- In situ treatments: Biodegradation, immobilization
- Monitored natural attenuation
- Longer institutional control with alternative/attractive end-use

→ Long-term monitoring

Former Reilly Tar & Chemical Corporation Plant

Rocky Flats National Wildlife Refuge

Long-term Monitoring: What to Expect….

DOE Mound Site

- Dewatering for the construction nearby

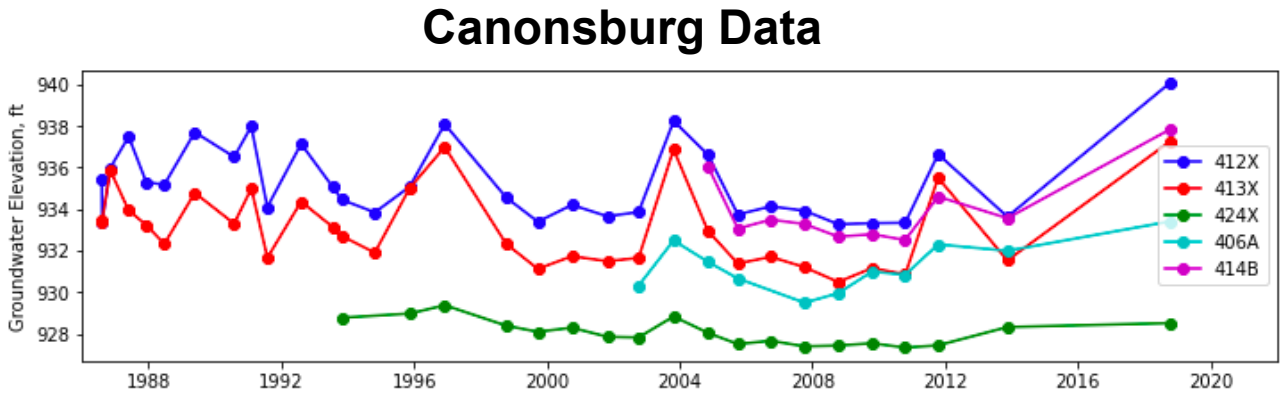
→ **Shift in the groundwater table and plume direction**

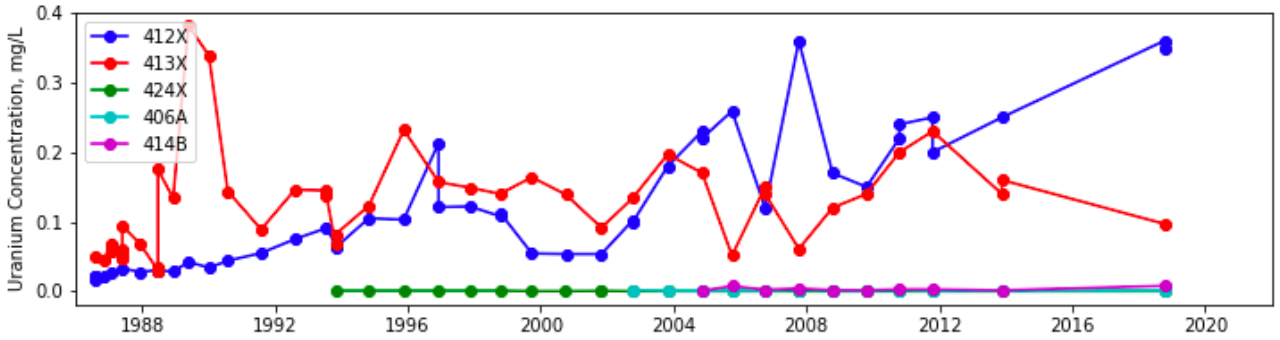
DOE Canonsburg Site

- Groundwater fluctuation associated with river stages

→ Contaminant concentration changes (hard to explain with sparse measurements)

→ Climate change?



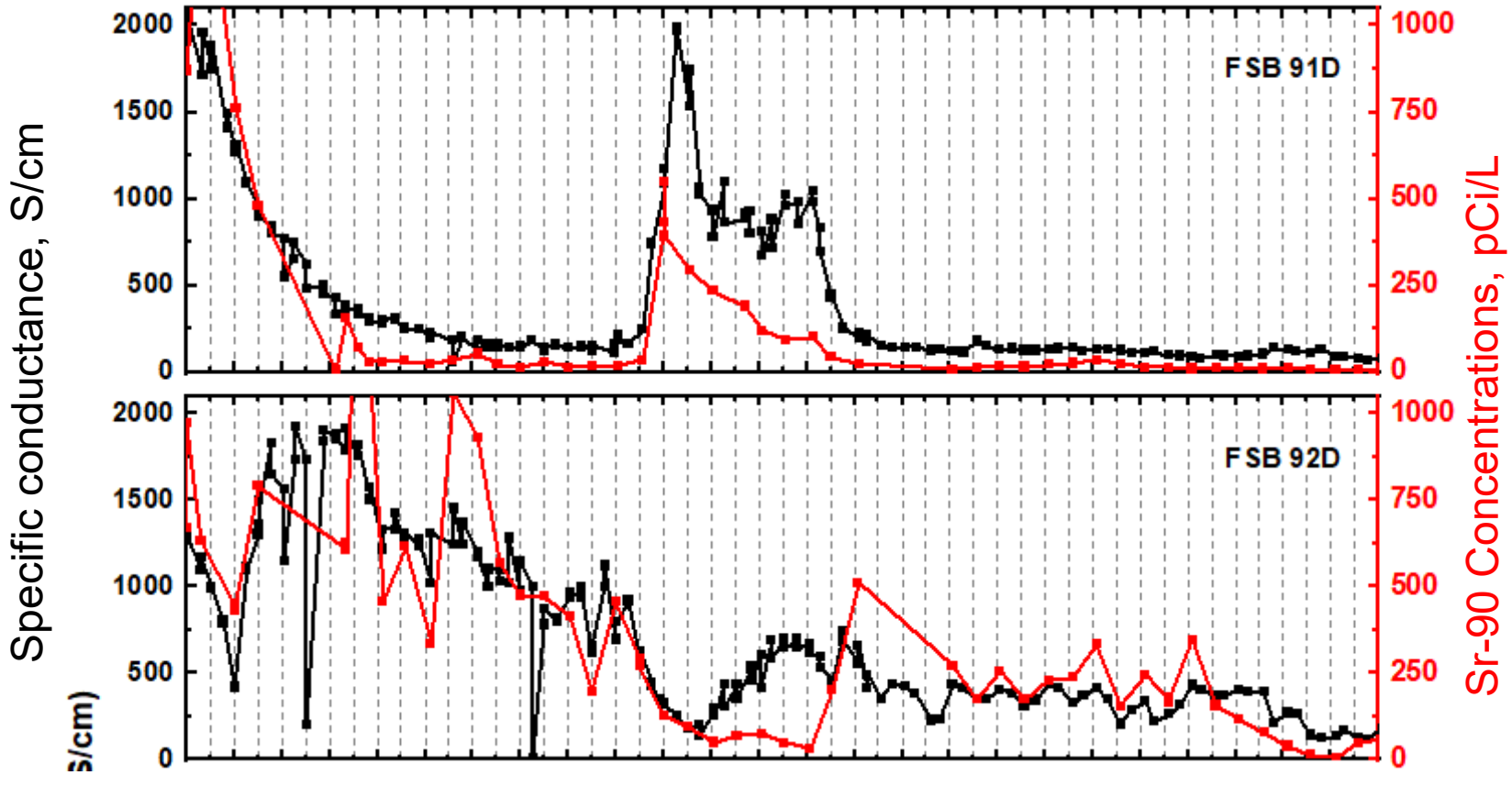


Long-term Monitoring: What to Expect….

DOE Savannah River Site F-Area

- Pump-and-treat system

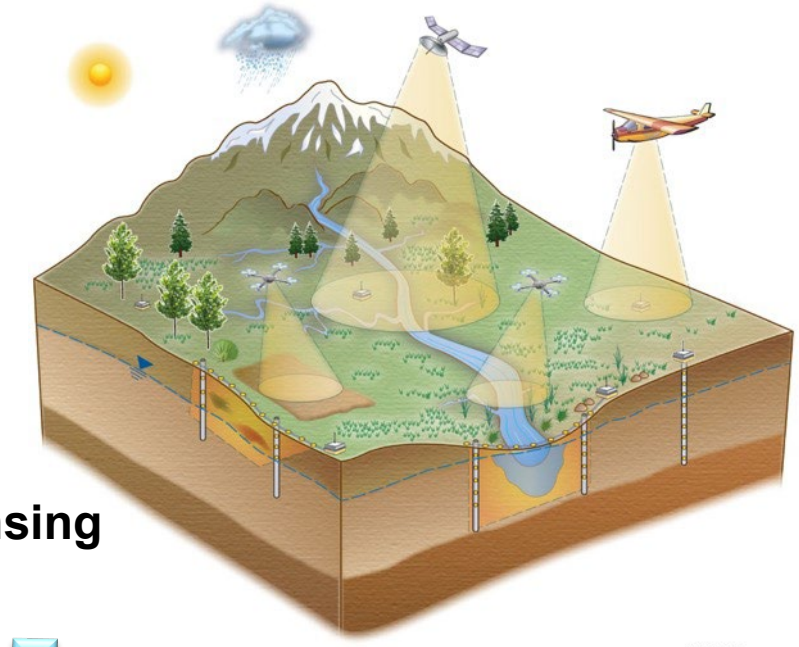
→ Re-injection increased cations → Sr-90 concentrations increased



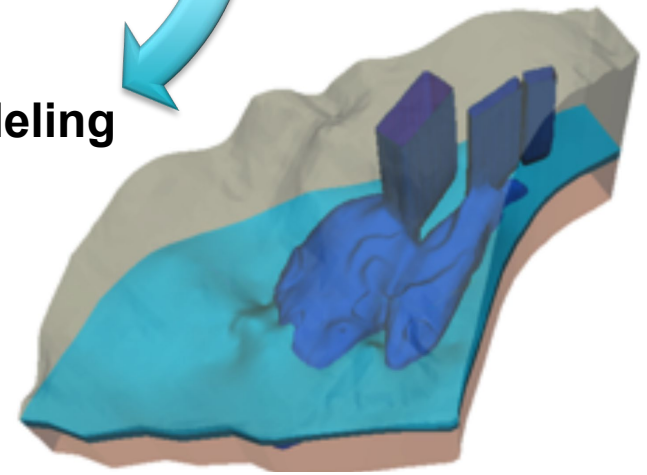
Advanced Long-term Environmental Monitoring Systems

ML/AI

Sensing



Modeling



ALTEMIS

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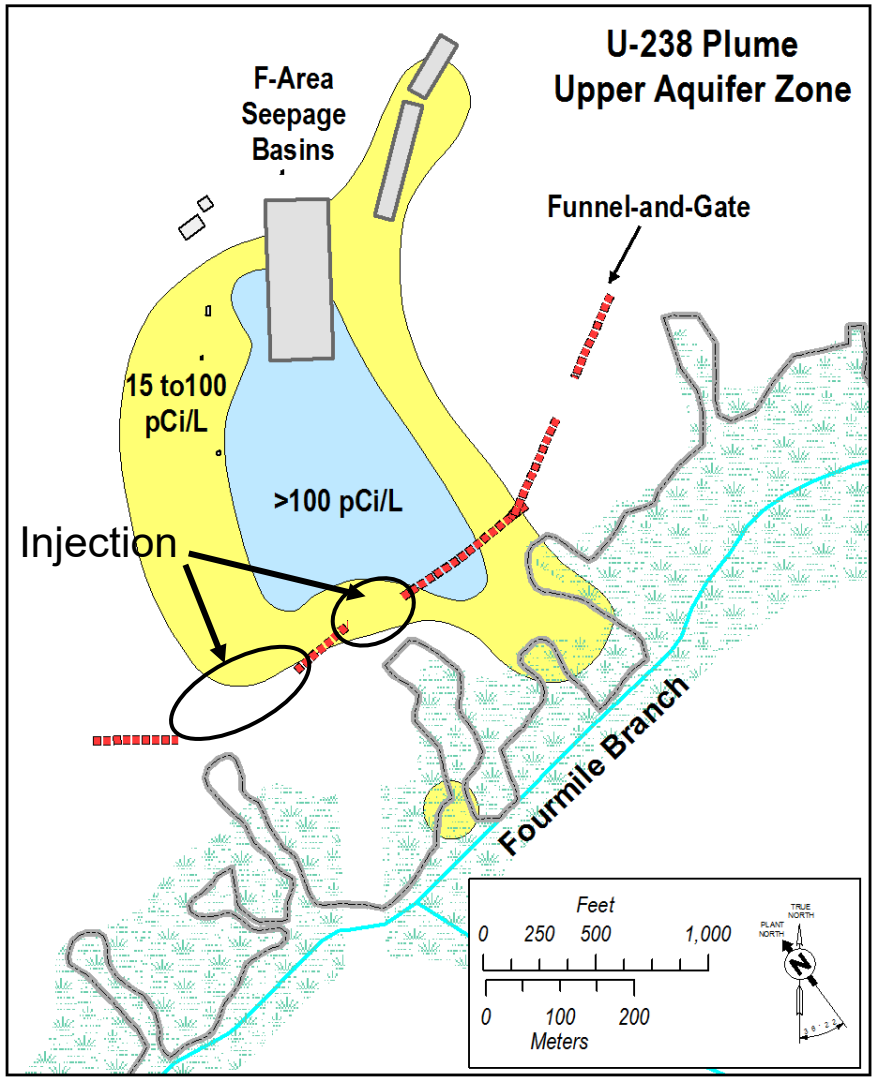
New paradigm for long-term monitoring

Savannah River Site F-Area: Testbed

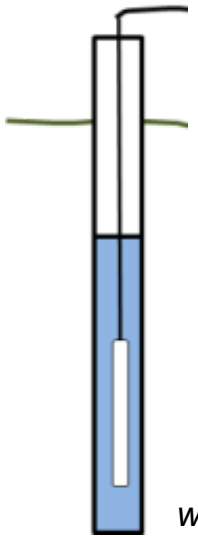
- **Disposal activities**:
  - Low-level radioactive waste from PUREX process (1955–1989)
  - Nitric acid plume: pH 3–3.5, U, ^{90}Sr, ^{129}I, ^{99}Tc, ^{3}H
- **Remediation approaches**
  - Pump & treat (the filters became highly radioactive; not sustainable)

  → Immobilization of U and ^{129}I



Current Groundwater Monitoring

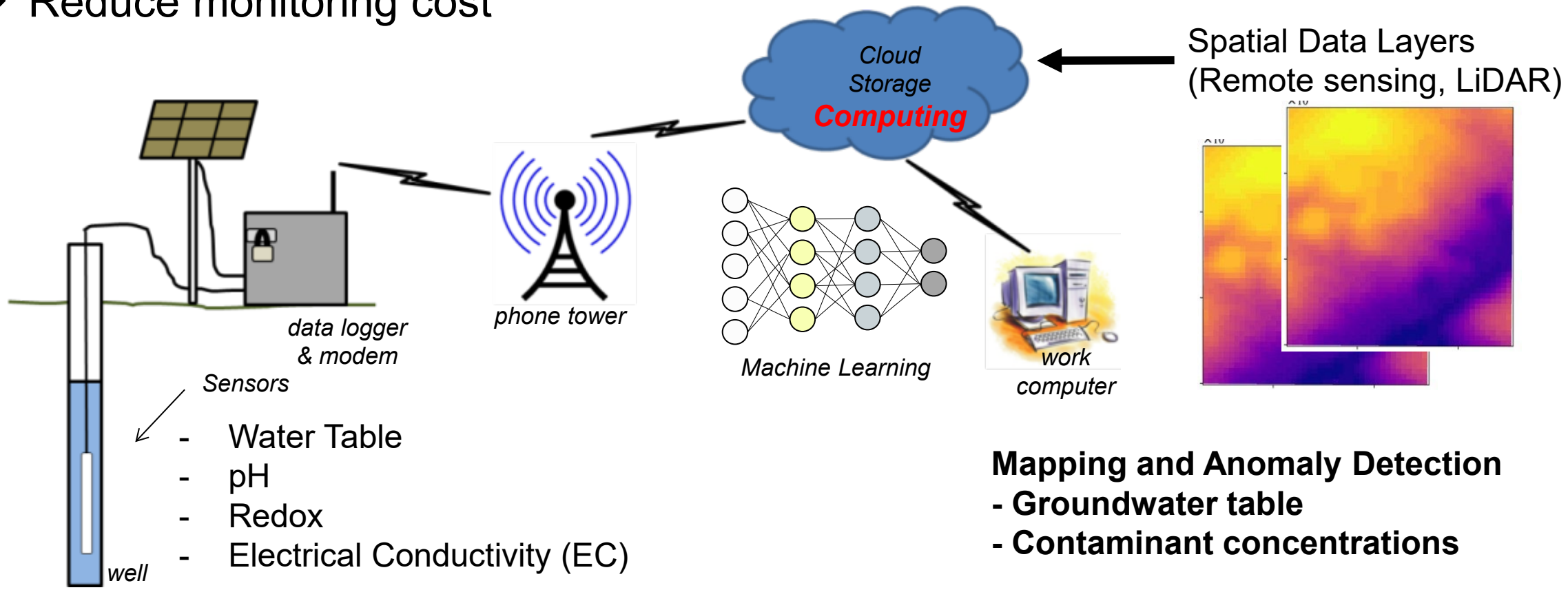
- **Groundwater Sampling → Laboratory Measurements**
  - Expensive: 10s – 100s of wells
  - Contamination issues (requires training, equipment)
  - Temporally sparse: every quarterly, annually → Miss anomalies
  - Compliance only (no analytics)



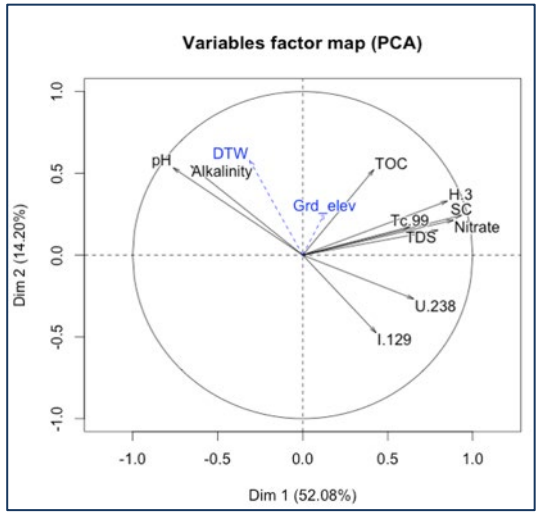
well

In situ Real-time Monitoring Strategies

- **Low-cost in situ sensors, wireless network, cloud computing**
  - → Continuous monitoring of **in situ variables**
  - → Detect changes real-time = ***Reactive*** Monitoring → ***Proactive*** Monitoring
  - → Reduce monitoring cost



Data Analytics Workflow

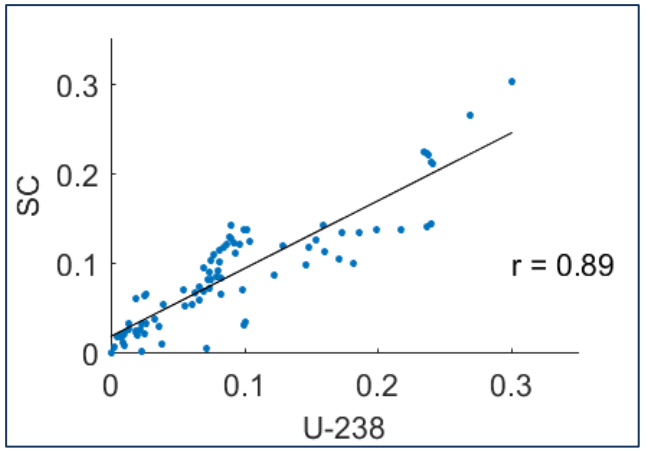


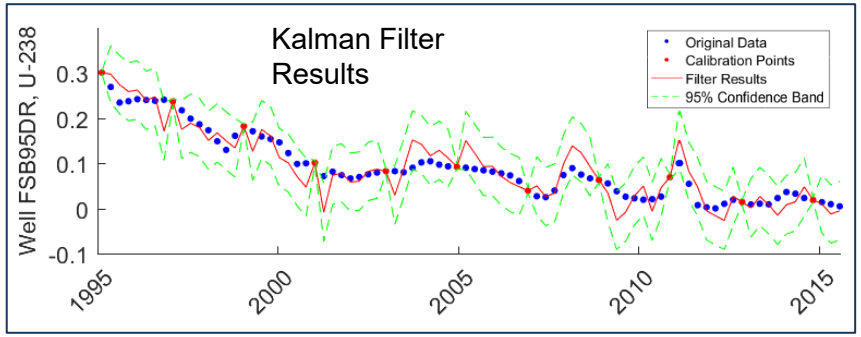
Exploratory Data Analysis

Quantification of Correlations

Contaminant Concentration Estimation

Machine Learning





Schmidt et al., 2018

Environmental Science & Technology

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Article

PyLEnM: A Machine Learning Framework for Long-Term Groundwater Contamination Monitoring Strategies

Aurelien O. Meray, Savannah Sturla, Masudur R. Siddiquee, Rebecca Serata, Sebastian Uhlemann, Hansell Gonzalez-Raymat, Miles Denham, Himanshu Upadhyay, Leonel E. Lagos, Carol Eddy-Dilek, and Haruko M. Wainwright*

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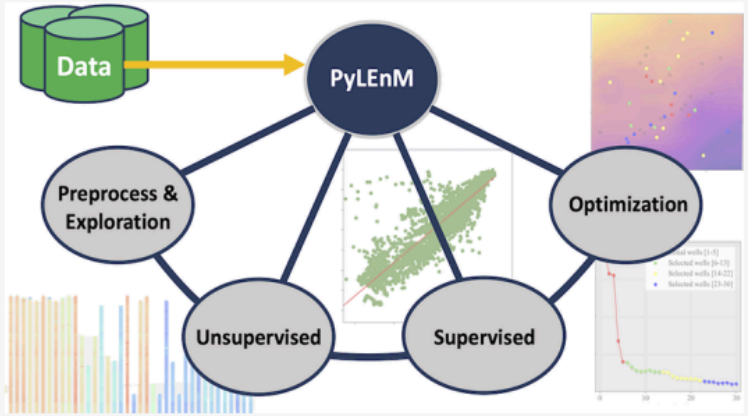
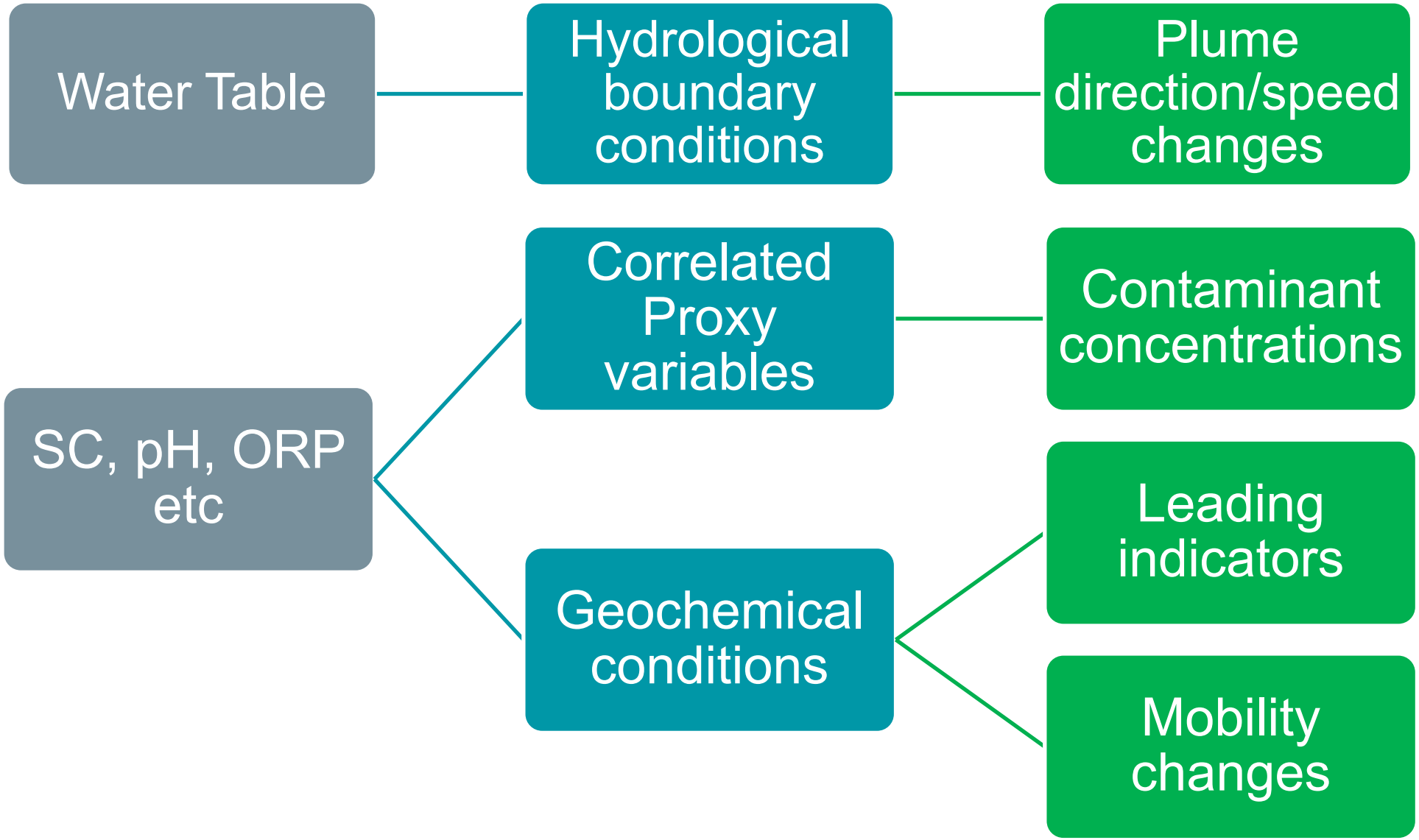
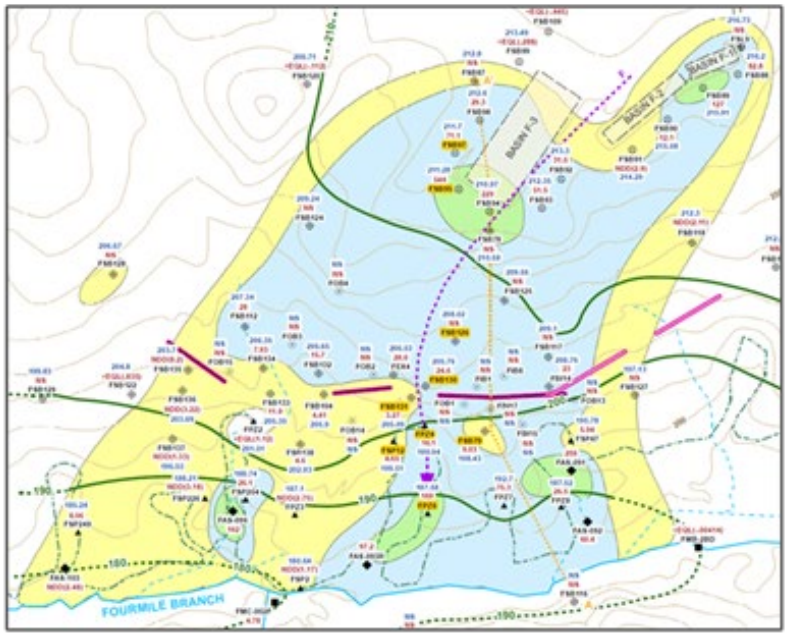
ABSTRACT: In this study, we have developed a comprehensive machine learning (ML) framework for long-term groundwater contamination monitoring as the Python package PyLEnM (Python for Long-term Environmental Monitoring). PyLEnM aims to establish the seamless data-to-ML pipeline with various utility functions, such as quality assurance and quality control (QA/QC), coincident/colocated data identification, the automated ingestion and processing of publicly available spatial data layers, and novel data summarization/visualization. The key ML innovations include (1) time series/multianalyte clustering to find the well groups that have similar groundwater dynamics and to inform spatial interpolation and well optimization, (2) the automated model selection and parameter tuning, comparing multiple regression models for spatial interpolation, (3) the proxy-based spatial interpolation method by including spatial

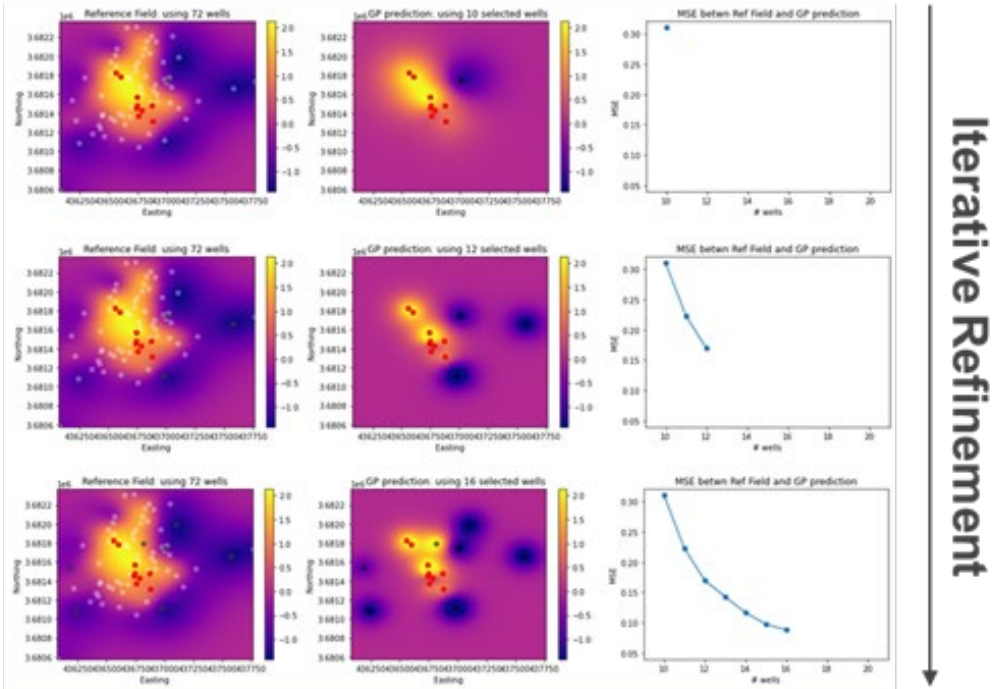


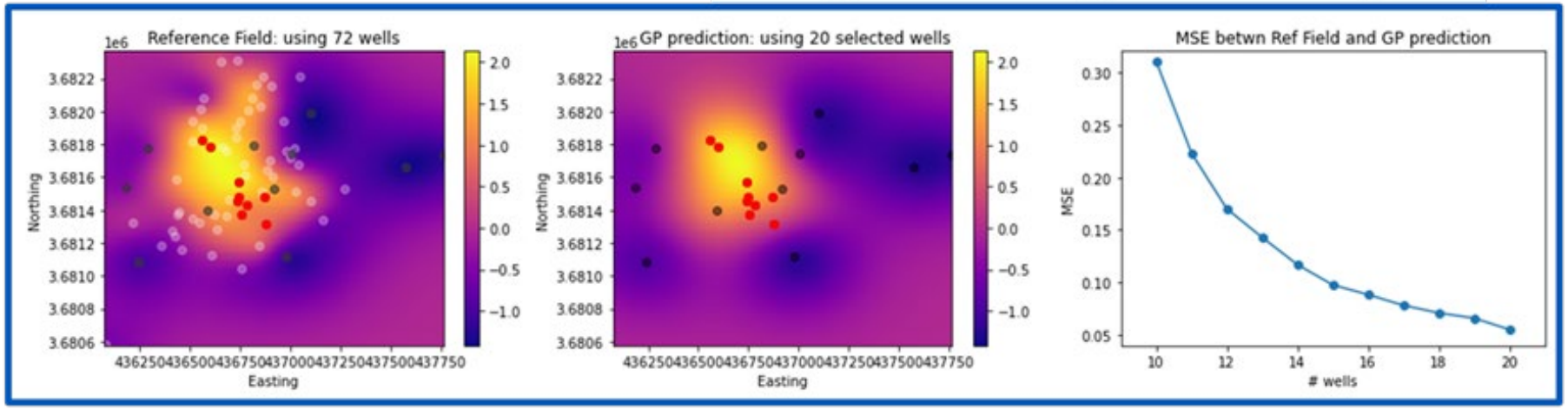
Integrated GW Monitoring



Spatial Optimization of Sensor Locations



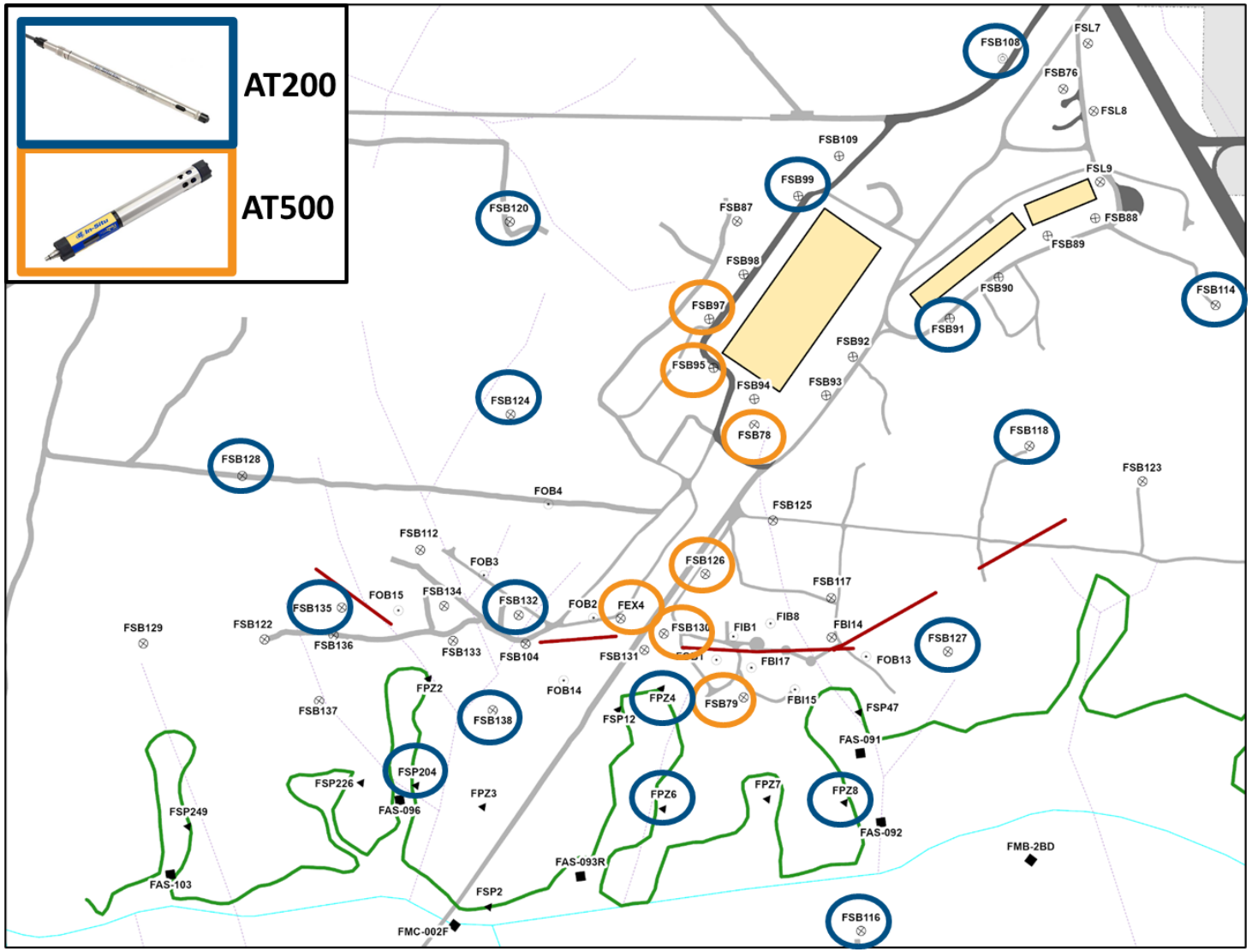




From: Wainwright, Haruko Upadhyay

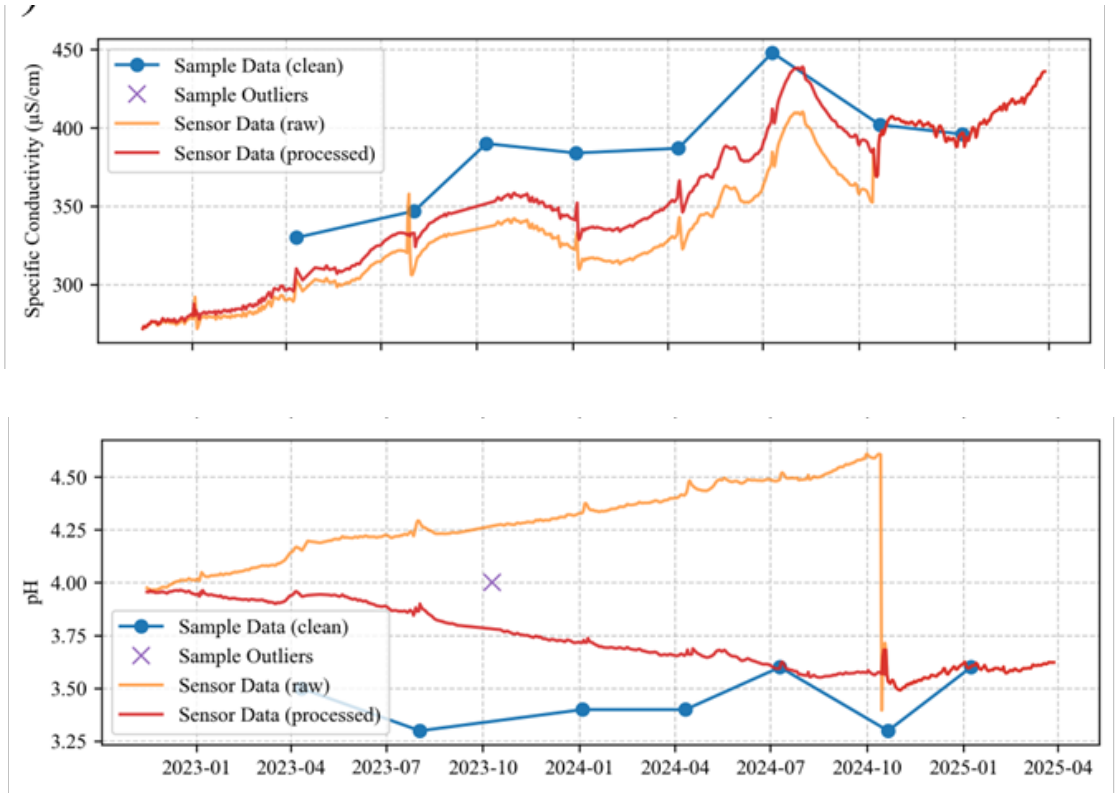
Siddiquee et al., 2024

Optimized Sensor Network Layout

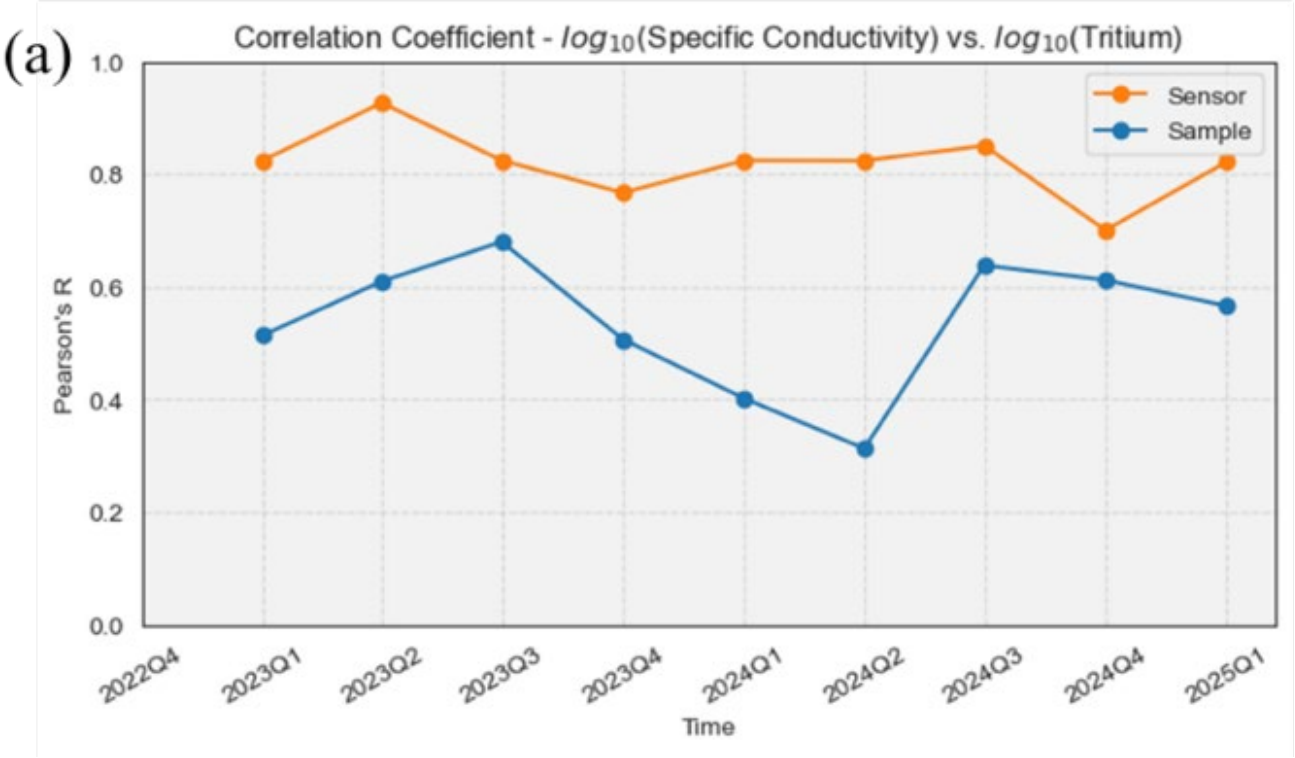


Sensor Data Preprocessing

Sensor Drift Correction

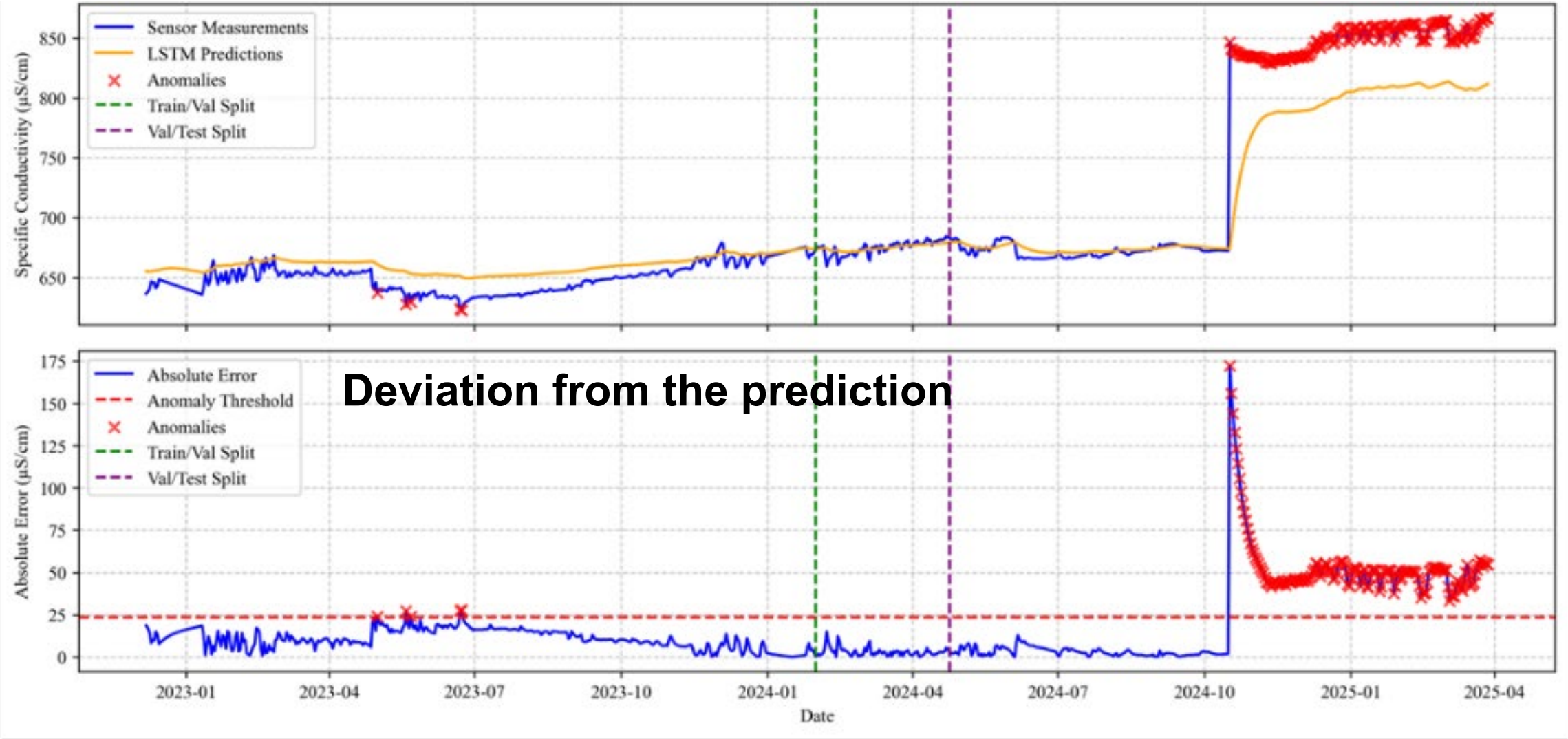


Correlation Over Time



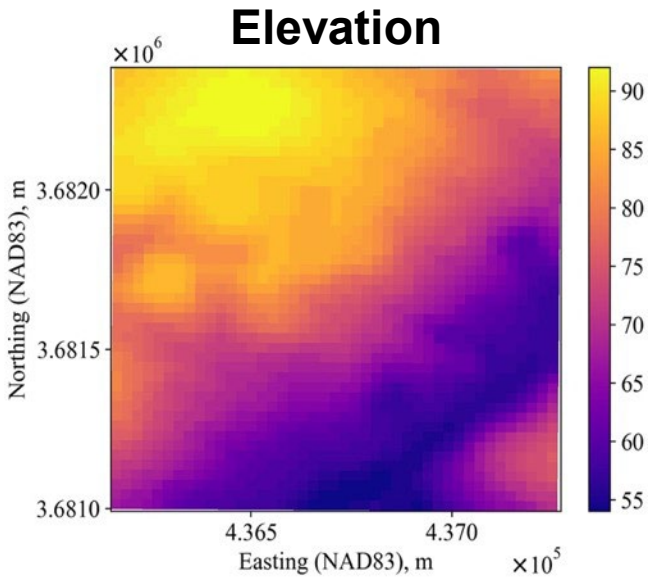
Anomaly Detection: LSTM NN

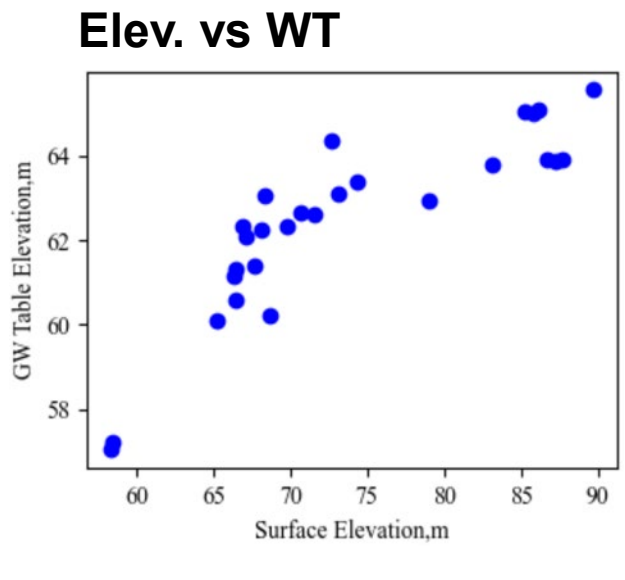
Sensor data and Short-term prediction (LSTM)

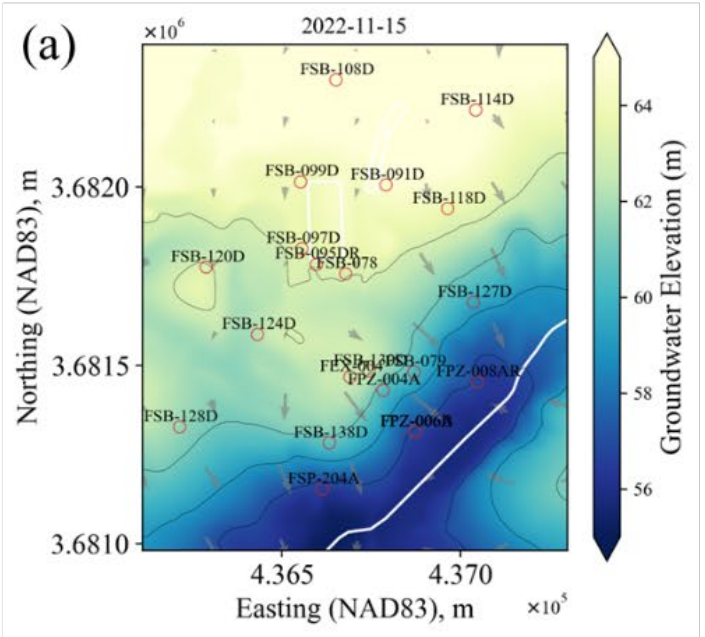


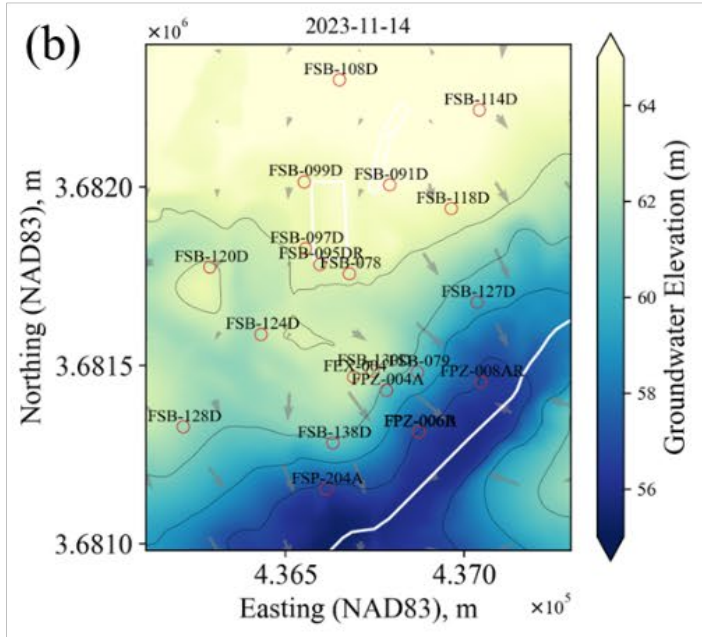
Real-time Water Table Estimation

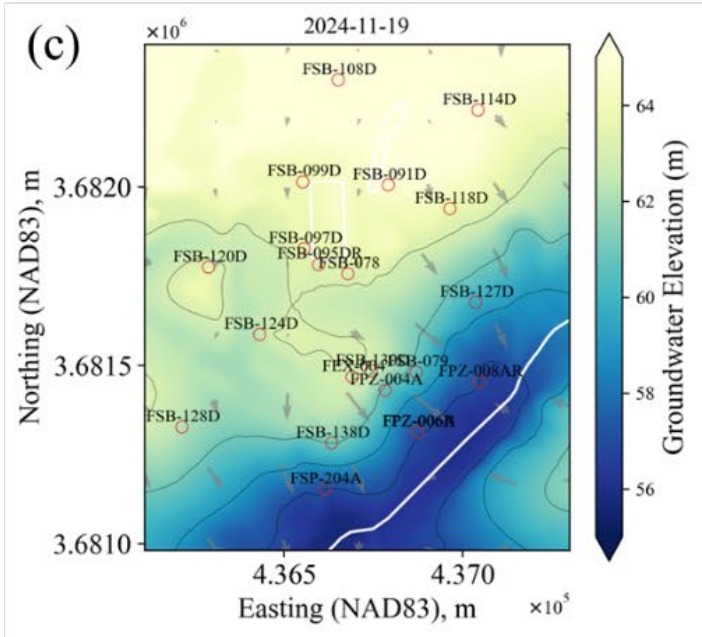
- **WT as a function of**
  - LiDAR elevation data
- **Gaussian process models**
  → Residual interpolation
- **Gradient** → Plume direction





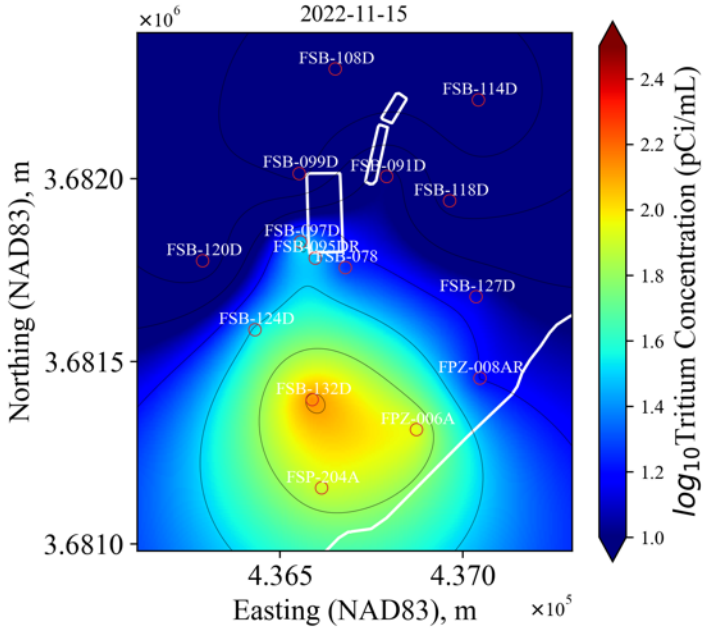




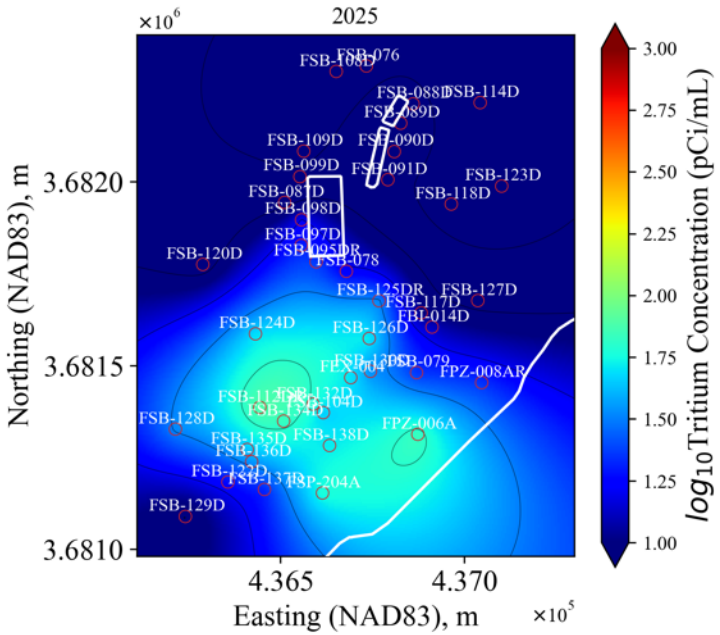


In situ Sensor + Sampling Data Integration

In situ Sensor Data (e.g., in situ proxies ~ contaminants)
Spatially sparse

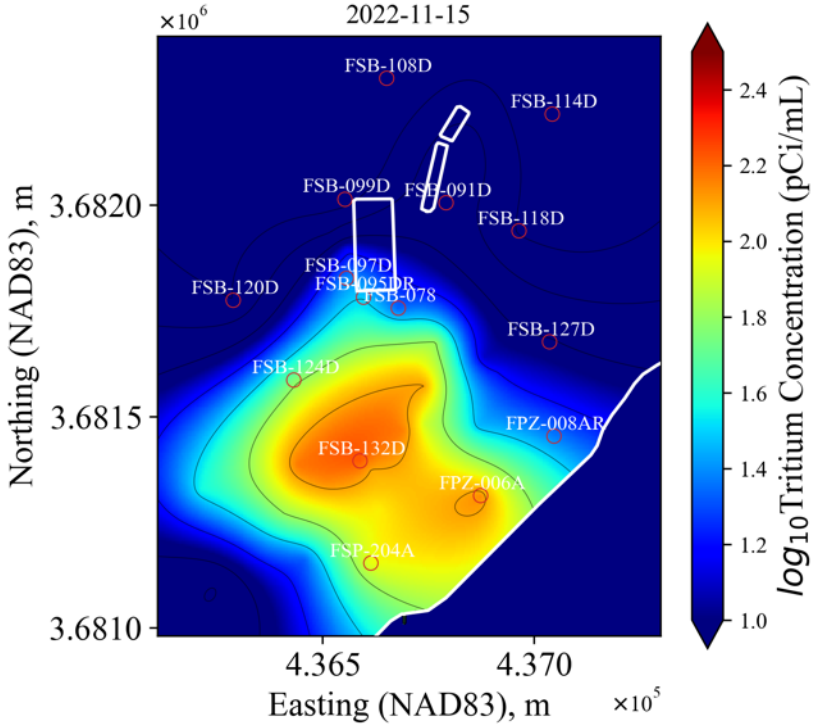


Concentrations at Wells
Temporary sparse: once a year



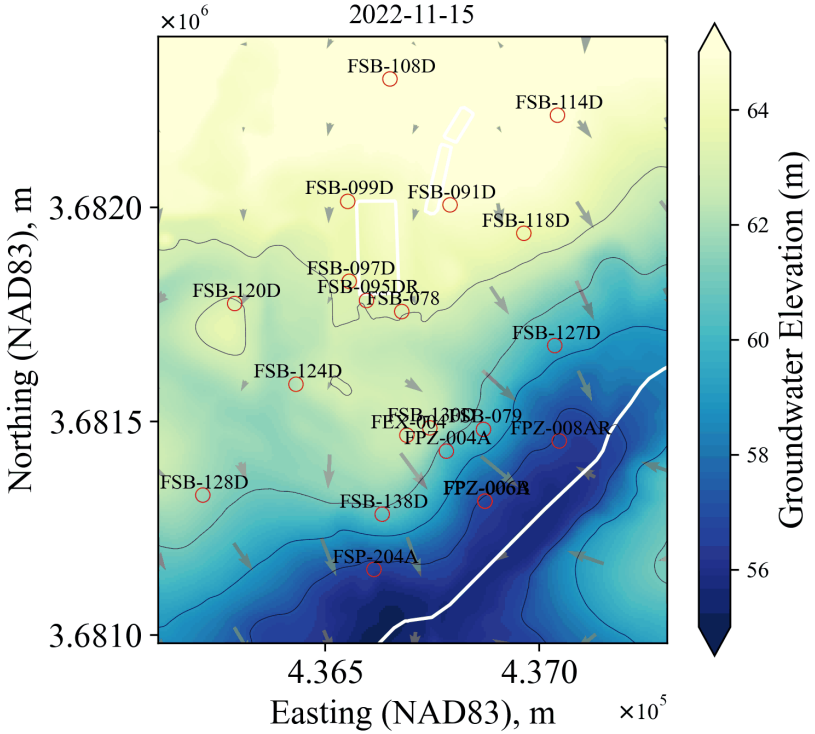
- Gaussian process regression
- Bayesian geostatistical method
- Combine different types of data in a consistent way

Integrated Map

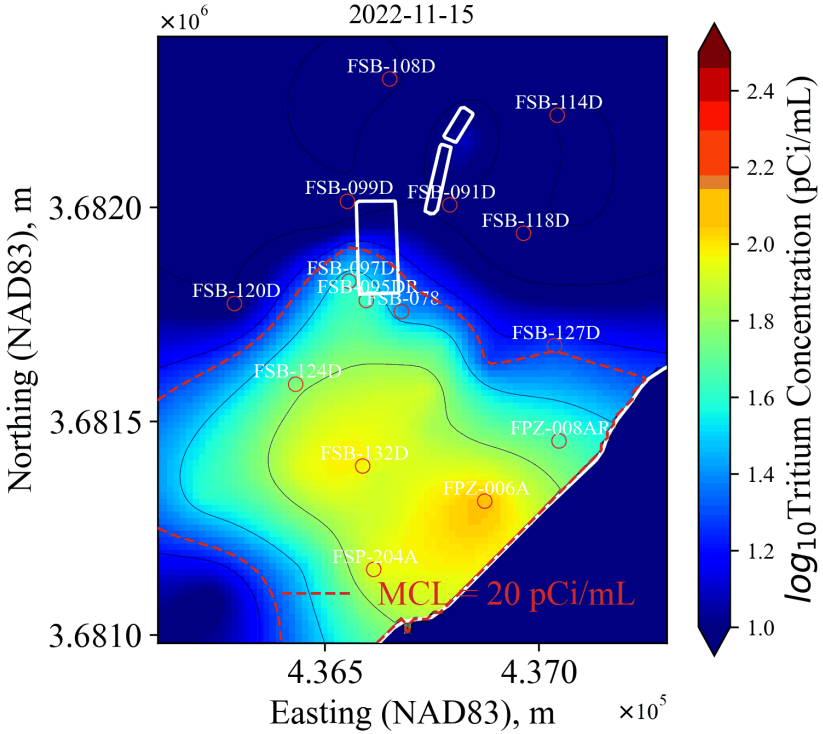


Spatial Estimation of Water Level, Tritium and Uranium

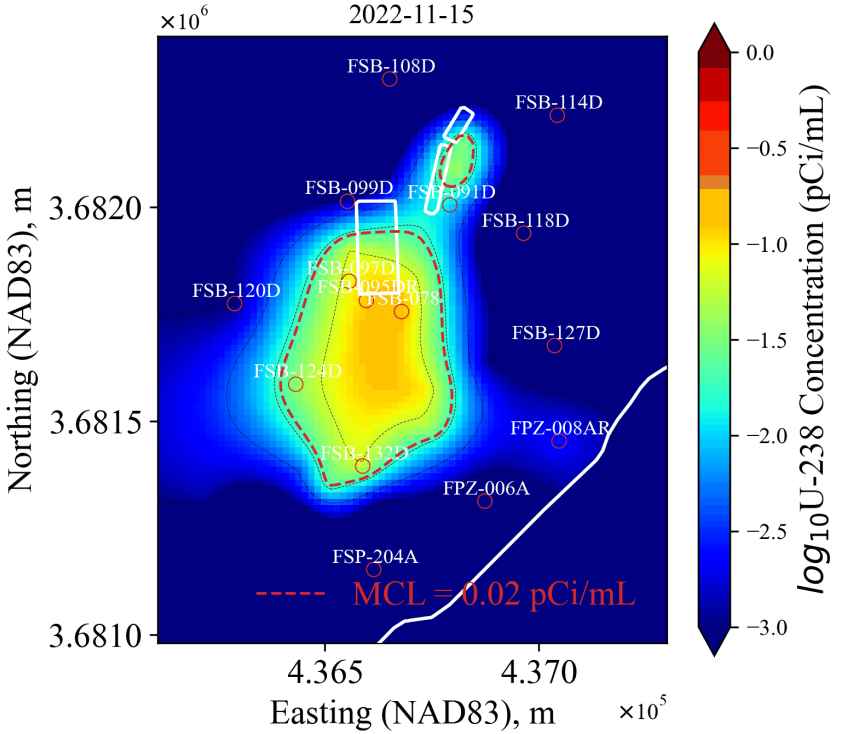
Water Table



Tritium



Uranium



Summary

- **Motivation: Sustainable remediation**
  - Net environmental impact: contaminant removal vs other side effects
  - Long-term institutional controls: passive remedies, natural attenuation

  → Importance of long-term soil and groundwater monitoring
- **ALTEMIS Project: innovation for long-term monitoring**
  - In situ real-time sensors, simulations, ML/AI
  - ML/AI framework for long-term monitoring
- **In situ sensor-based monitoring**
  - Sensor data processing
  - Anomaly detection based on LSTM
  - Water table estimation by integrating spatial and sensor data
  - Contaminant concentration estimation by integrating sensor and sample data

Thank You!

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