U.S. Department of Energy

Office of Science

Oak Ridge Field Research Center

Environmental Remediation Sciences

Environmental Remediation and Stewardship Research

Integrated Field-Scale Research Challenge

Characterization and Monitoring at the ORFRC using Geophysical Methods

ERSP Annual PI Meeting
Lansdowne, Virginia
April 16-19, 2007

ORFRC Characterization Subgroup
Susan Hubbard, Presenter

OAK RIDGE National Laboratory

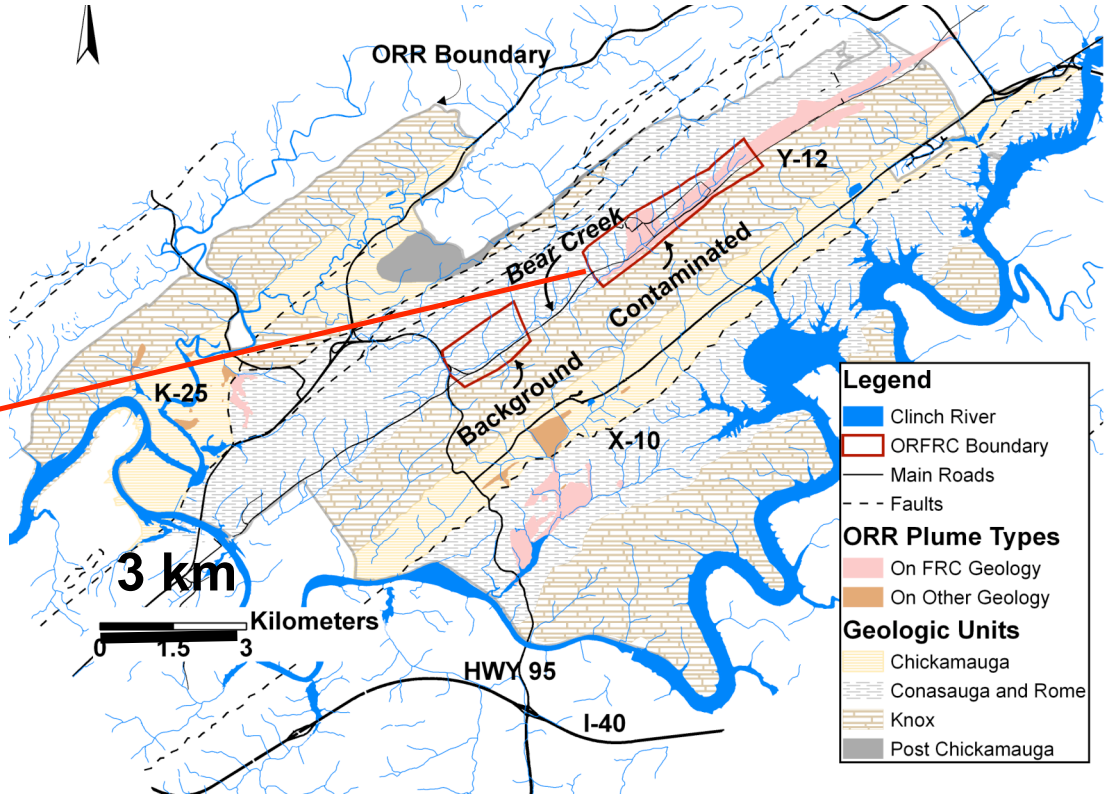
Outline

Motivation & General Challenges

Objectives, Previous Work, and Approaches:

- Watershed Characterization
- Monitoring Natural Recharge at the plume scale
- Monitoring Targeted Manipulations at the local scale

Task Timetable



Motivation

Heterogeneity influences contaminant distribution, dilution, reactivity, and remediation efficacy.

Remediation Investigations benefit from:

- **Characterization of Properties** needed to guide experimental design, predict treatment sustainability, and to assess results
  - Hydraulic conductivity
  - Fracture zonation
  - Hydrogeological unit zonation
  - Sediment Geochemistry

- **Monitoring of hydrological-biogeochemical processes** that occur during system transformations;
  - electron donor distribution
  - Changes in pore fluid chemistry
  - Products: Gas, precipitates, biofilms
  - Redox zonation

1. Hydrogeophysics Integration, Inversion, Uncertainty, Scale

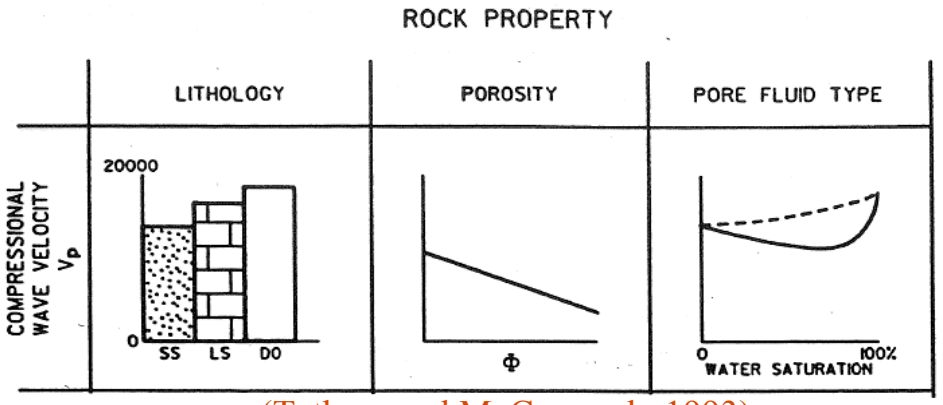
2. Biogeophysics: Sensitivity of geophysical methods to biogeochemical products

GENERAL CHALLENGES:
using Geophysical Methods For Characterization and Monitoring

Geophysical Measurements:

- Are **indirect** – they measure geophysical properties over support scale of the particular technique;
- Require **petrophysical** relationships or theory to link geophysical and biogeochemical-hydrological properties;
- Often respond **non-uniquely** to properties/processes.

There is no standard **Fusion Approach** to integrate different datasets, and most of the integration work has been performed at the **local scale**.



(Tatham and McCormack, 1993)

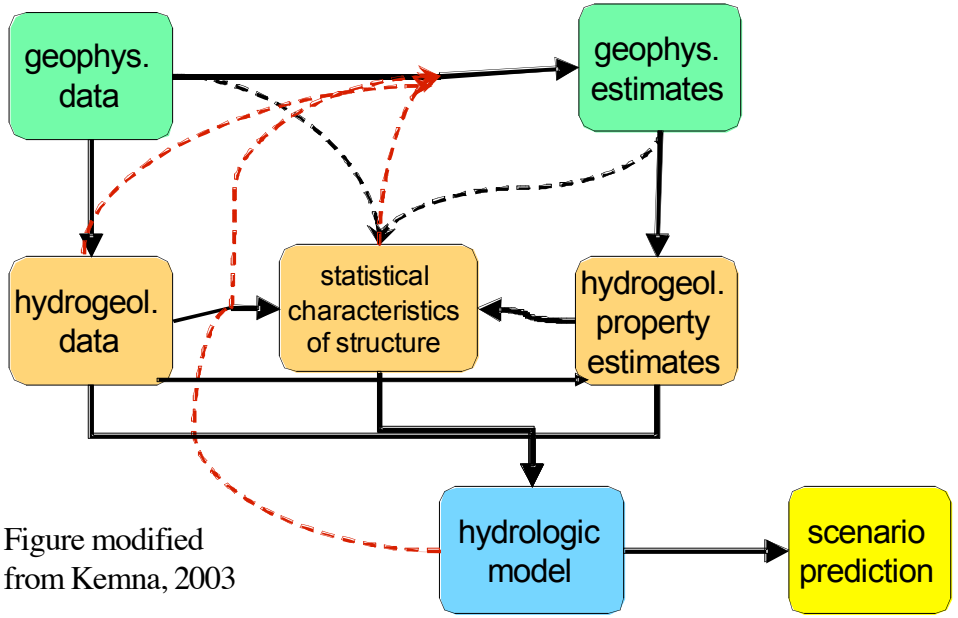


Figure modified from Kemna, 2003

OBJECTIVES

- Gross Watershed Characterization
- Monitor Recharge Processes
- Monitor Targeted Manipulation Processes

INVESTIGATION SUPPORT AND EXPECTED SCIENTIFIC PRODUCTS

- Provide framework for interpreting transient watershed data (Task B)
- Provide insight into rates and mechanisms of geochemical and hydrological processes associated with natural episodic, seasonal, and annual recharge over field-relevant scales (Task B)
- Provide insight into spatiotemporal distribution of treatment end-products as a function of local-scale heterogeneity (Task C)
- Guide targeted treatment processes (Task C)
- Parameterize/Validate /Refine characterization and monitoring approaches (measurement suites, inversion approaches);
- Advance understanding of utility of remote datasets for monitoring both natural and manipulated processes.

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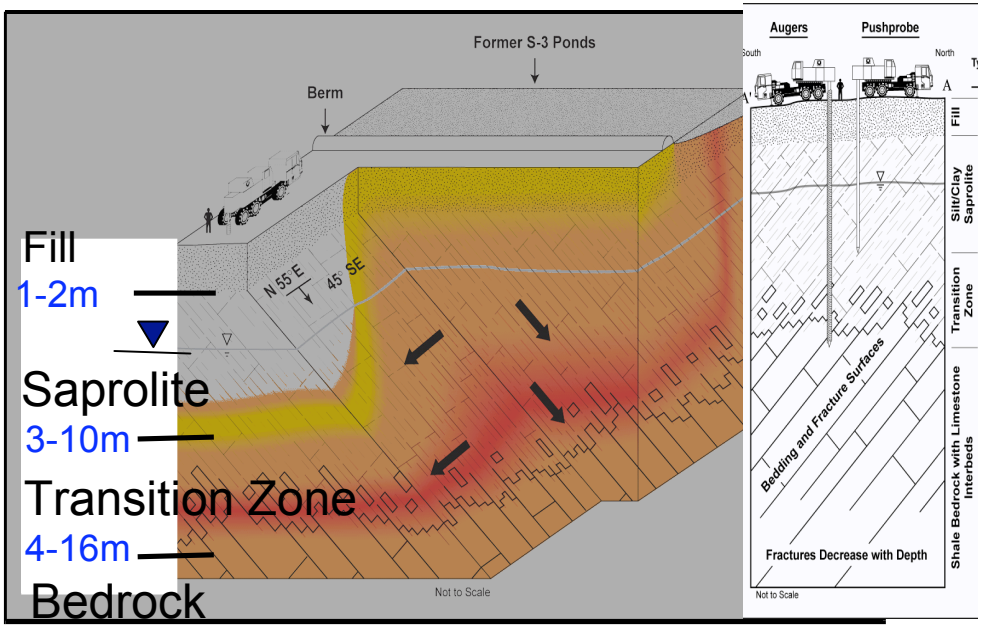
- **Parameterize/Validate/Refine site flow and transport model (Task D)**
- **Develop watershed-scale characterization and monitoring approaches** (measurement suites, inversion approaches);
- Advance understanding of utility of remote datasets for monitoring both natural and manipulated processes across scales

Goal #1:

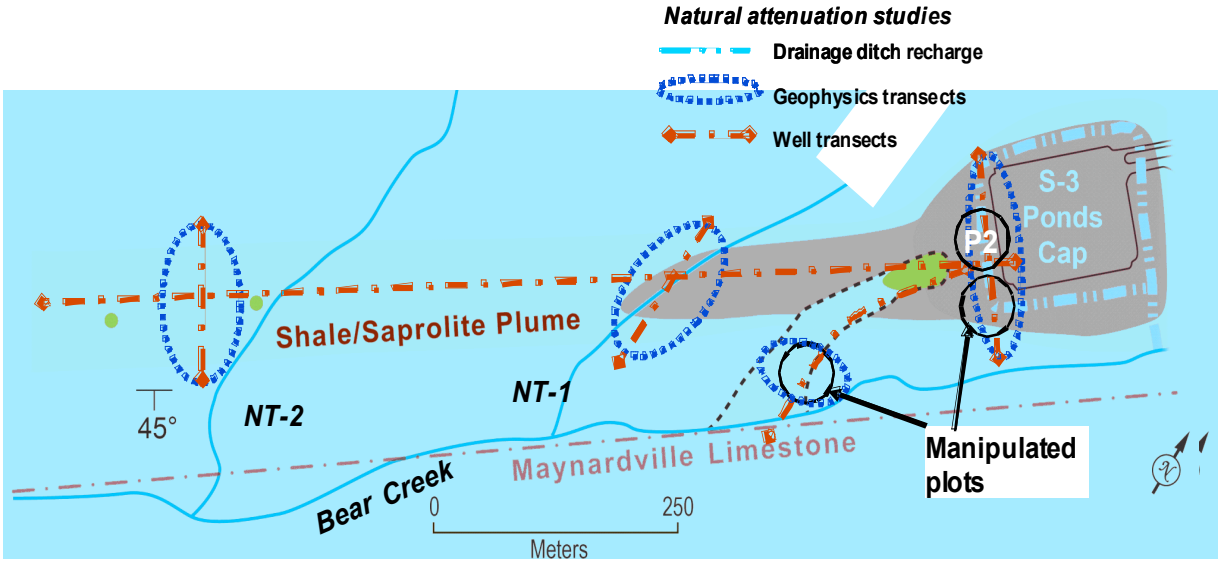
Define major flow pathways.

- Investigate **lateral continuity of transition zone**
- Investigate origin and hydraulic properties of **'low velocity anomaly'**

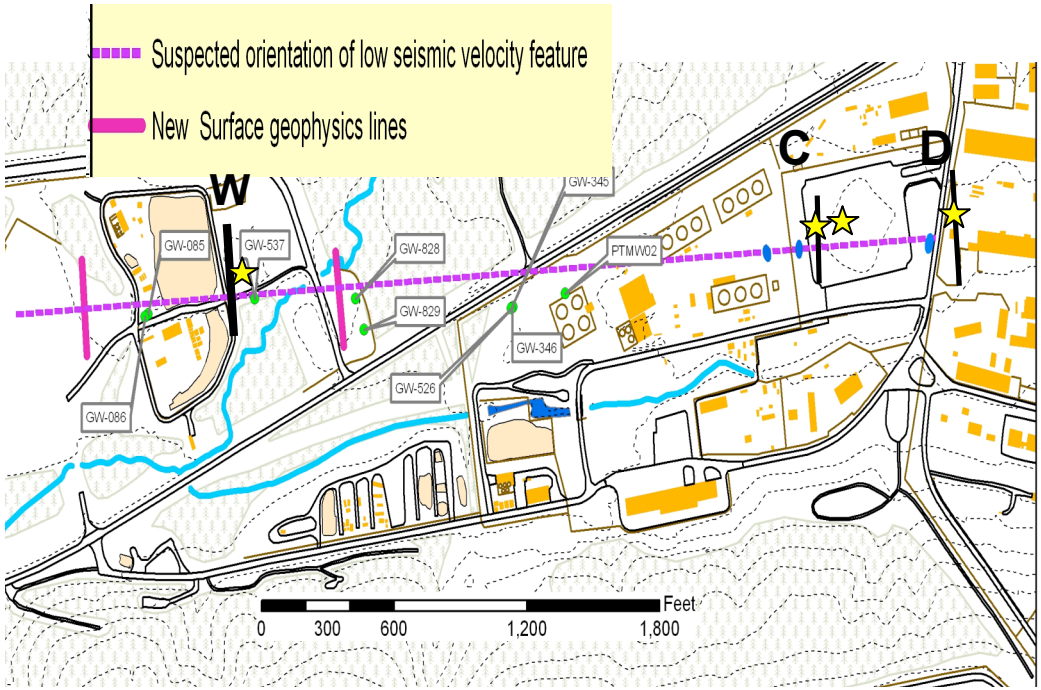


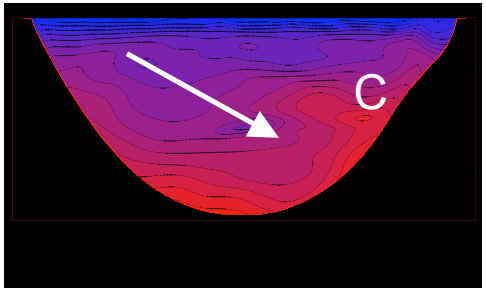
Approach:

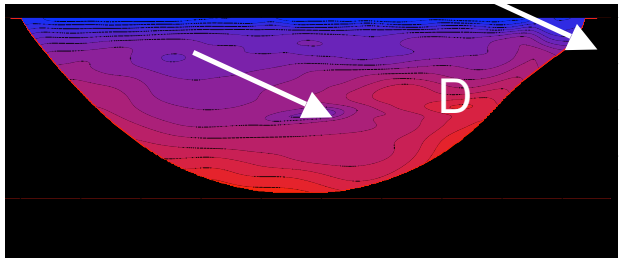
- Collect and reduce wellbore hydrogeochemical and crosshole-surface geophysical datasets (esp. seismic)
- Develop acquisition/interpretation strategies for watershed-scale characterization;

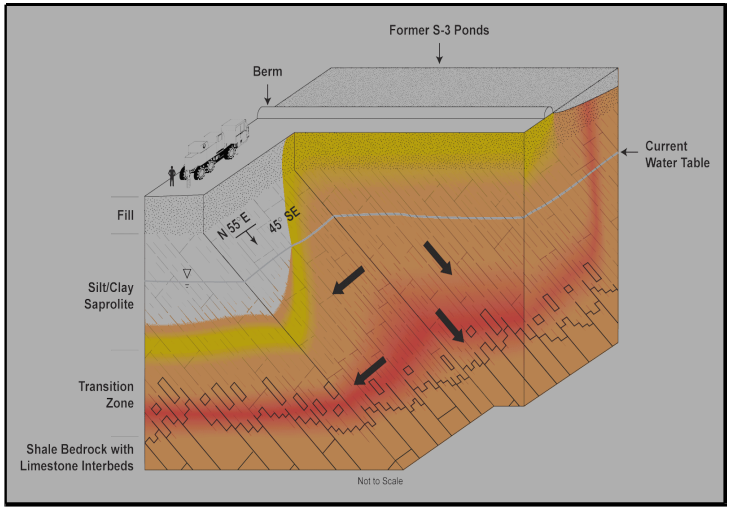


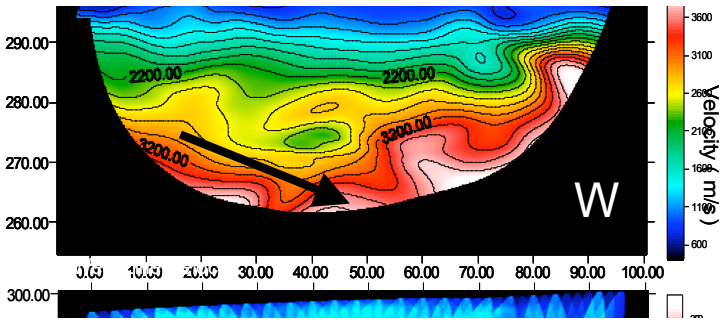
Origin of Low Velocity Anomaly: Seismic refraction profiles indicate an anomalous and laterally continuous north-dipping feature





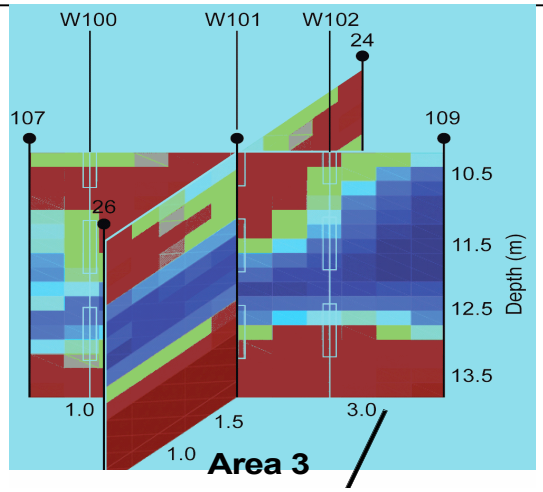






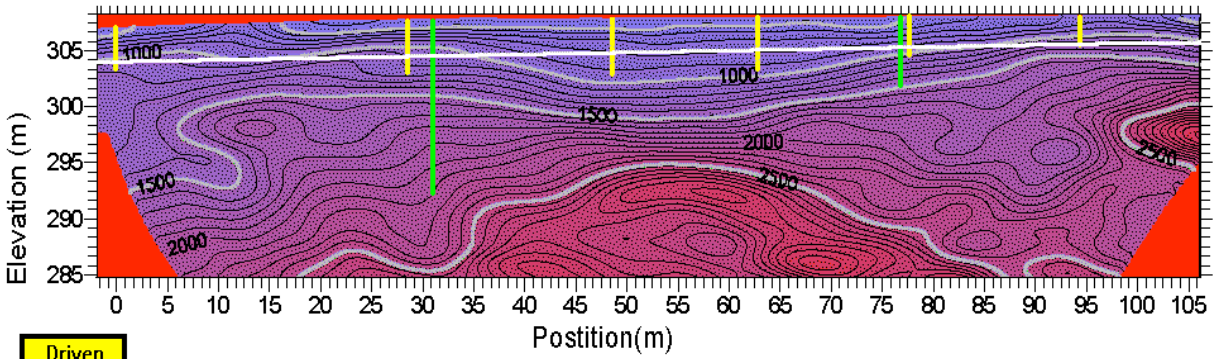
Jacob Sheehan
Battelle
The Business of Innovation

Method Development



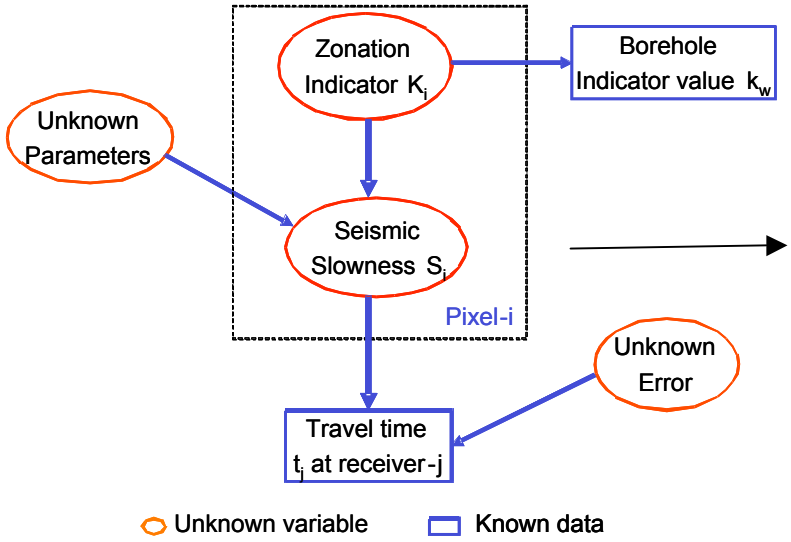
Chen et al., 2006 WRR

Watershed Scale Joint Inversion for Transition Zone Characterization



Seismic Methods useful for delineating base of transition zone and fracture zonation

Graphical model



Extend Bayesian joint inversion method for use with surface seismic refraction and wellbore information to **quantitatively define transition zone at watershed scale.**

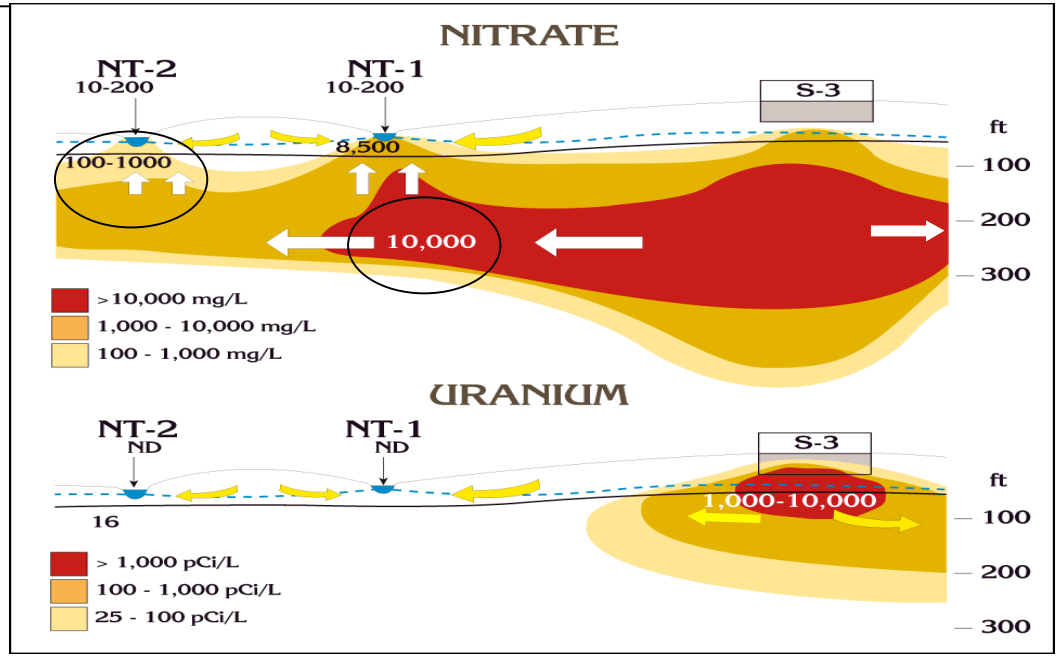
Goal #2:
Refine plume distribution
(nitrate)

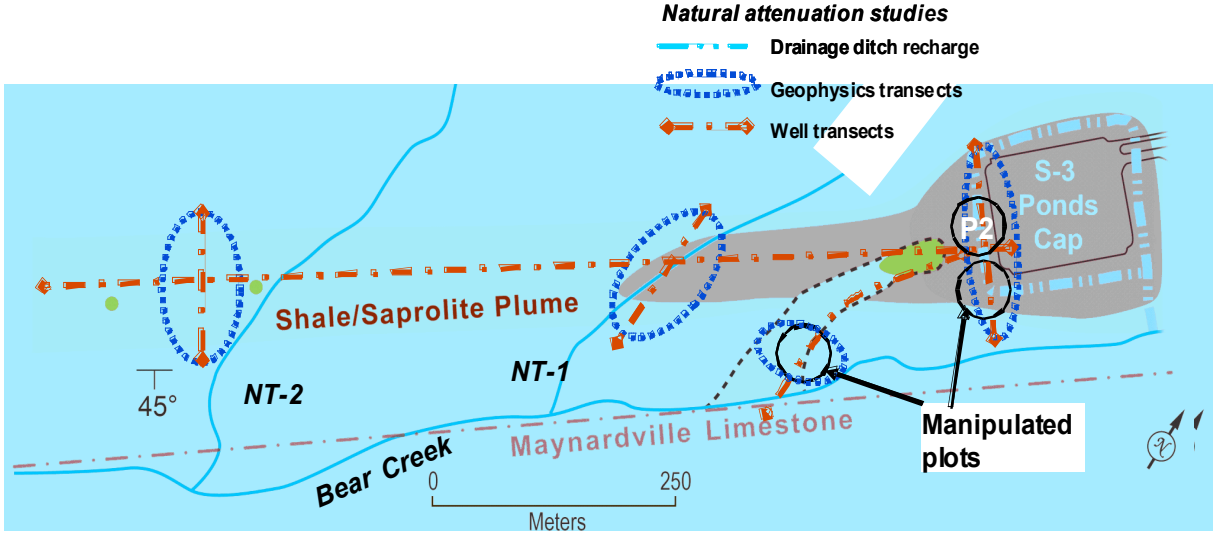
Approach:

Collect and Reduce

- Wellbore hydrogeochemical and surface geophysical datasets (esp. geoelectric)

Develop petrophysical relationships between electrical conductivity, pore fluid concentrations, and lithofacies





Previous Remote Plume Delineation

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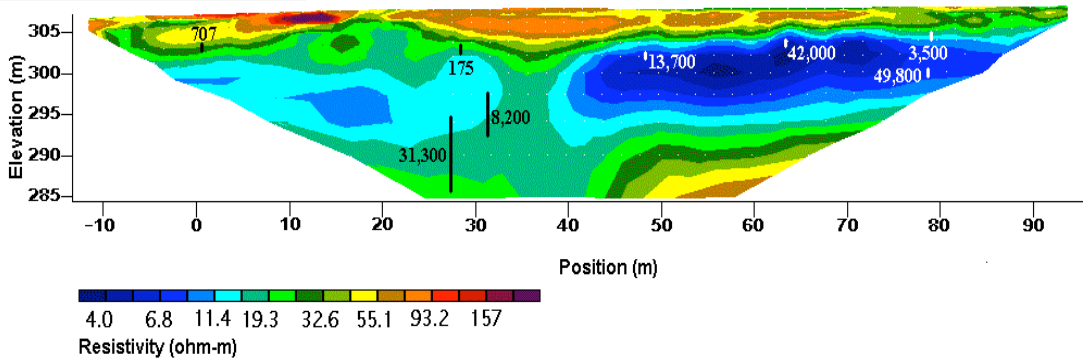
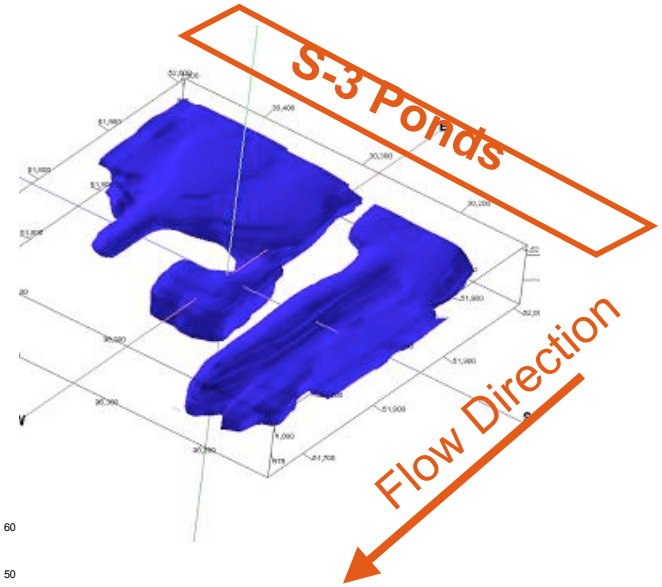
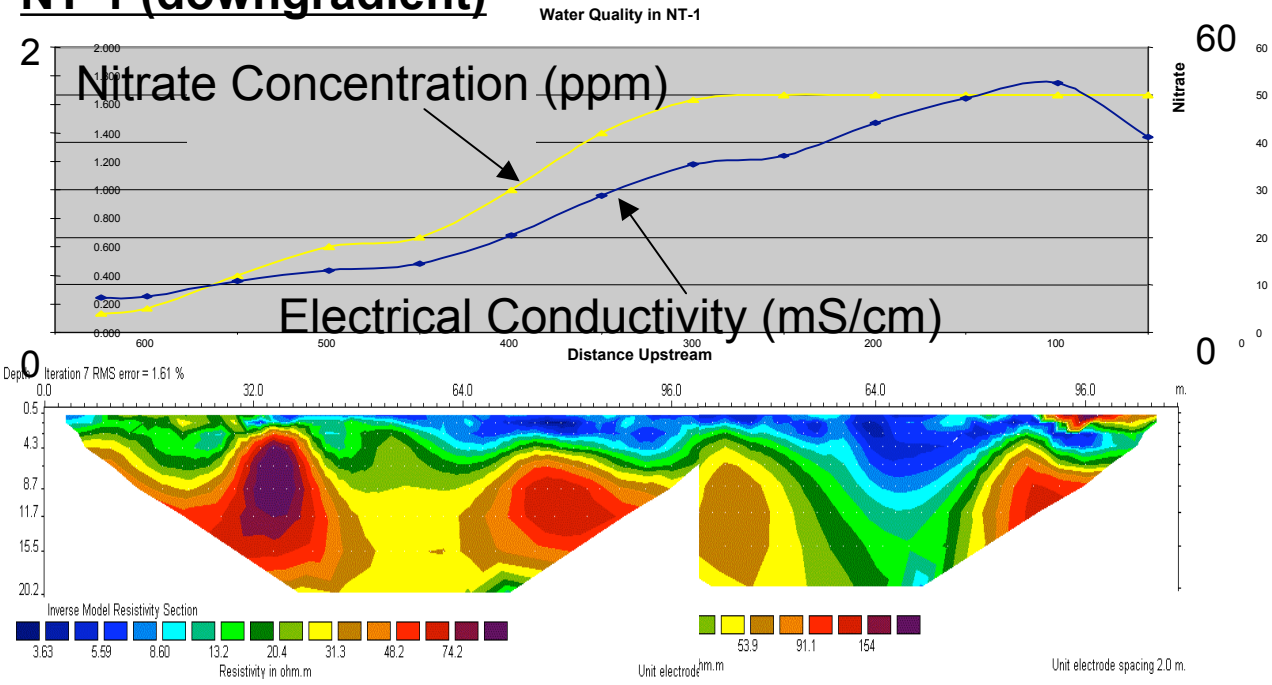
Electrical Methods for indicating regions of high ionic pore strength

SOURCE AREA





NT-1 (downgradient)



Investigate sensitivity of electrical methods for delineating plume as function of lithofacies

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TASK A: Exploring Relationships between Geophysical and Hydrogeochemical Properties

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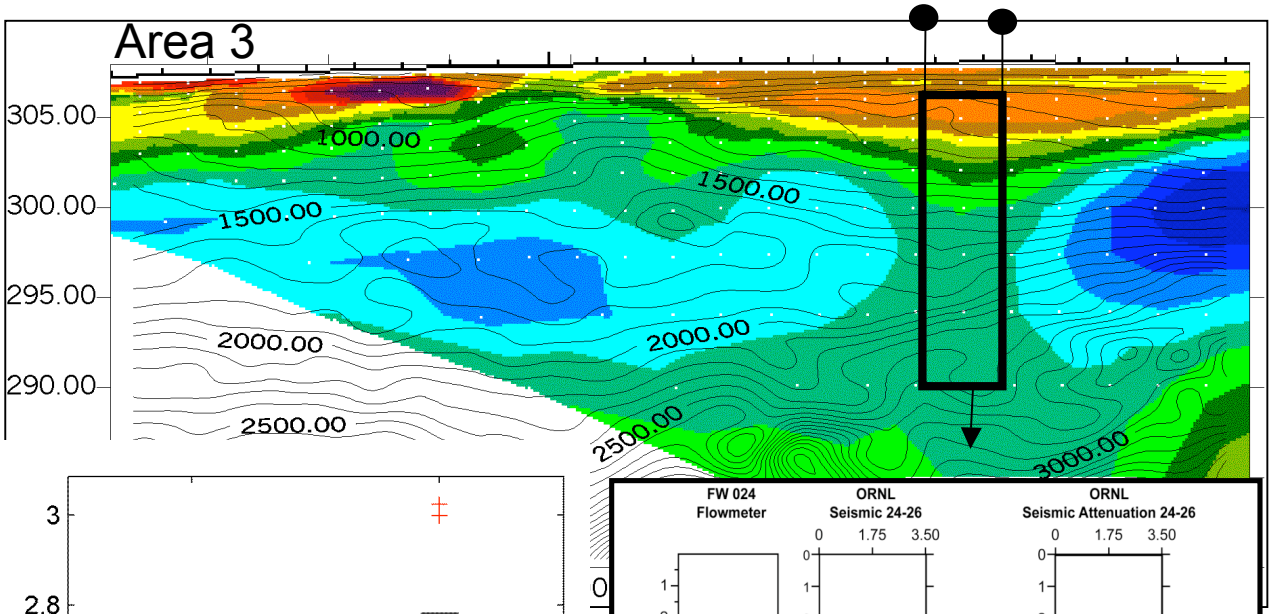
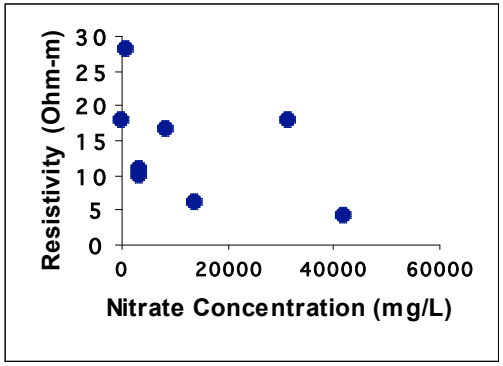
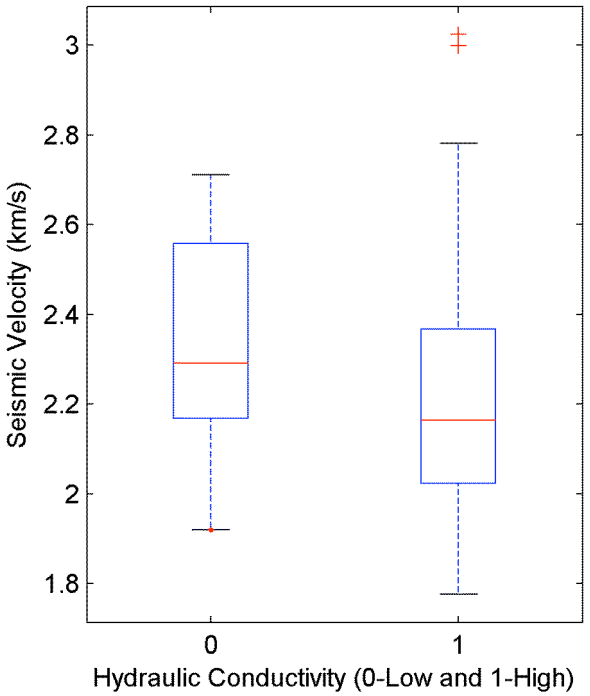
Investigations using primarily seismic, electrical, SP, and radar methods

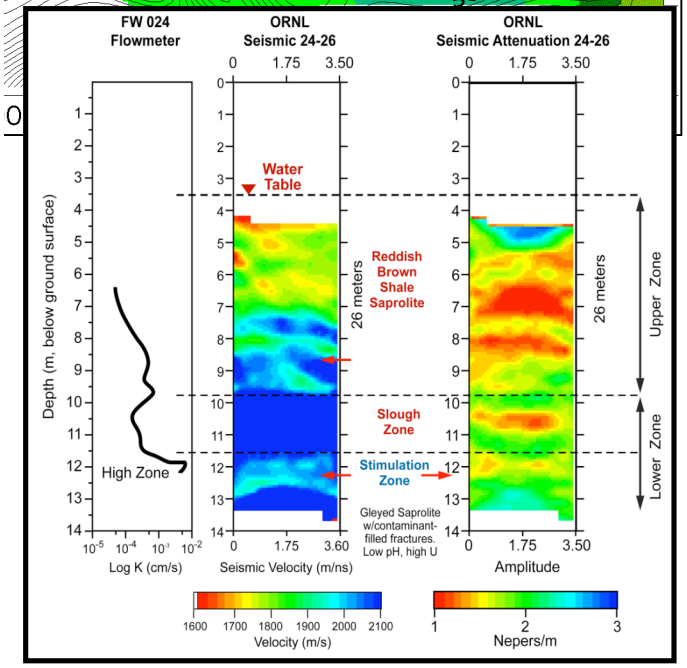




Electrical conductivity increases with increasing nitrates in groundwater

(ORNL background groundwater TDS ~200ppm)





Seismic velocity is lower in fractured transition zone relative to surrounding, more competent rock

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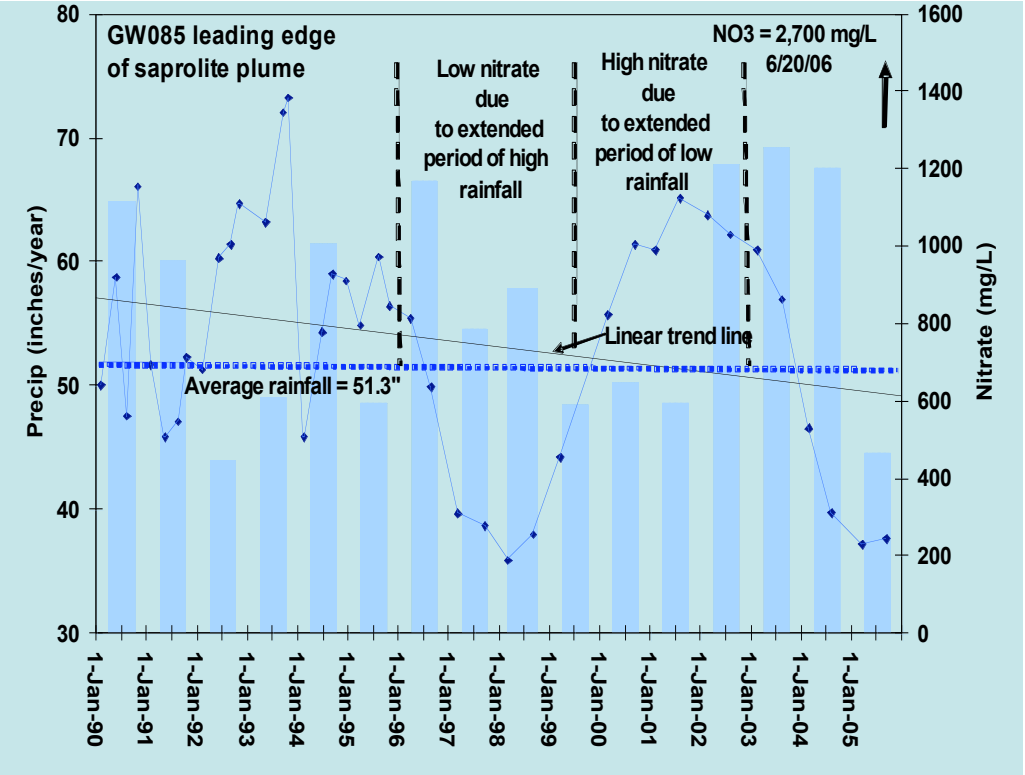
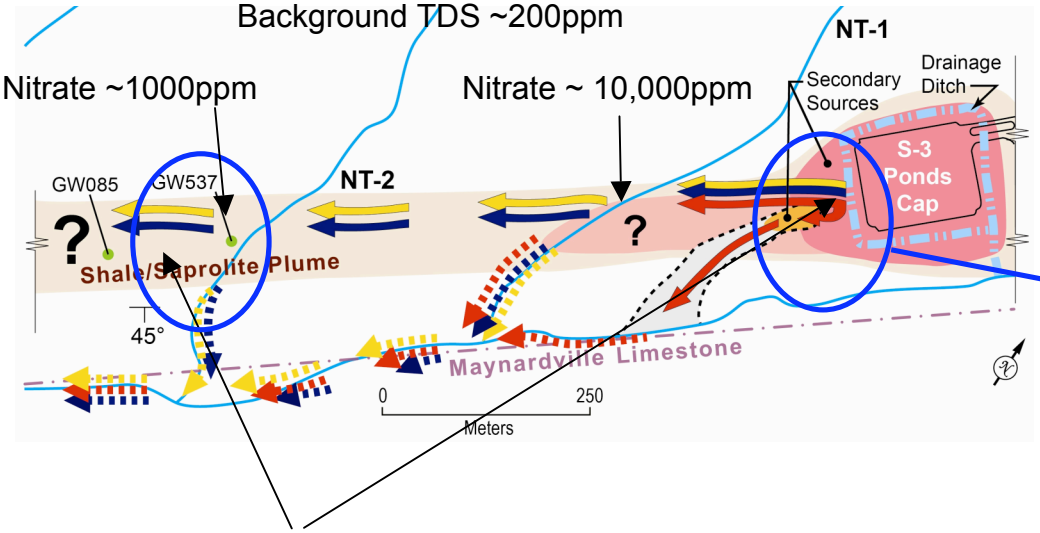
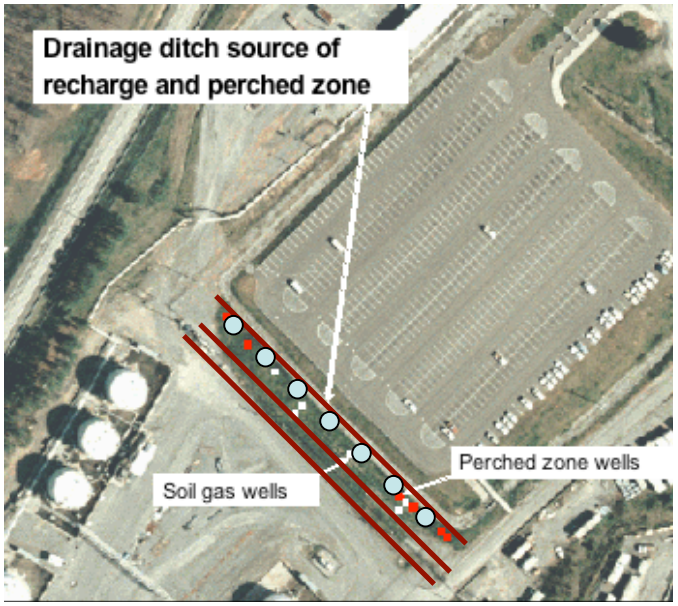
Motivation:

- Recharge creates large hydraulic and geochemical gradients that disrupt equilibrium;
- Difficulty in accessing spatiotemporal impacts of recharge using only well concentration data.



Understanding the impact of natural recharge on subsurface hydrogeochemistry at the plume scales could be important for guiding decisions associated with environmental remediation and long term stewardship





APPROACH:

1. **Collect Time-Lapse Datasets**:
   - Precipitation
   - Surface geophysical datasets (ERT and SP)
   - Crosshole geophysical and tracer tests
   - Wellbore geochemical (incl. isotopes), hydrological, geophysical datasets.
2. **Investigate geophysical 'error' associated with time-lapse datasets**
3. **Integrate** time-lapse datasets to:
   - Track recharge along identified key pathways in response to recharge events.
   - Elucidate biogeochemical transformations

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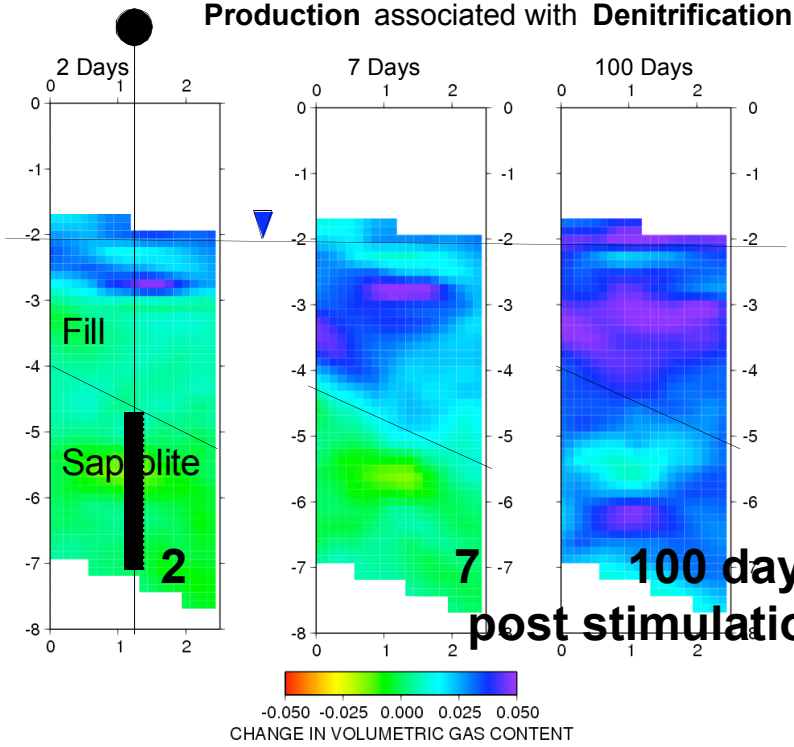
Previous Biogeophysical Monitoring at the ORFRC

Use of time-lapse geophysical methods to:
estimate the **distribution and extent of biogeochemical transformations** associated with targeted manipulations;
to explore the **impact of heterogeneity** on the transformations.

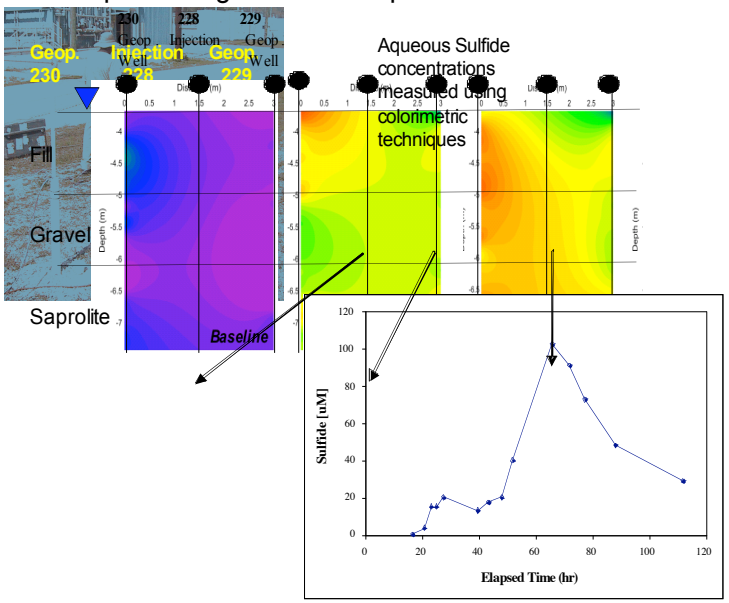
Denitrification

Area 1: Time lapse **Radar** Estimates of **Gas Production** associated with **Denitrification**



Sulfate Reduction

Area 2: Time -lapse changes in **SP** response coincident with **sulfide production**



0 25 46 hours post stimulation

Performed in collaboration with Jack Istok push-pull tests

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Monitoring pH Manipulations

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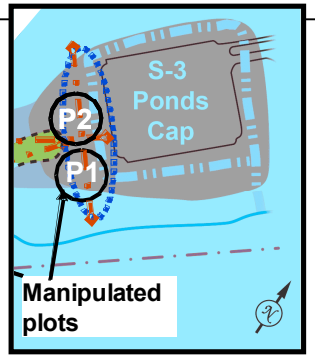
MOTIVATION

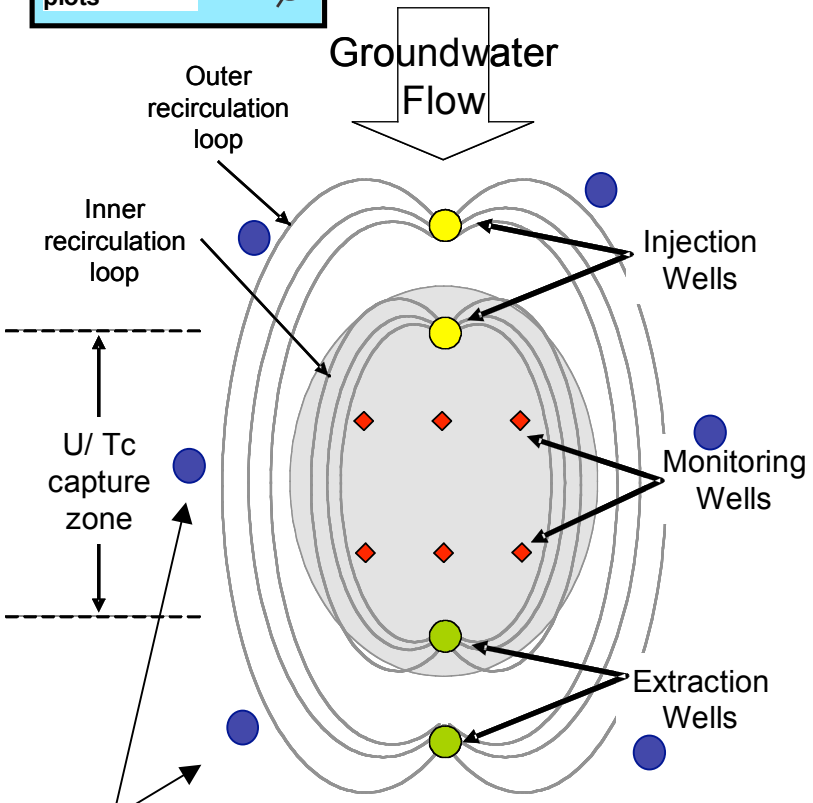
- Controlled pH adjustment could precipitate greater than 90% of soluble U(VI) and Tc(VII);
- Difficult to understand spatiotemporal distribution of expected **Al hydroxide precipitates** and **impact on flow** characteristics using wellbore data alone.

TASKS

- Time-lapse **biogeophysical imaging** of transformations:
  - Petrophysics
  - Data acquisition and reduction
  - Characterization
  - Monitoring: wellbore, crosshole, surface
- Explore influence of heterogeneity on transformation - requires field scale characterization

Task C.6





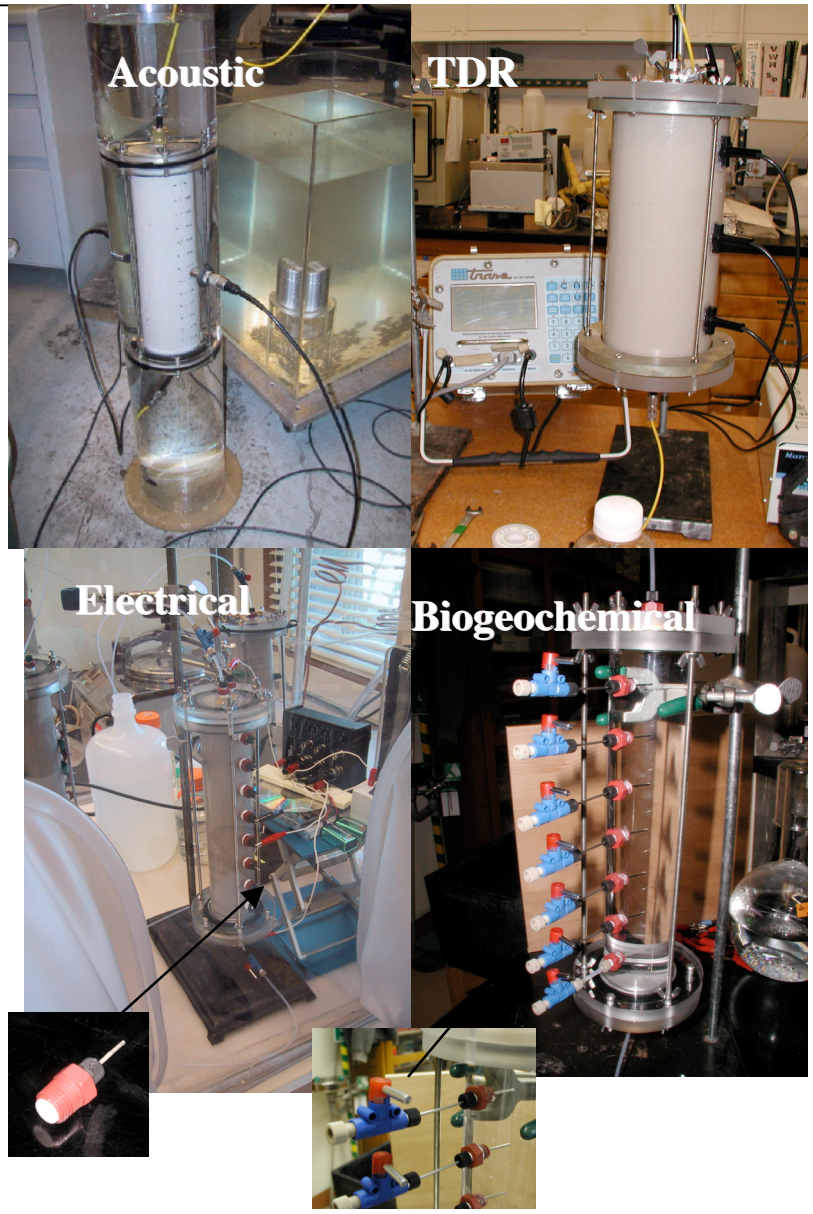
Collect geophysical measurements within and between wellbores

LABORATORY SCALE Investigations to determine sensitivities of geophysical methods to **biogeochemical-hydrological transformations associated with targeted manipulations**

Flow Through Column Experiments that Mimic field manipulation with:

- **GEOPHYSICAL MEASUREMENTS**
  - P and shear wave **seismic**, radar, **complex resistivity** (10^{-1}-10^{3}Hz) & SP.
- **BIOGEOCHEMICAL MEASUREMENTS**
  - Fluid and sediment geochemistry, biomass
- **HYDROGEOLOGICAL MEASUREMENTS**
  - Hydraulic conductivity, porosity

Use Lab Results to Guide Choice and Interpretation of Field Monitoring Methods.



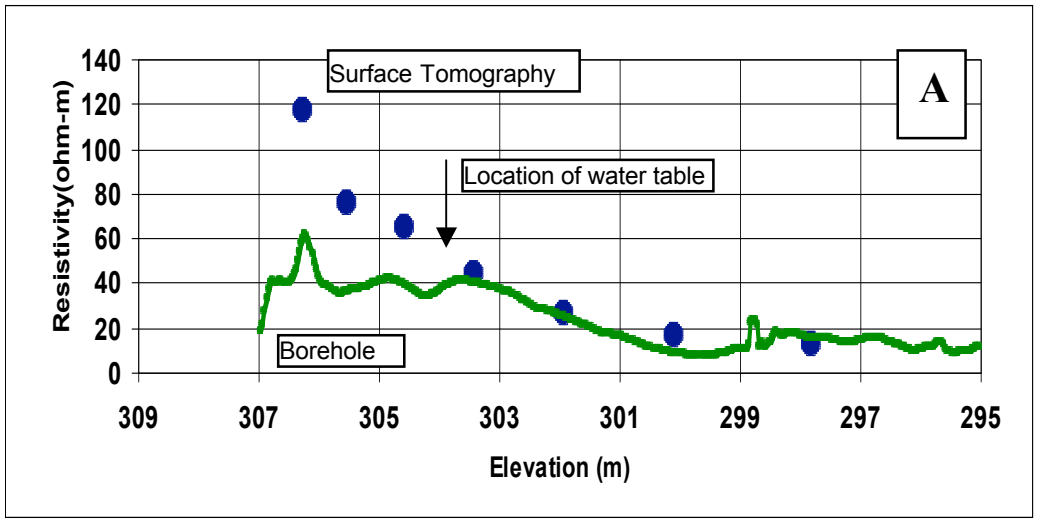
Geophysical Characterization & Monitoring Timeline

Year/Quarter TASK	FY07-08		Year 2-3	Year 3-4	Year 4-5
Link Geophysical Responses to Media (Task A.1)	Develop geophysical-hydrogeochemical petrophysical relationships				
Delineate Heterogeneity and Pathways (Task A.2)	Gross characterization and start development of joint inversion framework				
Monitor Natural Recharge Processes (Task B.3.2)	Geophysical error analysis and start of recharge monitoring				
Monitor Manipulation Transformations (Task C.6)	Column experiments and field characterization associated with pH manipulations				

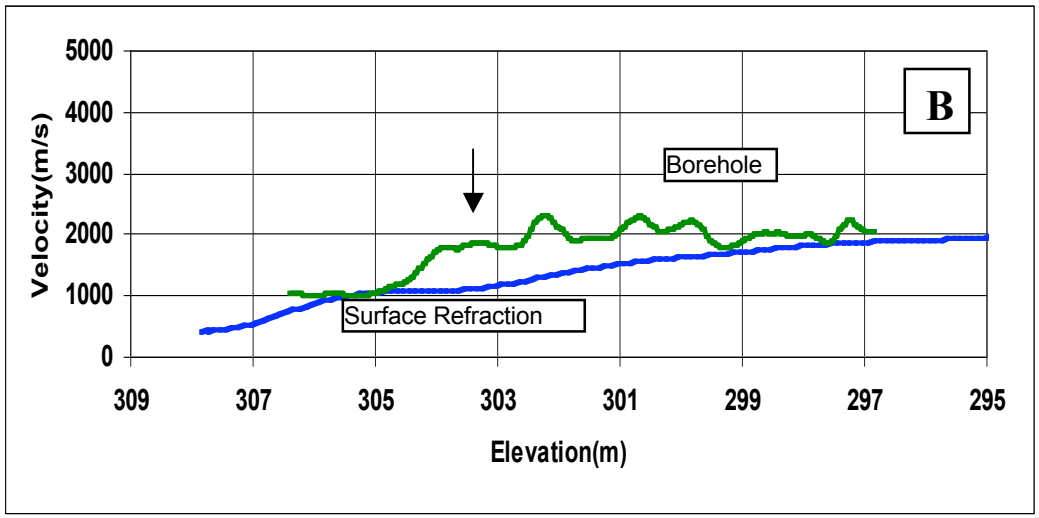
Agenda

- **Project Overview**: (speaker: Jardine) 15 min
- ***(Task B)* Natural Attenuation**: Rates and Mechanisms along pathways and within source zones (speaker: Watson) 20 min
- ***(Task C)* Targeted Manipulations**: Enhanced contaminant stability of source zones (speaker: Criddle) 20 min
- ***(Tasks A-C)* Geophysics**: Characterization and monitoring (speaker: Hubbard) 20 min
- ***(Tasks B & C)* Microbiology**: Characterization and monitoring as a function of scale (speaker: Kostka) 20 min
- ***(Task D)* Numerical Modeling**: Multiscale flow and transport modeling, upscaling, and advanced pattern recognition (speaker: Parker) 15 min
- **Research Outcomes, Site Contributions, and Opportunities**: (speaker: Jardine) 5 min

Previous research has indicated similar trends in geophysical attribute as a function of scale



Electrical



Seismic