Oak Ridge Field Research Center

Current Opportunities and Future Research Directions

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Contact Information:
David Watson (865-241-4749) - FRC Manager
Environmental Sciences Division
Oak Ridge National Laboratory
E-Mail: watsondb@ornl.gov

http://www.esd.ornl.gov/nabirfrc/

Presentation Outline

- Current FRC research opportunities
  - Current research results and findings
    - Field scale reduction
    - Inhibition/oxidation
    - Characterization and monitoring tools
    - Rates and mechanisms
    - Modeling
  - Near-term research opportunities
- Potential future research directions

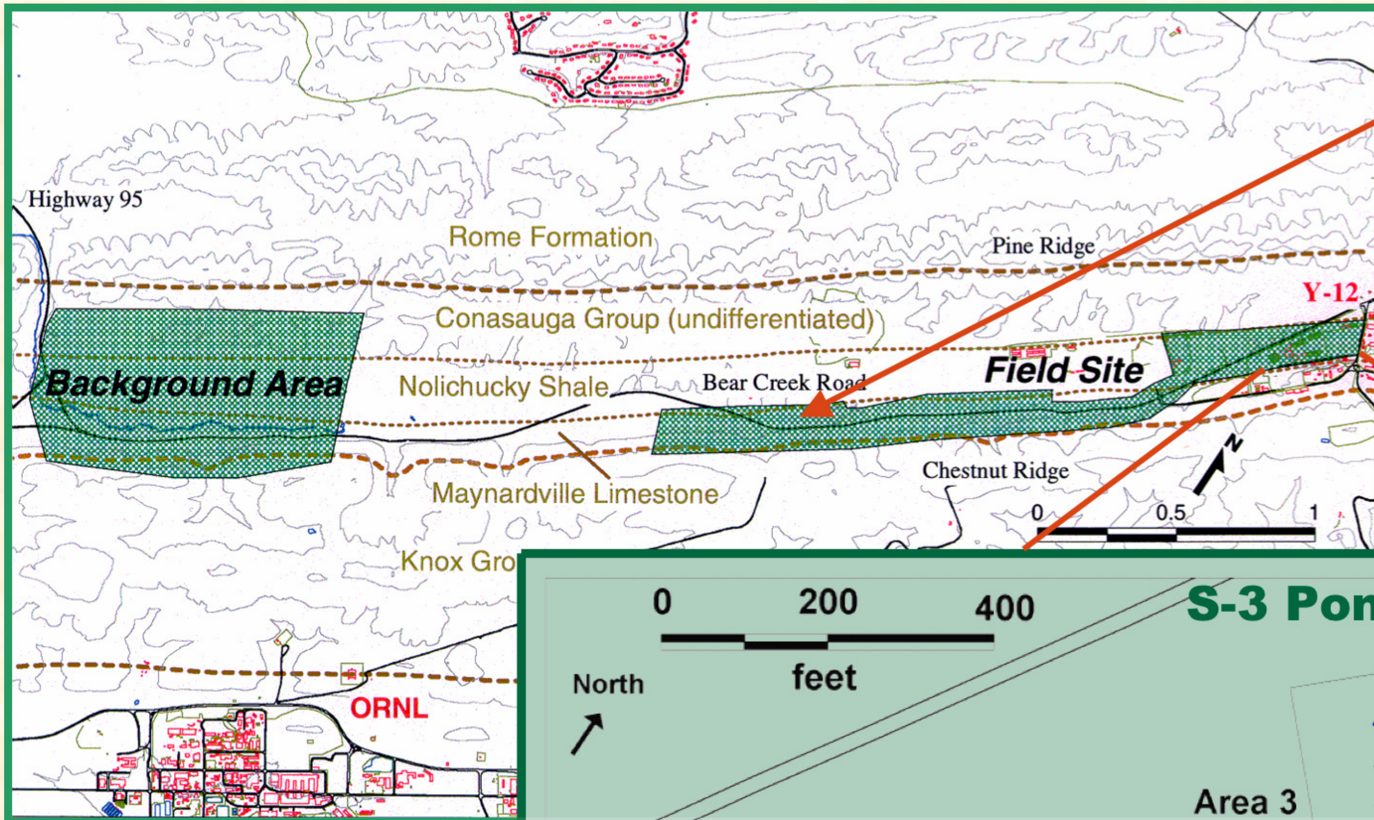
Original FRC Research Focus

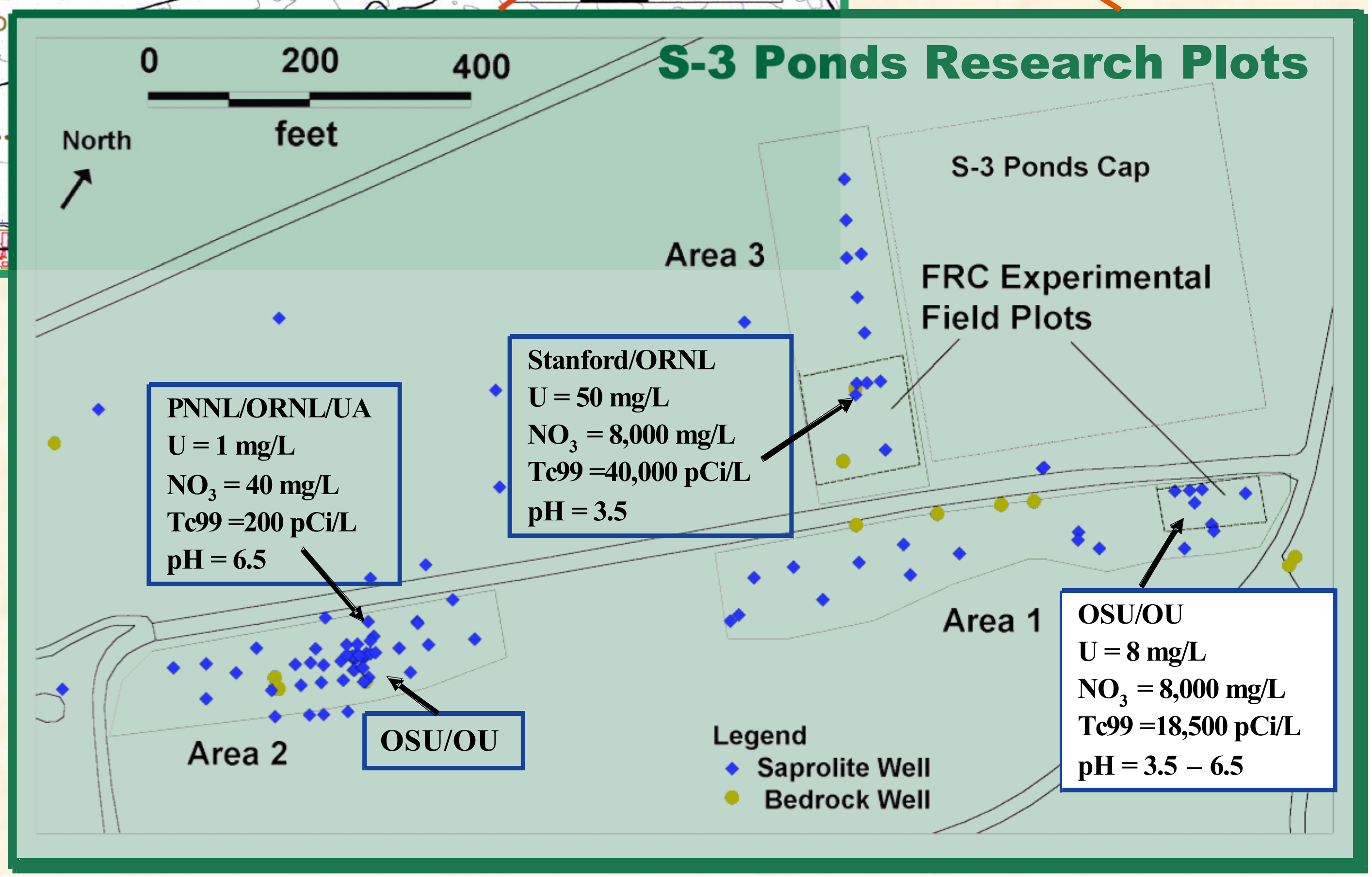
- **Objectives**
  - **Understand fundamental biogeochemical processes influencing the use of bioremediation approaches for cleaning up, managing, or understanding fate and transport of metals and radionuclides at DOE's contaminated legacy waste sites**
  - **Promote coordination and efficient use of resources, and facilitate comparison and integration of data**
- **Establish a field laboratory**
  - **Source of subsurface samples for NABIR, EMSP, GTL, JGI investigators**
  - **Resource for**
    - **Evaluation of new characterization and monitoring methods**
    - ***In situ* accelerated bioremediation research**

Multi-disciplinary *In Situ* Accelerated Bioremediation Field Research Projects

- ***In situ* uranium reduction experiments using push-pull techniques** (Oregon State University, Oklahoma University, PNNL, ORNL located in Areas 1 and 2)
- ***In situ* immobilization of uranium in structured porous media via biomineralization at the fracture/matrix interface** (PNNL, ORNL, and University of Alabama, located in Area 2)
- **Field-scale bioreduction of uranium** (Stanford and ORNL, located in Area 3)

Multiple Hydrogeologic Environments Available for Study





FRC Sample Collection, Analysis and Distribution

- 2,880 samples distributed to researchers for laboratory studies
  - Samples distributed to NABIR, GTL, EMSP, and JGI researchers
  - Samples shipped overseas to Switzerland, Denmark, and UK
  - Hg samples collected and shipped
- >12,000 samples collected for field studies
- Drilling
  - 111 wells installed – 2,900 feet
  - 114 coreholes (no wells) drilled – 2,200 feet
- Analyses (excludes analyses for PIs)
  - 20,000 FRC new analyses results
  - 39,000 historical analyses results entered into the database

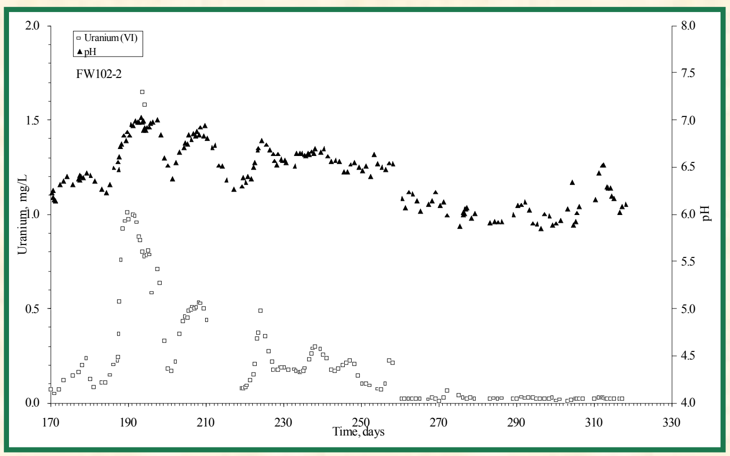
FRC Publications

- Over 25 publications published or in press
- Many more submitted or being prepared

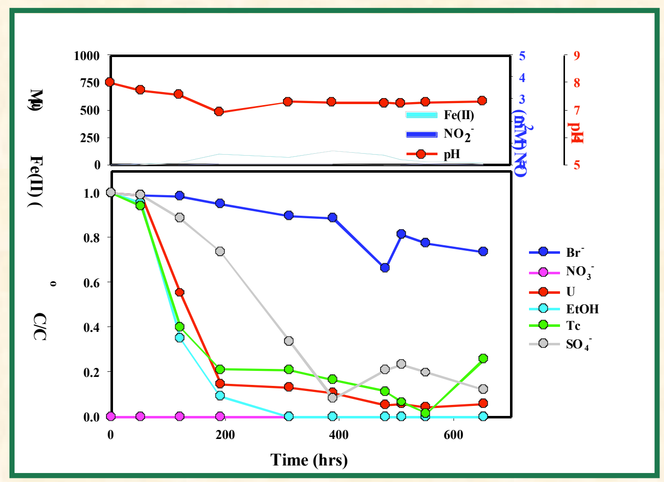
1. Impacts on microbial communities and cultivable isolates from groundwater contaminated with high levels of nitric acid-bearing uranium waste (Proof available online as of 2/26/2005).
2. Plume and Lithologic Profiling with Surface Resistivity and Seismic Tomography..
3. Change in Bacterial Community Structure during In Situ Biostimulation of Subsurface Sediment Cocontaminated with Uranium and Nitrate.
4. Coupling of functional gene diversity and eochemical data from environmental samples.
5. Isolation, characterization, and U(VI)-reducing potential of a facultatively anaerobic, acid-resistant bacterium from Low-pH, nitrate- and U(VI)-contaminated subsurface sediment and description
6. of Salmonella subterranea sp nov..
7. Soil Chemistry and Mineralogy: Kinetic Models (In) Encyclopedia of Soils in the Environment (in press).
8. In situ bioreduction of technetium and uranium in a nitrate-contaminated aquifer.
9. Sorption and binary exchange of nitrate, sulfate, and uranium on an anion-exchange resin.
10. Semi-Analytical, Homogeneous, Anisotropic Capture Zone Delineation.
11. A cultivation-independent investigation of microbial communities during in situ biostimulation of subsurface sediment co-contaminated with uranium and nitrate.
12. Composition and diversity of microbial communities recovered from surrogate minerals incubated in an acidic uranium-contaminated aquifer.
13. An application of Bayesian inverse methods to vertical deconvolution of hydraulic conductivity in a heterogeneous aquifer at Oak Ridge National Laboratory.
14. Utilization of microbial biofilms as monitors of bioremediation.
15. Molecular diversity and characterization of nitrite reductase gene fragments (nirS and nirK) from nitrate- and uranium-contaminated groundwater.
16. Geochemical reactions and dynamics during titration of a contaminated groundwater with high uranium, aluminum, and calcium.
17. Potential for in situ bioremediation of a low-pH, high-nitrate uranium-contaminated groundwater.
18. Conceptual and numerical model of uranium (VI) reductive immobilization in fractured subsurface sediments.
19. A nested-cell approach for in situ remediation.
20. A prohibitin-like protein of Shewanella oneidensis MR-1 is involved in iron homeostasis and oxidative damage protection (in press).
21. The Three-Point Problem, Vector Analysis and the Extension to the N-Point Problem.
22. Enumeration and characterization of iron(III)-reducing microbial communities from acidic subsurface sediments contaminated with uranium(VI).
23. Inhihition of bacterial U(VI) reduction by calcium.
24. Mass-transfer limitation for nitrate removal in a uranium-contaminated aquifer at Oak Ridge, TN.
25. HYDROGEOCHEM 4.0: A coupled model of fluid flow, thermal transport, and HYDROGEOCHEMical transport through saturated-unsaturated media: version 4.0.
26. HYDROGEOCHEM 5.0: A three-dimensional model of coupled fluid flow, thermal transport, and HYDROGEOCHEMical transport through variably saturated conditions: version 5.0.
27. U L3-Edge EXAFS Measurements of Sediment Samples from Oak Ridge National Laboratory, Tennessee, U.S.A.

Research Findings – Field-Scale Reduction

- **Microbially mediated reduction of U, Tc-99, and nitrate observed (Criddle and Istok experiments)**
  - **Aqueous phase reduction of dissolved U, Tc, nitrate, and ethanol; Increase in Fe(II)**
  - **Observation of reduced U(IV) near injection wells**
  - **Changes in solid phase Fe mineralogy observed** (Stucki et al.)
  - **Microbial populations increase and shift (SRB, FeRB, NRB)**
  - **Methanogenesis and sorption controlled via pH adjustments** (Criddle et al.)

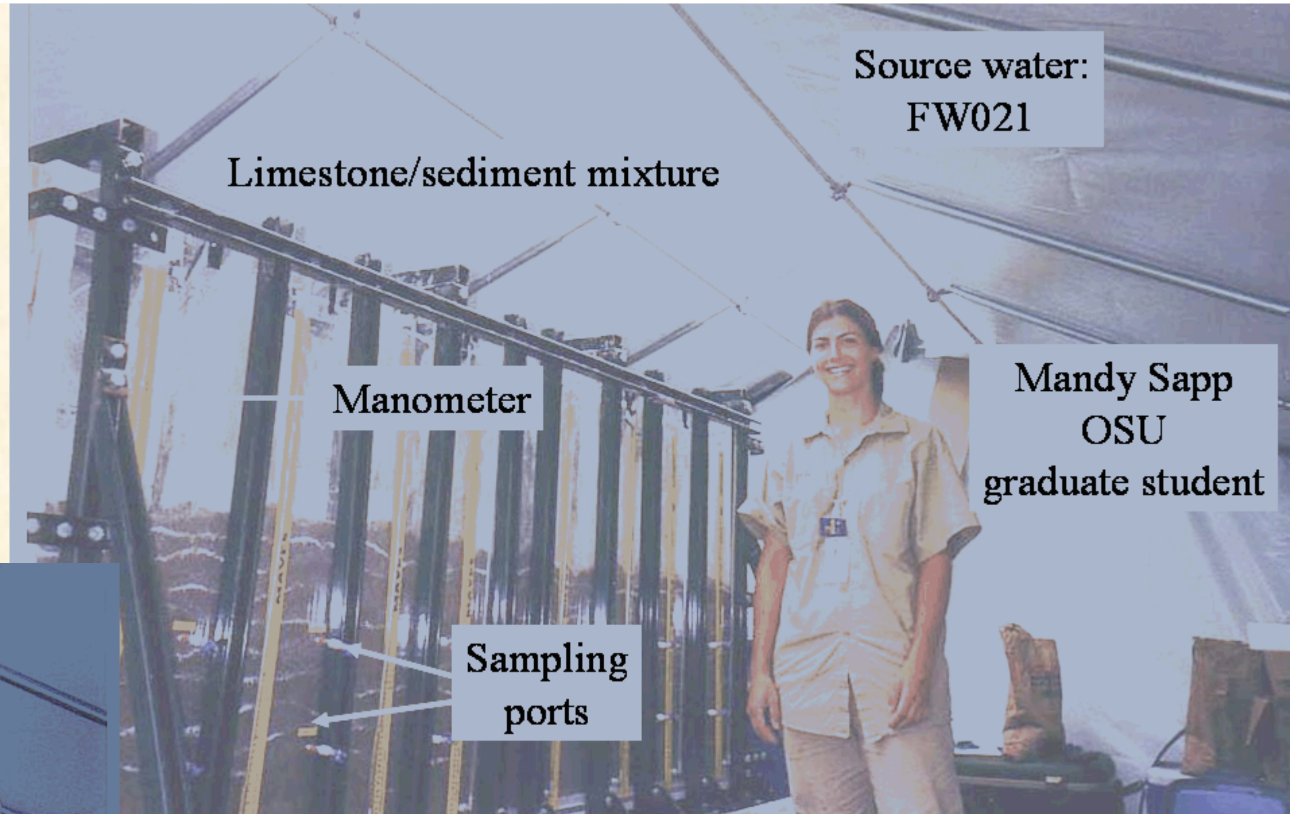


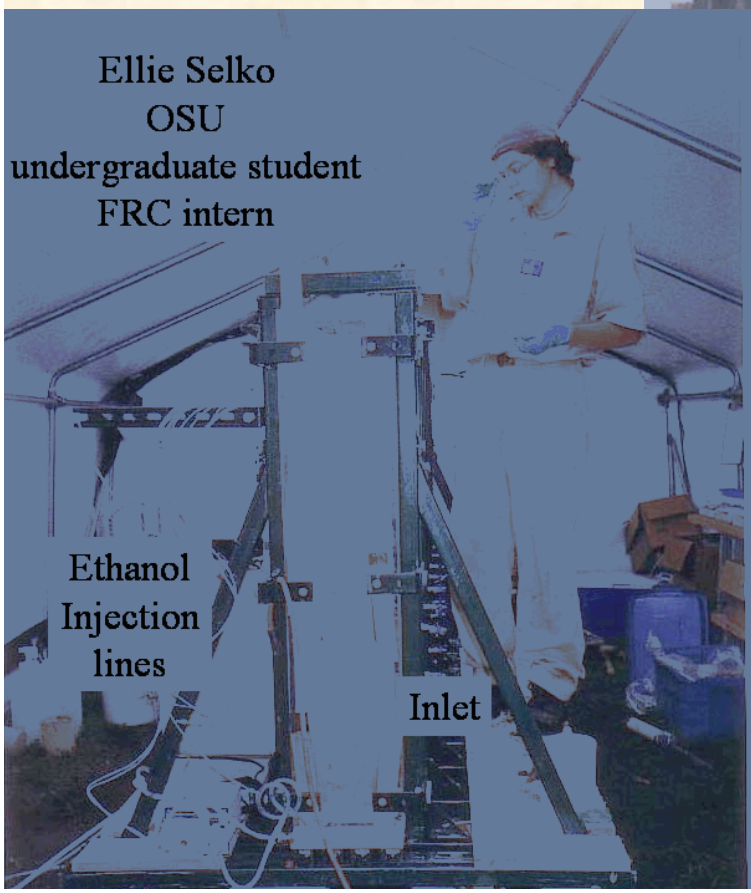
Uranium (VI) reduction during Area 3 field scale tests with addition of electron donor (ethanol)



Simultaneous uranium and technetium immobilization during field push-pull tests with addition of electron donor (ethanol)

Observing U and Tc reduction in flow cells for over 20 months





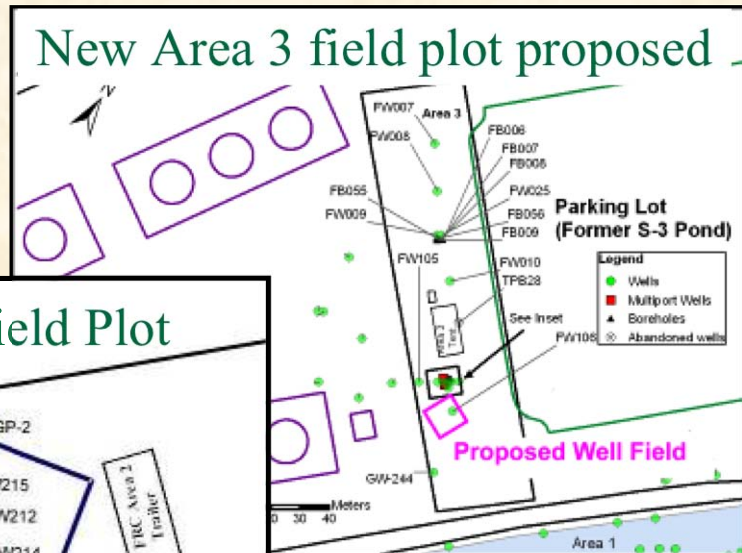
OSU Flow-Through Cells

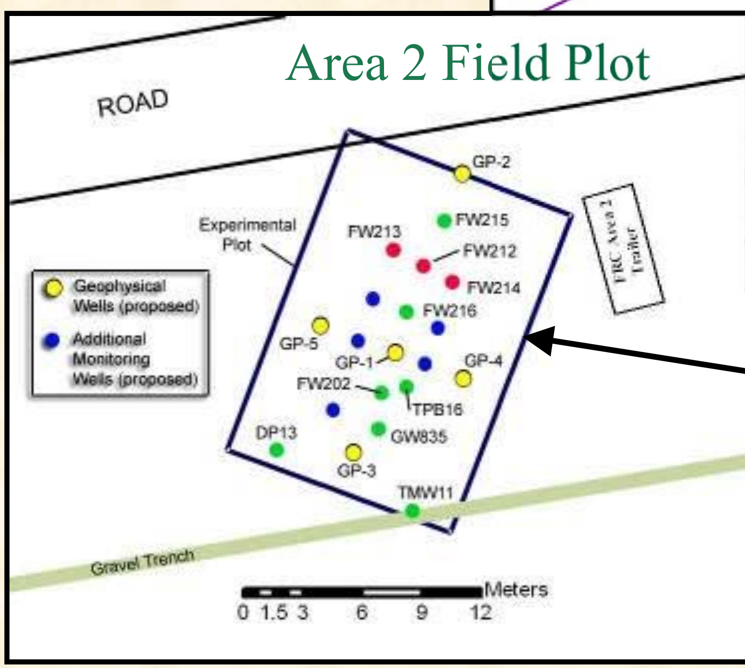
- Simulating subsurface biocurtain
- Two Cells at Areas 1 and 2
- Test and control cells

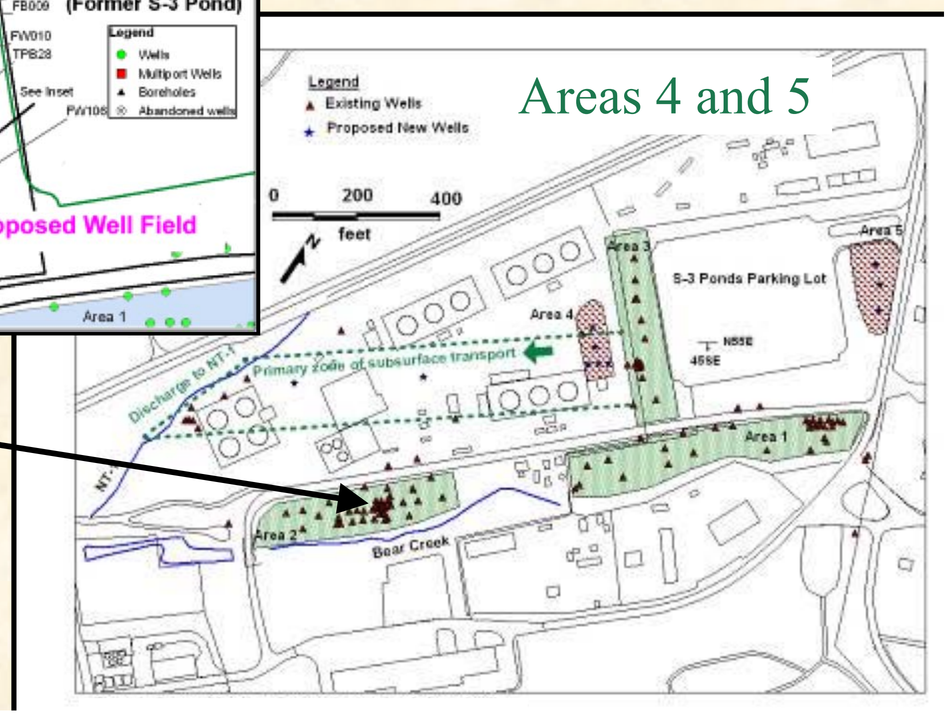
Field Research Center

Research Opportunities Field-Scale Reduction

- **Area 2 manipulations to begin this spring** (Scheibe – microbarriers)
- **New Area 3 field plot proposed** (Istok)
- **New Areas 4 and 5 available (U, Tc, nitrate, and organics)**

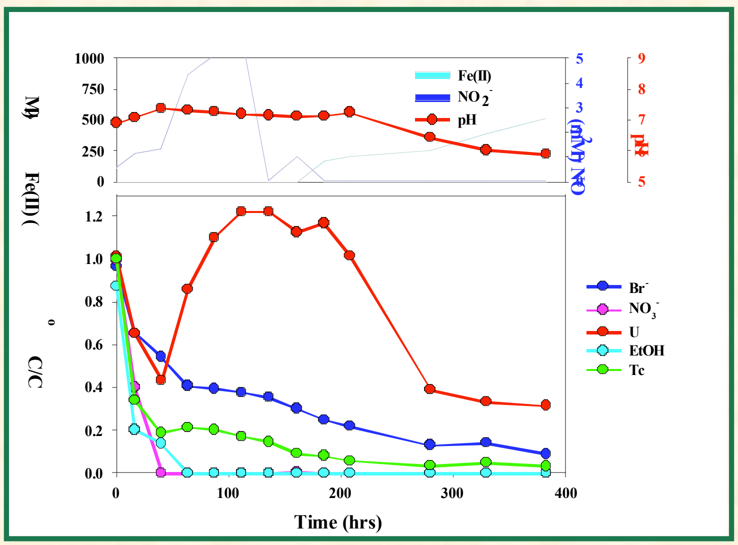




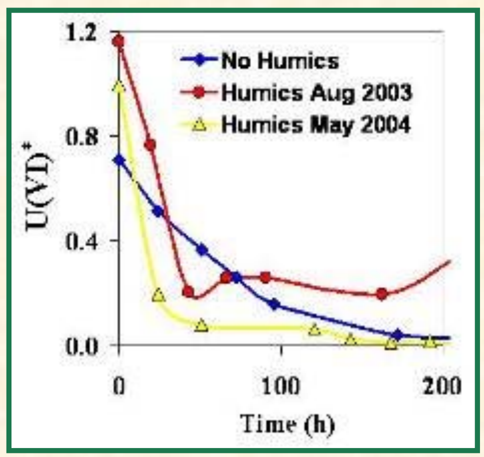


Research Findings – Inhibition/Reoxidation

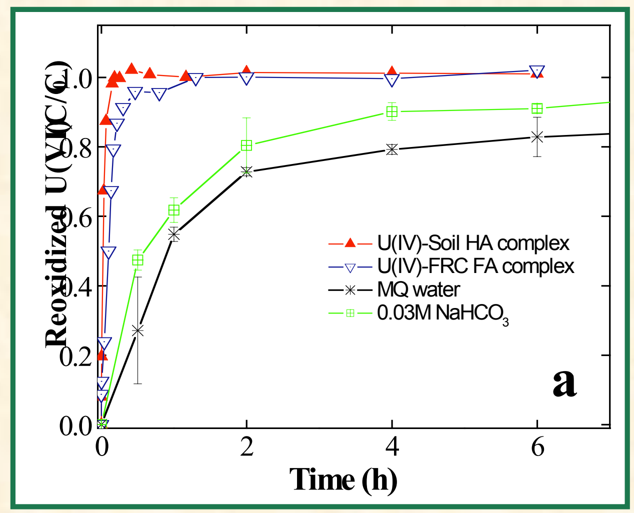
- **Nitrate, NO_x, and Fe significant role in reduction and reoxidation** (Senko, Krumholz, Istok, et al., Coates et al. Zachara et al.)
- **Ca inhibition** (Brooks et al.)
- **Al and Fe oxide pH buffering and precipitates** (Criddle et al.)
- **Humics** (Gu, Istok, et al.)
  - **Increased U reduction rates even in presence of Ca or Ni inhibitors**
  - **U-HA complexes increased rate of reoxidation (minutes)**



Oxidation and mobilization of U during push-pull test due to the presence of NO_2



U reduction rates increase during push-pull tests with FRC HA

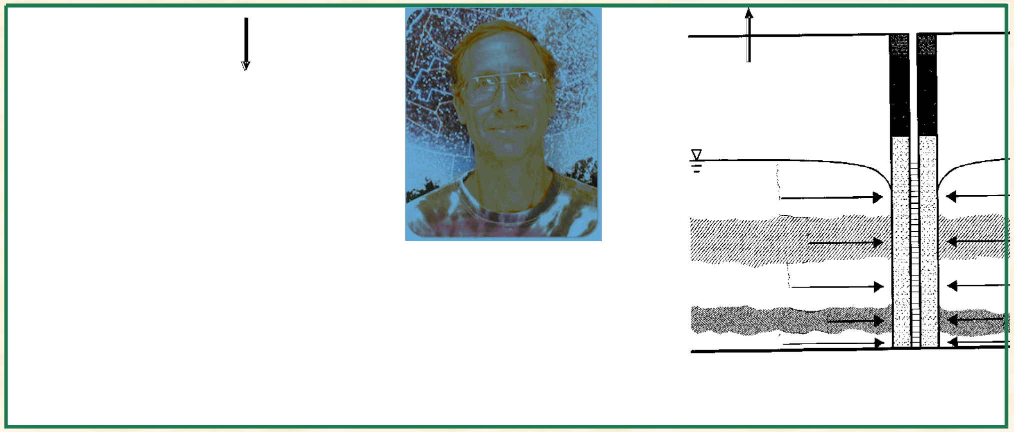


U(IV) oxidation rates increase with FRC HA complexes

Research Opportunities
Inhibition/Reoxidation

- **Future Area 3 field plot** (Criddle) **experiments will focus on reoxidation (O_2)**
- **Sequestration of U through reduction of sulfate and co-precipitation with sulfides** (Istok)

Uranium (VI) reduction/reoxidation experiments in Area 3 field plot



Push-Pull experiments in Areas 1 and 2

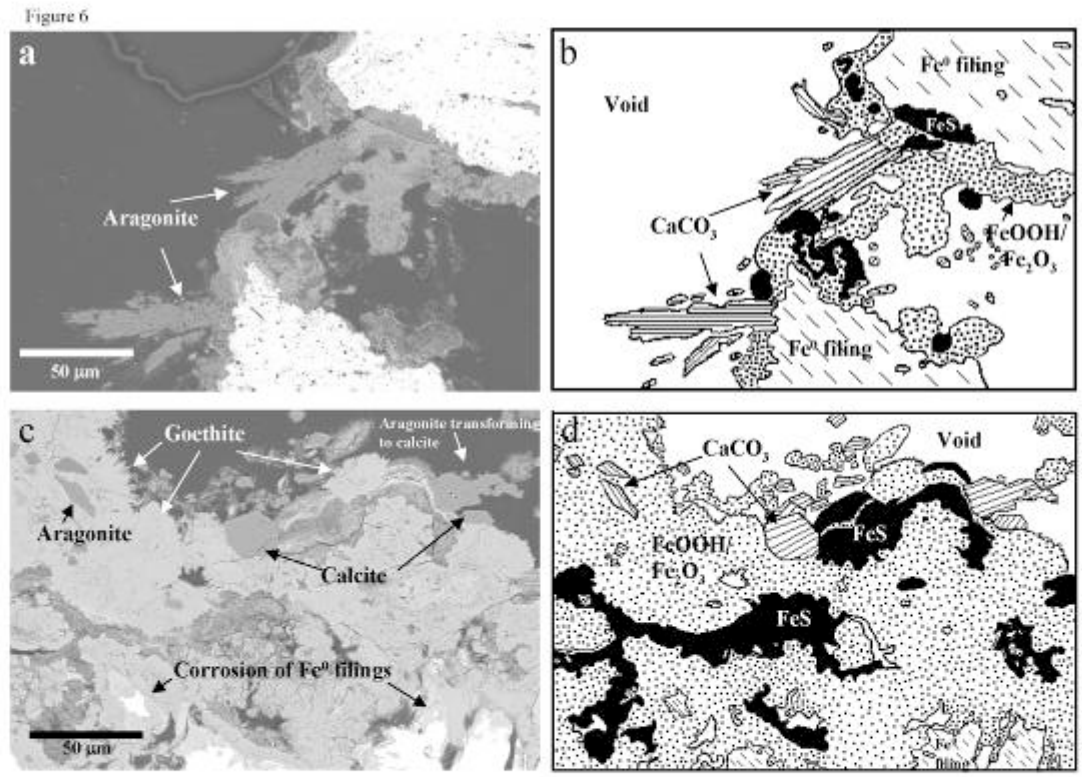
Research Opportunities

Inhibition/Reoxidation

- **Impact of aging of U, Tc, and other precipitates on sequestration and reoxidation**

Changes in Area 2 PRB from 15 months to 30 months

- cementation was greater
- amorphous FeS transformed into mackinawite
- aragonite transformed into calcite
- akaganeite transformed to goethite and lepidocrocite
- iron (oxy)hydroxides and calcium and iron carbonate minerals increased



Phillips, Watson et al.

Research Opportunities

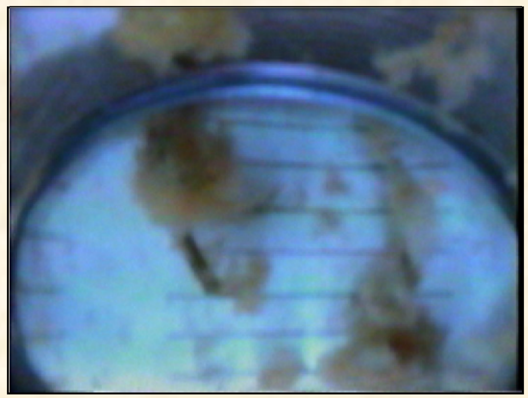
Inhibition/Reoxidation

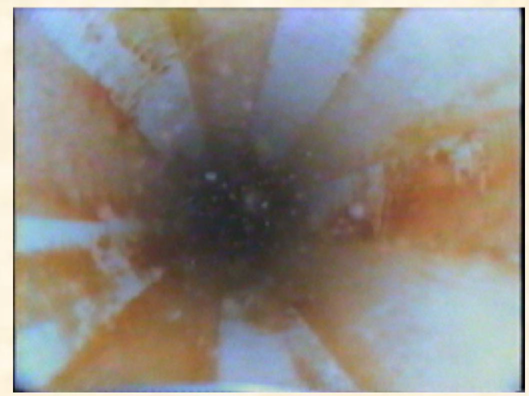
- **Aquifer clogging due to mineral precipitation and gas production**
- **Well screen clogging and refurbishment**

Well screen clogging in Area 3 Field Plot

Reference well (FW106) | Inner injection well | Inner extraction well

Pre-Cleaning





Post-Cleaning

FRC Research Findings – Microbial Communities (Kostka)

- **Lower microbial biomass and diversity in the contaminated FRC compared to Background Area** (Reardon et al., Fields)
- **Observed shifts in the dominant members of FRC subsurface material clone libraries as a result of stimulations (North et al.)**
- **Bacterial strains of metal-reducers (Salmonella, Geobacter) and nitrate-reducers (Alcaligenes, Acidovorax, Pseudomonas, Klebsiella, Agrobacterium) isolated from the contaminated area make it possible to understand physiology of organisms relevant to bioremediation** (Lovely, Kostka, Krumholz, and Fields)
- **Pure cultures indicate that a pH of < 5 is lethal to nitrate-reducers obtained from the site**
- **Isolates shown to contain metal resistance genes; a functional gene array is being developed to screen for metal resistance**

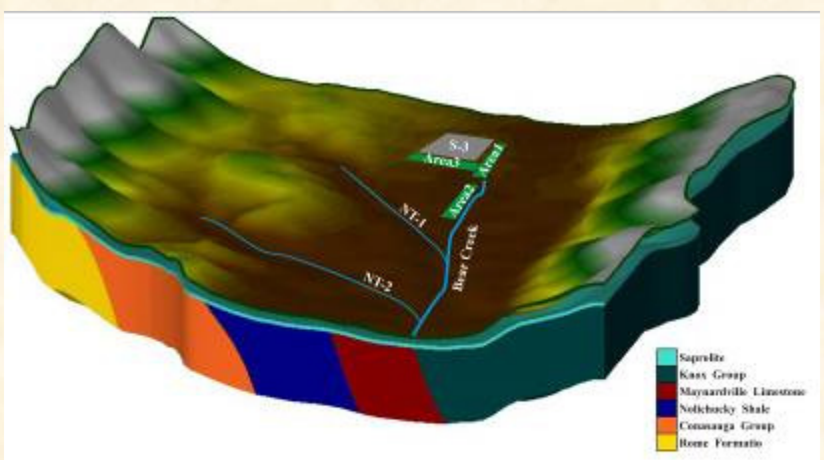
Research Opportunities
Microbial Characterization

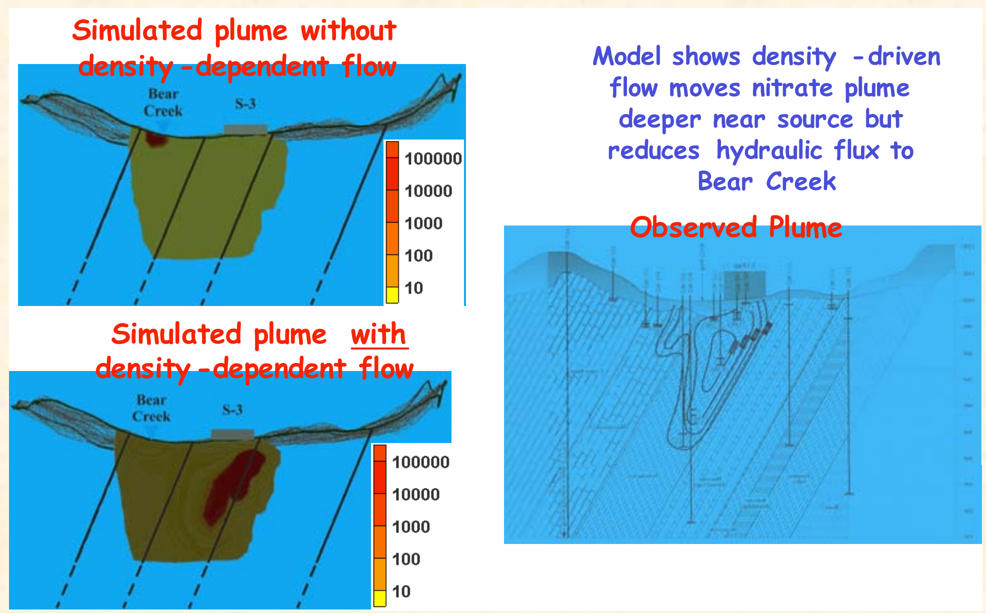
- **Physiology of organisms relevant to bioremediation**
- **Improved molecular approaches**
  - **Higher sample throughput**
  - **More quantitative**
  - **Better represent the *in situ* activity of subsurface microorganisms**
- **Competition and/or overlap of microbial communities catalyzing metal reduction, nitrate reduction, destruction of organics**
- **Sampling artifacts**
  - **Large diameter vs. small diameter wells, well purging etc.**
  - **Attached vs. detached organisms**
  - **Heterogeneity**
- **Spatial distribution of microorganisms**
  - **Relationship to geochemical and physical data**
  - **Scale of sampling between media**

Microorganism observed in Area 2 large diameter trench well with colloidal borescope

FRC Research Findings – Rates and Mechanisms (Burgos), and Modeling (Parker)

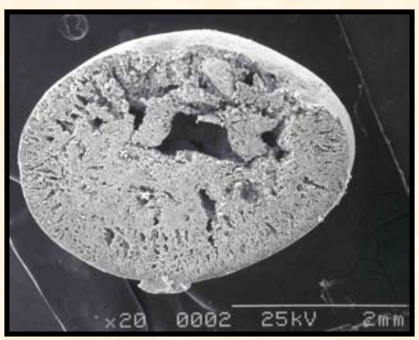
- **Rate data are being compiled in tables and report** (Burgos)
  - **To be enlarged and refined for submission as a peer-reviewed paper**
  - **Will propose and include different rate formulations and corresponding rate parameters**
- **Significant differences observed between rates measured in the lab with pure cultures, compared to rates estimated from push-pull tests**
  - **Some measured rates at the FRC 1,000 to 100,000 times slower than in laboratory experiments**
- **Input rates and mechanisms to numerical Model** (Parker)
  - **Identify important processes, knowledge gaps and prioritize research**
  - **Tool for researchers to plan and evaluate experiments**



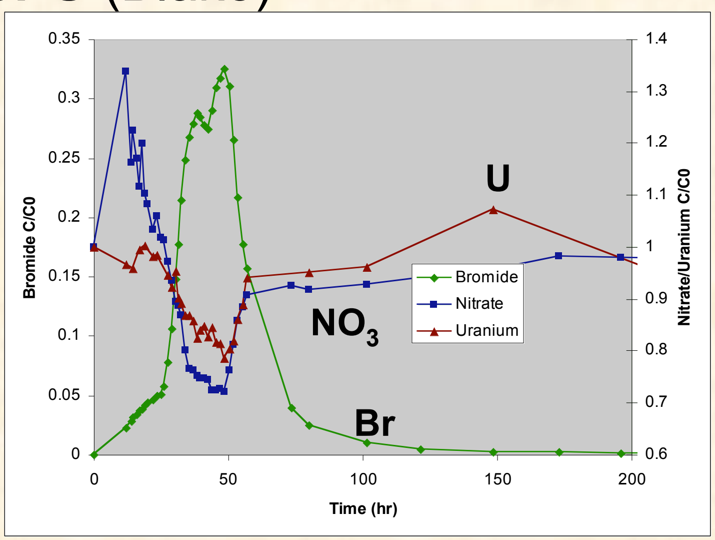


FRC Research Findings – Development of Characterization and Monitoring Tools (Jardine)

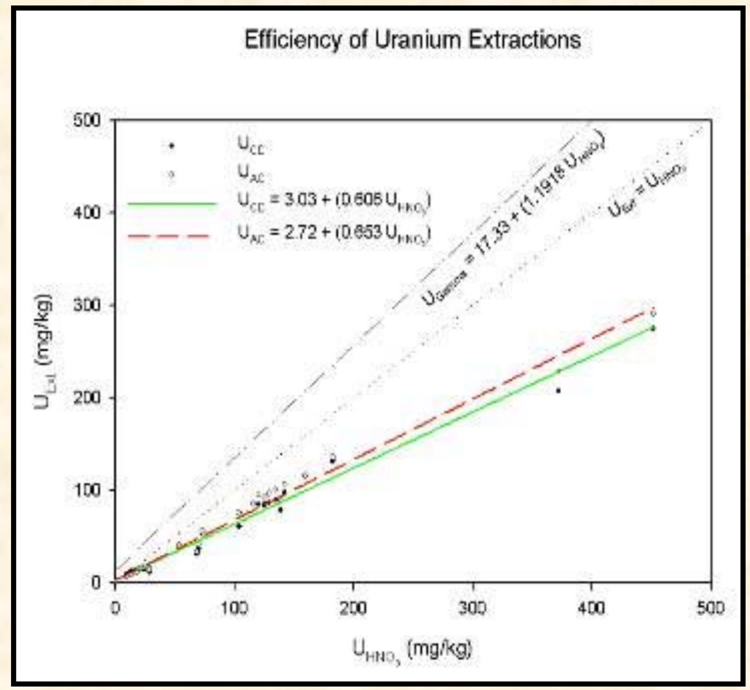
- **Coupons or bug traps** (Peacock et al. and Cummings, Reardon et al.)
- **Novel hydraulic testing – point dilution, tracer and flowmeter testing**
- **Solid Phase Characterization - XRD, SEM- BSE-EDX, TEM, EXAFS, XANES, Mossbauer, extraction methods**
- **Microbial analysis – DNA microarrays** (Zhou)**, Joint Genome Institute, Community Sequencing Program project** (Zhou and Hazen)**, and Genomes to Life (GTL) Virtual Institute of Microbial Stress and Survival (VIMSS) project** (Hazen)
- **Field portable immunoassay biosensor for U** (Blake)



Coupons or bug traps
Bio-Sep Beads® (Peacock)



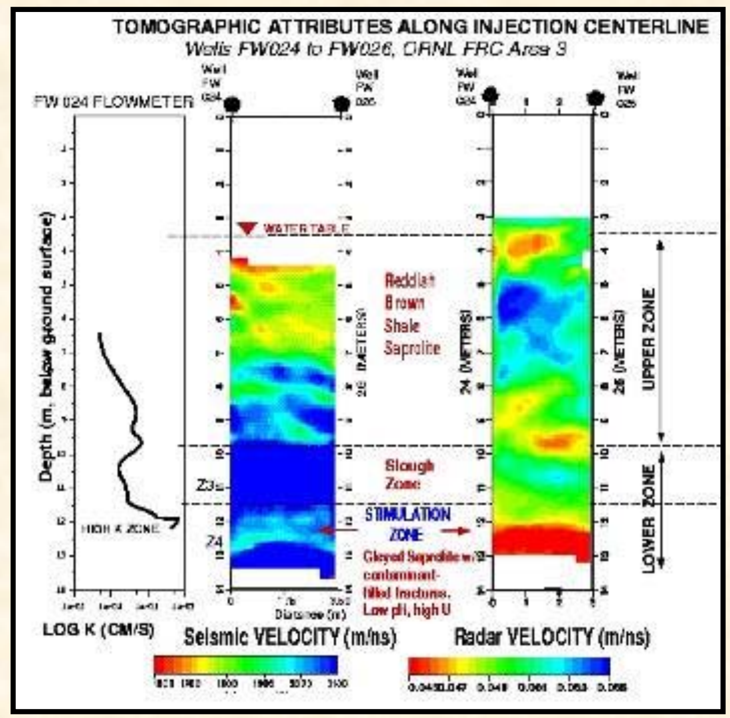
Bromide tracer test in Area 2
(Brooks and Scheibe)

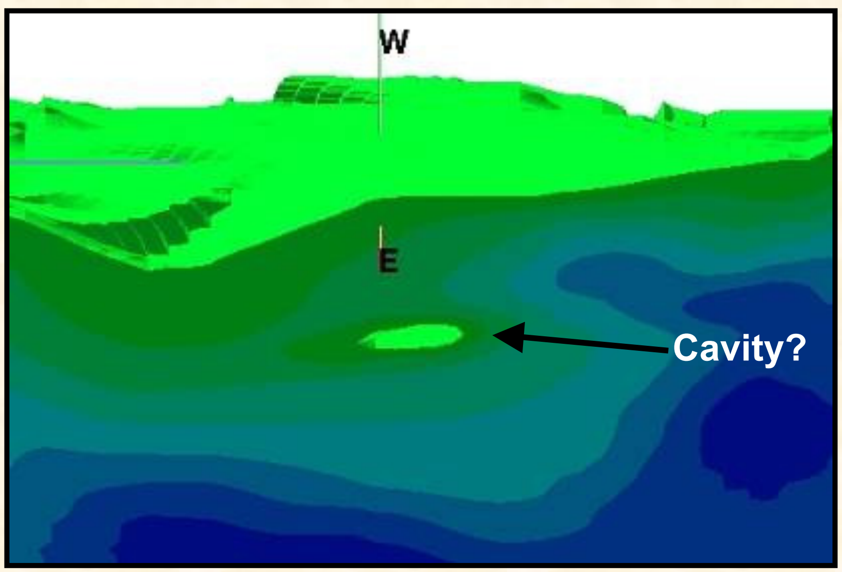


Comparison of U obtained by gamma counting, (total), and nitric acid, AO, and CD extraction

FRC Research Findings – Development of Characterization and Monitoring Tools

- **Geophysical characterization and monitoring of geochemical and hydraulic alterations**
  - **Conductivity probing, electromagnetic, *in situ* gamma**
  - **Resistivity and seismic tomography** (Watson et al.)
  - **Seismic, radar, and resistivity cross-borehole** (Hubbard and Williams)



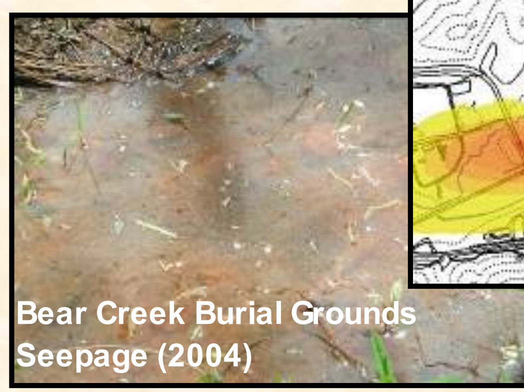


Seismic tomography in new Area 5 (2070m/sec contour)

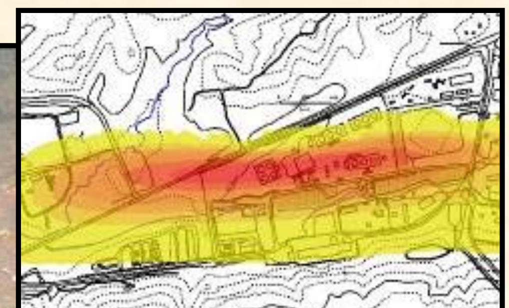
ORR Environmental Cleanup Situation

- Easy problems have been addressed
- ORR environment challenging
  - High recharge, shallow water table, conditions transient seasonally and long-term
  - Huge reservoirs of contamination in the matrix and fractures
  - Plumes have migrated long distances offsite and to surface water discharge points through ill-defined preferred flowpaths (fracture sets and karst)
- Excavation and capping are primary means of dealing with source areas
  - Limited source term actions are being taken
  - Extensive groundwater plumes will be allowed to attenuate

Capping WAG 4 (2004)



Bear Creek Burial Grounds Seepage (2004)



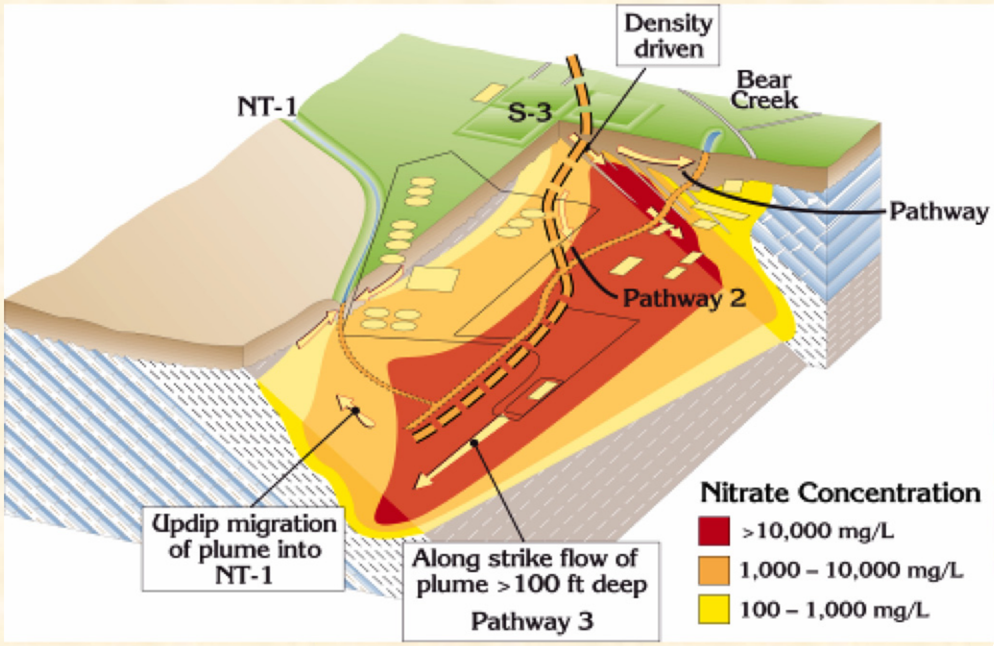
S-3 Ponds Plume

Stewardship issues that can be investigated at the FRC

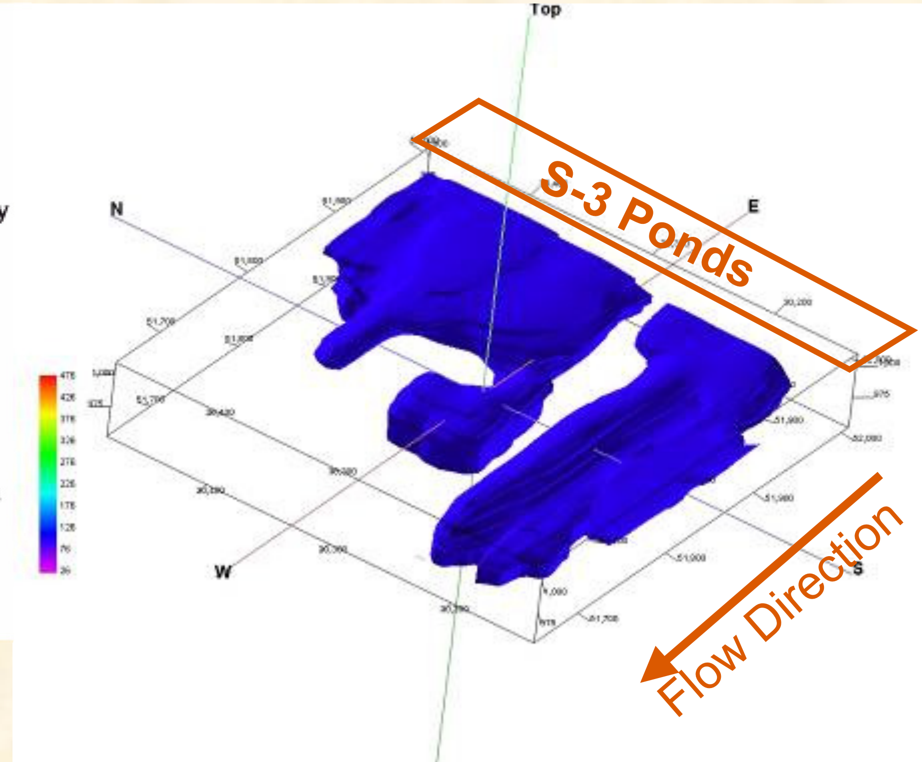
- **Attenuation and enhanced attenuation of mixed waste plumes and sources**
  - Interactions of U, Tc, nitrate, inorganics and organics
  - Multiple hydrobiogeochemical environments
- **Heterogeneity and scaling**
  - What parameters need to be measured to understand and predict long-term attenuation and remediation?
  - Impact of coupled processes on reactive transport
- **Characterization and imaging of preferred pathways**
  - Understanding long-term impacts on transport
  - Relationship with matrix and source
- **Improved characterization, sensors, and monitoring tools, and model predictions**
- **Mercury fate and transport studies, and remediation**
  - Contaminated and Background Areas identified
  - Vapor versus dissolved phase transport
  - Microbial studies by Sorensen:
    - Bacterial mercury resistance tolerance/capacity
    - Attempting to culture mercury resistant bacteria, and characterize plasmids, Hg resistance genes, etc.

Conceptual Model Vs. Reality

Preferred Pathways Dominate in Reality



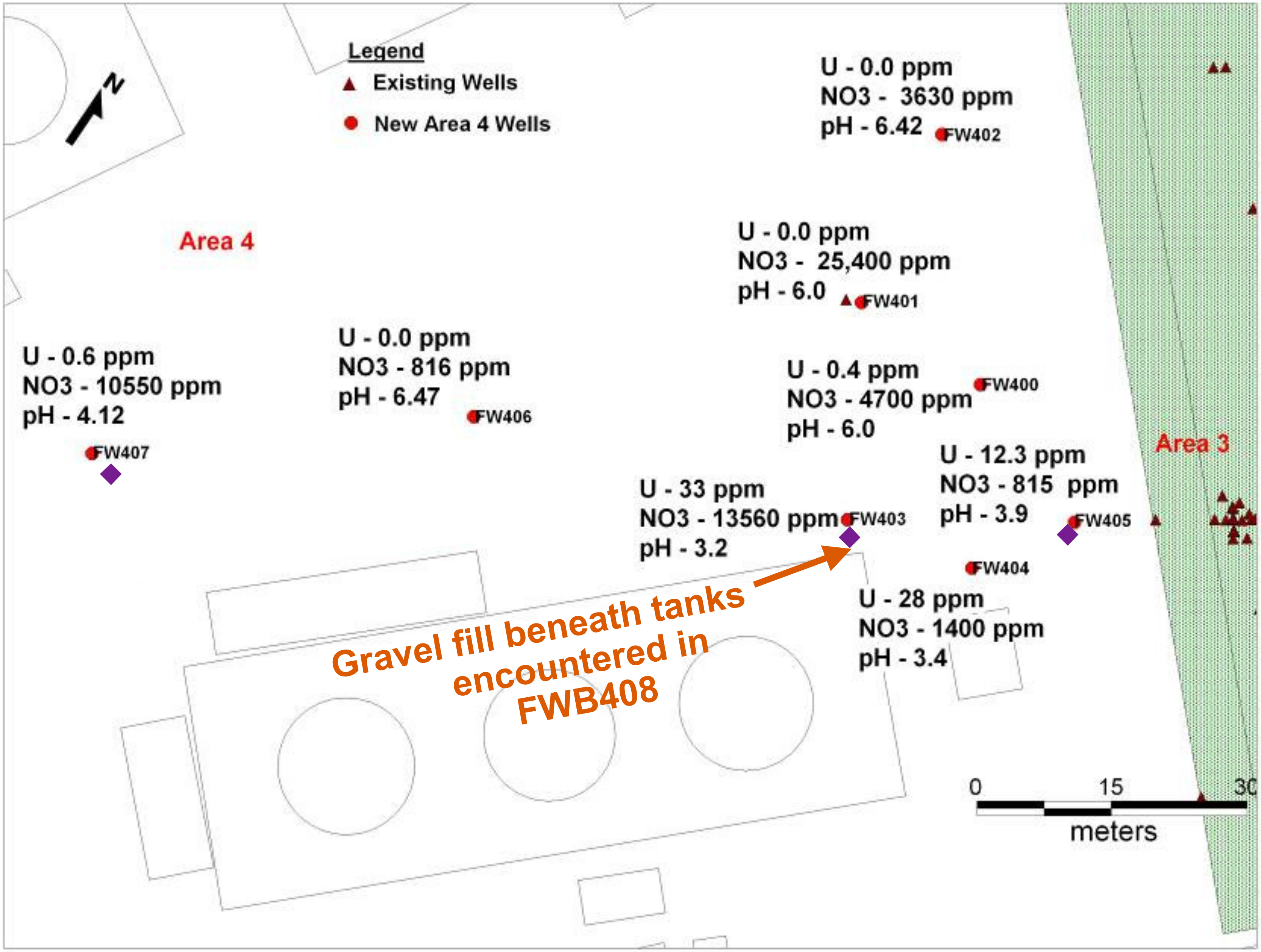
Conceptual model presented in Remedial Investigation Report



Observed conductivity plume model from surface resistivity (nitrate >3000mg/l)

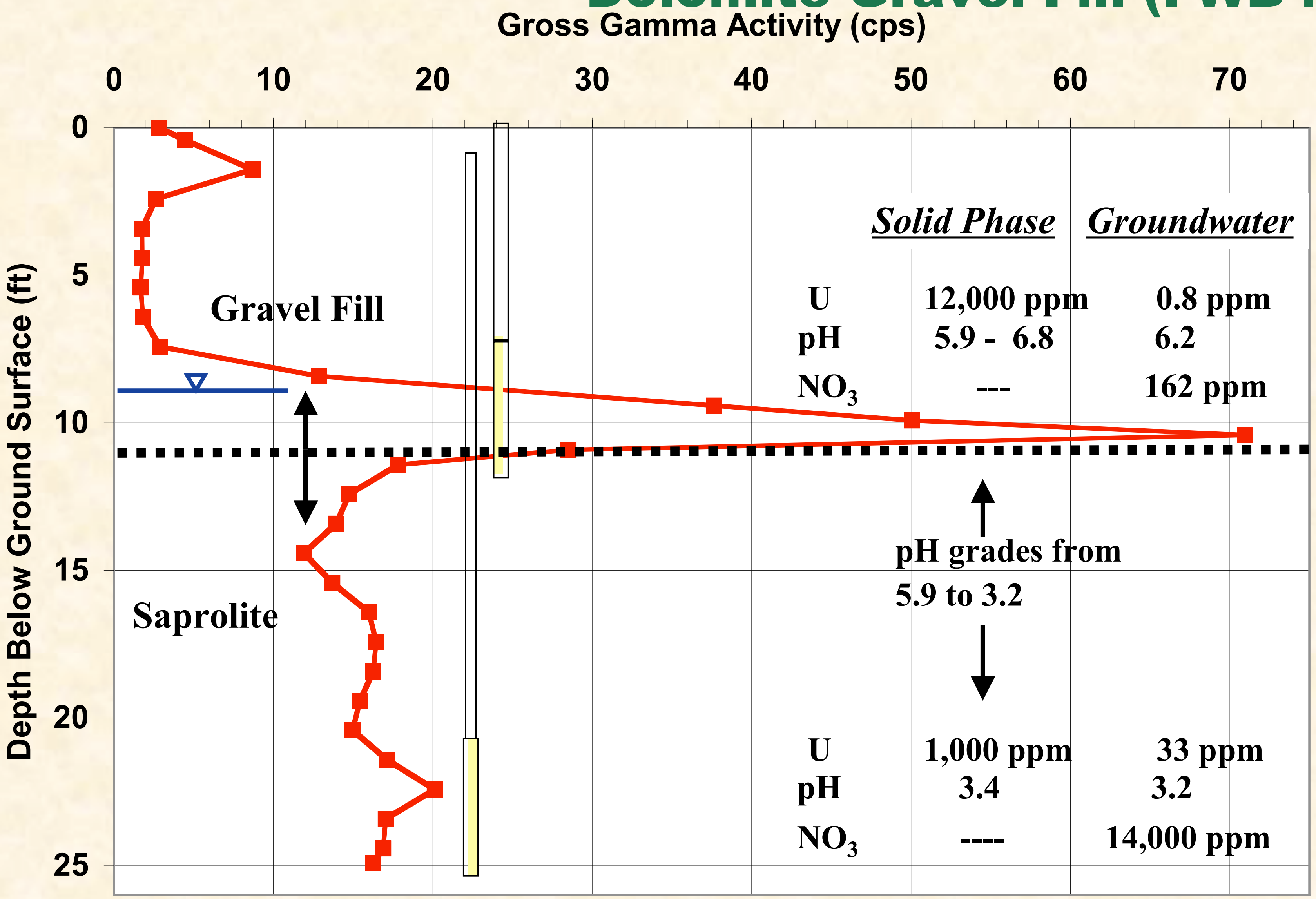
Preferred Pathways
S-3 Ponds Examples

1) Man made
   - Carbonate gravel fill (porous media)
   - Higher pH
2) Naturally occurring
   - Saprolite and bedrock (structured media)
   - Fractures and solution cavities



Example 1 – Carbonate Gravel Fill Preferred Pathway

High U detected in Area 4 Dolomite Gravel Fill (FWB408)



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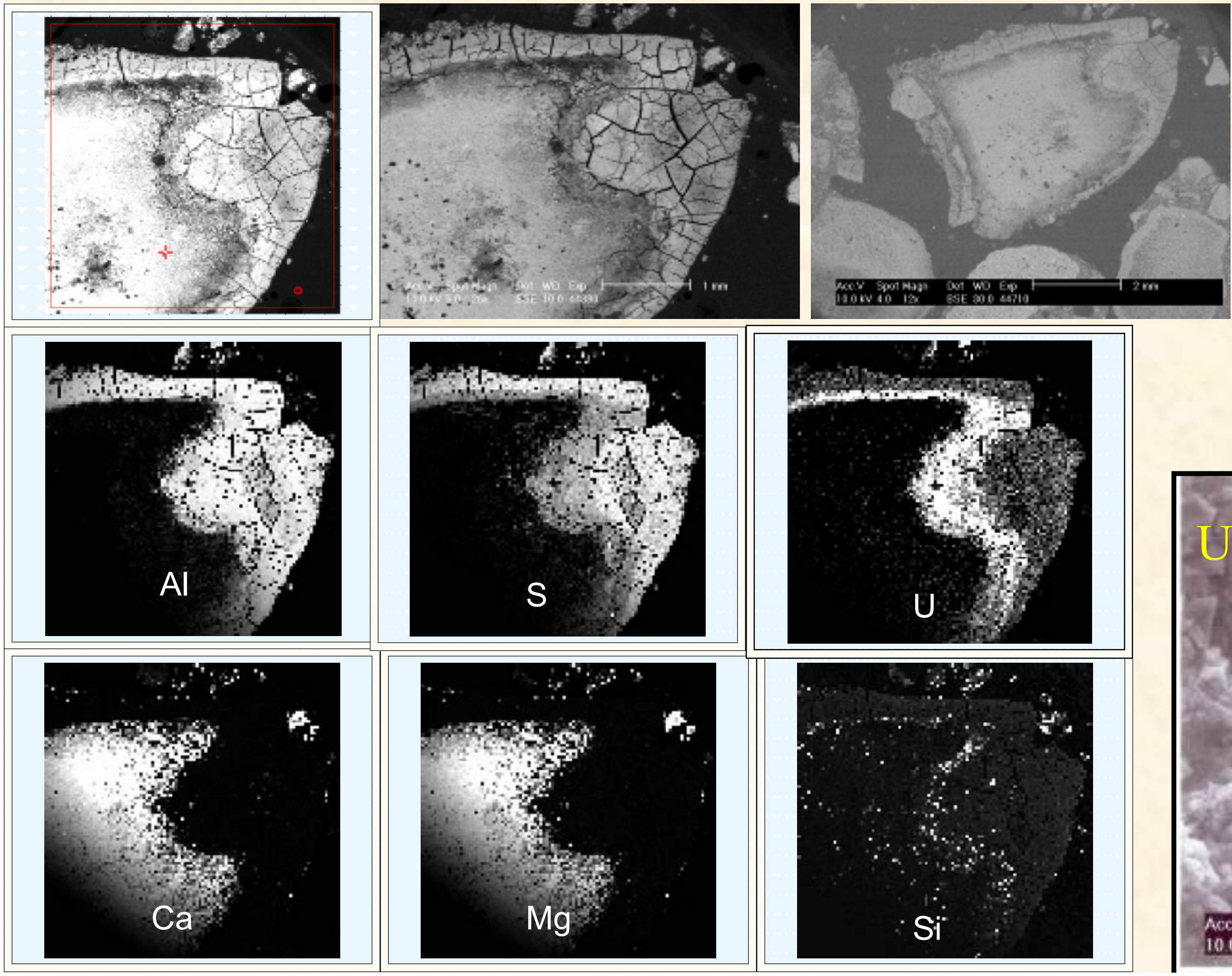
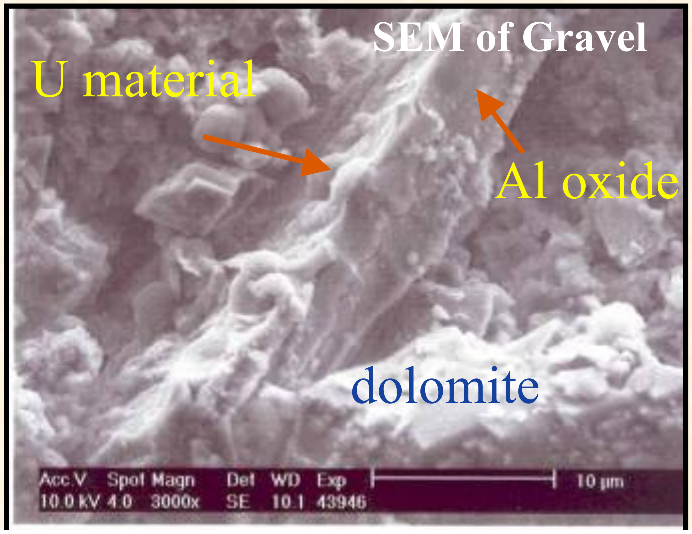
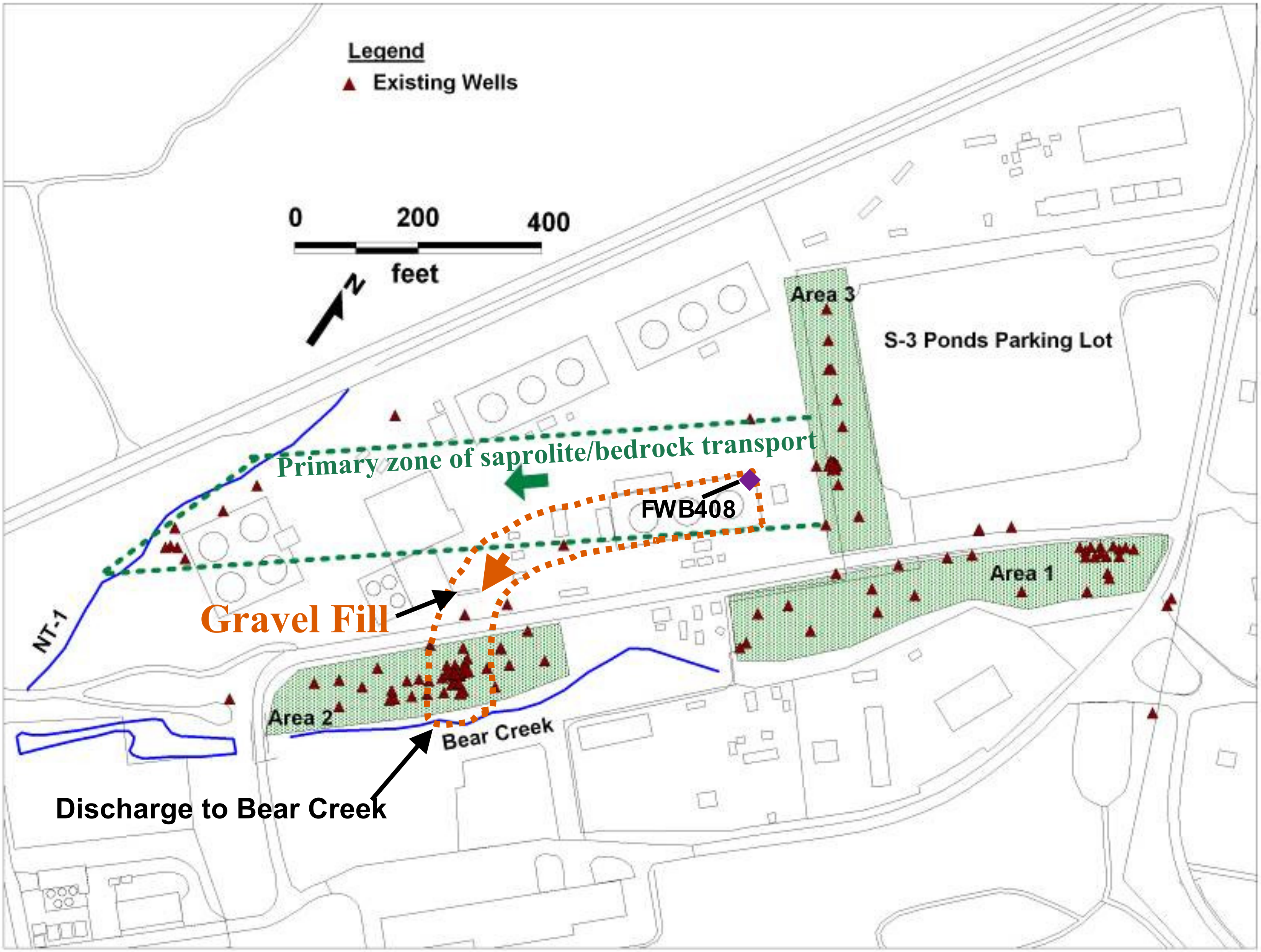
High U detected in Area 4 Dolomite Gravel Fill

Saprolite/Gravel interface

SEM-BSE element mapping



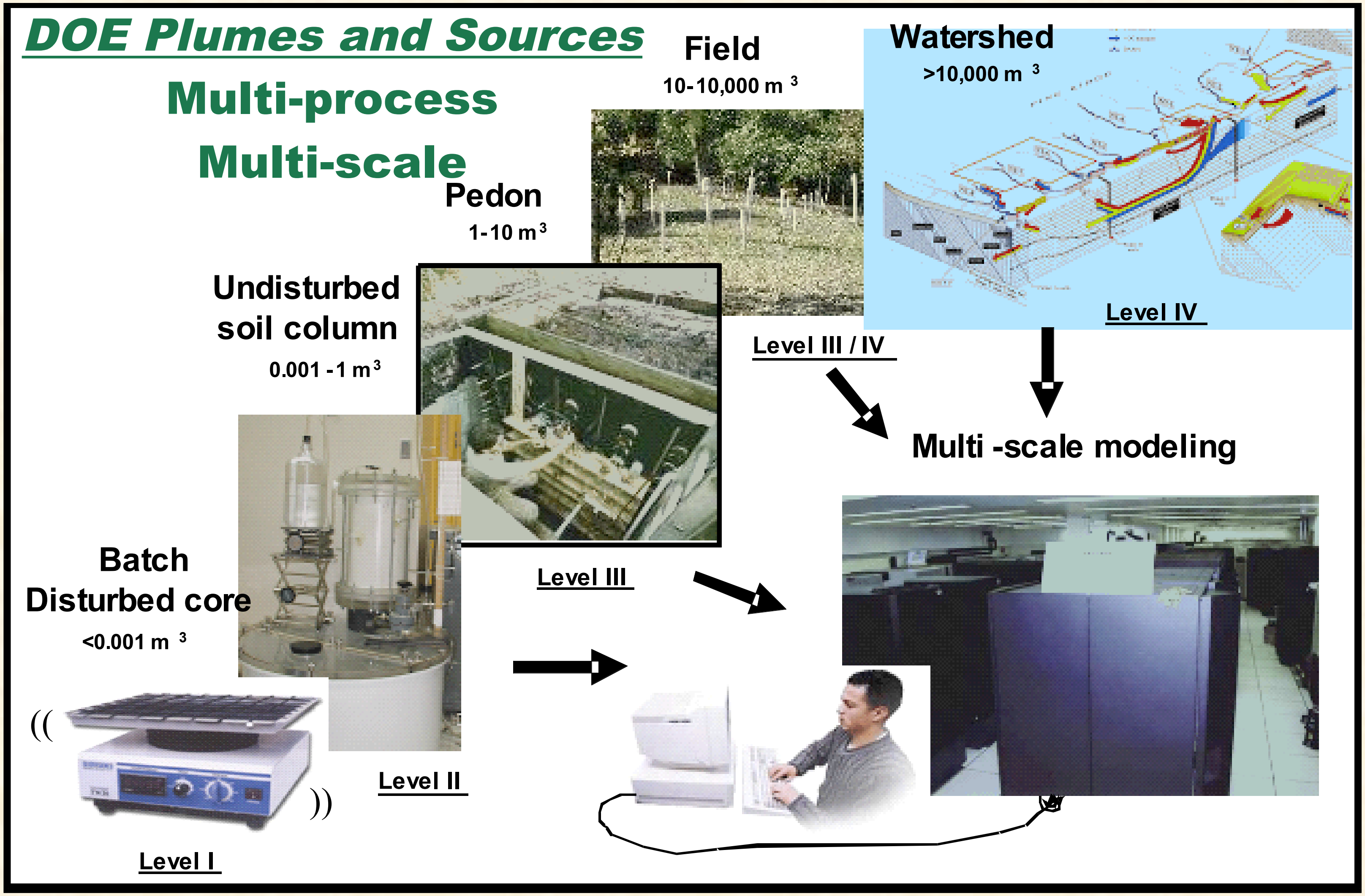




Extent of Shallow Gravel Preferred Pathway

The Oak Ridge Field Research Center

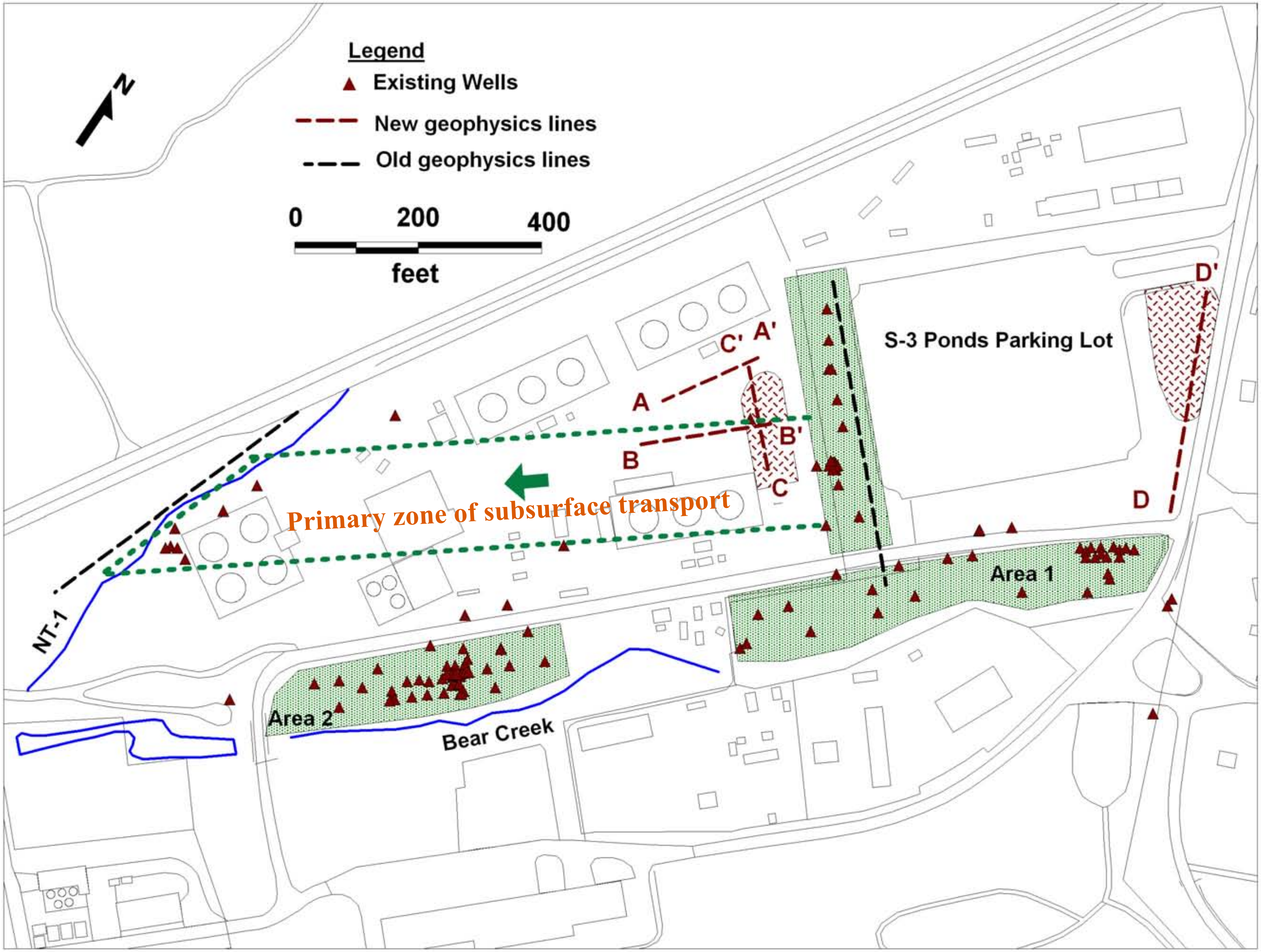
Advancing Scientific Understanding



Fate and Transport

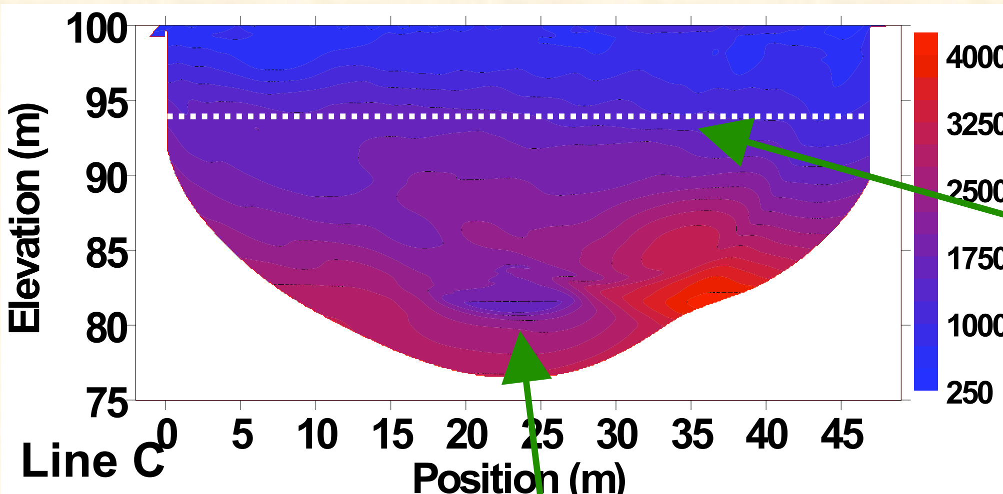
Monitoring and Characterization

Remediation, Stabilization, and Stewardship



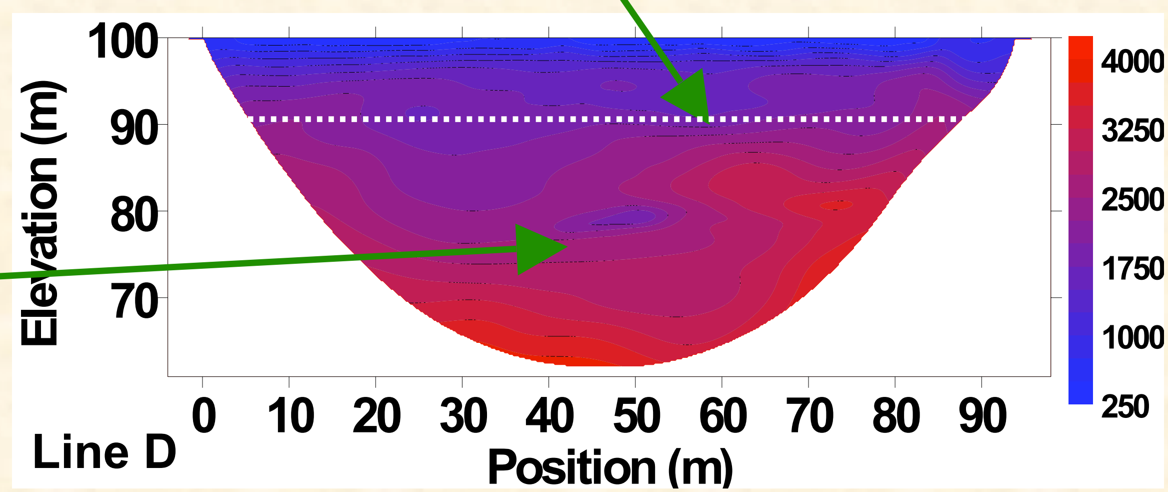
Example 2 – Saprolite/Bedrock Preferred Pathway

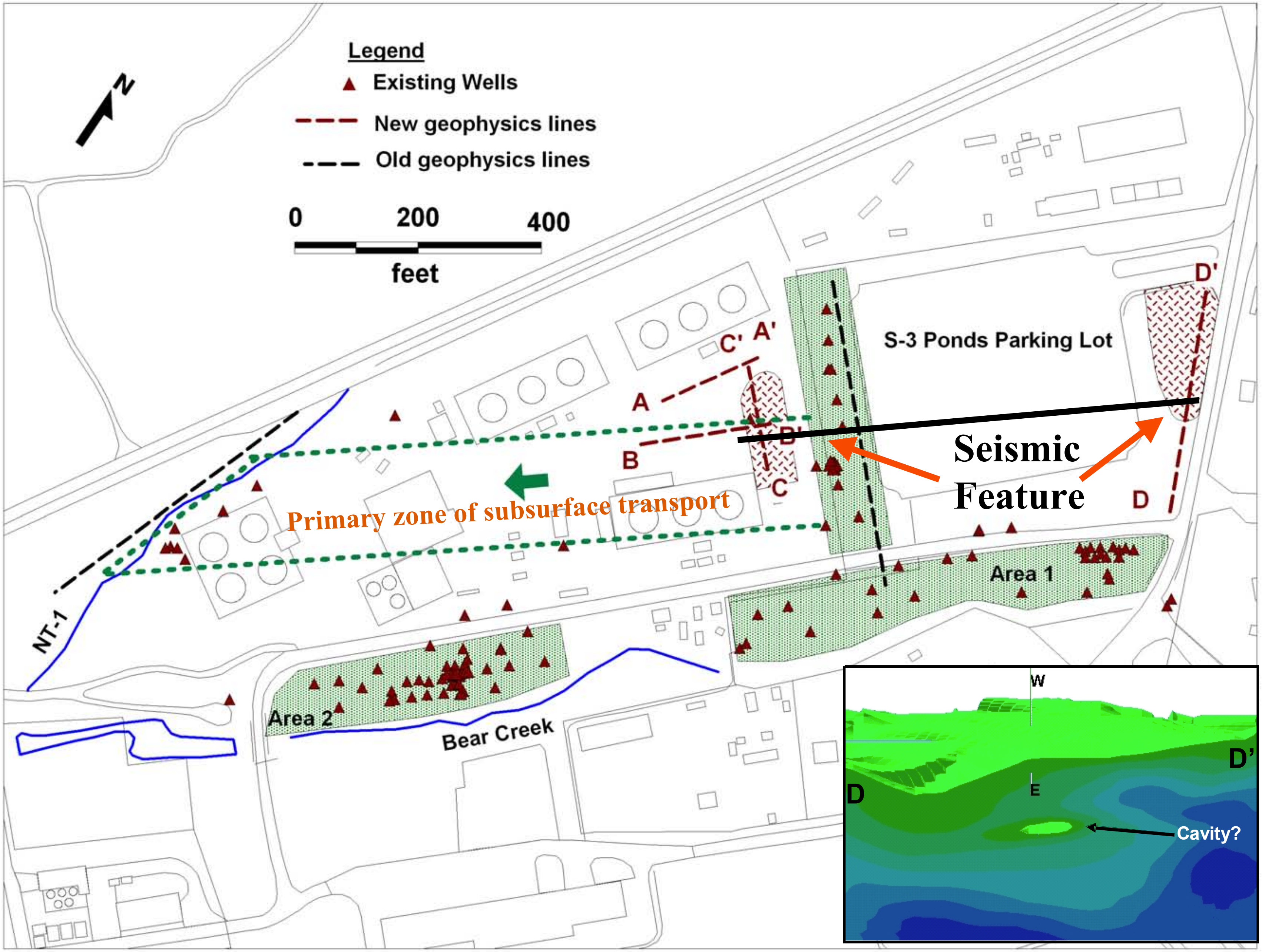
Area 4 and 5 Seismic Tomography Results



General depth of push-probe refusal

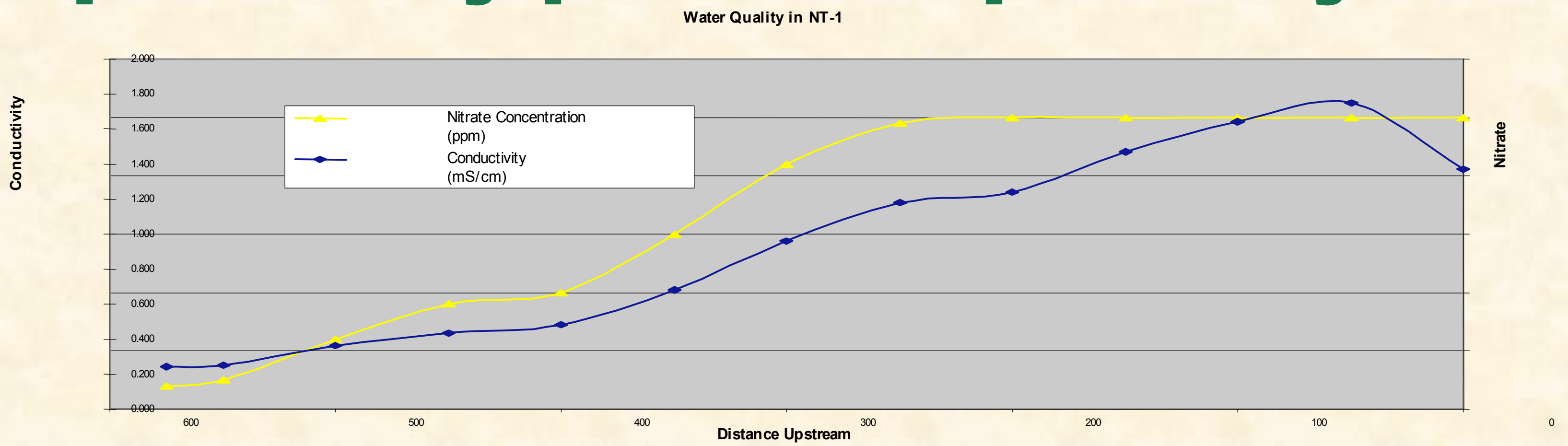
Low Velocity Zones

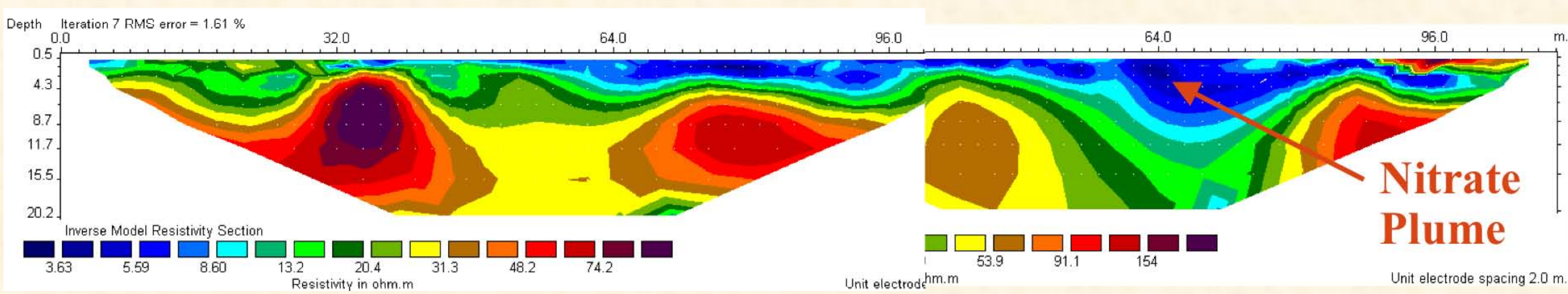




Seismic Feature Identified

Discharge at Bear Creek Tributary is impacted by preferred pathways





Correlating surface resistivity tomography profile at NT-1 and surface water quality helps locate preferred pathways and discharge