We are performing laboratory and field geophysical studies that build on previous work to address:

- Can we use geophysical prefracturing and post-fracturing methods to quantitatively interpret HRC distribution/concentration in the presence of fractures?
- Are the geophysical contrasts associated with fracturing/HRC injection sufficient to detect through post-injection characterization only?
- Which method (or combination of methods) is appropriate for development into a monitoring technology that can be used to routinely assist with development of delivery strategies?
- What is the cost savings realized when using geophysical methods to develop or validate an amendment delivery strategy?

During this first year of the project, we have initiated laboratory studies and have performed a reconnaissance field campaign at the FE Warren Site.

**LABORATORY EXPERIMENTS.** Since the fracture-filling fluid is a complex mixture consisting of both solid (sand) and fluid (HRC, water, borax soln.), phase experiments are being conducted to characterize both individual components and the complete mixture.

**FIELD EXPERIMENTS.** To prepare for the field fracturing/HRC injection experiments, we have collected/reconstructed geophysical measurements of the target zone and surrounding areas. This campaign included:

1. The site subsurface is very heterogeneous.
2. Borax data quality is excellent with high frequency content (see below) and MCL of Borax > HRC > Guar + Borax.
3. Electrical data quality is acceptable and water data quality is poor in places. The 5 kHz conductivity dipole source provides excellent P and SH wave signal transmission at frequencies up to 100 Hz. We recognize that the 1D/2D models will provide a superior approximation to the higher frequency responses around wellbore distances of up to ~50 ft.

**This study illustrated the potential of time-lapse field geophysical methods for assessing the distribution of injected amendments in the subsurface over field-relevant space and time scales.** The study also revealed challenges, including: the quantification of amendment distribution and the difficulty in distinguishing injected amendments from the subsequent end-products.

**PREVIOUS WORK: HRC BIOSTIMULATION AT FE WARREN**

We will assess the accuracy and cost-effectiveness of the technology at the F.E. Warren Joint Site 7 (JS7) area, where the groundwater is contaminated with tetrachloroethene (TCE, 50-1000 mg/L). The contaminated zone (25 and 55 feet below ground surface) is composed of alternating fine sands, silts, clays, and lenses of moderately to well cemented claystone and sandstone. The groundwater flow direction is from west to east. To test the bioavailability of the contaminants to the dissolved organic carbon (DOC) and total organic carbon (TOC) concentrations at both the site and the lower limit of the contaminant plume. The site conditions are continuously monitored using conventional approaches, a full-scale Remedial Action (RA) was designed and tested that involved amendment delivery (HRC and permanganate) to the low permeability unit by hydraulic fracturing.

**CONCEPTUAL MODEL DEVELOPMENT**

- Development of the conceptual model that guided the hydraulic fracturing amendment delivery strategy was performed over a 2 year period prior to designing a full-scale treatment.
- Physical fracture extent and general fracture characteristics were evaluated using conventional soil coring approaches.
- Detection of HRC distribution was much more difficult than detection of the purple precipitate, rendering significant uncertainty in the conceptual model that necessitated a conservative delivery strategy.

**FULL SCALE RA**

- Full-scale RA was implemented in 2005 at JS7.
- The RA included use of hydraulic fracturing to create approximately 644 fractures across 16 injection locations, with 3 to 6 fractures per location.
- Each fracture was emplaced with approximately 2,000 pounds (907 kg) of sand and 200 pounds (91 kg) of HRC. A total of approximately 180,000 pounds of sand and 3,300,000 pounds of sand were emplaced, cumulatively, during the campaign.
- Performance monitoring data indicated that the injection was effective in completing the fractures and reducing potential hydraulic conductivity.

**BIOGEOCHEMICAL TRANSFORMATIONS**

- Groundwater analyses demonstrated that HRC application increased selenium, alteration, and electrical conductivity, and decreased changes in TDS directly correlated to changes in electrical conductivity.
- Dissolution of dieminite minerals associated with reduction processes and calsequestrate precipitation decreased the electrical conductivity, increased the selenium alteration, and velocity, and increased the dielectric constant.

**FIELD STUDIES**

- Field studies were performed to assess the ability of time-lapse seismic and radar tomographic methods for monitoring HRC distribution and transformations in a Chloride-contaminated porous aquifer in Harvard Washington.

- An interpretation of the spatiotemporal distribution of HRC injection and field experiments was performed through qualitative interpretation of the field and geophysical datasets with the use of statistical methods to calculate the sensitivities of multiple geophysical attributes (from seismic, radar, and electrical methods) to the distribution of a slow-release lactate, HRC®.

- The study also revealed challenges, including: the quantification of amendment distribution and the difficulty in distinguishing injected amendments from the subsequent end-products.