U.S. Department of Energy Office of Science
Environmental Remediation Sciences Program

INTEGRATED FIELD RESEARCH CHALLENGE SITE
Hanford 300 Area

OVERVIEW:
Multi-Scale Mass Transfer Processes Controlling Natural Attenuation and Engineered Remediation: An IFRC Focused on Hanford's 300 Area Uranium Plume

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THEME AND GOALS

Overall Scientific Theme: Multi-scale mass transfer controlling contaminant behavior in a subsurface system with complex process coupling

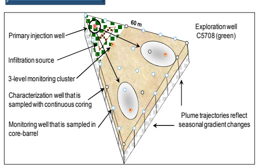
Goals:
- Characterize, understand, and model a complex field-scale biogeochemical system displaying kinetic processes and dynamic hydrology driven by groundwater-river coupling.
- Develop knowledge about the complex workings of the contaminated system that may be transferred to the Hanford Site for effective and sustainable remediation.
- Provide relevant materials and field-site access to other SESP researchers to maximize impact.
- Generate a lasting, accessible and high-quality data set that can be used for testing and validation of new conceptual and numerical models of reactive contaminant transport.

300 Area U(VI) plume

PRIMARY HYPOTHESES

- Mass transfer processes in the vadose and saturated zones control uranium resupply to groundwater as the water table rises into the capillary fringe and lower vadose zone, capturing uranium that was mobilized by infiltrating meteoric water or released locally by mass-transfer controlled desorption.
- Oscillating river stage creates changes in groundwater flowpaths, directions, and velocity that influence U reaction timescale, disequilibrium extent, and adsorption-controlled aqueous concentrations.
- The saturated zone biogeochemical system is oligotrophic and weakly poised with respect to redox state. Lithogenic energy sources are significant to in-situ microbiologic activity.

SITE DESIGN

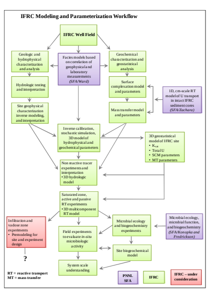


- 35 wells spaced 10 m to allow cross-hole geophysical interrogation for inter-well properties determination.
- State of the art monitoring system for continual monitoring of water levels, temperature, and specific conductance in wells and in the nearby Columbia River.
- Downhole pumps computer activated at necessary times for plume sampling during movement.
- Multi-level well clusters for characterizing depth profiles.
- 27 wells instrumented with 840 downhole ERT electrodes and thermisters.
- All wells permitted as potential injection points.
- Continual water level monitoring at 12 locations to quantify boundary conditions for modeling and interpretation.

IFRC areal

APPROACH

- Implement a comprehensive, science-based strategy to establish geostatistical relationships for properties controlling water transport, chemical migration, mass transfer, and microbiologic activity, including both field and laboratory characterization.
- Characterize the microbiology of the site in collaboration with the PNNL SFA and devise field experiments to identify factors controlling in-situ microbiologic activities including the role of mass transfer.
- Perform injection experiments to evaluate mass transfer influencing uranium adsorption and desorption within the saturated zone and the overall influence of these processes on uranium concentrations and plume behavior.
- Perform passive experiments utilizing river-stage induced changes in water table elevation, groundwater flow direction and velocity, and water composition to evaluate mechanisms for continued uranium supply to and mixing within the groundwater plume.
- Use modeling for integration of site characterization data and evaluation of field experiments; develop a field-scale reactive transport simulator for uranium based on mass-transfer limited surface complexation that incorporates spatial heterogeneities in physical, hydrologic, and chemical properties.
- Details and sequence to right.

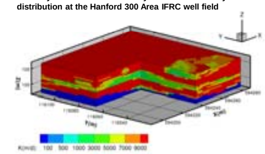


In-situ microcosm multi-level sampler

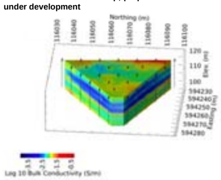
PROJECT STATUS AND IMPORTANT ISSUES

Accomplishments:
- Physical and geochemical characterization complete on more than 200 sediment samples.
- Field geophysical characterization completed using down-hole and surface measurements, producing electrical facies map of experimental domain (below). Corresponding pedo-transfer functions to extend results to physical and chemical properties nearing completion.
- Hydraulic conductivity characterization performed with multiple methods; geostatistical analysis of data provides multiple realizations for hydrologic models (right).
- Four field injection campaigns have been completed in the saturated zone; two large-scale non-reactive tracer experiments (with dilute solutes and chilled water) to refine the site hydrologic model, a non-reactive tracer experiment with salinity contrast to evaluate the geophysical array, and a preliminary desorption experiment with injection of lower U(VI) concentration water.
- A comprehensive monitoring experiment was performed during spring high Columbia River stage that provided the first direct evidence of U(VI) release from the lower vadose zone and origins of groundwater U.
- Colonization substrates and biogeochemical microcosms of varied type, and multi-level gas and water samplers were installed to monitor in-situ microbiologic activities and function.
- Two flow and reactive transport simulators iteratively parameterized with physical, hydrologic and geochemical measurements and parameters. Models applied to simulate field experimental results for publication.
- A comprehensive, project-wide electronic data base established for data sharing, manipulation, and integration.

Cutaway view of an estimated hydraulic conductivity distribution at the Hanford 300 Area IFRC well field

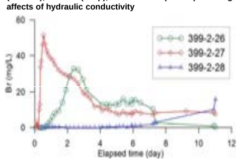


3-D site electrical facies map; properties correlations are under development



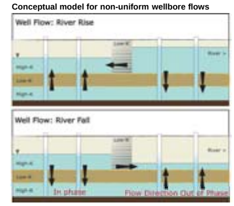
Key Observations:
- Three distinct hydraulic conductivity zones exist (above right and below) with complex spatial distribution.
- A paleo-erosional channel runs through the center of the well field that expedites solute transport at the base of the uranium-contaminated aquifer zone.
- Field-scale, mass transfer limited physical domains exist, in spite of the high average hydraulic conductivities.
- Intimate hydrologic communication occurs with the Columbia River; all river-stage changes produce head changes in IFRC wells; the behavior is well described by site hydrologic models.
- Labile, adsorbed contaminant uranium concentrations are low, but quantifiable in the saturated zone, these increase in the lower vadose zone and exhibit diagnostic isotopic signature.
- Surface complexation strength is relatively uniform in the Hanford formation with hot spots (left below).
- Significant concentrations of dissolved uranium are released from the lower vadose zone to groundwater in the SE quadrant of the site during spring high water.
- Natural mixing of groundwaters in different hydraulic conductivity zones is limited; high uranium remains in the upper aquifer zone months after high water.
- A relatively abundant, active, and phylogenetically-diverse subsurface microbial community has been observed and characterized by SFA collaborators (below).

Br breakthrough curves at the well cluster 399-2-26 (shallow), 399-2-27(deep), and 399-2-28 (middle) showing affects of hydraulic conductivity

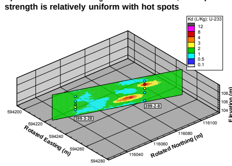


Important Issues:
- Vertical well-bore flows occur in the fully-screened wells; directions vary between wells, but magnitude and timing correlate with river stage (right).
- Vertical flows can reverse multiple times during field experiments, complicating interpretation of results.
- Non-reactive tracer tests have been difficult to simulate with IFRC site models because observed behaviors are not fully consistent with measured hydraulic conductivity values.
- Geochemical characterization of sediments is difficult because uranium is slow to desorb and difficult to remove from the sediments. This has led to an inability to develop strong, predictive correlations.
- Hydrologic/time-scale constraints on field experiments; apparent difference between laboratory versus field-scale behaviors.

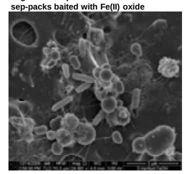
Conceptual model for non-uniform wellbore flows



Spatial distribution of K_d in the smear zone, adsorption strength is relatively uniform with hot spots



Organisms captured in IFRC wells with sep-packs baited with Fe(II) oxide



Issues Resolution:
1) Vertical well-bore flows. Use inflatable and custom packers to isolate zones. Incrementally add discrete depth wells.
2) Uncertainly in K. Fully integrate geophysics results and perform additional tracer experiments .
3) Weak geochemical correlations. Characterize more samples for explicit spatial parameterization.
4) Challenging hydrologic and time-scale constraints. Develop best possible similators and comprehensively premodel field experiments to optimize conditions.

FUTURE PLANS

- Complete characterization of the hydraulic conductivity field and the locations of mass-transfer limited domains (2010).
- Conduct temperature and tracer experiments to further refine the hydraulic conductivity field in the upper high K zone during the period of water table rise and fall (Spring 2010).
- Perform water-table monitoring and deuterium release experiment using new wells installed in March to trace chemical changes associated with water-table rise and fall (Spring 2010).
- Conduct small-scale push-pull experiments with non-reactive tracers and U in low K zones to characterize their physical mass transfer behavior (2010-2111).
- Evaluate in-situ desorption and adsorption rates by injection into upper high K zone (Fall 2010).
- Perform injection experiment to investigate the in-situ lability of adsorbed U(VI) in the saturated zone by isotopic exchange using groundwaters with different isotopic composition (2011).
- Integrate flux monitoring into passive monitoring and down-hole biogeochemistry experiments.
- Probe in-situ microbiologic activity through injection of distinct, stable isotope substrates in the lower K zone of the IFRC well field.
- Continue development of site simulators and apply to experimental design; integrate site characterization and experimental data, collaborate with the SciDAC modeling project to evaluate plume-scale issues.

SCIENCE CONTRIBUTIONS AND OPPORTUNITIES

- Characterizing, quantifying, and modeling reactive transport processes in a highly dynamic groundwater-river system. Time-scale effects.
- Evaluating the effects of different heterogeneity types on multi-scale mass transfer.
- Hydrologic, geophysical, geochemical, and microbiologic scaling studies from grain, to core, to field, to plume scales.
- Isotopic forensics of sources, sinks, and field scale reactive transport processes.
- Understanding the hydraulic, physical, and geochemical controls on microbial community structure, in-situ activity, and biogeochemical function over multiple length scales in a subsurface system with different and distinct biogeochemical regimes.
- Geophysics based estimation of hydrologic properties through electrical geophysical and hydrologic time lapse measurements.
- Establishing unique field data sets on passive and active flow and transport (heat, solutes) for evaluating coupled electrical geophysical and reactive transport models.

HANFORD SITE CONTRIBUTIONS

- Understanding a contaminated river corridor site with complex ground water-river linkage, and concepts for remediation.
- Integrated multi-scale characterization and modeling approaches.
- Significance of long-term site monitoring data in light of hydrologic complexity.
- Robust multi-process and heterogeneity models for assessment of remediation options and effectiveness.

POSTER SESSION

Conceptual Model Development
The increasingly comprehensive field characterization results are leading to a new conceptual model of uranium reaction and transport within the IFRC footprint and the 300 Area in general. Efforts have focused on developing a model of the physical heterogeneities at the site through application of geophysics and hydrologic characterization. The hydraulic conductivity structure of the site has been characterized through field tests and geostatistical analysis with results incorporated into a saturated zone hydraulic conductivity model. The geochemical heterogeneity model that will form the framework of reactive transport calculations is being developed through sediment analysis and geostatistical analyses. A geochemical reaction model for uranium has been developed from multi-scale laboratory experiments to evaluate the in-situ rates and magnitude of surface complexation. This model is being incorporated into site simulators.

Experimental Program
The experimental program consists of field measurements and experiments to understand the fundamental workings of the site. Uranium isotope geochemistry has been investigated to define the sources of U within the site and it's movement between different site compartments. A comprehensive monitoring experiment was performed during spring 2009 to monitor uranium release from the lower vadose zone and its mixing with the uranium plume in response to seasonal river stage changes. Three major field injection experiments were performed in 2009: a non-reactive tracer experiment to refine site hydrology; a non-reactive tracer experiment with salinity contrast to evaluate the down-hole geophysics monitoring array, and a preliminary U(VI) desorption experiment to enable more detailed planning. Colonization substrates and biogeochemical microcosms were installed in wells to monitor in-situ microbiologic activities and function.

Modeling Integration
A significant modeling effort is pursued for rigorous and robust site characterization and experiment interpretation. Several different stochastic and deterministic approaches, and associated models, are being used to facilitate integration and interpretation of data and experimental results. Several of the modeling activities have focused on coupled process modeling, including temperature, physical property measurements, and geophysics. Two reactive transport simulators are being iteratively parameterized with physical, hydrologic, and geochemical measurements, parameters, and information from the IFRC site. The models are being used for interpretation of field experimental results for publication. A significant issue of vertical flow within boreholes during field experiments, and in general, has been identified and is being addressed through additional characterization and modeling. The IFRC is working in collaboration with a SciDAC project to generate plume-scale simulations of 300 Area uranium to put the IFRC site into broader perspective.

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