INTEGRATED FIELD RESEARCH CHALLENGE SITE
Hanford 300 Area

U.S. Department of Energy Office of Science

Environmental Remediation Sciences Program

Hanford 300 Area

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

J. Zachara*, *PNNL*; M. Freshley, *PNNL*; B. Bjornstad, *PNNL*; J. Christensen, *LBNL*; M. Conrad, *LBNL*; J. Fredrickson, *PNNL*; G. Hammond, PNNL; R. Haggerty, *Oregon State U*; P. Jardine, *ORNL*; D. Kent, *USGS*; A. Konopka, *PNNL*; P. Lichtner, *LANL*; C. Liu, *PNNL*; J. McKinley, *PNNL*; M. Rockhold, *PNNL*; Y. Rubin, *U CA/Berkeley*; V. Vermeul, *PNNL*; R. Versteeg, *INL*; A. Ward, *PNNL*; C. Zheng, *U. Alabama*; and M. Thompson, DOE 300 A Site Steward

SCIENCE THEMES & CONCEPT

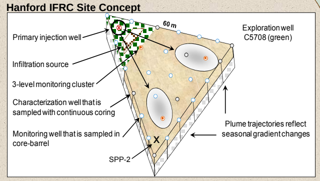
Hanford's 300 A Uranium Plume

- Large volumes of process waste from fuel fabrication resulted in extensive U groundwater contamination.
- Highly contaminated waste pond sediments excavated, Cu- and U- containing vadose zone sediments remain.
- Persistent U groundwater contamination remains above regulatory limits.
- Complex seasonal concentration trends associated with river stage changes and WT rise and fall.

South Process pond – Pit #2

- Significant ERSP research on 300 A sediments (~10 papers)
  - molecular speciation of adsorbed and precipitated species
  - adsorption/desorption and dissolution kinetics
  - bulk, surface, and microscopic mineralogy
  - mass transfer behavior and models

Hanford IFRC Site Concept

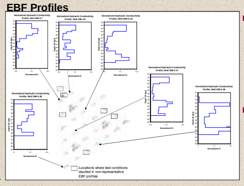


- Wells spaced 10 m to allow cross-hole geophysical interrogation for inter-well properties determination.
- Injection experiments (10^5 gallon) in the 6 m saturated zone under different seasonal gradients using site groundwaters.
- Passive experiments will exploit natural gradients and WT fluctuations
- Continual water level monitoring at 12 locations to quantify boundary conditions.
- Overall goal is to understand system scale behavior and controlling role of mass transfer.
- Site supports a technical theme of multi-scale characterization and modeling.

IMPORTANT PROGRESS

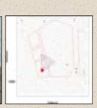
- State of the art well field and monitoring system installed and tested ("well-field report").
- Extensive hydrologic testing completed including a non-reactive tracer injection that has modified the site hydrologic model.
- Significant progress made toward the site 3-D geostatistical model ("Characterization Plan").
  - Laboratory chemical, physical, and electrical measurements.
  - Surface, downhole and cross-hole geophysical measurements.
  - Inversion modeling and geostatistical analysis.
- Modeling Plan nearly completed.
  - Data collection sequences.
  - Sequential modeling goals.
  - Roles and responsibilities.
- High quality samples obtained for microbiologic characterization that have shown surprising results
- Establishing collaborative strategy and experiments with PNNL SFA
- Completed low-water, multi-non reactive tracer and ΔT injection experiment in March 2009.

EBF Profiles



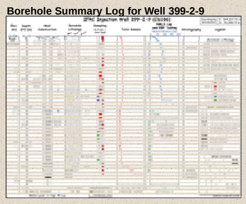
- General (although non-uniform) EBF profile structure indicating lower permeability materials over the middle portion of the aquifer.
- Consistent with tracer arrival response in middle zone of northern multi-level well cluster.

IFRC Site and SPP2



- 60 m site with 37 wells (extensive borehole documentation and logging, reports on web).
- Rigorous geophysical and hydrologic field site characterization and measurements (described by "Plan") .
- Carefully selected laboratory measurements on many sediments retrieved from wells (geostatistical relationships).
- Focus on upscaling of microscopic reaction information (from ERSP) and identifying physical/geologic features causing kinetic behavior at m+ scales.
- Attempt to characterize and model multi-process effects at multiple scales.

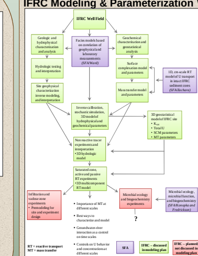
Borehole Summary Log for Well 399-2-9



- A report has recently been completed that summarizes all aspects of the IFRC well field: **"Borehole Completion and Conceptual Hydrogeologic Model for the IFRC Well Field, 300 Area, Hanford Site".**
- The figure to the left is an example of information summarized for each of the 35 IFRC wells in the report, borehole logs for each well are also included.
- A hydrogeologic model is developed for the site to inform reactive transport modeling.

CHARACTERIZATION

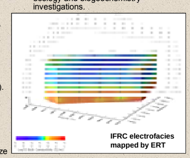
IFRC Modeling & Parameterization Workflow



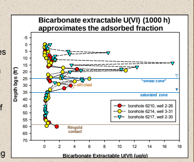
- A modeling plan is nearing completion that describes the various steps needed to model IFRC experimental results in the most robust manner possible.
- The plan holds for development of a 3-dimensional site geostatistical model of hydrologic and geologic properties, geochemical reaction parameters (surface complexation and mass transfer), and U concentration distribution through a new inversion modeling technique.
- This complex model will be formulated through field and laboratory measurements performed by the Hanford IFRC (green), and by the collaborating PNNL Science Focus Area (SFA) project (blue) investigating microenvironments and transition zones.
- A modeling team with expertise in multiple reactive transport codes, including MODFLOW, FLOTRAN, and STOMP, and inversion methods, are implementing the model using new characterization data and analysis of laboratory and field experimental results.
- Both Hanford IFRC and PNNL research will support future planned field experiments at the IFRC (pink) including vadose zone infiltration and U(VI) mobilization experiments, and microbial ecology and biogeochemistry investigations.

Ongoing Characterization

- U concentration distribution and operational forms.
  - Total U, bicarbonate extractable U, desorption fraction in SGW (on < 2 mm sediment).
- Geochemical reaction parameters.
  - Surface area, Kd (in IFRC groundwater and river water), extractable Fe(III) oxides, mass transfer rate (on < 2 mm sediment).
  - Retardation factors, kinetic parameters, and aqueous complexation effects (on intact cores).
- Physical properties.
  - GEA for SGLS interpretations (< 2 mm sediments and specific size fractions including > 2 mm).
  - Grain size distribution and particle density (lab).
  - Bulk density and porosity (in-field).
- Hydrologic parameters.
  - k, S, P relationships (on intact cores in lab).
  - k, S, P effects on soluble U(VI) (on intact cores in lab).
  - Ksat (in field).
- Geophysical properties.
  - Electrical resistivity as a function of water content (lab cores).
  - Chargeability and specific surface conductance (lab cores)
  - Cross-hole electrical resistance tomography and ground penetrating radar (field).
  - Borehole deviation and electrical conductivity (field).



IFRC electrofacies mapped by ERT

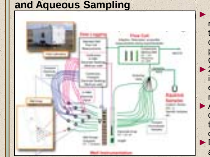


SIGNIFICANT NEW FINDINGS

- Correlated heterogeneity in IFRC-site saturated zone hydraulic properties.
- In-situ temperature monitoring allows characterization of groundwater flow paths.
- Enhanced connectivity of the Columbia River to the upper third of the saturated zone.
- Greater than expected groundwater-river coupling.
- Lower than expected groundwater travel times (< 3 m/d).
- Smear zone with significant labile, sorbed U(VI) inventory.
- Anomalous U(VI) adsorption to fines in all compartments.
- Significant mass transfer of contaminant U(VI) in intact, saturated zone sediments.
- Robust microbiologic community in the Hanford formation saturated zone.

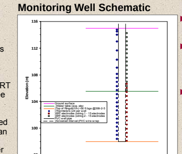
FIELD EXPERIMENTAL PLANS

Field Electrode Measurements and Aqueous Sampling



- The IFRC site has continual monitoring of water levels, temperature, and specific conductance in wells around its periphery, and in the nearby Columbia River.
- 27 of the wells have been instrumented with downhole ERT electrodes and thermistors (see right).
- All wells contain dedicated downhole pumps that are routed through a manifold system to an on-site laboratory .
- Downhole pumps are computer activated at necessary times for plume sampling during movement.

Monitoring Well Schematic

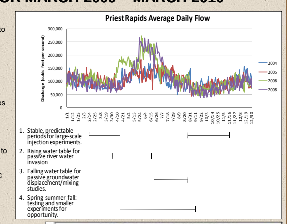


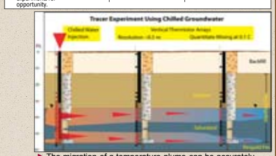
- 10 cm ERT electrodes spaced at 60cm.
- Thermistors for temperature measurements placed between ERT electrodes.
- Electrodes and thermitors in sand pack in vadose zone and dangle in groundwater to allow removal.

EXPERIMENTAL CAMPAIGNS FOR MARCH 2009 – MARCH 2010

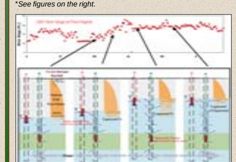
- Multi-tracer, cold water injection (completed March, 2009).*
  - A combination of cold water and multiple non-reactive tracers were injected into the IFRC site during a period of stable, toward-river groundwater flow.
  - In-situ temperature and specific conductance were monitored down-hole, and samples were collected for laboratory analyses of bromide and deuterium.
  - The objectives were to define horizontal heterogeneities in water flow paths in the IFRC site, and to quantify their effects on well-averaged tracer concentrations.
- Passive during rising water table (May – July, 2009).*
  - Groundwater temperature and chemical composition including U will be monitored as river stage increases in response to spring snow-melt and causes water table rise into the smear zone.
  - Well-averaged groundwaters and near-surface water from the upper 1' of the well will be sampled. Analytical results will be correlated with continuous monitoring data for river stage, peizometric surface, and temperature and specific conductance of all waters.
  - The objective is to determine if U(VI) is mobilized from the lower vadose zone to groundwater during periods of high water table.
- Desorption Injection (September, 2009).*
  - Upgradient groundwater with lower U(VI) concentration than found in the IFRC site along with two non-reactive tracers and a salinity contrast will be injected during a stable hydrologic period with toward-river groundwater flow.
  - Plume migration and mass transfer limited regions will be monitored in-situ by ERT and specific conductance, with laboratory analysis of the non-reactive tracers and U in sampled well waters.
  - The objective is to quantify the in-situ desorption kinetics of adsorbed contaminant U(VI) and how it varies in response to U concentration distribution and average water velocity.
- Adsorption Injection (March, 2010).*
  - 300 A U-plume groundwaters from a nearby well will be injected that contain a higher concentration of dissolved U(VI) , a 5° C temperature differential , and one non-reactive tracer into the IFRC well field during a period of stable, toward-river groundwater flow.
  - Plume migration will be monitored by down-hole temperature and specific conductance measurements, with field determination of pH, and robust (spatial, temporal) laboratory measurements of U(VI) and the target tracer. Groundwater compositional analyses may also be required depending on differences between the injected and in-situ groundwater.
  - The objectives are to investigate the in-situ retardation behavior of U by surface complexation, and the role of mass transfer in controlling the leading and trailing edges of the reaction plume.

**See figures on the right.*

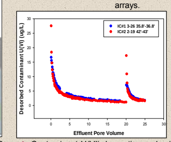


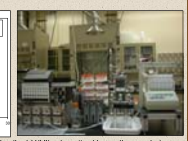


- The migration of a temperature plume can be accurately monitored in-situ and in 3D with our down-hole thermistor arrays.



- Passive experiments will monitor U(VI) release from the lower vadose zone and mixing with groundwater during water table rise and fall.





- Contaminant U(VI) desorption and spiked U(VI) adsorption/desorption are being measured on three intact cores from the IFRC well field to estimate in-situ reactive transport parameters for field experiment pre-modeling and later interpretation.

PLENARY SESSION CONTENT

Hanford 300 Area IFRC
John Zachara, PNNL Lead PI and research team members

Geophysical Characterization of the Hanford IFRC Site
Andy Ward (PNNL), Roelof Versteeg (INL), Timothy Johnson (INL), and Christopher Strickland (PNNL). [A joint contribution from the Hanford IFRC and the PNNL-SFA]

The Method of Anchored Distributions (MAD) for Integration and Inversion of IFRC Hydrogeological Data and for Establishing a Geostatistical Site Model
Yoram Rubin, (UC Berkeley), Haruko Murakami, (UC Berkeley), Xingyuan Chen (UC Berkeley), Hang Bai (UC Berkeley)

Hydrologic Characterization and Results from the First Tracer Experiment at Hanford's 300 Area IFRC Site
Mark Rockhold (PNNL), Vince Vermeul (PNNL), Chris Murray (PNNL), and John Zachara (PNNL)

Variability in Adsorbed Uranium Concentrations in Saturated-Zone Sediments from the IFRC Tracer-Test Well Array in Hanford's 300 Area Uranium Plume
Douglas Kent (USGS), Deborah Stoliker (USGS), and John Zachara (PNNL)

Modeling Field-Scale Uranium Mass Transfer at the Hanford IFRC Site
Chunmiao Zheng (University of Alabama), Rui Ma (University of Alabama), Henning Prommer (CSIRO, Australia), Chongxuan Liu (PNNL), Janek Greskowiak (CSIRO, Australia) , John Zachara (PNNL), and Mark Rockhold (PNNL)

Microbial Ecology in Subsurface Sediments from Hanford 300 Area Unconfined Aquifer
Allan Konopka (PNNL), Xueju Lin (PNNL), David Kennedy (PNNL), Jim K Fredrickson (PNNL) and Rob Knight (University of Colorado) [A PNNL-SFA contribution]

CONTRIBUTIONS TO SITE CLOSURE

- System scale understanding of factors controlling groundwater U(VI) concentrations
- Understanding of site heterogeneities (physical, chemical, and biologic) and implications to reactive transport.
- Robust multi-process models for assessment of remediation effectiveness.
- Comprehensive properties relationships and regressions for prediction.
- Documented multi-scale characterization and modeling approaches.
- Understanding of linked groundwater-river systems.

EXAMPLE OPPORTUNITIES FOR COLLABORATIVE RESEARCH

- In-situ adsorption/desorption experiments of various types.
- Laboratory to field comparisons.
- Evaluation of geophysical methods and inversion techniques.
- Mass transfer processes of different types at different scales.
- Microbiology of linked groundwater-river systems of low to high transmissivity.
- Geologic, hydrologic, geochemical, and biogeochemical modeling of different types.

MATERIALS AVAILABLE TO EXTERNAL INVESTIGATORS

- Historic U(VI)-contaminated source term materials (limited).
- Contaminated U(VI) vadose zone materials whose geochemical speciation and mass transfer properties have been determined (limited).
- Uncontaminated vadose zone and aquifer sediments from various locations.
- Circumneutral site groundwaters with variable U(VI), HCO_3, and Ca concentrations.
- Core materials and grab samples from vadose zone and aquifer experimental plots.
- Ringold formation aquifer sediments of variable redox properties (limited).
  See website for details: http://ifchanford.pnl.gov.

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