HANFORD IFRC QUARTERLY REPORT ~ OCTOBER 2008

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I. Overview and Highlights

This is the third Quarterly Report for the Hanford IFRC project that summarizes significant progress for the period of July 2008 to October 2008. Six major highlights deserve mention for this reporting period that will be discussed in sections that follow.

1. The Hanford IFRC completed installation of its well field during the first week of September 2008. The drilling, well instrumentation, borehole logging, and well completion project was finished within budget. Over 1000 sediment samples were collected for future characterization and experimentation, and use by other interested ERSD researchers.
2. A 165' (50 m) deep characterization borehole was completed next to the IFRC well-field that extends through the entire unconfined aquifer to the top of basalt. High-quality core samples were obtained for microbiological research that is being characterized by PNNL SFA scientists and other ERSD collaborators.
3. A hydrologic and geochemical characterization plan for the well-field has been completed that will be posted on the IFRC web-site on October 10, 2008.
4. Field hydrologic, geophysical, and geochemical characterization of the well-array has begun in earnest as described in the characterization plan, with many measurements being already completed.
5. Laboratory geophysical, hydrologic, chemical, and microbiologic characterization has begun on retrieved sediments in form of intact cores and grab samples.
6. The pass-word protected IFRC data base is now operational and is being populated by data collected from the drilling task.

II. Significant Changes

There have been no significant changes to the project scope or objectives since the last quarterly report in July 2008.

III. Management & Operations

Management and operations of the Hanford IFRC have proceeded without issue over this reporting quarter that has ended with the close of FY 08. Project spending has proceeded as planned, and $500 K has been carried over to FY 09 to ease difficulties imposed by the Congressional continuing budget resolution. This carryover will allow us to continue geophysical logging and hydrologic testing of the site in October, and prepare for and perform our first tracer experiment without delay during low river stage in November 2008. The IFRC project has been reviewed by an internal PNNL project management team and has received high marks for exceeding PNNL standards of research planning and documentation.

The management team worked with DOE-EM (at Richland Operations, DOE-RL) and the BER-ERSD management team to issue a press release and hold a media event at the completed IFRC field site on September 17, 2008. It was a beautiful day, and many activities were underway at the site including the testing of the down-hole ERT arrays and the groundwater sampling system. DOE-RL began the interview with brief history of the site that included its many enigmatic aspects. They also emphasized their appreciation of the DOE Office of Science investment in this highly visible and scientifically challenging site. The scientific phase of the interview highlighted the unique and comprehensive nature of the IFRC experimental site, and the potential science advances for both Hanford and subsurface science that will result in the years to come. Interviews were aired on local TV and Northwest National Public Radio. The press release was featured in over 20 venues (note list sent to ERSD). The feedback has been uniformly positive and supportive.

The internal and external project team has been working well together and all have been anxiously awaiting the completion of the well field and the receipt of samples and measurements from it. Finally this has occurred. In retrospect, all of our detailed planning for the drilling and well installation project was well spent. Drilling projects at Hanford are known to be challenging, and often go awry. Ours proceeded without major difficulty. Our core recovery was excellent, the complicated downhole monitoring systems were installed with minimal damage, and the completed well-field is one of the best of its kind in both the national and international scientific community. Sediment samples have now been processed, composited, and delivered to project experimentalists who have initiated their laboratory programs. Geophysical measurements of different type are being processed, interpreted, and delivered to the IFRC modeling team for development of a comprehensive site model. Project productivity has increased dramatically over the past month following experimental site completion, and these gains are expected to accelerate in the months to come. Many of these new results are highlighted in this report.

The internal PNNL staff is working well together, and the IFRC project has negotiated firm agreements with key staff as to their hours of commitment to the project in FY 09. Timely negotiation is an essential project need as the best staff are in high demand, and many of our planned field experiments require a dedicated field crew that will work though all hours to achieve the highest quality of experimental performance. Our external project participants have also reached full staffing in terms of graduate students and post-docs, and the project is proceeding full-speed ahead.

IV. Quarterly Highlights

For the purposes of this quarterly report, the following are reportable activities we establish the following as reportable project tasks: 1. Project Management, 2. Site Design and Installation, 3. Web Site and Data Management, 4. Field Site Characterization, 5.

Vadose Zone Experiments, 6. Saturated Zone Experiments, 7. Modeling and Interpretation, and 8. ERSD Outreach.

Task 1. Project Management

The IFRC project has found that the complexity of the 300 A site in terms of history, hydrogeology, and multiple process coupling requires that written planning be applied to all major infrastructure developments, characterization activities, and scientific campaigns. Our approach is to post these planning documents on the web-site for transparency, and to encourage feedback from knowledgeable individuals. The positive aspects of such planning is that valued DOE/BER investments in the site lead to the highest scientific accomplishments that are affordable and achievable given the project team expertise and other constraints. The negative aspects are that progress is more deliberate, and slower then some may desire. Additional fall-out is that key project participants spend time on planning documents that detracts from time spent on publications. As all recognize, there is only so much time in a given day. As a highly published project team, IFRC management is acutely aware of such trade-offs and seeks ERSD management and FREC feedback on our approach. Our goal is to provide ERSD with the best product in terms of scientific accomplishment and impact. Opinions on how to best achieve this goal are solicited.

The following project planning documents are under development, noted are responsible authors.

- Saturated zone experimental plan (Zachara) – This plan describes the nature, objectives and hypotheses, approach, and schedule of different experiment types to be performed within the saturated zone at the IFRC field site. The document has been under preparation for some time now, but its completion has required characterization data on the depth and spatial distributions of: i.) U(VI) concentrations and isotopic distributions, ii.) key hydraulic and hydrogeologic properties, and iii.) microbiological distributions (from PNNL SFA investigators). The IFRC project is actively seeking to complete these characterization measurements as soon as possible to facilitate plan completion.

- IFRC modeling team plan (Rockhold) – A plan is under development by the IFRC modeling coordinator that will describe major modeling activities that are underway within the project; codes that are being used for specific activities and tasks; new code developments necessary; key data needs for robust model development; critical task or activity sequencing; and major modeling contributions expected from each activity. The modeling plan will prioritize measurements described in the characterization plan so that those with greatest impact to site model development can be performed and processed/interpreted early in the characterization schedule. A clear description of modeling responsibilities for each P.I. team will be provided.

- Vadose zone infiltration gallery development plan (Freshley) – All FY 08 activities were focused on completion of the IFRC well-field, and field characterization of the saturated zone. Future research plans call for the development of a vadose zone site, or an infiltration gallery within the overall IFRC field site to investigate processes and phenomenology controlling contaminant U(VI) mobility from the vadose zone and capillary fringe. This plan will develop a plan for the vadose zone site that makes best use of the existing well array and its downhole instrumentation, and that is consistent with the IFRC budget. It is expected that these new site development activities would occur in late spring, 2009.

- Publication plan (IFRC team) – This internal project document that has been developed for the benefit of the IFRC project team. The plan includes specific publications that are targeted for the next two years including: the lead author who will shepherd data completion, synthesis, and manuscript development; a statement of scope and expected scientific contribution; additional field measurement, experimental, or modeling needs; and key collaborators and their roles. The plan identifies publication responsibilities and seeks to maximize publication productivity, timeliness, teamwork and collaboration, and scientific impact.

<u>Task 2. Site Design and Installation</u>

Thirty four new wells were drilled, installed, and instrumented to approximately 20 m depth (base of the unconfined aquifer) within the IFRC site (Figure 1). One additional borehole (C6209), the deep microbiological characterization well, was drilled to the top of basalt bedrock at 50 m depth. Over 1,000 geologic samples for physical, chemical, and microbiological characterization were collected from these wells. Prior to well completion, each hole was logged down-hole with the SGLS (spectral-gamma logging system) and neutron-moisture probes. Other documentation received on each well includes

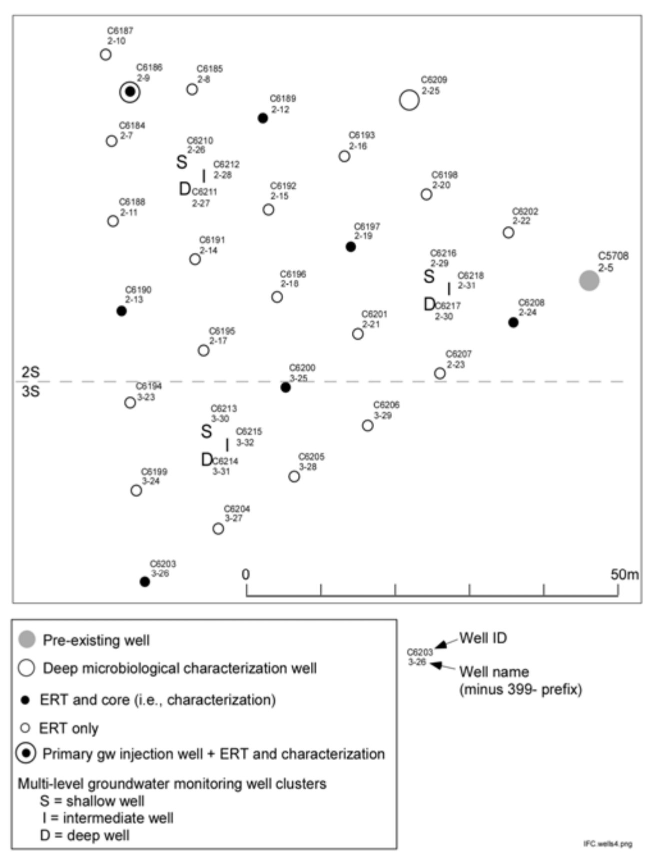

Figure 1. Well locations within the IFRC site. The deep microbiology borehole (C6209) lies just outside the bounds of the triangular well array.

a field-geologist log, well-construction summary, field-activity, well-development, sample-summary, and well-survey reports. All data and documentation are being entered into the IFRC online database and shall be summarized into a published IFRC borehole-summary report under preparation.

Significant findings to date include confirmation of extremely heterogeneous facies of the coarse-grained, highly permeable Hanford formation overlying mostly homogeneous, low-permeability silts and fine sands of the Ringold Formation. Large rip-up clasts of the cohesive, fine-grained Ringold material appear to be randomly distributed within the Hanford formation. The contact between the Hanford and Ringold formations, which represents a significant hydrologic boundary at the base of the unconfined aquifer, is shown in Figure 2. The elevation of this surface is estimated based on the preliminary, down-hole, spectral-gamma data presently available, and is subject to modification with additional information.

A sharp redox boundary occurs within the fine-grained Ringold Formation about a meter below the contact with the Hanford formation; the sediment closest to the contact is more oxidized. The deep microbiology characterization borehole revealed that the upper fine-grained Ringold sequence is about 5 m thick, underlain by about 15 m of coarse-grained fluvial Ringold sediments (Ringold unit E). Below this, 12 m of Ringold lower mud was drilled before encountering the strongly weathered flow top of the uppermost Columbia River basalt (Ice Harbor Member).

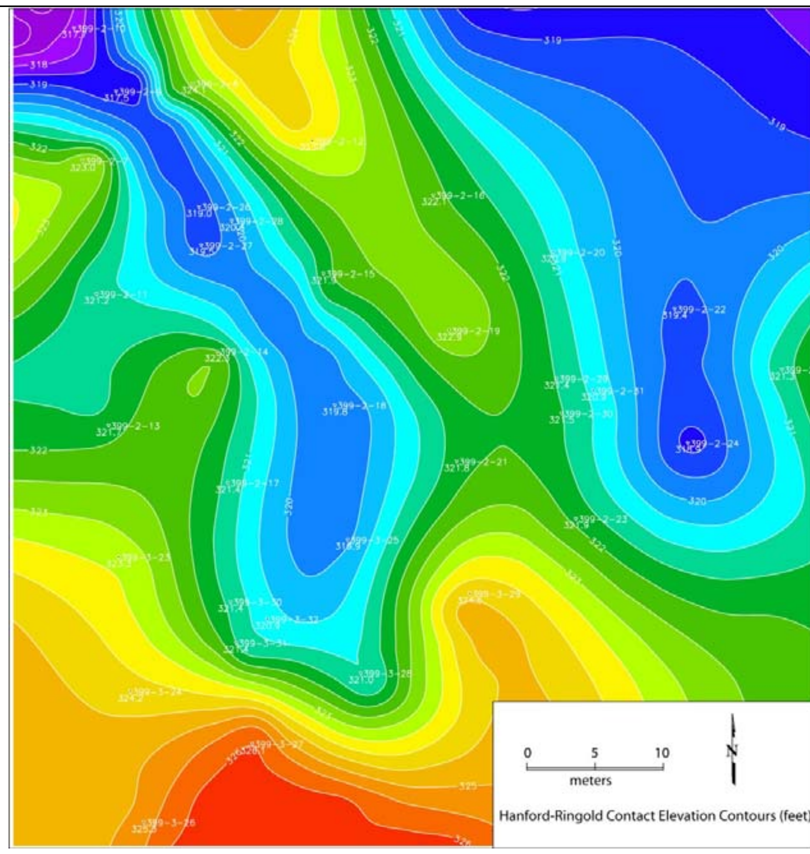

Figure 2. Structure-contour elevation map of the Hanford-Ringold contact. Note a ridge of higher-elevation Ringold (green to orange) generally trends north-south through the site.

A Borehole Drilling, Sampling, and Well Construction Report is nearing completion that will summarize the site geology and stratigraphy, the topography of the Hanford-Ringold contact, and all relevant technical aspects of the individual wells and the final configuration of the downhole monitoring system.

Task 3. Website and Data Management

The IFRC data management site came online (Figure 3) in mid August and was integrated with the PNNL website. The site provides authenticated users access to IFRC data of different types (Figure 4). All IFRC collaborators as well as DOE program managers have received user names and passwords to access the site.

The site is built using Zend Framework (an open source object oriented web application framework). While getting the basic structure to work was a substantial effort, this framework makes it easy to add new components and to maintain the site (and possibly transition it to other entities at project completion). The underlying database structure (implemented in MySQL) is in place, and population of the database is ongoing. Table 1 provides a (high level) summary of the data status

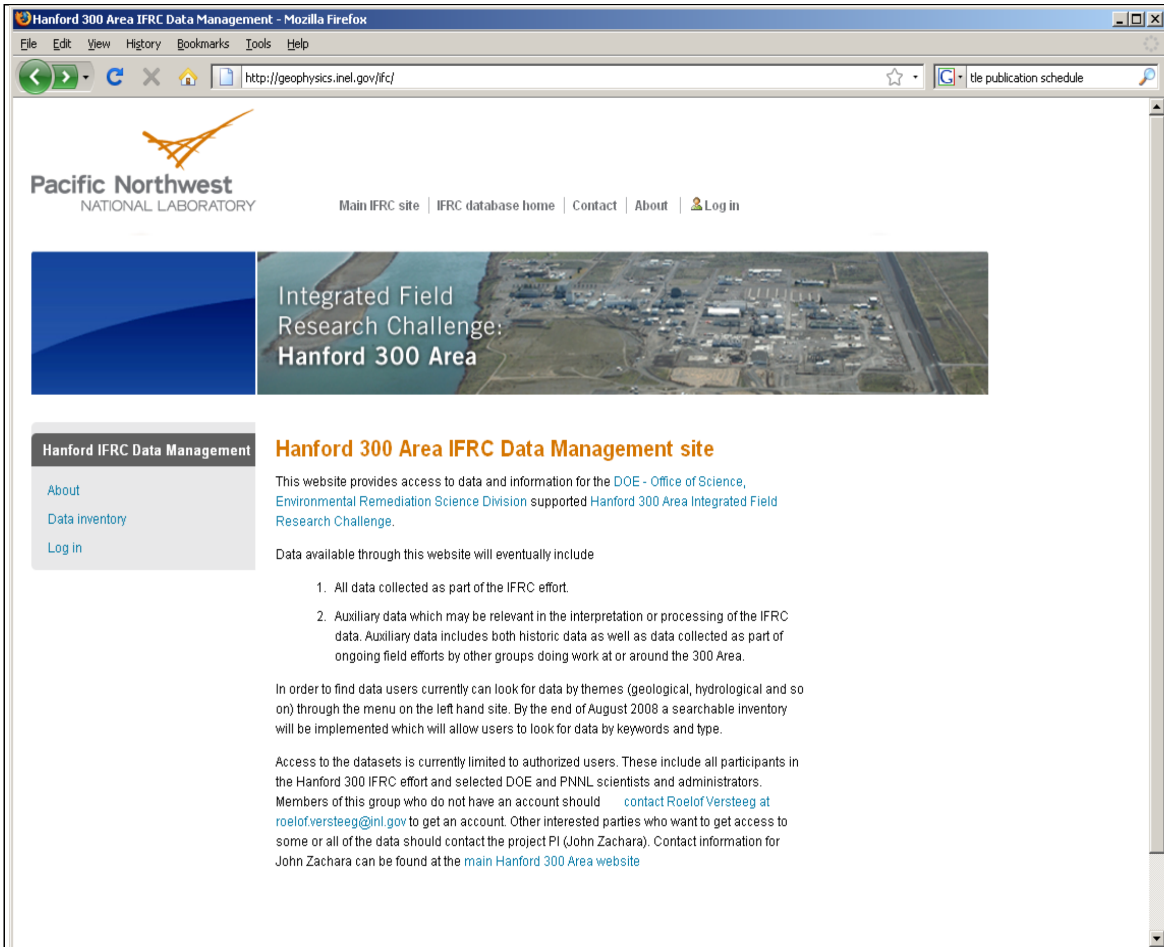

Figure 3. IFRC data management entry page. The data management site is housed at INL, but has the same look and feel as the main IFRC website so that users can seamlessly transition between these two sites.

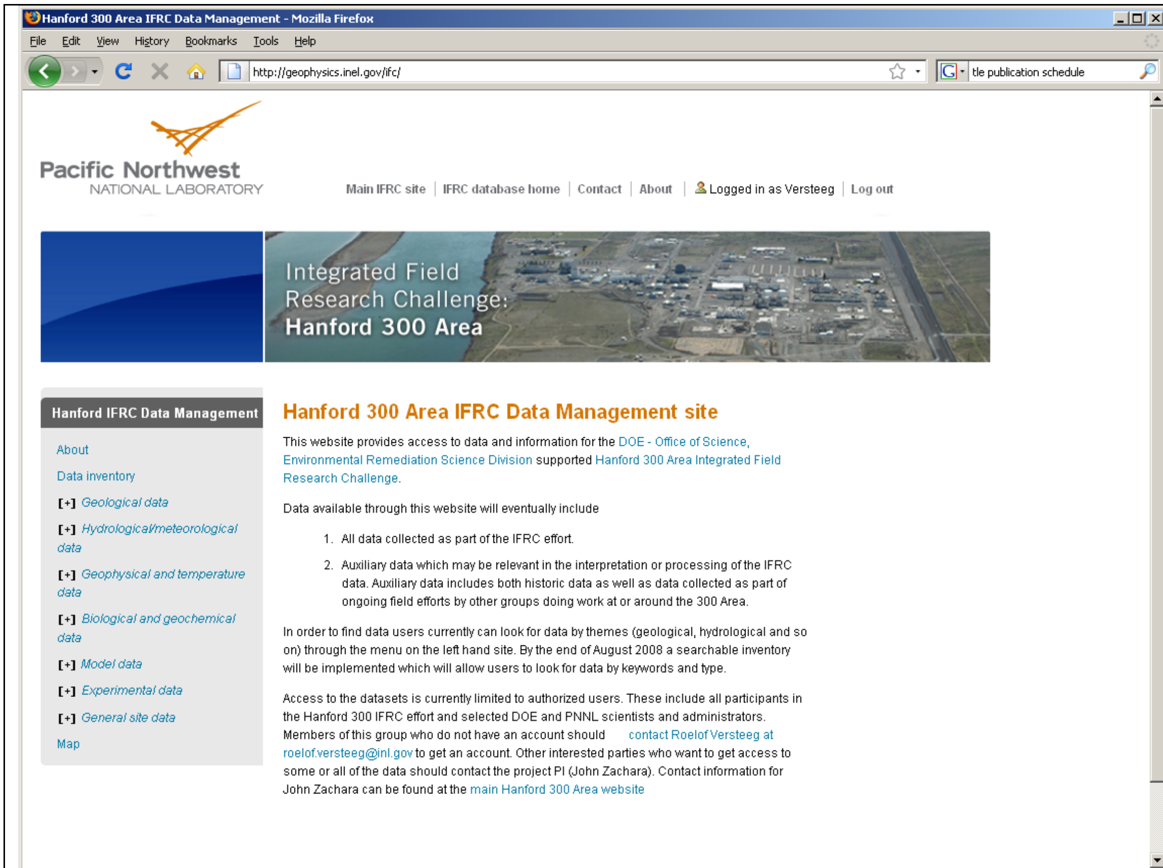

Figure 4. Once users log in, they can access different data through the menu on the left hand site.

Over the next reporting period many results from field and laboratory characterization will become available that will need to be passed on to project participants (geological and geophysical logs, sample results, interpretations of the well logs, and so on). The initial task is to enter this data into the database. Associated with this activity is the implementation and testing of a versatile sample tracking system to allow users to “tie” sample results together (e.g., to see on one page sample results from different researchers). Some of the results, such as those resulting from hydrological and geophysical characterization, have significant complexity that will require iterations between the data steward and the data base manager to determine the best way to both store and display such data. An important next step will be to link the continuous monitoring infrastructure at the IFRC well field (e.g., water level, ionic conductivity, and temperature) into the database with a fully automated data transmission system.

In conjunction with these activities will be the development of easy access tools for time series data. This should allow researchers to compare temperature data between two probes in different wells, and to visualize time series of different sort. Both map and text based tools will need to be developed. The map tool will expand on the existing Google Maps interface.

Table 1. Summary overview of database status.

Data	Status	Comment
IFRC wells	Metadata in database, awaiting borehole and geophysical logs	Borehole logs will need to be mapped into digital format for optimum use (currently will only be image format)
Samples	Sample metadata in database. Core and sample photos are at INL and are being added to database. Sample analysis results are starting to arrive from researchers and will be entered as they come in.	Need to add effective sample tracking system
Historic data	Hydrologic data in database. Historic well data in database.	Need to enter Earthvision interface model data and recent elevation/bathymetry data. Need to add pdf results of historic well logs.
Auxiliary data	Harvesting of hydrological data from USGS and COE in place	Need to determine what other data is needed

An important remaining issue is how to make the IFRC database most useful for project participants now that large amounts of data are being collected. This will need to be resolved through a dialogue with all project participants. From a technical perspective, one challenge is how to accurately capture the results of microbiological and geochemical experiments that can be idiosyncratic in design, results, and interpretation.

Task 4. Field Site Characterization

A Hydrologic and Geochemical Characterization Plan has been completed for the Hanford IFRC that describes: i.) geophysical measurements and logging for boreholes with temporary (steel) casing and completed PVC wells with sand pack, ii.) field hydrologic measurements for completed wells including pump tests, borehole flow-meter measurements, and non-reactive tracer tests, iii.) groundwater baseline characterization, and iv.) laboratory geochemical (e.g., U and important properties) and hydrophysical measurements on borehole sediment samples. The plan will be posted on the IFRC website on or about October 10, 2008.

The plan describes a tiered approach for IFRC characterization. It begins with down-hole geophysical measurements immediately after well drilling and hydrologic testing during and after well completion. It proceeds to measurement of a limited suite of essential properties on a large number of sediments to define the spatial distribution of key solid phase properties throughout the well-field. Results will serve as basis for development of predictive statistical relationships for a variety of required solid- and aqueous-phase properties. Characterization then progresses to more detailed study of specialized properties associated with individual processes. Proposed characterization measurements are summarized in Table 2 (at back of report). Those noted with * are either underway or completed.

Characterization has commenced according to the Hydrologic and Geochemical Characterization Plan noted above and significant progress has been made at the site.

Geophysical Characterization. During the last quarter, drilling was completed and all of the subsurface instruments installed and tested in-situ. Each thermistor was individually tested using a precision volt meter. In most wells, thermistors and resistivity electrodes were installed outside the well casing in the vadose zone whereas the saturated zone sensors were installed inside the well casing. In one well, C6186, all of the sensors were placed on the outside.

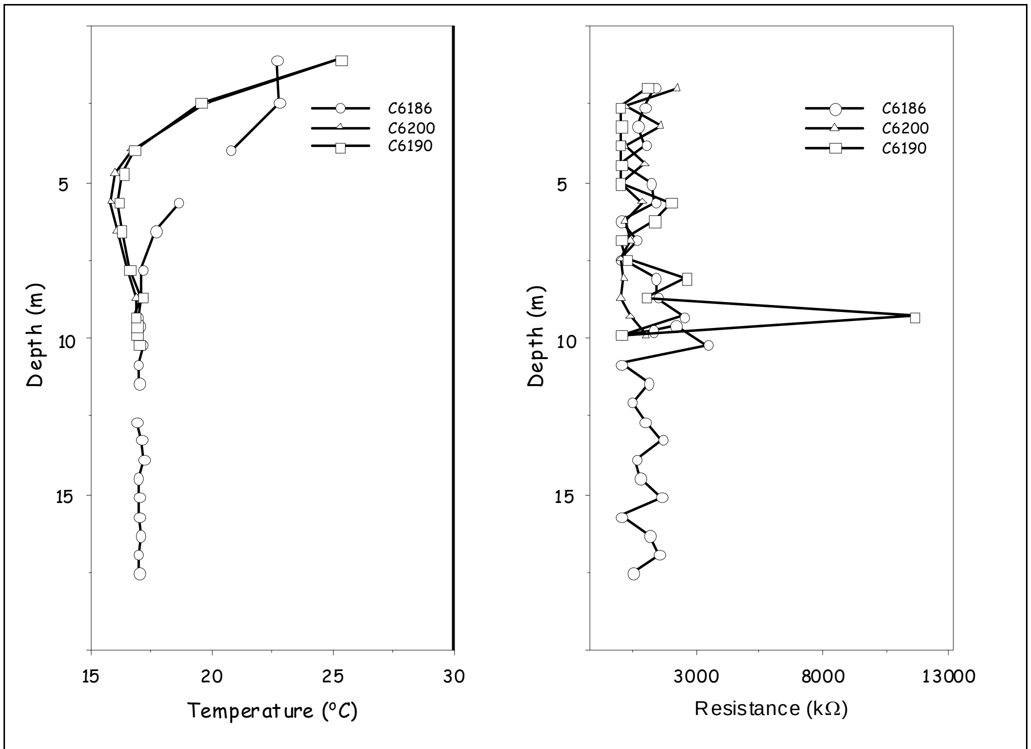

Figure 5. Examples of Post-completion Measurements in 3 IFRC Wells, C6186, C6200, and C6190, (a) Temperature, and (b) single-well electrical resistance.

All of the thermistors were calibrated prior to installation to allow conversion of voltage measurements to temperature in ^{o}C with a resolution of 0.1 ^{o}C. Of the more than 700 installed at the site for temperature measurements, only 5 appear to be non-functional. Figure 5a shows the temperature profiles at 3 wells, C6186, C6200, and C6190.

Periodic subsurface temperatures measured in wells at the IFRC range from about 17° C to 25° C. As can be expected, the highest temperatures are near the surface (1–m depth). Below this depth, temperature decreases almost exponentially with increasing depth to around 17° C in the aquifer. Figure 5a shows vadose zone temperatures of between 3 and 5^{o} C higher in C6186 than in other wells beyond the 2-m depth. This discrepancy may be due to differences in completion, and will be resolved once geophysical borehole logging (e.g., acoustic televiewer and density) is complete.

To test the integrity of the vertical electrical resistivity arrays, the resistance was measured across electrode pairs for all of the wells. All of the electrodes appear functional. Figure 5b compares the resistance profile measured across 2-electrode combinations for three wells. Resistance ranges from around 10 kΩ to around 3500 kΩ across the well field, with the highest values occurring mostly in the vadose zone. Figure 5b shows a large increase in resistance near the water table (≈ 8 bgs), which is an anomaly that appears in most of the wells. This can be attributed to the material used in the annulus of the wells. All of the wells were completed with a 10-20 sand pack in the saturated zone. However, to reduce the contact resistance in the vadose zone, a much finer 40-140 sand was used. In well C6190, the transition from the upper fine sand to lower coarse sand occurs around 8.8 m, which coincides with the peak in 2-electrode resistance. Borehole geophysical logs will be used to refine the location of these transitions so that they can be accounted for in geophysical data analysis and interpretation. A number of cross-well resistivity surveys have also been performed, and the resulting data inverted using a 3D inversion code developed at INL (Figure 6).

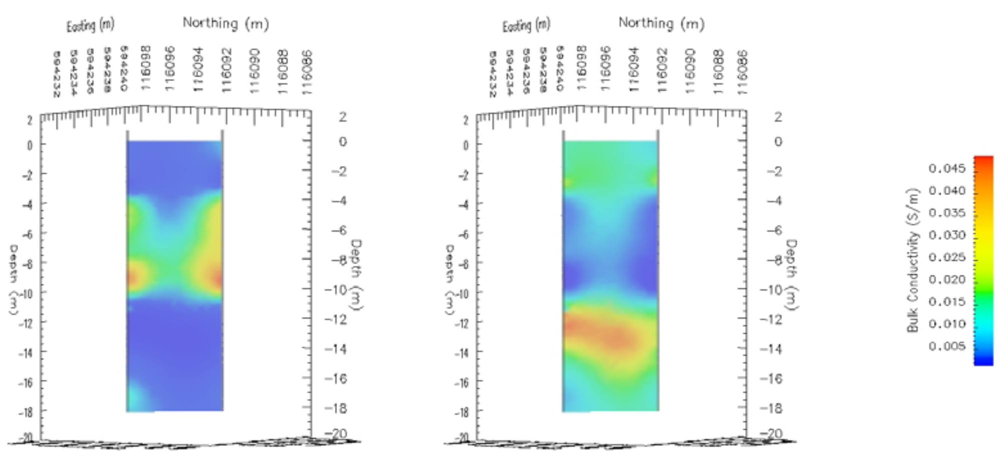

Figure 6. 3D Inversion of 2D cross-well resistivity data collected between wells CC6186 and C6187. Well C6186 is on the right and C6187 is on the left, (a) inverted bulk resistivity, and (b) inverted electrical conductivity.

The inversion results are plotted in cross section, but in reality the inversion mesh is 3D in which each element can take on a unique conductivity value. Consequently, the resolution is somewhat less would be expected with a 2D inversion. However, as data from the other well combinations become available, the resolution will improve.

Nonetheless, the results are consistent with observations of temperature, geology logs, and the location of the water table defined during drilling. Figure 6 shows a relative low resistivity (high conductivity) zone down to a depth of about 4 m, which is consistent with the backfill material and the fine sand in the annulus. A sharp decrease in resistivity (increase in conductivity) occurs around 10 m, where the water table occurs and the sand-pack changes from #40-140 to #10-20. A gradient in conductivity is evident below the water table which results from lithologic differences.

Geophysical borehole logging was initiated in mid-September under a subcontract to Golder Associates. Logs collected included borehole deviation (azimuth and tilt), magnetic susceptibility, total magnetic field, total gamma, and electrical conductivity on all the wells. Crosshole radar surveys, with a single offset configuration, were performed on all well pairs spaced 10 m or less. Logging was completed on September 30, and data reduction and analysis is in progress. Preliminary results show variation in tilt and azimuth below the water table. Magnetic field and magnetic susceptibility confirm the location of thermistor and resistivity electrodes, which show up as high conductivity anomalies with high magnetic susceptibility, especially in the vadose zone. Below the water table, where instruments can be retrieved to allow downhole logging, data quality is much better and changes due to differences in lithology are evident. The acoustic televiewer signal is dominated by the sand pack and vertical differences, including joints in the screen are evident. Good quality crosshole radar data required use of a 1000V transmitter. Both vadose zone and saturated zone measurements show evidence of structure although data quality in the saturated zone is much better.

During the last quarter, a crosshole seismic test was also conducted in collaboration with MSE using two wells. This test was performed to investigate the feasibility of conducting crosshole seismic measurements to characterize small-scale heterogeneities. The source was contained in a retrofitted rubber bladder to minimize the introduction of contaminants into the well. Even with amplitude and frequency dampening as a result of the bladder, the downhole seismic source generated sufficient energy to allow for cross-borehole imaging at distances of at least 50 meters between boreholes. The downhole source was able to generate reproducible frequency and amplitudes. The seismic tomography survey between wells C6186 and C6187 indicated similar stratigraphy with both a straight-ray and curved-ray approximation of the seismic energy propagation. Seismic velocities ranging from 1600 to 2000 m/s were indicated with a general trend of increasing velocity with depth.

Groundwater Geochemical Characterization. A background geochemical survey was performed on all well waters in mid-September using our automated pumping and manifold sampling system. The sampling system worked flawlessly. This is the low-flow season of the Columbia River. Groundwater flow is stable over this period where it sweeps across the site from northwest to southeast with discharge to the Columbia River. Groundwaters reach their highest concentration of major ions during this period. The sampling revealed that groundwaters were relatively uniform in composition throughout the well field, with an average U(VI) concentration of ~60 μg/L (two times the MCL), and ionic strength of 0.5 mM. There were minor hot spots in composition. Groundwater near the water table had slightly increased concentrations of U(VI) (e.g., ~70 μg/L) as displayed in samples collected from the three multiple depth well clusters. Also completed was a U isotopic survey of the IFRC waters and nearby monitoring wells with high precision analyses performed by John Christensen of LBNL. This information was critical to allow hydrologic testing (constant rate injection tests) to proceed using waters that would not perturb the existing U isotopic balance.

Hydrologic Characterization. Electromagnetic borehole flowmeter (EBF) measurements (Figure 7) have been completed in each fully screened monitoring well in the IFRC well network. During this EBF profiling campaign, measurements were collected at ~30 to 60 cm (1 to 2 ft) depth increments through the saturated zone under both ambient and dynamic flow (i.e., pumping) conditions. Analyses of these data are complicated by the presence of significant ambient flows (e.g., vertical) in site wells (up to ~ 6 L/min) that are both spatially and temporally variable. The ambient flows result from the hydrodynamics of the near river environment that cause pressure differentials across the fully screened monitoring wells. Interpretation and reduction of these data are ongoing, but Figure 8 provides a preliminary example of an effective hydraulic conductivity (K_{eff}) plot that was derived from the EBF profile results. These data, in conjunction with depth averaged hydraulic conductivity (K) measurements from soon to be performed constant rate injection tests, can be used to develop a vertically discrete K distribution at each well location. These distributions, in turn, will be one of a number of primary data sets that are integrated into the IFRC site geostatistical model by Rubin and others.

A second EBF campaign is now underway to better characterize the temporal variability in ambient vertical flows for IFRC site monitoring wells, and to determine whether the observed vertical flows correlate with river stage fluctuations. These measurements involve the installation of the flowmeter at a given well location and depth, and the monitoring of flow continuously for 24 h time periods or more. In addition to completing an evaluation of EBF testing results, additional characterization activities planned for the remainder of CY08 include: i.) constant-rate injection experiments in multiple site monitoring wells, and ii.) a low river stage, conservative tracer injection and drift experiment.

Figure 4-1. Electromagnetic borehole flowmeter (EBF) (www.qec-ebf.com).

Sediment Characterization. Geochemical, physical, and hydrologic characterization of a subset of 200 grab samples is underway as described in Table 2. The methodology for sediment processing and a strategy for sample selection is described in the Hydrologic and Geochemical Characterization Plan. The first tier of measurements being performed includes particle size distribution, γ-spectroscopy measurements (^{40}K, ^{232}Th, and ^{238}U) of select particle size fractions (to facilitate rigorous interpretation and use of spectral gamma down-hole logging), total contaminant U(VI), labile contaminant U(VI), U(VI) sorptivity [single point K_d measured in a synthetic groundwater representative of low river stage at 60 μg/L U(VI)], and saturated hydraulic conductivity (K_s).

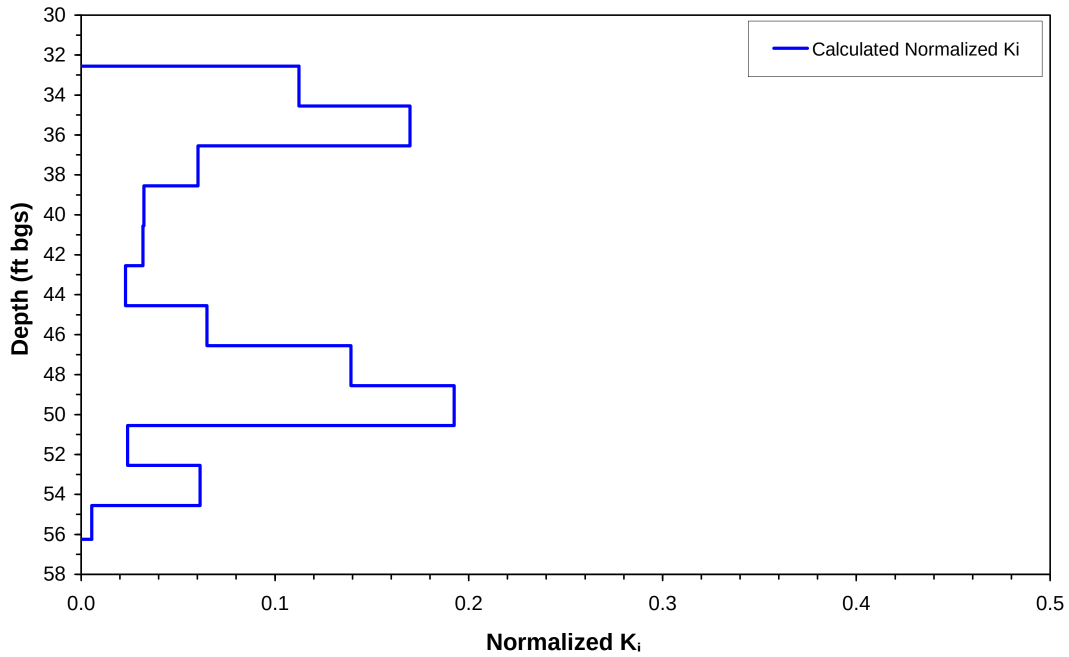

Figure 8. Effective hydraulic conductivity with depth at monitoring well 399-2-18.

Task 5. Vadose Zone Experimental Program

There has been no significant change to this task since the last report where the status was described as follows. A sequence of proposed vadose zone experiments (Phase I) is currently under planning in terms of objective/hypothesis, injection volume, tracer identity and concentration, uranium concentration, density of analytical measurements, and schedule. These plans are contingent upon the conditions found in the vadose zone during well installation with respect to facies distributions, and the results of characterization measurements on collected sediments including total contaminant uranium, labile adsorbed uranium, and other variables. Our characterization strategy will emphasize the early measurement of these key parameters to allow finalization of plans for vadose zone site development as described above.

Task 6. Saturated Zone Experimental Program

Our first saturated zone injection experiment is under active planning and will be performed over Nov-Dec 2008. It will be a non-reactive tracer, natural drift injection experiment performed primarily for hydrologic characterization during a period of low river stage where groundwater flows toward and discharges to the Columbia River. The experiment is described in the Hydrologic and Geochemical Characterization Plan and will involve injection of approximately 100,000 gallons of IFRC site groundwater spiked with NaBr. The primary objectives are to: i.) fully test the IFRC site infrastructure for geophysical monitoring, and groundwater chemical monitoring and sampling, ii.) improve understanding of IFRC site flowpath trajectories and velocities, and iii.) to refine the site geostatistical model by correlating heterogeneous solute transport with downhole geophysical and hydraulic conductivity measurements.

At least three other saturated zone experiments will be performed during FY 09 whose details are contingent on characterization results, including the first nonreactive tracer experiment. Each of these are described in the experimental plan, and are summarized below.

- A cold-month drift experiment (January-March) where chilled IFRC site groundwater (e.g., ~ 10^{o} C) is injected into ambient groundwater (e.g., ~ 17^{o} C), and its heterogeneous transport and dispersion monitored using our extensive down-hole thermistor array.
- A passive, natural gradient experiment during April to June that will comprehensively monitor groundwater head, temperature, ionic conductivity, and compositional changes that occur as Columbia River waters rise in response to snowmelt, inundate the lower vadose zone, and later fall as snowmelt ceases.
- A warm month (July-September) reactive transport experiment where upgradient groundwaters of low U(VI) concentration are injected in the IFRC site and the desorption plume monitored during transport to assess in-situ desorption and mass transfer kinetics, and their linkage to previously characterized flowpath and lithologic heterogeneities.

<u>Task 7. Modeling and Interpretational Program</u>

In our last quarterly report we described the breakdown in responsibilities for each of our modeling P.I.s that include: PNNL (Rockhold, Ward, and Liu), INL (Versteeg), LANL (Lichtner), U.C. Berkeley (Rubin), and U. of Alabama (Zheng). The modeling P.I.s have been working to these lines of responsibilities over this reporting period. Further specifications of modeling goals and their linkage to the characterization and experimental program will be described in the modeling plan that is under preparation.

The progress of the modeling team has been limited to large extent by the absence of geologic, hydrologic, and geochemical data on the IFRC site and sediments within it. This situation has now dramatically changed with the installation of the well-field, and a large amount of data, measurements, and information is now emerging for the team to begin development of a robust hydrogeologic model of the IFRC experimental domain. In spite of data limitations, notable progress has been made in several areas.

- U.C. Berkeley (UCB) has continued development of its new geostatistical modeling approach and program called the Method of Anchored Distributions

(MAD). MAD is as code for assimilating all relevant past and new field data to drive inverse calibration of hydrogeologic and geochemical parameters, realizations for forward conditional simulations of non-reactive and reactive tracer experiments, and stochastic modeling. It will be published as an IFRC research contribution when complete. The UCB modeling team is ready to accept data and will begin with spectral gamma and neutron moisture logging results from all 35 monitoring wells with an initial objective to assemble all necessary data to define a robust model of the spatial distribution of hydraulic conductivity. UCB researchers will collaborate with Peter Lichtner (LANL) and Glenn Hammond (PNNL, a new project participant) to apply new parallelized computational routines developed by SCiDAC for processing of large IFRC data sets. Their initial activity will be to link MAD with a parallelized version of Lichtner's reactive transport code, P-FLOTRAN.

- University of Alabama (Zheng) has developed an updated hydrologic model of the IFRC field using MODFLOW and MT3DMS. The model includes all new hydrologic data collected during FY08 on existing modeling wells proximate to the IFRC experimental domain. The model is being rapidly updated and made more comprehensive as data becomes available from the IFRC drilling campaign and geophysical and hydrologic characterization of the well field. During October 2008, Zheng will be pre-modeling our planned late November 2008 non-reactive tracer experiment. The pre-modeling will be used to optimize the experiment in terms of injection volumes and rates, and will also serve as metric of current hydrologic system understanding to which the field experimental results can be compared.

- The PNNL modeling team along with Versteeg (INL) has been updating the STOMP model to allow inverse modeling of the downhole electrical resistivity measurements in combination with other data to yield 3-D hydrologic and hydrology-related physical properties distributions. The geochemical module of the STOMP code has also been modified to perform more complex calculations of mass transfer based on experimental measurements of U(VI) and other solute reaction kinetics in 300 A sediments.

These activities and the long term goals of the modeling and interpretation program are being described in more detail in a Hanford IFRC modeling plan that will be completed over this next reporting period.

<u>Task 8. ERSD Outreach</u>

We have continued collaborations and sample exchanges with the ERSD and SBIR projects noted in the last quarterly report (Beyenal, Bussod, DePaolo, Kemner, Slater). Moreover, the SBIR investigator (Bussod) just spent two days visiting in early October 2008 where we exhaustively discussed possible applications of his core-scale imaging and processing capabilities to IFRC cores. The LBNL isotope geochemistry group (Christensen and DePaolo) has been extremely helpful and responsive in performing high precision U isotope measurements of IFRC well waters (with short turn around time), that have allowed us to protect the isotopic integrity of the site during hydrologic testing. [Hydrologic testing requires the pumping of large volumes of water from wells outside of the IFRC well array. The protection of isotopic integrity requires that waters used for hydrologic testing have identical isotopic ratios to the site. The LBNL group has found that U-isotopic ratios vary throughout the 300 A plume as a result of disposal of U waste streams with variable and different isotopic enrichments.]

The IFRC completed sampling of a unique, continuous 50 m core through the entire unconfined aquifer to the top of basalt. The borehole was located 10 m east of the IFRC well field, and was completed as a well in the more anoxic Ringold Formation. This core was primarily collected for microbiological characterization, and high-quality, intact subsurface cores were provided to PNNL's ERSD Scientific Focus Area researchers (Konopka and Fredrickson) and their external collaborators (Knight at the University of Colorado, Roden at the University of Wisconsin, and Loeffler at Georgia Tech). Core samples were also sent to ERSD investigator Joel Kostka at the University of Florida for investigations of microbial heterogeneity.

A full inventory of IFRC sediments collected during the drilling campaign has been posted on the web, and many of these are available to ERSD investigators should they ask.

V. Non-IFRC Project Activities

There have been no changes in this activity since the last reporting period.

VI. Funding Issues

Project spending was on track with projection for the final quarter of FY 08 and there were no funding issues. Spending on subcontracts to external collaborators was also on target. The two external experimentalists (Kent, USGS; and Haggerty, OSU) are underspent because they did not receive IFRC sediments until this week. The well drilling subcontract was completed on budget ($1600 K). We did not access our contingency fund for well drilling ($200 K) because of good luck and planning. Another $400 K was invested in essential site infrastructure that included: dedicated down-well pumps; ERT electrodes, thermistors, and connecting cables; ion selective electrode packages for 50% of the wells; the integrated well manifold sampling system; and the in-trailer flow-cell system for dynamic water quality parameter measurement. Ion selective electrode arrays for the remaining wells will be purchased in FY 09.

An intentional project carryover of $500 K was managed to assure that important IFRC research activities would continue without pause in early FY 09. Of this carryover, $200 K is directed toward our first injection experiment in November 2008. It is critical to the project that the first tracer experiment be completed before the end of December. The remainder of the carryover will be used for essential PNNL staff charges, remaining geophysical logging of the completed wells in October and data interpretation, ion selective electrode purchases, procuring other needed equipment for the injection experiment, and continuing the characterization measurements.

VII. Upcoming Plans/Issues

The following items summarize plans for the first quarter of FY 09.

- Install data loggers and complete wiring of the thermistor array to allow fully automated temperature measurements.
- Complete the Borehole Drilling, Sampling, and Well Construction Report and post to web-site.
- Collect density and porosity logs for all wells and post to data base.
- Complete borehole flow-meter measurements to resolve vertical fluxes in wells and perform constant rate injection experiments in 8 wells. Integrate and process data, and submit to modeling team.
- Perform full 3D field resistivity survey using all 840 electrodes that coordinates with hydrologic testing for the estimation of field-scale hydrologic properties.
- Complete first tier of essential characterization measurements on 200 samples including particle size distribution, contaminant and labile U(VI), U(VI) K_d, and laboratory saturated hydraulic conductivity; and γ-spectroscopy measurements of particle size isolates for SGLS interpretation.
- Finalize design for first non-reactive tracer injection experiment and write field test plan.
- Complete Multi-Year Experimental Plan for Saturated Zone Experiments beyond the first tracer test in November 2008. Circulate to IFRC research team and ERSD for review.
- Complete the IFRC Project Modeling Plan and Circulate to IFRC research team and ERSD for review.
- Initiate collaborative modeling activities with SCiDAC that link P-FLOTRAN with MAD for 3D geostatistical model development.
- Premodel first injection experiment using the most current geologic and hydrogeologic information from the IFRC site.
- Perform first non-reactive tracer experiment for hydrologic characterization.

VIII. Peer Reviewed Publications, Abstracts, and Presentations

Over the past reporting period, the PNNL IFRC team developed a two-year publication plan for internal use. The plan is ambitious and contains close to twenty potential manuscripts of varied scope that utilize the IFRC field site in different ways. This plan was described in Task 1, and is intended to develop momentum for and assign responsibilities for publication preparation and collaboration. To large extent the publications are based on geophysical, hydrologic, and geochemical measurements performed in the field, or characterization studies of different types on retrieved sediment samples from the well-field. Still others are based on the results and/or modeling of our first non-reactive tracer experiments. It will take time for these publications to emerge since these measurements have only been initiated over the past two months, and others will be performed in the near future. Nonetheless, our commitment is strong.

The following three publications were submitted this year using 300 A site materials that were collected before the installation of the IFRC well field. The publications were completed with partial support from the IFRC project and display our commitment to publish when data is available.

Um, W., J. M. Zachara, C. Liu, and D. Moore. 2008. Resupply mechanism to a contaminated aquifer: A laboratory study of U(VI) desorption from capillary fringe sediments. *Geochimica et Cosmochimica Acta* (Submitted).

Stubbs, J. E., L. A. Veblen, D. C. Elbert, J. M. Zachara, J. A. Davis, and D. R. Veblen. 2008. Newly recognized hosts for uranium in the Hanford Site vadose zone. *Environmental Science & Technology* (Submitted).

Singer, D. M., J. M. Zachara, and G. E. Brown. 2008. Uranium speciation as a function of depth in contaminated Hanford Site sediments – A micro-XRF, micro-XAFS, and micro-XRD study. *Environmental Science & Technology* (Submitted).

Table 2. Summary of baseline characterization measurements for IFRC well field.

Report Section	Measurement Subject	Measurement Type	Characterization Info.	Measurement Frequency and/or Number
2.1	Borehole with temporary casing	Neutron moisture*	Water content	Twenty-nine (of 35) wells at 7.5 cm resolution in vadose zone
2.1	Borehole with temporary casing	γ-ray spectroscopy*	Lithology	Twenty-nine (of 35) wells at 15 cm resolution
2.2	4” PVC well	Density probe	Bulk density	All wells with approximate 10 cm resolution
2.2	4” PVC well	Neutron porosity	Bulk density	All wells with approximate 10 cm resolution
2.2	4” PVC well	Electrical conductivity and magnetic susceptibility*	Integrates multiple effects; sensitive to porosity, saturation, dissolved salts, and temperature	All wells with 0.5 m resolution
2.2	4” PVC well	Borehole inclination*	Inclination, bearing, true depth	All wells
2.2	4” PVC well	Acoustic tele-viewer*	Acoustic information on region near the well casing, fractures, voids, etc.	All wells with ~ 3 cm resolution
2.2	4” PVC well	Neutron moisture	Changing water content in vadose zone	All wells with ~ 10 cm resolution in vadose zone
2.2	4” PVC well	Borehole radar with single off-set borehole surveys; more comprehensive measurements later*	Orientation and thickness of dissimilar units	All wells with ~ 0.2 m resolution in saturated zone
2.2	4” PVC well with ERT electrode strings	Crosshole resistivity*	Electrical properties related to lithology, water content, and salt content	28 instrumented resistivity wells containing 840 electrodes
3.0	4” PVC well	Opportunity pumped groundwater samples*	Dissolved concentrations of major and minor ions and U(VI)	Pumped samples from all wells at low, high, and two intermediate river stages (e.g., Sept., Jan., April, July)

3.0	4" PVC well	Passive, multi-level sampler	Vertical groundwater composition	Four wells during stable periods of low and high river stage
3.0	4" PVC well	Smear zone samples	Water composition at water table	Time-series for six wells at rising and declining river stage (spring/summer 09)
4.2	4" PVC wells/saturated zone	Electromagnetic borehole flowmeter*	Vertical distribution of horizontal hydraulic conductivity	All wells. Temporal measurements performed in 10 wells
4.2	4" PVC wells/saturated zone	Constant rate injection test	Quantitative hydraulic property estimates	Multiple; methodology and injection volume needs and rates under assessment
4.3	4" PVC wells	Non-reactive tracer experiment w ~ 100,000 gal of 80 ppm NaBr in IFRC well water	Assess heterogeneities and transport velocities in the saturated zone; test well-field infrastructure	One experiment planned for Dec. 2008
5.4	Borehole sediments	Particle size distribution*	Distribution of gravel, sand, silt, and clay; and subclasses	100 grab and 25 core samples
5.4	Borehole sediments	Hele-Shaw cell	Particle shape	25 separate size fractions
5.4	Borehole sediments	Porosity on loose and dense packs	Data for packing model	25 grab samples
5.4	Borehole sediments	Pyncnometer	Particle density	25 < 2 mm size fractions
5.4	Borehole sediments	Single point, N_2 adsorption	Surface area	25, < 2 mm size fractions of grab samples
5.4	Borehole sediments	Impedance spectroscopy as a function of saturation	Sediment electrical properties	50 intact cores
5.4	Borehole sediments	Electrical resistivity and induced polarization as a function of saturation	Sediment electrical properties	25 intact cores
5.4	Borehole sediments	Thermal properties as a function of saturation	Sediment heat capacity and diffusivity	25 intact cores
5.4	Borehole sediments	γ spectroscopy measurements of ^{40}K, ^{238}U, ^{232}Th*	Isotopic signatures for interpretation of SGLS	25 samples of gravel, sand, silt, and clay

5.5	Borehole sediments	Fusion and digestion*	Total and contaminant U	200 grab samples
5.5	Borehole sediments	2 week bicarbonate extraction*	Labile adsorbed U(VI)	200 grab samples
5.5	Borehole sediments	Acidified hydroxyl amine hydrochloride (AHH)	Reactive Al and Fe oxides	200 grab samples
5.5	Borehole sediments	Single point K_d measurements at 60 μg/L U(VI)	Linkage to surface complexation model	200 grab samples in two synthetic groundwaters representative of high and low river stage
5.5	Borehole sediments	X-ray diffraction	Mineral distribution	25 samples(each) of sand, silt, and clay from the saturated zone
5.5	Borehole sediments	Isotopic exchange	Labile adsorbed U(VI) and precipitated U(VI)	25, < 2 mm samples that vary in total U(VI)
5.5	Borehole sediments	Total carbon by combustion	Sediment inorganic and organic carbon	A total of 50 vadose and saturated zone sediments
5.5	Borehole sediments	Cation exchange capacity	Fixed negative charge on sediment particles	25, < 2 mm separates of saturated zone sediments
5.5	Borehole sediments	AAO and CBD extractions for Fe(III)	Amorphous and crystalline Fe(III) oxides	25, < 2 mm separates of saturated zone sediments
5.5	Borehole sediments	Stirred flow reactor adsorption/desorption experiments with 60 μg/L U(VI) in 300A SGW-1 and 300A SGW-2.	Grain-scale mass transfer rates	25, < 2 mm separates of saturated zone sediments
5.6	Borehole sediments	Constant and falling head methods	Saturated hydraulic conductivity (K_s)	40 intact cores and 40 repacked grab samples
5.6	Borehole sediments	Multistep outflow method	Relative permeability – saturation – capillary pressure relations	40 samples on which K_s measurements were performed