INTEGRATED FIELD RESEARCH CHALLENGE SITE
Hanford 300 Area

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

The Deep Vadose Zone as a Source of Uranium to the Unconfined Aquifer at the Hanford Site IFRC

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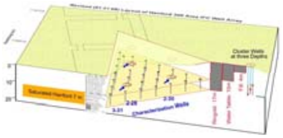


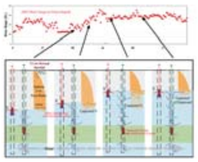
Background

The Columbia River exhibits large seasonal discharge/stage variations, particularly in the spring, which propagate directly into the near-river aquifer as water table fluctuations. The depth to water varies directly with these high-amplitude variations, and with smaller diurnal variations in river stage due to power generation needs and water discharges at upstream dams. A persistent uranium (U) plume is present in the aquifer, hypothesized to originate from seasonal U capture by the rising water table, with U potentially contributed from sediments over the extent of the water table's maximum vertical excursion. The portion of the aquifer that is intermittently in the saturated zone, approximately 2 m in height at the IFRC site, is termed the 'smear zone'. For this study, the contribution of U from the smear zone into the aquifer was evaluated by bailing the uppermost 15 cm of the aquifer, daily, over a significant portion of the IFRC footprint, during the seasonal rise in river stage associated with Spring snowmelt, from April 1 to June 18, 2009. Conventional pumped samples were collected along with the bailed samples, from the center of the fully screened wells, and from wells completed over relatively short shallow, intermediate, and deep intervals. During the experiment, the aquifer-top U concentration in some wells varied modestly above the values for samples pumped from the aquifer in mid-winter during low water (~50 ug U/L). In others, dramatic concentration increases were observed (>300 ug/L). The bailed-sample concentrations were generally higher than the concentration from corresponding pumped-samples, and in some wells the concentrations were much higher (3x the pumped-sample values). This behavior was observed during the multiple rise-and-fall cycles in river stage that occurred over the monitoring period. Although some vertical well flow was observed due to hydrologic head variations induced by river stage fluctuations, U solubilized from the smear zone did not mix with deeper groundwaters of the Hanford formation, yielding a stratified system. The overall concentration of U, indicated by three evenly distributed shallow-completion wells, increased unevenly across the site during the experiment, indicating that the contribution from the vadose sediments was broad, but heterogeneous. Uranium isotopic measurements indicated that compositional variation was present in vadose U, and the results overall indicated that the smear zone provided a seasonal, spatially heterogeneous source for seasonal recharge of U to the aquifer.

Hypothesis

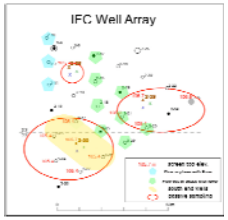
Uranium is contributed to the unconfined aquifer by contaminant capture during water table fluctuation.

- Significant U in contributed during Spring thaw and the associated water table rise of approximately 2 m.
- The uppermost portion (cm to 1 m) is the most impacted portion of the aquifer.
- U is mixed into the aquifer by advection.



Approach

- 11 wells chosen around three-well clusters.
- Sampled daily by bailing uppermost 15 cm, gauged by electric depth tape.
- (Wells were completed below uppermost level of the water table).
- Pumped from screen-centralized pump immediately after bailing.
- Recorded aquifer depth, river stage, time, and electrical conductivity for pumped samples.
- Duration April 1 – June 18.
- Analysis by KPA, IC, ICP-MS, Carbon Analyzer.
- Post-experiment analysis of U isotopic data for selected samples.
- MLS deployment and analysis of compositional profile during low water, after completion of experiment.
- Field analysis showed that there was some intra-well groundwater flow (Vermeul et al. poster).



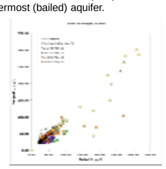
Sampled wells, shown with screen-top elevations, were near three-well depth clusters

Experimental Results

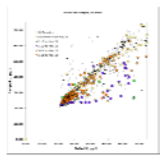
Pumped and Bailed Concentrations

- Concentrations in 'South End' wells (yellow overlay on well array plot) produced highest U concentrations (A).
- All other wells had U concentrations below 70 µg/L (B).
- Departures from 1:1 for pumped v. bailed (B) indicated a higher concentration in the uppermost (bailed) aquifer.

A



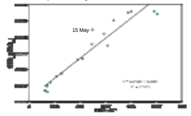
B



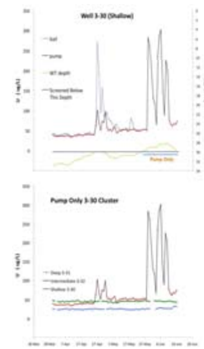
U Isotopics and Mixing

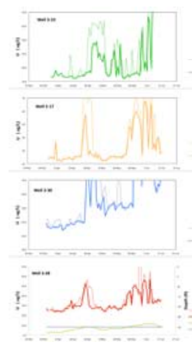
- Isotopic analyses of samples collected during the water table rise at several wells were begun recently (Christensen et al. poster).
- The first results, for Well 3-30 indicated a distinct isotopic composition for contaminants derived near that well and, with on exception (sample collected on May 15) plotted on a well-defined mixing line between the generalized aquifer composition (at a background U concentration of approximately 20 µg/L), and composition represented by the high concentration at Well 3-30 of approximately 300 µg/L.

Isotopic Mixing Line for Well 3-30



Uranium Concentrations and the Water Table Rise

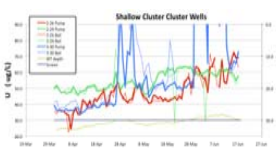


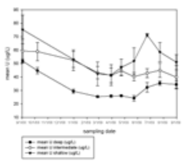


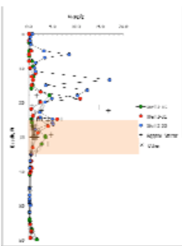
Left Panel:
- The water table rose in April, receded, then rose in late May (green line).
- Well 3-30 showed the most marked rise in U , with bailed concentrations exceeding pumped concentrations by three times when the water table was below the top of the well screen. Uppermost-aquifer concentrations may have far exceeded those observed when the water table was above the screen.
- For the three-well cluster at 3-30, the middle and lower portions of the aquifer were affected little by the inflow of U at the aquifer top.

Right Panel:
- The smear zone in the vicinity of the South End wells contributed far more U to the aquifer than other wells at the site (also see left plot).
- Bailed samples had consistently higher U concentrations than pumped samples.

Relationship to Aquifer Chemistry

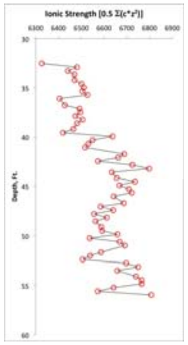






- To avoid potential intraflow complications (Vermeul et al. poster), the shallow members of the cluster wells were used to approximate the overall effect of the water table rise on the upper aquifer chemistry. As shown in the upper figure at left, the U concentration in, the upper aquifer zone approximately doubled during the experiment.
- For the aquifer at an annual scale, the upper aquifer zone fluctuated most, with the middle and lower aquifers following a similar, but subdued, seasonal cycle (lower figure at left).
- The relationship of contaminant U contributions to vadose zone and smear zone concentrations is complicated (Zachara et al. poster). As shown at right, the existence of U in the smear zone at abundances above background is consistent with the smear zone as a reservoir and source of the aquifer U plume.

The aquifer was sampled top to bottom during low water conditions in early March, 2010 in Well 2-20 at the northeastern edge of the IFRC. There were subtle but significant variations within the water column chemistry, as indicated by the variation in ionic strength. The overall solute load increased with depth, and it appeared that there was a distinct upper zone, down to a depth of 40 feet, with an average ionic strength of approximately 6500 (µmol basis). Below that, the ionic strength was higher, with an average of approximately 6700. Ongoing testing will determine whether this progression is true, whether it holds for differing seasons, and whether it corresponds to the high and low hydraulic conductivity boundaries (Vermeul et al. poster). U concentrations (not shown) also progressed, from approximately 21 µg/L at the aquifer top to 17 µg/L at the aquifer bottom.



Conclusions

- Significant contaminant U is contributed to the aquifer from the smear zone during water table fluctuations driven by varying river stage in the Columbia River.
- The U is distributed to the aquifer by advection, as indicated by decreases in U concentration between the surges in the water table observed during April and May, 2009.
- The contribution of available contaminant U to the aquifer is heterogeneous across the IFRC.
- As noted elsewhere, the results we obtained may have been influenced (most likely toward incorrectly lower concentrations) by the effects of intrawell flow, also driven by small diurnal changes in river stage.
- Intrawell flow effects could produce erroneously low or erratic aquifer concentration maxima when estimated from samples pumped from long screen intervals.
- The aquifer is stratified, with only longer term communication between upper and lower high-conductivity zones.
- The uppermost portion of the aquifer may contain and transport relatively high concentrations of contaminant U.

Related Posters

- Multi-Scale Mass Transfer Processes Controlling Natural Attenuation and Engineered Remediation: An IFC Focused on Hanford's 300 Area Uranium Plume, J.M. Zachara, et al.
- River Induced Wellbore Flow Dynamics in Hanford IFRC Monitoring Wells: Evidence, Implications, and Mitigation, V.R. Vermeul et al.
- Uranium Isotope Systematics in the 300 Area U Plume and the IFRC Plot: Progress Towards a Site U Isotopic Model, Christensen et al.

Future Research

- Additional shallow wells are under construction near the cluster-well locations to provide higher screen completion depths at the IFRC.
- Initial tests with packers (Vermeul et al. poster) indicated that intrawell flow could be significantly reduced by the installation of packers in the intermediate-depth low-conductivity zone. The IFRC site will be equipped with intermediate-zone packers in the near future.
- The labile U analysis for the smear zone (Zachara et al. poster) is almost compete for the entire IFRC. These will provide a more complete set of contaminant distribution data for use in interpreting passive experiment results.
- Isotopic analyses (Christensen et al. poster) indicated that the contaminant U, in addition to being heterogeneously distributed, had a heterogeneous isotopic composition. Additional isotopic analyses are underway.
- The isotopic and compositional analyses indicated that lateral groundwater flow was a component that should be included in the experiment.
- In Spring, 2010, the experiment will be repeated with the additional control provided by packers and additional wells, and will include a passive tracer test consisting of the addition of deuterated water at the center of the IFRC. This will provide an advective transport component to the results.

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