Flux-Based Evaluation of Perched-Water in the Deep Vadose Zone at the Hanford Site – 14051

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ABSTRACT

Perched-water conditions have been observed in the vadose zone in the vicinity of the B Complex facilities at the Department of Energy's Hanford site. Perched water, containing elevated concentrations of uranium and technetium-99, has collected on top of fine-grained material that is located a few meters above the water table. This perched-water zone is important to consider in evaluating the future flux of contaminated water from the vadose zone into the groundwater. Hydraulic analyses provide a means to evaluate the recharge and perching-layer hydraulic conductivity conditions that are consistent with the observed perched water at the B Complex and to consider future perched water dynamics. These analyses support remediation decisions by providing estimates of future contaminant flux to groundwater under different remediation scenarios.

INTRODUCTION

A perched-water zone in the subsurface is a saturated zone that is above and not directly connected to the regional water table. Perched-water develops when saturated conditions above a low-permeability layer are needed to move infiltrating water vertically through this layer. Perched water can occur under natural recharge conditions. Transient perched-water zones can also occur when infiltration is increased due to surface disturbance (e.g., construction activities or removal of vegetation) or as a result of a discharge of water (or aqueous waste) to the soil column. Significant perched water zones can occur in the arid western United States where thick unsaturated zones and highly heterogeneous sediments and fractured rocks are present (e.g., Birdsell et al. 2004; Nimmo et al., 2004; Robinson et al., 2011; Wu et al., 2004).

A perched-water zone is present in the vadose zone in the vicinity of the B Complex facilities at the Department of Energy's Hanford site (Figure 1). The vadose zone at the B-Complex is about 80-m thick. As shown conceptually in Figure 2, the configuration of the Cold Creek Unit within a portion of the vadose zone includes a low-permeability silt material, on top of which perched water has collected within a sandy portion of this unit. The perched water contains elevated uranium and technetium-99 concentrations, indicating that past waste discharges and leaks have contributed to the perched water. Currently, a 3.4 m thick perched water zone is present above the perching layer and has remained relatively stable over the last 1.5 years of monitoring (Oostrom et al. 2013). Pumping from a single extraction well (E33-344, Figure 1) has been initiated to remove contaminated perched water and decrease the total contaminant mass that would eventually move into the groundwater.

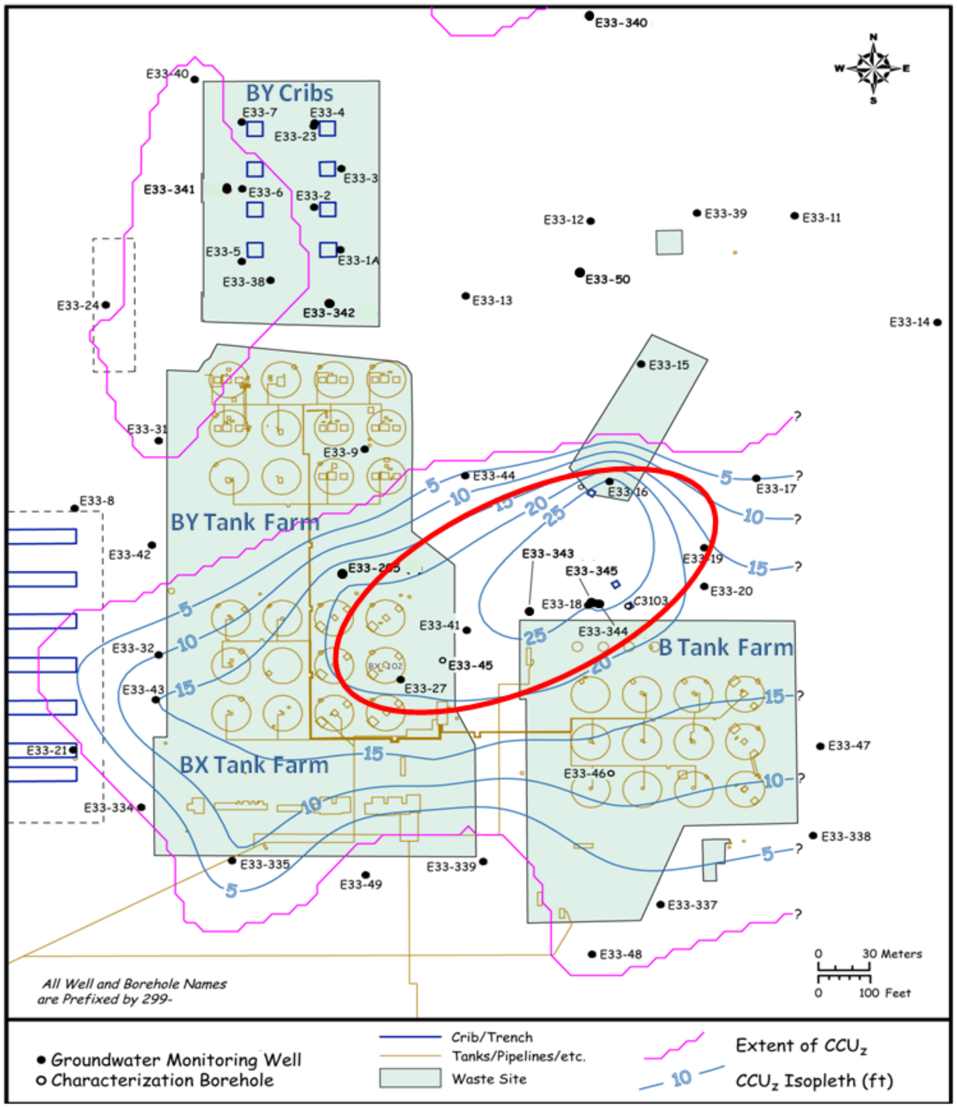

Figure 1. Hanford Site B-Complex and underlying extent and thickness of the Cold Creek Unit (CCU). Perched water has been observed within the red oval, generally following the 20 ft CCU isopleths where conditions are appropriate for perching (see Figure 2) (adapted from Oostrom et al. 2013).

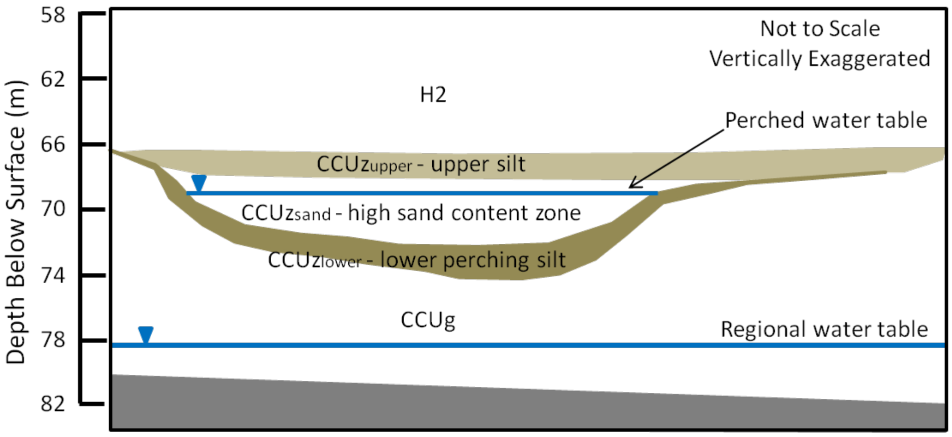

Figure 2. Conceptual cross section of the lower vadose zone and perched-water zone at the Hanford Site B-Complex. Stratigraphic units include the sand- and gravel-dominated H2 unit and the Cold Creek Unit (CCU). Within the CCU are an upper silt zone and a high sand content zone underlain by a low-permeability perching silt zone, which are collectively designated as the CCUz. The CCUz is underlain by a sand- and gravel-dominated CCUg zone that contains the regional water table.

Recently, a study was conducted to examine the perched-water conditions and quantitatively evaluate 1) factors that control perching behavior, 2) contaminant flux toward groundwater, and 3) associated groundwater impacts (Oostrom et al. 2013). Results of this study are summarized herein and discussed in the context of perched water remediation strategies.

METHODS

Oostrom et al. (2013) conducted an evaluation to improve the understanding of the formation and occurrence of the perched water and the future flux of contaminated water from the perched-water zone into the groundwater. The evaluation included transport simulations using the Subsurface Transport Over Multiple Phases (STOMP) code (White and Oostrom, 2006). Numerical simulations provided both steady-state and transient system estimates of water flow and contaminant transport behavior and were used to evaluate the range of conditions consistent with current observations of perched water height. In addition, the simulations provided predictions of future water and contaminant flux to groundwater for those conditions. The changes imposed by removal of perched water through pumping were also considered in simulations. Results from Oostrom et al. (2013) were evaluated with respect to contaminant fluxes into groundwater and extended to qualitatively consider candidate remedy impacts.

DISCUSSION

Based on average rainfall (~17.2 cm/yr) and surface conditions, current recharge is expected to be nominally ~6 cm/yr, though the value may range higher. Oostrom et al. (2013) estimated perched-water height over time as a function of recharge and hydraulic conductivity of the lower perching silt (Figure 3). Perched water is transient for higher hydraulic conductivity conditions in the perching layer with simulated perched water dynamics for the highest conductivity values not consistent with the observed relatively stable perched water conditions. To be consistent with current observations, the recharge rate is likely between 6 and 12 cm/yr with a hydraulic conductivity of the lower perching silt between 1e-7 and 6e-8 cm/s. As shown in Figure 4b, at 6 cm/yr recharge and about 1e-7 cm/s hydraulic conductivity, the water flux from the vadose zone into groundwater, though expected to be over 10 cm/yr for a short time, quickly reverts to a value equal to the recharge rate as the perched water height naturally declines under these conditions. If the current recharge rate were higher (e.g., ~12 cm/yr) at this same 1e-7 cm/s lower perching silt hydraulic conductivity, water flux from the vadose zone into groundwater would remain equal to the recharge rate with a stable perched water height. With a somewhat lower hydraulic conductivity of the lower perching silt (~6e-8 cm/s), a stable water flux equal to a recharge rate of 6 cm/yr would be maintained. These analyses illustrate that for the observed, relatively stable perched water height conditions that currently exist, the water flux from the vadose zone into groundwater is essentially controlled by the recharge rate.

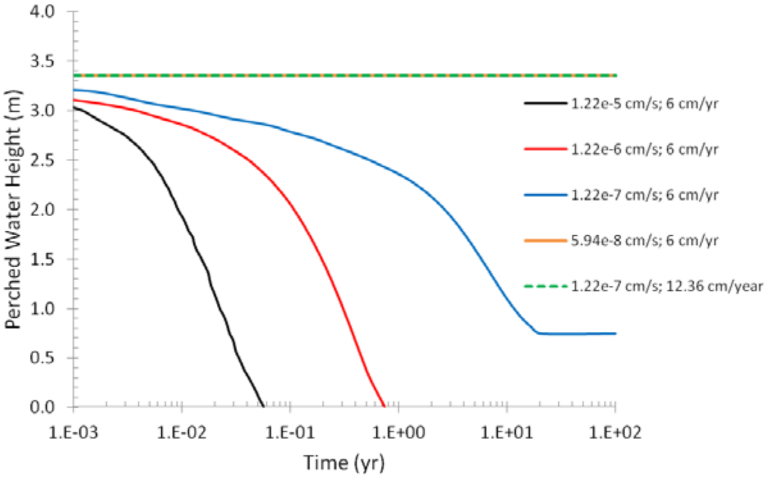

Figure 3. Simulated perched-water height starting from an imposed initial perched-water height of 3.36 m for selected perching-layer–saturated hydraulic conductivity values (cm/s) and a recharge rate of 6 cm/yr (Oostrom et al. 2013). Examples

of combinations of recharge and hydraulic conductivity values resulting in a stable perched-water height of 3.36 m are also shown.

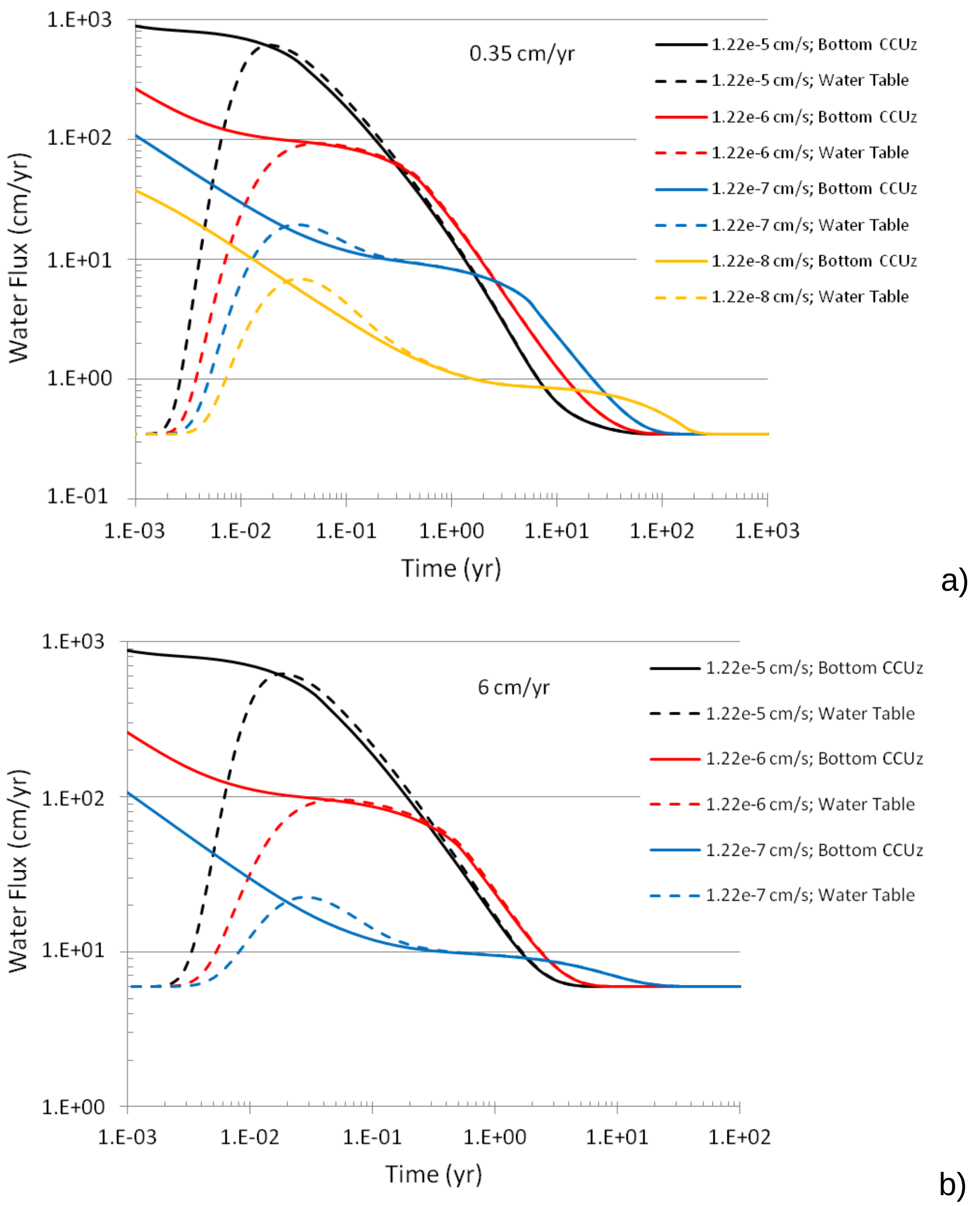

Figure 4. Simulated transient water flux (over 1 m^2) out the bottom of the perching layer (bottom CCUz) and to groundwater (water table) with an imposed initial perched-water height of 3.36 m for selected perching-layer–saturated hydraulic conductivity values and a recharge rate of a) 0.35 cm/yr and b) 6 cm/yr (Oostrom et al. 2013). Note that only transient condition cases are shown in the figure.

While focused on water flux from the vadose zone into groundwater, the above analysis also applies to contaminant flux when observed perched water contaminant concentrations are considered. For instance, at an observed nominal perched-water uranium concentration of about 50 mg/L, a 6 cm/yr recharge rate over the estimated 19,175 m^2 perched-water area corresponds to a uranium mass discharge into the groundwater of 14 kg/yr. This value represents a steady-state mass discharge once the uranium concentration front in the vadose zone has fully reached the groundwater. The mass discharge rate would continue until pore-water concentrations decline as the mobile uranium in vadose zone becomes expended. Sorption of uranium would lead to a tailing of the pore-water concentration due to desorption over time such that the decline in pore water concentration would not be abrupt. The mass of uranium in the perched water was estimated as likely between 300 and 500 kg by Oostrom et al. (2013). The perched water represents a collection of a large mass of uranium, but the mass discharge of uranium into the groundwater is primarily controlled by the recharge rate.

Imposing surface infiltration control to reduce the recharge rate leads to a reduced water and contaminant flux to the groundwater. However, transition to the lower flux conditions requires time. As shown in Figure 4a for several hydraulic conductivity conditions and a recharge rate of 0.35 cm/yr, transition from current perched water conditions and associated water flux values to a value controlled by the 0.35 cm/yr recharge rate requires decades. The steady-state uranium mass discharge to the groundwater at a recharge rate of 0.35 cm/yr for the observed nominal 50 mg/L uranium concentration in the perched water is about 0.8 kg/yr, a substantial reduction from the 14 kg/yr mass discharge at a 6 cm/yr recharge rate.

Short-term removal of a portion of the perched water, in conjunction with using surface infiltration control, would hasten the transition to water flux values controlled by the reduced recharge rate. Thus, perched-water pumping operations help reduce the future groundwater plume magnitude in this way. In addition, perched-water pumping removes uranium (and other contaminant) mass. Current estimated uranium mass in the perched water is 300 to 500 kg (Oostrom et al. 2013), 12.5% to 21% of the estimated 2400 kg of water-extractable (mobile) mass of uranium in the vadose zone (Serne et al. 2010). While the current perched water zone represents only a fraction of the mobile uranium in the vadose zone, the perched zone may act as a continuing collection point for mobile uranium continuing to drain from higher in the vadose zone profile. Thus, continued pumping from the perched-water zone as a collection point may enable a larger portion of the uranium mass to be removed using this remediation technique. However, the relatively large percentage of mobile uranium distributed within the vadose zone outside the perched water zone emphasizes the importance of surface infiltration control or potentially some other mechanism of limiting uranium mass discharge into the groundwater.

CONCLUSIONS

Quantitatively evaluating vadose zone conditions and associated water and contaminant fluxes provides key information with respect to future risk to groundwater and candidate remedy approaches. As shown in the discussion above, the perched water is an important feature in the vadose zone beneath the Hanford Site B-Complex. However, water and contaminant flux to groundwater are strongly related to the recharge rate, in addition to the hydraulic conditions in the perched-water zone. Thus, remedies may need to consider perched-water removal, surface infiltration control, and potentially other measures to limit future groundwater plumes. However, current efforts to remove perched water by pumping have multiple benefits with respect to reducing future groundwater plumes.

Specific flux and mass discharge values estimated in the above analyses must be considered in light of the relatively limited spatial resolution of data about the perched water and the use of simplifying assumptions in the simulation approach (see Oostrom et al. 2013 for discussion). In addition, there is a relatively short period of monitoring data currently available. Thus, it will be important to continue monitoring the perched system over time and updating both the conceptual and quantitative assessment of the vadose zone flux conditions. Coupled monitoring of the groundwater plumes will also help improve understanding of the system over time. In spite of these limitations, the quantitative analyses presented herein provide a suitable initial technical basis to support current remedy decisions.

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