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1. Purpose

The purpose of the fate and transport modeling is to evaluate the impacts to groundwater associated with the contamination in the vadose zone at the 216-A-4 and 216-A-5 Cribs in the 200-MW-1 Operable Unit. The estimates of the groundwater concentrations and contaminant arrival times during the 1,000 year evaluation period calculated using the model are compared to the MCLs for the specific contaminants. The results of site screening and simple screening models indicated that uranium at the 216-A-4 Crib and carbon-14 at the 216-A-5 could not be screened out as contaminants of concern with respect to the protection of groundwater pathway. As indicated in DOE/RL-2007-34, Rev. 0, RESRAD 1-D model results would be expected to yield vadose zone leachate and groundwater concentrations as much as an order of magnitude larger than 2-D model results for comparable run conditions and input parameters. Thus, the corresponding soil contamination levels that are protective of groundwater predicted from RESRAD results may be as much as 10 to 15 times lower (more conservative) than those determined using more robust and applicable 2-D model results. Based on the federal guidelines for the selection and use of model types and codes specifically for risk characterization purposes, it is indicated that 2-D fate and transport modeling is an appropriate model type for the central plateau of the Hanford Site as a subsequent screening and/or risk characterization method for evaluation groundwater protection (DOE/RL-2007-34, Rev. 0).

2. Methodology

The modeling to evaluate the possible impacts to groundwater caused by the vadose zone contamination at the 216-A-4 and 216-A-5 Cribs included the use of numerical two-dimensional flow, fate, and transport models. Portrayal of the two-dimensional model domains in cross-section view is illustrated in Figures 1 and 2. The basis and rationale for using this type of model for this type of evaluation, and the overall vadose zone model and code selection process, is described in DOE/RL-2007-34, Rev. 0. The STOMP (Subsurface Transport Over Multiple Phases) code was used to perform the calculations on the basis of its ability to incorporate adequately the Hanford vadose zone features, events, and processes (FEPs) and satisfy the other necessary code criteria and attributes identified in DOE/RL-2007-34, Rev. 0.

The 216-A-4 and 216-A-5 Crib modeling consisted of three stages. The first stage established steady state conditions within the model domain, with boundary conditions consistent with conditions assumed to exist prior to the construction of the Hanford site. The second stage represented the period 1944-2010, the beginning time of Hanford operations to the present. During this stage, the recharge boundary condition applied to the crib dimensions was increased to reflect the changed surface conditions associated with the construction of the cribs, and water source terms were included to simulate the discharge histories of the cribs. The third stage started in 2010 and represented future times. During this stage, the estimated vadose zone contaminant profile was input to the model, and the contaminant transport and groundwater impacts occurred and were calculated.

The only COPCs assessed in this evaluation are uranium for the 216-A-4 Crib and carbon-14 for the 216-A-5 Crib. The soil concentration data used to develop the contaminant

Figure 1. Two-dimensional cross-section view of the 216-A-4 Crib model.

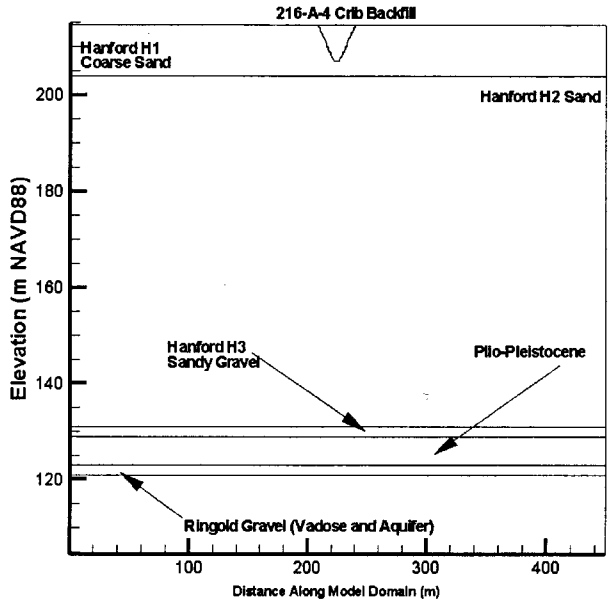
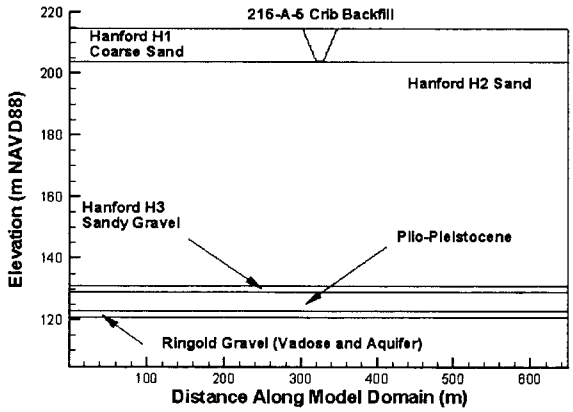


Figure 2. Two-dimensional cross-section view of the 216-A-5 Crib model.



profiles used in the models are documented in the Remedial Investigation Report (DOE/RL-2008-37, Remedial Investigation Report for the 200-MW -1 Miscellaneous Waste Group Operable Unit Supplemental Investigations). The point measurements of concentration were extrapolated into plumes vertically by means of interpolation of the measurement values between the points, and horizontally on the basis of the estimated areal extent of contamination. The recharge boundary condition applied to the crib dimensions was changed to reflect the changed surface conditions associated with the evaluated remedy of the cribs. The point of calculation of the groundwater concentration coincided with the location in the model of the highest modeled groundwater concentrations.

Groundwater MCLs for uranium (30 µg/L) and carbon-14 (2,000 pCi/L) were used as the protectiveness metric for defining unacceptable impacts to groundwater. Section 3 (Assumptions and Inputs) contains the description and basis for the other model input (parameter) values, which represent best estimates from within ranges of values applicable to the Hanford site vadose zone and the 216-A-4 and 216-A-5 Cribs evaluation. These values may differ from parameter estimates for other Hanford modeling performed for different purposes or areas of the Hanford Site, or at different scales.

Sensitivity analysis was performed in which certain model parameters were varied in order to determine model results as a function of changes in parameter values. The key input parameters varied in the sensitivity analysis include the post-remediation recharge rate, the initial contaminant distribution in the vadose zone, and the contaminant release mechanism (uranium only). For the purpose of this evaluation, maximum estimates of contaminant inventory developed on the basis of the sampling data were used for the inventory approximation. The reference case evaluation was based on the long term recharge rates representing the most probable surface end state after the minimum remediation has occurred: reclamation of the shrub-steppe surface and vegetation.

3. Assumptions and Inputs

DOE/RL-2007-34, Rev. 0 contains the description of the generalized models, conditions, and parameters applicable to the Hanford site vadose zone, which were refined and augmented for the 216-A-4 and 216-A-5 Cribs evaluation. The site-specific conceptual model components for the216-A-4 and 216-A-5 Cribs evaluation are listed below. Although the model domain and boundary conditions are not generally regarded as conceptual model elements, they are included in the list to emphasize the fundamental nature of boundary conditions in the modeling:

- Model domain and boundary conditions
- Geologic setting
- Source term
- Groundwater domain and characteristics
- Vadose zone hydrogeology and fluid transport
- Recharge
- Geochemistry

Pursuant to CERCLA and pertinent ARAR driven Washington State requirements for the purpose of determining soil cleanup levels for the uppermost part of the vadose zone soils, the evaluation used modeling assumptions and parameter estimates appropriate for the 216-A-4 and 216-A-5 Cribs site-specific conditions. Table 1 provides a summary of key

Table 1. Summary of Key Elements and Parameters Associated with Site-Specific Model Components for the 216-A-4 and 216-A-5 Cribs

Model Domain and Boundary Conditions	216-A-4 Crib, 450 m (1476 ft) x 1 m x 111 m (364 ft) 216-A-5 Crib, 650 m (2133 ft) x 1 m x 111 m (364 ft) Prescribed flux across the top (Recharge); no-flow along vertical side boundaries in the vadose zone; prescribed head at the along vertical side boundaries in the aquifer, including the capillary fringe; no-flow along the bottom of the model (aquifer)
Geologic Setting	Seven stratigraphic units from surface to groundwater consisting of the following: Crib Backfill Hanford H1 Coarse Sand Hanford H2 Sand Hanford H3 Sandy Gravel Plio-Pleistocene Ringold Gravel - Vadose Ringold Gravel – Aquifer (DOE/RL-2008-38, Decisional Draft)
Source Term	Specified contaminant source term dimensions (base cases): Length Parallel to Groundwater Flow: 216-A-4 Crib, 26.6 m (87 ft) rounded to 27 m (89 ft) (DOE/RL-2008-38, Decisional Draft) 216-A-5 Crib, 123.3 m (405 ft) rounded to nearest even number: 124 m (407 ft) (DOE/RL-2008-38, Decisional Draft) Source-term depths (m or ft-bgs, inclusive): 216-A-4 Crib, **5-19 m (16-62 ft)** 216-A-5 Crib, **10-24 m (33-79 ft)** Two Release Models Evaluated: Unlimited advective release, K_d control only (Uranium and Carbon-14) Solubility limited release in source area (Uranium only)

Table 1. Summary of Key Elements and Parameters Associated with Site-Specific Model Components for the 216-A-4 and 216-A-5 Cribs

Groundwater Domain and Characteristics	Long-term average water table elevation **approximately 119 m NAVD88** Groundwater thickness limited to **approximately 15 m;** Groundwater concentrations evaluated for upper **5 m** of aquifer Hydraulic gradient **approximately 0.00001 m/m** Average hydraulic conductivity **1,000 m/day**
Vadose Zone Hydrogeology and Fluid Transport	K_d-control for contaminant transport Hydrogeologic properties from *Vadose Zone Hydrogeology Data Package for Hanford Assessments* (PNNL-14702, Rev. 1) Hydraulic Conductivity and Dispersion Horizontal to Vertical Anisotropy **(10:1)**
Recharge	Recharge (Pre-Operational; undisturbed ground) **(4 mm/yr)** Recharge (Operational through Pre-Remediation) **(63 mm/yr [12/1955 through 2010])** Recharge (Post-Remediation; vegetated disturbed soil) **(8 mm/yr for 30 years, 4mm/yr long-term)**
Geochemistry	Uranium $\mathbf{K_d = 0.6}$ in all stratigraphic units Carbon-14 $\mathbf{K_d = 0}$ in all stratigraphic units

NAVD88 is the North American Vertical Datum of 1988, National Geodetic Survey, U.S. Department of Commerce.

bgs = below ground surface

elements and parameters for the conceptual model components. The following subsections for the individual conceptual model components provide the basis, rationale, and references for the values. These parameters represent the values selected for use in the model from the ranges of plausible parameter values. These values may differ from parameter estimates for other Hanford Site modeling performed for different purposes or areas of the Hanford Site, or at different scales.

Model Domain and Boundary Conditions

The model domain and boundary conditions establish both a framework and limiting conditions for the numerical model. The model domain for flow and transport in the vadose zone is represented numerically as a two-dimensional, vertical cross-section aligned in the general direction of groundwater flow. Aligning the vertical cross-sections with the general direction of groundwater flow allows concentrations to be calculated downgradient of the waste sites. The numerical model adapts the physical elements of the conceptual model to a Cartesian grid and also assigns numerical values to the parameters used in algorithms to represent the physical and geochemical systems and processes. The 216-A-4 and 216-A-5 Cribs modeling involved model domains of 450 m (1,476 ft) and 650 m (2,133) horizontally, respectively, by approximately 96 m (315 ft), by 1 m (3.3 ft) vertically, extending about 15 m (49 ft) below the water table. The grid for the 216-A-5 Crib required a larger domain to minimize boundary effects during the high volume discharge period 1955-1960. A horizontal-to-vertical node spacing of 1 m:1 m was used across 50 m (164 ft) in the center of the grid in the vicinity of the cribs, and a spacing of 2 m:1 m was used outside the center to the boundaries. The total number of nodes equaled 27,750 and 38,850, respectively. Two-dimensionally, the 216-A-4 Crib extended 32 m (105 ft) at the surface, tapering to 6 m (20 ft) at the base at a depth of 8 m (26 ft) (Figure 4-13 of DOE/RL-2008-38). The 216-A-5 Crib extended 45 m (148 ft) at the surface, tapering to 11 m (36 ft) at the base at a depth of 11 m (36 ft) (Drawing H-2-56050).

A specified-flux boundary condition was applied at the surface to simulate recharge. Recharge rates varied spatially and temporally along the upper boundary depending on site conditions, the location and physical dimensions of the waste site, and the time of waste site operations and surface conditions simulated. Boundary conditions at the sides of the model domain were assumed to be no flow in the vadose zone and prescribed head in the aquifer, including the capillary fringe. The bottom boundary of the unsaturated (vadose) zone is the water table and the bottom of the model (aquifer) was defined as a vertical no flow boundary condition.

Geologic Setting

The stratigraphy shown in Figure C3-1 of DOE/RL-2008-38 was adapted for use in the two-dimensional analysis of the waste sites. The stratigraphy was divided into the following hydrostratigraphic units with approximate unit thicknesses:

Stratigraphic Unit	Approximate Thicknesses Used for RTD Sites Model
Crib Backfill:	
216-A-4 Crib	8 m (representing 7.9 m or 26 ft)
216-A-5 Crib	11 m (representing 10.7 m or 35 ft)
Hanford H1 Coarse Sand	11 m (representing 11.28 m or 37 ft)
Hanford H2 Sand	73 m (representing 72.54 m or 238 ft)
Hanford H3 Sandy Gravel	2 m (representing 2.44 m or 8 ft)

Plio-Pleistocene	6 m (representing 5.79 m or 19 ft)
Ringold Gravel – Vadose	4 m (representing 3.96 m or 13 ft)
Ringold Gravel – Aquifer	15 m (representing 5 m or 15 ft)

The total thickness of the vadose zone is 96 meters (315 ft); where crib backfill exists it is contained within the depth of the Hanford H1 coarse sand. The two-dimensional model included one change from the stratigraphy shown in Figure C3-1 of DOE/RL-2008-38. The stratigraphy shown in that figure indicates that the Hanford H1 coarse sand extends in depth to approximately 19.5 m bgs (64 ft bgs). However, that depth is greater than the depth indicated for this unit in Section 3.1.1 and Appendix A of SGW-33959 (approximately 5.8 m [19 ft]), the depth indicated in Figure C5-1 (the stratigraphy of the 216-A-5 Crib) of DOE/RL-2008-38, and other generalized depictions of the geology in the PUREX area (e.g. approximately 9.1 m [30 ft] in PNNL-14702). For the two-dimensional model evaluation, which included both the 216-A-4 and 216-A-5 Cribs, the Hanford H2 sand extended from the bottom of the deeper crib (216-A-5) through a depth of 73 meters (240 ft). The Ringold Gravel aquifer unit adds approximately 2 m (6.6 ft) of capillary fringe from the Ringold Gravel vadose unit, which is directly above the water table. This model is proposed as an acceptable representation of the geologic setting for both the 216-A-4 and 216-A-5 Cribs.

Contaminant Source Term

The contaminant sources were assumed to be rectangular shaped, 27 m (89 ft) in length, 1 m (3.3 ft) wide, and 15 m (49 ft) thick at 216-A-4, and 124 m (407 ft) in length, 1 m (3.3 ft) wide, and 25 m (82 ft) thick at 216-A-5. The length of contamination at the 216-A-4 Crib was estimated on the basis of the distance between wells 299-E24-54 and 299-E24-23, where uranium was not measured above background quantities. The length of contamination at the 216-A-5 Crib was estimated by calculating the square root (123 m [404 ft]) of the contaminated zone area (15,194 m^2 [163,547 ft^2]) determined in Section C5.3.1.1 of DOE/RL-2008-38. Because of the 216-A-5 model grid spacing, the contaminated length had to be rounded up to 124 m (407 ft). The depths represent the maximum depth of the uranium and carbon-14 contamination believed to exist at the cribs according to the uranium contamination distribution conceptual model described in Section 4.2.2 and Appendix B of DOE/RL-2008-38, and the carbon-14 sampling data presented in DOE/RL-2008-38, respectively. The uranium and carbon-14 concentrations in the contaminant profile were assumed to be constant within the 1 m (3.3 ft) thick model row layers at the source depths identified in Tables 2 and 3.

There are two contaminant release conceptual models considered for the 216-A-4 Crib. For the purpose of this evaluation, transport and retardation of uranium through the vadose zone is considered separately from the release of uranium from the source area. The first conceptual model considers only advective release of uranium from the sediments. The release of uranium is unlimited by any mechanisms that would restrain the release, such as solubility limits, metal precipitation, or contaminant sequestration from the advective flow path. All of the uranium in the source area is available for advective transport, and the release occurs according to the equilibrium K_d, which is equal to 0.6 ml/g. The second

Table 2. Uranium and Carbon-14 vertical distributions on the basis of the sampling data at the 216-A-4 and 216-A-5 Cribs, respectively (DOE/RL-2008-38)

Uranium Concentration (mg/kg)	Depth (ft bgs)	Depth (m bgs)
0	15	4.6
1970	18.4	5.6
1970	20.7	6.3
0	33	18.3
Carbon-14 Concentration (pCi/g)	**Depth (ft bgs)**	**Depth (m bgs)**
0	32.8	10
25.5	37.3	11.4
5.43	40	12.2
11.4	52.1	15.9
3.5	60	18.3
36.4	62	18.9
5.12	67	20.4
0	82	25

conceptual model includes an estimate for the solubility limit for uranium in the source area of approximately 100 mg/L. Only the uranium at concentrations at or below 100 mg/L in the pore water in the source area is available for advective transport. The release of the remaining mass of contaminant is controlled by solubility limits, or other kinetically controlled processes as represented by the solubility limit concentration. Kinetically controlled releases occur at a much slower rate than advection-controlled releases, and generally result in lower peak concentration values in groundwater than unlimited advection-controlled releases. Elsewhere in the model domain, the K_d is equal to 0.6 ml/g.

To incorporate the solubility limit into the contaminant release conceptual models required a change to the numerical model construction pertaining to the contaminant source term. Within the model calculations in STOMP, the solubility limit is only applied to the release

Table 3. Uranium and Carbon-14 vertical distributions input to the 216-A-4 and 216-A-5 Crib models, respectively

Depth (m bgs)	Uranium Concentration Vertical Distribution (mg/kg)
4.5	0
5.5	985
6.5	1970
7.5	1888
8.5	1724
9.5	1560
10.5	1395
11.5	1231
12.5	1067
13.5	903
14.5	739
15.5	575
16.5	410
17.5	246
18.5	82
19.5	0

Table 3. Uranium and Carbon-14 vertical distributions input to the 216-A-4 and 216-A-5 Crib models, respectively.

Bottom of Depth Interval (m bgs)	Carbon-14 Concentration (Activity) Vertical Distribution (pCi/g)
9.5	0.0
10.5	12.8
11.5	25.5
12.5	5.4
13.5	7.4
14.5	9.4
15.5	11.4
16.5	8.8
17.5	6.1
18.5	3.5
19.5	36.4
20.5	5.1
21.5	3.8
22.5	2.6
23.5	1.3
24.5	0.0

term concentration. The release calculations do not factor in the existing aqueous concentration of the water entering the source area. Thus the aqueous concentration leaving the source area could exceed the prescribed solubility limit if sources interact. To prevent this from occurring, the source term was compressed into one model row layer, at a depth of approximately 10 m.

One contaminant release conceptual models is considered for the carbon-14 at the 216-A-5 Crib. This conceptual model considers only advective release of carbon-14 from the sediments. The release of carbon-14 is unlimited by any mechanisms that would restrain the release, such as solubility limits or contaminant sequestration from the advective flow path.

All of the carbon-14 in the source area is available for advective transport, and the release occurs according to the equilibrium K_d, which is equal to 0 ml/g.

The Effluent Volume to Soil Disposal Sites (EVSDS) module of the Hanford Virtual Library (http://vlprod.rl.gov/vlib/) provides estimates of the annual discharge to the waste sites. Those data are summarized in Table 4.

Table 4. Discharge volumes to the 216-A-4 and 216-A-5 Cribs

216-A-4 Crib			216-A-5 Crib		
Year	**Volume (L)**	**Cumulative**	**Year**	**Volume (L)**	**Cumulative**
1955	4.05E+05	4.05E+05	1955	1.50E+07	1.50E+07
1956	1.66E+06	2.07E+06	1956	2.46E+08	2.61E+08
1957	1.33E+06	3.40E+06	1957	1.28E+08	3.89E+08
1958	2.81E+06	6.21E+06	1958	2.61E+08	6.50E+08
			1959	3.33E+08	9.83E+08
			1960	4.07E+08	1.39E+09
			1961	2.39E+08	1.63E+09
			1966	3.86E+06	1.63E+09

Groundwater Domain and Characteristics

The direction of groundwater flow is generally northwest to southeast in the area around the 216-A-4 and 216-A-5 Cribs. The groundwater table is expected to drop over the next 300 years due to the cessation of large operational liquid discharges to the ground. It is estimated that in the eastern boundary of 200 East Area the water table will drop in elevation to about 119 m (390 ft) NAVD88 over the next 100 years, based on Appendix E of the *Composite Analysis for Low-Level Waste Disposal in the 200 Area Plateau of the Hanford Site* (PNNL-11800). Steady-state conditions are expected to occur by the year 2350. For this modeling activity, a long-term average groundwater hydraulic gradient of 0.00001 (estimated from Figure 2-8 in *Performance Assessment for the Disposal of Low-Level Waste in the 200 West Area Burial Grounds* [WHC-EP-0645]) is assumed, with a groundwater table elevation of 119 m (390 ft) NAVD88.

The aquifer, identified as Ringold Gravel - Aquifer, is separated from that portion of the Hanford H3 Sandy Gravel above the water table (Ringold Gravel – vadose), reflecting the distinctly different saturation conditions. Within the model domain, the aquifer extends to a depth of approximately 15 m (49 ft). The horizontal saturated hydraulic conductivity for the aquifer is estimated to be 1,000 m/day (3280 ft/day) on the basis of the *Groundwater Data Package for Hanford Assessments* (PNNL-14753). Table 5 presents a summary of the aquifer hydraulic parameters.

Vadose Zone Hydrogeology and Transport

The flow and transport pathway process used for 216-A-4 and 216-A-5 Cribs vadose zone modeling is porous media continuum flow. The vadose zone sediments at the Hanford Site

are composed of sediments ranging in particle size associated with gravels to silts or clays. Porous media continuum transport in unsaturated media of this type is regarded as the fundamental process and feature for modeling contaminant fate and transport behavior in the vadose zone at the Hanford Site (DOE/RL-2007-34, Rev. 0).

The hydraulic properties describing the water flow and retention characteristics associated with each of the 216-A-4 and 216-A-5 Cribs area geologic layers are approximated by average values, with each unit having different flow and transport parameter values (Table 6). PNNL-14702 includes statistical summaries of measurements of the hydraulic properties for Hanford Site vadose zone sediments. The summary statistics include minimum, maximum, mean, standard deviation, and for hydraulic conductivity, mean and standard deviation of the natural log transforms of the data.

Estimates of longitudinal dispersivity for each of the hydrostratigraphic units were estimated using the Gelhar and Axness (1983) "Three Dimensional Analysis of Macrodispersion in a Stratified Aquifer" stochastic solution (Table 7):

$$A_L = \sigma^2_{\ln(Ks)}\lambda$$

where:

A_L = longitudinal dispersivity (m or cm);

$\sigma^2_{\ln(Ks)}$ = the variance of the natural log of the saturated hydraulic conductivity measurements (dimensionless);

λ = vertical correlation scale (i.e., average distance over which conductivities are correlated) for log of the saturated hydraulic conductivity measurements (m or cm).

This stochastic model relates macrodispersive spreading to the spatial variability of saturated hydraulic conductivity in saturated porous media. The estimate of the correlation

Table 5. Soil Hydraulic Properties for Aquifer Soil Type at 216-A-4 Crib and 216-A-5 Cribs

Aquifer Soil Type	Bulk Density (g/cm^c)	Total Porosity	Saturated Moisture Content	Horizontal Saturated Hydraulic Conductivity[a,b] (m/day)	Longitudinal Dispersivity[c] (m)	Aquifer Hydraulic Gradient[a] (m/m)
Ringold Gravel (aquifer)	1.93	0.280	0.167	1000	1.9	1.0E-05

Aquifer soil hydraulic properties adopted from PNNL-14702, with the following exceptions:

a. Horizontal Saturated Hydraulic Conductivity and Aquifer Hydraulic Gradient estimated from PNNL-14753, Rev. 1 and 1944 hindcast water table map, respectively.

b. Vertical Saturated Hydraulic Conductivity equal to 1/10 of the Horizontal Saturated Hydraulic Conductivity (i.e., 100 m/day, assuming an anisotropy ratio of 10:1).

c. Longitudinal Dispersivity calculated using Gelhar and Axness (1983) equation; Transverse dispersivity assumed to be equal to 1/10 of the longitudinal dispersivity.

Table 6. Soil Hydraulic Properties for Vadose Zone Soil Types at 216-A-4 Crib and 216-A-5 Cribs

Soil Type	Bulk Density (g/cm[c])	Total Porosity[a]	Saturated Moisture Content	van Genuchten α (1/cm)	van Genuchten n	Residual Saturation	Residual Moisture Content[b]	Vertical Saturated Hydraulic Conductivity[c] (cm/s)	Longitudinal Dispersivity (m)[d]
Backfill (B)	1.94	0.276	0.262	0.019	1.4	0.162	0.042	5.98E-04 cm/s	0.8
Hanford H1 Coarse Sand (Hcs)	1.93	0.377	0.349	0.061	2.031	0.134	0.047	2.27E-03 cm/s	1.0
Hanford H2 Sand (Hfs)	1.49	0.403	0.379	0.027	2.168	0.162	0.061	3.74E-04 cm/s	0.2
Hanford H3 Sandy Gravel (Hg)	1.93	0.280	0.167	0.017	1.725	0.134	0.022	3.30E-04 cm/s	0.6
Plio-Pleistocence (PPlz)	1.60	0.419	0.419	0.005	2.249	0.086	0.036	5.57E-05 cm/s	1.9
Ringold Gravel - (vadose) (Hg)	1.93	0.280	0.167	0.017	1.725	0.134	0.022	3.30E-04 cm/s	1.9

Vadose zone soil hydraulic properties adopted from PNNL-14702, with the following exceptions:

a. Total porosity calculated from 1 – (bulk density/2.68 cm/g^3)

b. Residual Moisture Content calculated from Saturated Moisture Content * Residual Saturation

c. Horizontal Saturated Hydraulic Conductivity is equal to 10 times the vertical saturated hydraulic conductivity (assuming an anisotropy ratio of 10:1), except for backfill soil types, for which the vertical and horizontal saturated hydraulic conductivities are equal.

d. Longitudinal Dispersivity calculated using Gelhar and Axness (1983) equation; transverse dispersivity equal to 1/10 of the longitudinal dispersivity.

Table 7. Dispersivity Values for Vadose Zone Soil Types at 216-A-4 and 216-A-5 Cribs

216-A-4	Standard Deviation	Variance	Vertical Correlation Scale (cm)	Variance * Vertical Correlation Scale (cm)[a]	Layer Thickness Check (10%, m)	Longitudinal Dispersivity (m)	Transverse Dispersivity (m)
Backfill	3.359	11.28	30	350	0.8	0.8	0.08
Hanford H1 Coarse Sand	1.721	2.962	30	100	1.1	1	0.1
Hanford H2 Sand	2.657	7.060	30	200	7.3	2	0.2
Hanford H3 Sandy Gravel	3.265	10.66	30	300	0.2	0.2	0.02
Plio-Pleistocence	3.805	14.48	30	450	0.6	0.6	0.06
Ringold Gravel	3.265	10.66	30	300	1.9	1.9	0.19
216-A-5							
Backfill	3.359	11.28	30	350	1.1	1.1	0.11

[a]Rounded to nearest 50 cm increment.

length, λ, is based on saturated hydraulic conductivity estimates collected at approximate 30-cm intervals for a depth of 18 m within the Hanford formation (RPP-17209). The fitted spherical variogram of the data suggests a correlation length of about 50 cm (see Figure D-1 in RPP-17209). However, as indicated by Russo (1993), the correlation scale is expected to decrease as the moisture content decreases, hence a smaller value (30 cm) is used to determine the dispersivities.

Longitudinal dispersivity also appears to be correlated with the model domain scale. The correlation between the dispersivity and the model domain scale appears to be approximately 1:10. Therefore, the dispersivity of any single unit was not allowed to exceed $1/10^{th}$ of the sediment type's total thickness in the model. For the purpose of this calculation, the artificial division of Ringold Gravel – Vadose and – Aquifer was ignored. Longitudinal dispersivity (i.e., in the direction of flow) is assumed to be 10 times larger than dispersivity in the transverse direction, which is consistent with the 10:1 anisotropy ratio of the hydraulic conductivity. A molecular diffusion coefficient of 2.50×10^{-9} m^2/s is used, consistent with *Performance Assessment of Ground Double-Shell Tank Waste Disposal at Hanford* (WHC-SD-WM-EE-004).

Recharge

The magnitude of recharge for soils at the Hanford Site varies as a function of the soil type, condition of the vegetation cover, and soil integrity (e.g., disturbed versus undisturbed) (PNNL-13033, *Recharge Data Package for the Immobilized Low-Activity Waste 2001 Performance Assessment*; PNNL-14744, *Recharge Data Package for the 2005 Integrated Disposal Facility Performance Assessment*; PNNL 14702; and PNNL-14725, *Geographic and Operational Site Parameters List (GOSPL) for Hanford Assessments*). The range of recharge values reported in these documents represents distinct populations of data based on lysimetry and isotopic measurements, and interpretation, and in some instances extrapolation, by Hanford site subject matter experts. The natural background recharge rates represent a population for natural vegetated conditions. The range of values for operational, pre-remediation conditions represents a population of recharge rates for vegetation-free disturbed soil (sand).

The most appropriate soil type for estimates of recharge rates in the 200 East Area of the Hanford Central Plateau is the variety of Rupert sand appropriate for that area (PNNL-14702; PNNL-14725). The recharge rates representing the pre-operational natural soil conditions and the 55-year operational period prior to remedy implementation (1955 though 2010) were 4 mm/yr and 63 mm/yr, respectively. The most appropriate surface condition for waste sites that undergo backfilling and post-remediation re-vegetation is young shrub-steppe plant community that develops and matures (PNNL 14725; DOE/RL-2007-34, Rev. 0). The recharge rates were selected from the range of values reported as appropriate for the various soil types and conditions at the Hanford Site (e.g., PNNL-14702; PNNL-14725).

The long term post-remediation recharge rate estimate of 4 mm/yr is based on estimated values of long term recharge rates (LTRRs) for all Hanford soil types (PNNL-14702, PNNL-16688, *Recharge Data Package for Hanford Single-Shell Tanks Waste Management Areas*). These estimates indicate that for post-remedy LTRR, a post-remediation value of 8 mm/yr should be used for the first 30-years after site closure, followed by the value of 4 mm/yr thereafter. The applicability of these recharge rates include the inherent assumption that the natural shrub-steppe vegetation cover reclaims the ground surface. LTRRs for each of the

pre-operational, operational, post-operational, and classes for the Rupert sand soil type used in the modeling and evaluation are presented in Table 8.

The modeling assumptions and parameter estimates used here are based on the 216-A-4 and 216-A-5 Cribs site-specific conditions, which may differ from those used for other Hanford Site modeling performed for different purposes, areas, or scales. The recharge rate estimates selected for the 216-A-4 and 216-A-5 Cribs site-specific conditions and therefore will differ from those used for modeling at other scales because the most representative values appropriate for these modeling efforts involve different population(s) of recharge rate.

Table 8. Summary and Comparison of Recharge Rate Values for Rupert Sand and Disturbed Soil in the Modeling Evaluation of the 216-A-4 and 216-A-5 Cribs

	Pre-Operational Period	**Operational period (1955 through 2010)**	**Post-Remediation Period**	**Long-Term Post-Remediation Period**
Waste Site Condition	Undisturbed Rupert sand with shrub-steppe plant community (natural condition)	Rupert sand-disturbed, with no vegetation	ET Barrier (500 years) or Rupert sand-with young shrub-steppe plant community (30 years)	ET Barrier or Rupert sand-with mature shrub-steppe plant community
RTD Revegetation-Best Estimate	4 mm/yr	63 mm/yr	8 mm/yr	4 mm/yr

Geochemistry

The geochemistry conceptual model component for the modeling involves the technical basis and rationale for the specific contaminant partitioning behavior regarding release, retardation, and attenuation mechanisms, and any simplifying assumptions. The key aspects of this geochemistry conceptual model include the following, which are discussed in detail in DOE/RL-2007-34, Rev. 0:

- The rationale for the simplifying assumption that the use of a linear K_d isotherm is a reasonable conservative description for the release and attenuation of contaminants in the context of providing an upper-bounding condition
- The rationale and source(s) of the data used in the selection of contaminant Kd values
- The rationale for the use of a single K_d for all vadose zone units

The geochemistry conceptual models for the Hanford Site are based on extensive laboratory studies, testing, and measurements involving Hanford Site-specific sediments, contaminants, and conditions performed using batch and column tests in measurements of

adsorption and desorption coefficients under saturated and unsaturated conditions (e.g., PNNL-13895, *Hanford Contaminant Distribution Coefficient Database and Users Guide*; PNNL-11966, *Radionuclide Distribution Coefficients for Sediments Collected from Borehole 299-E17-21*; PNNL 13037, *Geochemical Data Package for the 2005 Hanford Integrated Disposal Facility Performance Assessment*; PNNL-15502, *Characterization of UP-1 Aquifer Sediments and Results of Sorption-Desorption Tests Using Spike Uncontaminated Groundwater*; PNNL-15121, *Uranium Geochemistry in Vadose Zone and Aquifer Sediments from the 300 Area Uranium Plume*).

The use of a single K_d value estimate of 0.6 ml/g for uranium was based on the fact that the best-estimate Kd values for each of the lithologic units were the same value (0.8 mL/g) in the hydrogeologic template (PNNL-14702) that describes the shallow disposal waste sites around PUREX. The uranium (VI) Kd value of 0.6 mL/g is regarded as a reasonable, conservatively representative estimate of the uranium Kd values for these units for the following reasons:

- This value is 25% lower than the best-estimate values for the PUREX Cribs template derived from the Hanford Kd database (PNNL-14702).

- Over 90% of the uranium (VI) adsorption K_d values (low impact) in the Hanford Kd database are between 0.6 and 4 mL/g (PNNL-11966, PNNL-13037).

The value 0.6 mL/g (±0.1 mL/g) from batch experiments was also recommended for Hanford sediments dominated by sand-sized particles (PNNL-11800). This value was also the median value of 13 Hanford sorption values for uranium (PNL-10379, *Geochemical Factors Affecting Radionuclide Transport Through Near and Far Fields at a Low-Level Waste Disposal Site. Available Sorption Constants and Recommendations for Future Studies*). This value is significantly lower than most experimentally determined desorption values, which range to values greater than 50 mL/g. Mass transfer rates for uranium (VI) for kinetically dominated release are significantly less than those for equilibrium partitioning and have apparent K_d values that range to greater than 50 mL/g.

The K_d value for carbon-14 is estimated to be 0 ml/g, which is a very conservative estimate according to PNNL-13037.

Point of Calculation, Protectiveness Metric, and Timeframe Considerations

In accordance with risk assessment guidelines, the determination of soil contamination impacts to groundwater also requires the definition and rationale for (1) the Point of Calculation (POCal) i.e., the place/point in the groundwater domain where modeled groundwater concentrations are to be assessed for potential impacts and protectiveness, (2) the protectiveness metric, i.e., the groundwater metric(s) to be used in the assessment of protectiveness at the POCal, and (3) the timeframe considered applicable for the calculation of impacts to groundwater.

The Point of Calculation for the protection of groundwater is related to the "Exposure Point" in the context of conventional human health risk assessments (EPA/540/1-89/002, *Risk Assessment Guidance for Superfund Volume 1, Human Health Evaluation Manual [Part A]*) and to "Point of Compliance" in federal and state regulations and guidelines (DOE/RL-2007-34, Rev. 0). The POCal is intended to effectively serve as the point where exposure point groundwater concentrations are evaluated in the model for for the purpose of evaluating protectiveness.

The POCal used for the modeling results was the location according to the model results where maximum concentrations in groundwater occurred. This aspect of the model methodology requires consideration of the model results as a function of distance downgradient in order to determine the POCal that yields the highest peak concentrations within the groundwater. As calculated in the model, lateral flow caused by the geologic stratigraphy and the contrast between the vertical and horizontal transport in the capillary fringe results in the maximum concentrations occurring downgradient from the waste site. For this evaluation, output groundwater concentrations were calculated at the edge of the waste site, 4 or 5 meters downgradient from the waste site (depending on whether the grid size resolution was 1 or 2 meters at the edge of the waste site), 10, 20, 30, 40, 60, and 100 meters downgradient from the waste site.

The aquifer mixing zone extended over the upper 5-meters of the aquifer. The 5-meter vertical interval corresponds to a conceptual groundwater monitoring well with the 15-ft well screen length (and mixing zone dimension) associated with state monitoring well descriptions (e.g., see WAC 173-340-747). To account further for the capillary fringe effects, the evaluation included two bases for calculating groundwater concentration. The first basis included only the upper 5 meters of the aquifer rows in the groundwater concentration calculations, the second included the first row of the capillary fringe with the upper 5 meters of the aquifer rows. The highest calculated concentration from either basis was used in the evaluation of impacts to groundwater.

The protectiveness metrics determined to be most appropriate for the evaluation of impacts to groundwater from vadose zone contamination at the 216-A-4 and 216-A-5 Cribs were the MCLs. Use of the MCLs as a protectiveness metric for groundwater is consistent with the intent of an effective "no growth" policy for groundwater contamination. In this context, the MCLs represent the “allowable concentrations” and/or “acceptable limits” of a contaminant for minimizing further degradation of groundwater in accordance with the conditions identified in state and federal anti-degradation goals (e.g., EPA/540/R-92/003; EPA/530-SW-87-017; DOE/RL 2002-59). Additional reasons for the selection of the MCLs included the following:

- They are metrics appropriate for a reasonable maximum exposure scenario in groundwater (i.e., potential future drinking water source).

- Their use is consistent with federal risk assessment guidance (EPA/540/R-92/003, Risk Assessment Guidance for Superfund Volume 1, Human Health Evaluation Manual [Part B, Development of Risk-Based Preliminary Remediation Goals), and federal regulatory requirements and guidelines for the establishment of media-specific cleanup levels (40 CFR 300; CERCLA; EPA/530-SW-87-017).

- Their use is consistent with the stated goals in the Hanford Site Groundwater Strategy (DOE/RL 2002-59).

- They are appropriate metrics for identifying waste-site scale impacts to groundwater.

Defining the protection of groundwater in the context of vadose zone fate and transport requires consideration of the soil and groundwater media as a hybrid or coupled pathway. This pathway involves the determination of future concentrations in the groundwater medium that result from the transport of contamination currently existing in the soil medium. The working definition of protectiveness for the protection of groundwater pathway at the 216-A-4 and 216-A-5 Cribs was, therefore, considered achieved if the contaminant levels in

the vadose zone soil do not cause groundwater concentrations to exceed MCLs at the POCal within the specified timeframe.

The timeframe for the evaluation period is limited to 1,000 years after remediation, which is assumed to begin in 2010.

Uncertainties, Assumptions, and Conservatisms

Potential sources of uncertainty in risk assessments are primarily in the categories of (1) model uncertainties, (2) scenario uncertainties, and (3) parameter uncertainties. Model uncertainty pertaining to the equations used as numerical representations of the natural processes is expected to be relatively small. DOE/RL-2007-34, Rev. 0 provides a summary evaluation of the comparisons of field data and field test results to corresponding model results obtained using the STOMP code, and the evaluation indicates that the equations used in STOMP adequately simulate the natural processes. The technical basis regarding scenario and parameter selection and the evaluation of uncertainty and variability is also documented in DOE/RL-2007-34 Rev. 0, and in the conceptual model sections discussed previously. Documentation is provided in Sections 4.0 and 5.0 of DOE/RL-2007-34 Rev. 0 on (1) dominant model factors, (2) model parameter values and plausible ranges of parameter values, (3) model assumptions and effects on model results, and (4) model limitations. The results of the sensitivity analyses are intended to address parameter uncertainty. It is notable that the main categories of factors that dominate model results are the same as those identified in the evaluation of model assumptions, sensitivity analyses, and model limitations. It is further indicated from the uncertainty analysis that the conservatism in the model assumptions, together with conservatism in parameter values, contribute to a conservative bias in the model results overall (i.e., lower maximum concentrations).

An evaluation of the primary and largely common assumptions associated with this vadose zone modeling approach at the Hanford Site is summarized in Table 5-4 in DOE/RL-2007-34, Rev. 0. The evaluation of these assumptions indicates that (1) most of the assumptions involve hydrogeologic and geochemical factors, (2) most of the assumptions are either conservative or neutral, (3) source-term uncertainty is potentially non-conservative, and (4) the majority of conservative assumptions range from moderate to high magnitudes in terms of their potential effect on risk and vadose zone model results. The evaluation of these assumptions indicates that, with the exception of the source-term uncertainty, the assumptions associated with model parameterization are largely conservative. Based on the assumptions evaluation, results of vadose zone modeling for the 216-A-4 and 216-A-5 Cribs should provide conservative estimates of risk in terms of impacts to groundwater from soil contaminants.

4. Software Applications, Descriptions, Installation & Checkout, and Statements of Validity

The vadose zone fate and transport calculations were performed using the STOMP (Subsurface Transport Over Multiple Phases) Version 3.2 code, HISI identification number 2471. STOMP was executed on the RANSAC Linux®[1] Cluster (ransac-0.pnl.gov) that is managed by Pacific Northwest National Laboratory (PNNL). The computer property tag

[1] Linux is the registered trademark of Linus Torvalds in the U.S. and other countries.

identifier for the frontend node is WD56054 (PNNL Property System). The frontend hardware (controller node) is a Dell®[2] PowerEdge® 2550 with dual 3.00-GHz (Intel®[3] Xeon®) processors and 2 GB of RAM loaded with the Red Hat® Enterprise Linux® WS[4] release 3 (Taroon Update 7) operating system.

Excel®[5] spreadsheets were used to calculate contaminant inventory values and approximate contaminant distributions, calculate crib discharge volumes, interpolate crib dimensions onto the numerical grid, calculate dispersivity values, and evaluate the results produced by STOMP. These calculations were performed on workstation WC95062. The hardware is a Dell® Optiplex® 755 with a 2.66-GHz Intel Core™ 2 Duo CPU E8200 processor and 2 GB of RAM loaded with the HLAN Windows® XP Image Version 3.0.1.0 operating system.

DOE/RL-2007-34, Rev. 0 contains a summary of the main model attributes and code selection criteria that serve as the basis for the demonstration of the adequacy of the STOMP code for use in vadose zone modeling at Hanford. The results of the evaluation in DOE/RL-2007-34, Rev. 0 show that the STOMP code is capable of meeting or exceeding the identified attributes and criteria. The comparison of the code selection criteria to the STOMP code capabilities indicates the STOMP code is capable of simulating all of the necessary FEPs, and that STOMP meets all of the other required code selection criteria. Section 6.4.1 of DOE/RL-2007-34, Rev. 0 addresses code selection criteria, including QA documentation of verification studies for specific model attributes (e.g., unsaturated flow, solute transport, infiltration, and drainage), and includes a discussion of other code related criteria (i.e., inter-code comparisons, hardware requirements, solution methodology, dimensionality, and output capability).

The results of CHPRC acceptance testing (CHPRC-00515, Rev. 0) demonstrate that the STOMP software is acceptable for its intended use by the CHPRC. Installations of the software are operating correctly, as demonstrated by the RANSAC Linux® Cluster system producing the same results as those presented for selected problems from the STOMP Application Guide (PNNL-11216).

5. Calculations

Domain Size

The side boundaries of the model domain are located far enough away to avoid interfering with the solution in the area of interest. This premise is confirmed by the results of the modeling from the period 1955 through 2010, which includes the high volume discharges at the cribs. Figures 3 and 4 present a time series plots of moisture content during the period 1944-2010 for three selected locations near the downgradient boundary of the 216-A-4 and 216-A-5 Crib models, respectively. These locations in the model coincide with stratigraphic unit changes in the model where pronounced lateral flow is most likely to occur. The results presented in the time series plots indicate that the calculations may have included some boundary effects as a consequence of with the high volume discharges to the 216-A-5 Crib

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[4] Red Hat and Enterprise Linux are registered trademarks of Red Hat, Inc.
[5] Excel and Windows are registered trademarks of Microsoft Corporation in the United States and other countries.

Figure 3. Time series plots of moisture content during the period 1944-2010 for three selected locations near the downgradient boundary of the 216-A-4 Crib model.

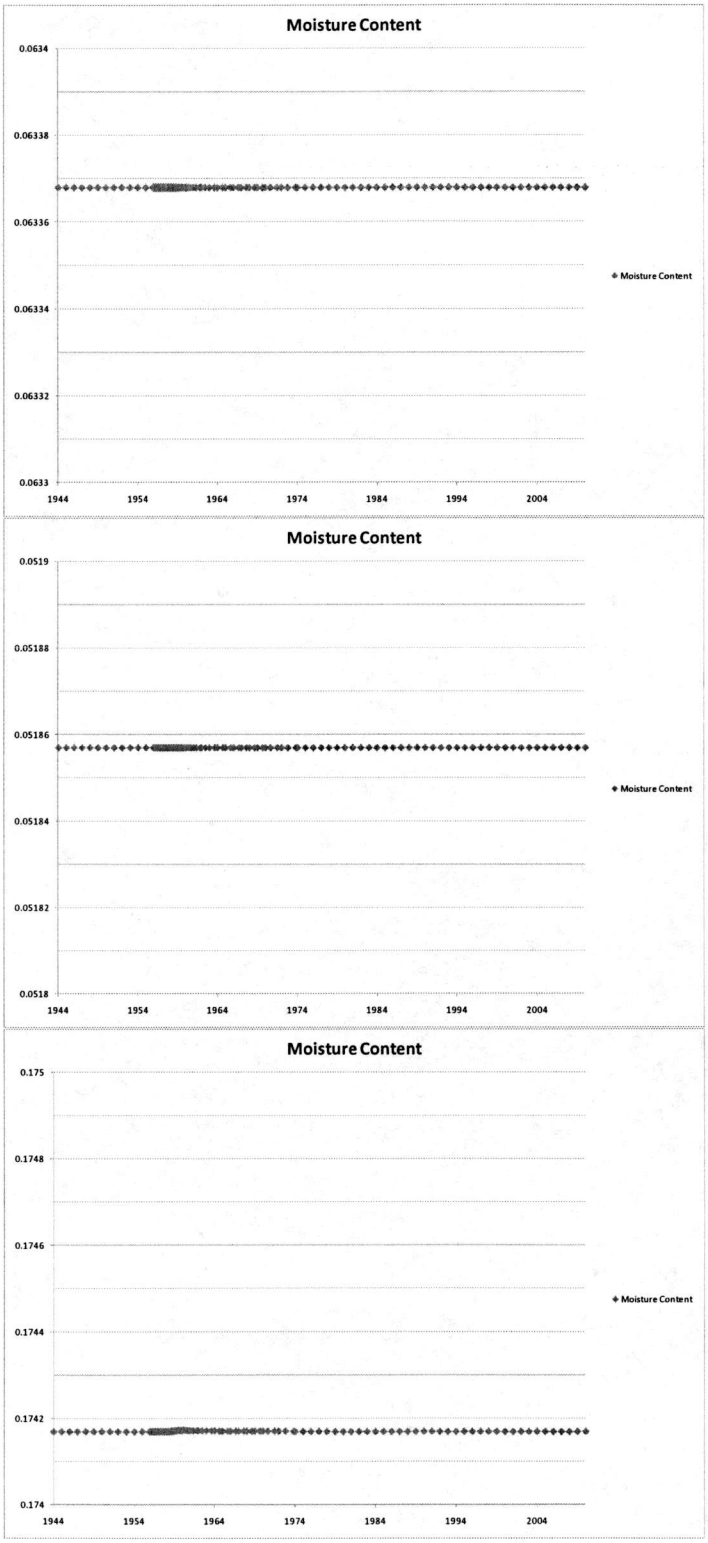


Figure 4. Time series plots of moisture content during the period 1944-2010 for three selected locations near the downgradient boundary of the 216-A-5 Crib model a) at the Plio-Pleistocence - Ringold Gravel interface, b) at the Hanford Sandy Gravel - Plio-Pleistocence interface, and c) at the Hanford Fine Sand - Hanford Sandy Gravel interface.

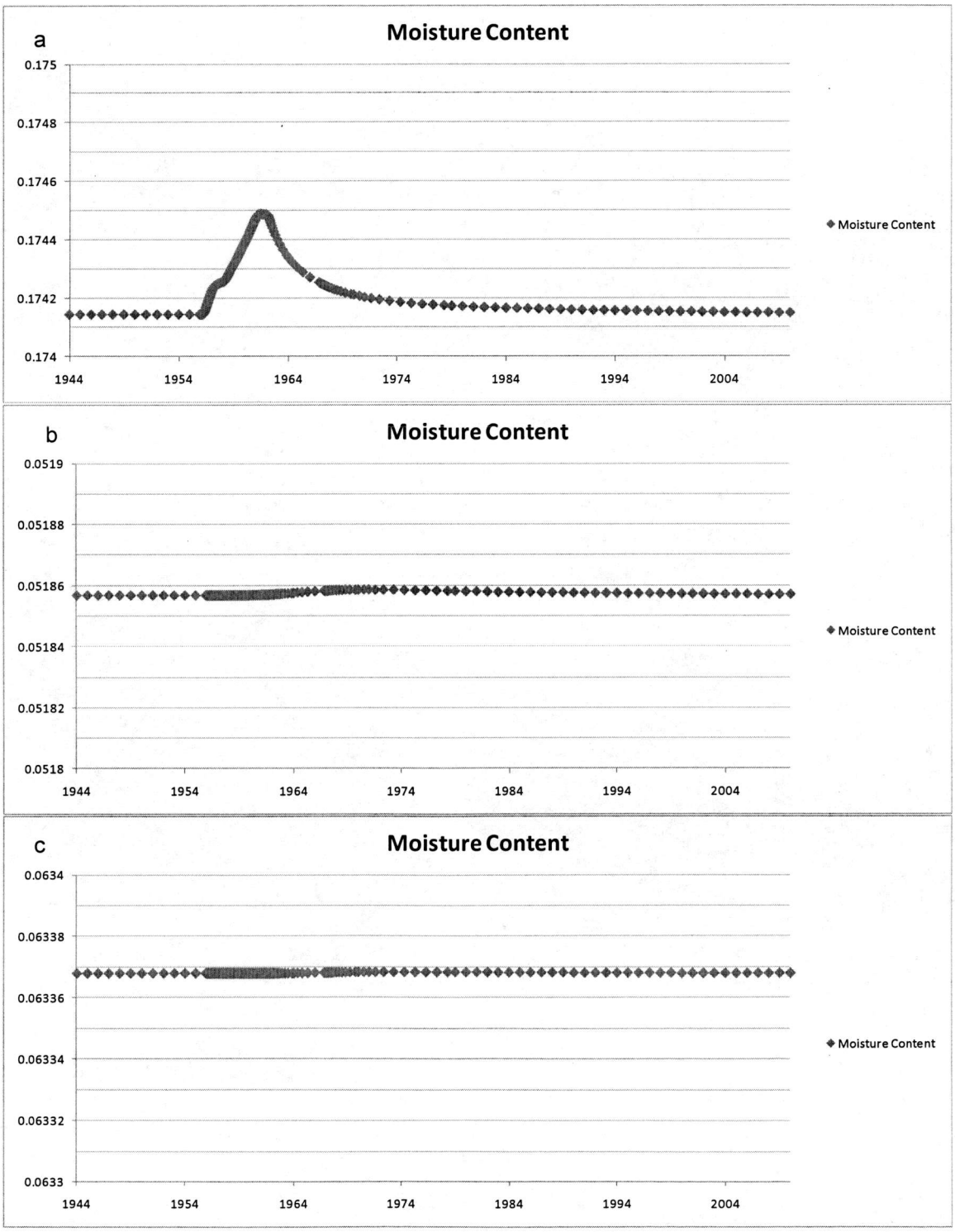
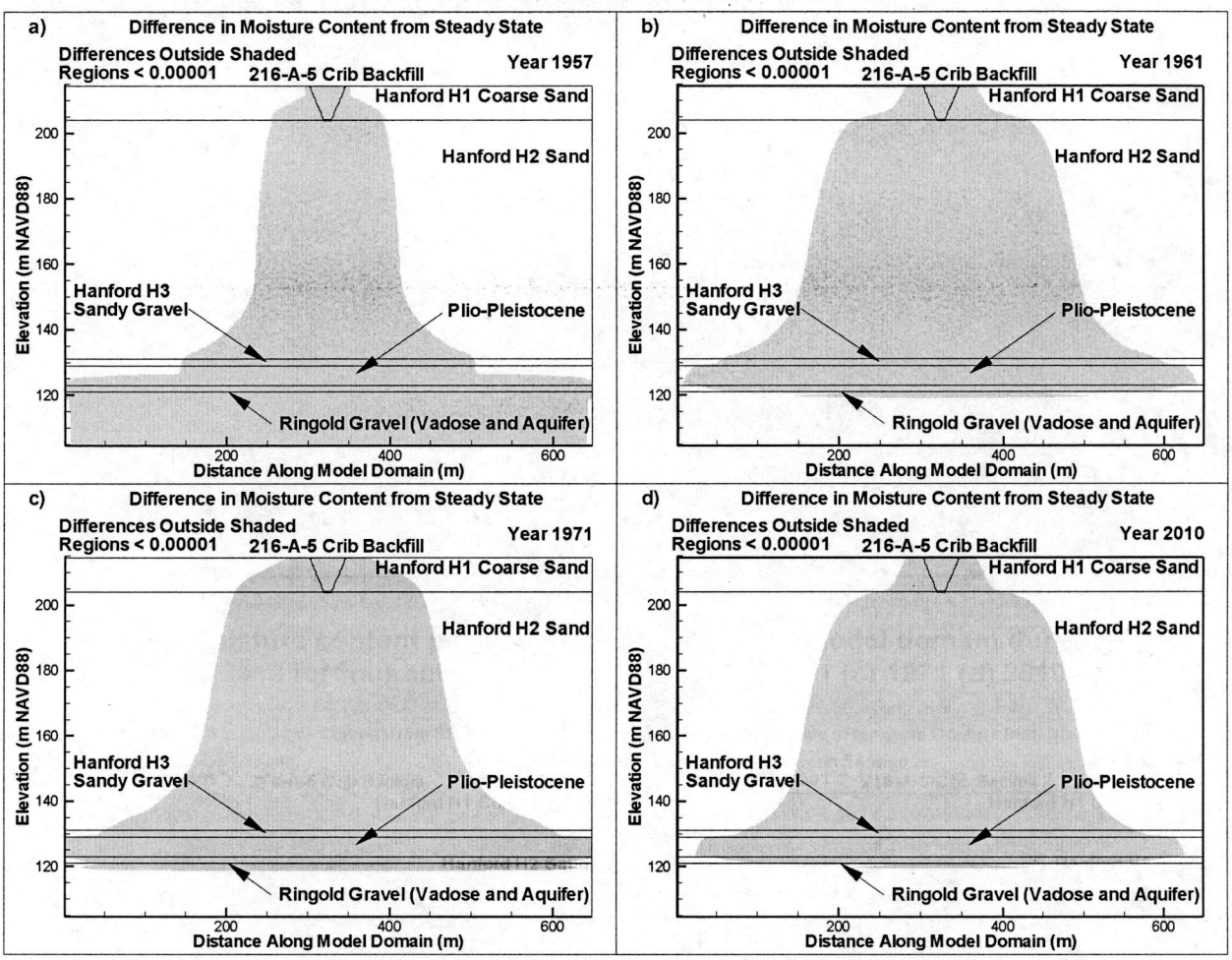


Figure 5. Moisture content profiles of the 216-A-5 Crib model domain during the period 1944-2010 for four selected times (a) 1957 (b) 1961 (c) 1971 (d) 2010.



infringing upon the boundaries of the model. No boundary effects appear to have occurred in the 216-A-4 Crib model. Figure 5 presents profiles of the moisture content changes for 4 key times during the discharge period of the 216-A-5 Crib. These profiles indicate that the changes in the moisture content at the boundary of the model are contained within a relatively small segment along the boundary near the water table and appear to be minor. These effects are considered minimal and have dissipated by the year 2010 in the model calculations. Consequently, they are not considered to effect adversely the evaluation of contaminant transport and groundwater impacts associated with contamination in the vadose zone at the 216-A-5 Crib, which begins in year 2010.

Numerical Solution Limitations

Results determined using numerical models will possibly be influenced by numerical dispersion, which is an artifact of the errors caused by the numerical discretization of the flow domain. To minimize these errors, the grid should be designed so that the Peclet Number, the ratio of the grid cell length and the dispersivity, is less than 1. However, maintaining this criterion can lead to grid spacing and an overall domain size that are not practical to implement. The grid size selected for the model appeared to provide an adequate balance between the two demands of solution integrity and practical implementation. The one-meter vertical spacing was sufficiently small to allow delineation of the major geologic units and the sloping of the contacts, and accommodate the 5 meter well screen interval used to evaluate the impacts to groundwater. The sensitivity analyses included an evaluation of the impacts of dispersion on the solution, including a simulation of the reference case using the same horizontal spacing but ¼ m spacing in the vertical dimension. The sensitivity analysis terminated after 11585 time steps (Year 15177) because of an interruption of service in the RANSAC Linux Cluster. The groundwater concentration calculated at the points of calculation at this time were the maximum values. Comparing these sensitivity values to the reference case values calculated at the same time in the model (Year 15177) showed differences ranging between 1.1 and 4.9% for the evaluation in the upper 5 meters of aquifer, and between 0.9 and 2.4% for the evaluation that included 1 meter of capillary fringe with the upper 5 meters of aquifer.

Reference Case Results

The results of modeling provide an indication to the amount of remediation necessary to achieve protection of groundwater at 216-A-4 and 216-A-5 Cribs. The results for the 216-A-4 Crib (Table 9) indicate that with natural vegetation reestablished on the surface, uranium does not reach the water table within 1,000 years. Even if no efforts to reestablish natural vegetation are made and shallow rooted invasive species such as cheatgrass were to dominate the surface, the (recharge remains 22 mm/yr indefinitely), the maximum groundwater concentration does not exceed the MCL during the first 1,000 years. The concentration at the end of the 1,000 year period is essentially zero (3.40E-11 µg/L), and the concentration does not exceed the MCL until 3,700 years into the future.

The results of the modeling indicate that carbon-14 at 216-A-5 Crib may not require any specific remedial action to achieve the protection of groundwater (Table 10). Even if no efforts to reestablish natural vegetation are made and shallow rooted invasive species such as cheatgrass were to dominate the surface (recharge remains 22 mm/yr indefinitely), the maximum groundwater concentration does not exceed the MCL. The maximum concentration during the 1,000 year evaluation period is 980 pCi/L, which is less than the MCL. With natural vegetation reestablished on the surface, the results indicate that with carbon-14 concentration remains less than the MCL.

Sensitivity Analysis

The parameter uncertainty discussion in DOE/RL-2007-34 Rev. 0 included vadose zone parameter sensitivity analyses from Hanford and non-Hanford sources. The results of the analyses indicate that vadose zone model results consistently have the greatest sensitivity to variability in infiltration/recharge rate, unsaturated zone thickness, and contaminant distribution coefficient. For this reason, the sensitivity analysis for the 216-A-4 and 216-A-5 cribs included multiple contaminant distributions and inventory masses, multiple post-

Table 9. Results of 216-A-4 Crib modeling for uranium

Kd	Post-Remediation Recharge Rate	Solubility Limit (mg/L)	Concentration at Year 3010 (mg/m^3)	Year of First Non-Zero Concentration Arrival	Year of First Arrival of MCL	Maximum Concentration (mg/m^3)	Year of Maximum Concentration
0.6	8 mm/yr and 4 mm/yr	N/A	0.00E+00	4,856	12,001	2,132	20,861
0.6	0.5 mm/yr and 1.0 mm/yr	N/A	0.00E+00	6,773	19,452	1,312	32,010
0.6	22 mm/yr	N/A	3.40E-11	2,848	4,782	5,767	7,679
0.6	63 mm/yr	N/A	2.81E+01	2,327	3,014	14,921	4,147
0.6	8 mm/yr and 4 mm/yr	100	0.00E+00	5,540	15,474	612	32,010
0.3	8 mm/yr and 4 mm/yr	N/A	0.00E+00	3,413	7,105	3,986	12,093

Table 10. Results of 216-A-5 Crib modeling for carbon-14

Post-Remediation Recharge Rate	Maximum Concentration (pCi/L)	Year of Maximum Concentration
8 mm/yr and 4 mm/yr	980	3392
0.5 mm/yr and 1.0 mm/yr	687	3735
22 mm/yr	1,224	2415
63 mm/yr	2,727	2184

remediation recharge rate scenarios, and, for uranium at the 216-A-4 crib, solubility controlled release from the source area, and two different Kd values.

At the 216-A-4 Crib, the distribution of uranium used in the reference case evaluation extends to a depth of 19 m bgs (62 ft), where the contamination terminates. According to the conceptual model described in Appendix C of DOE/RL-2008-37, this is the maximum estimated of the depth of the uranium contamination. Other discussion in the conceptual model description indicates that the contamination may be contained in shallower depths, possibly as shallow as 30 ft bgs (9 m bgs). The results of the reference case indicate that uranium does not arrive in groundwater in less than 1,000 years, and concentrations in groundwater won't exceed the MCL for approximately 10,000 years. The results of the evaluations of the alternate conceptual models of the uranium distribution, where the uranium is contained at shallower depths, 30 (9 m) and 45 ft (14 m) bgs, also necessarily indicate that the uranium is not going to arrive in groundwater in less than 1,000 years or exceed the MCL in less than 10,000 years. Thus for the purpose of this evaluation, uncertainty in the uranium inventory, within the depth range it appears to be contained, does not appear to impact the conclusion of the modeling evaluation.

At the 216-A-5 Crib, the distribution of carbon-14 used in the reference case evaluation was developed from the results of the sampling at well C6552. The contamination at the crib was assumed to extend laterally across a distance of 123 meters (37.5 m), consistent with the RESRAD analysis. There is no indication according to any analysis of the data that the contamination extends beyond this length. Thus, the reference case inventory approximation appears to encompass the maximum lateral distribution of carbon-14. Because the results of the reference case and the other recharge sensitivity analysis cases indicate that carbon-14 concentrations in groundwater won't exceed the MCL, sensitivity analysis of the alternate conceptual models of the carbon-14 distribution, where the carbon-14 is contained within a smaller lateral length, appeared unnecessary. Thus for the purpose of this evaluation, uncertainty in the carbon-14 inventory does not appear to impact the conclusion of the modeling evaluation.

Comparable post-remediation long-term recharge rate scenarios were considered at both of the cribs. The reference cases adopted the recharge rate considered to be most applicable to waste sites that undergo backfilling and post-remediation re-vegetation. The sensitivity analyses included scenarios representative of worst case no action, where only shallow rooted plant species such as cheatgrass dominate the surface vegetation, and the installation of a surface barrier that limits percolation of precipitated water by storage and evapotranspiration processes. These are considered to be the upper and lower bounding cases for post-remediation long term recharge rates. An additional sensitivity analysis, representative of the cribs being actively maintained free of vegetation indefinitely into the future, was also included solely for the purpose of comparison. The results of the no action evaluation for the 216-A-4 Crib indicate that uranium may arrive at the water table within 1,000 years post-remediation, but the maximum concentration estimated to occur during the 1,000 year post-remediation period is at a concentration level that is insignificant practically, i.e., could not be measured using any known instrumentation. The inclusion of a surface barrier, while postponing the arrival of uranium at the water table and the time when uranium may exceed the MCL, does not alter the results during the 1,000 year post-remediation

period. For the 216-A-5 Crib, neither bounding case scenario for the post-remediation long term recharge rates altered the conclusion of the modeling results that carbon-14 would not exceed the MCL.

The reference case evaluation of uranium at the 216-A-4 Crib did not include any solubility or kinetic controls on the release of uranium from the source area. Consequently in the model evaluation, pore water concentrations of uranium likely exceeded plausible solubility limits. However, imposing a solubility limit on the pore water concentration in the source area only decreases the maximum concentration at the point of calculation and postpones the arrival of uranium at the water table compared to the advection controlled release reference case. Thus for the purpose of this evaluation, the inclusion of uranium solubility limitations in the model does not appear to impact the conclusion of the modeling evaluation. The sensitivity cases also include evaluations of uranium impacts for two alternative Kd value estimates, 0.3 ml/g and 1.0 ml/g. The results of the sensitivity analysis that use an estimate of 0.3 ml/g for the uranium Kd value indicate that uranium does not arrive in groundwater in less than 1,000 years, and concentrations in groundwater do not exceed the MCL in less than 3,500 years. The results of the sensitivity analysis case that use an estimate of 1.0 ml/g for the uranium K_d value are less than the reference case results.

6. Results/Conclusions

The results of modeling provide an indication as to the amount of remediation necessary to achieve protection of groundwater at the 216-A-4 and 216-A-5 Cribs. The recharge rates shown in Table 8 represent the two probable end states after remediation, reclamation of the shrub-steppe surface and vegetation (4 mm/yr), either naturally or artificially enhanced, and a surface barrier that reduces or eliminates percolation of water through the contaminanted soil (0.5 mm/yr for 500 years and 1.0 mm/yr thereafter). The results for the 216-A-4 Crib (Table 9) indicate that with natural vegetation reestablished on the surface, uranium does not reach the water table within 1,000 years. Even if no efforts to reestablish natural vegetation are made and shallow rooted invasive species such as cheatgrass were to dominate the surface (i.e., recharge remains 22 mm/yr indefinitely), the maximum groundwater concentration does not exceed the MCL during the first 1,000 years. The concentration at the end of the 1,000 year period is essentially zero (3.40E-11 µg/L), and the concentration does not exceed the MCL until 2,700 years into the future.

The modeling results indicate that carbon-14 at the 216-A-5 Crib may not require any specific remedial action to achieve the protection of groundwater (Table 10). Even if no efforts to reestablish natural vegetation are made and shallow rooted invasive species such as cheatgrass were to dominate the surface, (i.e., recharge remains 22 mm/yr indefinitely), the maximum groundwater concentration does not exceed the MCL. The maximum concentration during the 1,000 year evaluation period is 1224 pCi/L, which is almost 1/3 of the MCL. With natural vegetation reestablished on the surface, the results indicate that with carbon-14 concentration remains less than 1,000 pCi/L, or ½ of the MCL.

Implications for Barrier Effectiveness

The main implications of these results for the 216-A-4 Crib is that recharge reduction to levels of about 4 mm/yr produce efficiencies in decreasing peak contaminant concentrations in groundwater, and reduction in peak groundwater arrival times, only slightly greater than those obtained with an ET barrier/cover. Thus, it is indicated that the primary risk mitigation

objectives of the "ET-barrier/cover" remedy may well be achieved by the restoration of the site to natural vegetation conditions, which is estimated to occur in a period of ≤ 30 years (DOE/RL-2007-34, Rev. 0). The cost benefit of an ET barrier for the mitigation of groundwater impacts of vadose zone contamination remaining at the 216-A-4 and 216-A-5 Cribs may, therefore, be minimal compared to restoration of the site(s) to natural conditions, in conjunction with an ongoing remedy such as monitored natural attenuation.

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Attachment:

Telecom approval for RF Martin and HR Palmer signatures

Mcmahon, William J

From: Robert.Martin@ch2m.com
Sent: Thursday, January 21, 2010 5:18 PM
To: Mcmahon, William J
Cc: Huckleberry.Palmer@ch2m.com
Subject: Environmental Calculation Check for 200-MW-1
Attachments: ECF-200MW1-10-0080_Senior_Review_Copy _3 _RFMandHRP_.pdf

Hi Bill,

Please see the attached sign off sheet for our review of the calculations related to ECF-200MW1-10-0080.

We reviewed the use of validated model, documented calculations, input values were correctly input, and the spreadsheet formulas used to calculate the input values, and generate the output reporting values.

Based on our review, our discussion and addressing comments, Huckleberry R Palmer and Bob F Martin Approve the calculations.

We will be submitting our summary of review procedures early next week.

Thanks
Bob

Bob Martin
Regional Project Delivery Manager
Vice President, Industrial Systems

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Environmental Calculation Cover Page

Calculation No.: ECF-200MW1-10-0080 **Revision No.:** 0

Project: 200-MW-1

Date: 18-Jan-2010

Calculation Title & Description:

200-MW-1 contaminant fate and transport model to evaluate impacts to groundwater in support of DOE/RL-2008-38 Decisional Draft.

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0	Initial Issue	21-Jan-2010	New

Document Review & Approval:

Originator: WJ McMahon / Senior Engineer
NAME/POSITION

SIGNATURE DATE

Checker: RF Martin / Senior Hydrogeologist and HR Palmer/Environmental Scientist
NAME/POSITION

Approved VIA telecom. 1/21/2010
SIGNATURE DATE

Senior Reviewer: WE Nichols / Modeling Team Leader
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SIGNATURE DATE