ECF-HANFORD-19-0121
Revision 0

Selection of Vadose Zone Flow and Transport Properties with Gravel Fraction Corrections for the Hanford Site Composite Analysis and Cumulative Impact Evaluation

Prepared for the U.S. Department of Energy
Assistant Secretary for Environmental Management

Contractor for the U.S. Department of Energy
under Contract DE-AC06-08RL14788

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Terms

CA	composite analysis
CCU2	Cold Creek unit localized sandy unit in the B Complex perched zone feature
CCU3	Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone
CCUsand	Cold Creek unit sand dominated
CCUsilt	Cold Creek unit silt dominated (note: Hanford standard nomenclature for this unit is CCUz, but this is denoted CCUsilt in this document for consistency with CA model development)
CIE	cumulative impact evaluation
CPVZ GFM	Central Plateau Vadose Zone Geoframework
DOE	U.S. Department of Energy
ECF	environmental calculation file
HSU	hydrostratigraphic unit
K_d	distribution coefficient
IDF	Integrated Disposal Facility
MCL	maximum contaminant level
OU	operable unit
PA	performance assessment
Rtf	Ringold Formation member of Taylor Flat
STOMP	Subsurface Transport Over Multiple Phases
TC & WM EIS	Tank Closure and Waste Management Environmental Impact Statement
VZ	vadose zone
WMA C	Waste Management Area C

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1 Purpose

This environmental calculation file (ECF) is a compilation of hydrologic and radiological/chemical properties to be used for the updated Hanford Site Composite Analysis (CA) and Cumulative Impact Evaluation (CIE) vadose zone (VZ) modeling. The CA will provide an all-pathways dose projection to a hypothetical future member of the public from all planned low-level radioactive waste disposal facilities and potential contributions from all other projected end-state sources of radioactive material left at the Hanford Site following site closure. Its primary purpose is to support the decision-making process of the U.S. Department of Energy (DOE) under DOE O 435.1 Chg 1, *Radioactive Waste Management*, related to managing low-level waste disposal facilities at the Hanford Site.

The CIE evaluates the effects of cleanup decisions regarding groundwater quality in the Hanford Site Central Plateau (DOE/RL-2018-69, *Cumulative Impact Evaluation Technical Approach Document*). Due to the complexity and large number of waste sites in source operable units (OUs), the computational tools used for the CIE must be capable of representing a range of site conditions and source terms in the VZ while also efficiently computing the impact that cleanup decisions have on the underlying aquifer. Waste-site proximity between and within source OUs has resulted in contaminants commingling in the vadose and saturated zones in complex ways. Plume commingling requires cleanup decisions to be evaluated considering the surrounding waste sites and existing groundwater contamination, therefore demonstrating the need to evaluate cumulative impacts from the VZ to groundwater.

2 Background

The objective of the CA and CIE VZ facets is to provide Central Plateau VZ models to evaluate fate and transport of contaminants numerically in the VZ and mass/activity fluxes into the aquifer. The development of such VZ models faces some unique challenges due to the size of the area with several hundred disposal sites, large disposal volumes and contaminant inventory, considerable thickness of the VZ, sediment heterogeneity, variable hydraulic and transport properties, and spatial and temporal variation in recharge.

Sixteen radionuclides were selected for inclusion in the CA VZ modeling (CP-62184, *Hanford Site Composite Analysis: Radionuclide Selection for Groundwater Pathway Evaluation*). These radionuclides are listed in Table 1. Four radionuclides and four chemical species were selected for the CIE VZ modeling (DOE/RL-2018-69). These constituents are listed in Table 1.

Table 1. Composite Analysis and Cumulative Impact Evaluation Vadose Zone Model Radionuclide and Chemical Constituents

Constituent	STOMP Solute Name	CA VZ Models	CIE VZ Models
Radionuclides			
Tritium	H-3	X	X
Carbon-14	C-14	X	
Chlorine-36	Cl-36	X	
Strontium-90	Sr-90	X	X
Technetium-99	Tc-99	X	X
Iodine-129	I-129	X	X
Rhenium-187	Re-187	X	

Table 1. Composite Analysis and Cumulative Impact Evaluation Vadose Zone Model Radionuclide and Chemical Constituents

Constituent	STOMP Solute Name	CA VZ Models	CIE VZ Models
Radium-226	Ra-226	X	
Thorium-230	Th-230	X	
Uranium -232	U-232	X	
Uranium-233	U-233	X	
Uranium-234	U-234	X	
Uranium-235	U-235	X	
Uranium-236	U-236	X	
Uranium-238	U-238	X	
Neptunium-237	Np-237	X	
Chemical Species			
Nitrate	NO_3		X
Chromium	Cr		X
Cyanide	Cn		X
Total uranium	U		X

CA = composite analysis
CIE = cumulative impact evaluation
STOMP = Subsurface Transport Over Multiple Phases
VZ = vadose zone

3 Methodology

Hydrologic properties of the VZ sediments and radiological and chemical properties of wastes disposed in the Central Plateau waste sites were compiled from various sources, as described in Chapter 7 below. These properties will be used as input parameters for the vadose zone models implemented in the Subsurface Transport Over Multiple Phases (STOMP) code to simulate VZ flow and contaminant transport for the CA and CIE analyses.

Because some of the sediments in the VZ contain a significant gravel fraction, the selected solid-aqueous distribution coefficient (K_d) values require a correction for the gravel content. Gravel-corrected K_d values were calculated using the method outlined in PNNL-17154, *Geochemical Characterization Data Package for the Vadose Zone in the Single-Shell Tank Waste Management Areas at the Hanford Site*, as follows:

- Calculate gravel fraction for each hydrostratigraphic unit (HSU).
- Apply gravel corrections based on the gravel fraction to K_d values for fine-grained (i.e., <2 mm) sediments.

Additional calculations include the following:

- Calculate particle density from bulk density and porosity.
- Calculate residual saturation from saturated water content and residual water content.

The Microsoft® Excel® spreadsheets for the calculations listed above are included in Appendix A.

4 Assumptions and Inputs

Except for gravel-corrected K_d values, particle density, and residual saturation, all properties discussed in this ECF were obtained from various sources as described in detail in Chapter 7.

Inputs for the gravel corrections, including gravel percent and documented K_d values, were obtained from CP-63883, *Vadose Zone Flow and Transport Parameters Data Package for the Hanford Site Composite Analysis,* and various other sources as described in detail in Chapter 7. Assumptions for the gravel corrections include the following:

1. Partitioning of solutes between the porous media and aqueous phase is assumed linear.
2. K_d measurements are generally conducted on Hanford Site sediment material that is <2 mm in size (PNNL-17154). Since sorption is directly related to surface area, K_d values based on the <2 mm sediment fraction will tend to overestimate sorption for units that contain gravel (Kaplan et al., 2000, "Gravel-Corrected Kd Values").
3. The average of sample gravel fractions for each HSU listed in Tables 1 through 9 in CP-63883 is representative of the overall gravel fraction of the unit.

5 Software Applications

Microsoft Excel was used to perform all calculations in this ECF.

6 Calculations

Gravel fractions (expressed as percentage) were calculated for each HSU listed in Tables 1 through 9 in CP-63883, as the average of the gravel percentages for individual samples.

PNNL-17154 provides two gravel correction factors for K_d values: one for high K_d contaminants (Equation 1) and one for low K_d contaminants (Equation 2). Although PNNL-17154 does not define a cutoff value for the low and high K_d contaminants, strontium is listed as a high K_d contaminant. Based on this, K_d gravel corrections for solutes with K_d values of 10 mL/g or more will be computed using Equation 1 and K_d gravel corrections for solutes with K_d values of <10 mL/g will be computed using Equation 2.

$$K_d(\text{gc}) = (1\text{-f})\ K_d(<2\text{ mm}) + (f)\ 0.23\ K_d(>2\text{ mm}) \quad \textbf{(Eq. 1)}$$

$$K_d(\text{gc}) = (1\text{-}f)\ K_d(<2\text{ mm}) \quad \textbf{(Eq. 2)}$$

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where:

K_d(gc)	=	the gravel-corrected K_d value
f	=	the weight fraction of gravel
K_d	=	(<2mm) is the K_d value determined using <2 mm material.

Particle density is calculated as:

$$\rho_p = \rho_b / (1 - \theta_s) \quad \textbf{(Eq. 3)}$$

where:

ρ_p	=	particle density
ρ_b	=	bulk density
θ_s	=	volumetric water content at full saturation (i.e., total porosity).

Residual (or minimum) saturation is calculated as:

$$S_r = \theta_r / \theta_s \quad \textbf{(Eq. 4)}$$

where:

S_r	=	residual (or minimum) saturation
θ_s	=	volumetric water content at full saturation
θ_r	=	residual volumetric water content.

7 Results and Conclusions

7.1 Hydrologic Properties of the Vadose Zone Sediments

The hydrostratigraphy of the VZ models is derived from the Central Plateau Vadose Zone Geoframework (CPVZ GFM) as described in CP-60925, *Model Package Report: Central Plateau Vadose Zone Geoframework Version 1.0*. The CPVZ GFM provides a three-dimensional representation of the VZ beneath the Central Plateau. The model is constructed based on the most up-to-date, three-dimensional interpretations of the Hanford Site's extensive geologic database. The CPVZ GFM represents the subsurface geologic structure vertically extending from the ground surface to the top of the Columbia River Basalt Group. The CPVZ GFM will be used to populate and assemble CA and CIE numerical model architectures, thus providing three-dimensional grids of the VZ geology consistent with the CPVZ GFM. Table 2 lists the HSUs for the 200 East and 200 West Areas.

Table 2. Hydrostratigraphic Units for the 200 East and 200 West Areas

HSU	Description
200 East HSUs	
Surface deposits	Backfill and/or eolian sand
Hf1	Hanford formation unit 1
Hf2	Hanford formation unit 2
Hf3	Hanford formation unit 3
CCUz	Upper Cold Creek unit silt dominated
CCUsand	Upper Cold Creek unit sand dominated
CCU2	Cold Creek unit localized sandy unit in the B Complex perched zone feature
CCU3	Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone
CCUg	Lower Cold Creek unit gravel-dominated
Rtf	Ringold Formation member of Taylor Flat
Rwie	Ringold Formation member of Wooded Island – unit E
Rlm	Ringold Formation member of Wooded Island – lower mud unit
Rwia	Ringold Formation member of Wooded Island – unit A
Basalt	Columbia River Basalt
200 West HSUs	
Surface deposits	Backfill
Hf1	Hanford formation unit 1
Hf2	Hanford formation unit 2
Hf3	Hanford formation unit 3
CCUsilt	Upper Cold Creek unit silt dominated
CCUc	Lower Cold Creek unit carbonate cemented paleosol unit
Rtf	Ringold Formation member of Taylor Flat
Rwie	Ringold Formation member of Wooded Island – unit E
Rlm	Ringold Formation member of Wooded Island – lower mud unit
Rwia	Ringold Formation member of Wooded Island – unit A
Basalt	Columbia River Basalt

HSU = hydrostratigraphic unit

STOMP requires several hydrologic properties as input for each HSU. These include density, porosity, residual saturation, saturated hydraulic conductivity, moisture-dependent anisotropy parameters, and the van Genuchten (van Genuchten, 1980, "A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils") fitting parameters α and n. Estimates of these properties for most of the HSUs were obtained from CP-63883, which contains a detailed description of the development of these parameters for the unconsolidated sediments overlying the basalt HSU in the Central Plateau. Properties for the perched zone units and the basalt HSU were obtained from other sources.

Table 3 lists soil moisture retention properties for HSUs in the 200 East Area. Most of the values are from Table 12 in CP-63883. Values for Ringold Formation member of Taylor Flat (Rtf) were taken from Table 14 in CP-63883 since there were no estimates for the 200 East Area. Values for the Cold Creek unit localized sandy unit in the B Complex perched zone feature (CCU2) were assumed to be the same as those for Cold Creek unit sand dominated (CCUsand) in the 200 East Area, and values for the Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone (CCU3) were assumed to be the same as those for CCUsilt in the 200 East Area. Saturated water content (i.e., total porosity) for the basalt HSU was calculated from bulk density and particle density (NUREG/CR-2352, *Repository Site Definition in Basalt: Pasco Basin, Washington*) using Equation 3. Residual water saturation and the van Genuchten parameters for the basalt HSU were obtained from EGG-GE-10068, *A Modeling Study of Water Flow in the Vadose Zone Beneath the Radioactive Waste Management Complex*.

Table 3. Soil Moisture Retention Parameter Estimates for the 200 East Area Hydrostratigraphic Units

HSU	Data Sources	Saturated Water Content θ_s (cm^3/cm^3)	Residual Water Content θ_r (cm^3/cm^3)	van Genuchten α parameter α (1/cm)	van Genuchten n parameter n (-)	Residual Saturation S_r
Surface deposits (backfill)	Table 12 in CP-63883	0.174	0.0038	0.08859	1.271	2.1839E-02
Surface deposits (eolian sand)	Table 12 in CP-63883	0.46708	0.04046	0.104735	1.3399	8.6623E-02
Hf1	Table 12 in CP-63883	0.174	0.0038	0.08859	1.271	2.1839E-02
Hf2	Table 12 in CP-63883	0.3838	0.0290	0.06419	1.6977	7.556E-02
Hf3	Table 12 in CP-63883	0.174	0.0038	0.08859	1.271	2.1839E-02
CCUz	Table 12 in CP-63883	0.3994	0.05421	0.00633	1.830	1.3573E-01
CCUsand	Table 12 in CP-63883	0.3001	0.0393	0.04827	1.925	1.3096E-01
CCU2	Assumed same as for CCUsand	0.3001	0.0393	0.04827	1.925	1.3096E-01
CCU3	Assumed same as for CCUsilt	0.3994	0.05421	0.00633	1.830	1.3573E-01
CCUg	Table 12 in CP-63883	0.174	0.0038	0.08859	1.271	2.1839E-02
Rtf	Table 14 in CP-63883	0.3098	0.047133	0.04559	1.52301	1.5214E-01
Rwie	Table 12 in CP-63883	0.174	0.0038	0.08859	1.271	2.1839E-02
Rlm	Table 12 in CP-63883	0.3994	0.05421	0.00633	1.830	1.3573E-01
Rwia	Table 12 in CP-63883	0.174	0.0038	0.08859	1.271	2.1839E-02

Table 3. Soil Moisture Retention Parameter Estimates for the 200 East Area Hydrostratigraphic Units

HSU	Data Sources	Saturated Water Content θ_s (cm³/cm³)	Residual Water Content θ_r (cm³/cm³)	van Genuchten α parameter α (1/cm)	van Genuchten *n* parameter *n* (-)	Residual Saturation S_r
Basalt	EGG-GE-10068; NUREG/CR-2352	0.226	0.015	0.03840*	1.474	6.6372E-02

References: CP-63883, *Vadose Zone Flow and Transport Parameters Data Package for the Hanford Site Composite Analysis*.
EGG-GE-10068, *A Modeling Study of Water Flow in the Vadose Zone Beneath the Radioactive Waste Management Complex*.
NUREG/CR-2352 (SAND81-2088), *Repository Site Definition in Basalt: Pasco Basin, Washington, Sandia National Laboratories*.
van Genuchten, 1980, "A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils."

*van Genuchten α parameter = 3.84 1/m (EGG-GE-10068).

CCU2 = Cold Creek unit localized sandy unit in the B Complex perched zone feature
CCU3 = Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone
CCUg = Cold Creek unit gravel
CCUsand = Cold Creek unit sand dominated
CCUz = Cold Creek unit silt
Hf1 = Hanford formation unit 1
Hf2 = Hanford formation unit 2
Hf3 = Hanford formation unit 3
HSU = hydrostratigraphic unit
Rlm = Ringold formation member of Wooded Island – lower mud unit
Rtf = Ringold Formation member of Taylor Flat
Rwia = Ringold Formation member of Wooded Island – unit A
Rwie = Ringold Formation member of Wooded Island – unit E

Table 4 lists saturated hydraulic conductivity estimates and pore connectivity-tortuosity coefficient estimates for HSUs in the 200 East Area. CP-63883 contains a detailed description of these parameters and the power-averaging and tensorial-connectivity tortuosity model. Table 4 includes values for low and intermediate anisotropy cases. For both these cases, saturated hydraulic conductivity estimates and pore connectivity-tortuosity coefficient values for the horizontal direction are in the $p = 1$ columns. For the low and intermediate anisotropy cases, values for the vertical direction are in the $p = 1/3$ and $p = 0$ columns, respectively.

Table 4. Saturated Hydraulic Conductivity and Pore Connectivity-Tortuosity Coefficient Values for the 200 East Area Hydrostratigraphic Units

HSU	Data Sources	$p = 1$ Horizontal, Low and Intermediate Anisotropy		$p = 1/3$ Vertical, Low Anisotropy		$p = 0$ Vertical, Intermediate Anisotropy	
		Ks (cm/s)	*L*	*Ks* (cm/s)	*L*	*Ks* (cm/s)	*L*
Surface deposits (backfill)	Table 13 in CP-63883	4.671E-02	0.637	7.714E-03	-0.225	3.790E-03	-0.111
Surface deposits (eolian sand)	Table 13 in CP-63883	7.33E-03	0.2496	2.80E-03	0.7848	8.04E-04	0.9622
Hf1	Table 13 in CP-63883	4.671E-02	0.637	7.714E-03	-0.225	3.790E-03	-0.111
Hf2	Table 13 in CP-63883	6.196E-03	-0.6833	6.157E-03	0.3747	6.575E-03	0.9157
Hf3	Table 13 in CP-63883	4.671E-02	0.637	7.714E-03	-0.225	3.790E-03	-0.111

Table 4. Saturated Hydraulic Conductivity and Pore Connectivity-Tortuosity Coefficient Values for the 200 East Area Hydrostratigraphic Units

HSU	Data Sources	*p* = 1 Horizontal, Low and Intermediate Anisotropy		*p* = 1/3 Vertical, Low Anisotropy		*p* = 0 Vertical, Intermediate Anisotropy	
		Ks **(cm/s)**	***L***	***Ks*** **(cm/s)**	***L***	***Ks*** **(cm/s)**	***L***
CCUsilt	Table 13 in CP-63883	2.41E-04	-1.2111	1.33E-04	0.1763	8.80E-05	1.1446
CCUsand	Table 13 in CP-63883	8.919E-03	-0.749	5.462E-03	0.297	4.166E-03	1.38
CCU2	Table 5 in PNNL-27846	9.144E-04	0.5	2.560E-05	0.5	2.560E-05	0.5
CCU3	Oostrom et al., 2013	1.000E-07	0.5	1.000E-07	0.5	1.000E-07	0.5
CCUg	Table 13 in CP-63883	4.671E-02	0.637	7.714E-03	-0.225	3.790E-03	-0.111
Rtf	Table 15 in CP-63883	5.13E-03	-1.42674	3.02E-03	-0.35489	2.27E-03	0.86572
Rwie	Table 13 in CP-63883	4.671E-02	0.637	7.714E-03	-0.225	3.790E-03	-0.111
Rlm	Table 13 in CP-63883	2.41E-04	-1.2111	1.33E-04	0.1763	8.80E-05	1.1446
Rwia	Table 13 in CP-63883	4.671E-02	0.637	7.714E-03	-0.225	3.790E-03	-0.111
Basalt	EGG-GE-10068; Mualem, 1976	3.390E-2*	0.5	3.390E-2*	0.5	3.390E-2*	0.5

References: CP-63883, *Vadose Zone Flow and Transport Parameters Data Package for the Hanford Site Composite Analysis*.

EGG-GE-10068, *A Modeling Study of Water Flow in the Vadose Zone Beneath the Radioactive Waste Management Complex*.

Mualem, 1976, "A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Media."

Oostrom et al., 2013, "Perched-water Analysis Related to Deep Vadose Zone Contaminant Transport and Impact to Groundwater."

PNNL-27846 (RPT-DVZ-CHPRC-0005), *Physical and Hydraulic Properties of Sediments from the 200-DV-1 Operable Unit*.

*Saturated hydraulic conductivity is 29.29 m/day (EGG-GE-10068).

CCU2 = Cold Creek unit localized sandy unit in the B Complex perched zone feature

CCU3 = Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone

CCUg = Cold Creek unit gravel dominated

CCUsand = Cold Creek unit sand dominated

CCUsilt = Cold Creek unit silk dominated

Hf1 = Hanford formation unit 1

Hf2 = Hanford formation unit 2

Hf3 = Hanford formation unit 3

HSU = hydrostratigraphic unit

Ks = the saturated hydraulic conductivity

L = the directionally dependent pore connectivity tortuosity parameter

p = the power-averaging factor (CP-63883)

Rlm = Ringold Formation member of Wooded Island – lower mud unit

Rtf = Ringold Formation member of Taylor Flat

Rwia = Ringold Formation member of Wooded Island – unit A

Rwie = Ringold Formation member of Wooded Island – unit E

Most of the Table 4 values are from Table 13 in CP-63883. Values for Rtf were taken from Table 15 in CP-63883 since there were no estimates for the 200 East Area. For CCU2, hydraulic conductivity values were derived from PNNL-27846, *Physical and Hydraulic Properties of Sediments from the 200-DV-1 Operable Unit*. Table 5 lists an arithmetic mean best estimate value of 0.79 m/day (9.144E-4 cm/s) and vertical to horizontal ratio of 0.028 for the perched water aquifer. Hydraulic conductivity values for CCU3 were taken from Oostrom et al., 2013, "Perched-water Analysis Related to Deep Vadose Zone Contaminant Transport and Impact to Groundwater." The hydraulic conductivity value selected for the basalt HSU was obtained from EGG-GE-10068. For all three of these HSUs (CCU2, CCU3, and basalt), the standard pore connectivity-tortuosity coefficient value of 0.5 (Mualem, 1976, "A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Media") was assumed. For CCU2, CCU3, and the basalt HSUs, saturated hydraulic conductivity and pore connectivity-tortuosity coefficient values are the same for both low and intermediate anisotropy cases.

Table 5. Bulk and Particle Density Estimates for the 200 East Area Hydrostratigraphic Units

HSU	Data Sources	Bulk Density ρ_b (g/cm^3)	Particle Density ρ_p (g/cm^3)
Surface deposits (backfill)	Table 16 in CP-63883	2.15	2.60
Surface deposits (eolian sand)	Table 16 in CP-63883	1.51*	2.83
Hf1	Table 16 in CP-63883	2.15	2.60
Hf2	Table 16 in CP-63883	1.67	2.71
Hf3	Table 16 in CP-63883	2.15	2.60
CCUsilt	Table 16 in CP-63883	1.59	2.65
CCUsand	Table 16 in CP-63883	1.66	2.37
CCU2	Assumed same as CCUsand	1.66	2.37
CCU3	Assumed same as CCUsilt	1.59	2.65
CCUg	Table 16 in CP-63883	2.15	2.60
Rtf	Table 17 in CP-63883	1.70	2.46
Rwie	Table 16 in CP-63883	2.15	2.60
Rlm	Table 16 in CP-63883	1.59	2.65
Rwia	Table 16 in CP-63883	2.15	2.60
Basalt	NUREG/CR-2352	2.30	2.97

References: CP-63883, *Vadose Zone Flow and Transport Parameters Data Package for the Hanford Site Composite Analysis*.

NUREG/CR-2352 (SAND81-2088), *Repository Site Definition in Basalt: Pasco Basin, Washington*.

*Lower end of the estimated bulk density range for Eolian sand; Table 16 in CP-63883.

CCU2 = Cold Creek unit localized sandy unit in the B Complex perched zone feature
CCU3 = Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone
CCUg = Cold Creek unit gravel dominated
CCUsand = Cold Creek unit sand dominated
CCUsilt = Cold Creek unit silk dominated
Hf1 = Hanford formation unit 1
Hf2 = Hanford formation unit 2
Hf3 = Hanford formation unit
HSU = hydrostratigraphic unit
Rlm = Ringold Formation member of Wooded Island – lower mud unit
Rtf = Ringold Formation member of Taylor Flat
Rwia = Ringold Formation member of Wooded Island – unit A
Rwie = Ringold Formation member of Wooded Island – unit E

Table 5 lists bulk and particle density estimates for HSUs in the 200 East Area. Particle density values were calculated from the bulk density estimates using Equation 3. Most of the bulk density estimates are average bulk density values from Table 16 in CP-63883. The lower end of the estimated bulk density range for Eolian sand was used instead of the estimated average because the particle density based on the average value was unrealistically high.

The average bulk density value for Rtf in the 200 West Area (Table 17 in CP-63883) was used for Rtf since there were no estimates for the 200 East Area. Values for CCU2 were assumed to be the same as those for CCUsand in the 200 East Area, and values for CCU3 were assumed to be the same as those for CCUsilt in the 200 East Area. Bulk density for the basalt HSU is based on Table D-1 in NUREG/CR-2352. It was assumed that the samples defined as "Breccia" and "Vesicular" have similar properties to the basalt HSU. The average value of the "Breccia" and "Vesicular" bulk density intervals was selected. Particle density for the basalt HSU was determined from Figure D-2 in NUREG/CR-2352 by averaging the grain density histogram values for the Columbia River Basalt samples.

Table 6 lists soil moisture retention properties for HSUs in the 200 West Area. Most of the values are from Table 14 in CP-63883. Values for the basalt HSU are from other sources as noted in the discussion of Table 3 in this ECF.

Table 6. Soil Moisture Retention Parameter Estimates for 200 West Area Hydrostratigraphic Units

HSU	Data Sources	Saturated Water Content θ_s (cm³/cm³)	Residual Water Content θ_r (cm³/cm³)	van Genuchten α parameter α (1/cm)	van Genuchten n parameter n (-)	Residual Saturation S_r
Surface deposits (backfill)	Table 14 in CP-63883	0.1917	0.0153	0.0187	1.3783	7.9812E-02
Hf1	Table 14 in CP-63883	0.1917	0.0153	0.0187	1.3783	7.9812E-02
Hf2	Table 14 in CP-63883	0.4009	0.0428	0.0106	1.6693	1.0676E-01
Hf3	Table 14 in CP-63883	0.1917	0.0153	0.0187	1.3783	7.9812E-02
CCUsilt	Table 14 in CP-63883	0.3994	0.05421	0.00633	1.830	1.3573E-01
CCUc	Table 14 in CP-63883	0.3236	0.0639	0.007925	1.56421	1.9747E-01
Rtf	Table 14 in CP-63883	0.3098	0.047133	0.04559	1.52301	1.5214E-01
Rwie	Table 14 in CP-63883	0.17056	0.01666	0.024207	1.454662	9.7678E-02
Rlm	Table 14 in CP-63883	0.3994	0.05421	0.00633	1.830	1.3573E-01
Rwia	Table 14 in CP-63883	0.17056	0.01666	0.024207	1.454662	9.7678E-02
Basalt	EGG-GE-10068; NUREG/CR-2352	0.226	0.015	0.03840*	1.474	6.6372E-02

References: CP-63883, *Vadose Zone Flow and Transport Parameters Data Package for the Hanford Site Composite Analysis*.
EGG-GE-10068, *A Modeling Study of Water Flow in the Vadose Zone Beneath the Radioactive Waste Management Complex*.
NUREG/CR-2352 (SAND81-2088), *Repository Site Definition in Basalt: Pasco Basin, Washington*.
van Genuchten, 1980, "A Closed-form Equation for Predicting the Hydraulic Conductivity of Unsaturated Soils."
*van Genuchten α parameter = 3.84 1/m (EGG-GE-10068).

Table 6. Soil Moisture Retention Parameter Estimates for 200 West Area Hydrostratigraphic Units

HSU	Data Sources	Saturated Water Content θ_s (cm³/cm³)	Residual Water Content θ_r (cm³/cm³)	van Genuchten α parameter α (1/cm)	van Genuchten *n* parameter *n* (-)	Residual Saturation S_r

CCU2 = Cold Creek unit localized sandy unit in the B Complex perched zone feature
CCU3 = Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone
CCUg = Cold Creek unit gravel dominated
CCUsand = Cold Creek unit sand dominated
CCUsilt = Cold Creek unit silk dominated
Hf1 = Hanford formation unit 1
Hf2 = Hanford formation unit 2
Hf3 = Hanford formation unit
HSU = hydrostratigraphic unit
Rlm = Ringold Formation member of Wooded Island – lower mud unit
Rtf = Ringold Formation member of Taylor Flat
Rwia = Ringold Formation member of Wooded Island – unit A
Rwie = Ringold Formation member of Wooded Island – unit E

Table 7 lists saturated hydraulic conductivity estimates and pore connectivity-tortuosity coefficient estimates for HSUs in the 200 West Area. Most of the values are from Table 15 in CP-63883. Values for the basalt HSU are from other sources as noted in the discussion of Table 4 in this ECF.

Table 7. Saturated Hydraulic Conductivity and Pore Connectivity-Tortuosity Coefficient Values for the 200 West Area Hydrostratigraphic Units

HSU	Data Sources	*p* = 1 Horizontal, Low and Intermediate Anisotropy		*p* = 1/3 Vertical, Low Anisotropy		*p* = 0 Vertical, Intermediate Anisotropy	
		K_s (cm/s)	*L*	K_s (cm/s)	*L*	K_s (cm/s)	*L*
Surface deposits (backfill)	Table 15 in CP-63883	2.38E-03	-1.918	9.73E-04	-1.019	6.29E-04	-0.104
Hf1	Table 15 in CP-63883	2.38E-03	-1.918	9.73E-04	-1.019	6.29E-04	-0.104
Hf2	Table 15 in CP-63883	1.96E-04	-0.3724	1.56E-04	0.470	1.40E-04	1.0426
Hf3	Table 15 in CP-63883	2.38E-03	-1.918	9.73E-04	-1.019	6.29E-04	-0.104
CCUsilt	Table 15 in CP-63883	2.41E-04	-1.2111	1.33E-04	0.1763	8.80E-05	1.1446
CCUc	Table 15 in CP-63883	2.63E-04	0.6238	1.50E-04	0.6571	1.04E-04	0.6334
Rtf	Table 15 in CP-63883	5.13E-03	-1.42674	3.02E-03	-0.35489	2.27E-03	0.86572
Rwie	Table 15 in CP-63883	1.15E-02	-1.8957	5.79E-03	-1.05357	3.13E-03	0.057882
Rlm	Table 15 in CP-63883	2.41E-04	-1.2111	1.33E-04	0.1763	8.80E-05	1.1446
Rwia	Table 15 in CP-63883	1.15E-02	-1.8957	5.79E-03	-1.05357	3.13E-03	0.057882

Table 7. Saturated Hydraulic Conductivity and Pore Connectivity-Tortuosity Coefficient Values for the 200 West Area Hydrostratigraphic Units

HSU	Data Sources	*p* = 1 Horizontal, Low and Intermediate Anisotropy		*p* = 1/3 Vertical, Low Anisotropy		*p* = 0 Vertical, Intermediate Anisotropy	
		K_s (cm/s)	*L*	K_s (cm/s)	*L*	K_s (cm/s)	*L*
Basalt	EGG-GE-10068; Mualem, 1976	3.390E-2*	0.5	3.390E-2*	0.5	3.390E-2*	0.5

References: CP-63883, *Vadose Zone Flow and Transport Parameters Data Package for the Hanford Site Composite Analysis*.
EGG-GE-10068, *A Modeling Study of Water Flow in the Vadose Zone Beneath the Radioactive Waste Management Complex*.
Mualem, 1976, "A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Media."

*Saturated hydraulic conductivity is 29.29 m/day (EGG-GE-10068).

CCU2 = Cold Creek unit localized sandy unit in the B Complex perched zone feature
CCU3 = Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone
CCUg = Cold Creek unit gravel dominated
CCUsand = Cold Creek unit sand dominated
CCUsilt = Cold Creek unit silk dominated
Hf1 = Hanford formation unit 1
Hf2 = Hanford formation unit 2
Hf3 = Hanford formation unit 3
HSU = hydrostratigraphic unit
K_s = the saturated hydraulic conductivity
L = the directionally dependent pore connectivity tortuosity parameter
p = the power-averaging factor (CP-63883)
Rlm = Ringold Formation member of Wooded Island – lower mud unit
Rtf = Ringold Formation member of Taylor Flat
Rwia = Ringold Formation member of Wooded Island – unit A
Rwie = Ringold Formation member of Wooded Island – unit E

Table 8 lists bulk and particle density estimates for HSUs in the 200 West Area. Particle density values were calculated from the bulk density estimates using Equation 3. Most of the bulk density estimates are average bulk density values from Table 17 in CP-63883. Values for the basalt HSU are from another source as noted in the discussion of Table 5 in this ECF.

Table 8. Bulk and Particle Density Estimates for the 200 West Area Hydrostratigraphic Units

HSU	Data Sources	Bulk Density ρ_b (g/cm^3)	Particle Density ρ_p (g/cm^3)
Surface deposits (backfill)	Table 17 in CP-63883	2.03	2.51
Hf1	Table 17 in CP-63883	2.03	2.51
Hf2	Table 17 in CP-63883	1.70	2.84
Hf3	Table 17 in CP-63883	2.03	2.51
CCUsilt	Table 17 in CP-63883	1.59	2.65
CCUc	Table 17 in CP-63883	1.55	2.29
Rtf	Table 17 in CP-63883	1.70	2.46
Rwie	Table 17 in CP-63883	2.13	2.57
Rlm	Table 17 in CP-63883	1.59	2.65
Rwia	Table 17 in CP-63883	2.13	2.57
Basalt	NUREG/CR-2352	2.30	2.97

Table 8. Bulk and Particle Density Estimates for the 200 West Area Hydrostratigraphic Units

HSU	Data Sources	Bulk Density ρ_b (g/cm^3)	Particle Density ρ_p (g/cm^3)

References: CP-63883, *Vadose Zone Flow and Transport Parameters Data Package for the Hanford Site Composite Analysis*.
NUREG/CR-2352 (SAND81-2088), *Repository Site Definition in Basalt: Pasco Basin, Washington*.

CCUc = Cold Creek unit caliche
CCUsilt = Cold Creek unit silt dominated
Hf1 = Hanford formation unit 1
Hf2 = Hanford formation unit 2
Hf3 = Hanford formation unit 3
HSU = hydrostratigraphic unit
Rlm = Ringold Formation member of Wooded Island – lower mud unit
Rtf = Ringold Formation member of Taylor Flat
Rwia = Ringold Formation member of Wooded Island – unit A
Rwie = Ringold Formation member of Wooded Island – unit E

7.2 Transport Properties of the Vadose Zone Models

Additional parameters are required for the STOMP transport simulations. These include properties of the solutes and properties that define interactions between the solutes and the porous media. The following sections describe these parameters and provide the rationale and information sources used to select these values.

7.2.1 Dispersion and Diffusion

Dispersivity is a property of the rock/soil type and is defined by a longitudinal component along the flow path and a transverse component perpendicular to the flow path. Recommended values for longitudinal and transverse dispersivity in Section 1.9.4 in CP-63883 will be used for the CA and CIE VZ modeling. Table 9 lists these values for each of the CA/CIE VZ HSUs. Recommended values for longitudinal dispersivity are 25 cm for sand-dominated units, 15 cm for gravel-dominated units, and 5 cm for fine-textured units. Recommended values for transverse dispersivity are one-tenth of the longitudinal dispersivity. A detailed description of the development of these parameters can be found in CP-63883. The recommended dispersivity values for the fine-textured units were also used for the basalt HSU.

CP-63883 recommends a molecular diffusion coefficient of 2.5×10^{-5} cm^2/s for all species in pore water. This value will be used for the CA and CIE VZ models.

Table 9. Longitudinal and Transverse Dispersivity Values for the Composite Analysis/Cumulative Impact Evaluation Vadose Hydrostratigraphic Units

HSU	Recommended Longitudinal Dispersivity (m)	Recommended Transverse Dispersivity (m)
Surface deposits (backfill)	0.15	0.015
Surface deposits (eolian sand)	0.25	0.025
Hf1	0.15	0.015
Hf2	0.25	0.025
Hf3	0.15	0.015
CCUsilt	0.05	0.005
CCUsand	0.25	0.025
CCU2	0.25	0.025

Table 9. Longitudinal and Transverse Dispersivity Values for the Composite Analysis/Cumulative Impact Evaluation Vadose Hydrostratigraphic Units

HSU	Recommended Longitudinal Dispersivity (m)	Recommended Transverse Dispersivity (m)
CCU3	0.05	0.005
CCUc	0.05	0.005
CCUg	0.15	0.015
Rtf	0.25	0.025
Rwie	0.15	0.015
Rlm	0.05	0.005
Rwia	0.15	0.015
Basalt	0.05	0.005

CCU2 = Cold Creek unit localized sandy unit in the B Complex perched zone feature
CCU3 = Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone
CCUc = Cold Creek unit caliche
CCUg = Cold Creek unit gravel dominated
CCUsand = Cold Creek unit sand dominated
CCUsilt = Cold Creek unit silt dominated
Hf1 = Hanford formation unit 1
Hf2 = Hanford formation unit 2
Hf3 = Hanford formation unit 3
HSU = hydrostratigraphic unit
Rlm = Ringold formation member of Wooded Island – lower mud unit
Rtf = Ringold Formation member of Taylor Flat
Rwia = Ringold formation member of Wooded Island – unit A
Rwie = Ringold formation member of Wooded Island – unit E

7.2.2 Sorption

For the CA/CIE VZ modeling, partitioning of solutes between the porous media and aqueous phase is assumed linear. Solid-aqueous K_d values for each radionuclide were selected based on K_d values in DOE/RL-2011-50, *Regulatory Basis and Implementation of a Graded Approach to Evaluation of Groundwater Protection*; NUREG/CR-5512, *Residual Radioactive Contamination from Decommissioning: Technical Basis for Translating Contamination Levels to Annual Total Effective Dose Equivalent*, and previous CAs and performance assessments (PAs). Appendix B lists references and associated K_d values used to select the CA/CIE VZ K_d values. Table 10 lists the K_d values recommended for CA/CIE VZ modeling. Gravel corrections will modify the actual K_d values used for HSUs with gravel content.

Table 10. Recommended Distribution Coefficient Values

Constituent	K_d (mL/g)
Radionuclides	
I-129	0.2
U-232, U-233, U-234, U-235, U-236, U-238	0.8
Np-237	10
C-14	0

Table 10. Recommended Distribution Coefficient Values

Constituent	K_d (mL/g)
Sr-90	22
Cl-36	0
H-3	0
Tc-99	0
Ra-226	14
Re-187	14
Th-230	1,000
Chemical Species	
Nitrate	0
Chromium	0
Cyanide	0
Uranium (total)	0.8

K_d = distribution coefficient

The following are other sources considered for K_d values:

- EPA 402-R-99-004A, *Understanding Variation in Partition Coefficients, Kd Values: Volume I: The Kd Model, Methods of Measurement, and Application of Chemical Reaction Codes*
- EPA 402-R-99-004B, *Understanding Variation in Partition Coefficients, Kd Values: Volume II: Review of Geochemistry and Available Kd Values for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium (3H), and Uranium*
- EPA 402-R-04-002C, *Understanding Variation in Partition Coefficients, Kd Values: Volume III: Review of Geochemistry and Available Kd Values for Americium, Arsenic, Curium, Iodine, Neptunium, Radium, and Technetium*

Volumes II and III (EPA 402-R-99-004A and EPA 402-R-99-004B, respectively) provide insights and recommended ranges of values for K_d for some of the radionuclides evaluated in the CA/CIE. These ranges are extracted and listed in Table 11. The ranges provided in this reference are typically wide, and values selected in this ECF (Table 10) fall within the range of values provided in these references.

Table 11. Distribution Coefficient Value Ranges

Element	Conditions	K_d Range	Reference
Carbon	No value	No value	--
Chlorine	No value	No value	--
Hydrogen (tritium)	Any	Zero	Section 5.10.5 in EPA 402-R-99-004B
Iodine	Hanford sediments	From minimum -0.03 to maximum 0.23	Table 5.11 in EPA 402-R-04-002C

Table 11. Distribution Coefficient Value Ranges

Element	Conditions	K_d Range	Reference
Neptunium	No value	No value	--
Radium	Sandy, arid soil samples from Utah, pH 7.6 to 7.8	214 ±15	Table 5.27, Soil IV in EPA-R-04-002C
Rhenium	No value	No value	--
Strontium	For near-neutral pH and low clay content soils	From minimum 2 to maximum 60	Table 5.13 in EPA 402-R-99-004B
Technetium	Hanford sediments	From minimum -0.28 to maximum 3.95	Table 5.29 in EPA 402-R-04-002C
Uranium	pH = 8 (slightly alkaline)	From minimum 0.4 to 250,000	Table 5.17 in EPA 402-R-99-004B
Thorium	For near-neutral pH and low concentrations of dissolved thorium ($<10^{-9}$ M)	From minimum 1,700 to maximum 170,000	Table 5.15 in EPA 402-R-99-004B

a. EPA 402-R-99-004B, *Understanding Variation in Partition Coefficients, Kd Values: Volume II: Review of Geochemistry and Available Kd Values for Cadmium, Cesium, Chromium, Lead, Plutonium, Radon, Strontium, Thorium, Tritium (3H), and Uranium*.

b. EPA 402-R-04-002C, *Understanding Variation in Partition Coefficients, Kd Values: Volume III: Review of Geochemistry and Available Kd Values for Americium, Arsenic, Curium, Iodine, Neptunium, Radium, and Technetium*.

K_d = distribution coefficient

For those radionuclides with K_d estimates included in DOE/RL-2011-50 (iodine, uranium, neptunium, carbon, and strontium), best-estimate K_d values for intermediate impact sand listed in Table 4-11 of that document were selected. For the remaining radionuclides that will be included in the CA/CIE VZ modeling, K_d values from previous CAs and PAs were selected, if available. K_d values for chlorine-36, hydrogen-3, technetium-99, radium-226, and thorium-232 were included in multiple documents (Appendix B). All sources that included chlorine-36, hydrogen-3, and technetium-99 agreed on a K_d value of 0.0 mL/g. Values for radium-226 ranged from 14 to 20 mL/g. Values for thorium-232 ranged from 300 to 3,200 mL/g. For these two radionuclides, the values from the draft Integrated Disposal Facility (IDF) PA (RPP-RPT-59958, *Performance Assessment for the Integrated Disposal Facility, Hanford Site, Washington*) were selected for the CA VZ modeling. The K_d value for rhenium-187, which was not included in any of the site-specific documents for the Hanford Site, was obtained from NUREG/CR-5512.

For the chemical species that will be included in the CIE VZ modeling, K_d values from DOE/RL-2011-50 and previous PAs were selected (Appendix B). For nitrate and chromium, both the Waste Management Area C (WMA C) PA (RPP-ENV-58782, *Performance Assessment of Waste Management Area C, Hanford Site, Washington*) and DOE/EIS-0391, *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington* (TC & WM EIS) used a K_d value of 0 mL/g. PNNL-13895, *Hanford Contaminant Distribution Coefficient Database and Users Guide,* supports this choice, stating that nitrate sorption is essentially zero and that typical K_d values for hexavalent chromium are zero or close to zero. Of the Hanford Site-specific documents reviewed, only the WMA C PA (RPP-ENV-58782) provides a K_d value, 0 mL/g, for cyanide. The choice of 0 mL/g for cyanide is supported by Kjeldsen, 1999, "Behaviour of Cyanides in Soil and Groundwater: A Review," which states that retardation of cyanide due to sorption processes is generally of minor importance in most soils. As with the radionuclides, the uranium K_d value of 0.8 mL/g from DOE/RL-2011-50 was selected.

Table 12 lists average gravel weight percent for each of the HSUs in the 200 East Area. Most of the averages were calculated from values presented in Tables 1 through 4 in CP-63883. The gravel percentage for the CCUsand was obtained from the Table 12 footnote in CP-63883, which indicates zero gravel content for the CCUsand. Gravel fraction data were not available for CCU2, CCU3, and Rtf. It was assumed that the gravel content for CCU2 is the same as CCUsand and that the gravel content for CCU3 is the same as CCUsilt. For the Rtf, the gravel content was assumed the same as Rtf in the 200 West Area.

Table 12. Gravel Percentages for the 200 East Area Hydrostratigraphic Units

HSU	Data Sources for Gravel Content	Average Gravel (%)
Surface deposits (backfill)	Table 3 in CP-63883	66.000
Surface deposits (eolian sand)	Table 1 in CP-63883	0.667
Hf1	Table 3 in CP-63883	66.000
Hf2	Table 2 in CP-63883	4.875
Hf3	Table 3 in CP-63883	66.000
CCUsilt	Table 4 in CP-63883	0
CCUsand	Table 12 footnote in CP-63883	0
CCU2	No data available; assumed to be the same as CCUsand	0
CCU3	No data available; assumed to be the same as CCUsilt	0
CCUg	Table 3 in CP-63883	66.000
Rtf	No data available; assumed to be the same as 200 West Rtf	16.500
Rwie	Table 3 in CP-63883	66.000
Rlm	Table 4 in CP-63883	0
Rwia	Table 3 in CP-63883	66.000

Reference: CP-63883, *Vadose Zone Flow and Transport Parameters Data Package for the Hanford Site Composite Analysis*.

CCU2 = Cold Creek unit localized sandy unit in the B Complex perched zone feature
CCU3 = Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone
CCUg = Cold Creek unit gravel dominated
CCUsand = Cold Creek unit sand dominated
CCUsilt = Cold Creek unit silt dominated
Hf1 = Hanford formation unit 1
Hf2 = Hanford formation unit 2
Hf3 = Hanford formation unit 3
HSU = hydrostratigraphic unit
Rlm = Ringold formation member of Wooded Island – lower mud unit
Rtf = Ringold Formation member of Taylor Flat
Rwia = Ringold formation member of Wooded Island – unit A
Rwie = Ringold formation member of Wooded Island – unit E

Gravel-corrected K_d values based on the selected CA/CIE K_d values (assumed to be K_d values for sediments with particle sized of <2 mm) in Table 10 and the gravel percentages in Table 12 are listed in Table 13 for each of the 200 East Area HSUs.

Table 13. Gravel-Corrected Distribution Coefficient Values (mL/g) for the 200 East Area Hydrostratigraphic Units

HSU	Gravel (%)	H-3, C-14, Cl-36, Tc-99, NO_3, Cr, Cn	I-129	Uranium Isotopes	Np-237	Ra-226, Re-187	Sr-90	Th-230
Backfill	66	0	0.068	0.272	4.92	6.89	10.8	492
Eolian sand	0.667	0	0.199	0.795	9.95	13.9	21.9	995
Hf1	66	0	0.068	0.272	4.92	6.89	10.8	492
Hf2	4.875	0	0.19	0.761	9.62	13.5	21.2	962
Hf3	66	0	0.068	0.272	4.92	6.89	10.8	492
CCUsilt	0	0	0.2	0.8	10	14	22	1,000
CCUsand	0	0	0.2	0.8	10	14	22	1,000
CCU2	0	0	0.2	0.8	10	14	22	1,000
CCU3	0	0	0.2	0.8	10	14	22	1,000
CCUg	66	0	0.068	0.272	4.92	6.89	10.8	492
Rtf	16.5	0	0.167	0.668	8.73	12.2	19.2	873
Rwie	66	0	0.068	0.272	4.92	6.89	10.8	492
Rlm	0	0	0.2	0.8	10	14	22	1,000
Rwia	66	0	0.068	0.272	4.92	6.89	10.8	492
Basalt	0	0	0.2	0.8	10	14	22	1,000

CCU2 = Cold Creek unit localized sandy unit in the B Complex perched zone feature
CCU3 = Cold Creek unit localized very fine-grained unit in the B Complex perched zone feature that acts as the lower aquitard of the perched zone
CCUg = Cold Creek unit gravel dominated
CCUsand = Cold Creek unit sand dominated
CCUsilt = Cold Creek unit silt dominated
Hf1 = Hanford formation unit 1
Hf2 = Hanford formation unit 2
Hf3 = Hanford formation unit 3
HSU = hydrostratigraphic unit
K_d = distribution coefficient
Rlm = Ringold formation member of Wooded Island – lower mud unit
Rtf = Ringold Formation member of Taylor Flat
Rwia = Ringold formation member of Wooded Island – unit A
Rwie = Ringold formation member of Wooded Island – unit E

Table 14 lists average gravel weight percent for each of the HSUs in the 200 West Area. The averages were calculated from values presented in Tables 4 through 9 in CP-63883.

Table 14. Gravel Percentages for the 200 West Area Hydrostratigraphic Units

HSU	Data Sources for Gravel Content	Average Gravel (%)
Surface deposits (backfill)	Table 6 in CP-63883	52.636
Hf1	Table 6 in CP-63883	52.636
Hf2	Table 5 in CP-63883	1.056
Hf3	Table 6 in CP-63883	52.636
CCUsilt	Table 4 in CP-63883	0

Table 14. Gravel Percentages for the 200 West Area Hydrostratigraphic Units

HSU	Data Sources for Gravel Content	Average Gravel (%)
CCUc	Table 8 in CP-63883	11.625
Rtf	Table 9 in CP-63883	16.500
Rwie	Table 7 in CP-63883	51.000
Rlm	Table 4 in CP-63883	0
Rwia	Table 7 in CP-63883	51.000

Reference: CP-63883, *Vadose Zone Flow and Transport Parameters Data Package for the Hanford Site Composite Analysis*.

CCUc = Cold Creek unit caliche
CCUsilt = Cold Creek unit silt dominated
Hf1 = Hanford formation unit 1
Hf2 = Hanford formation unit 2
Hf3 = Hanford formation unit 3
HSU = hydrostratigraphic unit
Rlm = Ringold formation member of Wooded Island – lower mud unit
Rtf = Ringold Formation member of Taylor Flat
Rwia = Ringold formation member of Wooded Island – unit A
Rwie = Ringold formation member of Wooded Island – unit E

Gravel-corrected K_d values based on the selected CA/CIE K_d values (assumed to be K_d values for sediments with particle sized of <2 mm) in Table 10 and the 200 West Area gravel percentages in Table 14 are listed in Table 15 for each of the 200 West Area HSUs.

Table 15. Gravel-Corrected Distribution Coefficient Values (mL/g) for 200 West Area Hydrostratigraphic Units

HSU	Gravel (%)	H-3, C-14, Cl-36, Tc-99, NO_3, Cr, Cn	I-129	Uranium Isotopes	Np-237	Ra-226, Re-187	Sr-90	Th-230
Backfill	52.636	0	0.0947	0.379	5.95	8.33	13.1	595
Hf1	52.636	0	0.0947	0.379	5.95	8.33	13.1	595
Hf2	1.056	0	0.198	0.792	9.92	13.9	21.8	992
Hf3	52.636	0	0.0947	0.379	5.95	8.33	13.1	595
CCUsilt	0	0	0.2	0.8	10	14	22	1,000
CCUc	11.625	0	0.177	0.707	9.1	12.7	20	910
Rtf	16.5	0	0.167	0.668	8.73	12.2	19.2	873
Rwie	51	0	0.098	0.392	6.07	8.5	13.4	607
Rlm	0	0	0.2	0.8	10	14	22	1,000
Rwia	51	0	0.098	0.392	6.07	8.5	13.4	607

Table 15. Gravel-Corrected Distribution Coefficient Values (mL/g) for 200 West Area Hydrostratigraphic Units

HSU	Gravel (%)	H-3, C-14, Cl-36, Tc-99, NO_3, Cr, Cn	I-129	Uranium Isotopes	Np-237	Ra-226, Re-187	Sr-90	Th-230
Basalt	0	0	0.2	0.8	10	14	22	1,000

CCUc = Cold Creek unit caliche
CCUsilt = Cold Creek unit silt dominated
Hf1 = Hanford formation unit 1
Hf2 = Hanford formation unit 2
Hf3 = Hanford formation unit 3
HSU = hydrostratigraphic unit
Rlm = Ringold formation member of Wooded Island – lower mud unit
Rtf = Ringold Formation member of Taylor Flat
Rwia = Ringold formation member of Wooded Island – unit A
Rwie = Ringold formation member of Wooded Island – unit E

7.2.3 Radionuclide Properties

For transport simulations involving radionuclides, STOMP requires input of radionuclide half-lives and definition of any decay chains. Half-life values for the CA/CIE VZ radionuclides were taken from EMDT-DE-0006, *Half-lives for Typical Hanford Site Radioactive Contaminants* (provided in Appendix C of this ECF) if they were included that reference, and DOE-STD-1196-2011, *Derived Concentration Technical Standard,* if not. These values are listed in Table 16.

Table 16. Composite Analysis/Cumulative Impact Evaluation Vadose Zone Radionuclide Half-Lives

Radionuclide	Half-Life (yr)	Source
H-3	12.32	EMDT-DE-0006
C-14	5,700	EMDT-DE-0006
Cl-36	301,000	DOE-STD-1196-2011
Sr-90	28.79	EMDT-DE-0006
Tc-99	211,100	EMDT-DE-0006
I-129	15,700,000	EMDT-DE-0006
Re-187	41,200,000,000	DOE-STD-1196-2011
Ra-226	1,600	EMDT-DE-0006
Th-230	75,380	EMDT-DE-0006
U-232	68.9	EMDT-DE-0006
U-233	159,200	EMDT-DE-0006
U-234	245,500	EMDT-DE-0006
U-235	704,000,000	EMDT-DE-0006
U-236	23,420,000	EMDT-DE-0006
U-238	4,468,000,000	EMDT-DE-0006

Table 16. Composite Analysis/Cumulative Impact Evaluation Vadose Zone Radionuclide Half-Lives

Radionuclide	Half-Life (yr)	Source
Np-237	2,144,000	EMDT-DE-0006

References: DOE-STD-1196-2011, *Derived Concentration Technical Standard*, U.S. Department of Energy, Washington, D.C.

EMDT-DE-0006, *Half-lives for Typical Hanford Site Radioactive Contaminants* (provided in Appendix C of this environmental calculation file).

As a part of the CA VZ modeling, it was decided to simulate decay of uranium-234 to thorium-230, and decay of thorium-230 to radium-226. STOMP input for decay chains consists of the parent radionuclide, the progeny radionuclide, and the fraction of the decaying parent that produces that progeny. ICRP Publication 107, *Nuclear Decay Data for Dosimetric Calculations*, shows that uranium-234 decays to thorium-230 only and that thorium-230 decays to radium-226 only. Based on this information, the decay fractions for both uranium-234 to thorium-230 and thorium-230 to radium-226 are input as 1.0.

The CIE chemical constituents total uranium, NO_3, chromium, and cyanide are assumed nondecaying. While uranium does undergo decay, for the CIE the total uranium is made up of many different isotopes with different half-lives as shown in Table 16. Assuming no decay for total uranium for the CIE is a conservative assumption.

7.2.4 Cutoff Concentration

STOMP allows for a lower limit of solute concentration where the Courant-limit control is no longer implemented. This lower limit was chosen based on maximum contaminant levels (MCLs), as defined in 40 CFR 141.66, "National Primary Drinking Water Regulations," "Maximum Contaminant Levels for Radionuclides," and 40 CFR 141.62, "Maximum Contaminant Levels for Inorganic Contaminants." Table 17 shows the MCLs for the CA/CIE VZ radionuclides and the source document for the value. MCLs for all the CA/CIE VZ radionuclides except the uranium isotopes and radium-226 are based on the 4 mrem/yr dose limit for beta particle and photon radioactivity (40 CFR 141.66). Iodine-129 has the lowest limit at 1 pCi/L. For the CA and CIE radionuclides, the aqueous cutoff concentration for Courant-limit control was set to a value of 1.0E-12 Ci/m^3 (0.001 pCi/L), a factor of 1,000 less than the iodine-129 MCL. For the CIE chemical constituents, the cutoff concentration was set to a value of 1.0E-12 kg/m^3 (1.0E-9 mg/L), far less than any of the chemical MCLs (40 CFR 141.62).

Table 17. Maximum Containment Levels for the Composite Analysis/Cumulative Impact Evaluation Vadose Zone Radionuclides Chemicals

Constituent	MCL	Source
Radionuclides (MCL Expressed in pCi/L)		
H-3	20,000	ECF-HANFORD-12-0023
C-14	2,000	ECF-HANFORD-12-0023
Cl-36	700	EPA, 2002
Sr-90	8	ECF-HANFORD-12-0023
Tc-99	900	ECF-HANFORD-12-0023
I-129	1	ECF-HANFORD-12-0023

Table 17. Maximum Containment Levels for the Composite Analysis/Cumulative Impact Evaluation Vadose Zone Radionuclides Chemicals

Constituent	MCL	Source
Re-187	9,000	EPA, 2002
Ra-226	5	ECF-HANFORD-12-0023
Th-230	15	ECF-HANFORD-12-0023
Np-237	15	ECF-HANFORD-12-0023
Uranium (total)	20.1 – 45.0*	40 CFR 141.66
Chemicals (MCL Expressed in mg/L)		
Nitrate	10	40 CFR 141.62
Chromium	0.1	40 CFR 141.62
Cyanide	0.2	40 CFR 141.62
Uranium (total)	0.03	40 CFR 141.66

References: 40 CFR 141.62, "National Primary Drinking Water Regulations," "Maximum Contaminant Levels for Inorganic Contaminants."

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*Based on 65 FR 76707, typical conversion factors for uranium activity (pCi/L) to concentration (µg/L) range from 0.67 to 1.5 pCi/µg. Using these factors, the 30 µg/L MCL for total uranium could range from 20.1 to 45.0 pCi/L.

MCL = maximum contaminant level

8 References

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Appendix A

Microsoft® Excel® Spreadsheets for Calculation of Gravel-Corrected Distribution Coefficient Values, Particle Density, and Residual Saturation

Microsoft Excel spreadsheets will be provided electronically.

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Appendix B

Literature Review for Distribution Coefficient Values

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Table B-1. Literature Review for CA/CIE VZ Modeling K_d Values

DOE/RL-2011-50 Best Estimate K_d Values (mL/g) for Intermediate Impact Sand					Previous CA and PA K_d Values (mL/g)							NUREG/CR-5512		Recommended CA/CIE K_d Values	
Radionuclide	Very Acidic	Very High Salt/ Very Basic	Chelates/High Salt Waste	Low Organic/ Low Salt/Near Neutral	Radionuclide	1998 CA[a]	2006 Data Package[b]	TC & WM EIS[c]	ERDF PA[d]	WMA C PA[e]	IDF PA[f]	Radionuclide	K_d (mL/g)	Radionuclide	K_d (mL/g)
I	0.2	0.1	0.2	0.2	I-129	0.5	0.2	0 & 0.2	0.2	0.2	0.25	Iodine	1	I-129	0.2
U	0.8	0.8	0.8	0.8	Uranium isotopes	3	0.8	0.6	0.8	0.6	1	Uranium	15	U-232, U-233, U-234, U-235, U-236, U-238	0.8
Np	10	200	5	10	Np-237	15	10	2.5	10	10	15	Neptunium	5	Np-237	10
C	0	7	0	0	C-14	5	0	4	0.5	1	5	Carbon	6.7	C-14	0
Sr	22	22	10	22	Sr-90	20	22	10	20	10	14	Strontium	15	Sr-90	22
					Cl-36	0	0	--	0	--	0	Chlorine	1.7	Cl-36	0
					H-3 (tritium)	0	0	0	0	0	0	Hydrogen	0	H-3	0
					Tc-99	0	0	0	0	0	0	Technetium	0.1	Tc-99	0
					Ra-226	20	--	--	20	10	14	Radium	500	Ra-226	14
					Re-187	--	--	--	--	--	--	Rhenium	14	Re-187	14
					Th-232	1,000		3,200	1,000	300	1,000	Thorium	3,200	Th-230	1,000
Chemical Species	Very Acidic	Very High Salt/ Very Basic	Chelates/High Salt Waste	Low Organic/ Low Salt/Near Neutral	Chemical Species	1998 CA[a]	2006 Data Package[b]	TC & WM EIS[c]	ERDF PA[d]	WMA C PA[e]	IDF PA[f]	Chemical Species	K_d (mL/g)	Chemical Species	K_d (mL/g)
Nitrate	--	--	--	--	Nitrate	--	--	0	--	0	--	--	--	Nitrate	0
Chromium	--	--	--	--	Chromium	--	--	0	--	0	--	--	--	Chromium	0
Cyanide	--	--	--	--	Cyanide	--	--	--	--	0	--	--	--	Cyanide	0
Uranium (total)	0.8	0.8	0.8	0.8	Uranium isotopes	3	0.8	0.6	0.8	0.6	1	U	15	Uranium (total)	0.8

References: DOE/EIS-0391, 2012, *Final Tank Closure and Waste Management Environmental Impact Statement for the Hanford Site, Richland, Washington (TC & WM EIS)*, U.S. Department of Energy, Office of River Protection, Richland, Washington. Available at: http://energy.gov/nepa/downloads/eis-0391-final-environmental-impact-statement.

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b. PNNL-14702, Table 4.11 (K_d Best estimates for low organic/low salt/near neutral, intermediate impact - sand or groundwater).

c. DOE/EIS-0391, Tables N-2 and N-3.

d. WCH-515, Table 25 (Best estimates for low organic/low salt/near neutral waste chemistry, not impacted sand).

e. RPP-ENV-58782, Table 6-11.

f. RPP-RPT-59958, Table 4-33 (Best estimates for far field sand sequence with natural recharge (no impact from wastes)).

CA	=	composite analysis
CIE	=	cumulative impact evaluation
ERDF	=	Environmental Restoration Disposal Facility
IDF	=	Integrated Disposal Facility
K_d	=	distribution coefficient
PA	=	performance assessment
TC & WM EIS	=	Tank Closure and Waste Management Environmental Impact Statement
VZ	=	vadose zone
WMA C	=	Waste Management Area C

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Appendix C

EMDT-DE-0006, *Half-lives for Typical Hanford Site Radioactive Contaminants*

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Environmental Modeling Data Transmittal Cover Page

No.: EMDT-DE-0006 **Revision No.:** 1

[Request EMDT number from Modeling Team Leader]

Title:* *Half-lives for Typical Hanford Site Radioactive Contaminants. **Date:** 18-May-2015

1. Data Description

Provide the description of data set or data type.

Radioactive half-lives for reported radionuclides at Hanford site.

2. Data Intended Use

Identify the data's intended use. Describe the rationale for its selection and how the data will be incorporated into a model, report, or database. Include discussion of the extent to which the data demonstrate the properties of interest.

Numerical simulation of contaminant transport and fate

3. Data Sources

List databases, documents, etc. – provide sufficient detail to enable data to be located by independent reviewer

ICRP, 2008, Nuclear Decay Data for Dosimetric Calculations, International Commission on Radiological Protection (ICRP), Publication 107, Vol 38-3, ISBN 978-0-7020-3475-6.

4. Impact of Use or Nonuse of Data

Describe the importance of the data to the model, report, and/or conclusions which they support. Identify the value added and discuss the impacts of not using the data.

The half-life data are required to be consistent with PA studies and the model implementations in GoldSim and STOMP

5. Prior Uses

Identify the data's prior uses. Describe whether the data have been used in similar applications by the scientific or regulatory community. Include the associated verification processes and prior reviews and review results.

The ICRP Publication 107 data is used by the U.S. EPA calculation tool for radiation dose and risk.

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Environmental Modeling Data Transmittal Cover Page

No.: EMDT-DE-0006 **Revision No.:** 1

[Request EMDT number from Modeling Team Leader]

Title: Half-lives for Typical Hanford Site Radioactive Contaminants. **Date:** 18-May-2015

6. Data Acquisition Method(s)

Describe the data acquisition method and associated QA/QC, considering the following:

a. Qualifications of personnel or organizations generating the data;
b. Technical adequacy of equipment and procedures used;
c. Environmental and programmatic conditions if germane to the data quality;
d. The extent to which acquisition processes reflect modeling requirements;
e. The quality and reliability of the measurement control program;
f. The degree to which independent audits of the process were conducted;
g. Extent and reliability of the associated documentation.

In addition to the listing tables in the ICRP publication 107 (ICRP, 2008), ICRP provides a database for electronic access. The database contains information on the half-lives, decay chains, yields and energies of radiations emitted in nuclear transformations of 1252 radionuclide isotopes of 97 elements. The database can be accessed by a user-defined software such as the Windows-based application provided by ICRP.

For databases, identify query language used to obtain data from database (SQL, etc.), briefly describe the query description and attach copy

The nuclear decay data are embodied in five formatted (hence can be viewed with an ASCII editor) direct-access files. Find a copy of text files and inquiry software: (P107JAICRP_38_3_Nuclear_Decay_Data_suppl_data.zip)

7. Corroborating Data

Identify and discuss any corroborating datasets. Provide any documentation that confirms the corroborating data substantiate existing parameter values, distributions, or data quality.

The ICRP half-lives were compared with three other sources that were listed in the rev 0 of this document. The best match to ICRP-P107 was source 2: DOE-STD-1196-2011, DOE Standard, Derived Concentration Technical Standard (April 2011). Differences were compared to four significant digits, while some half-lives were reported to only two significant digits.

8. Data Quality Considerations

Discuss data quality considerations not identified in other sections. Include discussion of data quality indicators (i.e., accuracy, precision, representativeness, completeness, and comparability).

For the radionuclides reported at the Hanford site, the ICRP half-life parameters match very closely the U.S. DOE standard DOE-STD-1196-2011, which is implemented in the U.S. EPA decay calculation tools. Additionally, the ICRP library is implemented in the GoldSim software that is approved for Hanford Site and used for PA's system models.

The %relative difference between the ICRP-P107 and the DOE-STD-1196-2011 data is less than 0.36% for all Hanford site radionuclides isotopes.

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Environmental Modeling Data Transmittal Cover Page

No.: EMDT-DE-0006 **Revision No.:** 1

[Request EMDT number from Modeling Team Leader]

Title: ***Half-lives for Typical Hanford Site Radioactive Contaminants.*** **Date:** 18-May-2015

9. Assumptions and Limitations on Data Use

Document known uncertainties, assumptions, constraints or limits on data.

The ICRP–P107 provides a reliable information on physical characteristics of a radionuclide (half-life, modes of decay, energies, intensities of the emitted radiations, etc.) that is the starting point in assessing the radiological significance of a radionuclide's presence in the workplace or in the environment. Uncertainties of these information would result from different limitation in accounting for the fraction of the available decay energy given to radiations of discrete energy (alpha particles, gamma rays, conversion electrons, Auger elections, and characteristic x rays) as well as the continuous energy spectra of beta particles. Accounting for such details requires very specific expertise and is a laborious task that is not needed for the subject calculation. The ICRP reported half-lifes provide adequate accuracy for the forward and backward decay calculations needed to accompany transport and fate studies of radionuclides in the environment and the associated risk.

Data Configuration Item Submittal:

Data Provider Submittal

Usama Zaher/ Environmental Engineer – Process Modeling Specialist
NAME/POSITION

Usama [signature] 6/12/2017
SIGNATURE DATE

Data Configuration Item Review and Verification:

10. Verification Process

Describe steps taken to verify that these data are appropriate for intended use, noting any limitations

Implementation in 1st and 2nd order decay calculations in spread sheet. Initial and decayed state estimations was verified in both forward and backward (regrow) decay. The forward decay was also compared with the integration solution in GoldSim. Secular equilibrium is considered for the 2nd order calculations with rapidly decaying daughters relative to parents.

11. Summary of Data Review

The review shall ensure that the report meets the listed criteria. Consideration includes ensuring that the data collection method employed was appropriate for the type of data being considered and confidence in the data acquisition and subsequent processing methodology is warranted.

Is documentation technically adequate, complete, and correct?	[X] Yes	[ ] No
Are uncertainties and limitations on appropriate use of data discussed?	[X] Yes	[ ] No
Are the assumptions, constraints, bounds, or limits on the data identified?	[X] Yes	[ ] No

Data Reviewer Approval	*Approval of Data Configuration Item* M Lord / Senior Hydrogeologist (Signature by WE Nichols with attached email authorization from M Lord) NAME/POSITION SIGNATURE	12 JUN 2017 DATE

EMDT accepted for Composite Analysis input in Data Readiness Review on 12/2/2019.

signature authorization

Michael Lord

Mon 6/12/2017 4:03 PM

To:Will Nichols <wnichols@intera.com>;

I give Will Nichols authorization to sign for me the Environmental Modeling Data Transmittal Cover Page (EMDT) document in file EMDT-DE-00060rev1.docx. I have inspected the data for the radioactive half-lives for reported radionuclides at the Hanford site. My suggested edits to the data and the EMDT document were implemented and with this authorization I am signing my approval of the data configuration item.

Michael Lord

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