ECF-100KR1-17-0087
Revision 2

Determination of Soil Screening Levels and Preliminary Remediation Goals for Waste Sites in the 100-K Source Operable Units

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

CH2MHILL
Plateau Remediation Company

P.O. Box 1600
Richland, Washington 99352

Approved for Public Release;
Further Dissemination Unlimited

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J. B. Fullerton
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P.O. Box 1600
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APPROVED
By Julia Raymer at 8:05 am, Feb 26, 2020

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ENVIRONMENTAL CALCULATION COVER PAGE

SECTION 1 - Completed by the Responsible Manager

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Qualifications Summary

Preparer(s):

Name: Jacob Fullerton

Degree, Major, Institution, Year: MS, Civil Engineering, Brigham Young University, 2017
BS, Civil and Environmental Engineering, Brigham Young University, 2016

Professional Licenses: Engineer in Training (EIT)

Brief Narrative of Experience: Jacob Fullerton's experience encompasses civil and environmental engineering, and is focused on the development and application of groundwater models using codes and platforms such as GMS, ArcMap, and GSSHA. He also brings expertise with coding web applications in multiple programming languages, including Javascript, HTML, JQuery, and Python. He has incorporated an analytic element groundwater model called TimML into a web app capable of performing general groundwater modeling tasks. Additionally, he has created an educational groundwater dewatering web app that simulates aquifer dewatering using wells and slurry trenches.

Checker(s):

Name: Helal Rashid

Degree, Major, Institution, Year: MS, Civil Engineering, Washington State University, 2010
BS, Civil Engineering, Bangladesh University of Engineering & Technology, 2007

Professional Licenses: Professional Engineer (PE), State of Washington

Brief Narrative of Experience: Helalur Rashid's professional experience encompasses numerical modeling of groundwater in the saturated and unsaturated zones, model calibration, groundwater management, geostatistics analysis, sediment transport, and hydraulic characterization of watersheds. He has applied a wide variety of modeling codes and geographic information system software including MODFLOW, MODFLOW-SURFACT, MT3DMS, MODPATH, PEST, Parallel PEST, STOMP, SWAT, HEC-HMS, ArcGIS, Leapfrog Hydro, Groundwater Vistas, RETC, and TecPlot. Helal has worked primarily on environmental restoration projects for the federal government. He is also skilled in using various laboratory and field instruments such as acoustic Doppler velocimeters, laser distance meters, and viscometers.

ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

Senior Reviewer(s):

Name: William Nichols

Degree, Major, Institution, Year: MS, 1990, Civil Engineering, Oregon State University
BS, 1987, Agricultural Engineering, Oregon State University

Professional Licenses:

Brief Narrative of Experience: William "Will" Nichols is a water resources engineer with 29 years of experience in the areas of hydrology, environmental site characterization, fate and transport modeling, pathway and exposure modeling, uncertainty and sensitivity analysis, integrated risk assessment, probabilistic modeling and simulation, and software quality assurance. He has applied his expertise in these areas to help solve problems of national importance in the areas of Resource Conservation and Recovery Act (RCRA)/ Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) remedial investigations and feasibility studies (RI/ FS), radioactive waste disposal facility licensing, National Environmental Policy Act (NEPA) reviews and environmental impact statement (EIS) development, and environmental restoration, dose reconstruction for legacy radioactive waste practices, and demonstration of compliance with applicable waste disposal regulatory requirements. He has successfully led science and engineering teams in software development efforts and scientific studies to deliver high-impact products, including scientific simulators used to evaluate environmental dose and total system performance assessment. Mr. Nichols' NEPA experience includes contributing to long-term consequences portions of EISs for nationally important facilities, including proposed and operating radioactive waste repositories.

SECTION 2 - Completed by Preparer

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SECTION 4 - Document Review and Approval

Preparer(s):

Jacob Fullerton	Groundwater Modeler	Jacob Fullerton	2/17/2020
Print First and Last Name	*Position*	*Signature*	*Date*

ENVIRONMENTAL CALCULATION COVER PAGE (Continued)

Checker(s):

Print First and Last Name	Position	Signature	Date
Helal Rashid	Hydrologist	S.M. Helalur Rashid	02/17/2020

Senior Reviewer(s):

Print First and Last Name	Position	Signature	Date
William Nichols	Modeling Team Leader	[signature]	17 FEB 2020

Responsible Manager(s):

Print First and Last Name	Position	Signature	Date
Alaa Aly	Risk & Model Integr Mgr	See below	JRR 2/26/20 per e-mail with W. Nichols

SECTION 5 - Applicable if Calculation is a Risk Assessment or Uses an Environmental Model

Prior to Initiating Modeling:

Required training for modelers completed:
Integration Lead:

Print First and Last Name	Signature	Date
William Nichols	[signature]	17 FEB 2020

Safety Software Approved:
Integration Lead:

Print First and Last Name	Signature	Date
William Nichols	[signature]	17 FEB 2020

Calculation Approved:
Risk/Modeling Integration Manager:

Print First and Last Name	Signature	Date
Alaa Aly	[signature]	2/18/2020

Environmental Calculation File

STOMP 1-D Modeling for Determination of Unit-Length Soil Screening Levels and Preliminary Remediation Goals for Waste Sites in the 100-K Source Operable Unit

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Abbreviations

ARARs	applicable regulations and requirements
AWLN	automated water level network
AWQL	applicable water quality standards
CHPRC	CH2M HILL Plateau Remediation Company
COPC	contaminant of potential concern
CPK	peak groundwater concentration
ECF	environmental calculation file
EPC	exposure point concentration
RDL	required detection limit
FEPs	features, events, and processes
HEIS	Hanford Environmental Information System (environmental database)
HISI	Hanford Information System Inventory (software database)
HSU	hydrostratigraphic unit
LSU	lithostratigraphic unit
MCL	maximum contaminant level
PNNL	Pacific Northwest National Laboratory
POCal	point of calculation
PRG	preliminary remediation goal
OHWL	ordinary high-water level
OU	Operable Unit
RAG	remedial action goal
RESRAD	RESidual RADiation (modeling software)
RUM	Ringold upper mud
SSL	soil screening level
STOMP	Subsurface Transport Over Multiple Phases (modeling software)
TINs	triangulated irregular networks
WAC	Washington Administrative Code
WQS	water quality standard

1 Purpose

The objective of this environmental calculation file (ECF) is to provide unit-length soil screening levels (SSLs) and unit-length preliminary remediation goals (PRGs) protective of surface water and protective of groundwater in the 100-KR-1 and 100-KR-2 source operable units (collectively referred to as the 100-K Area or 100-K OUs herein). This calculation is performed with models implemented in the STOMP©[1] (Subsurface Transport Over Multiple Phases) fate and transport simulation software (PNNL-11216, *STOMP Subsurface Transport Over Multiple Phases: Application Guide*; PNNL-12030, *STOMP Subsurface Transport Over Multiple Phases: Theory Guide*; PNNL-15782, *STOMP Subsurface Transport Over Multiple Phases: Version 4.0: User's Guide*). This calculation follows the approach set forth in DOE/RL-2011-50, *Regulatory Basis and Implementation of a Graded Approach to Evaluation of Groundwater Protection.* Detailed information on the development and basis of the models implemented in STOMP for this calculation is provided in SGW-50776, *Model Package Report: Vadose Zone Model for the River Corridor*. The model framework used in this analysis is identical to that used in ECF-HANFORD-11-0063, *STOMP 1-D Modeling for Determination of Soil Screening Levels and Preliminary Remediation Goals for Waste Sites in the 100-D and 100-H Source Operable Units*. Site-specific modeling and sensitivity analyses, allowed under the graded approach, were not needed for the 100-K Area.

SSLs are used to identify areas needing further investigation. PRGs represent soil concentration or radionuclide activity that can remain in the vadose zone at a site without causing an exceedance of groundwater, or surface water, quality standards. Unit-length SSLs and PRGs are provided because SSLs and PRGs are inherently dimensional values that depend on the extent of the contaminated soil in the direction of groundwater flow. Hence, unit-length values are provided that are readily scalable to the length of waste sites in the general direction of groundwater flow. Based on numerical flow and solute transport simulations developed using several conservative assumptions, unit-length SSLs and PRGs specific to the 100-K source OUs were calculated for 54 non-radionuclides and 15 radionuclides in groundwater and 54 non-radionuclides in surface water (specifically, the Columbia River). The approach used here is to calculate unit-length SSLs in the same manner as unit-length PRGs but using a more conservative recharge rate based on an irrigated farming scenario (recognizing this is not the planned land use for the 100-K Area). This approach honors the primary importance of recharge as the parameter influencing breakthrough rates for vadose zone contamination into groundwater, and uses irrigation recharge rates to provide an upper bound on this parameter for screening purposes. The resulting unit-length SSL and PRG values are only applicable to the 100-K Area waste sites where the assumptions and conditions described in this ECF are representative.

Conceptual and numerical models of flow and solute transport under variably saturated conditions were developed for conditions representative of the lithology and hydrology observed at various waste sites within the 100-K source OUs. Conditions specific to the larger 100 Area, or specific to the 100-K Area, include time-varying recharge rates specific to the 100 Area, 100-K-Area-specific vadose zone thickness and lithology, 100-K-Area-specific hydraulic properties, and 100-K-Area-specific aquifer fluxes. Numerical assumptions include that liquid-phase water flow and solute transport under variably saturated conditions are adequately described by the Richards equation and the advection-dispersion equation with radioactive decay and linear sorption and no volatilization or hydrodynamic dispersion, respectively.

Contaminant migration from waste sites in the 100-K OUs through the vadose zone to the underlying aquifer is controlled by the driving forces, interactions between water and sediments, and interactions between the contaminants and the sediments. The hydraulic driving forces include gravity; matric potential gradients; recharge, which is the net result of competition between precipitation, evaporation, transpiration,

[1] Battelle Memorial Institute (Battelle) retains copyright on all versions, revisions, and operational modes of the Subsurface Transport Over Multiple Phases (STOMP) software simulator, as permitted by the U.S. Department of Energy. STOMP is used here under a limited government use license.

infiltration, run-off, and run-on; and artificial (anthropogenic) discharges, such as those from liquid discharges to septic tank leach fields, ponds, lagoons, pipe and tank leaks, and by irrigation. The types, thicknesses, and properties of the sediments can all affect the rate and direction of solute and water movement to the aquifer. A contaminant's concentration in the groundwater and its concentration in the downgradient Columbia River, including the peak concentration, are dependent on the solute flux from the vadose zone; aquifer thickness, properties, and flux rates; travel distance; groundwater and river water mixing; and the location sampled. Each contaminant's propensity to sorb to vadose zone or aquifer materials can also be important controlling factors on the groundwater concentration determination.

The STOMP-W operational mode of STOMP (which solves for water mass conservation and dilute species mass conservation) was used to solve the Richards equation and the advection-dispersion equation that govern water flow and solute transport, respectively, under variably saturated conditions in porous media. The governing equations solved by the STOMP software are well-documented in PNNL-12030. Numerical simulations generated using STOMP provided predictions of groundwater concentration and time to reach the breakthrough of the maximum concentrations for a list of contaminants based on a range of recharge rates, sediment types, vadose-zone thicknesses, and properties appropriate to the 100-K OUs. The peak concentration within 1000 years was used in calculating unit-length SSLs and PRGs. The 1000-year limit was based on regulatory comment.

2 Methodology

Fate and transport simulations performed with the STOMP code were used to calculate peak groundwater concentrations resulting from a bounding representation of initial contaminant source in the vadose zone. The peak groundwater values obtained from those simulations were used to derive unit-length SSL and PRG values protective of groundwater, and protective of surface water, for the 100-K source OUs. The STOMP code was selected to perform the simulations on the basis of its ability to adequately simulate the vadose zone features, events, and processes (FEPs) relevant to calculating SSLs and PRGs in the 100-K OU and to satisfy the other code criteria and attributes identified in DOE/RL-2011-50, *Regulatory Basis and Implementation of a Graded Approach to Evaluation of Groundwater Protection*, a document that describes the approach and provides the regulatory basis for using STOMP in this type of evaluation. Detailed information on the development and basis of the models used in this calculation are provided in SGW-50776, *Model Package Report: Vadose Zone Model for the River Corridor*.

Many of the methodologies, model inputs, and assumptions for computing SSLs and PRGs were developed to determine remedial action goals (RAGs) as part of DOE/RL-96-17, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*. Although the calculation methods are similar, the RAGs were calculated with the RESRAD (RESidual RADiation) model (ANL/EAD-4, *User's Manual for RESRAD Version 6*) and the SSLs and PRGs in this calculation were calculated with the STOMP software. A notable difference in approach is that the RAGs were developed as single values based on an assumed waste site dimension, whereas the SSLs and PRGs in this claucaiton are provided on a unit-length basis appropriate for direct scaling for evalaution of waste sites by site-specific representative dimensions.

2.1 Definition of Soil Screening Levels and Preliminary Remediation Goals

SSLs are risk-based concentrations derived from standardized equations combining exposure information assumptions with EPA toxicity data (EPA/540/F095/041, *Soil Screening Guidance: Fact Sheet*). EPA provides a methodology for calculation of risk-based, site-specific SSLs for contaminants in soil that may be used to identify areas needing further investigation at National Priorities List sites. The approach used here is to derive SSLs in the same manner as PRGs (see below) but using a more conservative recharge rate based on an irrigated farming scenario. This approach recognizes the primary importance of recharge as parameter influencing breakthrough rates for vadose zone contamination into groundwater, and uses the irrigation based recharge rates as an upper bound on this parameter for screening purposes.

PRGs represent the maximum quantity, whether soil concentration or radionuclide activity, of a contaminant of potential concern (COPC) that can remain in the vadose zone without causing an exceedance of applicable regulatory standards. PRGs can be defined for protection of groundwater or protection of surface water simply by the choice of the applicable standard used in the calculation. The PRG calculation in this ECF is evaluated based on the peak release of a COPC under a native vegetation recharge scenario that is consistent with the land use plans for the 100-KR-1 and 100-KR-2 source OUs (Section 3.2.1.1). In contrast, the SSL calculation is based on a conservative (bounding) irrigation recharge scenario (Section 3.2.1.2). The value of a SSL or of a PRG for a COPC depends on several key factors:

- Waste site characteristics, specifically, source mass distribution and distance to the water table;
- Land cover condition and the associated net recharge rate;
- Interactions between the vadose zone geology and water movement;
- Interactions between the vadose zone geology and contaminant chemistry.

The unit-length SSLs and PRGs presented in this ECF are calculated for a unit-length source term and should not be applied at any given waste site without scaling by the appropriate length dimension, in the general direction of groundwater flow under the waste site to be evaluated. As described in Section 2.6, waste-site unit-length SSL and PRG values used for evaluation of exposure point concentrations (EPCs) are to be calculated by dividing the SSL or PRG value by the representative length of the waste site decision unit in the general direction of groundwater flow.

Model simulations were carried out for a comprehensive list of analytes that were detected in the remediated waste sites. Unit-length SSLs and PRGs protective of groundwater were calculated for all COPCs (radionuclide and non-radionuclide analytes) and unit-length SSLs and PRGs protective of surface water were calculated for all non-radionuclide COPCs.

2.2 Identification of Representative Lithostratigraphic Columns

Borehole data were used to identify representative lithostratigraphic columns for 100-K source OUs. Only 2 lithostratigraphic units (LSUs) are present in the 100-K vadose zone: the gravel-dominated Hanford formation and the Ringold Formation's E unit, which contains a slightly smaller percentage of coarse-grained sediments and a higher percentage of finer-grained sediments than the Hanford formation (SGW-44022, *Geohydrologic Data Package in Support of 100-BC-5 Modeling*; SGW-46279, *Conceptual Framework and Numerical Implementation of 100 Areas Groundwater Flow and Transport Model*). Using the June 2008 water table elevations to represent the highest annually occurring water table, a conservative (smaller) thickness of the vadose zone was computed for each well and borehole. The borehole data were also used to estimate the thicknesses of each LSU within the vadose zone and within the aquifer. The boreholes were divided into groups based on the proportion of each LSU and total vadose zone thickness. A representative lithostratigraphic column was selected for each borehole group within the 100-K source OUs, resulting in ten lithostratigraphic columns to be used in the STOMP simulations (refer to Section 3.1.1 below).

The water table elevations of June 2008 were selected to provide representative (not extreme) high water table conditions; the month of June is typically when the highest river stages occur in this reach of the Columbia River. Where boreholes did not have data for June 2008 similar water years during the month of June were evaluated to determine vadose zone thicknesses. Use of water table elevations from the high-water stage period result in a conservative (thinner) thickness of the vadose zone for each well and borehole to develop the representative stratigraphic profiles. Imposing conservative bias towards a thinner thickness reduces the travel distance for contaminants in the vadose zone, and thereby biases the resulting peak groundwater concentration calculated to arrive sooner and with greater magnitude – resulting in more

restrictive SSL and PRG values than otherwise. These well and borehole data were used to estimate the thicknesses of each lithostratigraphic unit in each source area within vadose zone and aquifer sediments. The wells and boreholes were grouped based on the proportion of each lithostratigraphic unit present and total vadose zone thickness. A representative stratigraphic column was selected for each well and borehole group within each source area.

The lowest portion of each representative lithostratigraphic column is used to represent the upper 5 meters (m) of the unconfined aquifer such that the water flux through this downgradient aquifer boundary of the model domain represents a 5 m monitoring well screen. This representation is consistent with the requirements for accounting for the aquifer mixing zone thickness specified in the Washington Administrative Code (WAC), specifically WAC 173-340-747[5][f][i], which stipulates that the aquifer mixing zone thickness shall not exceed 5 m in depth. Aquifer dilution is thus directly simulated in the STOMP solution based on the OU-specific hydraulic gradient imposed as a boundary condition across those nodes representing the aquifer portion of the representative lithostratigraphic column.

2.3 STOMP Flow and Transport Simulation

Peak groundwater concentrations in the aquifer at the downgradient edge of the modeled waste site within each of the representative stratigraphic columns were calculated using STOMP to solve the governing equations for flow and solute transport under variably saturated conditions (Sections 3 and 5). Peak concentrations of selected COPCs (Attachment A) were calculated for two different initial contaminant source distributions (Section 3.2.4) with two different recharge scenarios for each representative stratigraphic column (Section 3.1.1).

2.4 Calculation of Peak Groundwater Concentration within 1000 Years

Peak groundwater concentrations within 1000 years were calculated for each model time step along a portion of the domain's downgradient boundary corresponding to the top 5 m of the aquifer. Using the upper 5 m of the aquifer is consistent with the requirements for aquifer mixing zone thickness in WAC 173-340-747[5][f][i]. The concentration was conservatively estimated by calculating it in the aquifer beneath the downgradient edge of the waste site footprint. These groundwater concentrations and the year that they occurred were tabulated to find the peak concentration of contaminant in groundwater and its year of occurrence.

2.5 Point of Calculation, Point of Compliance, and Protectiveness Criteria

In accordance with risk assessment guidelines, the determination of soil contamination impacts to groundwater and surface water 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 (resulting from soil contamination at the point of compliance), and (2) the protectiveness metric, i.e., the groundwater and surface water metric(s) to be used in the assessment of protectiveness at the POCal (DOE/RL-2011-50).

The POCal for the protection of groundwater and surface water 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]*) in federal and state regulations and guidelines (DOE/RL-2011-50).

The "point of compliance" under the WAC is the soil throughout the vadose zone (WAC-173-340-740(6)(b)). The POCal is the point where the peak groundwater concentration resulting from the uniform initial soil concentration is calculated in the forward calculation. This peak groundwater concentration is then used to back-calculate the maximum allowable soil concentration at the point of compliance (all soil

in the vadose zone) to determine the maximum soil contamination level that will not result in exceedance of groundwater or surface water protection levels.

The representative columns are represented in STOMP as a single vertical column of computational grid blocks. For this calculation, the POCal is the outflow (downgradient) edge those grid blocks that correspond to the topmost 5 m of the aquifer, representing the screened portion of a monitoring well. The peak value of concentration within the topmost 5 m of the aquifer was scaled by the appropriate regulatory compliance criteria in a back-calculation step to determine unit-length SSL and PRG values for the point of compliance (vadose zone soil). The protectiveness criteria are the applicable water quality standards for groundwater and surface water (e.g., applicable regulations and requirements [ARARs], maximum contaminant levels [MCLs], or applicable water quality standards [AWQLs]) values for each contaminant. The applicable water quality standard for each contaminant for protectiveness of groundwater and surface water in the 100-K Area are listed in the tables of unit-length SSL values in Attachment A, and in the tables of unit-length PRG values in Attachment B, of this ECF.

2.6 Calculation of Unit-Length Soil Screening Level and Unit-Length Preliminary Remediation Goal Values

A simple calculation was employed to compute unit-length SSL and PRG values by scaling the peak concentration values against the regulatory compliance criteria and the initial soil concentration. As a measure of allowable quantity of contaminant in the soil, evaluation SSLs and PRGs are expressed as contaminant mass per mass of soil for non-radionuclides or as contaminant activity per mass of soil for radionuclides. Unit-length SSLs and PRGs are expressed as the product of length in the general direction of groundwater flow and either the contaminant mass per mass of soil for non-radionuclides or contaminant activity per mass of soil for radionuclides.

The unit-length SSL for each COPC is computed as:

$$SSL_{unit-length} = C_I \frac{WQS}{CPK} \tag{1a}$$

where,

$SSL_{unit-length} \equiv$ unit-length soil screening level $\left[\frac{\text{mg}}{\text{kg}}\cdot\text{m or } \frac{\text{pCi}}{\text{g}}\cdot\text{m}\right]$

$C_I \equiv$ initial soil mass, or activity, concentration $\left[\frac{\text{mg}}{\text{kg}}\cdot\text{m or } \frac{\text{pCi}}{\text{g}}\cdot\text{m}\right]$

$WQS \equiv$ water quality standard $\left[\frac{\text{mg}}{\text{L}} \text{or } \frac{\text{pCi}}{\text{L}}\right]$

$CPK \equiv$ peak groundwater mass, or activity, concentration $\left[\frac{\text{mg}}{\text{L}} \text{or } \frac{\text{pCi}}{\text{L}}\right]$

Similarly, the unit-length PRG for each COPC is computed as:

$$PRG_{unit-length} = C_I \frac{WQS}{CPK} \tag{1b}$$

where,

$PRG_{unit-length}$

$\equiv$ unit-length preliminary remediation goal $\left[\frac{\text{mg}}{\text{kg}}\cdot\text{m or } \frac{\text{pCi}}{\text{g}}\cdot\text{m}\right]$

C_I $\equiv$ initial soil mass, or activity, concentration $\left[\frac{\text{mg}}{\text{kg}}\cdot\text{m or } \frac{\text{pCi}}{\text{g}}\cdot\text{m}\right]$

WQS $\equiv$ water quality standard $\left[\frac{\text{mg}}{\text{L}}\text{or } \frac{\text{pCi}}{\text{L}}\right]$

CPK $\equiv$ peak groundwater mass, or activity, concentration $\left[\frac{\text{mg}}{\text{L}}\text{or } \frac{\text{pCi}}{\text{L}}\right]$

Peak groundwater concentrations (*CPK*) used in Equations (1a) and (1b) are obtained from the conservative irrigation recharge scenario simulations (Section 3.2.1.2) and the native vegetation recharge scenario simulations (Section 3.2.1.1), respectively.

Unit-length SSLs and PRGs are derived for protection of either surface water or of groundwater by using the applicable water quality standard as the *WQS* variable in Equations (1a) and (1b).

The unit-length SSL and PRG values are specified in terms of unit length to provide for direct scaling to representative waste site dimension in the general direction of groundwater flow ($L_{\|GW}$, expressed in meters) to obtain evaluation SSL and PRG values appropriate to evalaution of EPC values using Equations 2a and 2b, respectively:

$$SSL_{evaluation} = \frac{SSL_{unit-length}}{L_{\|GW}} \tag{2a}$$

$$PRG_{evaluation} = \frac{PRG_{unit-length}}{L_{\|GW}} \tag{2b}$$

The values of $SSL_{\text{unit-length}}$ and $PRG_{\text{unit-length}}$ calculated using Equations (1a) and (1b), respectively, are derived from model simulations representative of a soil column that extends a distance of one meter along the general direction of groundwater flow (Section 3.1). To determine waste-site values, the unit-length values are divided by the representative length of the waste site. To illustrate this concept, assume that the calculated $SSL_{\text{unit-length}}$ for some COPC is $1.0\,\frac{\text{mg}}{\text{kg}}\cdot\text{m}$ (Figure 2-1a). That means that a concentration of 1.0 mg/kg of the COPC in the vadose zone of a one-meter wide soil column results an outflow from that column of groundwater with a concentration equal to the MCL. Suppose, however, that the waste site under consideration has a representative length of 5 m – i.e., extends 5 m in the general direction of groundwater flow. This situation can be represented as five one-meter-wide soil columns assembled in series along the direction of groundwater flow (Figure 2-1b). In this case, the contamination from each individual column contributes to the outflow concentration in groundwater, so the five-meter effective SSL for evaluation of this specific waste site ($SSL_{evaluation}$) would be:

$$SSL_{evaluation} = \frac{SSL_{unit-length}}{L_{\|GW}} = \frac{1\ \frac{\text{mg}}{\text{kg}}\cdot\text{m}}{5\text{ m}} = 0.2\,\frac{\text{mg}}{\text{kg}}$$

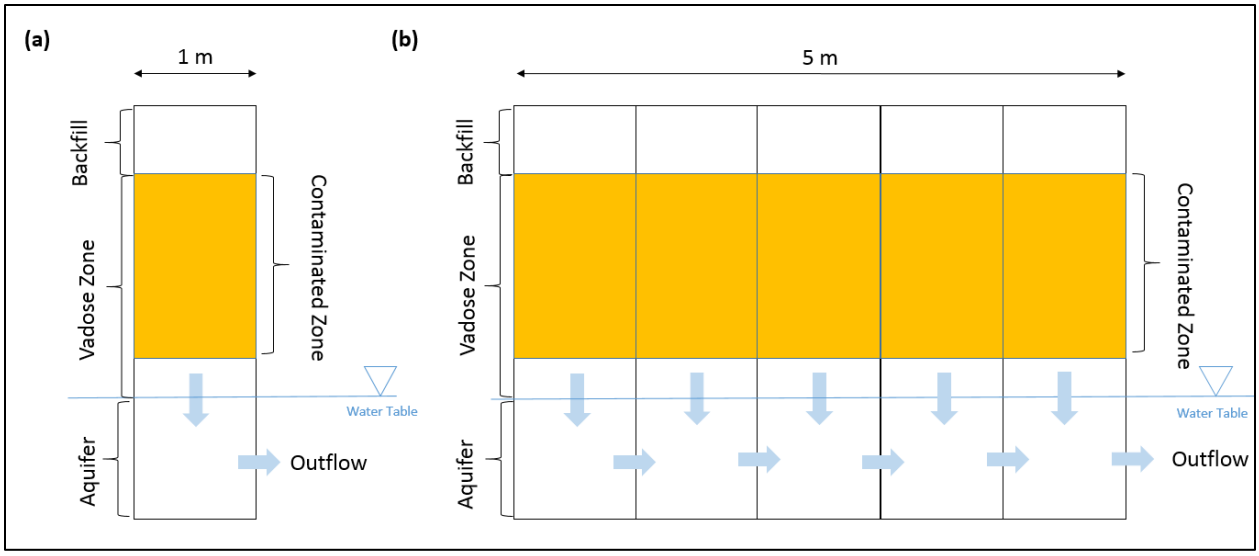

Figure 2-1. Example of Application of Unit-Length SSL or PRG to a Waste Site Decision Unit

When scaling the unit-length SSL or PRG values for use in comparison to EPC values, two additional checks are required;

1. It is possible that scaling by the representative waste site decision unit dimension could result in evaluation SSL or PRG values that are less than the background level for a given COPC; in these cases, the EPC will not be considered to exceed the evaluation (scaled) SSL or PRG values; and

2. It is possible that scaling by the representative waste site decision unit dimension could result in evaluation SSL or PRG values that are less than the required detection limit (RDL); in these cases, the EPC will not be considered to exceed the evaluation (scaled) SSL or PRG values.

2.6.1 Lower Threshold of Numerical Significance for Peak Groundwater Concentrations

Breakthrough is assumed not to occur in cases where the simulated peak groundwater concentration within the 1000-year limit does not exceed 0.0001 µg/L for non-radionuclide COPCs and 0.0001 pCi/m^3 for radionuclide COPCs. This breakthrough threshold is used to set a minimum level of numerical significance for groundwater peak concentrations reported by the numerical model. Use of values less than this breakthrough threshold would result in extremely high unit-length SSL or PRG values that would not constitute a meaningful limit on residual soil contamination. Consequently, where breakthrough does not occur under this assumption, the unit-length SSL or PRG value is encoded “NR” to signify a non-representative result.

2.6.2 Lower Threshold of Required Detection Limit for Unit-Length Soil Screening Levels and Unit-Length Preliminary Remediation Goals

If the unit-length SSL or PRG calculated for a given COPC is below the RDL for the soil concentration of that COPC, then the RDL is substituted for the unit-length SSL or PRG value as a lower bound. The soil RDL represents the lowest concentration that can be reliably measured within specified limits of precision and accuracy during routine laboratory operating conditions. RDLs are normally arbitrarily set rather than explicitly determined; for this calculation, RDLs are those specified in DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*.

2.6.3 Upper Threshold of Pore Space Maximum Contaminant Mass Capacity for Non-radionuclide Unit-Length Soil Screening Level and Unit-Length Preliminary Remediation Goal Values

Unit-length SSL and PRG values were calculated from the peak groundwater concentrations using Equations (1a) and (1b), respectively, and the applicable surface water and groundwater regulatory standards. Where simulated peak groundwater concentrations were very small, application of Equations (1a) and (1b) would yield physically unrealistic soil concentrations, e.g., 10 kg of aluminum per 1 kg of soil. Listing such unphysical protection levels is not meaningful, so an upper physical bound for unit-length SSL and PRG values is specified here that is derived based on considering the extreme of total contaminant mass that can occupy the soil pore space within a unit mass (1.0 kg) of bulk soil. The bulk density (ρ_b) of 100 Area soils is 1930 kg/m^3, so the total volume (V_T) of this soil (sum of soil and pore space) is calculated as

$$V_T = \frac{m_{soil}}{\rho_b} = \frac{1\ \text{kg}}{1930\,\frac{\text{kg}}{\text{m}^3}} = \ 5.18 \times 10^{-4}\ \text{m}^3 \tag{3}$$

At maximum, COPC mass is assumed to occupy the total porosity fully. Therefore, the maximum mass of COPC in the soil is calculated as

$$m_{max,p} = \ n_T \times V_T \times \rho_p \tag{4}$$

where n_T is the total porosity and ρ_p is the particle density of the COPC. In the 100 Area, the highest total porosity of the Hanford formation or of the Ringold Formation is 0.28. The particle density of the COPC is assumed equal the highest particle density of the Hanford formation or of the Ringold Formation, which is 2680 kg/m^3 for the Hanford formation (PNNL-18564, *Selection and Traceability of Parameters to Support Hanford-Specific RESRAD Analyses*). Substituting into Equation (4), the maximum mass of COPC in 1.0 kg soil is then calculated as

$$m_{max,p} = \ (0.28) \times \left(5.18 \times 10^{-4}\ \text{m}^3\right) \times \left(2680\ \frac{\text{kg}}{\text{m}^3}\right) = 0.389\ \text{kg} \times \left(\frac{1{,}000{,}000\ \text{mg}}{1\ \text{kg}}\right)$$
$$= 389{,}000\ \text{mg}$$

Thus, the maximum unit-length SSL or PRG value for non-radionuclides is 389,000 mg·m per kg of soil. Therefore, unit-length SSL or PRG values that exceed this physical upper bound are truncated at physical upper bound value 389,000 mg·m/kg. Note that this physical upper bound is not applied to radionuclide unit-length SSL or PRG values because these are expressed in terms of activity rather than mass.

A similar threshold was presented for maximum radioactivity in soil in SGW-50776. However, it was redundant to apply that limit here because a value for that would exceed that limit would also exceed the lower threshold of numerical significance for peak groundwater concentrations (Section 2.6.1).

2.6.4 Cleanup Levels for Hexavalent Chromium based on Limitation of Sorption Data

ECF-HANFORD-11-0165, *Evaluation of Hexavalent Chromium Leach Test Data Conducted on Vadose Zone Sediment Samples from the 100 Area*, provides quantitative evaluations of leach test results and the derivation of a conservative-basis K_d for hexavalent chromium for evaluation of future fate and transport of residual vadose zone contamination after interim remedial actions have been implemented for source waste sites in the vadose zone. These evaluations were based on the results of leaching studies conducted on soil samples from a large number (about 200) of leach studies for vadose zone soils across the River Corridor, including both high concentration/low volume waste sites, low concentration effluent waste sites,

and boreholes not associated with a waste site. The soil concentration data for which the K_d value was derived had a maximum value of 6.0 mg/kg, and hence there is no basis to infer greater soil cleanup levels for hexavalent chromium based on the limited range of these data. These leach test data also indicate that for hexavalent chromium at concentrations below 6.0 mg/kg are highly non-leachable. Therefore, the SSL and PRG values for hexavalent chromium using the K_d recommended in ECF-HANFORD-11-0165 (0.8 mg/L) are set to a soil concentration value of 6.0 mg/kg, consistent with the data range and leaching test results. This value is not scaled by the representative dimension in the general direction of groundwater flow because the basis for the K_d value are bounding results for intentionally aggressive leaching methods that showed Cr(VI) concentrations below 6 mg/kg in the vadose zone are highly non-leachable – a result that is not dependent on the dimensionality of the model. Additionally, note that the soil PRG values for protection of groundwater and surface water for hexavalent chromium is not based on the results of fate and transport modeling, but rather on interim cleanup actions (originally based on the "100 times rule") which assigns the more restrictive value of 2.0 mg/kg.

3 Assumptions and Inputs

Two sequential STOMP simulations were used to determine peak groundwater concentrations. The first stage, termed the historic pre-2010 simulation, modeled flow through the representative columns for a 2010-year period prior to the commencement of predictive modeling. The purpose of this arbitrarily long simulation period is merely to achieve equilibrium (steady state) in the flow conditions in the model domain. Review of the first-stage matric potential and volumetric water content values over the last 100 years confirmed that fluxes in the column had reached equilibrium conditions at the end of the simulation.

The second stage, termed the predictive post-2010 simulation, modeled flow and transport for a 1000-year period commencing in calendar year 2010, a year selected to represent the present. Denoting the starting year as 2010 is done to allow consistency with PRG and SSL calculations for other river corridor evaluations.

Results from the historic pre-2010 simulations established the initial aqueous pressure conditions for the 1000-year-long second-stage simulation, the predictive post-2010 simulation, which solved for both flow and solute transport. The predictive solute transport simulations tracked the fate of contaminants with COPC-specific distribution coefficients and radioactive decay constants through the vadose zone and into the aquifer. These results were used to identify the peak groundwater concentrations (within 1000 years) and year the peak concentration occurs.

STOMP estimates of peak groundwater concentration depend on the model inputs and assumptions. Inputs to the models and their underlying assumptions are presented in the following categories:

- Model domains
- Boundary conditions and initial conditions
- Hydraulic and transport parameters
- Contaminant source term

Each of these input categories is discussed in the sub-sections that follow.

3.1 Model Domain

Conceptually, the model represents a column of sediments that comprise a vadose zone underlain by an aquifer (referred to herein as the saturated zone). Recharge-driven flow moves downward through the vadose zone, where it encounters contamination that is eventually transported to an underlying aquifer, across which a pressure gradient drives horizontal flow. At the start of each predictive simulation, the

vadose zone comprises a cover of clean fill with constant thickness as well as contaminated and uncontaminated sediments of varying thickness. The saturated zone constitutes the base of the column.

3.1.1 Representative Lithostratigraphic Columns

The total column thickness and the thickness of the vadose zone vary according to the geology of each source area. Only the thickness of the clean backfill was held constant at 4.5 m. Thickness of the vadose zone, thickness of the saturated zone (that is, the aquifer), and the percentages of the different LSUs in each were determined using borehole data from the Hanford Environmental Information System (HEIS) borehole database (Table 3-1 and Table 3-2). A conservative (thinner) estimate of vadose zone thickness was calculated by taking the difference between ground surface elevation and the June 2008 water table elevation, which is representative of the seasonal high-water table elevation (conservatism here is with respect to minimizing the vadose zone travel distance for contaminants).

Because of natural variability in the thickness of various LSUs, it is impractical to calculate SSL and PRG values for all possible variations in thicknesses observed in the various boreholes. Instead, representative lithostratigraphic columns were identified to provide a representative range of LSU variability in the source OU. The representative lithostratigraphic columns were identified by collecting and reviewing geologic data from boreholes nearest to the waste sites in each geographic area (in total, 37 boreholes from the 100-K area were included in the analysis). All borehole data were taken from the HEIS borehole database. The representative lithostratigraphic columns include geologic material in both the vadose zone and the unconfined aquifer. Using water table elevations representing the annually occurring highest water table, a minimum thickness of the vadose zone was computed for each borehole (minimum thickness is conservatively selected to reduce contaminant transport time, thereby biasing peak groundwater concentrations higher). The borehole data also provided estimates of the thicknesses of each LSU within the vadose zone and within the aquifer. The boreholes were divided into groups based on the proportion of each LSU and total vadose zone thickness. This process yielded representative lithostratigraphic columns for each source area (Figure 3-2) derived from the borehole data using vadose zone thickness and lithostratigraphic composition (Table 3-1 and Table 3-2). Boreholes from each source area were divided into groups that represented the range of vadose zone thicknesses and lithostratigraphic compositions. The objective was to create a limited, practical number of representative lithostratigraphic columns for each source area so that the number of STOMP simulations would be reasonable, while capturing the range of variability throughout each area. This was accomplished by dividing the boreholes for each source area into groups based on a range of vadose zone-thickness intervals and then identifying one or more representative lithostratigraphic compositions. Where source areas meet at a shared borehole the same borehole was included in both groupings (as applicable).

A 5 m thickness of the saturated zone (aquifer) was used in STOMP simulations in accordance with WAC 173-340-747(5)(f)(i) and equation 747-4 for A, aquifer mixing zone. The representative lithostratigraphic columns at each source area are shown in Figure 3-2. Each column was assumed to include clean backfill in the uppermost 4.5 m of the column, representing conditions following interim remediation. STOMP's inactive nodes feature was not used for this model. In this ECF; "Ringold E", "Ringold Formation E", and "Ringold E Formation"; are used interchangeably to mean "Ringold Formation E".

Table 3-1. 100-K Representative Lithostratigraphic Columns

Representative Column Index	Representative Vadose Zone Thickness (m)	Representative Vadose Zone Composition	Thickness of Backfill in Vadose Zone (m)	Thickness of Hanford in Vadose Zone (m)	Thickness of Ringold E in Vadose Zone (m)	Corresponding Wells	Thickness of Backfill (m)	Thickness of Hanford (m)	Thickness of Ringold E (m)	Thickness of Ringold Upper Mud (m)	Actual Vadose Zone Thickness (m)	Assigned Saturated Zone (Aquifer) Thickness (m)
Column 1	25	18% Backfill 34% Hanford 48% Ringold E	4.5	8.5	12	199-K-173	0.3	10.4	42.5	2.0	25	5
						199-K-158	0.6	17.7	16.9	(N/P)		
						199-K-167	0.3	10.4	1.8	(N/P)		
Column 2A	16	28% Backfill 42% Hanford 34% Ringold E	4.5	1.5	10	199-K-32B	1.2	9.8	30.5	12.2	16	5
						199-K-32A	6.1	3.4	11.6	(N/P)		
						199-K-144	0.6	2.7	26.2	3.1		
						199-K-178	0.3	7.3	32.9	0.2		
						199-K-181	0.6	5.5	33.8	1.5		
						199-K-190	(N/P)	4.0	36.6	5.8		
						199-K-210	(N/P)	5.2	30.2	1.9		
Column 2B	18.5	20% Backfill 42% Hanford 34% Ringold E	4.5	7.75	6.25	199-K-163	0.9	11.3	21.3	1.1	18.4	5
						199-K-154	0.9	11.3	18.9	1.8		
Column 3	22.75	20% Backfill 53% Hanford 27% Ringold E	4.5	12	6.25	199-K-109A	11.7	(N/P)	35.5	3.9	22.6	5
						199-K-189	0.0	11.0	36.0	1.5		
						199-K-202	12.8	(N/P)	33.8	2.2		
						199-K-186	1.8	12.8	34.7	1.5		
Column 4	20.75	22% Backfill 18% Hanford 60% Ringold E	4.5	3.75	12.5	199-K-111A	9.0	(N/P)	38.3	9.1	20.6	5
						199-K-157	0.9	7.3	34.1	1.3		
Column 5A	25	18% Backfill 29% Hanford 53% Ringold E	4.5	7.25	13.25	199-K-165	0.3	8.5	44.9	1.3	25	5
						199-K-166	0.3	7.9	42.4	1.4		
						199-K-137	0.9	17.4	14.8	(N/P)		
						199-K-108A	9.1	(N/P)	19.4	(N/P)		

Table 3-2. 100-K Representative Lithostratigrphic Columns (cont'd)

Representative Column Index	Representative Vadose Zone Thickness (m)	Representative Vadose Zone Composition	Thickness of Backfill in Vadose Zone (m)	Thickness of Hanford in Vadose Zone (m)	Thickness of Ringold E in Vadose Zone (m)	Corresponding Wells	Thickness of Backfill (m)	Thickness of Hanford (m)	Thickness of Ringold E (m)	Thickness of Ringold Upper Mud (m)	Actual Vadose Zone Thickness (m)	Assigned Saturated Zone (Aquifer) Thickness (m)
Column 5B	23	20% Backfill 9% Hanford 72% Ringold E	4.5	2	16.5	199-K-106A	6.1	0.3	43.1	8.4	23.1	5
						199-K-107A	5.8	(N/P)	23.2	(N/P)		
						199-K-34	1.1	5.0	21.5	(N/P)		
						199-K-139	0.3	7.9	24.8	(N/P)		
Column A1	15.5	29% Backfill 32% Hanford 39% Ringold E	4.5	5	6	199-K-138	0.3	8.8	20.7	(N/P)	15.6	5
						199-K-132	0.2	8.1	18.6	(N/P)		
						199-K-33	7.6	(N/P)	12.5	(N/P)		
						199-K-32B	1.2	9.8	30.5	12.2		
Column B1	7	64% Backfill 36% Ringold E	4.5	(N/P)	2.5	199-K-144	0.6	2.7	26.2	3.0	7.1	5
						199-K-145	1.2	2.4	32.3	1.7		
						199-K-162	0.6	8.5	29.9	1.7		
						199-K-120A	0.9	(N/P)	28.3	1.5		
Column C1	8.5	53% Backfill 9% Hanford 38% Ringold E	4.5	0.75	3.25	199-K-117A	0.3	4.0	16.5	1.5	8.4	5
						199-K-125	0.5	4.1	18.3	0.9		
						199-K-118A	1.2	4.6	17.2	1.7		
						199-K-116A	1.2	5.2	20.1	1.5		
						199-K-115A	1.2	3.7	11.6	2.1		

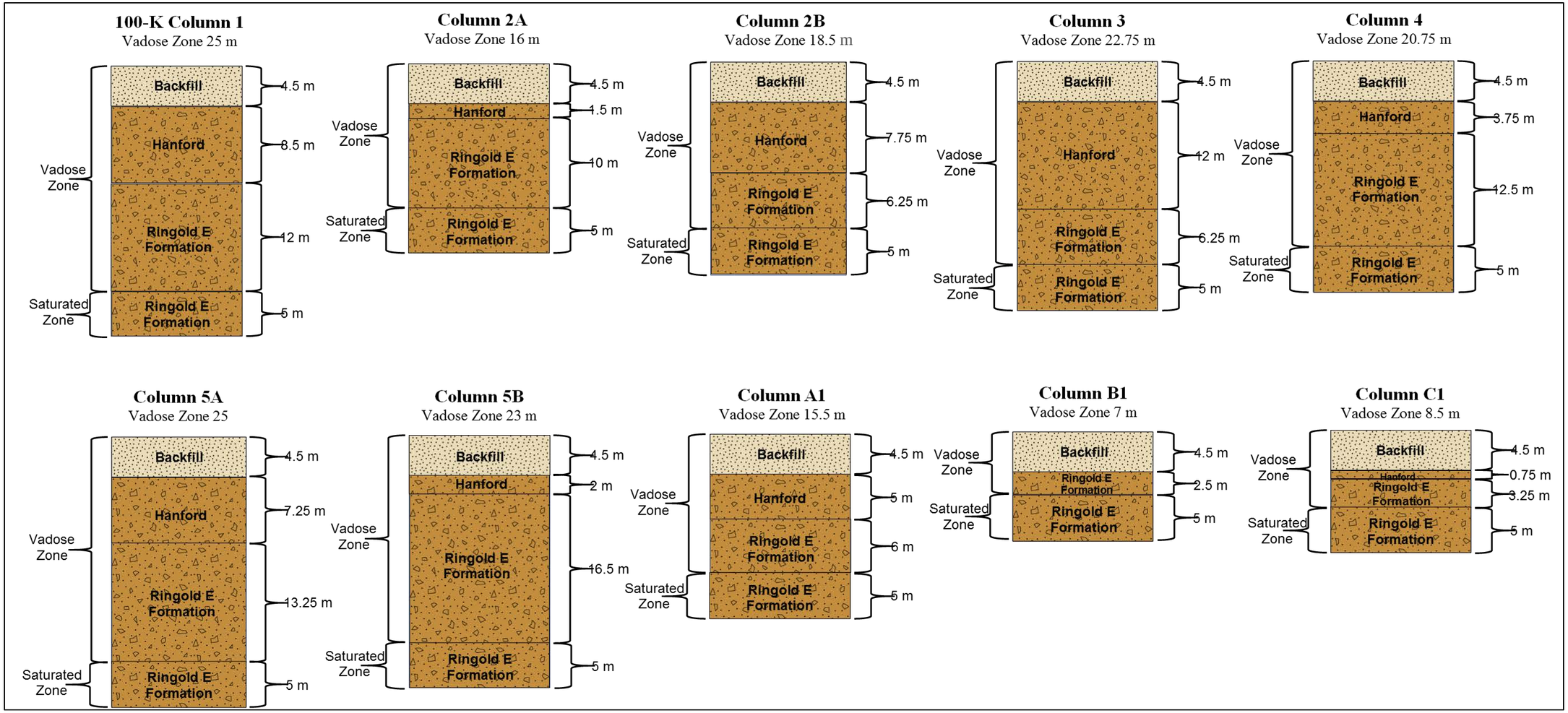

Figure 3-2. Representative Lithostratigraphic Columns for 100-K Source Areas

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3.1.2 Model Implementation

The model coordinate system is Cartesian, with the vertical (*z*) axis aligned with the direction of gravitational acceleration and the first horizontal (*x*) axis aligned with the general direction of groundwater flow. The second horizontal (*y*) axis is represented numerically by the STOMP simulator, but effectively no water flow or solute transport occurs in this direction because the boundary conditions on (*y*) axis cell faces are all assigned default no-flow conditions to represent an infinite extent of the waste site in the direction perpendicular to the general direction of groundwater flow.

The model domain consists of a vertical column of grid blocks intersected by a water table. Grid blocks above the water table comprise the vadose zone (VZ). Grid blocks below the water table comprise the saturated zone (SZ). The location of the water table is assigned in the initial configuration of the model and does not move up or down during simulations. Grid blocks are uniformly 0.25 m in height and 10 m in length throughout the model domain, with an arbitrarily assigned thickness of 1 m in the the effectively unused *y*-direction.

The thickness of the saturated zone was set to 5 m in all models to represent the screened well interval at the POCal (Section 2.5). Confirmatory simulations were performed to evaluate if using greater thicknesses for the saturated zone while evaluating concentration at the POCal (uppermost 5 m of saturated zone). The results confirmed that modeling saturated zone thicknesses greater than 5 m did not affect the concentration reported at the POCal.

The vertical dimension (*z*) of the model grid blocks were selected to provide appropriate resolution to represent the the lithostratigraphy and the contaminant source distribution, while also minimizing both the model run times and any undesirable numerical dispersion effects. The horizontal dimension in the general direction of groundwater flow (*x*) of the model grid blocks was selected to minimize potential numerical artifacts in simulated concentrations within saturated grid blocks. Numerical dispersion is a modeling artifact that can arise when the advective transport distance exceeds the grid block size within a single model time step. Numerical dispersion can be constrained to acceptable levels by setting limits on the minimum grid block size and/or the minimum model time step. Choosing limits that yield a Courant number value on the order of unity will minimize numerical dispersion (Huyakorn and Pinder, 1983). The Courant number is the dimensionless ratio of advective transport distance – defined as the product of groundwater velocity and the model time step, to grid block size (Huyakorn and Pinder, 1983). All simulations for this calculation used STOMP's Courant limitation scheme that automatically subdivides transport time steps within each time step for the flow solution to ensure that the Courant number for each grid block does not exceed the Courant limit (1.0) throughout the computational mesh.

Unit-length PRGs and SSLs are defined for a unit-length source term, which requires an effective horizontal (*x*) grid block length of 1 m. Such a small grid block length, when used in combination with values of saturated hydraulic conductivity or saturated head gradient, could force the Courant limitation scheme to adopt extremely short time steps. To complete simulations in reasonable times, the grid block length was therefore set to 10 m to limit run times while still ensuring numerical dispersion was minimized. This tenfold increase in the grid block horizontal (*x*) length increased the source term area from a unit value to a value of ten. Therefore, based on the linearity of the concentration with the horizontal distance, the simulated contaminant aqueous concentration value was divided by ten to yield the value appropriate for calculating unit-length PRG and SSL values. The accuracy of this methodology was verified with confirmatory simulations to compare how simulated aqueous concentrations varied with grid block size.

Grid block Courant numbers for the aquifer grid blocks, in which flow is horizontal under fully saturated conditions, were all less 1.0. Grid block Courant numbers for the vadose zone grid blocks, in which flow is vertical under variably saturated conditions, were all less 1.0 for all recharge scenarios.

3.2 Boundary and Initial Conditions

Solving the governing equations for variably saturated flow and transport requires stipulation of boundary and initial conditions. A complete set of boundary and initial conditions must be stipulated for each governing equation for input to STOMP. The boundary condition specifications for this model discussed in this section are graphically summarized in Figure 3-3.

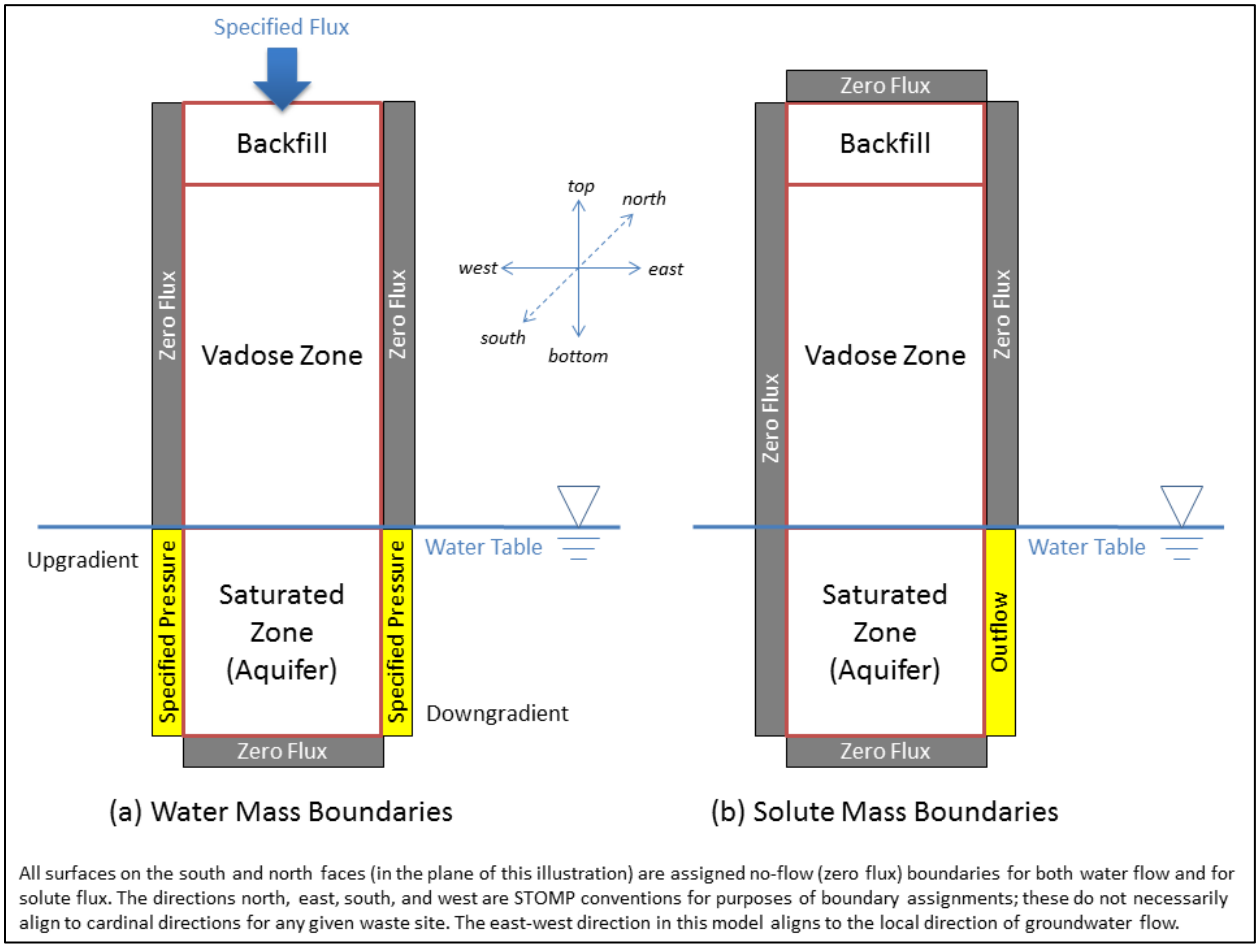


Figure 3-3. Boundary Conditions for (a) Water Mass and (b) Solute Mass Conservation Equations

For the water mass conservation equation, flow boundary conditions were specified to represent one-dimensional vertical flow in vadose zone resulting from recharge through the top boundary, and lateral flow in the saturated zone in response to the hydraulic gradient. A Neumann-type (specified flux) boundary condition was applied at the top surface to simulate effective recharge; the flux rate was varied, stepwise constant, to represent different recharge rates over time. Neumann-type boundary conditions with no flow (zero flux) were assigned to all the vertical boundaries (east, west, south, and north) of the vadose zone to maintain one-dimensional, vertical flow. The bottom boundary of the model domain was assigned a Neumann-type boundary condition with no-flow (zero flux) to constrain the aquifer to a 5 m thickness (Figure 3-3a). The east and west boundaries of the saturated zone portion of the domain was assigned a hydraulic gradient boundary condition to maintain the specified lateral flow rate in the aquifer, while the north and south boundaries were assigned Neumann-type boundary conditions with no flow (zero flux) to constrain the aquifer flow to one horizontal direction. Note here that in discussing lateral boundaries, the directions east, west, north, and south are conventions used in the STOMP code. For this model, these

direction references do not (necessarily) align to cardinal directions for any given actual waste site. Rather, the west-east (*x*) dimension in this STOMP representation is intended to align to the direction of groundwater flow for any waste site.

For the solute mass conservation equation, specified zero-flux boundaries were applied at the top of the model domain, along both edges of the vadose zone, along the upgradient edges of the aquifer grid blocks, and the bottom of the aquifer (Figure 3-3b). The downgradient edges of the aquifer grid blocks were assigned STOMP's outflow solute type boundary condition (see page 6.21 of PNNL-12030, and page 4.4 of PNNL-15782), which transports solute mass out of the domain according to the advective flux term in the solute mass conservation governing equation but does not allow solute to enter back into the domain.

3.2.1 Upper Boundary Conditions

For water flow, a time-varying Neumann-type (specified water flux) boundary condition was applied at the top surface (Figure 3-3a) to represent net infiltration (destined to become recharge). The net infiltration into the vadose zone, which is used in the model to represent the recharge into the aquifer, is driven by the competition between precipitation (including snow), potential evaporation, transpiration, run-off and run-on. In an arid or semi-arid climate, the net downward flux that results from these fluxes are episodic and usually infrequent. This effect is typically damped towards a nearly constant rate with increasing depth, however, as soil moisture variability with depth measured at Hanford Site lysimeters show (PNNL-17841, *Compendium of Data for the Hanford Site (Fiscal Years 2004 to 2008) Applicable to Estimation of Recharge Rates*). This is the basis for representing recharge in the vadose zone model using a constant rate applicable to a given soil type and vegetation cover (DOE/RL-2011-50). Studies have been carried out at the Hanford Site to ascertain representative long-term averages of the episodic fluxes, i.e., recharge rates, such as those compiled by Pacific Northwest National Laboratory (PNNL) in PNNL-14702, *Vadose Zone Hydrology Data Package for Hanford Assessments*) for the 100 Areas. The 100 Area specific recharge rates reported in PNNL-14702 vary with surface soil type, providing an estimate of the range of possible recharge rates for various land uses. The three surface soil types were the Ephrata sandy loam or stony loam, Burbank sandy loam and Rupert sand. Recharge rates for disturbed soil conditions were selected for use in calculation of unit-length SSLs and PRGs for the 100-K source OU.

Each calculation of a unit-length SSL or PRG with STOMP requires a pair of simulations; the first is a simulation of water flow only for historic recharge conditions, needed to obtain the soil moisture conditions throughout the model domain at the start time for the second simulation. The second is a coupled simulation of water flow and contaminant transport, starting from the assumed initial contaminant distribution (100:0 or 70:30 models) and the initial moisture distribution provided by the first simulation. Calendar year 2010 was set as the time when the first, historic (pre-2010) simulation ends and the second, predictive (post-2010) simulation begins. Recharge rates were conservatively simulated in STOMP as a specified flux boundary condition applied to the top boundary of the model (Figure 3-3a) for each recharge scenario and each soil type. Rates were assumed to change over time in step function-fashion for each recharge scenario.

For the historic (pre-2010) simulations, land use and recharge rates were assumed to transition from native vegetation (mature shrub-steppe) during pre-settlement conditions, to a historic irrigation period for 1880 to 1944, to a Hanford Site operational period with bare soil from 1944 to 2010. The pre-settlement phase was assumed to begin in calendar year 1, an arbitrary date that was selected merely to ensure steady-state moisture conditions are achieved in the solution for the applicable recharge rate by the assumed year of transition to historic irrigation (1880). Historic irrigation is included in the historic period because multiple land areas in the 100-K OUs were used for irrigated agriculture prior to construction of the Hanford Site. The historic irrigation period is conservatively assumed to commence in 1880, and is further conservatively assumed applicable to all waste sites in the 100-K source OUs. The Hanford Site operational period is conservatively assumed to consist of bare soil conditions, maintained vegetation free, for all waste sites. The recharge rates for each historic phase (pre-settlement with native vegetation, historic irrigation, Hanford operations) are applied to the top boundary as a constant rate within each phase.

For the predictive simulations (post-2010), two different recharge scenarios were evaluated, representing different future land uses. The native vegetation recharge scenario represents DOE's planned land use with restoration and maintenance of a native shrub-steppe plant community. The irrigation recharge scenario represents a bounding condition of irrigated agriculture.

For solute transport, specified zero-flux boundaries were applied at the top of the model domain, along both edges of the vadose zone, along the upgradient edges of the aquifer grid blocks, and the bottom of the aquifer (Figure 3-3b). The downgradient edges of the aquifer grid blocks were assigned STOMP's outflow solute boundary condition (see page 6.21 of PNNL-12030, and page 4.4 of PNNL-15782), which transports solute out of the domain according to the advective flux term in the governing equation and does not allow solute to enter back into the domain (Figure 3-3b).

3.2.1.1 Native Vegetation Recharge Scenario

The native vegetation recharge scenario (Table 3-3; Figure 3-4) is used for calculation of PRG values. This recharge scenario represents DOE's planned land use with restoration and maintenance of a native shrub-steppe plant community. The scenario is comprised of three historic phases discussed previously and four future phases that represent recharge rates changes corresponding to postulated future land use/cover transitions. The first future phase (2010 to 2015) represents the period of continued bare soil cover. The second future phase (2015 to 2020) represents an invasive cheatgrass cover. The third phase represents grasses and developing shrubs as vegetation matures during a 30-year transition (transition period duration from DOE/RL-2011-50). The final phase is mature shrub steppe that lasts for the remainder of the simulation. Recharge rates diminish in each successive phase for this scenario. Revegetation of waste sites following remediation is assumed in this scenario, consistent with revegetation that is occurring in the 100 Areas in accordance with the *Hanford Biological Resources Management Plan* (DOE/RL-96-32). Revegetation has been successfully conducted in the 100 Area following other remediation activities (for examples, refer to annual issues of the *River Corridor Closure Contractor Revegetation and Mitigation Monitoring Report*, including WCH-299 (2008), WCH-362 (2009), WCH-428 (2010), WCH-512 (2011), and WCH-554 (2012).

Table 3-3. Native Vegetation Recharge Scenario Phases and Recharge Rates (mm/yr)

	Historic Simulation (pre-2010) (calculation of initial hydraulic conditions)			Predictive Simulation (post-2010) (calculation of peak groundwater concentration)			
Surface Soil Type	**Pre-Settlement (< 1880)**	**Historic Irrigation [a] (1880-1944)**	**Hanford Operations (1944-2010)**	**Bare Soil (2010-2015)**	**Cheatgrass (2015-2020)**	**Developing Shrub-Steppe (2020-2050)**	**Mature Shrub-Steppe (2050 >)**
Hanford sand, disturbed	4.0 [b]	72.4 [c]	63.0 [d]	63.0 [d]	31.5 [e]	8.0 [f]	4.0 [g]

a. Irrigated agriculture was prevalent in the100-K Area prior to Hanford Site construction; irrigation therefore was conservatively assumed applicable to all 100-K sites from calendar years 1880 through 1944.

b. Source: PNNL-14702 Rev. 1, Table 4-15, all areas with soils disturbed by excavations; shrub steppe.

c. Recharge rates for historic irrigation phase is that from the long-term irrigation rate (Irrigation II) under the irrigation recharge scenario (Table 3-4).

d. Source: PNNL-14702 Rev. 1, Table 4-15, all areas with soils disturbed by excavations; no vegetation.

e. Source: PNNL-14702 Rev. 1, Table 4-15, all areas with soils disturbed by excavations; cheatgrass.

f. Source: PNNL-14702 Rev. 1, Table 4-15, all areas with soils disturbed by excavations; young shrub steppe.

g. Source: PNNL-14702 Rev. 1, Table 4-15, all areas with soils disturbed by excavations; shrub steppe.

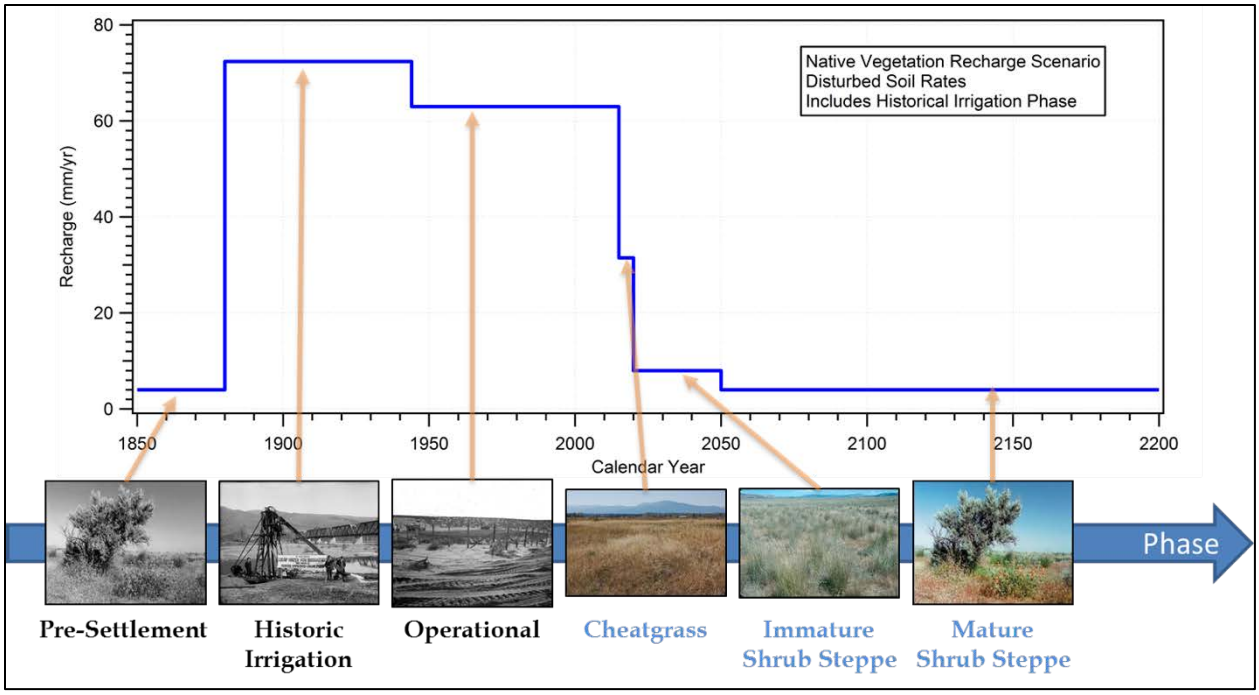


Figure 3-4. Native Vegetation Recharge Scenario

3.2.1.2 Irrigation Recharge Scenario

The irrigation recharge scenario (Table 3-4; Figure 3-5) is used for calculation of unit-length SSL values. This recharge scenario represents an upper bound based on recharge rates from irrigated agriculture land use. This recharge scenario is comprised of transition from bare soil conditions to long-term irrigation farming. Although this recharge scenario is inconsistent with DOE land use plans, it is used here to represent an upper bound on recharge rates for screening purposes. The bounding nature of this recharge scenario is reinforced further by the assumption that irrigated agriculture commences five years in the future, much sooner than is reasonable given that Hanford Site remediation activities are expected to continue for decades to come and constrain land use accordingly.

Recharge rates for the irrigation phases of this recharge scenario were estimated using the same approach used to assess interim remediation at 100 Area waste sites (DOE/RL-96-17) following Washington Department of Health guidance (WDOH/320-015, *Hanford Guidance for Radiological Cleanup*). These previous site assessments used Remedial Action Goals (RAGs) calculated from RESRAD simulations that assumed total recharge was a combination of irrigation and native vegetation (base case) recharge scenario rates. As the base case rates used in the RESRAD simulations were different from those adopted for the native vegetation recharge scenario (from PNNL-14702), the RESRAD equation for total recharge was back-solved to ascertain the recharge rate attributable to irrigation alone.

According to the RESRAD manual, total recharge rate is a function of precipitation, evapotranspiration, run-off, and applied irrigation and is defined as:

$$I = (1 - C_e)[(1 - C_r)P_r + I_{rr}] \quad (5)$$

where I = annual recharge rate (LT^{-1}), C_e = evapotranspiration coefficient (dimensionless), C_r = runoff coefficient (dimensionless), P_r = annual precipitation rate (LT^{-1}), and I_{rr} = annual irrigation rate (LT^{-1}). Using (5) with the DOE/RL-96-17 RESRAD values for these parameters, C_e = 0.91, C_r = 0.2, P_r = 0.16

m/yr, and I_{rr} = 0.76 m/yr, yielded a total recharge rate of 80 mm/yr. Solving (5) again with I_{rr} = 0 yielded the non-irrigation total recharge rate of 11.6 mm/yr. Therefore, the recharge attributable to irrigation alone was 68.4 mm/yr. This rate was then added to the native vegetation recharge rates for undisturbed soils to determine a rate for the irrigation phases (Figure 3-5).

Table 3-4. Irrigation Recharge Scenario Phases and Recharge Rates (mm/yr)

Surface Soil Type	Historic Simulation (pre-2010) (calculation of initial hydraulic conditions)			Predictive Simulation (post-2010) (calculation of peak groundwater concentration)		
	Pre-Settlement (< 1880)	Historic Irrigation [a] (1880-1944)	Hanford Operations (1944-2010)	Bare Soil (2010-2015)	Irrigation I (2015-2045)	Irrigation II (2045 >)
Hanford sand, disturbed	4.0 [b]	72.4 [c]	63.0 [d]	63.0 [d]	76.4 [e]	72.4 [e]

a. Irrigated agriculture was prevalent in the100-K Area prior to Hanford Site construction; irrigation therefore was conservatively assumed applicable to all 100-K sites from calendar years 1880 through 1944.

b. Source: PNNL-14702 Rev. 1, Table 4-15, all areas with soils disturbed by excavations; shrub steppe.

c. Recharge rates for historic irrigation phase is that from the long-term irrigation rate (Irrigation II phase).

d. Source: PNNL-14702 Rev. 1, Table 4-15, all areas with soils disturbed by excavations; no vegetation.

e. Recharge rates for future irrigation phases represent incremental increases over corresponding undisturbed native vegetation recharge rates, based on WDOH guidance (WDOH/320-015, *Hanford Guidance for Radiological Cleanup*). The recharge increment attributable to irrigation alone is 68.4 mm/yr. This increment is added to the corresponding rate for immature shrub steppe (8.0 mm/yr) and mature shrub steppe (4.0 mm/yr) phases of the native vegetation recharge scenario (Table 3-3) to obtain the total recharge rate.

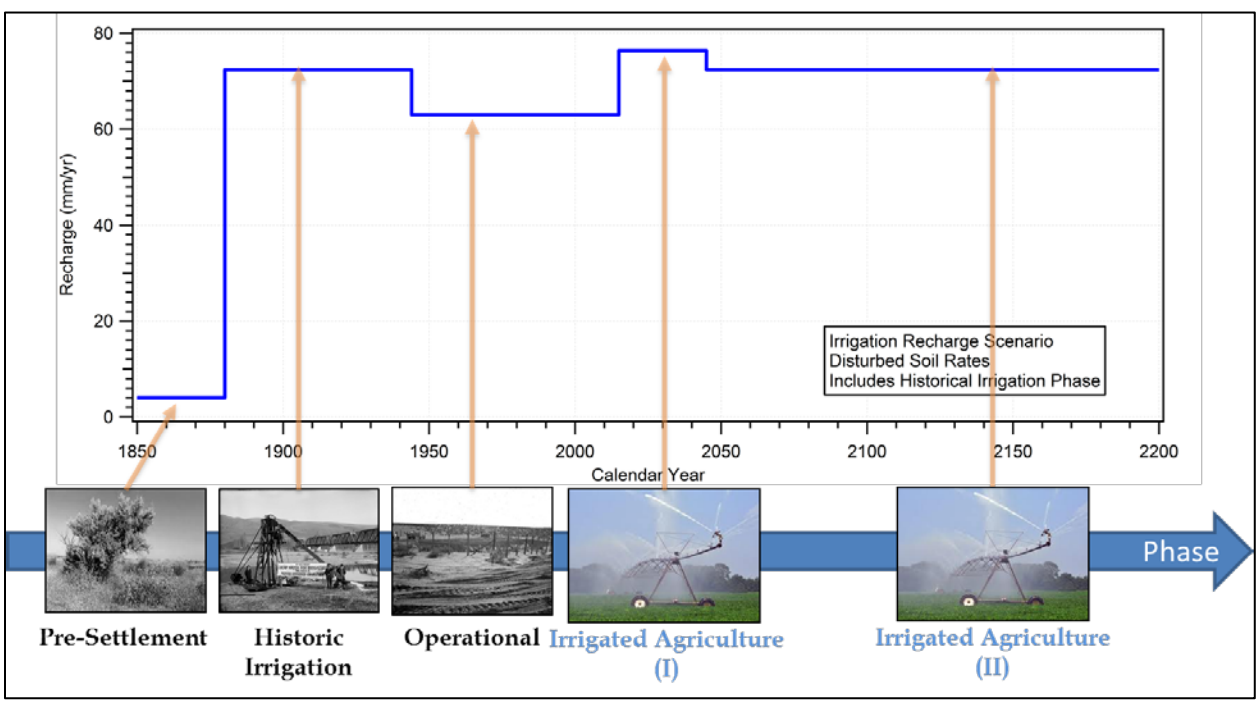


Figure 3-5. Irrigation Recharge Scenario

3.2.2 Lower Boundary Conditions

The bottom of the model domain is assigned a constant zero-flux boundary condition for both water mass and contaminant mass (solute) transport (Figure 3-3). This boundary condition limits the aquifer representation in this model to the appropriate thickness.

3.2.3 Lateral Boundary Conditions

For the portion of the model domain in the vadose zone (Figure 3-3a), a constant zero-flux boundary condition for both water transport and solute transport is assigned to restrict (with respect to arrival time of peak solute concentration and peak magnitude) the representation in the vadose zone to one-dimensional vertical flow. This is a conservative representation with respect to the arrival time and the magnitude of the peak concentration.

For the portion of the model domain in the saturated zone (aquifer; refer to Figure 3-3a), a constant Dirichlet type (specified head) boundary condition is specified for water transport at opposite edges aligned to the hydraulic gradient to represent the water table at the desired elevation and impose the desired hydraulic gradient. The hydraulic gradients used for the simulations were based on Automated Water Level Network (AWLN) data obtained from HEIS. Hydraulic head data from March 2008 were used to calculate the hydraulic gradient for the 100-K OUs. Triangulated irregular networks (TINs) were fitted to the wells using ArcGIS®[2] and hydraulic gradients were computed for each TIN (Table 3-5). The median, a measure of the central tendency of the computed gradients, was selected as a representative value, yielding hydraulic gradients of 0.00389 m/m for 100-K. The details on the method for calculating hydraulic gradients is reported in ECF-HANFORD-14-0028, *Median Hydraulic Gradient Calculation to Support Development of Soil Screening Levels and Preliminary Remediation Goals in the 100 Area*. The summarized results from the 100-K hydraulic gradient study are found in SGW-50776 in Table 4-3.

Aquifer conditions are dynamic in the 100 Area; the hydraulic gradient, thickness, and in many cases direction of flow vary throughout the year. The use of median gradients is intended to provide a broadly representative value for use in calculation of unit-length SSLs and PRGs that will be applicable for the range of locations in each geographic area. This gradient is applied to a model stratigraphy that is based on high-river stage conditions for minimizing the vadose zone thickness as a bounding condition to minimize transport time.

Table 3-5. Hydraulic Gradients for 100-K

Source Area	Number of Triangular Irregular Networks [(a)]	Hydraulic Gradient (m/m) [(a)]				
		Minimum	Maximum	Median	Arithmetic Average	Geometric Average
100-K	35	0.00085	0.00759	0.00389	0.00379	0.00341

a. Source: SGW-50776, Rev. 3, Table 4-3

For solute transport, the upgradient edge of the portion of the model domain in the aquifer and all edges of the model domain in the vadose zone portion of the model domain are assigned zero-flux boundary conditions (Figure 3-3b). The downgradient edges (Figure 3-3b) of the aquifer grid blocks were assigned STOMP's outflow solute boundary condition (see page 6.21 of PNNL-12030 and page 4.4 of PNNL-15782). This boundary condition provides for transport of solute out of the domain according to the advective flux term in the governing equation, but does not allow solute to enter back into the domain.

[2] ArcGIS is a registered trademark of registered trademarks, or service marks of ESRI in the United States, the European Community, or certain other jurisdictions.

3.2.4 Initial Conditions

For hydraulic initial conditions, an arbitrary value was assigned as the initial pressure for the historic (pre-2010) flow simulations. A value of 86,656.8 Pa, approximately equivalent to –1.5 m matric potential, was assigned to the nodes in the vadose zone whereas the aquifer grid blocks were assigned values that matched the boundary condition pressures. Final pressures from the historic (pre-2010) simulations were used as the initial pressures for the predictive (post-2010) coupled flow and transport simulations.

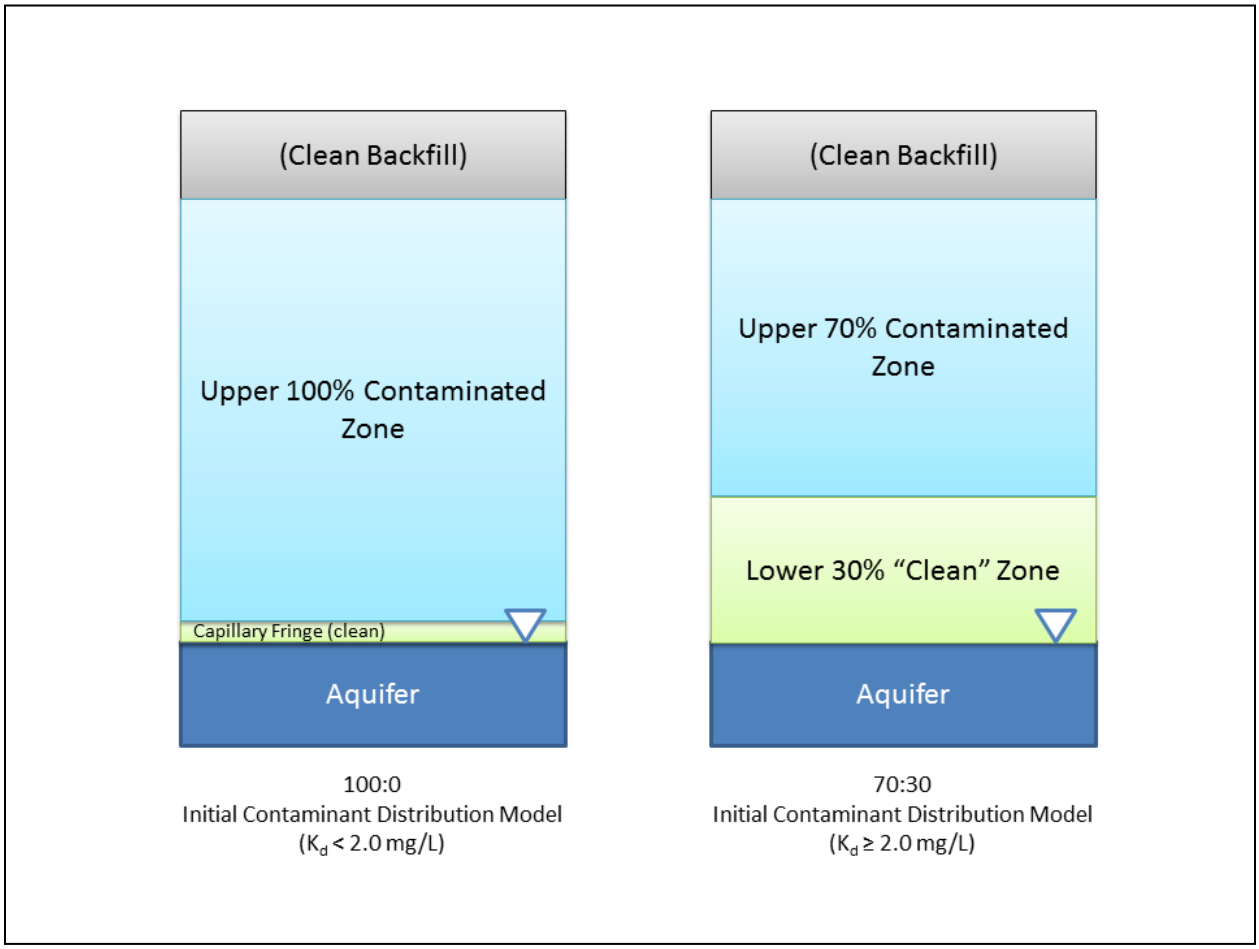
Contaminant initial conditions are imposed based on the objective and methodology of the calculation. Determination of unit-length SSL and PRG values is accomplished in a two-step calculation process: first, STOMP is used in a forward calculation step to calculate peak groundwater concentration resulting from a uniform initial concentration over an appropriate vertical depth range of the vadose zone. For this forward calculation step, the initial concentration applied is a unit concentration (1.0 mg/kg for nonradionuclide COPCs, or 1.0 pCi/kg for radionuclide COPCs). The second, back-calculation, step (represented by use of Equations 1 and 2), is where the peak groundwater concentration resulting from the initial uniform unit concentration is scaled by the appropriate regulatory compliance criterion to determine the maximum initial soil concentration that could be present and not result in an exceedance of that criterion. The maximum value obtained from this back-calculation step is assigned as the SSL or PRG value (these differ only with respect to the recharge scenario used; irrigation for SSLs versus native vegetation for PRGs). As a measure of maximum allowable contaminant concentration in the soil, SSLs and PRGs are expressed as contaminant mass per mass of soil for non-radionuclides (e.g., mg/kg) and as contaminant activity per mass of soil for radionuclides (e.g., pCi/g). The use of a unit initial concentration in the forward-calculation step with STOMP is therefore only a convenience to support calculation of unit-length SSLs and PRGs in the back-calculation step. The peak groundwater concentration that is calculated with STOMP will be proportional to the initial soil concentration value. Hence, any initial value for soil concentration could be used in the forward-calculation step, and when scaled against the resulting peak groundwater concentration in the back-calculation step in Equations 1 or 2 will yield the same SSL or PRG. The unit concentration, therefore, is not to be confused as constituting an actual observed waste site residual soil concentration. Further detail on this calculation approach is provided in SGW-50776.

Based on SGW-51818, *Conceptual Basis for Distribution of Highly Sorbed Contaminants in 100 Areas Vadose Zone*, and the analysis reported below (in Section 3.5), all contaminants were grouped into two groups, one with lower distribution coefficients in the range K_d < 2 mL/g, and other with the higher distribution coefficients in the range ≥ 2 mL/g.

For the lower K_d contaminants (K_d < 2 mL/g), a uniform concentration of 1.0 mg/kg was applied in the entire vadose zone, from below the clean backfill down to 0.5 m (two simulation grid blocks) above the water table. This is termed the 100:0 initial source distribution (Figure 3-6). Initial concentration in the 0.5-m-zone above the water table was not applied due to the presence of capillary fringe and water table movement in the periodically rewetted zone that would result from river stage fluctuations. Placing the initial mass at the water table can also result in unrepresentative large peak releases in the simulation start because of the extreme concentration gradients created by the application of this initial condition.

For the higher K_d contaminants (K_d ≥ 2 mL/g), based on information presented in SGW-51818, the conservative assumption of contamination throughout the full thickness of the vadose zone is modified. For these contaminants, the upper 70% of the vadose zone below the clean backfill was assumed to be contaminated while the lower 30% is treated as uncontaminated; this is termed the 70:30 initial source distribution (Figure 3-6). The 70:30 initial source distribution assumption is deemed conservative for the high K_d contaminants, with respect to peak groundwater concentration, based on observed limited vertical extent of such contaminants. Where borehole measurements of deeper contamination of higher K_d contaminants but of limited vertical extent are found, this conservatism can be tested using those data.

A notable exception to the K_d based assignment of an initial source distribution was made for the COPC strontium-90. Because field data revealed that this COPC was found throughout the vadose zone at several sites, use of a 70:30 initial source distribution for this COPC would clearly be non-conservative. Accordingly, SSL and PRG values were calculated for strontium-90 using the 100:0 initial source distribution at all sites. Strontium-90 is distributed throughout the vadose zone despite its relatively high K_d value for reasons having to do with historic discharge practices that no longer dominate the subsurface. A complete discussion of the nature and extent of contamination is found in Chapter 4 of the remedial investigation/feasibility study report for the 100-K OUs (DOE/RL-2010-97). This exception might be considered as a site-specific treatment, but was applied to all sites for this COPC only in the first-level modeling under the graded approach (DOE/RL-2011-50).



Note: Strontium-90 (K_d = 25 mL/g) is an exception, simulated with 100:0 model; see text for explanation.

Figure 3-6. 100:0 and 70:30 Initial Contaminant Distribution Models

3.3 Hydraulic Parameters

To the extent possible, OU-specific hydraulic and transport parameter values were used in the STOMP simulations. Based on previous Hanford studies, and on the fact that all available measurements of hydraulic properties were made under the same assumption, the sediments were assumed to follow the van Genuchten (1980) moisture retention constitutive relation and the Mualem–van Genuchten relative permeability

constitutive relation (Mualem, 1976), thus requiring the following values to be specified in STOMP for each LSU:

- K_s, saturated hydraulic conductivity (LT^{-1})
- n_T, total porosity (L^3L^{-3})
- θ_s, saturated volumetric water content, called diffusive porosity n_D in STOMP (L^3L^{-3})
- s_r, residual saturation (dimensionless), equal to the residual volumetric water content θ_r divided by the saturated volumetric water content θ_s
- α, van Genuchten fitting parameter (L^{-1}), proportional to the inverse of the air entry matric potential
- n, van Genuchten exponential fitting parameter (dimensionless)

Mualem-van Genuchten for Hanford formation and Ringold E soils in the 100-K area are based on RPP-20621, *Far-Field Hydrology Data Package for the Integrated Disposal Facility Performance Assessment* are presented in Table 3-4. These form the basis for estimates of Mualem-van Genuchten used in this calculation. Hydraulic parameters used in this calculation are shown in Table 3-6 and Table 3-7 with discussion of the basis of these parameters below.

Table 3-6. Mualem-van Genuchten Hydraulic Parameters for the 100 Area Vadose Zone [a,b]

Sample	HSU [c]	Source Area	Well Number	Depth (m)	% Gravel	θ_s *Saturated Volumetric Moisture Content* (cm³/ cm³)	θ_r *Residual Volumetric Moisture Content* (cm³/ cm³)	α van Genuchten Inverse Air Entry Head Fitting Parameter (1/cm)	n van Genuchten Exponential Fitting Parameter (-)	Fitted K_s Fitted Saturated Hydraulic Conductivity [d,e] (cm/s)
2-1307	Ringold	100-HR-3	199-D5-14	18.90	43	0.236	0.0089	0.0130	1.447	1.29E-04
2-1308	Ringold	100-HR-3	199-D5-14	30.64	58	0.120	0.0208	0.0126	1.628	6.97E-05
2-1318	Hanford	100-HR-3	199-D8-54A	15.54	60	0.124	0.0108	0.0081	1.496	1.67E-04
2-2663	Hanford	100-BC-5	199-B2-12	8.20	61	0.135	0.0179	0.0067	1.527	6.73E-05
2-2664	Ringold	100-BC-5	199-B2-12	24.84	73	0.125	0.0136	0.0152	1.516	1.12E-04
2-2666	Hanford	100-BC-5	199-B4-9	21.49	71	0.138	0.00	0.0087	1.284	1.02E-04
2-2667	Hanford	100-BC-5	199-B4-9	23.93	75	0.094	0.00	0.0104	1.296	1.40E-04
3-0570	Hanford	100-KR-1	116-KE-4A	3.50	60	0.141	0.00	0.0869	1.195	2.06E-02
3-0577	Hanford	100-FR-3	199-F5-43B	7.16	66	0.107	0.00	0.0166	1.359	2.49E-04
3-0686	Hanford	100-FR-1	116-F-14	6.49	55	0.184	0.00	0.0123	1.600	5.93E-04
3-1702	Hanford	100-DR-2	199-D5-30	9.78	68	0.103	0.00	0.0491	1.260	1.30E-03
4-1086	Ringold	100-K	199-K-110A	12.77	65	0.137	0.00	0.1513	1.189	5.83E-02
4-1090	Hanford	100-K	199-K-111A	8.20	50	0.152	0.0159	0.0159	1.619	4.05E-04
4-1118	Hanford	100-K	199-K-109A	10.30	66	0.163	0.00	0.2481	1.183	3.89E-02
4-1120	Ringold	100-K	199-K-109A	18.90	63	0.131	0.0070	0.0138	1.501	2.85E-04

Table 3-6. Mualem-van Genuchten Hydraulic Parameters for the 100 Area Vadose Zone [a,b]

Sample	HSU [c]	Source Area	Well Number	Depth (m)	% Gravel	θ_s *Saturated Volumetric Moisture Content* (cm³/ cm³)	θ_r *Residual Volumetric Moisture Content* (cm³/ cm³)	α van Genuchten Inverse Air Entry Head Fitting Parameter (1/cm)	n van Genuchten Exponential Fitting Parameter (-)	Fitted K_s Fitted Saturated Hydraulic Conductivity [d,e] (cm/s)

a. Source: RPP-20621 Rev .0

b. Moisture retention data were measured on the non-gravel sediment fraction (< 2mm size) and corrected for gravel fraction.

c. HSU = hydrostratigraphic unit

d. Assumed to represent vertical hydraulic conductivity

e. Hydraulic conductivities were measured on the bulk samples that included the gravel fraction using the constant-head permeameter method for saturated hydraulic conductivity (K_s) and the unit gradient method for unsaturated hydraulic conductivity.

Table 3-7. Hydraulic Parameters used for 100-K Source Areas

Geographic Area	Zone	Unit	n_T Total Porosity (cm³/cm³)	n_D Diffusive Porosity (cm³/cm³)	α van Genuchten Air Entry Fitting Parameter (1/cm)	n van Genuchten Exponential Fitting Parameter (-)	s_r Residual Saturation (-)	$K_{s\|h}$ Horizontal Saturated Hydraulic Conductivity (cm/s)	$K_{s\|v}$ Vertical Saturated Hydraulic Conductivity (cm/s)
100-K	Backfill	Hanford	0.276 [a]	0.262 [a]	0.019 [a]	1.400 [a]	0.103 [a]	5.98E-04 [a]	5.98E-04 [a]
	Vadose	Hanford	0.280 [b]	0.247 [b]	0.117 [c]	1.332 [c]	0.021 [c]	6.87E-02 [d]	6.87E-03 [d]
	Vadose	Ringold E	0.293 [e]	0.267 [e]	0.083 [f]	1.345 [f]	0.013 [f]	4.08E-02 [g]	4.08E-03 [g]
	Saturated	Ringold E	0.293 [e]	0.267 [e]	0.083 [f]	1.345 [f]	0.013 [f]	6.53E-03 [h]	6.53E-04 [h]

a. Source: arithmetic mean of hydraulic parameters for backfill calculated for six samples that were collected within the Hanford Site (hydraulic conductivity assumed isotropic for backfill) reported in PNNL-18564, Table A.12 (these are also the site-wide values for backfill listed in PNNL-14702 Rev. 1, Table 4.5)

b. Source: PNNL-18564, Tables 6.3 and 6.4, values for total and effective porosity for Hanford gravelly sand (Hgs), site-wide. Note the saturated volumetric moisture content values listed in Table 3-6 were determined by applying a gravel correction factor to the values determined in the laboratory on the < 2 mm fraction. However, these values appeared to be underestimated and were inconsistent with the high K_s values estimated, so this site-wide estimate was used.

c. Source: computed arithmetic mean of values for three Hanford formation samples from 100-K (Table 3-6, samples 3-0570, 4-1090 and 4-1118).

d. Source: computed geometric mean of values for three Hanford formation samples from 100-K (Table 3-6, samples 3-0570, 4-1090 and 4-1118) for vertical value; horizontal value computed based on assumed anisotropic ratio of 0.1.

e. Source: PNNL-18564, Tables 6.3 and 6.4, values for total and effective porosity for Ringold gravel (Rg), site-wide.

f. Source: computed arithmetic mean of values for two Ringold Formation samples from 100-K (Table 3-6, samples 4-1086 and 4-1120).

g. Source: computed geometric mean of values for two Ringold Formation samples from 100-K (Table 3-6, samples 4-1086 and 4-1120); horizontal value computed based on assumed anisotropic ratio of 0.1.

h. Source: vertical saturated hydraulic conductivity for saturated zone units was calculated as the geometric mean of aquifer test measurements for the Ringold formation in the 100-K areas of data reported in SGW-40781 Rev. 2, Table 7-1.

The Mualem-van Genuchten hydraulic properties for the Hanford formation in the vadose zone were estimated for each geographic area by averaging the individual parameter values for all samples collected from those respective geographic areas:

- Two Ringold E formation samples from boreholes 199-K-109A and 199-K-110A were selected to provide mean properties for 100-K OU
- Three Hanford formation samples from boreholes 116-KE-4A, 199-K-111A, and 199-K-109A (Table 3-6) were selected to provide mean properties for the 100-K OU for the Hanford formation (Table 3-7).

Vertical saturated hydraulic conductivity of the Hanford and Ringold E formations were obtained by using the geometric mean of the selected measurements, whereas the other parameters were averaged using the arithmetic mean of the applicable measurements. Horizontal hydraulic conductivity was calculated by assuming an anisotropy ratio of 0.1.

In the absence of more site-specific data, Hanford-wide mean parameter values for the backfill were used. Mean hydraulic parameters for six samples of backfill that were collected within the Hanford site (PNNL-18564) were selected to represent these units within the 100 Area. The backfill parameters used for the 100 Area simulations were also used in flow and transport simulations under variably-saturated conditions at other waste sites, such as the 200-MW-1 and PW-1/3/6 waste sites in the 200 Area (Table 8 in ECF-200MW1-10-0080, *200-MW-1 Contaminant Fate and Transport Model to Evaluate Impacts to Groundwater in Support of DOE/RL-2008-38 Decision Draft*; Table 11 in ECF-200PW1/3/6-10-0326, *Screening Process and Contaminant Fate and Transport Model to Evaluate Impacts to Groundwater in Support of DOE/RL-2007-27 DRAFT B*).

3.3.1 Vadose Zone

The van Genuchten m fitting parameter was assumed to be fixed and equal to $(n - 1)/n$ and the Mualem β exponent was assumed to be fixed at 0.5 (Mualem 1976; RPP-20621, *Far-Field Hydrology Data Package for the Integrated Disposal Facility Performance Assessment*). Hanford and Ringold E units are well to poorly sorted sandy gravels or sandy silty gravels whereas the backfill consists of poorly sorted sand and gravel with varying fractions of eolian loess and silt (RPP-20621; SGW-44022; SGW-46279; PNNL-18564). Within the 100-K source OU, the Hanford formation tends to be coarser grained than the Ringold E. The former tends to contain larger gravel clasts than the latter, and the Ringold E unit in the 100-K vadose zone consists of semi-indurated clay, silt, fine- to coarse-grained sand, and pebble to cobble-size gravel (SGW-46279). Where present, the Ringold upper mud (RUM) was assumed to act as a lower bound (aquitard) for the aquifer (SGW-46279) and so was not directly included in the STOMP simulations.

OU-specific values for several Mualem-van Genuchten hydraulic parameters were obtained for the Hanford formation from data packages SGW-44022 (applicable to the 100-BC and 100-D/H Areas) and SGW-46279 (applicable to the entire 100 Area). The first data package cites the data table for the unsaturated hydraulic properties of 15 samples of sandy gravels from the 100 Area operable units, which were originally described in RPP-20621. These 100 Area sediments are dominated by the gravel fraction (> 2-mm size), with gravel clasts accounting for 43 to 75% of the total sample mass (RPP-20621). Moisture retention data were measured on the non-gravel sediment fraction (< 2mm size) and corrected for gravel fraction, whereas hydraulic conductivities were measured on the bulk samples that included the gravel fraction using the constant-head permeameter method for saturated hydraulic conductivity (K_s) and the unit gradient method for unsaturated hydraulic conductivity (RPP-20621). The fitted K_s estimates were assumed to represent vertical hydraulic conductivity.

3.3.2 Saturated Zone

The horizontal K_s for Ringold E in the saturated zone was calculated as the geometric mean of aquifer test measurements for the Ringold formation in the 100-K areas of data reported in SGW-40781, Table 7-1, *100-HR-3 Remedial Process Optimization Modeling Data Package*.

Following convention for Hanford sediments (SGW-44022; SGW-46279), an anisotropy ratio of vertical to horizontal saturated hydraulic conductivity of 0.1 was applied to obtain vertical hydraulic conductivity values from the horizontal values discussed above.

3.4 Contaminant Transport Parameters

The contaminant transport parameters required by STOMP are the particle density of each unit, dispersion coefficients, half-lives for each radiological COPC, and the distribution coefficient for each COPC.

The particle density (ρ_p) values of the backfill, Hanford, and Ringold units can be calculated using the bulk density (ρ_B) and porosity. Bulk density is needed for retardation scaling factor calculations. Estimates of bulk density for Hanford and Ringold units were obtained from PNNL-14702, which gave 1.91 g/cm^3 for the Hanford and 1.90 g/cm^3 for the Ringold. The bulk density estimate of 1.94 g/cm^3 for backfill was obtained from PNNL-18564.

Hydrodynamic dispersion was conservatively assumed negligible, so dispersivity values were all set to zero. Note, however, that diffusion was included. Setting dispersivity values to zero yields higher peak groundwater concentrations than would be obtained using non-zero values. This, therefore, is a conservative assumption with respect to unit-length SSL and PRG values. (Numerical dispersion is a separate consideration; steps taken to minimize numerical dispersion in the STOMP code calculations are discussed in Section 3.1.)

Distribution coefficient (K_d) values for all COPCs were obtained from ECF-HANFORD-12-0023, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*. These values are listed for each COPC in the tables of unit-length SSL values listed in Attachment A, and of PRG values listed in Attachment B, of this ECF. Uranium requires further discussion as no value is assigned in ECF-HANFORD-12-0023. Specific to the 100-K OU a K_d value of 70 mL/g was selected for simulating retarded transport of Uranium. The 100-K specific K_d value for Uranium was selected by simulating Uranium transport in the 199-K-222 borehole. Borehole 199-K-221 was not considered in the site-specific K_d study for Uranium as the soil concentrations for Uranium at all depths were lower than the Uranium measurements in 199-K-222. By iteratively solving Uranium transport through a STOMP simulation representing 199-K-222, two K_d values were obtained to represent the measured average concentration and the sitewide background concentration for the year 2015. The measured average Uranium concentration at 199-K-222 was calculated to be 3.626 µg/L for the top 5 meters of the saturated aquifer while the sitewide background concentration is listed as 9.85 µg/L (DOE/RL-96-61, Table 6-1). The calculated K_d values that best match the measured average and sitewide average were 200 mL/g and 70 mL/g, respectively. By selecting K_d for Uranium in the 100-K unit as 70 mL/g we are conservatively assuming that Uranium will travel faster than otherwise indicated by the existing Uranium concentrations present in the area. The decreased travel time required for Uranium to leave the vadose zone and enter the aquifer system yields higher concentration peak values than could be achieved if a greater K_d value were used (i.e. longer travel times).

Hexavalent chromium also requires further discussion regarding its K_d value. A site-specific, bounding value is selected in ECF-HANFORD-12-0023 for this COPC that was derived from the site-specific analysis for the 100 Area presented in ECF-HANFORD-11-0165, *Evaluation of Hexavalent Chromium Leach Test Data Conducted on Vadose Zone Sediment Samples from the 100-Area)*. The leach test data analyzed in ECF-HANFORD-11-0165 included 100-K area samples (Figure 3-7). The empirical cumulative distribution function for K_d estimates from these leaching tests are shown with respect to each

reactor area within the River Corridor in Figure 3-8. This K_d value for Cr(VI) is considered bounding because it was selected on the basis that 90% of the K_d values in that analysis had higher sorption values. Thus, this value would not be appropriate to represent hexavalent chromium migration in a predictive model, but is appropriate for use in this bounding calculation of unit-length SSL and PRG values. Further, this value for K_d of hexavalent chromium is applicable only to the residual fraction of hexavalent chromium remaining in the vadose zone; it is inapplicable to the mobile fraction that migrated out of the vadose zone in the past.

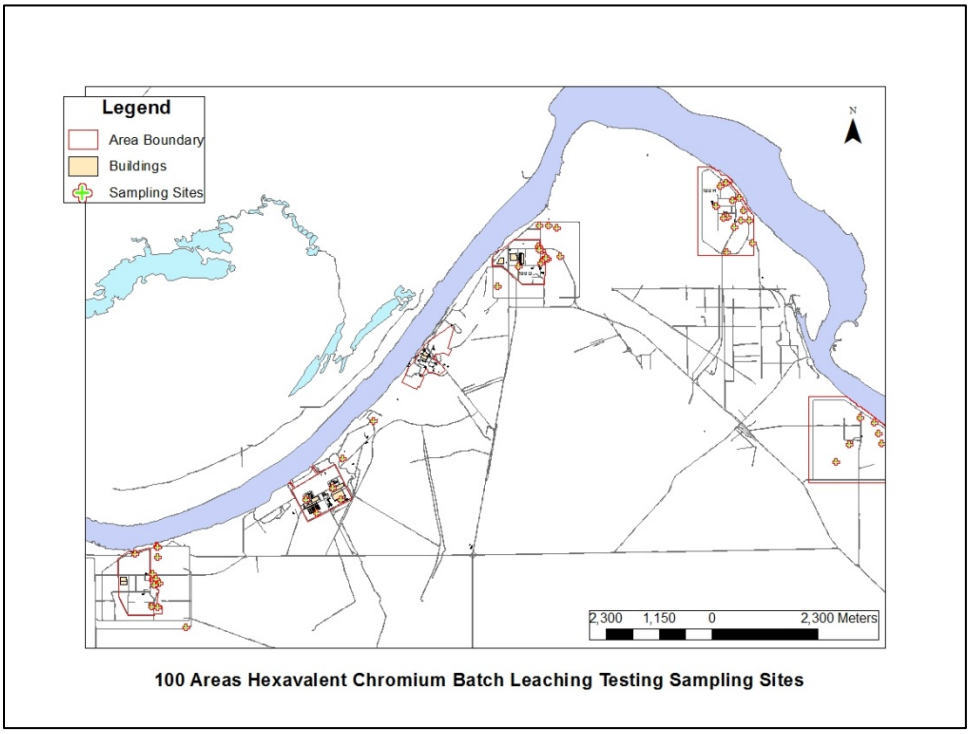
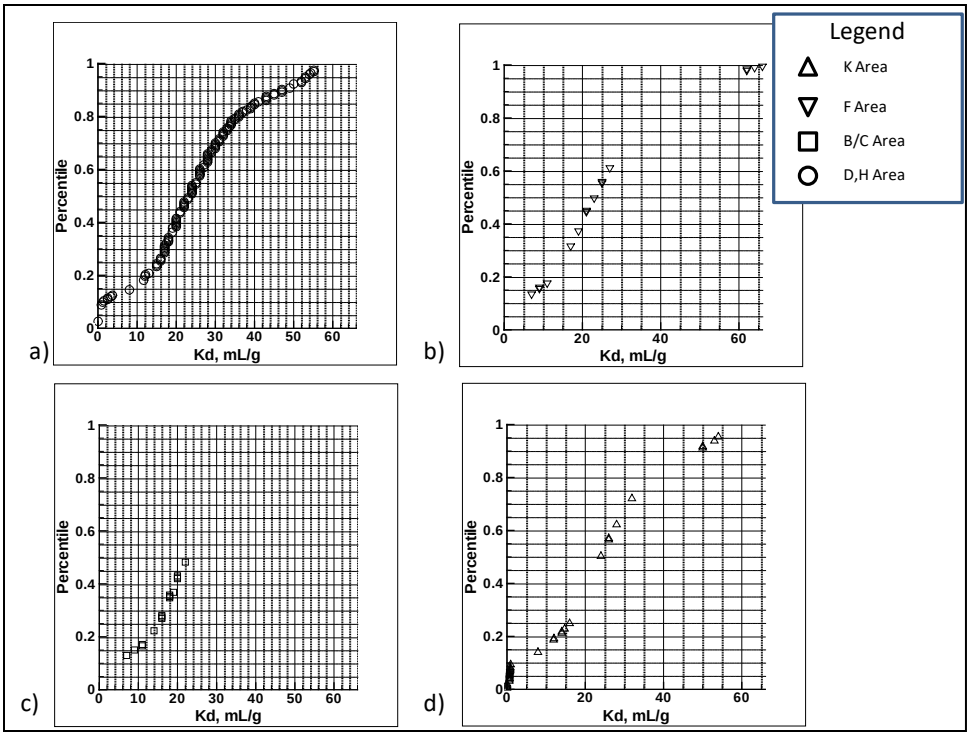


Figure 3-7. Location of Leach Test Data Samples Evaluated for Derivation of a Bounding, Site-specific K_d Value for Residual Hexavalent Chromium



Source: ECF-HANFORD-11-0165, Figure 3

Figure 3-8. Empirical Cumulative Distribution Function for K_d Estimates from Leaching Tests Symbolized to Indicate Reactor Area within the River Corridor

STOMP accounts for contaminant first-order decay in the solute mass conservation equation (PNNL-12030). Half-life values ($t_{1/2}$) for radionuclide COPCs were obtained from EMDT-DE-0006 (A copy is provided in Attachment C to this ECF). These values are listed in those tables pertaining to radionuclides in Attachments A and B of this ECF for each radionuclide COPC. Chain decay is not accounted for in this calculation because no radionuclide COPC evaluated has significant daughter products.

Biodegradation is neglected in this calculation, which is generally a conservative assumption because the result is to overstate the persistence of a COPC by neglecting its biodegradation. However, in some circumstances this may be nonconservative where biodegradation products are also COPCs. For example, COPCs such as chloroform can degrade to methylene chloride and chloromethane, which have higher cancer slope factors. Dichloroethylene can eventually degrade to vinyl chloride, which has a higher cancer slope factor than dichloroethylene.

Volatilization and gas phase transport are conservatively neglected in this calculation to maximize the peak groundwater concentration predicted by the model.

Predictive (post-2010) simulations of water flow and contaminant transport were run for 1000 years to produce peak groundwater concentrations for each COPC based on its K_d value, and accounting for radioactive decay for radionuclide COPCs, using the K_d values and half-lives listed in the tables in Attachments B and C of this ECF.

3.5 Simulation Duration

A 1000-year limit was established for purposes of unit-length SSL and PRG calculation by agreement with regulatory agencies. Accordingly, the peak concentration within the 1000-year predictive (post-2010) simulation was used to calculate the unit-length SSL and PRG values.

The time of occurrence for peak groundwater concentration may be after the 1000-year limit for contaminants subject to high sorption. Because of the 1000-year limit, however, only the peak groundwater concentration within 1000 years is used as the basis for unit-length SSL or PRG values. Typically, breakthrough at numerically significant levels is not simulated within 1000 years for contaminants with high sorption values, although the threshold for breakthrough will depend on the recharge scenario used. These cases commonly result in an "NR" (non-representative) coding assigned for the unit-length SSL or PRG (Section 2.6.1).

3.6 Uncertainties, Assumptions, and Conservatism

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-2011-50).

STOMP has been shown through comparison to analytical solutions, benchmarking against other codes, and field validation to solve the governing equations it incorporates for flow and transport processes correctly, but that the representativeness of any given model implemented using STOMP is inherently limited by the accuracy of the conceptual representation and the representativeness of the parameterization.

DOE/RL-2011-50 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-2011-50. Documentation is provided in DOE/RL-2011-50 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.

Application of the PRG values calculated herein requires an understanding of which assumptions and modeling choices were conservative and which were not. Conservative assumptions and modeling choices include:

- Recharge was represented in the numerical model by uniform flux rates specified over periods so that vadose zone flow is always downward. In contrast, recharge in an arid vadose zone occurs only as often as the combination of precipitation and antecedent moisture conditions allow, i.e., sporadically or infrequently, so that there can be long periods when shallow vadose-zone pore water movement is controlled more by evaporation and transpiration near the surface than gravity, resulting in upward movement or reduced downward seepage velocity.

- The model implementation in a single column forces all contamination through the vadose zone down to the aquifer, whereas infiltrating water and solutes tend to migrate laterally as the wetting front redistributes following an infiltration event.

- The recharge rates for the native vegetation scenario used to calculate PRGs uses bounding native vegetation rates based on numerous lysimeter and tracer recharge studies (PNNL-17841).

- The unit-length SSL values to be used for screening calculated for bounding recharge rates postulated in the irrigation recharge scenario. This is not the expected land use, and the irrigation is assumed to commence much sooner than is reasonable.

- The initial condition (either the 100:0 or 70:30 model) represents a bounding initial condition that effectively assumes the maximum residual soil contamination level is uniformly present over the entire

applicable vadose zone thickness (a peak concentration would not be expected to occur over the entire depth range).

- The vadose zone thicknesses for the representative lithostratigraphic columns were minimized by using water tables from a typical high-water month when developing the lithostratigraphic columns for use in an average annual model; this minimizes contaminant transport time, thereby resulting in higher and earlier groundwater peak concentrations.
- Dilution upon mixing of groundwater with Columbia River water is neglected in the determination of SSL and PRG values protective of surface water.
- Dispersion is assumed negligible, which leads to larger peak concentrations than if dispersion had been included.
- Volatile organic compounds are assumed to have negligible volatilization so that the resulting peak concentrations are larger than if volatilization had been included.
- Geometric means of measured aquifer horizontal hydraulic conductivity values are lower, and thus more conservative, than arithmetic means because the values typically span several orders of magnitude.

Assumptions that may or may not be conservative include:

- The median hydraulic gradient value for each source area may be too large by several-fold for waste sites near the Columbia River and may be several times too large for waste sites that are far inland from the river.

4 Software Applications

STOMP was the primary software used for this calculation; as approved software, the information required is provided in this section.

Microsoft Excel® spreadsheets were used to calculate contaminant inventory values and approximate contaminant solute concentrations, back-calculate PRG values, and evaluate the results produced by STOMP.

4.1 Approved Software

The vadose zone fate and transport calculations are performed using CHPRC Build 4 of the STOMP software, registered in the Hanford Information System Inventory (HISI) under identification number 2471. STOMP use by CHPRC is managed under the following software lifecycle documents: CHPRC-00222, STOMP *Functional Requirements Document*; CHPRC-00176, *STOMP Software Management Plan*; CHPRC-00211, *STOMP Software Test Plan*; CHPRC-00515, STOMP *Acceptance Test Report*; and CHPRC-00269, STOMP *Requirements Traceability Matrix*.

4.1.1 Description

The following required information for the STOMP software package used for this calculation is provided here:

- Software Title: STOMP
- Software Version: CHPRC Build 4

- HISI Identification Number: 2471
- Workstation type and property number (from which software is run): STOMP was executed on the INTERA Richland OLIVE Linux®[3] Cluster that is owned and managed by INTERA, Inc., a pre-selected subcontractor to CHPRC. The computer property tag for the front-end node is #825 at INTERA's office in Richland, Washington. This node is a Dell® PowerEdge® R530 Server with 12 Intel®[4] Xeon E5-2680 v3 CPU (x2) Cores (48 processors) @ 2.5 GHz with 30 MB Cache and 128 GB of RAM. The workstation storage consists of 26 TB RAID-5 disk array. As given by the command "uname –a", the operating system details are

```
Linux olive 4.4.0-38-generic #57~14.04.1-Ubuntu SMP Tue Sep 6 17:20:43
UTC 2016 x86_64 x86_64 x86_64 GNU/Linux
```

4.1.2 Software Installation and Checkout

A copy of the *Software Installation and Checkout Form* for the STOMP installation used for this calculation is provided in Attachment D to this ECF. The STOMP options analysis, which is performed to ensure that al options used in the STOMP code have been NQA-1 tested, is provided in Attachment E to this ECF.

4.1.3 Statement of Valid Software Application

DOE/RL-2011-50 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-2011-50 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 can simulate all the necessary FEPs, and that STOMP meets all of the other required code selection criteria. Section 6.4.1 of DOE/RL-2011-50 addresses code selection criteria, including quality assurance 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) 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 INTERA Linux® Cluster system producing the same results as those presented for selected problems from the STOMP application guide (PNNL-11216) in accordance with the software test plan (CHPRC-00211).

5 Calculation

STOMP simulations were created and run using the representative lithostratigraphic columns, boundary conditions, initial conditions, and parameter values described in Section 3. A description of the calculation of unit-length SSL and PRG values is presented in Section 5.1.

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

[4] Intel® is a registered trademark of Intel Corporation.

5.1 Calculation of Unit-Length Soil Screening Levels and Unit-Length Preliminary Remediation Goals

The source-area-specific unit-length SSL values for the 100-K source OUs are presented in Attachment A of this ECF. The source-area-specific PRG values are presented for 100-K OUs in Attachment B of this ECF. Details of this calculation are provided below.

5.1.1 Time Step and Solution Control

The STOMP simulator solves a wide variety of nonlinear, single- or multiphase flow and transport problems for variably saturated geologic media. Partial differential conservations equations for component mass, energy, and solute mass comprise the fundamental equations for the simulator. STOMP solves flow and transport problems in the subsurface environment in one, two, or three dimensions. STOMP solves the fundamental equations for flow using an integral volume finite difference approach with the nonlinearities in the discretized equations resolved through Newton-Raphson iteration. The fundamental equation for solute transport are discretized to algebraic form following the integrated finite difference method of Patankar (1980) that is implicit using backward Euler time differencing, or by other techniques available in STOMP (e.g., TVD). STOMP solves the linear systems of equations that result from the Newton-Raphson linearization or the solute transport solution using either a direct, banded matrix solver or an indirect conjugate gradient-based solver.

For this calculation, the STOMP-W operational mode (solving for water mass and solute mass conservation) with the direct, banded matric solver was used for all simulations. The Patankar (1980) technique was used for solute transport simulation.

For solution control, the maximum time step permitted for predictive transport simulations was 0.01 years. The selected grid dimension of 10.0 m in the horizontal direction by 0.25 m in the vertical direction were also deliberately specified to maintain grid Courant numbers below the threshold of 1.0 to minimize numerical dispersion in the saturated zone (3.1.2). STOMP's automatic Courant limitation feature was used to control numerical dispersion in the unsaturated nodes: this feature further sub-divided transport solution time steps within the time steps allowed for the flow solution to maintain the Courant limit and thereby control numerical dispersion.

The aqueous concentrations calculated using STOMP was scaled down to unit horizontal grid (*x*-direction) length (1.0 m) by dividing the aqueous concentrations by 10. The accuracy of this methodology was verified through simulation of varying grid dimensions (details not presented in this ECF).

5.1.2 Peak Groundwater Concentration Calculation

STOMP was used to simulate groundwater concentration for each model time step along a portion of the domain's downgradient boundary corresponding to the top 5 m of the aquifer for the following set of simulations:

- → Two recharge scenarios, each for:
  - → Ten lithostratigraphic columns (Figure 3-2), each for:
    - → All COPCs with their respective K_d values and decay half-lives (Attachments A and B of this ECF)

Fluxes through the downgradient boundary were written to a surface flux file, one of STOMP's standard output options. For each time step, STOMP writes the water mass and solute mass flux rates passing through the surface as well as the cumulative water and solute mass that have passed through the surface. Groundwater concentration within the 5-m-long surface was conservatively estimated by calculating it at the aquifer edge beneath the downgradient edge of the waste site footprint. The solute mass flux per unit

time was divided by the water volume flux per unit time to yield a groundwater concentration at each time step.

5.1.3 Dilution Factor

Dilution of vadose zone contaminant release in the aquifer is directly accounted for within the STOMP simulation because the aquifer is directly represented in the model domain as a function of the aquifer thickness and the hydraulic gradient. Consequently, an aquifer dilution factor is not applied to scale the concentrations reported by STOMP, but rather it is implicit in the concentrations reported by STOMP in this formulation. For comparison purposes, the effective dilution factor in this model can be calculated. The dilution factor is as the ratio of the combined aquifer and vadose zone water fluxes to the vadose zone water flux (WAC 173-340-747):

$$DF = \frac{Q_{VZ} + Q_A}{Q_{VZ}} \qquad \text{Equation 1}$$

where DF is the dilution factor (dimensionless), Q_{VZ} equals the volumetric flux from the vadose zone into the aquifer (L^3T^{-1}) and Q_A represents the volumetric flux through the topmost 5 m of the aquifer (L^3T^{-1}).

The effective dilution factors calculated using Equation 1 for recharge rates for each recharge phase in the predictive period (treated as steady-state values) are listed in Table 5-1. These factors are calculated using the recharge rates for each scenario and phase (Table 3-3; Table 3-4), median hydraulic gradients (Table 3-5), and aquifer saturated hydraulic conductivities (Table 3-7), along with dimensions of the STOMP model domain (Section 3.1). The dilution factors are substantially higher where the aquifer is comprised of Hanford formation than where the aquifer is comprised of Ringold Formation because the higher hydraulic conductivity in the Hanford formation results in greater fluxes for a similar gradient. The dilution factors presented in Table 5-1 provide an indication of the magnitude of dilution calculated by STOMP. It is emphasized here, however, that these factors were not explicitly applied to STOMP results. Rather, dilution is calculated within the STOMP solution using the instantaneous water fluxes in the model domain, time step by time step. Thus, dilution is implicitly accounted for within the model results, rather than applied explicitly in a post-calculation step to model results.

Table 5-1. Effective Dilution Factors

Area	Aquifer Formation	Effective Dilution Factors[a] by Recharge Scenario Phase			
Native Vegetation Recharge Scenario		Bare Soil (2010-2015) 63 mm/yr	Cheatgrass (2015-2020) 31.5 mm/yr	Developing Shrub-Steppe (2020-2050) 8.0 mm/yr	Mature Shrub-Steppe (2050 >) 4.0 mm/yr
100-K	Ringold E	64.78	128.57	503.30	1005.60
Irrigation Recharge Scenario		Bare Soil (2010-2015) 63 mm/yr	Irrigation I (2015-2045) 76.4 mm/yr		Irrigation II (2045 >) 72.4 mm/yr
100-K	Ringold E	64.78	53.60		56.50

a. Dilution factors calculated per Washington Administrative Code (WAC 173-340-747); calculation of dilution is for the steady-state recharge rate in each recharge phase. Instantaneous dilution in STOMP varies as a function of the instantaneous water flux from the vadose zone entering the aquifer at the water table, which changes in response to time-varying recharge rates.

For context, if the default fixed parameter three-phase partition model (WAC 173-340-747(3)(a)) were used to establish soil concentrations for groundwater protection, the default groundwater dilution factor is 20 for unsaturated zone soil. However, this default is not applicable to this calculation, because it uses alternative fate and transport models (WAC 173-340-747(8)) and not the default parameter three-phase partition model. Where alternative fate and transport models are used, however, the WAC requires that dilution "be based on site-specific measurements or estimated using a model incorporating site-specific characteristics". This requirement is met in this calculation by using STOMP to model the aquifer with the appropriate aquifer thickness and a median hydraulic gradient based on site-specific measurements.

The WAC requires the following about the dilution factor where upgradient contamination is present for use of alternative fate and transport models:

> **WAC 173-340-747 (8)(b)(vi)**: Dilution. Dilution shall be based on site-specific measurements or estimated using a model incorporating site-specific characteristics. If detectable concentrations of hazardous substances are present in upgradient groundwater, then the dilution factor may need to be adjusted downward in proportion to the background (upgradient) concentration.

Adjustments to the dilution factor are not warranted in this case because these values were applied to establish soil contamination levels protective of groundwater for the post-remedy period. There is no natural background level of Cr(VI) contamination in groundwater in the 100-K area; the present plume is anthropogenic in origin and is being addressed by an interim remedy that will address any vadose zone sources that leach to groundwater during the remedy implementation period. The interim or final remedy will continue until contamination levels in groundwater have achieved cleanup levels. Hence, the unit-length SSLs and PRGs protective of groundwater and of surface water that were calculated without adjustment for upgradient (background) concentration are protective for the post-remedial period.

5.1.4 Calculation of Unit-Length Soil Screening Levels and Preliminary Remediation Goals

In post-processing of the STOMP surface flux files, the peak groundwater concentration within 1000 years for the predictive simulations (Section 5.1.2) was identified for each simulation. For each COPC, and for the 100-K source area, the maximum of the peak concentrations simulated for the representative lithostratigraphic columns for that source area (Figure 3-2) was selected as the basis for calculation of the unit-length SSL (if the irrigation recharge scenario) or PRG (if the native vegetation recharge scenario). This process of using the maximum groundwater concentration result provided an additional bounding aspect to this calculation, because SSL and PRG values for all waste sites in each source area are based on results for the lithostratigraphic column that is least protective for the range of lithostratigraphic columns representative of that source area.

Evaluation of unit-length SSL and PRG calculations for the full set of representative lithostratigraphic columns developed for all 100-K Area source OU indicates that the K_d threshold value (the K_d value at which the peak groundwater concentration does not exceed the breakthrough concentration threshold) is strongly influenced by the vadose zone thickness as well as the recharge scenario. Generally, for 70:30 initial source distributions, thicker vadose zone columns result in smaller K_d threshold values. For the complete breakdown of each COPC unit-length SSL and PRG value, please refer to Attachments A and B. Tabulations of unit-length SSL and PRG values are presented in ascending K_d order (Tables A-1, A-2, and A-3; Tables B-1, B-2, and B-3) and in analyte-name ascending order for lookup convenience (Tables A-4, A-5 and A-6; Tables B-4, B-5 and B-6).

5.2 Site-Specific Modeling

DOE-RL/2011-50 provides a graded approach for calculation of unit-length SSL and PRG values. Under this graded approach, for which the first-level, generalized model is non-representative, or in cases where the bounding assumptions merit reconsideration for specific site conditions, the waste site may be evaluated

further using a site-specific modeling approach. This approach combines the efficiency of a generalized modeling approach (first level) with the judicious use of site-specific modeling (second level) only where the additional modeling is merited.

5.2.1 Site-Specific SSLs with Representative Columns

Waste sites selected for site-specific consideration shown in Table 5-2 were chosen to further evaluate sites failing the exposure point concentration comparison with the generalized (first level) SSL values (ECF-100KR4-17-0240). Site-specific SSLs were calculated for those particular COPCs and waste sites using the representative column based on the borehole that was nearest to the waste site under further evaluation. Using the representative soil columns that are nearest to the listed waste sites relaxes the conservatism of using the most restrictive soil column from the range that represents the entire OU, and instead calculates the protective level based on only a soil column that most closely represents that site from the range of soil columns. The calculation of site-specific unit-length SSL values for each waste site in question otherwise follows the same pattern as described in Section 2.6. The resulting site-specific SSL values calculated in this manner are listed in Table 5-3 and Table 5-4 for protection of groundwater and of surface water, respectively. For those cases where a waste site extent crosses the range of several representative soil columns, the maximum of the selected columns (based on maximum calculated peak concentration) is denoted within parenthases. None of the site/COPC combinations that exceeded the generalized SSL level exceeded the site-specific values.

Table 5-2. Waste Sites Considered for Site-Specific Analysis

Waste Sites for Site-Specific Consideration			
100-K-110	126-KE-2	100-K-34	100-K-91
118-K-1	100-K-30	1607-K3	128-K-2
600-29	100-K-31	100-K-46	
100-K-102	100-K-32	100-K-63	
100-K-14	100-K-33	100-K-84	

Table 5-3. Site-Specific Soil Screening Levels Protective of Groundwater

Waste Site	Analyte Name	CAS No.	WQS (µg/L)	Site-Specific Cpk (µg/L)	Site-Specific Unit-Length SSL for Groundwater Protection [a] $\left(\frac{\mu g}{kg} \cdot m\right)$	Representative Soil Column Number [b]
100-K-110	Antimony	7440-36-0	6.00E+00	2.40E-14	NR	Column 1
100-K-110	Iron	7439-89-6	1.12E+04	1.17E-08	NR	Column 1
118-K-1	Antimony	7440-36-0	6.00E+00	5.97E-10	NR	Column 4
118-K-1	Iron	7439-89-6	1.12E+04	8.85E-06	NR	Column 4
600-29	Nickel	7440-02-0	1.00E+02	0.00E+00	NR	Column (1) 3, 5A

Notes:

Table 5-3. Site-Specific Soil Screening Levels Protective of Groundwater

Waste Site	Analyte Name	CAS No.	WQS (µg/L)	Site-Specific Cpk (µg/L)	Site-Specific Unit-Length SSL for Groundwater Protection [a] $\left(\frac{\mu g}{kg} \cdot m\right)$	Representative Soil Column Number [b]

a. The following restrictions were applied to soil screening levels:
• "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 µg/L (a value set as the lower limit of numerical significance).
• Value was limited to a physical upper bound of 389,000 mg/kg, based on the maximum pore space contaminant mass capacity.
b. In the case of sites having multiple representative columns, the soil column with the highest peak concentration is used for the site-specific SSL calculation. The column with the highest peak concentration is denoted within parenthases.

Table 5-4. Site-Specific Soil Screening Levels Protective of Surface Water

Waste Site	Analyte Name	CAS No.	WQS (µg/L)	Site-Specific Cpk (µg/L)	Site-Specific Unit-Length SSL for Groundwater Protection [a] $\left(\frac{\mu g}{kg} \cdot m\right)$	Representative Soil Column Number [b]
100-K-102	Mercury	7439-97-6	1.20E-02	0.00E+00	NR	Column 1
100-K-110	Iron	7439-89-6	1.00E+03	1.17E-08	NR	Column 1
100-K-110	Mercury	7439-97-6	1.20E-02	0.00E+00	NR	Column 1
100-K-110	Zinc	7440-66-6	9.10E+01	0.00E+00	NR	Column 1
100-K-14	Mercury	7439-97-6	1.20E-02	8.38E-13	NR	Column 3
126-KE-2	Mercury	7439-97-7	1.20E-02	8.38E-13	NR	Column 3
100-K-30	Mercury	7439-97-6	1.20E-02	8.38E-13	NR	Column 3
100-K-31	Mercury	7439-97-6	1.20E-02	8.38E-13	NR	Column 3
100-K-32	Mercury	7439-97-6	1.20E-02	0.00E+00	NR	Column 1
100-K-33	Mercury	7439-97-6	1.20E-02	0.00E+00	NR	Column 1
100-K-34	Copper	7440-50-8	9.90E+00	1.41E-07	NR	Column 1
100-K-102	Copper	7440-50-8	9.90E+00	1.41E-07	NR	Column 1
1607-K3	Copper	7440-50-8	9.90E+00	1.41E-07	NR	Column 1
100-K-46	Copper	7440-50-8	9.90E+00	5.85E-06	NR	Column 3
100-K-63	Zinc	7440-66-6	9.10E+01	1.29E-06	NR	Column 2A, (A1)
100-K-84	Copper	7440-50-8	9.90E+00	5.66E-05	NR	Column 4
100-K-84	Mercury	7439-97-6	1.20E-02	4.57E-11	NR	Column 4
100-K-91	Mercury	7439-97-6	1.20E-02	0.00E+00	NR	Column 1

Table 5-4. Site-Specific Soil Screening Levels Protective of Surface Water

Waste Site	Analyte Name	CAS No.	WQS (µg/L)	Site-Specific Cpk (µg/L)	Site-Specific Unit-Length SSL for Groundwater Protection [a] $\left(\frac{\mu g}{kg} \cdot m\right)$	Representative Soil Column Number [b]
118-K-1	Copper	7440-50-8	9.90E+00	5.66E-05	NR	Column 4
118-K-1	Iron	7439-89-6	1.00E+03	8.85E-06	NR	Column 4
118-K-1	Zinc	7440-66-6	9.10E+01	1.83E-12	NR	Column 4
128-K-2	Copper	7440-50-8	9.90E+00	1.41E-07	NR	Column (1), 5A
600-29	Copper	7440-50-8	9.90E+00	5.85E-06	NR	Column 1, (3) 5A
600-29	Nickel	7440-02-0	5.20E+01	0.00E+00	NR	Column (1), 3, 5A

Notes:

a. The following restrictions were applied to soil screening levels:

• "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 µg/L (a value set as the lower limit of numerical significance).

• Value was limited to a physical upper bound of 389,000 mg/kg, based on the maximum pore space contaminant mass capacity.

b. In the case of sites having multiple representative columns, the soil column with the highest peak concentration is used for the site-specific SSL calculation. The column with the highest peak concentration is denoted within parenthases.

6 Results/Conclusions

The results of this calculation include tabulated SSL and PRG values are described in Section 6.1.

6.1 Soil Screening Value and Preliminary Remediation Goal Results

As described in Section 5.1, the maximum of the peak groundwater concentrations calculated with STOMP for the range or lithostratigraphic columns for the 100-K source OUs using the irrigation recharge scenario was used in Equation 1 to compute the SSL value for each COPC. The resulting SSL values protective of surface water and of groundwater are reported for each COPC in Attachment A to this ECF.

Similarly, the maximum of the peak groundwater concentrations from the range of lithostratigraphic columns simulated for the 100-K source OUs using the native vegetation recharge scenario was used in Equation 2 to compute the PRG value for each COPC. The resulting PRG values protective of surface water and groundwater are reported for each COPC in Attachment B to this ECF.

Note the following provisions apply to SSLs and PRGs reported in Attachments A and B to this ECF, respectively:

- For COPCs for which an applicable water quality standard is not available, the "NA" code was applied to the SSL and PRG values (Section 2.6).
- Breakthrough was assumed not to occur if the simulated peak concentrations in groundwater within the 1000-year limit did not exceed 0.0001 µg/L for non-radionuclide COPCs or 0.0001 pCi/m^3 for radionuclide COPCs, in at least one representative lithostratigraphic columns simulated (Section 2.6.1). In these instances, the “NR” code was applied for these COPCs to designate a non-representative result, signifying that the results were below a level of numerical significance.
- If the calculated value for any SSL or PRG was less than the required detection limit (RDL) for soil concentration for a given COPC, then the SSL or PRG value was set equal to the RDL for that COPC (Section 2.6.2).
- If the calculated SSL or PRG value for any COPC exceeded the physical upper bound (389,000 mg/kg), then that SSL or PRG value was truncated at 389,000 mg/kg (Section 2.6.3).
- The cleanup level for hexavalent chromium is set to 6.0 mg/kg based on the evaluation in ECF-HANFORD-11-0165; this value is not dependent on waste site size (Section 2.6.4).

The SSL and PRG values reported in this calculation are applicable only to sites and COPCs where the conditions and assumptions underpinning this calculation are representative. Some waste sites may require a more rigorous investigation of site-specific conditions than those underlying the SSL and PRG values listed in Attachments A and B to this ECF.

7 References

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Attachment A

Unit-Length Soil Screening Levels Protective of Groundwater and Unit-Length Soil Screening Levels Protective of Surface Water for the 100-K Source Operable Units

Note

Tabulated soil screening level (SSL) values are presented in Tables A-1, A-2, and A-3 in ascending mobility (K_d) order. This sorting order reveals the correlation between analyte K_d values and resulting SSL values. The "NR" (nonrepresentative result) code reflects that the model simulations did not predict breakthrough within 1000 years, defined here as a peak groundwater concentration exceeding 0.0001 µg/L for non-radionuclide analytes, or 0.0001 pCi/m^3 for radionuclide analytes), a value set as the lower limit of numerical significance for model groundwater concentration results.

The same SSL values are presented again in Tables A-4, A-5, and A-6, but in ascending analyte name order to enable lookup by the reader using the analyte name.

Table A-1. Unit-Length Soil Screening Levels for Non-radionuclides Protective of Groundwater in 100-K Source Operable Units (Increasing mobility order by K_d)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [(a)] (mL/g)	Groundwater Standard [(a)] (µg/L)	Required Detection Limit [(b)] (mg/kg)	Soil Screening Level Protective of Groundwater [(c,d)] (mg/kg)·m
14797-55-8	Nitrate	Nitrate	0.00E+00	4.50E+04	7.50E-01	1.28E+03
14797-65-0	Nitrite	Nitrite	0.00E+00	3.30E+03	7.50E-01	9.38E+01
NO2+NO3-N	Nitrogen in Nitrite and Nitrate	Nitrogen in Nitrite and Nitrate	0.00E+00	1.00E+04	7.50E-01	2.84E+02
67-64-1	Acetone	Acetone	5.75E-04	7.20E+03	2.00E-02	2.07E+02
107-21-1	Ethylene glycol	Ethelyne glycol	1.00E-03	1.60E+04	3.30E-01	4.63E+02
75-09-2	Methylene chloride	methylene chloride	1.00E-02	5.00E+00	5.00E-03	1.69E-01
18540-29-9	Hexavalent Chromium	chromium(VI)	8.00E-01	4.80E+01	5.00E-01	6.00E+00 [e]
91-20-3	Naphthalene	naphthalene	1.19E+00	1.60E+02	3.30E-01	1.10E+02
84-74-2	Di-n-butylphthalate	di-butyl phthalate	1.57E+00	1.60E+03	3.30E+02	1.43E+03
7440-42-8	Boron	Boron	3.00E+00	3.20E+03	2.00E+00	5.38E+03
TPH	Total petroleum hydrocarbons	Total petroleum hydrocarbons	4.00E+00	5.00E+02	---	1.12E+03
83-32-9	Acenaphthene	acenaphthene	4.90E+00	9.60E+02	3.30E-01	2.62E+03
7782-49-2	Selenium	selenium and compounds	5.00E+00	5.00E+01	1.00E+00	1.39E+02
7440-43-9	Cadmium (Diet)	cadmium	6.70E+00	5.00E+00	5.00E-01	1.88E+01
86-73-7	Fluorene	fluorene	7.71E+00	6.40E+02	3.30E-01	2.83E+03
7440-22-4	Silver	silver	8.30E+00	8.00E+01	2.00E-01	3.85E+02
7439-98-7	Molybdenum	molybdenum	2.00E+01	8.00E+01	2.00E+00	9.54E+02
7440-50-8	Copper	copper	2.20E+01	6.40E+02	1.00E+00	8.40E+03
120-12-7	Anthracene	anthracene	2.35E+01	4.80E+03	3.30E-01	6.73E+04
7439-89-6	Iron	Iron	2.50E+01	1.12E+04	---	1.67E+05
7440-38-2	Arsenic	arsenic, inorganic	2.90E+01	1.00E+01	1.00E+01	1.73E+02
7440-24-6	Strontium	strontium	3.50E+01	9.60E+03	1.00E+00	2.07E+05
7440-39-3	Barium	Barium	4.10E+01	2.00E+03	2.00E+00	5.37E+04
7440-36-0	Antimony	antimony	4.50E+01	6.00E+00	6.00E-01	1.86E+02
7440-48-4	Cobalt	Cobalt	4.50E+01	4.80E+00	2.00E+00	1.49E+02
206-44-0	Fluoranthene	fluoranthene	4.91E+01	6.40E+02	3.30E-01	2.30E+04
7439-97-6	Mercury (Mercuric chloride)	mercury (using mercuric chloride)	5.20E+01	2.00E+00	2.00E-01	7.93E+01
7440-66-6	Zinc	zinc	6.20E+01	4.80E+03	1.00E+00	2.66E+05
7439-96-5	Manganese	manganese	6.50E+01	3.84E+02	5.00E+00	2.34E+04
7440-02-0	Nickel	nickel soluble salts	6.50E+01	1.00E+02	4.00E+00	6.10E+03
129-00-0	Pyrene	pyrene	6.80E+01	4.80E+02	3.30E-01	3.22E+04
7440-61-1	Uranium	Uranium	7.00E+01	3.00E+01	1.00E+00	2.14E+03
7440-28-0	Thallium	Thallium, soluable salts	7.10E+01	5.00E-01	---	3.68E+01
12674-11-2	Aroclor-1016	aroclor 1016 (PCB)	1.07E+02	5.00E-01	1.70E-02	9.96E+01
117-81-7	Bis(2-ethylhexyl) phthalate	bis(2-ethylhexy) phthalate	1.11E+02	6.00E+00	3.30E-01	1.31E+03
11097-69-1	Aroclor-1254	aroclor 1254 (PCB)	1.31E+02	4.40E-02	1.70E-02	1.50E+01
16984-48-8	Fluoride	fluoride (using fluorine)	1.50E+02	9.60E+02	5.00E+00	3.89E+05
7440-31-5	Tin	tin	2.50E+02	9.60E+03	1.00E+01	3.89E+05
56-55-3	Benzo(a)anthracene	Benzo(a)anthracene	3.58E+02	8.80E-01	1.50E-02	7.67E+03
218-01-9	Chrysene	Chrysene	3.98E+02	8.80E+01	1.00E-01	3.89E+05
7440-41-7	Beryllium	beryllium	7.90E+02	4.00E+00	5.00E-01	NR
11096-82-5	Aroclor-1260	aroclor 1260 (PCB)	8.22E+02	4.40E-02	1.70E-02	NR
50-32-8	Benzo(a)pyrene	Benzo(a)pyrene	9.69E+02	8.80E-02	1.50E-02	NR
7440-47-3	Chromium	chromium (total)	1.00E+03	1.00E+02	1.00E+00	NR
7440-62-2	Vanadium	vanadium	1.00E+03	8.00E+01	2.50E+00	NR
205-99-2	Benzo(b)fluoranthene	Benzo(b)fluoranthene	1.23E+03	8.80E-01	1.50E-02	NR
207-08-9	Benzo(k)fluoranthene	Benzo(k)fluoranthene	1.23E+03	8.80E+00	1.50E-02	NR
7429-90-5	Aluminum	Aluminum (soluble)	1.50E+03	1.60E+04	---	NR

Table A-1. Unit-Length Soil Screening Levels for Non-radionuclides Protective of Groundwater in 100-K Source Operable Units (Increasing mobility order by K_d)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [(a)] (mL/g)	Groundwater Standard [(a)] (µg/L)	Required Detection Limit [(b)] (mg/kg)	Soil Screening Level Protective of Groundwater [(c,d)] (mg/kg)·m
53-70-3	Dibenz[a,h]anthracene	Dibenz[a,h]anthracene	1.79E+03	8.80E-02	3.00E-02	NR
193-39-5	Indeno(1,2,3-cd)pyrene	Indeno(1,2,3-cd)pyrene	3.47E+03	8.80E-01	3.30E-01	NR
7439-92-1	Lead	lead	1.00E+04	1.50E+01	5.00E+00	NR
TPHDIESEL	Total petroleum hydrocarbons - diesel range	Total petroleum hydrocarbons - diesel range	---	---	---	NA
TPHDIESELEXT	Total petroleum hydrocarbons - diesel range extended to C36	Total petroleum hydrocarbons - diesel range extended to C36	---	---	---	NA
TPH/OILH	Total petroleum hydrocarbons - motor oil (high boiling)	Total petroleum hydrocarbons - motor oil (high boiling)	---	---	---	NA

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington. K_d values reported here were used in calculations and may differ in precision (rounding) from values reported in ECF-HANFORD-12-0023, but were derived from the same electronic data set.

b. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

c. The following restrictions were applied to unit-length soil screening levels:
   - "NA" was assigned where no applicable water quality standard was available.
   - "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 µg/L (a value set as the lower limit of numerical significance).
   - Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.
   - Value was limited to a physical upper bound of 389,000 mg/kg, based on the maximum pore space contaminant mass capacity.

d. Soil screening levels protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these soil screening levels, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the soil screening level for evaluation use.

e. The soil screening level for hexavalent chromium is set to 6.0 mg/kg based on the evaluation in ECF-HANFORD-11-0165; this value is not dependent on waste site size.

Table A-2. Unit-Length Soil Screening Levels for Non-radionuclides Protective of Surface Water in 100-K Source Operable Units (Increasing mobility order by K_d)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Surface Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Soil Screening Level Protective of Surface Water [c,d] (mg/kg)·m
14797-55-8	Nitrate	Nitrate	0.00E+00	---	7.50E-01	NA
14797-65-0	Nitrite	Nitrite	0.00E+00	---	7.50E-01	NA
NO2+NO3-N	Nitrogen in Nitrite and Nitrate	Nitrogen in Nitrite and Nitrate	0.00E+00	---	7.50E-01	NA
67-64-1	Acetone	Acetone	5.75E-04	---	2.00E-02	NA
107-21-1	Ethylene glycol	Ethelyne glycol	1.00E-03	---	3.30E-01	NA
75-09-2	Methylene chloride	methylene chloride	1.00E-02	---	5.00E-03	NA
18540-29-9	Hexavalent Chromium	chromium(VI)	8.00E-01	1.00E+01	5.00E-01	6.00E+00 [e]
91-20-3	Naphthalene	naphthalene	1.19E+00	---	3.30E-01	NA
84-74-2	Di-n-butylphthalate	di-butyl phthalate	1.57E+00	---	3.30E+02	NA
7440-42-8	Boron	Boron	3.00E+00	---	2.00E+00	NA
TPH	Total petroleum hydrocarbons	Total petroleum hydrocarbons	4.00E+00	---	---	NA
83-32-9	Acenaphthene	acenaphthene	4.90E+00	---	3.30E-01	NA
7782-49-2	Selenium	selenium and compounds	5.00E+00	5.00E+00	1.00E+00	1.39E+01
7440-43-9	Cadmium (Diet)	cadmium	6.70E+00	7.20E-01	5.00E-01	2.71E+00
86-73-7	Fluorene	fluorene	7.71E+00	---	3.30E-01	NA
7440-22-4	Silver	silver	8.30E+00	2.60E+00	2.00E-01	1.25E+01
7439-98-7	Molybdenum	molybdenum	2.00E+01	---	2.00E+00	NA
7440-50-8	Copper	copper	2.20E+01	9.90E+00	1.00E+00	1.30E+02
120-12-7	Anthracene	anthracene	2.35E+01	---	3.30E-01	NA
7439-89-6	Iron	Iron	2.50E+01	1.00E+03	---	1.49E+04
7440-38-2	Arsenic	arsenic, inorganic	2.90E+01	1.50E+02	1.00E+01	2.59E+03
7440-24-6	Strontium	strontium	3.50E+01	---	1.00E+00	NA
7440-39-3	Barium	Barium	4.10E+01	---	2.00E+00	NA
7440-36-0	Antimony	antimony	4.50E+01	---	6.00E-01	NA
7440-48-4	Cobalt	Cobalt	4.50E+01	---	2.00E+00	NA
206-44-0	Fluoranthene	fluoranthene	4.91E+01	---	3.30E-01	NA
7439-97-6	Mercury (Mercuric chloride)	mercury (using mercuric chloride)	5.20E+01	1.20E-02	2.00E-01	4.76E-01
7440-66-6	Zinc	zinc	6.20E+01	9.10E+01	1.00E+00	5.04E+03
7439-96-5	Manganese	manganese	6.50E+01	---	5.00E+00	NA
7440-02-0	Nickel	nickel soluble salts	6.50E+01	5.20E+01	4.00E+00	3.17E+03
129-00-0	Pyrene	pyrene	6.80E+01	---	3.30E-01	NA
7440-61-1	Uranium	Uranium	7.00E+01	---	1.00E+00	NA
7440-28-0	Thallium	Thallium, soluable salts	7.10E+01	---	---	NA
12674-11-2	Aroclor-1016	aroclor 1016 (PCB)	1.07E+02	1.40E-02	1.70E-02	2.79E+00
117-81-7	Bis(2-ethylhexyl) phthalate	bis(2-ethylhexy) phthalate	1.11E+02	---	3.30E-01	NA

Table A-2. Unit-Length Soil Screening Levels for Non-radionuclides Protective of Surface Water in 100-K Source Operable Units (Increasing mobility order by K_d)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Surface Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Soil Screening Level Protective of Surface Water [c,d] (mg/kg)·m
11097-69-1	Aroclor-1254	aroclor 1254 (PCB)	1.31E+02	1.40E-02	1.70E-02	4.77E+00
16984-48-8	Fluoride	fluoride (using fluorine)	1.50E+02	---	5.00E+00	NA
7440-31-5	Tin	tin	2.50E+02	---	1.00E+01	NA
56-55-3	Benzo(a)anthracene	Benzo(a)anthracene	3.58E+02	---	1.50E-02	NA
218-01-9	Chrysene	Chrysene	3.98E+02	---	1.00E-01	NA
7440-41-7	Beryllium	beryllium	7.90E+02	---	5.00E-01	NA
11096-82-5	Aroclor-1260	aroclor 1260 (PCB)	8.22E+02	1.40E-02	1.70E-02	NR
50-32-8	Benzo(a)pyrene	Benzo(a)pyrene	9.69E+02	---	1.50E-02	NA
7440-47-3	Chromium	chromium (total)	1.00E+03	7.40E+01	1.00E+00	NR
7440-62-2	Vanadium	vanadium	1.00E+03	---	2.50E+00	NA
205-99-2	Benzo(b)fluoranthene	Benzo(b)fluoranthene	1.23E+03	---	1.50E-02	NA
207-08-9	Benzo(k)fluoranthene	Benzo(k)fluoranthene	1.23E+03	---	1.50E-02	NA
7429-90-5	Aluminum	Aluminum (soluble)	1.50E+03	8.70E+01	---	NR
53-70-3	Dibenz[a,h]anthracene	Dibenz[a,h]anthracene	1.79E+03	---	3.00E-02	NA
193-39-5	Indeno(1,2,3-cd)pyrene	Indeno(1,2,3-cd)pyrene	3.47E+03	---	3.30E-01	NA
7439-92-1	Lead	lead	1.00E+04	2.10E+00	5.00E+00	NR
TPHDIESEL	Total petroleum hydrocarbons - diesel range	Total petroleum hydrocarbons - diesel range	---	---	---	NA
TPHDIESELEXT	Total petroleum hydrocarbons - diesel range extended to C36	Total petroleum hydrocarbons - diesel range extended to C36	---	---	---	NA
TPH/OILH	Total petroleum hydrocarbons - motor oil (high boiling)	Total petroleum hydrocarbons - motor oil (high boiling)	---	---	---	NA

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington. K_d values reported here were used in calculations and may differ in precision (rounding) from values reported in ECF-HANFORD-12-0023, but were derived from the same electronic data set.

b. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

c. The following restrictions were applied to soil screening levels:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 µg/L (a value set as the lower limit of numerical significance).
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.
- Value was limited to a physical upper bound of 389,000 mg/kg, based on the maximum pore space contaminant mass capacity.

d. Soil screening levels protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these soil screening levels, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the soil screening level for evaluation use.

e. The soil screening level for hexavalent chromium is set to 6.0 mg/kg based on the evaluation in ECF-HANFORD-11-0165; this value is not dependent on waste site size

Table A-3. Unit-Length Soil Screening Levels for Radionuclides Protective of Groundwater in 100-K Source Operable Units (Increasing mobility order by K_d)

Radionuclide	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Maximum Contaminant Level [a] (pCi/L)	Half-life [b] (yr)	Required Detection Limit [c] (mg/kg)	Dimensional Soil Screening Level Protective of Groundwater [d,e] (pCi/g)·m
Carbon-14 [f]	0.00E+00	2.00E+03	5.70E+03	2.00E+00	5.70E+01
Tritium	0.00E+00	2.00E+04	1.23E+01	---	1.04E+03
Uranium-233/234	2.00E+00	---	1.59E+05	1.00E+00	NVR
Uranium-235	2.00E+00	---	7.04E+08	5.00E-01	NVR
Uranium-238	2.00E+00	---	4.47E+09	1.00E+00	NVR
Strontium-90	2.50E+01	8.00E+00	2.88E+01	1.00E+00	2.25E+04
Nickel-63	3.00E+01	5.00E+01	1.00E+02	3.00E+01	1.90E+04
Cesium-137	5.00E+01	2.00E+02	3.02E+01	1.00E-01	3.89E+05
Cobalt-60	5.00E+01	1.00E+02	5.27E+00	5.00E-02	NR
Americium-241	2.00E+02	1.50E+01	4.32E+02	1.00E+00	9.21E+04
Europium-152	2.00E+02	2.00E+02	1.35E+01	1.00E-01	NR
Europium-154	2.00E+02	6.00E+01	8.59E+00	1.00E-01	NR
Europium-155	2.00E+02	6.00E+02	4.76E+00	1.00E-01	NR
Plutonium-238	2.00E+02	1.50E+01	8.77E+01	1.00E+00	NR
Plutonium-239/240	2.00E+02	---	6.56E+03	1.00E+00	NA

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington. K_d values reported here wre used in calculations and may differ in precision (rounding) from values reported in ECF-HANFORD-12-0023, but were derived from the same electronic data set.

b. EMDT-DE-0006, 2015, *Half-lives for Typical Hanford Site Radioactive Contaminants*, Rev. 1 (copy provided in Attachment E of this ECF)

c. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

d. The following restrictions were applied to soil screening levels:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 pCi/m^3 (a value set as the lower limit of numerical significance).
- “NVR” was assigned where no value was required.
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.

e. Soil screening levels protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these soil screening levels, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the soil screening level for evaluation use.

f. Carbon-14 in liquid form (typically associated with reactor gas condensate).

Table A-4. Unit-Length Soil Screening Levels for Non-radionuclides Protective of Groundwater in 100-K Source Operable Units (Alphabetical order by analyte)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Ground Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Soil Screening Level Protective of Groundwater [c,d] (mg/kg)·m
83-32-9	Acenaphthene	acenaphthene	4.90E+00	9.60E+02	3.30E-01	2.62E+03
67-64-1	Acetone	Acetone	5.75E-04	7.20E+03	2.00E-02	2.07E+02
7429-90-5	Aluminum	Aluminum (soluble)	1.50E+03	1.60E+04	---	NR
7440-36-0	Antimony	antimony	4.50E+01	6.00E+00	6.00E-01	1.86E+02
120-12-7	Anthracene	anthracene	2.35E+01	4.80E+03	3.30E-01	6.73E+04
12674-11-2	Aroclor-1016	aroclor 1016 (PCB)	1.07E+02	5.00E-01	1.70E-02	9.96E+01
11097-69-1	Aroclor-1254	aroclor 1254 (PCB)	1.31E+02	4.40E-02	1.70E-02	1.50E+01
11096-82-5	Aroclor-1260	aroclor 1260 (PCB)	8.22E+02	4.40E-02	1.70E-02	NR
7440-38-2	Arsenic	arsenic, inorganic	2.90E+01	1.00E+01	1.00E+01	1.73E+02
7440-39-3	Barium	Barium	4.10E+01	2.00E+03	2.00E+00	5.37E+04
56-55-3	Benzo(a)anthracene	Benzo(a)anthracene	3.58E+02	8.80E-01	1.50E-02	7.67E+03
50-32-8	Benzo(a)pyrene	Benzo(a)pyrene	9.69E+02	8.80E-02	1.50E-02	NR
205-99-2	Benzo(b)fluoranthene	Benzo(b)fluoranthene	1.23E+03	8.80E-01	1.50E-02	NR
207-08-9	Benzo(k)fluoranthene	Benzo(k)fluoranthene	1.23E+03	8.80E+00	1.50E-02	NR
7440-41-7	Beryllium	beryllium	7.90E+02	4.00E+00	5.00E-01	NR
117-81-7	Bis(2-ethylhexyl) phthalate	bis(2-ethylhexy) phthalate	1.11E+02	6.00E+00	3.30E-01	1.31E+03
7440-42-8	Boron	Boron	3.00E+00	3.20E+03	2.00E+00	5.38E+03
7440-43-9	Cadmium (Diet)	cadmium	6.70E+00	5.00E+00	5.00E-01	1.88E+01
7440-47-3	Chromium	chromium (total)	1.00E+03	1.00E+02	1.00E+00	NR
218-01-9	Chrysene	Chrysene	3.98E+02	8.80E+01	1.00E-01	3.89E+05
7440-48-4	Cobalt	Cobalt	4.50E+01	4.80E+00	2.00E+00	1.49E+02
7440-50-8	Copper	copper	2.20E+01	6.40E+02	1.00E+00	8.40E+03
53-70-3	Dibenz[a,h]anthracene	Dibenz[a,h]anthracene	1.79E+03	8.80E-02	3.00E-02	NR
84-74-2	Di-n-butylphthalate	di-butyl phthalate	1.57E+00	1.60E+03	3.30E+02	1.43E+03
107-21-1	Ethylene glycol	Ethelyne glycol	1.00E-03	1.60E+04	3.30E-01	4.63E+02
206-44-0	Fluoranthene	fluoranthene	4.91E+01	6.40E+02	3.30E-01	2.30E+04
86-73-7	Fluorene	fluorene	7.71E+00	6.40E+02	3.30E-01	2.83E+03
16984-48-8	Fluoride	fluoride (using fluorine)	1.50E+02	9.60E+02	5.00E+00	3.89E+05
18540-29-9	Hexavalent Chromium	chromium(VI)	8.00E-01	4.80E+01	5.00E-01	6.00E+00 [e]
193-39-5	Indeno(1,2,3-cd)pyrene	Indeno(1,2,3-cd)pyrene	3.47E+03	8.80E-01	3.30E-01	NR
7439-89-6	Iron	Iron	2.50E+01	1.12E+04	---	1.67E+05
7439-92-1	Lead	lead	1.00E+04	1.50E+01	5.00E+00	NR
7439-96-5	Manganese	manganese	6.50E+01	3.84E+02	5.00E+00	2.34E+04
7439-97-6	Mercury (Mercuric chloride)	mercury (using mercuric chloride)	5.20E+01	2.00E+00	2.00E-01	7.93E+01
75-09-2	Methylene chloride	methylene chloride	1.00E-02	5.00E+00	5.00E-03	1.69E-01
7439-98-7	Molybdenum	molybdenum	2.00E+01	8.00E+01	2.00E+00	9.54E+02
91-20-3	Naphthalene	naphthalene	1.19E+00	1.60E+02	3.30E-01	1.10E+02
7440-02-0	Nickel	nickel soluble salts	6.50E+01	1.00E+02	4.00E+00	6.10E+03
14797-55-8	Nitrate	Nitrate	0.00E+00	4.50E+04	7.50E-01	1.28E+03
14797-65-0	Nitrite	Nitrite	0.00E+00	3.30E+03	7.50E-01	9.38E+01
NO2+NO3-N	Nitrogen in Nitrite and Nitrate	Nitrogen in Nitrite and Nitrate	0.00E+00	1.00E+04	7.50E-01	2.84E+02

Table A-4. Unit-Length Soil Screening Levels for Non-radionuclides Protective of Groundwater in 100-K Source Operable Units (Alphabetical order by analyte)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Ground Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Soil Screening Level Protective of Groundwater [c,d] (mg/kg)·m
129-00-0	Pyrene	pyrene	6.80E+01	4.80E+02	3.30E-01	3.22E+04
7782-49-2	Selenium	selenium and compounds	5.00E+00	5.00E+01	1.00E+00	1.39E+02
7440-22-4	Silver	silver	8.30E+00	8.00E+01	2.00E-01	3.85E+02
7440-24-6	Strontium	strontium	3.50E+01	9.60E+03	1.00E+00	2.07E+05
7440-28-0	Thallium	Thallium, soluable salts	7.10E+01	5.00E-01	---	3.68E+01
7440-31-5	Tin	tin	2.50E+02	9.60E+03	1.00E+01	3.89E+05
TPH	Total petroleum hydrocarbons	Total petroleum hydrocarbons	4.00E+00	5.00E+02	---	1.12E+03
TPHDIESEL	Total petroleum hydrocarbons - diesel range	Total petroleum hydrocarbons - diesel range	---	---	---	NA
TPHDIESELEXT	Total petroleum hydrocarbons - diesel range extended to C36	Total petroleum hydrocarbons - diesel range extended to C36	---	---	---	NA
TPH/OILH	Total petroleum hydrocarbons - motor oil (high boiling)	Total petroleum hydrocarbons - motor oil (high boiling)	---	---	---	NA
7440-61-1	Uranium	Uranium	7.00E+01	3.00E+01	1.00E+00	2.14E+03
7440-62-2	Vanadium	vanadium	1.00E+03	8.00E+01	2.50E+00	NR
7440-66-6	Zinc	zinc	6.20E+01	4.80E+03	1.00E+00	2.66E+05

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington. K_d values reported here were used in calculations and may differ in precision (rounding) from values reported in ECF-HANFORD-12-0023, but were derived from the same electronic data set.

b. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

c. The following restrictions were applied to soil screening levels:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 µg/L (a value set as the lower limit of numerical significance).
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.
- Value was limited to a physical upper bound of 389,000 mg/kg, based on the maximum pore space contaminant mass capacity.

d. Soil screening levels protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these soil screening levels, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the soil screening level for evaluation use.

e. The soil screening level for hexavalent chromium is set to 6.0 mg/kg based on the evaluation in ECF-HANFORD-11-0165; this value is not dependent on waste site size

Table A-5. Unit-Length Soil Screening Levels for Non-radionuclides Protective of Surface Water in 100-K Source Operable Units (Alphabetical order by analyte)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Surface Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Soil Screening Level Protective of Surface Water [c,d] (mg/kg)·m
83-32-9	Acenaphthene	acenaphthene	4.90E+00	---	3.30E-01	NA
67-64-1	Acetone	Acetone	5.75E-04	---	2.00E-02	NA
7429-90-5	Aluminum	Aluminum (soluble)	1.50E+03	8.70E+01	---	NR
7440-36-0	Antimony	antimony	4.50E+01	---	6.00E-01	NA
120-12-7	Anthracene	anthracene	2.35E+01	---	3.30E-01	NA
12674-11-2	Aroclor-1016	aroclor 1016 (PCB)	1.07E+02	1.40E-02	1.70E-02	2.79E+00
11097-69-1	Aroclor-1254	aroclor 1254 (PCB)	1.31E+02	1.40E-02	1.70E-02	4.77E+00
11096-82-5	Aroclor-1260	aroclor 1260 (PCB)	8.22E+02	1.40E-02	1.70E-02	NR
7440-38-2	Arsenic	arsenic, inorganic	2.90E+01	1.50E+02	1.00E+01	2.59E+03
7440-39-3	Barium	Barium	4.10E+01	---	2.00E+00	NA
56-55-3	Benzo(a)anthracene	Benzo(a)anthracene	3.58E+02	---	1.50E-02	NA
50-32-8	Benzo(a)pyrene	Benzo(a)pyrene	9.69E+02	---	1.50E-02	NA
205-99-2	Benzo(b)fluoranthene	Benzo(b)fluoranthene	1.23E+03	---	1.50E-02	NA
207-08-9	Benzo(k)fluoranthene	Benzo(k)fluoranthene	1.23E+03	---	1.50E-02	NA
7440-41-7	Beryllium	beryllium	7.90E+02	---	5.00E-01	NA
117-81-7	Bis(2-ethylhexyl) phthalate	bis(2-ethylhexy) phthalate	1.11E+02	---	3.30E-01	NA
7440-42-8	Boron	Boron	3.00E+00	---	2.00E+00	NA
7440-43-9	Cadmium (Diet)	cadmium	6.70E+00	7.20E-01	5.00E-01	2.71E+00
7440-47-3	Chromium	chromium (total)	1.00E+03	7.40E+01	1.00E+00	NR
218-01-9	Chrysene	Chrysene	3.98E+02	---	1.00E-01	NA
7440-48-4	Cobalt	Cobalt	4.50E+01	---	2.00E+00	NA
7440-50-8	Copper	copper	2.20E+01	9.90E+00	1.00E+00	1.30E+02
53-70-3	Dibenz[a,h]anthracene	Dibenz[a,h]anthracene	1.79E+03	---	3.00E-02	NA
84-74-2	Di-n-butylphthalate	di-butyl phthalate	1.57E+00	---	3.30E+02	NA
107-21-1	Ethylene glycol	Ethelyne glycol	1.00E-03	---	3.30E-01	NA
206-44-0	Fluoranthene	fluoranthene	4.91E+01	---	3.30E-01	NA
86-73-7	Fluorene	fluorene	7.71E+00	---	3.30E-01	NA
16984-48-8	Fluoride	fluoride (using fluorine)	1.50E+02	---	5.00E+00	NA
18540-29-9	Hexavalent Chromium	chromium(VI)	8.00E-01	1.00E+01	5.00E-01	6.00E+00 [e]
193-39-5	Indeno(1,2,3-cd)pyrene	Indeno(1,2,3-cd)pyrene	3.47E+03	---	3.30E-01	NA
7439-89-6	Iron	Iron	2.50E+01	1.00E+03	---	1.49E+04
7439-92-1	Lead	lead	1.00E+04	2.10E+00	5.00E+00	NR
7439-96-5	Manganese	manganese	6.50E+01	---	5.00E+00	NA
7439-97-6	Mercury (Mercuric chloride)	mercury (using mercuric chloride)	5.20E+01	1.20E-02	2.00E-01	4.76E-01
75-09-2	Methylene chloride	methylene chloride	1.00E-02	---	5.00E-03	NA
7439-98-7	Molybdenum	molybdenum	2.00E+01	---	2.00E+00	NA
91-20-3	Naphthalene	naphthalene	1.19E+00	---	3.30E-01	NA
7440-02-0	Nickel	nickel soluble salts	6.50E+01	5.20E+01	4.00E+00	3.17E+03
14797-55-8	Nitrate	Nitrate	0.00E+00	---	7.50E-01	NA
14797-65-0	Nitrite	Nitrite	0.00E+00	---	7.50E-01	NA
NO2+NO3-N	Nitrogen in Nitrite and Nitrate	Nitrogen in Nitrite and Nitrate	0.00E+00	---	7.50E-01	NA
129-00-0	Pyrene	pyrene	6.80E+01	---	3.30E-01	NA
7782-49-2	Selenium	selenium and compounds	5.00E+00	5.00E+00	1.00E+00	1.39E+01
7440-22-4	Silver	silver	8.30E+00	2.60E+00	2.00E-01	1.25E+01

Table A-5. Unit-Length Soil Screening Levels for Non-radionuclides Protective of Surface Water in 100-K Source Operable Units (Alphabetical order by analyte)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Surface Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Soil Screening Level Protective of Surface Water [c,d] (mg/kg)·m
7440-24-6	Strontium	strontium	3.50E+01	---	1.00E+00	NA
7440-28-0	Thallium	Thallium, soluable salts	7.10E+01	---	---	NA
7440-31-5	Tin	tin	2.50E+02	---	1.00E+01	NA
TPH	Total petroleum hydrocarbons	Total petroleum hydrocarbons	4.00E+00	---	---	NA
TPHDIESEL	Total petroleum hydrocarbons - diesel range	Total petroleum hydrocarbons - diesel range	---	---	---	NA
TPHDIESELEXT	Total petroleum hydrocarbons - diesel range extended to C36	Total petroleum hydrocarbons - diesel range extended to C36	---	---	---	NA
TPH/OILH	Total petroleum hydrocarbons - motor oil (high boiling)	Total petroleum hydrocarbons - motor oil (high boiling)	---	---	---	NA
7440-61-1	Uranium	Uranium	7.00E+01	---	1.00E+00	NA
7440-62-2	Vanadium	vanadium	1.00E+03	---	2.50E+00	NA
7440-66-6	Zinc	zinc	6.20E+01	9.10E+01	1.00E+00	5.04E+03

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington. K_d values reported here were used in calculations and may differ in precision (rounding) from values reported in ECF-HANFORD-12-0023, but were derived from the same electronic data set.

b. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

c. The following restrictions were applied to soil screening levels:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 µg/L (a value set as the lower limit of numerical significance).
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.
- Value was limited to a physical upper bound of 389,000 mg/kg, based on the maximum pore space contaminant mass capacity.

d. Soil screening levels protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these soil screening levels, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the soil screening level for evaluation use.

e. The soil screening level for hexavalent chromium is set to 6.0 mg/kg based on the evaluation in ECF-HANFORD-11-0165; this value is not dependent on waste site size

Table A-6. Unit-Length Soil Screening Levels for Radionuclides Protective of Groundwater in 100-K Source Operable Units (Alphabetical order by analyte)

Radionuclide	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Maximum Contaminant Level [a] (pCi/L)	Half-life [b] (yr)	Required Detection Limit [c] (mg/kg)	Dimensional Soil Screening Level Protective of Groundwater [d,e] (pCi/g)·m
Americium-241	2.00E+02	1.50E+01	4.32E+02	1.00E+00	9.21E+04
Carbon-14 [f]	0.00E+00	2.00E+03	5.70E+03	2.00E+00	5.70E+01
Cesium-137	5.00E+01	2.00E+02	3.02E+01	1.00E-01	3.89E+05
Cobalt-60	5.00E+01	1.00E+02	5.27E+00	5.00E-02	NR
Europium-152	2.00E+02	2.00E+02	1.35E+01	1.00E-01	NR
Europium-154	2.00E+02	6.00E+01	8.59E+00	1.00E-01	NR
Europium-155	2.00E+02	6.00E+02	4.76E+00	1.00E-01	NR
Nickel-63	3.00E+01	5.00E+01	1.00E+02	3.00E+01	1.90E+04
Plutonium-238	2.00E+02	1.50E+01	8.77E+01	1.00E+00	NR
Plutonium-239/240	2.00E+02	---	6.56E+03	1.00E+00	NA
Strontium-90	2.50E+01	8.00E+00	2.88E+01	1.00E+00	2.25E+04
Tritium	0.00E+00	2.00E+04	1.23E+01	---	1.04E+03
Uranium-233/234	2.00E+00	---	1.59E+05	1.00E+00	NVR
Uranium-235	2.00E+00	---	7.04E+08	5.00E-01	NVR
Uranium-238	2.00E+00	---	4.47E+09	1.00E+00	NVR

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington. K_d values reported here wre used in calculations and may differ in precision (rounding) from values reported in ECF-HANFORD-12-0023, but were derived from the same electronic data set.

b. EMDT-DE-0006, 2015, *Half-lives for Typical Hanford Site Radioactive Contaminants*, Rev. 1 (copy provided in Attachment E of this ECF)

c. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

d. The following restrictions were applied to soil screening levels:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 pCi/m^3 (a value set as the lower limit of numerical significance).
- “NVR” was assigned where no value was required.
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.

e. Soil screening levels protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these soil screening levels, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the soil screening level for evaluation use.

f. Carbon-14 in liquid form (typically associated with reactor gas condensate).

Attachment B

Unit-Length Preliminary Remediation Goals Protective of Groundwater and Surface Water for the 100-K Source Operable Unit

Note

Tabulated preliminary remediation goal (PRG) values are presented in Tables B-1, B-2, and B-3 in ascending mobility (K_d) order. This sorting order reveals the correlation between analyte K_d values and resulting PRG values. The "NR" (nonrepresentative result) code reflects that the model simulations did not predict breakthrough within 1000 years, defined here as a peak groundwater concentration exceeding 0.0001 µg/L for non-radionuclide analytes, or 0.0001 pCi/m^3 for radionuclide analytes), a value set as the lower limit of numerical significance for model groundwater concentration results.

The same PRG values are presented again in Tables B-4, B-5, and B-6, but in ascending analyte name order to enable lookup by the reader using the analyte name.

Table B-1. Unit-Length Preliminary Remediation Goals for Non-radionuclides Protective of Groundwater in 100-K Source Operable Units (Increasing mobility order by K_d)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Ground Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Preliminary Remediation Goal Protective of Groundwater [c, d] (mg/kg)·m
14797-55-8	Nitrate	Nitrate	0.00E+00	4.50E+04	7.50E-01	1.73E+03
14797-65-0	Nitrite	Nitrite	0.00E+00	3.30E+03	7.50E-01	1.27E+02
NO2+NO3-N	Nitrogen in Nitrite and Nitrate	Nitrogen in Nitrite and Nitrate	0.00E+00	1.00E+04	7.50E-01	3.84E+02
67-64-1	Acetone	Acetone	5.75E-04	7.20E+03	2.00E-02	2.79E+02
107-21-1	Ethylene glycol	Ethelyne glycol	1.00E-03	1.60E+04	3.30E-01	6.25E+02
75-09-2	Methylene chloride	methylene chloride	1.00E-02	5.00E+00	5.00E-03	2.25E-01
18540-29-9	Hexavalent Chromium	chromium(VI)	8.00E-01	4.80E+01	5.00E-01	6.00E+00 [e]
91-20-3	Naphthalene	naphthalene	1.19E+00	1.60E+02	3.30E-01	6.45E+02
84-74-2	Di-n-butylphthalate	di-butyl phthalate	1.57E+00	1.60E+03	3.30E+02	1.22E+04
7440-42-8	Boron	Boron	3.00E+00	3.20E+03	2.00E+00	1.18E+05
TPH	Total petroleum hydrocarbons	Total petroleum hydrocarbons	4.00E+00	5.00E+02	---	2.93E+04
83-32-9	Acenaphthene	acenaphthene	4.90E+00	9.60E+02	3.30E-01	8.13E+04
7782-49-2	Selenium	selenium and compounds	5.00E+00	5.00E+01	1.00E+00	4.40E+03
7440-43-9	Cadmium (Diet)	cadmium	6.70E+00	5.00E+00	5.00E-01	8.01E+02
86-73-7	Fluorene	fluorene	7.71E+00	6.40E+02	3.30E-01	1.40E+05
7440-22-4	Silver	silver	8.30E+00	8.00E+01	2.00E-01	2.07E+04
7439-98-7	Molybdenum	molybdenum	2.00E+01	8.00E+01	2.00E+00	1.95E+05
7440-50-8	Copper	copper	2.20E+01	6.40E+02	1.00E+00	3.89E+05
120-12-7	Anthracene	anthracene	2.35E+01	4.80E+03	3.30E-01	3.89E+05
7439-89-6	Iron	Iron	2.50E+01	1.12E+04	---	3.89E+05
7440-38-2	Arsenic	arsenic, inorganic	2.90E+01	1.00E+01	1.00E+01	6.97E+04
7440-24-6	Strontium	strontium	3.50E+01	9.60E+03	1.00E+00	3.89E+05
7440-39-3	Barium	Barium	4.10E+01	2.00E+03	2.00E+00	3.89E+05
7440-36-0	Antimony	antimony	4.50E+01	6.00E+00	6.00E-01	1.54E+05
7440-48-4	Cobalt	Cobalt	4.50E+01	4.80E+00	2.00E+00	1.23E+05
206-44-0	Fluoranthene	fluoranthene	4.91E+01	6.40E+02	3.30E-01	3.89E+05
7439-97-6	Mercury (Mercuric chloride)	mercury (using mercuric chloride)	5.20E+01	2.00E+00	2.00E-01	7.97E+04
7440-66-6	Zinc	zinc	6.20E+01	4.80E+03	1.00E+00	3.89E+05
7439-96-5	Manganese	manganese	6.50E+01	3.84E+02	5.00E+00	3.89E+05
7440-02-0	Nickel	nickel soluble salts	6.50E+01	1.00E+02	4.00E+00	3.89E+05
129-00-0	Pyrene	pyrene	6.80E+01	4.80E+02	3.30E-01	3.89E+05
7440-61-1	Uranium	Uranium	7.00E+01	3.00E+01	1.00E+00	NR
7440-28-0	Thallium	Thallium, soluable salts	7.10E+01	5.00E-01	---	NR
12674-11-2	Aroclor-1016	aroclor 1016 (PCB)	1.07E+02	5.00E-01	1.70E-02	NR
117-81-7	Bis(2-ethylhexyl) phthalate	bis(2-ethylhexy) phthalate	1.11E+02	6.00E+00	3.30E-01	NR
11097-69-1	Aroclor-1254	aroclor 1254 (PCB)	1.31E+02	4.40E-02	1.70E-02	NR
16984-48-8	Fluoride	fluoride (using fluorine)	1.50E+02	9.60E+02	5.00E+00	NR
7440-31-5	Tin	tin	2.50E+02	9.60E+03	1.00E+01	NR
56-55-3	Benzo(a)anthracene	Benzo(a)anthracene	3.58E+02	8.80E-01	1.50E-02	NR
218-01-9	Chrysene	Chrysene	3.98E+02	8.80E+01	1.00E-01	NR
7440-41-7	Beryllium	beryllium	7.90E+02	4.00E+00	5.00E-01	NR
11096-82-5	Aroclor-1260	aroclor 1260 (PCB)	8.22E+02	4.40E-02	1.70E-02	NR

Table B-1. Unit-Length Preliminary Remediation Goals for Non-radionuclides Protective of Groundwater in 100-K Source Operable Units (Increasing mobility order by K_d)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Ground Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Preliminary Remediation Goal Protective of Groundwater [c, d] (mg/kg)·m
50-32-8	Benzo(a)pyrene	Benzo(a)pyrene	9.69E+02	8.80E-02	1.50E-02	NR
7440-47-3	Chromium	chromium (total)	1.00E+03	1.00E+02	1.00E+00	NR
7440-62-2	Vanadium	vanadium	1.00E+03	8.00E+01	2.50E+00	NR
205-99-2	Benzo(b)fluoranthene	Benzo(b)fluoranthene	1.23E+03	8.80E-01	1.50E-02	NR
207-08-9	Benzo(k)fluoranthene	Benzo(k)fluoranthene	1.23E+03	8.80E+00	1.50E-02	NR
7429-90-5	Aluminum	Aluminum (soluble)	1.50E+03	1.60E+04	---	NR
53-70-3	Dibenz[a,h]anthracene	Dibenz[a,h]anthracene	1.79E+03	8.80E-02	3.00E-02	NR
193-39-5	Indeno(1,2,3-cd)pyrene	Indeno(1,2,3-cd)pyrene	3.47E+03	8.80E-01	3.30E-01	NR
7439-92-1	Lead	lead	1.00E+04	1.50E+01	5.00E+00	NR
TPHDIESEL	Total petroleum hydrocarbons - diesel range	Total petroleum hydrocarbons - diesel range	---	---	---	NA
TPHDIESELEXT	Total petroleum hydrocarbons - diesel range extended to C36	Total petroleum hydrocarbons - diesel range extended to C36	---	---	---	NA
TPH/OILH	Total petroleum hydrocarbons - motor oil (high boiling)	Total petroleum hydrocarbons - motor oil (high boiling)	---	---	---	NA

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington.

b. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

c. The following restrictions were applied to preliminary remediation goals:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 µg/L (a value set as the lower limit of numerical significance).
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.
- Value was limited to a physical upper bound of 389,000 mg/kg, based on the maximum pore space contaminant mass capacity.

d. Preliminary remediation goals protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these preliminary remediation goals, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the preliminary remediation goal for evaluation use.

e. The preliminary remediation goal for hexavalent chromium is set to 6.0 mg/kg based on the evaluation in ECF-HANFORD-11-0165; this value is not dependent on waste site size

Table B-2. Unit-Length Preliminary Remediation Goals for Non-radionuclides Protective of Surface Water in 100-K Source Operable Units (Increasing mobility order by K_d)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Surface Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Preliminary Remediation Goal Protective of Surface Water [c,d] (mg/kg)·m
14797-55-8	Nitrate	Nitrate	0.00E+00	---	7.50E-01	NA
14797-65-0	Nitrite	Nitrite	0.00E+00	---	7.50E-01	NA
NO2+NO3-N	Nitrogen in Nitrite and Nitrate	Nitrogen in Nitrite and Nitrate	0.00E+00	---	7.50E-01	NA
67-64-1	Acetone	Acetone	5.75E-04	---	2.00E-02	NA
107-21-1	Ethylene glycol	Ethelyne glycol	1.00E-03	---	3.30E-01	NA
75-09-2	Methylene chloride	methylene chloride	1.00E-02	---	5.00E-03	NA
18540-29-9	Hexavalent Chromium	chromium(VI)	8.00E-01	1.00E+01	5.00E-01	6.00E+00 [e]
91-20-3	Naphthalene	naphthalene	1.19E+00	---	3.30E-01	NA
84-74-2	Di-n-butylphthalate	di-butyl phthalate	1.57E+00	---	3.30E+02	NA
7440-42-8	Boron	Boron	3.00E+00	---	2.00E+00	NA
TPH	Total petroleum hydrocarbons	Total petroleum hydrocarbons	4.00E+00	---	---	NA
83-32-9	Acenaphthene	acenaphthene	4.90E+00	---	3.30E-01	NA
7782-49-2	Selenium	selenium and compounds	5.00E+00	5.00E+00	1.00E+00	4.40E+02
7440-43-9	Cadmium (Diet)	cadmium	6.70E+00	7.20E-01	5.00E-01	1.15E+02
86-73-7	Fluorene	fluorene	7.71E+00	---	3.30E-01	NA
7440-22-4	Silver	silver	8.30E+00	2.60E+00	2.00E-01	6.72E+02
7439-98-7	Molybdenum	molybdenum	2.00E+01	---	2.00E+00	NA
7440-50-8	Copper	copper	2.20E+01	9.90E+00	1.00E+00	3.15E+04
120-12-7	Anthracene	anthracene	2.35E+01	---	3.30E-01	NA
7439-89-6	Iron	Iron	2.50E+01	1.00E+03	---	3.89E+05
7440-38-2	Arsenic	arsenic, inorganic	2.90E+01	1.50E+02	1.00E+01	3.89E+05
7440-24-6	Strontium	strontium	3.50E+01	---	1.00E+00	NA
7440-39-3	Barium	Barium	4.10E+01	---	2.00E+00	NA
7440-36-0	Antimony	antimony	4.50E+01	---	6.00E-01	NA
7440-48-4	Cobalt	Cobalt	4.50E+01	---	2.00E+00	NA
206-44-0	Fluoranthene	fluoranthene	4.91E+01	---	3.30E-01	NA
7439-97-6	Mercury (Mercuric chloride)	mercury (using mercuric chloride)	5.20E+01	1.20E-02	2.00E-01	4.78E+02
7440-66-6	Zinc	zinc	6.20E+01	9.10E+01	1.00E+00	3.89E+05
7439-96-5	Manganese	manganese	6.50E+01	---	5.00E+00	NA
7440-02-0	Nickel	nickel soluble salts	6.50E+01	5.20E+01	4.00E+00	3.89E+05
129-00-0	Pyrene	pyrene	6.80E+01	---	3.30E-01	NA
7440-61-1	Uranium	Uranium	7.00E+01	---	1.00E+00	NA
7440-28-0	Thallium	Thallium, soluable salts	7.10E+01	---	---	NA
12674-11-2	Aroclor-1016	aroclor 1016 (PCB)	1.07E+02	1.40E-02	1.70E-02	NR
117-81-7	Bis(2-ethylhexyl) phthalate	bis(2-ethylhexy) phthalate	1.11E+02	---	3.30E-01	NA
11097-69-1	Aroclor-1254	aroclor 1254 (PCB)	1.31E+02	1.40E-02	1.70E-02	NR
16984-48-8	Fluoride	fluoride (using fluorine)	1.50E+02	---	5.00E+00	NA
7440-31-5	Tin	tin	2.50E+02	---	1.00E+01	NA
56-55-3	Benzo(a)anthracene	Benzo(a)anthrace ne	3.58E+02	---	1.50E-02	NA
218-01-9	Chrysene	Chrysene	3.98E+02	---	1.00E-01	NA
7440-41-7	Beryllium	beryllium	7.90E+02	---	5.00E-01	NA

Table B-2. Unit-Length Preliminary Remediation Goals for Non-radionuclides Protective of Surface Water in 100-K Source Operable Units (Increasing mobility order by K_d)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Surface Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Preliminary Remediation Goal Protective of Surface Water [c,d] (mg/kg)·m
11096-82-5	Aroclor-1260	aroclor 1260 (PCB)	8.22E+02	1.40E-02	1.70E-02	NR
50-32-8	Benzo(a)pyrene	Benzo(a)pyrene	9.69E+02	---	1.50E-02	NA
7440-47-3	Chromium	chromium (total)	1.00E+03	7.40E+01	1.00E+00	NR
7440-62-2	Vanadium	vanadium	1.00E+03	---	2.50E+00	NA
205-99-2	Benzo(b)fluoranthene	Benzo(b)fluoranthene	1.23E+03	---	1.50E-02	NA
207-08-9	Benzo(k)fluoranthene	Benzo(k)fluoranthene	1.23E+03	---	1.50E-02	NA
7429-90-5	Aluminum	Aluminum (soluble)	1.50E+03	8.70E+01	---	NR
53-70-3	Dibenz[a,h]anthracene	Dibenz[a,h]anthracene	1.79E+03	---	3.00E-02	NA
193-39-5	Indeno(1,2,3-cd)pyrene	Indeno(1,2,3-cd)pyrene	3.47E+03	---	3.30E-01	NA
7439-92-1	Lead	lead	1.00E+04	2.10E+00	5.00E+00	NR
TPHDIESEL	Total petroleum hydrocarbons - diesel range	Total petroleum hydrocarbons - diesel range	---	---	---	NA
TPHDIESELEXT	Total petroleum hydrocarbons - diesel range extended to C36	Total petroleum hydrocarbons - diesel range extended to C36	---	---	---	NA
TPH/OILH	Total petroleum hydrocarbons - motor oil (high boiling)	Total petroleum hydrocarbons - motor oil (high boiling)	---	---	---	NA

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington.

b. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

c. The following restrictions were applied to preliminary remediation goals:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 µg/L (a value set as the lower limit of numerical significance).
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.
- Value was limited to a physical upper bound of 389,000 mg/kg, based on the maximum pore space contaminant mass capacity.

d. Preliminary remediation goals protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these preliminary remediation goals, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the preliminary remediation goal for evaluation use.

e. The preliminary remediation goal for hexavalent chromium is set to 6.0 mg/kg based on the evaluation in ECF-HANFORD-11-0165; this value is not dependent on waste site size

Table B-3. Preliminary Remediation Goal for Radionuclides Protective of Groundwater for 100-K Source Operable Units (Increasing mobility order by K_d)

Radionuclide	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Maximum Contaminant Level [a] (pCi/L)	Half-life [b] (yr)	Required Detection Limit [c] (mg/kg)	Preliminary Remediation Goal Protective of Groundwater [d,e] (pCi/g)·m
Carbon-14 [f]	0.00E+00	2.00E+03	5.70E+03	2.00E+00	7.69E+01
Tritium	0.00E+00	2.00E+04	1.23E+01	---	1.07E+03
Uranium-233/234	2.00E+00	---	1.59E+05	1.00E+00	NVR
Uranium-235	2.00E+00	---	7.04E+08	5.00E-01	NVR
Uranium-238	2.00E+00	---	4.47E+09	1.00E+00	NVR
Strontium-90	2.50E+01	8.00E+00	2.88E+01	1.00E+00	3.89E+05
Nickel-63	3.00E+01	5.00E+01	1.00E+02	3.00E+01	NR
Cesium-137	5.00E+01	2.00E+02	3.02E+01	1.00E-01	NR
Cobalt-60	5.00E+01	1.00E+02	5.27E+00	5.00E-02	NR
Americium-241	2.00E+02	1.50E+01	4.32E+02	1.00E+00	NR
Europium-152	2.00E+02	2.00E+02	1.35E+01	1.00E-01	NR
Europium-154	2.00E+02	6.00E+01	8.59E+00	1.00E-01	NR
Europium-155	2.00E+02	6.00E+02	4.76E+00	1.00E-01	NR
Plutonium-238	2.00E+02	1.50E+01	8.77E+01	1.00E+00	NR
Plutonium-239/240	2.00E+02	---	6.56E+03	1.00E+00	NA

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington.

b. EMDT-DE-0006, 2015, *Half-lives for Typical Hanford Site Radioactive Contaminants*, Rev. 1 (copy provided in Attachment E of this ECF)

c. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

d. The following restrictions were applied to preliminary remediation goals:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 pCi/m^3 (a value set as the lower limit of numerical significance).
- “NVR” was assigned where no value was required.
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.

e. Preliminary remediation goals protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these preliminary remediation goals, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the preliminary remediation goal for evaluation use.

f. Carbon-14 in liquid form (typically associated with reactor gas condensate).

Table B-4. Unit-Length Preliminary Remediation Goals for Non-radionuclides Protective of Groundwater in 100-K Source Operable Units (Alphabetical order by analyte)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Groundwater Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Preliminary Remediation Goal Protective of Groundwater [c,d] (mg/kg)·m
83-32-9	Acenaphthene	acenaphthene	4.90E+00	9.60E+02	3.30E-01	8.13E+04
67-64-1	Acetone	Acetone	5.75E-04	7.20E+03	2.00E-02	2.79E+02
7429-90-5	Aluminum	Aluminum (soluble)	1.50E+03	1.60E+04	---	NR
7440-36-0	Antimony	antimony	4.50E+01	6.00E+00	6.00E-01	1.54E+05
120-12-7	Anthracene	anthracene	2.35E+01	4.80E+03	3.30E-01	3.89E+05
12674-11-2	Aroclor-1016	aroclor 1016 (PCB)	1.07E+02	5.00E-01	1.70E-02	NR
11097-69-1	Aroclor-1254	aroclor 1254 (PCB)	1.31E+02	4.40E-02	1.70E-02	NR
11096-82-5	Aroclor-1260	aroclor 1260 (PCB)	8.22E+02	4.40E-02	1.70E-02	NR
7440-38-2	Arsenic	arsenic, inorganic	2.90E+01	1.00E+01	1.00E+01	6.97E+04
7440-39-3	Barium	Barium	4.10E+01	2.00E+03	2.00E+00	3.89E+05
56-55-3	Benzo(a)anthracene	Benzo(a)anthracene	3.58E+02	8.80E-01	1.50E-02	NR
50-32-8	Benzo(a)pyrene	Benzo(a)pyrene	9.69E+02	8.80E-02	1.50E-02	NR
205-99-2	Benzo(b)fluoranthene	Benzo(b)fluoranthene	1.23E+03	8.80E-01	1.50E-02	NR
207-08-9	Benzo(k)fluoranthene	Benzo(k)fluoranthene	1.23E+03	8.80E+00	1.50E-02	NR
7440-41-7	Beryllium	beryllium	7.90E+02	4.00E+00	5.00E-01	NR
117-81-7	Bis(2-ethylhexyl) phthalate	bis(2-ethylhexy) phthalate	1.11E+02	6.00E+00	3.30E-01	NR
7440-42-8	Boron	Boron	3.00E+00	3.20E+03	2.00E+00	1.18E+05
7440-43-9	Cadmium (Diet)	cadmium	6.70E+00	5.00E+00	5.00E-01	8.01E+02
7440-47-3	Chromium	chromium (total)	1.00E+03	1.00E+02	1.00E+00	NR
218-01-9	Chrysene	Chrysene	3.98E+02	8.80E+01	1.00E-01	NR
7440-48-4	Cobalt	Cobalt	4.50E+01	4.80E+00	2.00E+00	1.23E+05
7440-50-8	Copper	copper	2.20E+01	6.40E+02	1.00E+00	3.89E+05
53-70-3	Dibenz[a,h]anthracene	Dibenz[a,h]anthracene	1.79E+03	8.80E-02	3.00E-02	NR
84-74-2	Di-n-butylphthalate	di-butyl phthalate	1.57E+00	1.60E+03	3.30E+02	1.22E+04
107-21-1	Ethylene glycol	Ethelyne glycol	1.00E-03	1.60E+04	3.30E-01	6.25E+02
206-44-0	Fluoranthene	fluoranthene	4.91E+01	6.40E+02	3.30E-01	3.89E+05
86-73-7	Fluorene	fluorene	7.71E+00	6.40E+02	3.30E-01	1.40E+05
16984-48-8	Fluoride	fluoride (using fluorine)	1.50E+02	9.60E+02	5.00E+00	NR
18540-29-9	Hexavalent Chromium	chromium(VI)	8.00E-01	4.80E+01	5.00E-01	6.00E+00 [e]
193-39-5	Indeno(1,2,3-cd)pyrene	Indeno(1,2,3-cd)pyrene	3.47E+03	8.80E-01	3.30E-01	NR
7439-89-6	Iron	Iron	2.50E+01	1.12E+04	---	3.89E+05
7439-92-1	Lead	lead	1.00E+04	1.50E+01	5.00E+00	NR
7439-96-5	Manganese	manganese	6.50E+01	3.84E+02	5.00E+00	3.89E+05
7439-97-6	Mercury (Mercuric chloride)	mercury (using mercuric chloride)	5.20E+01	2.00E+00	2.00E-01	7.97E+04
75-09-2	Methylene chloride	methylene chloride	1.00E-02	5.00E+00	5.00E-03	2.25E-01
7439-98-7	Molybdenum	molybdenum	2.00E+01	8.00E+01	2.00E+00	1.95E+05
91-20-3	Naphthalene	naphthalene	1.19E+00	1.60E+02	3.30E-01	6.45E+02
7440-02-0	Nickel	nickel soluble salts	6.50E+01	1.00E+02	4.00E+00	3.89E+05
14797-55-8	Nitrate	Nitrate	0.00E+00	4.50E+04	7.50E-01	1.73E+03
14797-65-0	Nitrite	Nitrite	0.00E+00	3.30E+03	7.50E-01	1.27E+02
NO2+NO3-N	Nitrogen in Nitrite and Nitrate	Nitrogen in Nitrite and Nitrate	0.00E+00	1.00E+04	7.50E-01	3.84E+02
129-00-0	Pyrene	pyrene	6.80E+01	4.80E+02	3.30E-01	3.89E+05

Table B-4. Unit-Length Preliminary Remediation Goals for Non-radionuclides Protective of Groundwater in 100-K Source Operable Units (Alphabetical order by analyte)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Groundwater Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Preliminary Remediation Goal Protective of Groundwater [c,d] (mg/kg)·m
7782-49-2	Selenium	selenium and compounds	5.00E+00	5.00E+01	1.00E+00	4.40E+03
7440-22-4	Silver	silver	8.30E+00	8.00E+01	2.00E-01	2.07E+04
7440-24-6	Strontium	strontium	3.50E+01	9.60E+03	1.00E+00	3.89E+05
7440-28-0	Thallium	Thallium, soluable salts	7.10E+01	5.00E-01	---	NR
7440-31-5	Tin	tin	2.50E+02	9.60E+03	1.00E+01	NR
TPH	Total petroleum hydrocarbons	Total petroleum hydrocarbons	4.00E+00	5.00E+02	---	2.93E+04
TPHDIESEL	Total petroleum hydrocarbons - diesel range	Total petroleum hydrocarbons - diesel range	---	---	---	NA
TPHDIESELEXT	Total petroleum hydrocarbons - diesel range extended to C36	Total petroleum hydrocarbons - diesel range extended to C36	---	---	---	NA
TPH/OILH	Total petroleum hydrocarbons - motor oil (high boiling)	Total petroleum hydrocarbons - motor oil (high boiling)	---	---	---	NA
7440-61-1	Uranium	Uranium	7.00E+01	3.00E+01	1.00E+00	NR
7440-62-2	Vanadium	vanadium	1.00E+03	8.00E+01	2.50E+00	NR
7440-66-6	Zinc	zinc	6.20E+01	4.80E+03	1.00E+00	3.89E+05

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington.

b. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

c. The following restrictions were applied to preliminary remediation goals:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 µg/L (a value set as the lower limit of numerical significance).
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.
- Value was limited to a physical upper bound of 389,000 mg/kg, based on the maximum pore space contaminant mass capacity.

d. Preliminary remediation goals protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these preliminary remediation goals, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the preliminary remediation goal for evaluation use.

e. The preliminary remediation goal for hexavalent chromium is set to 6.0 mg/kg based on the evaluation in ECF-HANFORD-11-0165; this value is not dependent on waste site size

Table B-5. Unit-Length Preliminary Remediation Goals for Non-radionuclides Protective of Surface Water in 100-K Source Operable Units (Alphabetical order by analyte)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Surface Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Preliminary Remediation Goal Protective of Surface Water [c,d] (mg/kg)·m
83-32-9	Acenaphthene	acenaphthene	4.90E+00	---	3.30E-01	NA
67-64-1	Acetone	Acetone	5.75E-04	---	2.00E-02	NA
7429-90-5	Aluminum	Aluminum (soluble)	1.50E+03	8.70E+01	---	NR
7440-36-0	Antimony	antimony	4.50E+01	---	6.00E-01	NA
120-12-7	Anthracene	anthracene	2.35E+01	---	3.30E-01	NA
12674-11-2	Aroclor-1016	aroclor 1016 (PCB)	1.07E+02	1.40E-02	1.70E-02	NR
11097-69-1	Aroclor-1254	aroclor 1254 (PCB)	1.31E+02	1.40E-02	1.70E-02	NR
11096-82-5	Aroclor-1260	aroclor 1260 (PCB)	8.22E+02	1.40E-02	1.70E-02	NR
7440-38-2	Arsenic	arsenic, inorganic	2.90E+01	1.50E+02	1.00E+01	3.89E+05
7440-39-3	Barium	Barium	4.10E+01	---	2.00E+00	NA
56-55-3	Benzo(a)anthracene	Benzo(a)anthracene	3.58E+02	---	1.50E-02	NA
50-32-8	Benzo(a)pyrene	Benzo(a)pyrene	9.69E+02	---	1.50E-02	NA
205-99-2	Benzo(b)fluoranthene	Benzo(b)fluoranthene	1.23E+03	---	1.50E-02	NA
207-08-9	Benzo(k)fluoranthene	Benzo(k)fluoranthene	1.23E+03	---	1.50E-02	NA
7440-41-7	Beryllium	beryllium	7.90E+02	---	5.00E-01	NA
117-81-7	Bis(2-ethylhexyl) phthalate	bis(2-ethylhexy) phthalate	1.11E+02	---	3.30E-01	NA
7440-42-8	Boron	Boron	3.00E+00	---	2.00E+00	NA
7440-43-9	Cadmium (Diet)	cadmium	6.70E+00	7.20E-01	5.00E-01	1.15E+02
7440-47-3	Chromium	chromium (total)	1.00E+03	7.40E+01	1.00E+00	NR
218-01-9	Chrysene	Chrysene	3.98E+02	---	1.00E-01	NA
7440-48-4	Cobalt	Cobalt	4.50E+01	---	2.00E+00	NA
7440-50-8	Copper	copper	2.20E+01	9.90E+00	1.00E+00	3.15E+04
53-70-3	Dibenz[a,h]anthracene	Dibenz[a,h]anthracene	1.79E+03	---	3.00E-02	NA
84-74-2	Di-n-butylphthalate	di-butyl phthalate	1.57E+00	---	3.30E+02	NA
107-21-1	Ethylene glycol	Ethelyne glycol	1.00E-03	---	3.30E-01	NA
206-44-0	Fluoranthene	fluoranthene	4.91E+01	---	3.30E-01	NA
86-73-7	Fluorene	fluorene	7.71E+00	---	3.30E-01	NA
16984-48-8	Fluoride	fluoride (using fluorine)	1.50E+02	---	5.00E+00	NA
18540-29-9	Hexavalent Chromium	chromium(VI)	8.00E-01	1.00E+01	5.00E-01	6.00E+00 [e]
193-39-5	Indeno(1,2,3-cd)pyrene	Indeno(1,2,3-cd)pyrene	3.47E+03	---	3.30E-01	NA
7439-89-6	Iron	Iron	2.50E+01	1.00E+03	---	3.89E+05
7439-92-1	Lead	lead	1.00E+04	2.10E+00	5.00E+00	NR
7439-96-5	Manganese	manganese	6.50E+01	---	5.00E+00	NA
7439-97-6	Mercury (Mercuric chloride)	mercury (using mercuric chloride)	5.20E+01	1.20E-02	2.00E-01	4.78E+02
75-09-2	Methylene chloride	methylene chloride	1.00E-02	---	5.00E-03	NA
7439-98-7	Molybdenum	molybdenum	2.00E+01	---	2.00E+00	NA
91-20-3	Naphthalene	naphthalene	1.19E+00	---	3.30E-01	NA
7440-02-0	Nickel	nickel soluble salts	6.50E+01	5.20E+01	4.00E+00	3.89E+05
14797-55-8	Nitrate	Nitrate	0.00E+00	---	7.50E-01	NA
14797-65-0	Nitrite	Nitrite	0.00E+00	---	7.50E-01	NA
NO2+NO3-N	Nitrogen in Nitrite and Nitrate	Nitrogen in Nitrite and Nitrate	0.00E+00	---	7.50E-01	NA
129-00-0	Pyrene	pyrene	6.80E+01	---	3.30E-01	NA

Table B-5. Unit-Length Preliminary Remediation Goals for Non-radionuclides Protective of Surface Water in 100-K Source Operable Units (Alphabetical order by analyte)

CAS No.	Analyte	Alternate Name Referenced in EPA Regional Screening Table	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Surface Water Standard [a] (µg/L)	Required Detection Limit [b] (mg/kg)	Preliminary Remediation Goal Protective of Surface Water [c,d] (mg/kg)·m
7782-49-2	Selenium	selenium and compounds	5.00E+00	5.00E+00	1.00E+00	4.40E+02
7440-22-4	Silver	silver	8.30E+00	2.60E+00	2.00E-01	6.72E+02
7440-24-6	Strontium	strontium	3.50E+01	---	1.00E+00	NA
7440-28-0	Thallium	Thallium, soluable salts	7.10E+01	---	---	NA
7440-31-5	Tin	tin	2.50E+02	---	1.00E+01	NA
TPH	Total petroleum hydrocarbons	Total petroleum hydrocarbons	4.00E+00	---	---	NA
TPHDIESEL	Total petroleum hydrocarbons - diesel range	Total petroleum hydrocarbons - diesel range	---	---	---	NA
TPHDIESELEXT	Total petroleum hydrocarbons - diesel range extended to C36	Total petroleum hydrocarbons - diesel range extended to C36	---	---	---	NA
TPH/OILH	Total petroleum hydrocarbons - motor oil (high boiling)	Total petroleum hydrocarbons - motor oil (high boiling)	---	---	---	NA
7440-61-1	Uranium	Uranium	7.00E+01	---	1.00E+00	NA
7440-62-2	Vanadium	vanadium	1.00E+03	---	2.50E+00	NA
7440-66-6	Zinc	zinc	6.20E+01	9.10E+01	1.00E+00	3.89E+05

a. ECF-HANFORD-12-0023, 2017, *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington.

b. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

c. The following restrictions were applied to preliminary remediation goals:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 µg/L (a value set as the lower limit of numerical significance).
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.
- Value was limited to a physical upper bound of 389,000 mg/kg, based on the maximum pore space contaminant mass capacity.

d. Preliminary remediation goals protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these preliminary remediation goals, divide the listed value by a representative length across the waste site decision unit in the general direction of groundwater flow to obtain the preliminary remediation goal for evaluation use.

e. The preliminary remediation goal for hexavalent chromium is set to 6.0 mg/kg based on the evaluation in ECF-HANFORD-11-0165; this value is not dependent on waste site size

Table B-6. Preliminary Remediation Goal for Radionuclides Protective of Groundwater for 100-K Source Operable Units (Alphabetical order by analyte)

Radionuclide	100 Areas K_d Value used to Calculate Groundwater Protection [a] (mL/g)	Maximum Contaminant Level [a] (pCi/L)	Half-life [b] (yr)	Required Detection Limit [c] (mg/kg)	Preliminary Remediation Goal Protective of Groundwater [d,e] (pCi/g)·m
Americium-241	2.00E+02	1.50E+01	4.32E+02	1.00E+00	NR
Carbon-14 [f]	0.00E+00	2.00E+03	5.70E+03	2.00E+00	7.69E+01
Cesium-137	5.00E+01	2.00E+02	3.02E+01	1.00E-01	NR
Cobalt-60	5.00E+01	1.00E+02	5.27E+00	5.00E-02	NR
Europium-152	2.00E+02	2.00E+02	1.35E+01	1.00E-01	NR
Europium-154	2.00E+02	6.00E+01	8.59E+00	1.00E-01	NR
Europium-155	2.00E+02	6.00E+02	4.76E+00	1.00E-01	NR
Nickel-63	3.00E+01	5.00E+01	1.00E+02	3.00E+01	NR
Plutonium-238	2.00E+02	1.50E+01	8.77E+01	1.00E+00	NR
Plutonium-239/240	2.00E+02	---	6.56E+03	1.00E+00	NA
Strontium-90	2.50E+01	8.00E+00	2.88E+01	1.00E+00	3.89E+05
Tritium	0.00E+00	2.00E+04	1.23E+01	---	1.07E+03
Uranium-233/234	2.00E+00	---	1.59E+05	1.00E+00	NVR
Uranium-235	2.00E+00	---	7.04E+08	5.00E-01	NVR
Uranium-238	2.00E+00	---	4.47E+09	1.00E+00	NVR

a. ECF-HANFORD-12-0023, 2017 *Groundwater and Surface Water Cleanup Levels and Distribution Coefficients for Nonradiological and Radiological Analytes in the 100 Areas and 300 Area*, Rev. 4, CH2M-HILL Plateau Remediation Company, Richland, Washington.

b. EMDT-DE-0006, 2015, *Half-lives for Typical Hanford Site Radioactive Contaminants*, Rev. 1 (copy provided in Attachment E of this ECF),

c. DOE/RL-96-17, 2009, *Remedial Design Report/Remedial Action Work Plan for the 100 Area*, Rev. 6, U.S. Deparment of Energy, Richland Operations Office, Richland, Washington.

d. The following restrictions were applied to preliminary remediation goals:

- "NA" was assigned where no applicable water quality standard was available.
- "NR" was assigned where a non-representative result was obtained in cases where breakthrough was not simulated to occur in more than one representative lithostratigraphic column within 1000 years, where breakthrough is defined as groundwater concentration exceeding 0.0001 pCi/m^3 (a value set as the lower limit of numerical significance).
- “NVR” was assigned where no value was required.
- Value defaults to the required detection limit for any analyte where the calculated value is less than the required detection limit.

e. Preliminary remediation goals protective of groundwater and protective of surface water are provided on a unit-length basis. To apply these preliminary remediation goals, divide the listed value by a representative length across the waste site in the general direction of groundwater flow to obtain the preliminary remediation goal for evaluation use.

f. Carbon-14 in liquid form (typically associated with reactor gas condensate).

Attachment C

Electronic Model Data Transmittal EMDT-DE-0006 Rev. 1 “Half-lives for Typical Hanford Site Radioactive Contaminants”

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.

CH2MHILL Plateau Remediation Company

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.

CH2MHILL Plateau Remediation Company

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

Usmaher
SIGNATURE

6/12/2017
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

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

Attachment D

Software Installation and Checkout Form for STOMP

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM

Software Owner Instructions:

Complete Fields 1-13, then run test cases in Field 14. Compare test case results listed in Field 15 to corresponding Test Report outputs. If results are the same, sign and date Field 19. If not, resolve differences and repeat above steps.

Software Subject Matter Expert Instructions:

Assign test personnel. Approve the installation of the code by signing and dating Field 21, then maintain form as part of the software support documentation.

GENERAL INFORMATION:

1. Software Name: STOMP (Subsurface Transport Over Multiple Phases) Software Version No.: Bld 4

EXECUTABLE INFORMATION:

2. Executable Name (include path):

MD5 File Signature	Executable File Name
6536b8e12d8c5b83dca76f2c947b6153	stomp-wae-bcg-chprc04i.x
e0cdf04bc1a2f6c55c5a1b499939f663	stomp-wae-bcg-chprc04l.x
6e72340bb39f6056e232fe5ff241c4d4	stomp-wae-bd-chprc04i.x
3f837a0fb8d9f47dbcada686f542d7fc	stomp-wae-bd-chprc04l.x
7c5b4cc36a8991b3d5a0ea2ed155ce47	stomp-wae-cgsq-chprc04i.x
00a898c0c3ec06817485781ad1c9ec46	stomp-wae-cgsq-chprc04l.x
f18ff5ab5667065d8ab12657344fb6a0	stomp-wae-cgst-chprc04i.x
061af86cf21ad8435b046d0efabe971b	stomp-wae-cgst-chprc04l.x
3c8111a9855dc0e430bf3c8a7abcf37e	stomp-w-bcg-chprc04i.x
20436d615a94955a2ce8eecdb8cba546	stomp-w-bcg-chprc04l.x
8b3df29df21d040189c3e2a50ef823bb	stomp-w-bd-chprc04i.x
066a289a75aedb933eb2536da5d7d1ff	stomp-w-bd-chprc04l.x
c8e62ad7a0d9b6fca39d8a8952ef5d8e	stomp-w-cgsq-chprc04i.x
28ad16806e1307aca51fd7bf89793e75	stomp-w-cgsq-chprc04l.x
6c25051016db2fe1f883a7caaaable97	stomp-w-cgst-chprc04i.x
ff9ff6f29b3469419ffaece87d7e772b	stomp-w-cgst-chprc04l.x
0c3e3fba40f5b93e71bcf9586432fd27	stomp-w-r-bcg-chprc04i.x
78492aee80a8c2d0a4e82aabf4a9c213	stomp-w-r-bcg-chprc04l.x
84b129786aba9c4be884e15e45a67389	stomp-w-r-bd-chprc04i.x
e990f1566c8099a8d54508de3da9cd88	stomp-w-r-bd-chprc04l.x
18a589a2b55aab2db290efea19b39351	stomp-w-r-cgsq-chprc04i.x
6569959476772a137df35ce874821889	stomp-w-r-cgsq-chprc04l.x

3. Executable Size (bytes): MD5 signatures above uniquely identify each executable file

COMPILATION INFORMATION:

4. Hardware System (i.e., property number or ID):

Tellus Subsurface Modeling Platform

5. Operating System (include version number):

Linux tellusmgmt.rl.gov 2.6.18-308.4.1.el5 #1 SMP Tue Apr 17 17:08:00 EDT 2012 x86_64 x86_64 x86_64 GNU/Linux

INSTALLATION AND CHECKOUT INFORMATION:

6. Hardware System (i.e., property number or ID):

INTERA's Olive Linux System

7. Operating System (include version number):

Linux olive 3.19.0-25-generic #26~14.04.1~Ubuntu SMP Fri Jul 24 21:16:20 UTC 2015 x86_64 x86_64 x86_64 GNU/Linux

8. Open Problem Report? ◉ No ○ Yes PR/CR No.

CHPRC SOFTWARE INSTALLATION AND CHECKOUT FORM (continued)

1. Software Name: STOMP (Subsurface Transport Over Multiple Phases) Software Version No.: Bld 4

TEST CASE INFORMATION:

9. Directory/Path:

[redacted]/bin

10. Procedure(s):

CHPRC-00211 Rev 1, STOMP Software Test Plan

11. Libraries:

N/A (static linking)

12. Input Files:

Input files for ITC-STOMP-1, ITC-STOMP-2, and ITC-STOMP-3
(Baseline for comparison are results files from ATC-STOMP-1, ATC-STOMP-2, and ATC-STOMP-3 prepared on Tellus during acceptance testing)

13. Output Files:

plot.* files produced by STOMP in testing

14. Test Cases:

ITC-STOMP-1, ITC-STOMP-2, and ITC-STOMP-3

15. Test Case Results:

Pass for all executable files listed above.

16. Test Performed By: WE Nichols

17. Test Results: (●) Satisfactory, Accepted for Use ( ) Unsatisfactory

18. Disposition (include HISI update):

Accepted; Installation noted in HISI for all approved users of OLIVE who have completed STOMP SMP and STP required reading assignments.

Prepared By:

19. Software Owner (Signature)	WE Nichols Print	23 NOV 2015 Date

20. Test Personnel:

Sign	WE Nichols Print	23 NOV 2015 Date
Sign	Print	Date
Sign	Print	Date

Approved By:

21. Software SME (Signature)	N/R (per CHPRC-00211 Rev 1) Print	Date

Page 2 of 2 A-6005-149 (REV 0)

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Attachment E

STOMP Options Analysis

STOMP Option NQA-1 Status Check

Input Files: all used to derive SSL and PRG values in River Corridor (see ECF list below); example evaluated "input_0-2010_SS_100D_RS_RE_HF.tpl"
Option status check by: WE Nichols, 05/05/2016

Input Card	Input Parameter	Input Option	NQA-1 Tested?	Alternative
Simulation Title	Simulation Title	-	Yes	
Simulation Title	Simulation Documentation Information	-	Yes	
Solution Control	Execution Mode Option	Restart Mode	Yes	
Solution Control	Operational Mode Options	Water	Yes	
	Transport Modifiers	Transport w/ Courant	Yes	
Grid	Method of Grid Input	Uniform Cartesian	Yes	
Grid	Grid spacing specification option	Count and Cell Size	Yes	
Rock/Soil Zonation	Method of Zonation	Explicit Zonation	Yes	
Mechanical Properties	Compressibility Option	Pore Compressibility	Yes	
Mechanical Properties	Tortuosity Function	Millington and Quirk Model	Yes	
Hydraulic Properties	Method of Hydraulic Property Input	Hydraulic Conductivity	Yes	
Saturation Function	Saturation Function Option	van Genuchten	Yes	
Aqueous Relative Permeability	Relative Permeability Option	Mualem	Yes	
Initial Conditions	Initial Saturation Option	Aqueous Pressure and Gas Pressure	Yes	
Initial Conditions	State Variable Option	Gas Pressure	Yes	
Initial Conditions	State Variable Option	Aqueous Pressure	Yes	
Initial Conditions	State Variable Option	Solute Volumetric Concentration, Overwrite	Yes	
Initial Conditions	Parameter Specification Option	Direct Input	Yes	
Boundary Conditions	Aqueous Boundary Condition Options	Neumann	Yes	
Boundary Conditions	Aqueous Boundary Condition Options	Dirichlet Hydraulic Gradient	Yes	
Boundary Conditions	Solute Boundary Condition Options	Outflow	Yes	
Solute/Fluid Interactions	Effective Diffusion Option	Conventional	Yes	
Solute/Fluid Interactions	Solid/Aqueous Partition Option	Continuous	Yes	
Solute/Fluid Interactions	Reaction Options	Radioactive Decay	Yes	
Solute/Porous Media Interactions	Consistent with Solute/Fluid Interactions	Consistent with Solute/Fluid Interactions	Yes	
Output Control	Reference Node Output	Aqueous Saturation	Yes	
Output Control	Reference Node Output	Aqueous Pressure	Yes	
Output Control	Reference Node Output	Aqueous Hydraulic Head	Yes	
Output Control	Reference Node Output	Aqueous Matric Potential	Yes	
Output Control	Reference Node Output	xnc Aqueous Volumetric Flux	Yes	
Output Control	Reference Node Output	znc Aqueous Volumetric Flux	Yes	
Output Control	Reference Node Output	Aqueous Courant Number	Yes	
Output Control	Reference Node Output	Total Water Mass	Yes	
Output Control	Reference Node Output	Solute Aqueous Concentration	Yes	
Output Control	Reference Node Output	Solute Volumetric Concentration	Yes	
Output Control	Plot Node Output	Aqueous Saturation	Yes	
Output Control	Plot Node Output	Aqueous Pressure	Yes	
Output Control	Plot Node Output	Aqueous Hydraulic Head	Yes	
Output Control	Plot Node Output	Aqueous Matric Potential	Yes	
Output Control	Plot Node Output	Aqueous Moisture Content	Yes	
Output Control	Plot Node Output	xnc Aqueous Volumetric Flux	Yes	
Output Control	Plot Node Output	znc Aqueous Volumetric Flux	Yes	
Output Control	Plot Node Output	Aqueous Courant Number	Yes	
Output Control	Plot Node Output	Total Water Mass	Yes	
Output Control	Plot Node Output	Solute Aqueous Concentration	Yes	
Output Control	Plot Node Output	Solute Volumetric Concentration	Yes	
Surface Flux Card	Surface Output File Option	Single Surface Output File	Yes	
Surface Flux Card	Defining Surface for the Output Fluxes	Range of Node Indices	Yes	
Surface Flux Card	Surface Output Flux Types	Aqueous Volumetric Flux	Yes	
		Solute Flux	Yes	

Impacted ECF	ECF Title
ECF-100KR1-17-0087	STOMP 1-D Modeling for Determination of Unit-Length Soil Screening Levels and Preliminary Remediation Goals for Waste Sites in the 100-K Source Operable Unit
ECF-100NR1-12-0017	STOMP 1-D Modeling for Determination of Soil Screening Levels and Preliminary Remediation Goals for the 100-NR-1 Source Operable Unit
ECF-300FF5-11-0153	STOMP 1-D Modeling for Determination of Soil Screening Levels and Preliminary Remediation Goals for 300 Area Source Areas
ECF-HANFORD-11-0063	STOMP 1-D Modeling for Determination of Soil Screening Levels and Preliminary Remediation Goals for Waste Sites in the 100-D and 100-H Source Operable Units
ECF-HANFORD-12-0004	STOMP 1-D Modeling for Determination of Soil Screening Levels and Preliminary Remediation Goals for 100 Area F and IU Source Areas
ECF-HANFORD-15-0129	STOMP 1-D Modeling for Determination of Soil Screening Levels and Preliminary Remediation Goals for Waste Sites in the 100-BC-1 and 100-BC-2 Source Operable Units