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Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

Selection and Traceability of Parameters To Support Hanford-Specific RESRAD Analyses

Fiscal Year 2008 Status Report

GV Last
ML Rockhold
CJ Murray
KJ Cantrell

July 2009

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Pacific Northwest National Laboratory
Richland, Washington 99352

Abstract

In fiscal years 2007 and 2008, the Hanford Site Groundwater Remediation Project, formerly managed by Fluor Hanford, Inc., requested the Pacific Northwest National Laboratory (PNNL) to support the development and initial implementation of a strategy to establish and maintain, under configuration control, a set of Hanford-specific flow and transport parameter estimates that can be used to support Hanford Site assessments. The motivation for this work was the realization that previous site assessments have used different parameters, and that published references often do not provide direct traceability of the parameters back to the raw data and analytical approaches used to derive the assessment parameters.

The goals of the work described in this report are to improve the consistency, defensibility, and traceability of parameters and their ranges of variability, and to ensure a sound basis for assigning parameters for flow and transport models. The strategy was to identify the existing parameter data sets most recently used in site assessments, documenting those parameter data sets and the raw data sets on which they were based, and use the existing parameter sets to define best-estimate parameters for use in the RESRAD code. The RESRAD code is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials. The Hanford-specific assessment parameters compiled for use in RESRAD are traceable back to the professional judgment of the authors of published documents. This document provides a summary of those efforts, culminating in a set of best-estimate Hanford-specific parameters for use in place of the default parameters used in the RESRAD code.

Future activities will work to improve the traceability and defensibility of the parameter data sets and to address limitations and technical issues associated with the existing assessment parameter data sets.

Preface

This technical report was originally completed in June 2008 for limited distribution to Fluor Hanford, Inc., then manager of the Hanford Site Groundwater Remediation Project. CH2M HILL Plateau Remediation Company took over management of the project in October 2008. Their staff and subcontractor staff completed a review of the report during spring 2009. Those comments led to significant improvements to this final report.

Acknowledgments

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The authors would also like to acknowledge Mike Fayer for his technical reviews of both the original 2008 report and the revised 2009 version of the report. Special thanks are also provided to Andrea Currie for copyediting, editorial reviews, and managing document production, and to Kathy Neiderhiser and Kay Hass for text processing support for production of the 2008 and 2009 versions of this technical report.

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1.0 Introduction

The Hanford Site Groundwater Remediation Project, formerly managed by Fluor Hanford, Inc., requested the services of the Pacific Northwest National Laboratory (PNNL) to support the development and maintenance of a set of Hanford-specific estimates of flow and transport parameters that can be used to support Hanford Site assessments.(a) The goal of this work was to develop and initiate implementation of an overall technical approach (path forward) to facilitate and improve the consistency, defensibility, and traceability of parameter estimates and their ranges, and to ensure a sound parameterization basis for flow and transport modeling for various site assessments. This report summarizes those efforts, culminating in selection of best-estimate Hanford-specific parameters for use in place of default parameters included in the RESRAD code. The RESRAD code is a computer model designed to estimate radiation doses and risks from RESidual RADioactive materials (Yu et al. 2001). The code often is used as a screening tool at the Hanford Site to estimate peak groundwater concentrations expected from existing concentrations of contaminants in the soil column.

2.0 Scope

The primary objectives for fiscal year 2008 (FY08) were to finalize the technical approach developed in FY07 and initiate implementation of this approach by compiling existing assessment parameters into a focused parameter data set that could be used as Hanford Site-specific parameters for vadose zone assessments performed using RESRAD. The scope of this work was focused primarily on existing vadose zone flow and transport parameters (primarily from the 200 Areas). Other key parameter data sets, such as those related to contaminant source terms, recharge, or groundwater inputs, are not directly discussed in this report.

This report provides brief background information on efforts to manage environmental data, select input parameters for numerical site assessments at the Hanford Site, and improve consistency, defensibility, and traceability of the parameter estimates. The bulk of the report focuses on review of existing Hanford Site data and parameters used in previous assessments, culminating in a compilation of Hanford-specific flow and transport parameters (primarily from the 200 Areas) for use in place of the default parameters included in the RESRAD computer program. Finally, brief discussions are provided on limitations and technical issues associated with flow and transport parameters compiled for this report, and on possible future work that could help resolve some of these issues.

3.0 Background and Previous Work

Site characterization, conceptual model development, and predictive modeling to support site assessments have traditionally been driven by project-specific goals and funding, with very little integration between projects or site contractors. In the early 1990s, efforts were initiated to develop an integrated

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(a) The term *assessment* is used throughout this report to refer to any type of qualitative or quantitative evaluation or prediction regarding the nature and extent of contamination, its transport and fate, and its potential risk to humans or the environment.

Hanford environmental information system (HEIS) focused on monitoring data. In the late 1990s and early 2000s, the Groundwater/Vadose Zone Integration Project Characterization of Systems task initiated efforts to consolidate orphan (e.g., project-specific) site characterization data sets and to develop tools to facilitate the use of these data for development of improved site-specific conceptual and numerical models. Today, under the Remediation Decision Support function of the Hanford Site Groundwater Remediation Project, efforts are being made to better manage the vast amounts of raw data and to develop rigorous interpretation and analytical tools to generate site- and assessment-specific parameter data sets that are traceable, defensible, and reproducible.

As a consequence of the variety of site assessments that have taken place and the many different contractors and principal investigators who have conducted those assessments, different nomenclature has been used to define various hydrostratigraphic units. Different approaches also have been used to estimate associated physical, hydrologic, and geochemical properties. For example, Khaleel and Freeman (1995b) evaluated a set of physical and hydraulic property data from Hanford sediments and suggested that the sediments be grouped into six classes, based on textural (i.e., particle size) differences in the International Society of Soil Science (ISSS) classification (<2-mm size fraction only), gravel content (>2-mm size fraction), and moisture retention characteristics. Those six sediment classes were later augmented by four new sediment classes that 1) separate out Cold Creek unit sediments, which typically have much different texture, cementation, and mineralogy than Hanford formation sediments; 2) add more detail for sand-dominated Hanford formation sediments; and 3) add a new class for very coarse gravel with little to no matrix (Last et al. 2006).

Lindsey (1991, 1995) identified several facies, facies associations, and informal members within the Ringold Formation, which have been used as the basis to define hydrostratigraphic units within the unconfined aquifer (Thorne et al. 1993, p. 13; Thorne et al. 2006, p. 5.2). DOE (1993) developed a conceptual model for the chemical composition of background soils in the Hanford vadose zone based on eight primary facies and several varieties of subordinate materials. DOE (2002) identified facies and facies associations for post-Ringold Formation sediments. Some characteristics of these facies (e.g., sedimentary structures) are difficult to recognize in drill cuttings, and the stratigraphic relationships of these facies and facies associations to sedimentary sequences or hydrogeologic layers are not clear-cut. Thus, in practice, delineation of hydrogeologic model units (layers) and estimation of their associated physicochemical and hydrologic properties is performed largely on a project-by-project basis.

Freeman (2003) explored methods for the selection and calculation of unsaturated hydraulic conductivity and made several recommendations, including development of probability distributions for the physical and hydrologic properties for different sediment categories. Murray et al. (2007) reexamined the sample data set used by Last et al. (2006) and compared hydraulic parameter distributions for various sediment classes to those that would result from classifying the samples according to the standardized geologic nomenclature (DOE 2002). Multivariate statistical methods were used to examine the statistical uniqueness of hydraulic parameter distributions based on different sediment classifications. Their results indicate that there is overlap in hydraulic parameters assigned to various sediment types. This may be due, in part, to artifacts of the sampling and analysis methods (i.e., disaggregated samples screened of their gravel fraction) and large variability in some of the smaller data sets. Murray et al. (2007) suggested that perhaps some of the sediment classes (within a give formation) could be combined to increase the sample size and improve the statistical separation between sediment classes. They also suggested that grain size data might be useful in distinguishing between the different geologic units and clusters of similar hydraulic properties and for estimating the hydraulic properties. They further suggested that it will be necessary to estimate the probability that a particular sediment type is present at a particular location based on qualitative geologists' and drillers' logs, where grain size or other quantitative data are unavailable, and that probability distributions of unsaturated hydraulic parameters be continually improved for the various sediment types (lithofacies).

DOE (2007c) prepared guidelines to assist operable unit managers in the selection of Hanford site-specific contaminant partitioning coefficients (K_d) based on data compiled in the *Vadose Zone Hydrogeologic Data Package for Hanford Assessments* (Last et al. 2006). DOE (2007a, p. 4-17) suggested that parameters used for base-case flow and transport modeling should represent best-estimate values for the actual site conditions and properties and, if possible, should incorporate a moderate bias toward the conservative side of site-specific "best-estimate" values for most model parameters and boundary conditions (e.g., hydrogeologic properties, lithologies, K_d values, and pre-closure recharge rate), such that the assessment models yield conservative and/or or upper-bounding estimates of risk. Conservative values are those that increase potential groundwater contamination estimates relative to similar estimates resulting from the selection of different but plausible values. At the same time, however, DOE (2007a, p. 4-17) suggested that the average values within the parameter range have the greatest accuracy and lowest uncertainty and therefore were considered the best-estimate values.

4.0 Technical Approach

In FY07, in collaboration with staff of Fluor Hanford, Inc. (FH) and CH2M HILL Hanford Group (CHG) (i.e., the Parameter Selection Working Group(a)), PNNL began defining the needs and path forward for selection and traceability of transport parameter estimates. This section summarizes and builds on that effort.

4.1 Need

The U.S. Department of Energy "Report to the House and Senate Committees on Appropriations on Groundwater Vadose Zone Organization and Operations at the Hanford Site"(b) stated, in part, that

- The DOE Richland Operations Office (RL) and Office of River Protection (ORP) will use common databases and parameter assumptions for site risk assessments.
- Key databases and parameter assumptions will be placed under DOE configuration control.
- The Hanford Site Groundwater Remediation Project (at that time managed by FH), with participation from ORP, will provide the central clearinghouse for all models, parameters, and assumptions used by Hanford risk assessments.

(a) An informal working group consisting of technical and programmatic staff involved with contaminant transport and risk analyses at the Hanford Site.

(b) Rispoli JA. 2006. Letter to the Honorable Thad Cochran (Chairman, Senate Appropriations Committee) from James A. Rispoli (Assistant Secretary for Environmental Management, U.S. Department of Energy), March 29, 2006.

In early FY07, a number of meetings were held with the Parameter Selection Working Group[a] to better define the needs and path forward for this work. There was consensus among the staff with programmatic responsibility (e.g., the soil and groundwater project managers), informally polled in FY07, on the following issues:

- The scale, resolution, and complexity of fate and transport analyses (used to support risk assessments) are variable and changing, depending on project and regulatory needs.
- There is increased scrutiny and review of all fate and transport analyses.
- There is a need for better consistency and defensibility.
- There is a need to provide guidance (particularly to subcontractors) on what parameters to use for every assessment.
- There is a need to define data gaps and technical issues to resolve uncertainties and increase defensibility.

Technical staff informally polled in FY07 indicated that

- Needs depend on assessment basis (e.g., purpose, dimensionality, scale).
- There is a general need for thorough documentation on what the uncertainties are and how the assessment approach (basis) was selected.
- There is a need to document and justify the selection of input parameters, based on the assessment basis and technical approach, which is traceable back to raw data (managed under configuration control).
- There is need for effective (up-scaled) parameters, which are dependent on model scale (grid block and domain).
- There is a need for consistency in how the hydrogeologic units are defined.

4.2 Path Forward

The general philosophy expressed by the Parameter Selection Working Group was that the technical approach should start by identifying the existing parameter data sets most recently used in site assessments, documenting these data sets, and ensuring their traceability. They recognized that the necessary parameters and supporting data sets are related directly to the assessment basis (e.g., the purpose, dimensionality, scale) of the problem to be solved. Therefore, a target problem was identified to further focus initial efforts on parameter data sets needed for fairly simple site assessments. The target problem was defined initially (in FY07) as a two-dimensional model using the Subsurface Transport Over Multiple Phases (STOMP) computer program (White and Oostrom 2000). However, this was changed in FY08 to focus on a one-dimensional model that would be conducted using the RESRAD computer program to estimate peak groundwater concentrations from existing concentrations of contaminants in the

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(a) The Parameter Selection Working Group met three times in FY07 (October 12 and October 26, 2006, and January 4, 2007). Participants included Raz Khaleel, Fred Mann, Mike Connelly, Marcus Wood, Bill McMahon, Jeff Serne, Chris Murray, Jason Keller, Bob Bryce, George Last, Tom Fogwell, Mark Rockhold, Will Nichols, and Jim Hoover.

soil column, similar to the assessment conducted using RESRAD for the 200-CS-1 Operable Unit feasibility study (DOE 2007b).

Continued efforts should be made to enhance the defensibility and traceability of these parameter data sets to address limitations and technical issues associated with the existing assessment data sets. Additional data types and analysis tools should also be developed and documented in support of more complex assessments.

The technical approach and general implementation strategy developed by the Parameter Selection Working Group was tailored to focus on RESRAD analyses, and consisted of the following steps:

1. Identify the needed RESRAD input parameters.
2. Define the raw data(a) sets on which the parameter estimates should be based.
3. Summarize the best-estimate parameters previously used in recent Hanford assessments.
4. Compile Hanford-specific best-estimate parameters, traceable to existing documentation and/or the raw data.
5. Address limitations of the databases and analytical methods currently available to the Hanford community to support the Hanford-specific best-estimate parameters.
6. Recommend technical approaches that can improve defensibility and traceability of Hanford-specific parameters to the raw data.

The targeted assessment basis for this initial focus was a rather simple assessment to estimate peak groundwater concentrations from existing concentrations of contaminants in the soil column, similar to the assessment conducted using RESRAD for the 200-CS-1 Operable Unit feasibility study (DOE 2007b). This targeted assessment basis would

- Support waste-site–specific remedial investigation/feasibility study documentation (e.g., baseline risk assessment).
- Be one-dimensional.
- Use the RESRAD computer program.
- Be deterministic; not directly addressing uncertainty in the parameters and conceptual model, but able to evaluate parameter sensitivity.
- Be far field, where the K_d approach is applicable, (i.e., where geochemical conditions remain fairly constant, and contaminant loading of the adsorption sites is low [Cantrell et al. 2002]).
- Have initial conditions based on interpretation of the nature and extent of contamination.
- Involve aqueous waste (not solid waste, containerized waste, or non–aqueous-phase liquids).

Longer-term objectives (beyond this initial implementation) should be aimed at supporting increasingly more complex site assessments, including the target assessment basis initially defined by the Parameter Selection Working Group in FY07 that would

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(a) *Raw data* (sometimes called *source data* or *primary data*) refers to measurements or observations resulting from execution of a field or laboratory procedure and that have not been processed or otherwise manipulated.

- Support waste-site–specific remedial investigation/feasibility study documentation (e.g., baseline risk assessment).
- Be two-dimensional and capable of vertical resolution of less than 2 m.
- Use the STOMP computer program.
- Address uncertainty in both parameters and the conceptual model(s).
- Be far field and consider contaminants and concentrations that would be amenable to analysis using a K_d approach.
- Have initial conditions based on interpretation of the nature and extent of contamination and realistic soil moisture conditions.
- Involve aqueous waste (not solid waste, containerized waste, or non-aqueous phases).

The following sections focus on vadose zone parameters used in the RESRAD code to estimate peak groundwater concentrations from existing concentrations of contaminants in the soil column. Section 5 identifies the parameters of interest, summarizes the availability of relevant raw data, and summarizes parameter estimates previously used in Hanford assessments. Section 6 identifies selected parameter data sets that could be used as Hanford-specific parameters in lieu of the default parameters typically used in the RESRAD code. Section 7 presents some of the limitations of the current parameter estimates and raw databases and provides recommendations for addressing these limitations to improve traceability and defensibility for future revisions to these Hanford-specific parameter estimates.

5.0 Review and Compilation of Existing Raw and Parameter Data Sets

This section identifies the RESRAD parameters of interest and summarizes pertinent raw data and parameter estimates used in previous Hanford assessments. The key inputs to estimating the peak groundwater concentration and corresponding year from existing concentrations of contaminants in the soil column can be grouped into six types: 1) a simplified model of contaminant distributions within the soil column beneath the waste site of interest, 2) deep drainage/recharge-related parameters, 3) the hydrostratigraphy, 4) associated flow and transport parameters, 5) contaminant distribution coefficients, and 6) groundwater-related parameters. The focus of this report is on vadose zone flow and transport parameters and does not include recharge- or groundwater-related parameters.

5.1 Contaminant Distribution Model

The contaminant distribution model (also known as the soil contamination model) specifies the concentration of contaminants of potential concern (COPCs) in the surface and subsurface soils that are assumed to be present in layers, with each layer having a uniform concentration of the contaminants. The contaminant distribution is something that must be uniquely defined for each individual waste site and COPC (typically through site-specific characterization). There is not one general Hanford Site contaminant distribution model that can be used to support flow and transport assessments.

Data used to derive the site-specific soil contamination model are generally taken from the Hanford Environmental Information System (HEIS) database and interpreted in concert with information on the hydrostratigraphy. Typically, a contaminated zone is represented by a single hydrostratigraphic zone based on the maximum soil concentration for a specific COPC. Often, the depth of these contaminated zones and corresponding hydrostratigraphic thicknesses (see Section 5.2) are different for different COPCs and thus require separate model configurations and model runs that are later summed for composite risk estimates. Because the soil contamination distribution model is something that must be uniquely defined for each individual waste site and COPC, it will not be discussed further in this document.

5.2 Hydrostratigraphy

The hydrostratigraphy and the related input parameters used to describe the representative flow and transport properties of each hydrostratigraphic layer within the soil column beneath each waste site must be defined for input into the RESRAD code. The physical architecture (e.g., geology, hydraulic properties, and geochemical properties) beneath the Hanford Site varies by location. The geometry and configuration of hydrostratigraphic facies and associated heterogeneities can be quite complex when viewed at a small scale. However, for RESRAD and other simple types of analyses aimed at simulating release of mobile contaminants from the vadose zone to the groundwater on a large scale, the vadose zone can be simulated as a sequence of homogeneous layers. This assumes that small-scale stratifications and variations in texture can be represented by effective parameters for an equivalent homogeneous medium.

For the RESRAD analysis of interest presented in this document, the vadose zone beneath each waste site is represented by a one-dimensional soil column. RESRAD allows the soil column to be divided into four main zones: 1) uncontaminated cover, 2) contaminated zone, 3) uncontaminated unsaturated zone, and 4) saturated zone (Yu et al. 2001). RESRAD allows only one hydrostratigraphic layer per zone, except for the uncontaminated unsaturated zone, which can be subdivided into as many as five horizontal strata (Yu et al. 2001). For RESRAD, each defined hydrostratigraphic unit requires several parameters related to the hydraulic and geochemical properties of that unit. Available raw and interpreted hydraulic and geochemical data sets available to support interpretation of the hydrostratigraphy for a modeled waste site, as well as the hydrostratigraphic models previously used in Hanford assessments, are summarized in Appendix A.

5.3 Unsaturated Zone Hydrologic Parameters

Hydrologic input parameters typically needed for vadose zone flow and transport modeling in RESRAD for all unsaturated zone layers (i.e., the cover layer, the contaminated unsaturated layer, and all of the uncontaminated unsaturated layers) include (Yu et al. 2001)

- bulk density (ρ_b)
- total porosity (p_t)
- effective porosity (p_e)
- volumetric water content at field capacity (θ_{fc})
- volumetric water content at saturation (θ_s)
- saturated hydraulic conductivity (K_s)
- soil-specific pore-interaction parameter (b).

Hanford-specific data that can be used to derive these parameter estimates come from a number of different sources. A brief discussion of each of the main parameters of interest, including a summary of the Hanford-specific raw data sets and the parameter estimates used most recently in Hanford assessments, is provided in Appendix A.

5.4 Contaminant Distribution Coefficients

Contaminant distribution coefficients (K_d) are formally defined as the ratio of the mass of solute adsorbed or precipitated on the soil (per unit of dry mass) to the solute concentration in the liquid (Yu et al. 2001). Site-specific values can vary over many orders of magnitude, depending on the chemical form of waste, soil type, pH, redox potential, and presence of other ions. Therefore, Yu et al. (2001) highly recommend the use of site-specific distribution coefficients. In the approach used here, distribution coefficients are specified for each hydrostratigraphic layer (see Section 5.2).

K_d values are empirical parameters that may be applicable for only the conditions under which they were measured. Many geochemical factors affect K_d values, including sediment mineralogy, surface area, and a variety of solution chemical parameters. As a result, determining the appropriate K_d value for a particular application generally requires the expert judgment of a geochemist familiar with the environmental geochemistry of the contaminant of concern, the geochemistry of the site or aquifer where the K_d value is to be applied, and the conditions under which the K_d values were measured.

It should be noted that defining the K_d value as the mass of solute adsorbed *or precipitated* on the soil (per unit of dry mass) to the solute concentration in the liquid, as done in the RESRAD model (Yu et al. 2001), is a simplification of the geochemical transport process. Under certain specific conditions, the linear sorption model (K_d) can provide an accurate representation of adsorption (Cantrell et al. 2002). However, if precipitation has occurred during the measurement of the K_d value, or if a K_d value measured in the absence of precipitation is used to represent a situation in which precipitation has occurred, the model results will be highly uncertain. This is because precipitation and dissolution are not linear processes as required by the assumptions inherent in the linear distribution coefficient (K_d) model. Appendix A provides a summary of the available raw K_d values measured on Hanford sediments, as well as K_d values previously used in recent Hanford assessments.

6.0 Input Parameters for Hanford-Specific RESRAD Analyses

This section presents a compilation of the existing parameter data sets that could be used as Hanford-specific parameters in RESRAD assessments. The key inputs of particular interest to this document and to RESRAD vadose zone flow and transport analyses include the hydrostratigraphy and associated flow and transport parameters. These parameters should be used only when waste–site-specific data are lacking.

The hydrostratigraphy and associated flow and transport parameters can be site-specific and may be generally applicable to a select set of conditions under which the parameters were measured or estimated. Many physical, hydrologic, and geochemical factors affect these parameter values, including the depositional environment, particle size distribution, sedimentary structures, compaction and cementation, sediment mineralogy, surface area, and a variety of solution chemical parameters. As a result, determining the appropriate hydrostratigraphy and associated flow and transport parameters for a specific application generally requires the expert judgment of a hydrogeologist, soil scientist, and geochemist familiar with the environmental conditions, contaminants of concern, the hydrogeochemistry of the site or aquifer, and the conditions under which the parameter values were measured or estimated.

6.1 Hydrostratigraphy

Combining the stratigraphic subdivisions developed by Bjornstad (2004), Last et al. (2006), and Reidel and Chamness (2007) provides a reasonable and consistent stratigraphic framework for future assessments that can be related back to recent assessments. Table 6.1 presents an overview of these hydrostratigraphic unit assignments. Note that the presence, thickness, and hydrogeochemical properties of these units are dependent on the specific location of the model domain.

In developing the RESRAD model layers, comparison of the model domain location with the location of the nearest boreholes with geologic contact information (Bjornstad 2004; Reidel and Chamness 2007) can provide the best-estimate representation of the hydrostratigraphic column. Comparison of the sediment descriptions for each stratigraphic unit identified in the nearest borehole geologic contacts with the representative hydraulic property sediment classes defined by Last et al. (2006) and Khaleel (2007) provides a reasonable approach for defining the best-estimate hydraulic property sediment classes (Table 6.1). Note that hydraulic property sediment classes are not defined for all hydrostratigraphic units (e.g., Ringold Member of Taylor Flat), and one sediment class (e.g., PPlz) may be used to represent more than one hydrostratigraphic unit (see Table 6.1).

6.2 Unsaturated Zone Hydrologic Parameters

Hydrologic parameters typically needed for all unsaturated zone layers (i.e., the cover layer, the contaminated unsaturated layer, and all of the uncontaminated unsaturated layers) to support RESRAD analyses include (Yu et al. 2001)

- bulk density (ρ_b)
- total porosity (p_t)
- effective porosity (p_e)
- field capacity (θ_{fc})
- volumetric water content at saturation (θ_s)
- saturated hydraulic conductivity (K_s)
- soil-specific exponential (pore-interaction) parameter (b).

Table 6.1. Hydrostratigraphic Units for Which Physical, Hydrologic, and Geochemical Data Can Be Defined To Support Future Site Assessments (after Last et al. 2006; Reidel and Chamness 2007; Khaleel 2007)

		Representative Hydraulic Property Sediment Class(es)		
Formation/ Unit	**Subunit (Symbol)**	**After Last et al. (2006)**	**After Khaleel et al. (2006a, 2006b)**	**Qualitative Sediment Description**
Holocene Deposits	Backfill (Bf)	Bf	Backfill	Poorly sorted sand and gravel mixed with finer fraction.
Hanford formation	Unit H1a (H1a)	Hfs, Hcs	NA	Mostly sand-dominated sediment with some silt but may contain some gravelly sediments.
	Unit H1 (H1)	Hgs, Hg	Gravelly sand H1	Gravel-dominated sediments with coarse sand found in 200 West Area.
	Unit H2 (H2)	Hfs, Hcs	Sand H2	A mixture of sandy and silty sediment in 200 West Area.
	Unit H2a (H2a)			A transitional sand and gravel unit between H2 and H3.
	Unit H3 (H3)	Hgs, Hg	Gravelly sand H3	Laterally discontinuous gravelly sediment at the base of the Hanford formation.
	Unit H4 (H4), Undifferentiated Hanford/Cold Creek Unit (Hf/CCU)	Hss, Hcs	NA	Laterally discontinuous silty sediment at the base of the Hanford formation, including undifferentiated silty Hanford/Cold Creek Unit sediments.
Cold Creek Unit	Cold Creek Unit Silt (CCUz)	PPlz	Cold Creek (Unit 4)	Stratified very fine sand to clayey silt at least partially correlative with the "early Palouse soils."
	Cold Creek Unit Carbonate (CCUc)	PPlc	Cold Creek (Unit 4)	Calcium-carbonate cemented clay, silt, sand, and/or gravel.
	Cold Creek Unit Gravels (CCUg)	NA	Cold Creek (pre-Missoula gravels)	Gravelly sand to gravel equivalent to the pre-Missoula gravels.
Ringold Formation	Member of Taylor Flat (Rtf)	PPlz	NA	Well-bedded fine to coarse sand to silt.
	Member of Wooded Island, subunit E ($Rwi_{(e)}$)	Rg	Ringold sandy gravel	Fluvial gravel, moderate to strongly cemented, and interstratified with finer-grained deposits.
	Lower Mud (Rlm)	NA	NA	
	Member of Wooded Island, subunit A ($Rwi_{(a)}$)	NA	NA	
Saddle Mountains Formation	Elephant Mountain Member (Tem)	NA	NA	

NA = Not available.

Unsaturated zone hydrologic parameters assembled for recent Hanford assessments and published in technical reports represent the best professional judgment of the technical experts conducting those specific assessments. Although these assessment-specific data sets may not be traceable directly back to the raw data, they are, through published references, traceable back to the professional judgment of the technical experts who authored the published documents.

6.2.1 Best-Estimate Bulk Density Values

All recent Hanford assessments have defined the best-estimate values for dry bulk density (ρ_b) as the average of the individual values they selected to be representative of the specific model domain(s). However, definition of the individual stratigraphic units, their sediment types, and the representative bulk density measurements for those stratigraphic units has varied. Because the individual assessments represent the best professional judgment of the technical experts conducting those assessments, it seems appropriate that, in the near term, future assessments conducted in or near those model domains should use similar properties. Thus, the best-estimate values assembled for near-term RESRAD assessments are based on those previous assessments but are modified to provide some consistency in the sediment class nomenclature (Table 6.2).

6.2.2 Best-Estimate Total Porosity (p_t) Values

The most reliable estimates of total porosity (p_t) for Hanford Site sediments are calculated from measured bulk and particle densities or from measured bulk densities and average particle densities. However, most assessment data packages use θ_s as an estimate of p_t because that is the most complete data set available. Using θ_s as an estimate for p_t generally is not recommended because in many cases this may be a fitted parameter representing an unconstrained fit of water retention data (Schaap et al. 2003). Klute (1986) states that θ_s is typically 80% to 90% of the total porosity because of entrapped or encapsulated air, but this is soil-dependent.

The best-estimate total porosity values assembled for use with RESRAD were derived by averaging the total porosity values reported by Freeman and Last (2003), Freeman (2004), and Khaleel (2004) for selected hydrostratigraphic units and geographic areas as provided in the data set “Hydraulic_Properties_2006-03-07 DCR-0045.xls” placed under configuration control by Last et al. (2006) and modified for this report (see Table 6.3 and Appendix B).

6.2.3 Best-Estimate Effective Porosity Values

The best effective porosity (p_e) data currently available for the Hanford Site are calculated by subtracting the residual volumetric water content (θ_r) from the total porosity (p_t). Using θ_s as an estimate for effective porosity is not recommended because it probably overestimates the effective porosity, which may lead to overestimating the transport time. Thus, the best-estimate effective porosity values assembled for use with RESRAD are derived by taking the averaged results of the total porosity (p_t) minus the residual water content (θ_r) (as reported by Freeman and Last 2003, Freeman 2004, and Khaleel 2004) for selected hydrostratigraphic units and geographic areas in keeping with Khaleel et al. (2006a, 2006b), Last et al. (2006), and Khaleel (2007) (Table 6.4).

Table 6.2. Best-Estimate Bulk Density (ρ_b) Values for Selected Hydrostratigraphic Units and Geographic Areas Within the Separations Areas

Sediment Class – Description	Best-Estimate Bulk Density (g/cm^3)						
		200 West Area				200 East Area	
	Site-Wide[(a)]	200 W[(a)]	S 200 W; 200W, S[(a)]	S-SX Tank Farm[(b)]	N 200 W; 200W, N[(a)]	S 200 E; 200E, S[(a)]	C Tank Farm[(c)]
Bf – Backfill	1.94	NA	NA	2.13	NA	NA	2.13
Hss – Hanford formation silty sand	1.61	1.67	1.58	NA	1.80	NA	NA
Hfs – Hanford formation fine sand	1.60	1.70	1.72	1.76	1.68	1.65	1.76
Hcs – Hanford formation coarse sand	1.67	1.65	NA	NA	1.56	1.67	NA
Hgs – Hanford formation gravelly sand	1.94	1.81	NA	1.94	NA	NA	1.94
Hg – Hanford formation sandy gravel	1.93	1.89	2.09	NA	1.79	NA	2.07
Hrg – Hanford formation gravel (>60% gravel)	1.97	NA	NA	NA	NA	NA	NA
CCUz – Cold Creek Unit silt	1.68	1.68	1.71	1.65	1.58	NA	NA
CCUc – Cold Creek Unit carbonate	1.72	1.71	NA	1.65	1.68	NA	NA
CCUg – Cold Creek Unit gravels	NA	NA	NA	NA	NA	NA	2.13
Rg – Ringold Formation sandy gravel	1.90	1.84	1.82	2.13	NA	NA	2.13

(a) After Last et al. (2006).
(b) After Khaleel et al. (2006a), Khaleel (2007).
(c) After Khaleel et al. (2006b), Khaleel (2007).
NA = Not available.

Table 6.3. Best-Estimate Total Porosity Values for Selected Hydrostratigraphic Units and Geographic Areas Within the Separations Areas

	Best-Estimate Total Porosity (cm^3/cm^3)						
		200 West Area				**200 East Area**	
Sediment Class – Description	**Site-Wide(a)**	**200 W(a)**	**S 200 W(a)**	**S-SX Tank Farm(b)**	**N 200 W(a)**	**BC(a)**	**C Tank Farm(c)**
Bf – Backfill	*0.210*	NA	NA	NA	NA	NA	NA
Hss – Hanford formation silty sand	0.448	0.354	0.392	NA	*0.329*	NA	NA
Hfs – Hanford formation fine sand	0.406	0.323	0.341	NA	*0.318*	0.422	NA
Hcs – Hanford formation coarse sand	0.386	*0.384*	NA	NA	*0.410*	0.390	NA
Hgs – Hanford formation gravelly sand	0.280	*0.335*	NA	NA	NA	0.300	NA
Hg – Hanford formation sandy gravel	0.258	0.235	*0.231*	NA	0.237	NA	NA
Hrg – Hanford formation gravel (>60% gravel)	0.259	NA	NA	NA	NA	NA	NA
CCUz – Cold Creek Unit silt	0.404	0.404	0.355	NA	*0.452*	NA	NA
CCUc – Cold Creek Unit carbonate	0.340	0.340	NA	NA	0.352	NA	NA
CCUg – Cold Creek Unit gravels	NA	NA	NA	NA	NA	NA	NA
Rg – Ringold Formation sandy gravel	0.293	0.299	0.313	NA	NA	NA	NA

(a) Average total porosity from data set used by Last et al. (2006).
(b) After Khaleel et al. (2006a), Khaleel (2007).
(c) After Khaleel et al. (2006b), Khaleel (2007).
NA = Not available.
Values in *red italic* represent values with lower confidence that were based on averages of few (3 or less) samples and/or included estimates calculated with assumed rather than measured particle density.

Table 6.4. Best-Estimate Effective Porosity Values for Selected Hydrostratigraphic Units and Geographic Areas Within the Separations Areas

	Best-Estimate Effective Porosity (cm^3/cm^3)						
		200 West Area				200 East Area	
Sediment Class – Description	**Site-Wide(a)**	**200 W(a)**	**S 200 W(a)**	**S-SX Tank Farm(b)**	**N 200 W(a)**	**BC(a)**	**C Tank Farm(c)**
Bf – Backfill	*0.158*	NA	NA	NA	NA	NA	NA
Hss – Hanford formation silty sand	0.374	0.297	0.326	NA	*0.282*	NA	NA
Hfs – Hanford formation fine sand	0.373	0.279	0.299	NA	*0.277*	0.388	NA
Hcs – Hanford formation coarse sand	0.361	*0.348*	NA	NA	*0.395*	0.364	NA
Hgs – Hanford formation gravelly sand	0.247	*0.305*	NA	NA	NA	0.260	NA
Hg – Hanford formation sandy gravel	0.227	0.213	*0.202*	NA	0.218	NA	NA
Hrg – Hanford formation gravel (>60% gravel)	0.239	NA	NA	NA	NA	NA	NA
CCUz – Cold Creek Unit silt	0.360	0.360	0.308	NA	*0.420*	NA	NA
CCUc – Cold Creek Unit carbonate	0.288	0.288	NA	NA	0.297	NA	NA
CCUg – Cold Creek Unit gravels	NA	NA	NA	NA	NA	NA	NA
Rg – Ringold Formation sandy gravel	0.267	0.258	0.266	NA	NA	NA	NA

(a) Average of total porosity (p_t) minus the residual water content ($(\theta_r)_t$) from data set used by Last et al. (2006).
(b) After Khaleel et al. (2006a) and Khaleel (2007).
(c) After Khaleel et al. (2006b) and Khaleel (2007).
NA = Not available.
Values in *red italic* represent values with lower confidence that were based on averages of few (three or fewer) samples and/or included estimates calculated with assumed rather than measured particle density.

6.2.4 Best-Estimate Field Capacity Values

Best-estimate field capacity values for use as Hanford-specific values for input in RESRAD analyses have been estimated from existing van Genuchten (1980) model water retention parameters. The term *field capacity* has been used traditionally in agriculture to refer to the water content at which drainage from a field soil becomes negligible (Hillel 1980).

Three different estimates of field capacity are provided in Table 6.5. For agricultural applications, field capacity typically is calculated as the water content at 1/3 bar (340 cm) of soil-moisture tension. Hillel (1980) argues, however, that field capacity should be based on a drainage rate that is considered to be negligible after a thorough irrigation, usually after about 24 to 48 hours. Meyer et al. (1997) calculated field capacity as the water content at which the unsaturated hydraulic conductivity equals 10^{-8} cm/s ($\cong$ = 3 mm/yr) using the van Genuchten (1980) model. Meyer et al. (1997) argued that 10^{-8} cm/s represents a flux at which contaminant transport is likely to be insignificant. This approach requires that the van Genuchten model be numerically inverted to estimate $\theta_{(q = 1.e\text{-}8\ cm/s)}$. The third estimate of field capacity in Table 6.5 is simply the residual water content, θ_r, which is a fitting parameter in the van Genuchten (1980) model of water retention. In the absence of other estimates, and assuming van Genuchten model parameters are available, θ_r often is used as an estimate of field capacity because, by definition, hydraulic conductivity is zero at θ_r.

For transport calculations, RESRAD computes a value of water content for the unsaturated zone from the user-specified infiltration rate, K_s, and the “b” parameter. If the computed value of water content is less than the user-specified value of field capacity, RESRAD uses the field capacity as the water content. Therefore, for conservative transport calculations, the largest of the three estimates of field capacity given in Table 6.5 should be used. In all but two cases, the largest estimates of field capacity correspond to $\theta_{(1/3\ bar)}$. For other assessments, $\theta_{(q = 1.e\text{-}8\ cm/s)}$ should be used. Whatever basis is used for estimating field capacity should be explicitly stated in the assessment. In addition, analyses should be performed to evaluate the sensitivity of RESRAD results to field capacity and the other parameters.

6.2.5 Best-Estimate Saturated Water Content Values

The best-estimate saturated water content values for use as Hanford Site-specific values for use with RESRAD are based on those defined for selected hydrostratigraphic units and geographic areas for use in specific assessments, in keeping with Khaleel et al. (2001, 2006a, 2006b), Khaleel (2004, 2007), and Last et al. (2006) (see Table 6.6). These generally represent one of the fitted parameters estimated by curve fitting gravel corrected moisture retention data using the RETC, MULSTP, or SFOPT computer programs.

6.2.6 Best-Estimate Saturated Hydraulic Conductivity Values

The best-estimate saturated hydraulic conductivity (K_s) values for use in Hanford-specific RESRAD analyses are based on those defined for selected hydrostratigraphic units and geographic areas for use in specific assessments, in keeping with Khaleel et al. (2001), Khaleel (2004, 2007), Khaleel et al. (2006a, 2006b), and Last et al. (2006) (see Table 6.7). These generally represent one of the fitted parameters estimated by curve fitting gravel corrected moisture retention data using the RETC, MULSTP, or SFOPT computer programs. Note that fitted K_s values may not necessarily provide accurate estimates of the actual K_s values for these sediments.

Table 6.5. Best-Estimate Field Capacity Values for Hanford Site-Wide Sediment Classes for Use in RESRAD Analyses. These values are based on previously determined van Genuchten (1980) model parameters taken from a 2007 hydraulic properties data set used by Murray et al. (2007).

Sediment Class – Description	**Field Capacity, θ_{fc}, (cm^3/cm^3)**		
	θ_r [(a)]	**Best-Estimate, $\theta_{(q=1.e\text{-}8\ cm/s)}$** [(b)]	$\theta_{(h=1/3\ bar)}$ [(b)]
Bf – Backfill	NA	NA	NA
Hss – Hanford formation silty sand	0.072	0.175	0.250
Hfs – Hanford formation fine sand	0.039	0.123	0.122
Hcs – Hanford formation coarse sand	0.035	0.074	0.069
Hgs – Hanford formation gravelly sand	0.041	0.083	0.105
Hg – Hanford formation sandy gravel	0.023	0.061	0.073
Hrg – Hanford formation gravel (>60% gravel)	0.020	0.032	0.060
CCUz – Cold Creek Unit silt	0.037	0.134	0.257
CCUc – Cold Creek Unit carbonate	0.072	0.135	0.174
CCUg – Cold Creek Unit gravels	NA	NA	NA
Rg – Ringold Formation sandy gravel	0.037	0.096	0.120

(a) For comparison only.

(b) For conservative calculation, use the larger of these two values.

Table 6.6. Best-Estimate Values for Saturated Water Content, θ_s, for Use with RESRAD

	Best-Estimate Saturated Water Content, θ_s (cm^3/cm^3)								
		200 West Area				**200 East Area**			
Soil Class	**Site-Wide(a)**	**200W(a)**	**South, 200-U1 & U2; 200WS(a)**	**South, S-SX Tank Farms' 200WSS(b)**	**North, 200-ZP-1; 200NW(a)**	**North, B-BX-BY Tank Farms; 200ENB(c)**	**South, BC; 200ESB(a)**	**South, IDF; 200ESI(d)**	**North, C Tank Farm; 200ENC(e)**
Bf – Backfill	0.262	NA	NA	0.1380	NA	0.2688	NA	NA	0.1380
Hss – Hanford formation silty sand	0.445	0.398	0.437	NA	0.351	0.4349	NA	NA	NA
Hfs – Hanford formation fine sand	0.379	0.356	0.347	0.3819	0.366	0.3819	0.380	0.394	0.3819
Hcs – Hanford formation coarse sand	0.349	0.318	NA	NA	0.292	NA	0.357	NA	NA
Hgs – Hanford formation gravelly sand	0.238	*0.273*	NA	0.2126	NA	0.2688	NA	NA	0.2688
Hg – Hanford formation sandy gravel	0.167	0.154	*0.150*	0.2126	0.155	0.2126	NA	NA	0.2126
Hrg – Hanford formation gravel (>60% gravel)	0.102	NA	NA	NA	NA	NA	NA	0.138	NA
CCUz – Cold Creek Unit silt	0.419	0.419	0.398	0.4349	0.448	NA	NA	NA	NA
CCUc – Cold Creek Unit carbonate	0.281	0.281	NA	NA	0.286	NA	NA	NA	NA
CCUg – Cold Creek Unit gravels	NA	NA	NA	NA	NA	NA	NA	NA	0.1380
Rg – Ringold Formation sandy gravel	0.177	0.297	0.315	0.1380	NA	0.1380	NA	NA	0.1380

(a) After Last et al. (2006).
(b) After Khaleel et al. (2006a), Khaleel (2007).
(c) After Khaleel et al. (2001).
(d) After Khaleel (2004).
(e) After Khaleel et al. (2006b), Khaleel (2007).
NA = Not available.
Values in *red italic* represent values with lower confidence that were based on averages of few (3 or less) samples and/or included estimates calculated with assumed rather than measured particle density.

Table 6.7. Hanford-Specific Values for Saturated Hydraulic Conductivity, K_s, for Use with RESRAD

	Best-Estimate Saturated Hydraulic Conductivity, K_s, (cm/s)								
		200 West Area				**200 East Area**			
Soil Class	**Site-Wide[a]**	**200W[a]**	**South, 200-U1 & U2; 200WS[a]**	**South, S-SX Tank Farms' 200WSS[b]**	**North, 200-ZP-1; 200NW[a]**	**North, B-BX-BY Tank Farms; 200ENB[c]**	**South, BC; 200ESB[a]**	**South, IDF; 200ESI[d]**	**North, C Tank Farm; 200ENC[e]**
Bf – Backfill	5.98E-4	NA	NA	5.60E-4	NA	5.60E-4	NA	NA	5.60E-4
Hss – Hanford formation silty sand	8.58E-5	1.91E-5	2.49E-5	NA	6.55E-6	2.40E-4	NA	NA	NA
Hfs – Hanford formation fine sand	3.74E-4	3.67E-5	1.71E-5	9.88E-5	7.88E-5	9.88E-5	2.25E-3	4.15E-3	9.88E-5
Hcs – Hanford formation coarse sand	2.27E-3	1.09E-3	NA	NA	1.49E-3	NA	5.32E-3	NA	NA
Hgs – Hanford formation gravelly sand	6.65E-4	*2.35E-4*	NA	2.62E-4	NA	5.15E-4	NA	NA	5.15E-4
Hg – Hanford formation sandy gravel	3.30E-4	1.48E-3	*2.88E-4*	2.62E-4	3.65E-3	2.62E-4	NA	NA	2.62E-4
Hrg – Hanford formation gravel (>60% gravel)	1.46E-3	NA	NA	NA	NA	NA	NA	5.60E-4	NA
CCUz – Cold Creek Unit silt	5.57E-5	5.57E-5	7.27E-6	2.40E-4	7.11E-4	NA	NA	NA	NA
CCUc – Cold Creek Unit carbonate	8.48E-4	5.00E-4	NA	NA	1.03E-3	NA	NA	NA	NA
CCUg – Cold Creek Unit gravels	NA	NA	NA	NA	NA	NA	NA	NA	5.60E-4
Rg – Ringold Formation sandy gravel	4.13E-4	1.06E-4	7.83E-5	5.60E-4	NA	5.60E-4	NA	NA	5.60E-4

(a) After Last et al. (2006).
(b) After Khaleel et al. (2006a), Khaleel (2007).
(c) After Khaleel et al. (2001).
(d) After Khaleel (2004).
(e) After Khaleel et al. (2006b), Khaleel (2007).
NA = Not available.
Values in *red italic* represent values with lower confidence that were based on averages of few (three or fewer) samples.

6.2.7 Best-Estimate "b" Parameter Values for Use with RESRAD

Currently there is little information on appropriate RESRAD "b" parameter values for Hanford sediments apart from relating published "b" values to grain size and/or other appropriate hydrogeologic parameters. The "b" values can be estimated from the available raw data by either 1) refitting the raw water retention data for Hanford sediments using the simplified power function model (Campbell 1974) to generate new estimates of "b" or 2) using the existing parameter estimates for other models (e.g., van Genuchten and Brooks-Corey) to estimate values of "b," with either published formulas for converting from van Genuchten model parameters to Brooks-Corey model parameters, and from Brooks-Corey to Campbell (or Clapp and Hornberger) parameters, or generating discrete data from the previous model parameters and refitting the discrete data with the Campbell model (Brooks and Corey 1964; Campbell 1974; Clapp and Hornberger 1978).

Work is in progress to review the existing raw data in order to establish its traceability as well as to ensure reproducibility of previous parameter estimates using the van Genuchten (1980) model. The best-estimate "b" values were estimated from the database of existing van Genuchten model parameters that were generated initially by Khaleel and Freeman (1995b), and that has been supplemented over the years with parameter estimates from other sources (Freeman et al. 2001, 2002; Freeman and Last 2003a) and summarized by Murray et al. (2007). The procedure used for estimating the "b" parameters from existing van Genuchten (1980) model water retention parameters is described below. Users are cautioned that the initial estimates of "b" parameters reported here likely will change as the historical data are reviewed and as new data are generated and added to the database.

To estimate the Campbell model "b" parameter, the database of van Genuchten model water retention parameters (as compiled by Murray et al. 2007) was used to generate discrete soil water content, θ, and tension, h, data. These data were then fit using the Campbell model. Figure 6.1 depicts a set of discrete θ-h values generated from van Genuchten model parameters representing a sample of Hanford fine sand, and a curve representing the Campbell function, which was fitted to the discrete θ-h values using the solver in Excel. As is evident from Figure 6.1, the Campbell model has a sharp air-entry pressure, and the water content goes to zero at high tensions.

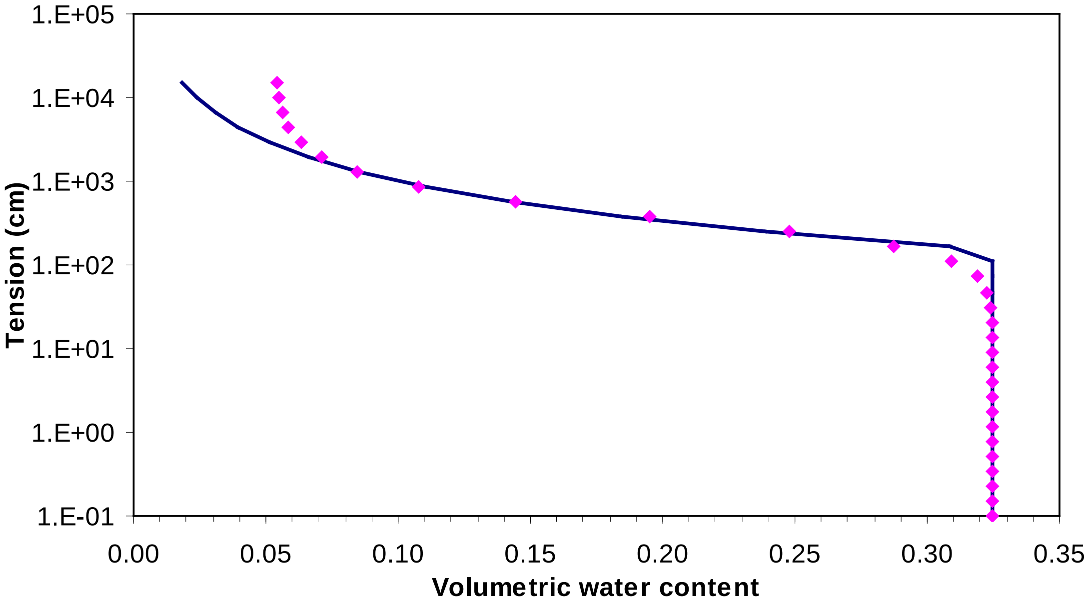

Figure 6.1. Discrete Volumetric Water Content (θ) and Tension (h) Data Pairs (pink symbols) Generated from van Genuchten (1980) Model Water Retention Parameters and Fitted Function (Campbell 1974; blue curve) for a Sample (B8814-115) of Hanford Formation Fine Sand

Table 6.8 summarizes the "b" parameter estimates on a site-wide basis needed for RESRAD applications for different Hanford formation sediment types. Future work will provide estimates of the "b" parameter for relevant sub-areas within the Hanford Site.

Table 6.8. Best Estimates of the "b" Parameter for Hanford Site-Wide Sediment Classes for Use in RESRAD Analyses. These values are based on previously determined van Genuchten (1980) model parameters, taken from the data set used by Murray et al. (2007).

Sediment Class – Description	b
Bf – Backfill	NA
Hss – Hanford formation silty sand	2.63
Hfs – Hanford formation fine sand	2.31
Hcs – Hanford formation coarse sand	2.03
Hgs – Hanford formation gravelly sand	2.53
Hg – Hanford formation sandy gravel	2.96
Hrg – Hanford formation gravel (>60% gravel)	2.75
CCUz – Cold Creek Unit silt	1.77
CCUc – Cold Creek Unit carbonate	3.54
CCUg – Cold Creek Unit gravels	NA
Rg – Ringold Formation sandy gravel	3.15

Note that the upper Ringold (Rtf) is assumed have characteristics similar to those of the CCUz (see Table 6.1).

6.3 Contaminant Distribution Coefficients

Most recent Hanford Site assessments have primarily relied on, or built on, the generic distribution coefficients compiled by Last et al. (2006). Thus, these values provide the most logical basis for Hanford-specific K_d values for use with RESRAD, where data specific to the waste site are lacking.

6.3.1 Best-Estimate K_d Values for Uncontaminated Vadose and Groundwater Sediments

Table 6.9 presents best-estimate K_d values compiled for uncontaminated sediments (sediments not impacted by waste solutions; i.e., sediments having natural porewater or groundwater chemistry, taken from Cantrell et al. 2008 as modified from Last et al. 2006 when available) for various sediment classes. The K_d values for sediments with a relatively high weight-percent gravel were modified in accordance with Cantrell et al. (2008) and Kaplan et al. (2000) using gravel correction factors calculated for high K_d contaminants (best estimate K_d > 10 for sand-dominated sediment) and low K_d contaminants ($K_d < 10$) using Equations (6.1) and (6.2), respectively. The estimated gravel fraction for the various soil classes was based on the mean weight-percent gravel provided by Last et al. (2006, Table 4.5).

$$K_d(gc) = (1 - 0.77f)\, K_d(< 2\text{ mm}) \tag{6.1}$$

$$K_d(gc) = (1 - f)\ K_d(< 2mm) \qquad (6.2)$$

where $K_d(gc)$ = gravel corrected K_d value

f = weight fraction gravel

$K_d(<2\ mm)$ = K_d value determined using material less than 2 mm.

Table 6.9. Best-Estimate K_d Values for Uncontaminated Vadose Zone Layers Used in RESRAD (after Cantrell et al. 2008, Table 3.4). Values are rounded to two significant digits.

	Gravel-Dominated (>60% gravel)	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**	**Silt-Dominated**	**Carbonate-Dominated**
Soil Classes:	**Hrg**	**Hg, Rg, CCUg**	**Bf, Hgs**	**Hss, Hfs, Hcs**	**CCUz**	**CCUc**
Est. wt% Gravel	**67.6%**	**50.0%**	**30.0%**	**2.0%**	**0.4%**	**16.7%**
High K_d (>10) Correction Factor	**0.48**	**0.62**	**0.77**	**NA**	**NA**	**NA**
Low K_d (<10) Correction Factor	**0.32**	**0.50**	**0.70**	**NA**	**NA**	**NA**
Chemicals						
F-	0.03	0.05	0.07	0.1	0.2	0
Cr(VI)	0	0	0	0	0	0
Hg(II)	72	92	120	150	150	150
NO3-, NO2-	0	0	0	0	0	0
Pb(II)	24	31	38	50	100	50
U(VI), all isotopes	0.26	0.4	0.56	0.8	1.5	4
Radionuclides						
241Am(III)	140	180	230	300	300	150
14C	1.6	2.5	3.5	5[(a)]	5	15
60Co(II,III)	4.8	6.2	7.7	10	10	15
137Cs	960	1200	1500	2000	2000	2000
Eu(III), all isotopes	140	180	230	300[(a)]	300	150
3H	0	0	0	0	0	0
129I as iodide	0.06	0.1	0.14	0.2	0.2	0.2
63Ni	140	180	230	300	300	300
237Np(V)	3.2	5	7	10	20	10
Pu, all isotopes	290	370	460	600	600	300
226Ra(II)	10	12	15	20	40	40
79Se(VI,IV)	1.6	2.5	3.5	5	5	5
126Sn(IV)	24	31	38	50	100	50
90Sr	10	12	15	20[(a)]	40	40
99Tc(VII)	0	0	0	0	0	0

(a) Modified slightly from those published in Last et al. (2006) and Cantrell et al. (2007).

6.3.2 Best-Estimate K_d Values for the Contaminated Zone

Based on K_d values developed by Last et al. (2006) and Cantrell et al. (2007), best-estimate K_d values for contaminated sediments (those impacted by waste) were compiled for six waste chemistry/source categories. The six categories were 1) very acidic, 2) very high salt/very basic, 3) chelates/high salts, 4) low organic/low salt/near neutral, 5) IDF vitrified waste, and 6) IDF cementitious waste. The K_d values compiled for the fourth class (low organic/low salt/near neutral) are identical to those presented in Table 6.9 for uncontaminated sediments. Thus, Table 6.9 should be used to select best-estimate K_d values for sediments contaminated with low organic/low salt/near neutral waste. The following sections present the best-estimate K_d values for contaminated sediments impacted by the other five waste chemistry/source categories.

6.3.2.1 Best-Estimate K_d Values for Sediment Contaminated by Very Acid Waste

Best-estimate K_d values compiled for various classes of sediments impacted by very acid waste are shown in Table 6.10. When available, the tabulated values for various constituents are from Cantrell et al. (2007, Appendix B). Values for other constituents were estimated by the authors. Gravel corrections were determined as indicated previously.

6.3.2.2 Best-Estimate K_d Values for Sediments Contaminated by Very High Salt/Very Basic Waste

Best-estimate K_d values compiled for contaminated sediments impacted by very high salt/very basic waste are shown in Table 6.11 for various sediment classes. When available, values for most constituents are from Cantrell et al. (2007, Appendix B). Values for other constituents are from Cantrell et al. (2008, Table 3.3). Exceptions include K_d values for Ra(II), which was assumed to equal that of Sr(II) from Cantrell et al. (2007, Appendix B), and Am (III), which was assumed to equal that of Eu(III) from Cantrell et al. (2007, Appendix B). Gravel corrections were determined as indicated previously.

6.3.2.3 Best-Estimate K_d Values for Contaminated Sediments Impacted by Chelates and/or High Salt Waste

Best-estimate K_d values compiled for contaminated sediments impacted by chelates and/or high salt waste are shown in Table 6.12 for various sediment classes. When available, K_d values are from Cantrell et al. (2007, Appendix B). Values for other constituents are from Cantrell et al. (2008, Table 3.9). Exceptions include Am (III), which was taken to equal that of Eu(III) from Cantrell et al. (2007, Appendix B). Gravel corrections were determined as indicated previously.

6.3.2.4 Best-Estimate K_d Values for Contaminated Sediments Impacted by Integrated Disposal Facility Formulated Vitrified Waste

Best-estimate K_d values compiled for contaminated sediments impacted by vitrified waste formulated for the IDF are shown in Table 6.13 for various sediment classes. When available, K_d values are from Cantrell et al. (2007, Appendix B). Values for other constituents are from Cantrell et al. (2007, Appendix C), except Hg(II), which was estimated for this report. Gravel corrections were determined as indicated previously.

Table 6.10. Best-Estimate K_d Values for Contaminated Vadose Zone Layers Impacted by Very Acidic Waste for Use in RESRAD. After Cantrell et al. (2007, Appendix B) for available constituents. Others were estimated. Values are rounded to two significant digits.

	Gravel-Dominated (>60% gravel)	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**
Soil Classes:	**Hrg**	**Hg, Rg, CCUg**	**Bf, Hgs**	**Hss, Hfs, Hcs**
Est. wt% Gravel	**67.6%**	**50.0%**	**30.0%**	**2.0%**
High K_d (>10) Correction Factor	**0.48**	**0.62**	**0.77**	**NA**
Low K_d (<10) Correction Factor	**0.32**	**0.50**	**0.70**	**NA**
Chemicals				
F-	0	0	0	0
Cr(VI)	0	0	0	0
Hg(II)	4.8	6.2	7.7	10
NO_3-, NO_2-	0	0	0	0
Pb(II)	4.8	6.2	7.7	10
U(VI) - all isotopes	0.06	0.1	0.14	0.2
Radionuclides				
^{241}Am(III)	9.6	12	15	20
^{14}C	0	0	0	0
^{60}Co(II,III)	0.48	0.62	0.77	1
^{137}Cs	480	620	770	1000
Eu(III) - all isotopes	9.6	12	15	20
^{3}H	0	0	0	0
^{129}I - as iodide	1.3	2	2.8	4
^{63}Ni	4.8	6.2	7.7	10
^{237}Np(V)	0	0	0	0
Pu - all isotopes	0.19	0.25	0.31	0.4
^{226}Ra(II)	4.8	6.2	7.7	10
^{79}Se(VI,IV)	1.6	2.5	3.5	5
^{126}Sn(IV)	0	0	0	0
^{90}Sr	4.8	6.2	7.7	10
^{99}Tc(VII)	0	0	0	0

Table 6.11. Best-Estimate K_d Values for Contaminated Vadose Zone Layers Impacted by Very High Salt/Very Basic Waste for Use in RESRAD. Taken from Cantrell et al. (2007, Appendix B) when available and Cantrell et al. (2008, Table 3.3) for other constituents. Values were rounded to two significant digits.

	Gravel-Dominated (>60% gravel)	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**
Soil Classes:	**Hrg**	**Hg, Rg, CCUg**	**Bf, Hgs**	**Hss, Hfs, Hcs**
Est. wt% Gravel	**67.6%**	**50.0%**	**30.0%**	**2.0%**
High K_d (>10) Correction Factor	**0.48**	**0.62**	**0.77**	**NA**
Low K_d (<10) Correction Factor	**0.32**	**0.50**	**0.70**	**NA**
Chemicals				
F-	0	0	0	0
Cr(VI)	0.02	0.03	0.04	0.05
Hg(II)	0	0	0	0
NO_3-, NO_2-	0	0	0	0
Pb(II)	1.4	1.9	2.3	3
U(VI) - all isotopes	0.26	0.4	0.56	0.8
Radionuclides				
^{241}Am(III)	96	120	150	200
^{14}C	32	50	70	100
^{60}Co(II,III)	0	0	0	0
^{137}Cs	4.8	6.2	7.7	10
Eu(III) - all isotopes	96	120	150	200
^{3}H	0	0	0	0
^{129}I - as iodide	0.01	0.01	0.01	0.02
^{63}Ni	0	0	0	0
^{237}Np(V)	0	0	0	0
Pu - all isotopes	96	120	150	200
^{226}Ra(II)	11	14	17	22
^{79}Se(VI,IV)	0	0	0	0
^{126}Sn(IV)	0	0	0	0
^{90}Sr	11	14	17	22
^{99}Tc(VII)	0	0	0	0

Table 6.12. Best-Estimate K_d Values for Contaminated Vadose Zone Layers Impacted by Chelates and/or High Salt Waste for Use in RESRAD. Taken from Cantrell et al. (2007, Appendix B) when available and from Cantrell et al. (2008, Table 3.9) for other constituents. Values were rounded to two significant digits.

	Gravel-Dominated (>60% gravel)	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**
Soil Classes:	**Hrg**	**Hg, Rg, CCUg**	**Bf, Hgs**	**Hss, Hfs, Hcs**
Est. wt% Gravel	**67.6%**	**50.0%**	**30.0%**	**2.0%**
High K_d (>10) Correction Factor	**0.48**	**0.62**	**0.77**	**NA**
Low K_d (<10) Correction Factor	**0.32**	**0.50**	**0.70**	**NA**
Chemicals				
F-	0	0	0	0
Cr(VI)	0.32	0.5	0.7	1
Hg(II)	0	0	0	0
NO_3-, NO_2-	0	0	0	0
Pb(II)	1.4	1.9	2.3	3
U(VI) - all isotopes	0.06	0.1	0.14	0.2
Radionuclides				
^{241}Am(III)	9.6	12	15	20
^{14}C	0	0	0	0
^{60}Co(II,III)	0	0	0	0
^{137}Cs	4.8	6.2	7.7	10
Eu(III) - all isotopes	9.6	12	15	20
^{3}H	0	0	0	0
^{129}I - as iodide	0.06	0.1	0.14	0.2
^{63}Ni	0	0	0	0
^{237}Np(V)	0.65	1	1.4	2
Pu - all isotopes	4.8	6.2	7.7	10
^{226}Ra(II)	0.48	0.62	0.77	1
^{79}Se(VI,IV)	0	0	0	0
^{126}Sn(IV)	0	0	0	0
^{90}Sr	0.48	0.62	0.77	1
^{99}Tc(VII)	0	0	0	0

Table 6.13. Best-Estimate K_d Values for Contaminated Vadose Zone Layers Impacted by IDF Vitrified Waste for Use in RESRAD. Values are taken from Cantrell et al. (2007, Appendix B) when available, otherwise from Cantrell et al. (2007, Appendix C), except Hg(II), which was estimated for this report. Values are rounded to two significant digits.

	Gravel-Dominated (>60% gravel)	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**
Soil Classes:	**Hrg**	**Hg, Rg, CCUg**	**Bf, Hgs**	**Hss, Hfs, Hcs**
Est. wt% Gravel	**67.6%**	**50.0%**	**30.0%**	**2.0%**
High K_d (>10) Correction Factor	**0.48**	**0.62**	**0.77**	**NA**
Low K_d (<10) Correction Factor	**0.32**	**0.50**	**0.70**	**NA**
Chemicals				
F-	0	0	0	0
Cr(VI)	0	0	0	0
Hg(II)	0	0	0	0
NO_3-, NO_2-	0	0	0	0
Pb(II)	4.8	6.2	7.7	10
U(VI) - all isotopes	0.06	0.1	0.14	0.2
Radionuclides				
^{241}Am(III)	2.4	3.1	3.9	5
^{14}C	0	0	0	0
^{60}Co(II,III)	0.1	0.12	0.15	0.2
^{137}Cs	0.72	0.92	1.2	1.5
Eu(III) - all isotopes	2.4	3.1	3.9	5
^{3}H	0	0	0	0
^{129}I - as iodide	0.03	0.05	0.07	0.1
^{63}Ni	0.1	0.12	0.15	0.2
^{237}Np(V)	0.06	0.1	0.14	0.2
Pu - all isotopes	4.8	6.2	7.7	10
^{226}Ra(II)	7.2	9.2	12	15
^{79}Se(VI,IV)	0.32	0.5	0.7	1
^{126}Sn(IV)	0.1	0.12	0.15	0.2
^{90}Sr	7.2	9.2	12	15
^{99}Tc(VII)	0	0	0	0

6.3.2.5 Best-Estimate K_d Values for Contaminated Sediments Impacted by Cementitious Waste Formulated for the Integrated Disposal Facility

Best-estimate K_d values compiled for contaminated sediments impacted by IDF cementitious waste are shown in Table 6.14 for various sediment classes. When available, K_d values are from Cantrell et al.

(2007, Appendix B). Values for other constituents are from Cantrell et al. (2007, Appendix C), except Ra(II), which was assumed to equal that of Sr(II) from Cantrell et al. (2007, Appendix B), and Hg(II), which was estimated for this report. Gravel corrections were determined as indicated previously.

Table 6.14. Best-Estimate K_d Values for Contaminated Vadose Zone Layers Impacted by IDF Cementitious Waste for Use in RESRAD Analyses. Values are taken from Cantrell et al. (2007, Appendix B) when available; otherwise, they were estimated from best estimates in Cantrell et al. (2007, Appendix C), except Ra(II), which was assumed to equal that of Sr(II) from Cantrell et al. (2007, Appendix B), and Hg(II), which was estimated for this report. Values were rounded to two significant digits.

	Gravel-Dominated (>60% gravel)	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**
Soil Classes:	**Hrg**	**Hg, Rg, CCUg**	**Bf, Hgs**	**Hss, Hfs, Hcs**
Est. wt% Gravel	**67.6%**	**50.0%**	**30.0%**	**2.0%**
High K_d (>10) Correction Factor	**0.48**	**0.62**	**0.77**	**NA**
Low K_d (<10) Correction Factor	**0.32**	**0.50**	**0.70**	**NA**
Chemicals				
F-	0	0	0	0
Cr(VI)	0	0	0	0
Hg(II)	48	62	77	100
NO_3-, NO_2-	0	0	0	0
Pb(II)	2400	3100	3800	5000
U(VI) - all isotopes	32	50	70	100
Radionuclides				
^{241}Am(III)	240	310	380	500
^{14}C	0	0	0	0
^{60}Co(II,III)	48	62	77	100
^{137}Cs	14	18	23	30
Eu(III) - all isotopes	240	310	380	500
^{3}H	0	0	0	0
^{129}I - as iodide	0.65	1	1.4	2
^{63}Ni	48	62	77	100
^{237}Np(V)	65	100	140	200
Pu - all isotopes	240	310	380	500
^{226}Ra(II)	4.8	6.2	7.7	10
^{79}Se(VI,IV)	0.32	0.5	0.7	1
^{126}Sn(IV)	48	62	77	100
^{90}Sr	4.8	6.2	7.7	10
^{99}Tc(VII)	0	0	0	0

7.0 Summary and Recommendations

This report 1) identifies the needed RESRAD input parameters; 2) identifies the raw data sets on which the parameter estimates ultimately should be based; 3) summarizes the best-estimate parameters used in recent Hanford assessments; and 4) compiles best-estimate parameters, traceable back to existing documentation and/or the raw data. Additionally, this report outlines a general strategy for management of assessment parameters to ensure their consistency, defensibility, and traceability. The strategy is to start by identifying the existing parameter data sets used most recently in site assessments, documenting these data sets and the raw data sets on which they are based, and then working to ensure their traceability and defensibility. The initial parameter data sets—the focus of this report—are aimed at RESRAD types of vadose zone flow and transport analyses.

Within published references on recent site assessments, the parameter estimates used in these assessments often are not directly traceable back to the raw data and analytical approaches used to derive them. Future efforts should be directed at verifying the raw data and fully documenting the derivation of Hanford-specific parameters, to ensure traceability and reproducibility of the assessment parameters. Several recommendations are provided to improve the completeness, traceability, reproducibility, and defensibility of the Hanford-specific assessment parameters.

7.1 Compile and Verify Raw Physical and Geochemical Property Data

An extensive amount of site-specific physical and hydraulic properties data is available for the Hanford Site. This data is currently being managed in an informal database maintained at PNNL using SoilVision. Efforts are ongoing to migrate this database into a HEIS compatible format where it will be maintained and periodically updated under configuration control (Rockhold 2008; Rockhold et al. 2009).

It is important to continue to manage supporting raw databases by fully compiling and verifying all the raw physical, hydrologic, and geochemical property data currently available for the Hanford Site, and to resolve potential discrepancies. The raw data are derived primarily from laboratory measurements made on borehole samples. These samples were collected using a variety of drilling and sampling methods as well as sample handling and preparation methods. Many of the measurements were made on repacked samples and often on only the less-than 2-mm fraction. It is important to identify the procedures used to measure or estimate (i.e., model fit) the parameters, including identification of those values that were gravel-corrected and how.

Verification, validation, and/or confirmation of these raw data sets (particularly the bulk density, particle density, and porosity measurements and estimates) has been difficult, mostly owing to the fact that the data were collected by different individuals and contractors over the past 20+ years (Rockhold 2008). Similarly, individual raw residual water content values in the database have not been easily traced back to the methods used to either measure or estimate the values. Thus, it may be important to develop property transfer models to provide independent estimates of physical, hydrologic, and geochemical properties from other measurements such as particle size.

7.2 Verify Assignment to Stratigraphic Units and Hydrofacies

It is important to implement a rigorous process, as quantitative as possible, to assign and classify samples and their corresponding physical, hydrologic, and geochemical properties to stratigraphic units (formations or members), facies associations, and lithofacies and/or hydrofacies classes in a defensible and reproducible way. Assignment and classification of soil samples in published references have been qualitative and lack traceability and reproducibility. Murray et al. (2007) found it difficult to reproduce the assignment of specific sample data to specific stratigraphic units and sediment classes and used a different geologic interpretation to classify the samples, based on interpretation of available borehole logs for all sampled intervals. In addition, statistical analyses by Murray and colleagues suggested that the variability in the laboratory data and estimated parameters led to significant overlap in physical and hydrologic properties between the current system of 11 sediment classes. They further indicated that independent multivariate statistical analyses of the physical and hydrologic property values suggest the samples could be grouped into just four lithologic classes with significantly different properties.

Definition of dominant hydrofacies (sediment classes) and criteria for assignment of sample data to those sediment classes need to be more quantitative (such as using grain size to assign sediment samples to the Folk/Wentworth classification scale) so that it is traceable, more defensible, and reproducible. Efforts should be made also to evaluate the sensitivity of RESRAD results to the input parameters and to evaluate the number of distinct, statistically significant lithofacies populations supported by the raw data and sensitivity analysis.

7.3 Verify Assessment Parameter Estimates

Once the raw data have been verified and quantitatively assigned to sediment classes and stratigraphic units, it will be important to re-estimate the “b” parameter for the various Hanford-specific sediment classes, particularly the coarser gravelly sediment classes. It is also important to develop and reach consensus on how effective parameters should be derived from the raw data. Effective parameters should then be verified and developed from the raw data in a traceable, reproducible, and defensible way.

7.4 Evaluate Sensitivity and Reduce Uncertainty

It is important to evaluate the sensitivity of assessment results to uncertainty in field capacity and the other parameters, and to identify those parameters that lead to the greatest uncertainty in assessment results. Those parameters should be targeted for additional measurements in order to reduce that uncertainty. It is also important to continue to measure important physical and hydrologic parameters on discrete, spatially distributed soil classes or lithofacies for which there are few data points or that have high variability or uncertainty. Many of the sediment classes for which parameter estimates have been developed have few raw data points, particularly when it comes to values for geographically specific area. The statistical significance of these small data sets is of concern. Efforts should be made to prioritize and reduce the uncertainty in the most sensitive, most uncertain parameter data sets by improving the sample size and spatial distribution of key lithofacies-specific data sets.

Another way in which uncertainty could be reduced would be by development of auxiliary (i.e., soft) data providing cheaper estimates of parameters. For examples, a number of methods have recently been developed in academia and the national laboratories for estimation of hydraulic and reactive transport properties from grain-size and borehole geophysical data, providing a valuable tool for estimating the spatial distribution of hydraulic and geochemical properties. However, grain-size data are not available for many boreholes at the Hanford Site, and grain-size analyses are not routinely requested for all boreholes drilled at the site. Grain-size measurements should be made routinely on uncontaminated samples from new and recently drilled boreholes. As more data become available, it may become important to further reduce the uncertainty in key lithofacies by further subdividing or grouping the lithofacies-specific sediment classes into spatial data sets.

7.5 Update and Maintain Assessment Parameter Database

The assessment parameter database (Appendix B) will ultimately be migrated to HEIS and managed to maintain configuration control and traceability. This database will be maintained by compiling all effective (or upscaled) parameters used in site assessments. In addition, it is important to develop and reach consensus on how effective parameters should be derived from the raw data. The selection of "best-estimate" Hanford-specific vadose zone flow and transport parameters should also be expanded to include other parameters such as recharge as well as other input parameters (e.g., van Genuchten's α and n) to support assessments conducted with codes other than RESRAD and to address the importance of heterogeneity on upscaling and anisotropy for assessments conducted in two or three dimensions.

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Appendix A

Review and Compilation of Existing Raw Data and Assessment Parameter Data Sets

Appendix A

Review and Compilation of Existing Raw Data and Assessment Parameter Data Sets

Pertinent raw data and parameter estimates used in previous Hanford assessments are compiled and summarized in this appendix. The data and parameters key to this report are 1) the hydrostratigraphy, 2) associated flow and transport parameters, and 3) contaminant distribution coefficients.

A.1 Hydrostratigraphy

The physical architecture (e.g., geology, hydraulic properties, and geochemical properties) beneath the Hanford Site varies by location and can be quite complex. However, for simple types of analyses, the vadose zone can be treated as a sequence of homogeneous layers. This assumes that small-scale stratifications and variations in texture can be represented by effective parameters for an equivalent homogeneous medium.

A.1.1 Available Raw and Interpreted Data

Raw data and information to support interpretation of the hydrostratigraphic units present in the soil column from surface to groundwater are derived primarily from borehole geologic and geophysical log data and laboratory analyses for various soil properties (Horton et al. 2005). Subjective and qualitative interpretations of these data have produced several interpreted sets of geologic contacts for the 200 Areas (e.g., Bjornstad 2004; Reidel and Chamness 2007).

A.1.2 Previous Assessment Data Sets

Definition of the individual stratigraphic units, their sediment types, and the representative physical and hydrologic properties for those stratigraphic units has varied by assessment, with different contractors or principal investigators using different approaches and nomenclature to define the hydrostratigraphic units for their specific model domain(s). DOE (2002) attempted to promote consistency by standardizing the geologic nomenclature to identify the various geologic facies and facies associations throughout the Hanford Site. However, many of these facies are difficult to fully recognize in drill cuttings and are not uniquely defined by stratigraphic position. Thus, definition of the stratigraphic units has continued to be on an ad hoc basis. Additionally, the hydraulic and geochemical properties have traditionally been assembled for various soil and sediment classes based primarily on grain size and mostly independent from their geologic formation or stratigraphic position.

Last et al. (2001, 2004, 2006) defined a number of generalized hydrostratigraphic templates throughout the 200 Areas for use in 1D and 2D Hanford assessments that did not address horizontal heterogeneity. These hydrostratigraphic templates used nomenclature consistent with that defined by DOE (2002) and were tied to, but modified from, the sediment classes originally identified by Khaleel and Freeman (1995b). Khaleel and Freeman's soil classes were based on textural (i.e., particle size) differences in the International Society of Soil Science (ISSS) classification (<2-mm size fraction only), gravel content (>2-mm size fraction), and moisture retention characteristics.

Oostrom et al. (2004) mapped a number of the existing stratigraphic data sets to a common set of stratigraphic units for use in numerical flow and transport modeling of the 216-Z-9 Trench. They further assigned flow and transport properties to these stratigraphic units by mapping them to various soil and sediment classes for which hydraulic property data were available (e.g., Khaleel and Freeman 1995b). Figure A.1 illustrates how the stratigraphic units are mapped to Folk and Wentworth sediment classes and how those are mapped to the hydraulic property classes used by Last et al. (2001) and Khaleel and Freeman (1995b).

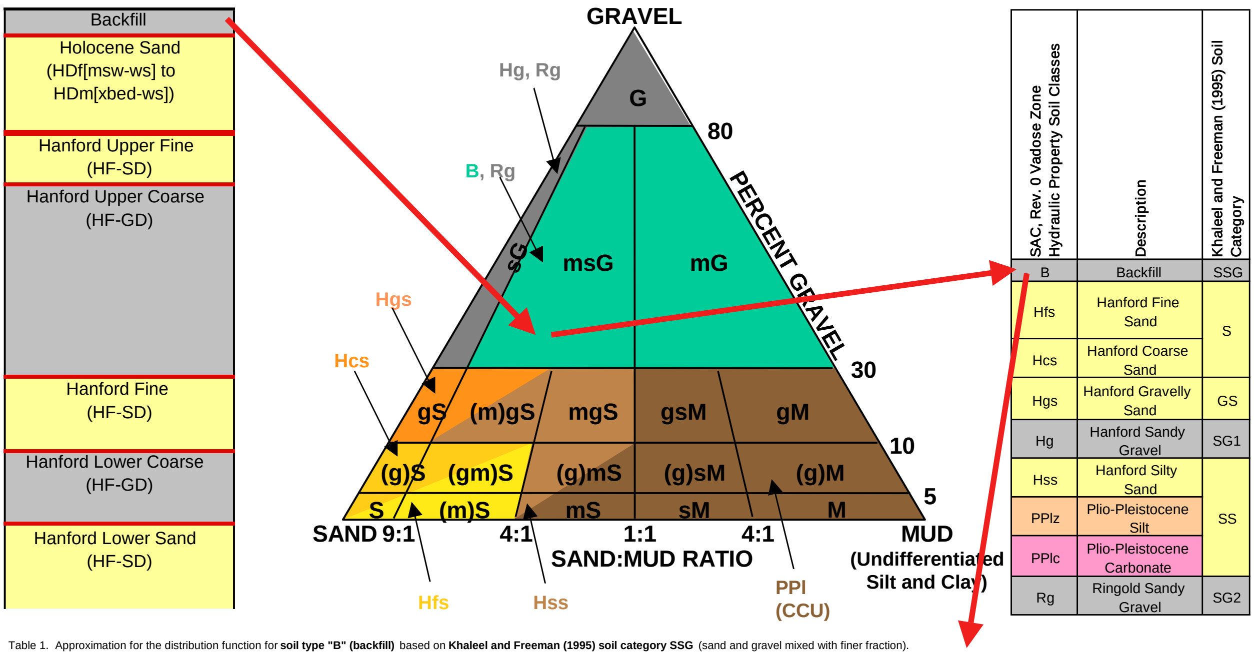
Most recently, Reidel and Chamness (2007) defined the stratigraphy beneath each of the single-shell tank farms, based in part on the Hanford formation subdivisions identified for the 200 West Area by Lindsey et al. (2000) (H1a, H1, H2, H2a, H3, and H4) and for the 200 East Area by Lindsey et al. (2001) (H1, H2, H3). However, Reidel and Chamness (2007) cautioned that it is difficult to correlate specific stratigraphic layers in the Hanford formation across large areas and suggested that paleomagnetic polarity data indicate that these Hanford subdivisions—upper coarse-dominated (H1), sand-dominated (H2), and lower coarse-dominated (H3)—are not the same flooding event in both 200 East and 200 West Areas and thus do not represent the same sedimentary sequences. Nevertheless, these subdivisions are useful for delineating hydrostratigraphic units within localized areas. Khaleel et al. (2006a, 2006b) and Khaleel (2007) defined five different sediment classes (material types) used to represent the hydrogeologic strata beneath the tank farms.

A.2 Unsaturated Zone Hydrologic Parameters

Hydrologic input parameters typically needed for vadose zone flow and transport modeling in RESRAD for all unsaturated zone layers (i.e., the cover layer, the contaminated unsaturated layer, and all of the uncontaminated unsaturated layers) include (Yu et al. 2001)

- bulk density (ρ_b)
- total porosity (p_t)
- effective porosity (p_e)
- volumetric water content at field capacity (θ_{fc})
- volumetric water content at saturation (θ_s)
- saturated hydraulic conductivity (K_s)
- soil-specific pore-interaction parameter (b).

Hanford-specific data that can be used to derive these parameter estimates come from a number of different sources. Most of the data are from laboratory measurements made on disturbed repacked borehole samples (Freeman et al. 2002). Other measurements are from excavations or other geologic outcrop samples. Still other data are derived from field tests (e.g., infiltration tests, air permeameter) and/or indirectly from other measurements (e.g., water retention data or particle-size data).



SAC, Rev. 0 Vadose Zone Hydraulic Property Soil Classes	Description	Khaleel and Freeman (1995) Soil Category
B	Backfill	SSG
Hfs	Hanford Fine Sand	S
Hcs	Hanford Coarse Sand	
Hgs	Hanford Gravelly Sand	GS
Hg	Hanford Sandy Gravel	SG1
Hss	Hanford Silty Sand	SS
PPlz	Plio-Pleistocene Silt	
PPlc	Plio-Pleistocene Carbonate	
Rg	Ringold Sandy Gravel	SG2

Table 1. Approximation for the distribution function for **soil type "B" (backfill)** based on **Khaleel and Freeman (1995) soil category SSG** (sand and gravel mixed with finer fraction).

B		Raw					Transformed (normal distribution)				Beta Distribution		Truncation Limits	
Parameter	Number of samples	Low	High	Mean	Standard Deviation	Stochastic Distribution	Low	High	Mean	Standard Deviation	A	B	Lower	Upper
θ_S	6	0.187	0.375	0.262	0.072	Normal							0.149	0.942
θ_R	6	0	0.064	0.03	0.029	Normal							0.150	0.879
s_r	7	0	0.212952381	0.101598768	0.089458717	Beta					1.0572	9.3483	0.000	0.213
α (1/cm)	6	0.003	0.103	0.032	0.036	Lognormal			-3.957	1.166			0.100	0.926
n	6	1.256	1.629	1.4	0.131	Normal							0.136	0.960
K_s (cm/s)	6	2.76E-05	6.80E-02	1.50E-02	2.70E-02	Log Ratio	-10.854	2.995	-5.262	5.499			0.010	0.990
Longitudinal Dispersivity^1 (m)	NA	0.027	0.178	0.09		Uniform								
Bulk Density^2	NA			1.94		Constant								
Particle Density (g/cm^3)				2.65		Constant								

^{1} Taken from Ho, et. al., 1999 [Stochastic Parameter Development for PORFLOW Simulations of the Hanford AX Tank Farm]

^{2} Taken from Khaleel, et. al. 2000 (Modeling Data Package for S-SX Field Investigation Report (FIR) [DRAFT])

Figure A.1. Example of Mapping Stratigraphic Units to Sediment and Soil Classes for Assigning Hydraulic Properties (after Oostrom et al. 2004). Note that sediment class and general particle-size distribution for a stratigraphic unit from a prior report can be used to identify the comparable soil category (or lithofacies) for which hydraulic properties have been estimated.

Although there is a large amount of site-specific hydraulic properties data available for the Hanford Site, these data are not uniquely defined under one authoritative configuration-controlled database. Instead, two (or more) similar informal databases are in use—one maintained at PNNL and managed using SoilVision[(a)] (contact M. L. Rockhold), and the other maintained by the Fluor Government Group (FGG) (contact R. Khaleel). While both systems share some of the same information, each is a standalone and developed along different evolutionary paths.

Freeman et al. (2002) described three types of data: 1) raw data collected in the laboratory or the field, 2) publications that contain raw data and calculated values derived from the data, and 3) publications in which the raw data have been translated to function parameters. Freeman et al. (2002) suggested that the best data to work with are the raw data because the information can then be manipulated by whatever methods an investigator may like to use. With processed data, the investigator may be forced to use parameters that may be based on subjective assumptions and manipulations by

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(a) SoilVision, a knowledge-based database system for saturated/unsaturated soil properties, is a product of SoilVision Systems Ltd., Saskatoon, Saskatchewan, Canada.

previous users. If an error was introduced in the previous calculations, or an improved method is available with which to derive the parameters, there may not be enough information about the derived parameters to back out the original values. Also, during processing, the data may be approximated (e.g., different number of significant digits), so unless the exact procedure is known, it may not be possible to exactly recover the original data.

Although there is no single authoritative, configuration-controlled database, these data have been summarized in a number of reports by Connelly et al. (1992a; 1992b), Khaleel and Freeman (1995a, 1995b) Khaleel et al. (2000, 2006a, 2006b), Last et al. (2001, 2006), Freeman et al. (2001; 2002), and Khaleel (2004). A brief discussion of each of the main parameters of interest follows, including a summary of the Hanford-specific raw data sets, and the parameter estimates most recently used in Hanford assessments.

A.2.1 Bulk Density (ρ_b)

The dry bulk density (ρ_b) is the mass of solids in a sample divided by the total (bulk) volume of the sample. Due to the potential for disturbance during sampling and handling (e.g., repacking of grab samples), bulk density measured in the laboratory may vary from that of the in situ material. Bulk density generally is used in the calculation of porosity and retardation coefficients.

A.2.1.1 Raw Bulk Density Data

Engelman et al. (1995) summarized about 550 bulk density measurements for the unsaturated Hanford formation sediments. These values, taken from Rhoads et al. (1992), Rohay et al. (1993), Swanson (1992), and Wright et al. (1994), as well as unpublished data from a Westinghouse Hanford Company database (Khaleel and Freeman 1995a), were from ex situ laboratory measurements of borehole samples. Engelman et al. (1995) reported that these values had a mean value of 1.81 g/cm^3.

Khaleel et al. (2000) reported bulk density measurements for five different soil types, made on 45 boreholes samples taken from four sites in the vicinity of the S-SX tank farms as well as from the 100 Areas. These values ranged from 1.6 g/cm^3 for one sample identified as representative of the Cold Creek Unit to 2.32 g/cm^3 for one sample identified as representative of sandy gravel in the Ringold Formation. They also reported bulk density measurements, ranging from 1.46 to 1.57 g/cm^3, made on seven clastic dike samples.

Freeman et al. (2001; 2002) and Freeman and Last (2003) cataloged 501 bulk and particle density measurements available for the Hanford Site, with about half (249) of these coming from the 200 Areas. Freeman and Last (2003) further reported 46 and 112 bulk density measurements for 200 West Area and 200 East Area, respectively, in a prototype vadose zone hydraulic properties database.

Khaleel (2004) reported the measured bulk density values for 32 borehole samples representative of sandy sediments collected from the Integrated Disposal Facility (IDF) site in FYs 1998 and 2001, along with 15 samples of gravelly sediments from the 100 Area and 7 clastic dike samples. These values varied from 1.52 to 1.98 g/cm^3 for the sandy sediments and from 2.06 to 2.38 g/cm^3 for the gravelly sediments.

Khaleel et al. (2006b) reported the measured bulk density values for 41 borehole samples that they selected as representative of five different hydrogeologic strata in the 241-C Tank Farm area. Similarly, Khaleel et al. (2006a) reported the bulk density values for 47 borehole samples they selected as representative of five different hydrogeologic strata at the S and SX tank farms.

Bulk Density Estimates Used in Recent Assessments

Khaleel et al. (2000) presented estimates of effective bulk density, $E[\rho_b]$, to serve as input to flow and transport modeling for the S-SX Field Investigation Report. They took the average of the bulk density (ρ_b) measurements for each of five different soil classes, as well as for clastic dike samples, to define the estimates of $E[\rho_b]$ for the base-case numerical simulations (Table A.1). Last et al. (2001) also used these same average bulk density estimates to represent the six different soil classes used in the initial assessment performed with the System Assessment Capability (SAC) (Table A.2).

Khaleel (2004) did not specifically identify bulk density estimates to be used in the base-case flow and transport modeling for the IDF Performance Assessment (but did use a similar approach (and thus inferring the use similar bulk density estimates) to that of Khaleel et al. (2000).

Table A.1. Effective (Average) Bulk Density Estimates for the S and SX Tank Farms (from Khaleel et al., 2000)

Strata/Material Type	Effective (Average) Bulk Density (g/cm^3)
Backfill	1.94
Sand	1.76
Gravelly sand/sandy gravel	2.07
Cold Creek Unit (Plio-Pleistocene)	1.65
Sandy gravel	2.13
Clastic dike	1.52

Table A.2. Bulk Density Estimates Used in the Initial Site-Wide Assessment Conducted Using the System Assessment Capability (from Last et al. 2001, as modified from Khaleel 2000)

Sediment Class/Representative Stratigraphic Unit	Mean Bulk Density (g/cm^3)
Backfill	1.94
Sand/Holocene sand, Hanford formation sand, and Ringold Formation sand	1.76
Gravelly sand/Hanford formation gravelly sand	2.07
Sandy gravel with < 60% gravel/Hanford formation gravel and undifferentiated Hanford formation and coarse Cold Creek (Plio-Pleistocene) deposits	2.07
Sand mixed with finer fraction/Hanford formation silty sand, fine-grained Cold Creek (Early Palouse Soil), caliche, and Ringold Formation mud	1.65
Sandy gravel with > 60% gravel/Ringold Formation gravel	2.07

Last et al. (2004, 2006) classified 286 bulk density values, selected from a catalog and prototype database of vadose zone hydraulic properties (Freeman et al. 2002; Freeman and Last 2003), into 10 general sediment classes. They generated statistical distributions for each sediment class for use in Hanford assessments, assuming that the bulk density measurements were normally (Gaussian) distributed. The mean bulk density estimates ranged from 1.6 g/cm^3 for Hanford fine sand to 1.97 for Hanford gravel. In addition to the site-wide estimates, Last et al. (2004, 2006) further generated statistical distributions of bulk density for each sediment class for selected areas, including BC cribs, U1 and U2, 200-ZP-1, and 200 West Area. The sediment class designations for these selected areas are identified by a corresponding suffix: _BC, _U, _Z, or _2W, respectively.

Khaleel et al. (2006a, 2006b) described the data used for initial assessment of closure of the C and S and SX Tank Farms. Khaleel et al. (2006b) defined the $E[\rho_b]$ for five hydrogeologic strata selected to represent the C Tank Farm area, while Khaleel et al. (2006a) defined the $E[\rho_b]$ for five hydrogeologic strata selected to represent the S and SX Tank Farm areas. Table A.3 provides the best-estimate $E[\rho_b]$ values they defined for use in the reference and base-case transport modeling.

Khaleel (2007) summarized the available data on soil physical and hydraulic properties and the effective bulk density used in the Field Investigation Report and Single-Shell Tank Performance Assessment modeling. Khaleel reported *measured* bulk densities for tank farm sediments for five general sediment types: 1) backfill, Cold Creek, and Ringold sandy gravel sediments; 2) Hanford formation sandy sediments (representing the H2 unit); 3) Hanford formation gravelly-sand (H3) sediments; 4) Hanford formation gravelly-sand (H1) sediments; and 5) clastic dike sediments. Khaleel (2007) also reported an average *effective* bulk density of four sediment types from Waste Management Area C, ranging from $E[\rho_b]$ values of 1.74 g/cm^3 for Hanford formation sand (Unit H2) to 2.13 g/cm^3 for backfill, Cold Creek Unit, and Ringold Formation gravels.

DOE (2007a) used the average (mean) values of flow and transport parameter values (e.g., hydraulic conductivity, bulk density, and dispersivity) for each hydrostratigraphic unit selected to represent the 200-UW-1 Operable Unit, as taken from Last et al. (2004). A summary of the bulk density values they used for flow and transport modeling is provided in Table A.4.

Table A.3. Effective Bulk Density Values for S-SX and C Tank Farms (after Khaleel et al. 2006a, 2006b)

Strata/Material Type	Effective (Average) Bulk Density (g/cm^3) for S-SX Tank Farms (after Khaleel et al. 2006a)	Effective (Average) Bulk Density (g/cm^3) for C Tank Farm (after Khaleel et al. 2006b)
Backfill	2.13	2.13
Gravelly sand (H1)	NA	2.07
Sand (H2)	1.76	1.76
Gravelly sand (H3)	2.07	1.94
Cold Creek Unit	1.65	NA
Cold Creek Unit (pre-Missoula gravels)	NA	2.13
Ringold Formation gravels	2.13	2.13

NA = Not available.

Table A.4. Summary of Dry Bulk Density Values Selcted for Use in Fate and Transport Modeling for the 200-UW-1 Operable Unit (DOE 2007a, Table 4-2)

Geologic Unit	Description	Soil Class (after Last et al. 2004)	Dry Bulk Density, ρ_b, (g/cm^3)
Surface stabilization fill	Sand and gravel	Bf	1.94
Crib excav. backfill H1[(a)]	Loose H1	Hcs_2W	1.65
Crib drain gravel[(b)]	Clean gravel	NA	1.66
Hanford formation H1 – gravel-dominated	Coarse sand and sandy gravel	Hcs_2W	1.65
Hanford formation H2 – sand-dominated	Silty to fine, medium, and coarse sand	Hfs_U	1.72
Cold Creek Unit – upper	Silt and fine-sand	PPlz_U	1.71
Cold Creek Unit – lower	Calcium carbonate cemented	PPlc	1.71
Upper Ringold Formation	Medium to coarse sand	Hcs	1.66
Upper Ringold Formation	Medium to coarse sand	PPlz_U	1.71
Ringold Formation Unit E – vadose	Cemented sandy gravel	Rg_U	1.82

(a) Same as Hanford H1.
(b) Calculated as 2.86*(1-θs).
NA = Not applicable.

DOE (2007b) used the mean bulk density values from Last et al. (2006) in its RESRAD analyses (see Table A.5) in the feasibility study for the 200-CS-1 Operable Unit.

Table A.5. Bulk Density of Soil Classes Used In RESRAD Analyses for the 200-CS-1 Operable Unit Feasibility Study (DOE 2007b)

Sediment Class – Description	Hanford Site Average (Used for 200 East Area sites), Bulk Density (g/cm^3)	200 West Average (Used for 200 West Area sites), Bulk Density (g/cm^3)
Bf – Backfill	1.94	NA
Hss – Hanford formation silty sand	1.61	1.67
Hfs – Hanford formation fine sand	NA	1.70
Hcs – Hanford formation coarse sand	1.67	NA
Hgs – Hanford formation gravelly sand	1.94	1.81
Hg – Hanford formation gravel	1.93	1.89
Rg – Ringold Formation sand and gravel	1.90	1.84

NA = Not applicable.

A.2.2 Total Porosity (p_t)

Total porosity (p_t) is the fraction of the total volume that is not occupied by solid soil particles (Yu et al. 2001). It is the volume of voids in a sample (the air- and liquid-filled volume) divided by the total volume of the sample and is typically calculated by

$$p_t = 1 - \frac{\rho_b}{\rho_s}$$

where ρ_b and ρ_s are the bulk and particle densities, respectively. Where only the bulk density has been measured, a particle density of 2.65 g/cm^3 has generally been assumed (Freeman 2004). This may not always be a good assumption, however, particularly for gravel- and cobble-dominated sections of the Hanford formation, which appear to have particle densities greater than 2.7 g/cm^3 (Williams et al. 2006, Table 3).

Estimates sometimes also are made using the fitted saturated volumetric water content (θ_s) to approximate the porosity—see Section A.2.5. It should be noted also that for some porous media, a fraction of the pore space may be disconnected or otherwise inaccessible, such that a portion of the pore space cannot take part in flow. For these materials, a distinction between total and effective porosity may be necessary (see Section A.2.3).

A.2.2.1 Raw Total Porosity Data

Freeman and Last (2003) reported 41 and 99 porosity estimates (calculated from bulk density and particle density measurements) for 200 West Area and 200 East Area, respectively, in a prototype vadose zone hydraulic properties database. These values ranged from 0.14 to 0.519 cm^3/cm^3 for 200 East Area samples and from 0.194 to 0.624 cm^3/cm^3 for 200 West Area samples.

Khaleel (2004) reported the porosity values (calculated from the bulk density and the average particle density) for 32 borehole samples representative of sandy sediments collected from the IDF site in FYs 1998 and 2001 and for 7 clastic dike samples. These values ranged from 0.299 to 0.444 cm^3/cm^3 for the sandy sediments and from 0.424 to 0.464 cm^3/cm^3 for the clastic dike samples.

Freeman (2004) updated the prototype vadose zone hydraulic properties database and reported additional porosity estimates, including many from the 100 Areas, calculated using an assumed particle density of 2.65 g/cm^3.

A.2.2.2 Total Porosity Estimates Used in Recent Assessments

Most data packages developed to support recent assessments (e.g., Khaleel et al. 2000, 2001, 2002, 2006a, 2006b; Khaleel 2004, 2007; and Last et al. 2006) have not directly specified the total porosity values. However, DOE (2007a) did specify the total porosity as calculated from 1-(ρ_b /ρ_s), except for the Cold Creek Unit silt (PPlz_U) where the total porosity was specified as equal to the saturated water content (θ_S). DOE (2007b) specified the porosity values used in its RESRAD analyses conducted for the 200-CS-1 Operable Unit feasibility study (Table A.6) as being equal to the saturated volumetric water content (θ_s) defined for the various sediment classes of Last et al. (2006). The θ_s values used by Last

Table A.6. Total Porosity of Soil Classes Used in RESRAD Analyses for the 200-CS-1 Operable Unit Feasibility Study (DOE 2007b)

Sediment Class – Description	Hanford Site Average (Used for 200 East Area sites), Total Porosity (cm^3/cm^3)	200 West Average (Used for 200 West Area sites), Total Porosity (cm^3/cm^3)
Bf – Backfill	0.262	NA
Hss – Hanford formation silty sand	0.445	0.398
Hfs – Hanford formation fine sand	NA	0.356
Hcs – Hanford formation coarse sand	0.349	NA
Hgs – Hanford formation gravelly sand	0.238	0.273
Hg – Hanford formation gravel	0.167	0.154
Rg – Ringold Formation sand and gravel	0.177	0.294

NA = Not applicable.

et al. (2006) were derived from both laboratory measurements and output generated from the RETention Curve (RETC) computer program (van Genuchten et al. 1991), as cataloged by Freeman et al. (2002) and Freeman and Last (2003).

A.2.3 Effective Porosity (p_e)

Effective porosity (p_e) is the fraction of interconnected pores that contributes to fluid flow. It is less than the total porosity because not all pores are interconnected or contribute to advective flow. Effective porosity most often is estimated from other measured parameters, such as the total porosity minus residual volumetric water content (θ_r) (Stephens et al. 1998). Stephens et al. (1998) found that these estimation methods tended to overestimate the effective porosity, and that field tracer tests provide the most direct method for determining the effective porosity. Data from field tracer tests at the Hanford Site are fairly limited; thus, in most cases, effective porosity has been calculated from the total porosity minus the residual water content (θ_r). As stated in Section A.2.2, where measured bulk density and particle density data are not available, some estimates of total porosity have been assumed to be equal to the saturated volumetric water content (θ_s), so in those cases the effective porosity has been estimated by subtracting θ_r from θ_s.

A.2.3.1 Raw Effective Porosity Data

Vadose zone physical and hydrologic property databases managed by FGG and PNNL do not explicitly contain effective porosity data. However, they do contain measurements or estimates of total porosity, saturated water content, and residual water content from which effective porosity estimates are generally derived.

Dual well tracer tests conducted in 200 East Area near the 216-B-5 Reverse Well indicate that the effective porosity of the aquifer material ranges between 0.22 and 0.3 (DOE 1996, p. 4-16). Although the formation represented by these aquifer materials is unclear in this report, Smith (1980, Figure 6 and p. 10) indicated that the unconfined aquifer is wholly contained within the Ringold Formation. Spane et al.

(2001a, 2001b, 2002, 2003), and Spane and Newcomer (2008) reported effective porosity values from a number of tracer-pumpback tests of 200 West Area wells (Ringold Formation, Unit E) ranging from 0.020 to 0.354. Spane and Newcomer (2004) reported one effective porosity value from a tracer-pumpback test of a 200 East Area well (Hanford formation) of 0.373.

A.2.3.2 Effective Porosity Estimates Used in Recent Assessments

Most data packages developed to support recent assessments (e.g., Khaleel et al. 2000, 2001, 2002, 2006a, 2006b; Khaleel 2004, 2007; Last et al. 2006) have not directly specified the effective porosity values used or applicable to unsaturated zone flow and transport assessments. However, DOE (2007b) specified the effective porosity values used in its RESRAD analyses conducted for the 200-CS-1 Operable Unit feasibility study as being equal to the total porosity (Table A.6), which was assumed to equal the saturated volumetric water content (θ_s) defined for the various sediment classes of Last et al. (2006). Where effective porosity values have not been differentiated from total porosity values or θ_s, it is inferred that θ_s was used as a surrogate for effective porosity. The θ_s values used by Last et al. (2006) were derived from both laboratory measurements and output generated from the RETC computer program, as cataloged by Freeman et al. (2002) and Freeman and Last (2003). However, using θ_s as a surrogate for the effective porosity of unsaturated sediments most likely overestimates the actual effective porosity.

A.2.4 Field Capacity (θ_{fc}) and Residual Water Content (θ_r)

RESRAD uses estimates of the field capacity (θ_{fc}) to set the lower limit of the volumetric water content for the purposes of calculating the saturation ratio. Meyer et al. (1997) calculated field capacity as the water content at which the unsaturated hydraulic conductivity equals 10^{-8} cm/s (~3 mm/yr) using the van Genuchten (1980) model. Meyer et al. (1997) argued that 10^{-8} cm/s represents a flux at which contaminant transport is likely to be insignificant.

Field capacity has not been specifically measured or estimated at the Hanford Site, and, as such, raw data are currently unavailable. In the absence of other estimates, the residual water content, θ_r, has frequently been used as an estimate of field capacity.

Residual volumetric water content (θ_r) is widely available for the Hanford Site and thus has been the primary data used to estimate field capacity. However, residual volumetric water content is an empirical parameter and thus is generally a fitting parameter in the van Genuchten (1980) and Brooks and Corey (1964) models of water retention. As such, it has no particular physical significance, although it tends to be representative of the pendular water regime, which is the water content below which water becomes discontinuous in porous media and no longer flows by capillarity.

A.2.4.1 Raw Residual Volumetric Water Content (θ_r) Data

Residual volumetric water content data for Hanford soil and sediment samples are available in informal databases managed by FGG and PNNL. However, traceability of individual raw residual water content values back to the methods used to either measure or estimate the values such that the values could be reproduced is generally lacking or difficult at best.

Khaleel and Freeman (1995a) summarized existing data on moisture retention properties, including θ_r, for 95 data sets taken from seven sites in the 200 Areas. They used the gravel correction approach of Bouwer and Rice (1983) to correct both the laboratory-measured moisture retention and saturated hydraulic conductivity estimates. These corrected values were then used to estimate the van Genuchten parameters, including θ_r, by curve-fitting using the RETC computer program (van Genuchten et al. 1991).

Freeman and Last (2003) reported 36 and 118 θ_r values for 200 West Area and 200 East Area, respectively, in a prototype vadose zone hydraulic properties database. These and all previously reported θ_r values were identified as fitted parameters. The reported values for θ_r ranged from 0 to 0.2412 cm^3/cm^3 for 200 West Area samples and up to 0.2705 cm^3/cm^3 for 200 East Area samples. Freeman (2004) updated the prototype vadose zone hydraulic properties database and reported additional θ_r estimates including many from the 100 Areas.

Khaleel (2004) reported the θ_r values (fitted using either the MULSTP [van Dam et al. 1990] or SFOPT [Tuli et al. 2001] computer program)for 31 borehole samples, representative of sandy sediments collected from the IDF site in FY 1998 and 2001, and 7 clastic dike samples. These values ranged from 0.002 to 0.046 cm^3/cm^3 for the sandy sediments and from 0.019 to 0.063 cm^3/cm^3 for the clastic dike samples.

A.2.4.2 Residual Volumetric Water Content Estimates Used in Recent Assessments

Khaleel et al. (2000) defined effective (upscaled) values of flow and transport parameters for use as input to perform flow and transport modeling through the vadose zone for the Field Investigation Report for Waste Management Area S-SX. They identified composite, fitted van Genuchten-Mualem parameters, including θ_r, for five different strata, based on simultaneous fitting of both moisture retention and unsaturated conductivity predictions using the RETC computer program (Table A.7). In addition to θ_r values, Table A.7 contains values for other parameters in the van Genuchten (1980) water retention and permeability models.

Khaleel et al. (2001) defined effective (upscaled) input parameters for flow and transport modeling for Waste Management Area B-BX-BY. They identified composite, fitted van Genuchten-Mualem parameters, including θ_r, for six different strata. These parameters were based on simultaneous fitting of both moisture retention and unsaturated conductivity predictions using the RETC computer program (Table A.8).(a) These parameters are the same as those identified by Khaleel et al. (2000) with the exception of data listed in Table A.8 for backfill, which appear to be a new data set. The other residual water content values are identical and, in some cases, are used to describe different strata; for example, the parameters listed by Khaleel et al. (2000) for the Plio-Pleistocene strata, as shown in Table A.7, are the same as those defined in Table A.8 for the silty sand strata (presumably of the Hanford formation) as taken from Khaleel et al. (2001). Note also that the parameters Khaleel et al. (2000) identified for backfill were used for gravelly sand of the H3 unit, and those for sandy gravel were used for Ringold Formation gravel/sandy gravel.

(a) Note that all the fitted values of saturate hydraulic conductivity (K_s), such as those in Table A.8, are very similar, even for dissimilar porous media. This is a result of the fitting process in which measured values of unsaturated hydraulic conductivity were used as match points for the observed and model-predicted unsaturated hydraulic conductivity. Thus, the fitted values may not necessarily provide accurate estimates of the actual values for these sediments.

Table A.7. Composite van Genuchten-Mualem Parameter for the S-SX Waste Management Area (after Khaleel et al. 2000)

Strata	Number of Samples	θ_s	θ_r	α (1/cm)	n	γ	Fitted K_s (cm/s)
Backfill	8	0.2688	0.0151	0.0197	1.4194	0.5	5.15E-04
Sand	12	0.3819	0.0443	0.0117	1.6162	0.5	9.88E-05
Gravelly sand/sandy gravel	11	0.2126	0.0032	0.0141	1.3730	0.5	2.62E-04
Plio-Pleistocene	4	0.4349	0.0665	0.0085	1.8512	0.5	2.40E-04
Sandy gravel (Ringold)	10	0.1380	0.0100	0.0210	1.374	0.5	5.60E-04

Table A.8. Composite van Genuchten-Mualem Parameters for Various Strata at the B-BX-BY Waste Management Area (after Khaleel et al. 2001)

Strata	Number of Samples	θ_s	θ_r	α (1/cm)	n	γ	Fitted K_s (cm/s)
Backfill	8	0.2688	0.0151	0.0197	1.4194	0.5	5.15E-04
Sand (H2)	12	0.3819	0.0443	0.0117	1.6162	0.5	9.88E-05
Gravelly sand (H1)	11	0.2126	0.0032	0.0141	1.3730	0.5	2.62E-04
Gravelly sand (H3)	8	0.2688	0.0151	0.0197	1.4194	0.5	5.15E-04
Silty sand	4	0.4349	0.0665	0.0085	1.8512	0.5	2.40E-04
Ringold Formation gravel/ sandy gravel	10	0.1380	0.0100	0.0210	1.374	0.5	5.60E-04

Khaleel et al. (2002) defined effective (upscaled) input parameters for flow and transport modeling for an initial assessment of closure for C Tank Farm. They identified composite, fitted van Genuchten-Mualem parameters, including θ_r, for five different strata. These parameters were again based on simultaneous fitting of both moisture retention and unsaturated conductivity predictions using the RETC computer program (Table A.9). These parameters were identical to those identified by Khaleel et al. (2001), except for those identified for backfill, which are the same as those for the Plio-Pleistocene/ Ringold Formation sand gravel and the Ringold Formation gravel/sandy gravel of Khaleel et al. (2001).

Table A.9. Composite van Genuchten-Mualem Parameters for Various Strata at the C Tank Farm (after Khaleel et al. 2003)

Strata	Number of Samples	θ_s	θ_r	α (1/cm)	n	γ	Fitted K_s (cm/s)
Backfill	10	0.1380	0.0100	0.0210	1.374	0.5	5.60E-04
Sand (H2)	12	0.3819	0.0443	0.0117	1.6162	0.5	9.88E-05
Gravelly sand (H1)	11	0.2126	0.0032	0.0141	1.3730	0.5	2.62E-04
Gravelly sand (H3)	8	0.2688	0.0151	0.0197	1.4194	0.5	5.15E-04
Plio-Pleistocene/Ringold Formation sandy gravel	10	0.1380	0.0100	0.0210	1.374	0.5	5.60E-04

Khaleel (2004) defined effective (upscaled) values of flow and transport parameters for the far-field vadose zone to serve as input to VAM3DF (Huyakorn and Panday 1995) in performing far-field modeling for the IDF Performance Assessment. He identified composite, fitted van Genuchten-Mualem parameters, including θ_r, for two soils (sedimentary sequences), sandy sequences, and gravelly sequences. These parameters, based on available data from borehole samples obtained from the IDF site as well as samples from the 100 Areas, were obtained using the RETC computer program and simultaneously fitting both moisture retention and unsaturated conductivity predictions for all four unknown parameters θ_r, θ_s, α, and γ (Table A.10).

Khaleel et al. (2006a) provided revised estimates of composite van Genuchten-Mualem parameters for various strata beneath the S-SX Tank Farms. These estimates were identical to those by Khaleel et al. (2000) as shown in Table A.7 except for the backfill, which included two additional samples. Table A.11 provides the revised parameter estimates for the backfill.

Khaleel et al. (2006b) and Khaleel (2007) provided revised estimates of the composite van Genuchten-Mualem parameters for various strata beneath the C Tank Farm. These estimates were identical to those by Khaleel et al. (2002), as shown in Table A.9. Additionally, Khaleel (2007) recommended data sets for tank farm sediments and further recommended that the data set by Khaleel et al. (2006b) be used for Waste Management Area S-SX and 200 West Area.

Last et al. (2006) provided statistical distributions of van Genuchten model parameters (including θ_r) for 10 different soil classes derived from the laboratory measurements of 284 soil samples described by Freeman et al. (2001, 2002) and Freeman and Last (2003). Some of these measurements are known to have been gravel-corrected, but it is not clear that all samples were treated in a consistent manner. The high, low, mean, and standard deviation values were calculated for each of the soil classes. The residual water content (θ_r) was assumed to have a normal (Gaussian) distribution. In addition to calculating the statistical distributions for the full data set assigned to each soil class, Last et al. (2006) assembled subsets of samples for the soil classes from near areas of interest, specifically 200 West Area, BC cribs and trenches, 200-UP-1, and 200-ZP-1. Last et al. (2006) summarized the mean hydraulic property estimates for the Hanford Site-wide set as well as selected subarea (site-specific) data sets (Table A.12).

Table A.10. Composite Far-Field van Genuchten-Mualem Parameters for the Sand- and Gravel-Dominated Sequences for the Integrated Disposal Facility Performance Assessment (after Khaleel 2004)

Strata	Number of Samples	θ_s	θ_r	α (1/cm)	n	γ	Fitted K_s (cm/s)
Sandy (from IDF site samples)	44	0.394	0.049	0.0631	2.047	0.5	4.15E-03
Gravelly (from the 100 Areas)	15	0.138	0.010	0.021	1.374	0.5	5.60E-04

Table A. 11. Revised Composite van Genuchten-Mualem Parameters for Backfill Beneath the S-SX Tank Farms (after Khaleel et al. 2006a)

Strata	Number of Samples	θ_s	θ_r	α (1/cm)	n	γ	Fitted K_s (cm/s)
Backfill	10	0.1380	0.0100	0.0210	1.3740	0.5	5.60E-04

Table A.12. Summary of Statistical Mean van Genuchten Model Parameter Values for the Hanford Site, 200 West Area, and Other Subareas (after Last et al. 2006)

Strata	Number of Samples	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n	γ	K_s (cm/s)
Backfill (Bf)[a]	6	0.262	0.030	0.019	1.400	NP	5.98E-04
Hanford formation							
Silty sand (Hss)	38	0.445	0.072	0.008	1.915	NP	8.58E-05
Silty sand, 200 West Area (Hss-2W)	11	0.398	0.057	0.005	2.116	NP	1.91E-05
Silty sand, U1 and U2 area (Hss-U)	6	0.437	0.066	0.007	2.347	NP	2.49E-05
Silty sand, 200-ZP-1 (Hss-Z)	5	0.351	0.047	0.003	1.840	NP	6.55E-06
Fine sand (Hfs)	36	0.379	0.032	0.027	2.168	NP	3.74E-04
Fine sand, BC Area (Hfs – BC)	18	0.380	0.033	0.201	2.507	NP	2.25E-03
Fine sand, 200 West Area (Hfs-2W)	8	0.356	0.042	0.010	2.177	NP	3.67E-05
Fine sand, U1 and U2 (Hfs-U)	4	0.347	0.042	0.013	2.451	NP	1.71E-05
Fine sand, 200-ZP-1 (Hfs-Z)	4	0.366	0.042	0.008	1.903	NP	7.88E-05
Coarse sand (Hcs)	81	0.349	0.027	0.061	2.031	NP	2.27E-03
Coarse sand, BC Area (Hcs – BC)	46	0.357	0.026	0.072	2.047	NP	5.32E-03
Coarse sand, 200 West Area	7	0.318	0.026	0.042	1.759	NP	1.09E-03
Coarse sand, 200-ZP-1 (Hcs-Z)	5	0.292	0.021	0.067	1.692	NP	1.49E-03
Gravelly sand (Hgs)	16	0.238	0.033	0.014	2.120	NP	6.65E-04
Gravelly sand, 200 West Area (Hgs-2W)	2	0.273	0.030	0.008	2.223	NP	2.35E-04
Sandy gravel (Hg)	28	0.167	0.022	0.017	1.725	NP	3.30E-04
Sandy gravel, 200 West Area (Hg-2W)	12	0.154	0.027	0.017	1.745	NP	1.48E-03
Sandy gravel, U1 and U2 (Hg-U)	3	0.150	0.029	0.011	1.845	NP	2.88E-04
Sandy gravel, 200-ZP-1 (Hg-Z)	8	0.155	0.022	0.016	1.703	NP	3.65E-03
Gravel (Hrg)	40	0.102	0.020	0.007	1.831	NP	1.46E-03
Cold Creek Unit							
Silt (CClz)(a)	9	0.419	0.040	0.005	2.249	NP	5.57E-05
Silt, U1 and U2 (CClz-U)	5	0.398	0.047	0.004	2.285	NP	7.27E-06
Silt, 200-ZP-1 (CClz-Z)	4	0.448	0.033	0.007	2.203	NP	7.11E-04

Table A.12. (contd)

Strata	Number of Samples	θ_s (cm^3/cm^3)	θ_r (cm^3/cm^3)	α (1/cm)	n	γ	K_s (cm/s)
Caliche (CCUc)[a]	14	0.281	0.054	0.011	1.740	NP	8.45E-04
Caliche, 200-ZP-1 (CClc-Z)	13	0.286	0.056	0.011	1.750	NP	1.03E-03
Ringold Formation							
Gravels (Rg)	18	0.177	0.026	0.008	1.660	NP	4.13E-04
Gravels, 200 West Area (Rg-2W)	8	0.297	0.041	0.013	1.753	NP	1.06E-04
Gravels, U1 and U2	7	0.315	0.047	0.014	1.675	NP	7.83E-05

(a) Assumed to be the same for all subareas although some differences or inconsistencies were noted between different tables in Last et al. 2006.

NP = Not provided but assumed to have been kept constant at 0.5.

DOE (2007b, Appendix E) used the residual volumetric moisture content (selected from Last et al. 2006) as the field capacity for each of the unsaturated strata. These values ranged from 0.022 to 0.072 (DOE 2007b, Table E-13).

A.2.5 Saturated Volumetric Water Content (θ_S)

Yu et al. (2001) define the saturated water content (θ_S) as the water content when the soil material is saturated and infer that it is equal to the total porosity (p_t) of the soil. However, as Meyer and Serne (1999) point out, soils often cannot be saturated to their full porosity; thus, θ_s is sometimes a fitted parameter, in which case it represents field-saturated water content. Klute (1986) found that field-saturated water content is typically 80 to 90% of the total porosity.

A.2.5.1 Raw Saturated Volumetric Water Content Data

Khaleel and Freeman (1995a) summarized existing data on moisture retention properties, including θ_s, for 95 data sets taken from seven sites in the 200 Areas. They used the gravel correction approach of Bouwer and Rice (1983) to correct both the laboratory-measured moisture retention and saturated hydraulic conductivity estimates. These corrected values were then used to estimate the van Genuchten parameters, including θ_s, by curve fitting using the RETC computer program.

Freeman and Last (2003) reported 36 and 118 θ_s values for 200 West Area and 200 East Area, respectively, in a prototype vadose zone hydraulic properties database. It is unclear which of these values may be from laboratory measurements versus those that are fitted parameters. However, a crosscheck of values reported for the same samples as those of Khaleel and Freemen (1995a), accounting for differences caused by rounding, suggests that they may be the same and thus suggests that they represent fitted parameters rather than measured parameters. The reported values for θ_s ranged from 0.0557 to 0.6772 cm^3/cm^3 for 200 East Area samples and from 0.0718 to 0.6306 cm^3/cm^3 for 200 West Area samples. Freeman (2004) updated the prototype vadose zone hydraulic properties database and reported additional θ_s estimates, including many from the 100 Areas.

Khaleel (2004) reported the θ_s values (fitted using either the MULSTP or SFOPT program) for 31 borehole samples representative of sandy sediments collected from the IDF site in FYs 1998 and 2001, and for 7 clastic dike samples. These values ranged from 0.299 to 0.444 cm^3/cm^3 for the sandy sediments and from 0.424 to 0.454 cm^3/cm^3 for the clastic dike samples.

A.2.5.2 Saturated Volumetric Water Content Estimates Used in Recent Assessments

Khaleel et al. (2000, 2001, 2003, 2006a, 2006b), Khaleel (2004, 2007), and Last et al. (2006) defined input parameters, including θ_s, for flow and transport modeling to support recent assessments (see Tables A.7 through A.12).

A.2.6 Saturated Hydraulic Conductivity (K_s)

Saturated hydraulic conductivity (K_s) is generally described as the proportionality constant relating water flux to the potential gradient in Darcy's Law and can be measured using a variety of methods (Klute and Dirksen 1986). K_s can exhibit anisotropy, with the value depending on the direction in which it is measured.

Saturated hydraulic conductivity often is measured on small-scale laboratory samples; some of these samples have had the gravel fraction removed and were then repacked for use in a Tempe cell and pressure kettle apparatus (Klute 1986; Khaleel and Freeman 1995a). These samples required correction to account for the effect of gravel (Bouwer and Rice 1983). However, in some cases the hydraulic conductivity was measured directly on splitspoon samples and did not require gravel correction (Khaleel and Freeman 1995a).

A.2.6.1 Raw Saturated Hydraulic Conductivity (K_s) Data

Khaleel and Freeman (1995a) summarized existing data on saturated hydraulic conductivity data for 95 data sets taken from seven sites in the 200 Areas. They identified which samples were splitspoon samples versus those that were not and provided source information for each set of analyses. However, it is not explicitly stated which saturated hydraulic conductivity values were corrected for gravel and which were not.

Freeman and Last (2003) reported 45 and 114 K_s values for 200 West Area and 200 East Area, respectively, in a prototype vadose zone hydraulic properties database. Again, it is unclear which of these values is from small-scale repacked samples and corrected for gravel as opposed to those that were from direct laboratory measurement of splitspoon samples. However, a crosscheck with the samples reported by Khaleel and Freeman (1995a) does provide information about which samples were collected as splitspoon samples. Additionally, four of these samples have K_s values of −9.99E+2, which is assumed to represent no value. The reported values for K_s ranged from 8.80E-08 to 4.20E-02 cm/s for 200 West Area samples and 1.40E-08 to 1.30E-1 cm/s for 200 East Area samples. Freeman (2004) updated the prototype vadose zone hydraulic properties database and reported additional K_s estimates, including many from the 100 Areas.

Khaleel (2004) reported the K_s values measured on 31 intact core samples (splitspoon samples in liners) from boreholes drilled near the IDF site in FYs 1998 and 2001, and 7 clastic dike samples.

Saturated hydraulic conductivity was measured using either the constant head method of Klute and Dirksen (1986) or a falling-head method (e.g., PNL 1993). Measurements were made several times on some samples to verify that a steady value of conductivity was achieved. These values ranged from 2.65E-4 to 4.93E-2 cm/s for the sandy sediments and from 1.84E-4 to 5.43E-3 cm/s for the clastic dike samples.

Thorne and Newcomer (1992, 2002) presented a summary of saturated hydraulic conductivity measurements from various aquifer tests. Much of this information was presented independent of geologic formation or unit. However, Hartman et al. (2000) indicated that the hydraulic conductivity of the Hanford formation sediments is generally 10 to 100 times greater than that of Ringold Formation gravels. Thorne et al. (2006) identified the hydraulic conductivity of various hydrogeologic units based on inverse calibration of the groundwater model (Table A.13).

Table A.13. Ranges in Hydraulic Conductivity for Each Groundwater Model Unit (after Thorne et al. 2006), Rounded to Three Significant Digits

Unit ID	Formation or Unit Description	Hydraulic Conductivity, Minimum (m/d)	Hydraulic Conductivity, Maximum (m/d)	Hydraulic Conductivity, Minimum (cm/s)	Hydraulic Conductivity, Maximum (cm/s)
1	Hanford formation gravel	6.06E+00	2.02E+04	7.01E-03	2.34E+01
2	Fluvial/eolian facies of the Cold Creek Unit	NA	NA	NA	NA
3	Coarse-grained multilithic facies and calcium-rich paleosol sequence of the Cold Creek Unit	1.84E+00	5.72E+03	2.13E-03	6.62E+00
4	Silt and clay faces of the Upper Ringold Unit	5.00E-04	5.00E-04	5.79E-07	5.79E-07
5	Lindsey’s (1995) Ringold gravel units E and C	2.39E-01	2.56E+03	2.77E-04	2.97E+00
6	Fine-grained overbank and paleosol deposits that vertically separate Lindsey’s (1995) init B from overlying unit C	1.00E-02	1.00E-02	1.16E-05	1.16E-05
7	Lindsey’s (1995) Ringold gravel units B and D	2.27E-02	1.01E+02	2.63E-05	1.17E-01
8	Lower Ringold mud units (Lindsey 1995)	1.00E-05	1.00E-05	1.16E-08	1.16E-08
9	Lindsey’s (1995) Ringold unit A	5.10E-04	4.24E+00	5.90E-07	4.91E-03

NA = Unit not found below water table.

A.2.6.2 Saturated Hydraulic Conductivity Estimates Used in Recent Assessments

Khaleel et al. (2000, 2001, 2003, 2006a, 2006b), Khaleel (2004, 2007), and Last et al. (2006) defined input parameters, including K_s, for flow and transport modeling to support recent assessments (see Tables A.7 through A.12).

A.2.7 Soil-Specific Exponential Parameter, "b"

The "b" parameter is an empirically derived exponent in a power function model of water retention characteristics by Campbell (1974). Mathematically, the "b' parameter is the slope of the soil-moisture retention curve plotted as the log Ψ (matric potential) vs. log θ. This model is similar to the well-known Brooks and Corey (1964) model except it does not contain the residual water content (θ_r) term. A table of "b" (and other hydraulic) parameters in Clapp and Hornberger (1978) represents average values for the 11 soil classes in the U.S. Department of Agriculture (USDA) textural triangle (all < 2-mm size fraction). These are the default parameters identified in the RESRAD user manual (Yu et al. 2001).

A.2.7.1 Raw "b" Parameter Data

The "b" parameter has not been routinely estimated for Hanford Site soils or sediments, and no database currently exists that captures this information.

A.2.7.2 "b" Parameter Estimates Used in Recent Assessments

The only known use of the "b" parameters in recent Hanford Site assessments has been in conjunction with RESRAD analyses. DOE (2007b) used default values of "b" from the RESRAD user manual (Yu et al. 2001) that were taken from Clapp and Hornberger (1978). These values represent the average values for the 11 soil classes in the USDA textural triangle that excludes gravel (all classes are in the < 2-mm size fraction). Note that the default RESRAD values used by DOE (2007b) represent suggested values for loam, loamy sand, or sand and may not properly represent the coarser gravelly sediments at Hanford (Table A.14). DOE (2007b) used the "b" parameter for sand (4.05) to represent all soil classes except Hanford silty sand (Hss), which was assigned the default value for sandy loam (4.90), and the Hanford fine sand (Hfs) that was given the loamy sand value of 4.38.

Table A.14. "b" Parameter Estimates Used in RESRAD Analyses for the 200-CS-1 Operable Unit Feasibility Study (DOE 2007b)

Soil Class	216-A-29	216-B-63	216-S-10 Ditch	216-S-10 and 216-S-11 Ponds
Bf – Backfill	4.05	4.05	4.05	4.05
Hss – Hanford formation silty sand	4.90	4.90	4.90	4.90
Hfs – Hanford formation fine sand	4.38	4.38	4.38	4.38
Hcs – Hanford formation coarse sand	4.05	4.05	4.05	4.05
Hgs – Hanford formation gravelly sand	4.05	4.05	4.05	4.05
Hg – Hanford formation sandy gravel	4.05	4.05	4.05	4.05
Rg – Ringold Formation sandy gravel	4.05	4.05	4.05	4.05

A.3 Contaminant Distribution Coefficients

Contaminant distribution coefficients (K_d) are formally defined as the ratio of the mass of solute adsorbed or precipitated on the soil (per unit of dry mass) to the solute concentration in the liquid (Yu et al. 2001). Site-specific values can vary over many orders of magnitude, depending on the chemical form of waste, soil type, pH, redox potential, and presence of other ions.

A.3.1 Raw K_d Data

Cantrell et al. (2002, 2003) compiled available K_d values measured with Hanford sediment for radionuclides and toxic compounds that have the greatest potential for driving risk to human health and safety in the vadose zone and groundwater at the Hanford Site. These data were assembled into a database that is now accessible through the Virtual Library (http://vlprod.rl.gov/vlib/app/index.cfm). This database is updated periodically and currently contains nearly all (>90%) of the available published K_d values measured on Hanford sediment for 15 different contaminants. Some data that were not adequately documented have been intentionally excluded from the database.

A.3.2 K_d Estimates Assembled for Recent Hanford Assessments

Kaplan and Serne (2000, Appendix B) identified best-estimate K_d values (and ranges) for 25 radionuclides for far-field sediment conditions for use in the Immobilized Low Activity Waste (ILAW, now the IDF) Performance Assessment. Khaleel et al. (2000) used a K_d value for cesium-137 of 500 cm^3/g (based on data from Kaplan and Serne 2000) for all sediment types to support modeling for the S-SX Field Investigation Report. The other species of interest to this report (Tc-99, Cr, and NO_3) were estimated to have a K_d value of zero. Khaleel et al. (2001) selected a K_d value of 0.6 cm^3/g for uranium (based on data from Kaplan and Serne 2000) for use as input to perform flow and transport modeling for the B-BX-BY Waste Management Area. They also specified the K_d values to be used for Tc-99 and NO_3, as zero. Khaleel (2004) used K_d values for cesium, strontium, uranium, and selenium reported by Kaplan et al. (1998) and corrected for the gravel fraction, to estimate retardation factors for the IDF Performance Assessment. A gravel correction factor of about 2 appears to have been used, cutting the sand-dominated K_d values roughly in half to estimate the gravel-dominated K_d values.

Krupka et al. (2004) provided estimates of K_d values covering a broader range of contaminants of interest for the IDF Performance Assessment. They provided K_d values for several different geochemical zones and include a reasonably conservative K_d value, a best-estimate (or most probable) K_d value, and upper and lower K_d limits. The geochemical zones for which K_d estimates were made included Near Field/Vitrified Waste; Near Field/Cementitious Secondary Waste; Chemically Impacted Far Field in Sand Sequence; Far Field in Sand Sequence with Natural Recharge; Chemically Impacted Far Field in Gravel Sequence; Far Field Gravel Sequence; and Unconfined Far-Field Aquifer. For the Near Field/ Cementitious Secondary Waste zone, K_d value estimates were provided for three temporal environments: young concrete (pH ~ 12.5), moderately aged concrete (pH ~ 10.5), and aged concrete (pH ~ 8.5).

Last et al. (2006) identified best-estimate K_d values and ranges for 12 radionuclides for use in Hanford assessments. K_d values were estimated for six different waste chemistry groups (very acidic; very high salt/very basic; having chelates/high salt; low organic/low salt/near neutral pH; IDF vitrified waste; and IDF cementitious waste) and four different hydrogeologic conditions (the near-field or high impact zone; the far-field or intermediate impact zone with either sand-dominated or gravel-dominated sediment; and the groundwater). Khaleel et al. (2006b) specified a K_d value for uranium of 0.6 based on data from Kaplan and Serne (2000). Cantrell et al. (2007, Appendix B) provided tables of generic Hanford Site-wide K_d ranges by waste chemistry/source area, based on those provided by Last et al. (2006). DOE (2007b) identified the distribution coefficients for 15 radionuclides for both sand-dominated and gravel-dominated sediments, based largely on those reported by Last et al. (2006) as well as a few other references.

Serne (2007) published a compilation of K_d values for agricultural and surface soils for Hanford Site use scenarios (farm, residential, and Columbia River shoreline) that could exist today or potentially exist in the future when portions of the Hanford Site are released for farming, residential, and recreational use after DOE defense waste cleanup activities are completed. Best value and ranges of K_d values were provided and are intended to be used to estimate the fate and transport of contaminants and their availability for plant and animal uptake in selected non-groundwater scenarios included in Hanford Site environmental impact statements, risk assessments, and specific facility performance assessments.

Cantrell et al. (2008) summarized the best-estimate K_d values (as well as their range) for key contaminants at each of the single-shell tank waste management areas. They estimated the K_d values for three different zones depending on the impacts of the waste chemistry (high impact, intermediate impact, no impact) and on the dominant sediment type (sand, silt, or carbonate dominated). Similar to Kaplan and Serne (2000), they recommended different gravel correction factors for high K_d contaminants and low K_d contaminants.

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Appendix B

Hanford-Specific RESRAD Parameter Database

Table B.1. Hanford-Specific Hydrologic Parameters

Stratigraphic Unit	Sediment Class Description	Geographic Area Description	Sediment Class ID	Bulk Density (ρ_b) (g/cm^3)	Bulk Density Source	Total Porosity (p_t) (cm^3/cm^3)	Total Porosity Source	Effective Porosity (p_e) (cm^3/cm^3)	Effective Porosity Source	Field Capacity (θ[q=1.e-8 cm/s]) (cm^3/cm^3)	Field Capacity Source	Saturated Water Content (θ_s) (cm^3/cm^3)	Saturated Water Content Source	Saturated Hydraulic Conductivity (K_s)	Saturated Hydraulic Conductivity Source	“b” Parameter	“b” Parameter Source
Holocene sediments	Backfill	Site-wide	Bf	1.94	Last et al. (2006)	0.21	Last et al. (2009)	0.158	Last et al. (2009)	NA	NA	0.262	Last et al. (2006)	5.98E-04	Last et al. (2006)	NA	NA
Holocene sediments	Backfill	200 East Area, North, B-BX-BY Area	Bf-2ENB									0.2688	Khaleel (2001)	5.60E-04	Khaleel (2001)	NA	NA
Holocene sediments	Backfill	200 East Area, South, BC Crib Area	Bf-2ESB	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Holocene sediments	Backfill	200 East Area, South, IDF Area	Bf-2ESI									NA	NA	NA	NA	NA	NA
Holocene sediments	Backfill	200 East Area, North, C Tank Farm Area	Bf-2ENC	2.13	Khaleel et al. (2006b); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.138	Khaleel et al. (2006b) and Khaleel (2007)	5.60E-04	Khaleel et al. (2006b) and Khaleel (2007)	NA	NA
Holocene sediments	Backfill	200 West Area	Bf-2W	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Holocene sediments	Backfill	200 West Area, South, S-SX Tank Farm Area	Bf-2WSS	2.13	Khaleel et al. (2006a); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.138	Khaleel et al. (2006a) and Khaleel (2007)	5.60E-04	Khaleel et al. (2006a) and Khaleel (2007)	NA	NA
Holocene sediments	Backfill	200 West Area, South	Bf-2WS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Holocene sediments	Backfill	200 West Area, North	Bf-2WN	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Silty sand	Site-wide	Hss	1.61	Last et al. (2006)	0.448	Last et al. (2009)	0.374	Last et al. (2009)	0.175	Last et al. (2009)	0.445	Last et al. (2006)	8.58E-05	Last et al. (2006)	2.63	Last et al. (2009)
Hanford formation	Silty sand	200 East Area, North, B-BX-BY Area	Hss-2ENB									0.4349	Khaleel (2001)	2.40E-04	Khaleel (2001)	NA	NA
Hanford formation	Silty sand	200 East Area, South, BC Crib Area	Hss-2ESB	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Silty sand	200 East Area, South, IDF Area	Hss-2ESI									NA	NA	NA	NA	NA	NA
Hanford formation	Silty sand	200 East Area, North, C Tank Farm Area	Hss-2ENC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Silty sand	200 West Area	Hss-2W	1.67	Last et al. (2006)	0.354	Last et al. (2009)	0.297	Last et al. (2009)	NA	NA	0.398	Last et al. (2006)	1.91E-05	Last et al. (2006)	NA	NA
Hanford formation	Silty sand	200 West Area, South	Hss-2WS	1.58	Last et al. (2006)	0.392	Last et al. (2009)	0.326	Last et al. (2009)	NA	NA	0.347	Last et al. (2006)	2.49E-05	Last et al. (2006)	NA	NA
Hanford formation	Silty sand	200 West Area, South, S-SX Tank Farm Area	Hss-2WSS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Silty sand	200 West Area, North	Hss-2WN	1.8	Last et al. (2006)	0.329	Last et al. (2009)	0.282	Last et al. (2009)	NA	NA	0.351	Last et al. (2006)	6.55E-06	Last et al. (2006)	NA	NA
Hanford formation	Fine sand	Site-wide	Hfs	1.6	Last et al. (2006)	0.406	Last et al. (2009)	0.373	Last et al. (2009)	0.123	Last et al. (2009)	0.379	Last et al. (2006)	3.74E-04	Last et al. (2006)	2.31	Last et al. (2009)
Hanford formation	Fine sand	200 East Area, North, B-BX-BY Area	Hfs-2ENB									0.3819	Khaleel (2001)	9.88E-05	Khaleel (2001)	NA	NA
Hanford formation	Fine sand	200 East Area, South, BC Crib Area	Hfs–2ES	1.65	Last et al. (2006)	0.422	Last et al. (2009)	0.388	NA	NA	NA	0.38	Last et al. (2006)	2.25E-03	Last et al. (2006)	NA	NA

Table B.1. (contd)

Stratigraphic Unit	Sediment Class Description	Geographic Area Description	Sediment Class ID	Bulk Density (ρ_b) (g/cm^3)	Bulk Density Source	Total Porosity (p_t) (cm^3/cm^3)	Total Porosity Source	Effective Porosity (p_e) (cm^3/cm^3)	Effective Porosity Source	Field Capacity (θ[q=1.e-8 cm/s]) (cm^3/cm^3)	Field Capacity Source	Saturated Water Content (θ_s) (cm^3/cm^3)	Saturated Water Content Source	Saturated Hydraulic Conductivity (K_s)	Saturated Hydraulic Conductivity Source	"b" Parameter	"b" Parameter Source
Hanford formation	Fine sand	200 East Area, South, IDF Area	Hfs-2ESI									0.394	Khaleel (2004)	4.15E-03	Khaleel (2004)	NA	NA
Hanford formation	Fine sand	200 East Area, North, C Tank Farm Area	Hf-2ENC	1.76	Khaleel et al. (2006b); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.3819	Khaleel et al. (2006b) and Khaleel (2007)	9.88E-05	Khaleel et al. (2006b) and Khaleel (2007)	NA	NA
Hanford formation	Fine sand	200 West Area	Hfs-2W	1.7	Last et al. (2006)	0.323	Last et al. (2009)	0.279	Last et al. (2009)	NA	NA	0.356	Last et al. (2006)	3.67E-05	Last et al. (2006)	NA	NA
Hanford formation	Fine sand	200 West Area, South	Hfs-2WS	1.72	Last et al. (2006)	0.341	Last et al. (2009)	0.299	Last et al. (2009)	NA	NA	0.347	Last et al. (2006)	1.71E-05	Last et al. (2006)	NA	NA
Hanford formation	Fine sand	200 West Area, South, S-SX Tank Farm Area	Hfs-2WSS	1.76	Khaleel et al. (2006a); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.3819	Khaleel et al. (2006a) and Khaleel (2007)	9.88E-05	Khaleel et al. (2006a) and Khaleel (2007)	NA	NA
Hanford formation	Fine sand	200 West Area, North	Hfs-2WN	1.68	Last et al. (2006)	0.318	Last et al. (2009)	0.277	Last et al. (2009)	NA	NA	0.366	Last et al. (2006)	7.88E-05	Last et al. (2006)	NA	NA
Hanford formation	Coarse sand	Site-wide	Hcs	1.67	Last et al. (2006)	0.386	Last et al. (2009)	0.361	Last et al. (2009)	0.074	Last et al. (2009)	0.349	Last et al. (2006)	2.27E-03	Last et al. (2006)	2.03	Last et al. (2009)
Hanford formation	Coarse sand	200 East Area, North, B-BX-BY Area	Hcs-2ENB									NA	NA	NA	NA	NA	NA
Hanford formation	Coarse sand	200 East Area, South, BC Crib Area	Hcs–2ES	1.67	Last et al. (2006)	0.39	Last et al. (2009)	0.364	Last et al. (2009)	NA	NA	0.357	Last et al. (2006)	5.32E-03	Last et al. (2006)	NA	NA
Hanford formation	Coarse sand	200 East Area, South, IDF Area	Hcs-2ESI									NA	NA	NA	NA	NA	NA
Hanford formation	Coarse sand	200 East Area, North, C Tank Farm Area	Hcs-2ENC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Coarse sand	200 West Area	Hcs-2W	1.65	Last et al. (2006)	0.384	Last et al. (2009)	0.348	Last et al. (2009)	NA	NA	0.318	Last et al. (2006)	1.09E-03	Last et al. (2006)	NA	NA
Hanford formation	Coarse sand	200 West Area, South	Hcs-2WS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Coarse sand	200 West Area, South, S-SX Tank Farm Area	Hcs-2WSS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Coarse sand	200 West Area, North	Hcs-2WN	1.56	Last et al. (2006)	0.41	Last et al. (2009)	0.395	Last et al. (2009)	NA	NA	0.292	Last et al. (2006)	1.49E-03	Last et al. (2006)	NA	NA
Hanford formation	Gravelly sand	Site-wide	Hgs	1.94	Last et al. (2006)	0.28	Last et al. (2009)	0.247	Last et al. (2009)	0.083	Last et al. (2009)	0.238	Last et al. (2006)	6.65E-04	Last et al. (2006)	2.53	Last et al. (2009)
Hanford formation	Gravelly sand	200 East Area, North, B-BX-BY Area	Hgs-2ENB									0.2688	Khaleel (2001)	5.15E-04	Khaleel (2001)	NA	NA
Hanford formation	Gravelly sand	200 East Area, South, BC Crib Area	Hgs-2ESB	NA	NA	0.3	Last et al. (2009)	0.260	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Gravelly sand	200 East Area, South, IDF Area	Hgs-2ESI									NA	NA	NA	NA	NA	NA

Table B.1. (contd)

Stratigraphic Unit	Sediment Class Description	Geographic Area Description	Sediment Class ID	Bulk Density (ρ_b) (g/cm^3)	Bulk Density Source	Total Porosity (p_t) (cm^3/cm^3)	Total Porosity Source	Effective Porosity (p_e) (cm^3/cm^3)	Effective Porosity Source	Field Capacity (θ[q=1.e-8 cm/s]) (cm^3/cm^3)	Field Capacity Source	Saturated Water Content (θ_s) (cm^3/cm^3)	Saturated Water Content Source	Saturated Hydraulic Conductivity (K_s)	Saturated Hydraulic Conductivity Source	"b" Parameter	"b" Parameter Source
Hanford formation	Gravelly sand	200 East Area, North, C Tank Farm Area	Hgs-2ENC	1.94	Khaleel et al. (2006b); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.2688	Khaleel et al. (2006b) and Khaleel (2007)	5.15E-04	Khaleel et al. (2006b) and Khaleel (2007)	NA	NA
Hanford formation	Gravelly sand	200 West Area	Hgs-2W	1.81	Last et al. (2006)	0.335	Last et al. (2009)	0.305	Last et al. (2009)	NA	NA	0.273	Last et al. (2006)	2.35E-04	Last et al. (2006)	NA	NA
Hanford formation	Gravelly sand	200 West Area, South	Hgs-2WS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Gravelly sand	200 West Area, South, S-SX Tank Farm Area	Hgs-2WSS	1.94	Khaleel et al. (2006a); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.2126	Khaleel et al. (2006a) and Khaleel (2007)	2.62E-04	Khaleel et al. (2006a) and Khaleel (2007)	NA	NA
Hanford formation	Gravelly sand	200 West Area, North	Hgs-2WN	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Sandy gravel	Site-wide	Hg	1.93	Last et al. (2006)	0.258	Last et al. (2009)	0.227	Last et al. (2009)	0.061	Last et al. (2009)	0.167	Last et al. (2006)	3.30E-04	Last et al. (2006)	2.96	Last et al. (2009)
Hanford formation	Sandy gravel	200 East Area, North, B-BX-BY Area	Hg-2ENB									0.2126	Khaleel (2001)	2.62E-04	Khaleel (2001)	NA	NA
Hanford formation	Sandy gravel	200 East Area, South, BC Crib Area	Hg-2ESB	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Sandy gravel	200 East Area, South, IDF Area	Hg-2ESI									NA	NA	NA	NA	NA	NA
Hanford formation	Sandy gravel	200 East Area, North, C Tank Farm Area	Hg-2ENC	2.07	Khaleel et al. (2006b); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.2126	Khaleel et al. (2006b) and Khaleel (2007)	2.62E-04	Khaleel et al. (2006b) and Khaleel (2007)	NA	NA
Hanford formation	Sandy gravel	200 West Area	Hg-2W	1.89	Last et al. (2006)	0.235	Last et al. (2009)	0.213	Last et al. (2009)	NA	NA	0.154	Last et al. (2006)	1.48E-03	Last et al. (2006)	NA	NA
Hanford formation	Sandy gravel	200 West Area, South	Hg-2WS	2.09	Last et al. (2006)	0.231	Last et al. (2009)	0.202	NA	NA	NA	0.15	Last et al. (2006)	2.88E-04	Last et al. (2006)	NA	NA
Hanford formation	Sandy gravel	200 West Area, South, S-SX Tank Farm Area	Hg-2WSS	NA	NA	NA	NA	NA	NA	NA	NA	0.2126	Khaleel et al. (2006a) and Khaleel (2007)	2.62E-04	Khaleel et al. (2006a) and Khaleel (2007)	NA	NA
Hanford formation	Sandy Gravel	200 West Area, North	Hg-2WN	1.79	Last et al. (2006)	0.237	Last et al. (2009)	0.218	Last et al. (2009)	NA	NA	0.155	Last et al. (2006)	3.65E-03	Last et al. (2006)	NA	NA
Hanford formation	Gravel	Site-wide	Hrg	1.97	Last et al. (2006)	0.259	Last et al. (2009)	0.239	Last et al. (2009)	0.032	Last et al. (2009)	0.102	Last et al. (2006)	1.46E-03	Last et al. (2006)	2.75	Last et al. (2009)
Hanford formation	Gravel	200 East Area, North, B-BX-BY Area	Hrg-2ENB									NA	NA	NA	NA	NA	NA
Hanford formation	Gravel	200 East Area, South, BC Crib Area	Hrg-2ESB	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Gravel	200 East Area, South, IDF Area	Hrg-2ESI									0.138	Khaleel (2004)	5.60E-04	Khaleel (2004)	NA	NA

Table B.1. (contd)

Stratigraphic Unit	Sediment Class Description	Geographic Area Description	Sediment Class ID	Bulk Density (ρ_b) (g/cm^3)	Bulk Density Source	Total Porosity (p_t) (cm^3/cm^3)	Total Porosity Source	Effective Porosity (p_e) (cm^3/cm^3)	Effective Porosity Source	Field Capacity (θ[q=1.e-8 cm/s]) (cm^3/cm^3)	Field Capacity Source	Saturated Water Content (θ_s) (cm^3/cm^3)	Saturated Water Content Source	Saturated Hydraulic Conductivity (K_s)	Saturated Hydraulic Conductivity Source	"b" Parameter	"b" Parameter Source
Hanford formation	Gravel	200 East Area, North, C Tank Farm Area	Hrg-2ENC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Gravel	200 West Area	Hrg-2W	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Gravel	200 West Area, South	Hrg-2WS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Gravel	200 West Area, South, S-SX Tank Farm Area	Hrg-2WSS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Hanford formation	Gravel	200 West Area, North	Hrg-2WN	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cold Creek Unit	Silt	Site-wide	CCUz	1.68	Last et al. (2006)	0.404	Last et al. (2009)	0.360	Last et al. (2009)	0.134	Last et al. (2009)	0.419	Last et al. (2006)	5.57E-05	Last et al. (2006)	1.77	Last et al. (2009)
Cold Creek Unit	Silt	200 East Area, North, B-BX-BY Area	CCUz-2ENB									NA	NA	NA	NA	NA	NA
Cold Creek Unit	Silt	200 East Area, South, BC Crib Area	CCUz-2ESB	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cold Creek Unit	Silt	200 East Area, South, IDF Area	CCUz-2ESI									NA	NA	NA	NA	NA	NA
Cold Creek Unit	Silt	200 East Area, North, C Tank Farm Area	CCUz-2ENC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cold Creek Unit	Silt	200 West Area	CCUz-2W	1.68	Last et al. (2006)	0.404	Last et al. (2009)	0.360	Last et al. (2009)	NA	NA	0.419	Last et al. (2006)	5.57E-05	Last et al. (2006)	NA	NA
Cold Creek Unit	Silt	200 West Area, South	CCUz-2WS	1.71	Last et al. (2006)	0.355	Last et al. (2009)	0.308	Last et al. (2009)	NA	NA	0.398	Last et al. (2006)	7.27E-06	Last et al. (2006)	NA	NA
Cold Creek Unit	Silt	200 West Area, South, S-SX Tank Farm Area	CCUz-2WSS	1.65	Khaleel et al. (2006a); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.4349	Khaleel et al. (2006a) and Khaleel (2007)	2.40E-04	Khaleel et al. (2006a) and Khaleel (2007)	NA	NA
Cold Creek Unit	Silt	200 West Area, North	CCUz-2WN	1.58	Last et al. (2006)	0.452	Last et al. (2009)	0.420	Last et al. (2009)	NA	NA	0.448	Last et al. (2006)	7.11E-04	Last et al. (2006)	NA	NA
Cold Creek Unit	Caliche	Site-wide	CCUc	1.72	Last et al. (2006)	0.34	Last et al. (2009)	0.288	Last et al. (2009)	0.135	Last et al. (2009)	0.281	Last et al. (2006)	8.48E-04	Last et al. (2006)	3.54	Last et al. (2009)
Cold Creek Unit	Caliche	200 East Area, North, B-BX-BY Area	CCUc-2ENB									NA	NA	NA	NA	NA	NA
Cold Creek Unit	Caliche	200 East Area, South, BC Crib Area	CCUc-2ESB	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cold Creek Unit	Caliche	200 East Area, South, IDF Area	CCUc-2ESI									NA	NA	NA	NA	NA	NA
Cold Creek Unit	Caliche	200 East Area, North, C Tank Farm Area	CCUc-2ENC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cold Creek Unit	Caliche	200 West Area	CCUc-2W	1.71	Last et al. (2006)	0.34	Last et al. (2009)	0.288	Last et al. (2009)	NA	NA	0.281	Last et al. (2006)	5.00E-04	Last et al. (2006)	NA	NA
Cold Creek Unit	Caliche	200 West Area, South	CCUc-2WS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table B.1. (contd)

Stratigraphic Unit	Sediment Class Description	Geographic Area Description	Sediment Class ID	Bulk Density (ρ_b) (g/cm^3)	Bulk Density Source	Total Porosity (p_t) (cm^3/cm^3)	Total Porosity Source	Effective Porosity (p_e) (cm^3/cm^3)	Effective Porosity Source	Field Capacity (θ[q=1.e-8 cm/s]) (cm^3/cm^3)	Field Capacity Source	Saturated Water Content (θ_s) (cm^3/cm^3)	Saturated Water Content Source	Saturated Hydraulic Conductivity (K_s)	Saturated Hydraulic Conductivity Source	"b" Parameter	"b" Parameter Source
Cold Creek Unit	Caliche	200 West Area, South, S-SX Tank Farm Area	CCUc-2WSS	1.65	Khaleel et al. (2006a); Khaleel (2007)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cold Creek Unit	Caliche	200 West Area, North	CCUc-2WN	1.68	Last et al. (2006)	0.352	Last et al. (2009)	0.297	Last et al. (2009)	NA	NA	0.286	Last et al. (2006)	1.03E-03	Last et al. (2006)	NA	NA
Cold Creek Unit	Gravels	Site-wide	CCUg	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cold Creek Unit	Gravels	200 East Area, North, B-BX-BY Area	CCUg-2ENB									NA	NA	NA	NA	NA	NA
Cold Creek Unit	Gravels	200 East Area, South, BC Crib Area	CCUg-2ESB	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cold Creek Unit	Gravels	200 East Area, South, IDF Area	CCUg-2ESI									NA	NA	NA	NA	NA	NA
Cold Creek Unit	Gravels	200 East Area, North, C Tank Farm Area	CCUg-2ENC	2.13	Khaleel et al. (2006b); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.138	Khaleel et al. (2006b) and Khaleel (2007)	5.60E-04	Khaleel et al. (2006b) and Khaleel (2007)	NA	NA
Cold Creek Unit	Gravels	200 West Area	CCUg-2W	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cold Creek Unit	Gravels	200 West Area, South	CCUg-2WS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	v	NA	NA
Cold Creek Unit	Gravels	200 West Area, South, S-SX Tank Farm Area	CCUg-2WSS	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Cold Creek Unit	Gravels	200 West Area, North	CCUg-2WN	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ringold Formation	Gravels	Site-wide	Rg	1.9	Last et al. (2006)	0.293	Last et al. (2009)	0.267	Last et al. (2009)	0.096	Last et al. (2009)	0.177	Last et al. (2006)	4.13E-04	Last et al. (2006)	3.15	Last et al. (2009)
Ringold Formation	Gravels	200 East Area, North, B-BX-BY Area	Rg-2ENB									0.138	Khaleel (2001)	5.60E-04	Khaleel (2001)	NA	NA
Ringold Formation	Gravels	200 East Area, South, BC Crib Area	Rg-2ESB	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Ringold Formation	Gravels	200 East Area, South, IDF Area	Rg-2ESI									NA	NA	NA	NA	NA	NA
Ringold Formation	Gravels	200 East Area, North, C Tank Farm Area	Rg-2ENC	2.13	Khaleel et al. (2006b); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.138	Khaleel et al. (2006b) and Khaleel (2007)	5.60E-04	Khaleel et al. (2006b) and Khaleel (2007)	NA	NA
Ringold Formation	Gravels	200 West Area	Rg-2W	1.84	Last et al. (2006)	0.299	Last et al. (2009)	0.258	Last et al. (2009)	NA	NA	0.297	Last et al. (2006)	1.06E-04	Last et al. (2006)	NA	NA
Ringold Formation	Gravels	200 West Area, South	Rd-2WS	1.82	Last et al. (2006)	0.313	Last et al. (2009)	0.266	Last et al. (2009)	NA	NA	0.315	Last et al. (2006)	7.83E-05	Last et al. (2006)	NA	NA
Ringold Formation	Gravels	200 West Area, South, S-SX Tank Farm Area	Rd-2WSS	2.13	Khaleel et al. (2006a); Khaleel (2007)	NA	NA	NA	NA	NA	NA	0.138	Khaleel et al. (2006a) and Khaleel (2007)	5.60E-04	Khaleel et al. (2006a) and Khaleel (2007)	NA	NA
Ringold Formation	Gravels	200 West Area, North	Rd-2WN	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table B.1. (contd)

Stratigraphic Unit	Sediment Class Description	Geographic Area Description	Sediment Class ID	Bulk Density (ρ_b) (g/cm^3)	Bulk Density Source	Total Porosity (p_t) (cm^3/cm^3)	Total Porosity Source	Effective Porosity (p_e) (cm^3/cm^3)	Effective Porosity Source	Field Capacity (θ[q=1.e-8 cm/s]) (cm^3/cm^3)	Field Capacity Source	Saturated Water Content (θ_s) (cm^3/cm^3)	Saturated Water Content Source	Saturated Hydraulic Conductivity (K_s)	Saturated Hydraulic Conductivity Source	"b" Parameter	"b" Parameter Source

NA = Not available.

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Table B.2. Hanford-Specific Geologic Parameters

	Uncontaminated Sediments				**Sediments Impacted by Very Acid Waste**				**Sediments Impacted by Very High Salt/ Very Basic Waste**				**Sediments Impacted by Waste Containing Chelates and/or High Salts**				**Vadose Zone Sediments Impacted by IDF Vitrified Waste**				**Sediments Impacted by IDF Cementitious Waste**			
	Gravel-Dominated (>60% gravel)	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**	**Gravel-Dominated (>60% gravel)**	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**	**Gravel-Dominated (>60% gravel)**	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**	**Gravel-Dominated (>60% gravel)**	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**	**Gravel-Dominated (>60% gravel)**	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**	**Gravel-Dominated (>60% gravel)**	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**
Chemicals																								
F-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cr(VI)	0.32	0.5	0.7	1	0	0	0	0	0.02	0.03	0.04	0.05	0.32	0.5	0.7	1	0	0	0	0	0	0	0	0
Hg(II)	0	0	0	0	4.8	6.2	7.7	10	0	0	0	0	0	0	0	0	0	0	0	0	48	62	77	100
NO_3-, NO_2-	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pb(II)	1.4	1.9	2.3	3	4.8	6.2	7.7	10	1.4	1.9	2.3	3	1.4	1.9	2.3	3	4.8	6.2	7.7	10	2400	3100	3800	5000
U(VI) – all isotopes	0.06	0.1	0.14	0.2	0.06	0.1	0.14	0.2	0.26	0.4	0.56	0.8	0.06	0.1	0.14	0.2	0.06	0.1	0.14	0.2	32	50	70	100
Radionuclides																								
^{241}Am(III)	9.6	12	15	20	9.6	12	15	20	96	120	150	200	9.6	12	15	20	2.4	3.1	3.9	5	240	310	380	500
^{14}C	0	0	0	0	0	0	0	0	32	50	70	100	0	0	0	0	0	0	0	0	0	0	0	0
^{60}Co(II,III)	0	0	0	0	0.48	0.62	0.77	1	0	0	0	0	0	0	0	0	0.1	0.12	0.15	0.2	48	62	77	100
^{137}Cs	4.8	6.2	7.7	10	480	620	770	1000	4.8	6.2	7.7	10	4.8	6.2	7.7	10	0.72	0.92	1.15	1.5	14	18	23	30
Eu(III) – all isotopes	9.6	12	15	20	9.6	12	15	20	96	120	150	200	9.6	12	15	20	2.4	3.1	3.9	5	240	310	380	500
^{3}H	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
^{129}I – as iodide	0.06	0.1	0.14	0.2	1.3	2	2.8	4	0.01	0.01	0.01	0.02	0.06	0.1	0.14	0.2	0.03	0.05	0.07	0.1	0.65	1	1.4	2
^{63}Ni	0	0	0	0	4.8	6.2	7.7	10	0	0	0	0	0	0	0	0	0.1	0.12	0.15	0.2	48	62	77	100
^{237}Np(V)	0.65	1	1.4	2	0	0	0	0	0	0	0	0	0.65	1	1.4	2	0.06	0.1	0.14	0.2	65	100	140	200
Pu – all isotopes	4.8	6.2	7.7	10	0.19	0.25	0.31	0.4	96	120	150	200	4.8	6.2	7.7	10	4.8	6.2	7.7	10	240	310	380	500
^{226}Ra(II)	0.48	0.62	0.77	1	4.8	6.2	7.7	10	11	14	17	22	0.48	0.62	0.77	1	7.2	9.2	12	15	4.8	6.2	7.7	10
^{79}Se(VI,IV)	0	0	0	0	1.6	2.5	3.5	5	0	0	0	0	0	0	0	0	0.32	0.5	0.7	1	0.32	0.5	0.7	1
^{126}Sn(IV)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.1	0.12	0.15	0.2	48	62	77	100
^{90}Sr	0.48	0.62	0.77	1	4.8	6.2	7.7	10	11	14	17	22	0.48	0.62	0.77	1	7.2	9.2	12	15	4.8	6.2	7.7	10
^{99}Tc(VII)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Gravel Correction Factors

	Gravel-Dominated (>60% gravel)	**Sandy Gravel**	**Gravelly Sand**	**Sand-Dominated**
Soil class	Hrg	Hg, Rg, CCUg	Bf, Hgs	Hss, Hfs, Hcs
Est. wt% Gravel	67.60%	50.00%	30.00%	2.00%
High K_d (>10) Correction factor	0.48	0.62	0.77	NA
Low K_d (<10) Correction factor	0.32	0.5	0.7	NA

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