Sandia National Laboratories

Scientific Analysis/Calculation Administrative Change Notice

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6. Approvals:

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xi, xiii, 1-1, 1-2, 3-1, 4-1, 4-2, 4-3, 4-4, 4-5, 4-5a, 5-2, 5-4, 6-6, 6-7, 6-8, 6-19, 6-21, 6-25, 6-27, 6-29, 6-29a, 6-33, 6-35, 6-36, 6-55, 6-58, 6-59, 6-60, 6-61, 6-67, 6-72, 6-76, 6-77, 6-78, 7-2, 7-3, 7-4, 7-4a, 8-2, 8-6, 8-7, 8-8, B-1, C-1	Editorial changes to address DOE comments and reflect changes to Lead Lab procedures effective October 2, 2006 following transition from BSC procedures. This ACN incorporates data used as direct input from DTN: MO0608SPASDFIM.006 [DIRS 178082] that supersedes DTN: MO0606SPASDFIM.005 [DIRS 177030] used in REV00 of this document. Although the DTN cited as direct input has changed, the source files used in the analysis (named revised soil depth file.csv and revised soil depth file.txt) are identical in both versions of the DTN. A management evaluation of compliance to SCI-PRO-005 determined the changes to the data used to create the soils units map (Figures 6-1 and 6-10) had no effect on the methods employed, direct input sources, or product output and results. Therefore, a complete revision to this document is unnecessary.

TABLES

Page

ACRONYMS

DOE	U.S. Department of Energy
DTN	Data Tracking Number
ED	Euclidean Distance
FC	Field Capacity
GEL	Westinghouse Hanford Company Geotechnical Laboratory
GIS	Geographic Information Systems
MRC	Moisture Retention Curve
NRCS	Natural Resource Conservation Service (USDA)
PDC	Primary Drainage Curve
PNNL	Pacific Northwest National Laboratory
PTF	Pedotransfer Function
PWP	Permanent Wilting Point
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WHC	Water Holding Capacity
YMP	Yucca Mountain Project

1. PURPOSE

This analysis documents the development of site-specific soil units, hydraulic parameter values for soil units, associated descriptive statistics, and uncertainties for Yucca Mountain. This work supports the U.S. Department of Energy (DOE) goal to provide credible, traceable, and transparent site-specific infiltration estimates for Yucca Mountain, and establish confidence in infiltration modeling in preparation for license application submittal.

This analysis has been developed in accordance with *Technical Work Plan for: Infiltration Model Assessment, Revision, and Analyses of Downstream Impacts* (BSC 2006 [DIRS 177492]). The work scope of this analysis is limited to an evaluation of the technical adequacy of the soil unit groups and their delineation in the Yucca Mountain area, and the associated hydraulic parameter values and statistics for use in infiltration modeling (BSC 2006 [DIRS 177492], Sections 1.1.2 and 1.1.3). Output from this analysis provides verification of the soil units delineated in the infiltration model (BSC 2004 [DIRS 170007]). In addition, output from this analysis provides new soil unit hydraulic parameters and descriptive statistics that are both traceable and transparent to support the development of a replacement infiltration model (BSC 2006 [DIRS 177492], Section 1.1.3).

This analysis deviates from the technical work plan (BSC 2006 [DIRS 177492], Section 9) in the use of the software code ARCINFO V.7.2.1. STN: 10033-7.2.1-00 [DIRS 157019]. ARCINFO was used in conjunction with ArcGIS Desktop V9.1. STN: 11205-9.1-00 [DIRS 176015] to process and display geospatial data associated with soil unit distributions from existing data and to support the calculation of percent area that each soil unit covers in the infiltration model area.

Soil units, soil unit hydraulic parameter values, descriptive statistics, and uncertainties developed herein describe the spatial variability of the surficial soil parameters that can affect infiltration. The output of this analysis is intended to be used as input to the simulation of net infiltration for the Yucca Mountain area.

The technical work plan (BSC 2006 [DIRS 177492]) cites procedures that were in effect at the time the work described in this report was planned and approved. Following the transition of the Science Work Scope from Bechtel SAIC to Sandia National Laboratories, new procedures were issued and became effective on or after October 2, 2006. This report has been revised to reflect the change to Sandia National Laboratories governing procedures (Table 1-1), that directly relate to this ACN. BSC procedures that govern some aspects of the scientific analysis, technical inputs and outputs, and control of software are not impacted by this ACN have not been updated. Before October 2, 2006, the governing procedure used for this report was the BSC procedure *Scientific Analyses*, LP-SIII.9Q-BSC. This procedure has been superseded by the Sandia procedure *Scientific Analyses and Calculations*, SCI-PRO-005. A review of the revised procedure found only minor differences. The only difference requiring action regarding this ACN was to identify the importance of the report, as stated in SCI-PRO-005 under requirements for the Purpose section. A statement is included in the first paragraph of this section.

In addition to the changes noted with regard to the governing procedure for this analysis report (*Scientific Analyses and Calculations*, SCI-PRO-005), the following procedures implemented in the course of performing this ACN have changed from those identified in the governing TWP

(BSC 2006 [DIRS 177492]). For this ACN, the Sandia procedures listed in Table 1-1 have been implemented:

Table 1-1. Crosswalk for Procedures Implemented in the Current ACN

Procedure/Title	BSC Procedure ID Identified in BSC 2006 [DIRS 177492]	Sandia Procedure ID
Records Management	AP-17.1Q	DM-PRO-002
Control of the Electronic Management of Information	IT-PRO-0009	IM-PRO-002
Managing Technical Product Inputs	PA-PRO-0301	SCI-PRO-004
Scientific Analyses and Calculations[1]	LP-SIII.9Q-BSC	SCI-PRO-005

[1]NOTE: For BSC procedure LP-SIII.9Q-BSC, the title is "*Scientific Analyses*."

Some aspects of the implementation of the procedures in Table 1-1 were performed using the BSC procedures before October 2 2006, but were not revised for the purposes of this ACN. Furthermore, the BSC procedures identified in Table 1-2 were implemented in the report before transition but were not required for the development of the ACN. There are no impacts of these procedure changes on this analysis report.

Table 1-2. Crosswalk for Procedures not Implemented in the Current ACN but used in Developing this Analysis Report

Procedure/Title	BSC Procedure ID Identified in BSC 2006 [DIRS 177492]	Sandia Procedure ID (After Transition)
Submittal and Incorporation of Data to the Technical Data Management System	AP-SIII.3Q	TST-PRO-001
Software Management	IT-PRO-0011	IM-PRO-003
Qualification of Unqualified Data	LP-SIII.2Q-BSC	SCI-PRO-001
Document Review	PA-PRO-0601	SCI-PRO-003

3. USE OF SOFTWARE

Table 3-1 lists the controlled and baselined software used in the development of this analysis.

Table 3-1. Computer Software

Software Title and Version (V)	Software Tracking Number	Code Usage and Limitations	Computer Platform, Operating System
ARCINFO V.7.2.1 [DIRS 157019]	10033-7.2.1-00	ARCINFO was used to calculate the number of cells associated with each soil type	SGI computer with IRIX 6.5
ArcGIS Desktop V9.1 [DIRS 176015]	11205-9.1.00	ArcGIS Desktop was used to plot the soil zone map and the soil sample locations	IBM PC-compatible platform with Windows® XP
JMP® Version 5, Release 5.1 (JMP 2002 [DIRS 171549])	NA	Perform statistical analysis hydraulic parameter data	IBM PC-compatible platform with Windows® 2000

NA = not applicable.

ARCINFO and ArcGIS Desktop were selected for use because they are the standard Geographic Information Systems (GIS) software used by the YMP, they use widely accepted standard GIS protocol used by the general scientific community, and they have the required capabilities to read and transform information in digital source files into the file format required for use in an infiltration model. The application of the software is appropriate for this analysis and is consistent with the intended use of the software.

The software was obtained in accordance with IT-PRO-0011, *Software Management*. The range of use for ArcGIS Desktop and ARCINFO is limited to the input and output of digital data in accordance with *Requirements Document for: ArcGIS Desktop 9.1* (DOE 2005 [DIRS 176462], Sections 2.3 and 2.5) and *Requirements Document for Arc/Info Version 7.2.1.* (CRWMS M&O 2000 [DIRS 176460], Sections 2, 3, 4, 5, and 9), respectively. The software codes were used only within the range of their validation as specified in software qualification documentation in accordance with IT-PRO-0011.

The standard functions of Microsoft® Excel® 2000, 9.0.6926 SP-3, as well as those of JMP® which are exempt commercial off-the-shelf software per IT-PRO-0011, Sections 1.4 and 1.4.6, are also used in this analysis. Excel® is used in Section 6 to calculate the area and percent that each soil covers in the area of interest, the soil hydraulic parameter descriptive statistics for each of the soil units, and the moisture retention curves using the van Genuchten equation (van Genuchten 1980 [DIRS 100610], Equation 3). Additionally, Excel® is used to manage, process, and summarize soil unit matching and tabulation of the results. JMP® is used in Section 6 and in Appendix D to plot histograms of the hydraulic parameter data and support statistical analysis of the data. Non-Q DTNs: MO0608SPAPEDOT.000 and MO0608SPANYECT.000 were prepared with the commercially available non-Q code ROSETTA (Schaap et al. 1998 [DIRS 177199]) under the guidance of *Technical Work Plan for: Infiltration Model Assessment, Revision, and Analyses of Downstream Impacts* (BSC 2006 [DIRS 177492], Sections 1.1.6, 4.2, and 8.2) and under the requirements of *Augmented Quality Assurance Program* (DOE 2006 [DIRS 177173]). The data developed with this commercially

4. INPUTS

4.1 DIRECT INPUTS

This analysis uses available data from the Technical Data Management System for verification of soil unit grouping, areal distribution, and soil grain-size distribution from laboratory analyses of samples. A collection of soil sample grain-size distribution and hydraulic parameter values developed from laboratory testing of soil samples from the DOE Hanford Site in Washington is also used as direct input. The input parameters used in this analysis and their associated sources are listed in Table 4-1. The appropriateness of these inputs for soil zone verification and soil sample hydraulic parameter calculations is discussed in Sections 4.1.1 to 4.1.4.

Table 4-1. Direct Inputs

Input Data Description	Parameter	Source
Section 6.2 Development of Representative Soil Units		
Soil units (Table 6-2)	Description of the grouping of mapped surficial deposits into soil units used in the infiltration model (BSC 2004 [DIRS 170007])	DTN: GS960408312212.005 [DIRS 146299]
Map area (Table 6-3)	Distribution of soil units in the area of interest	DTN: MO0608SPASDFIM.006 [DIRS 178082]
Section 6.3 Development of Soil Hydraulic Parameters		
Surficial map unit, soil sample texture, and rock fragment content	Sand, silt, and clay content (fraction) Rock fragment content (fraction) Surficial soil unit designation	DTN: MO0512SPASURFM.002 [DIRS 175955]
		DTN: GS031208312211.001 [DIRS 171543]
Soil sample texture for Soil Unit 6 (sand ramp sand)	Sand and silt plus clay content (fraction)	DTN: GS000383351030.001 [DIRS 148444]
Rock fragment content for Soil Unit 6	Rock fragment content (fraction)	DTN: GS940108315142.004 [DIRS 160344], p. 11 of 13
Analogous soil hydraulic parameter values	Saturated hydraulic conductivity (cm/sec)	Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B
	Moisture retention curve fitting parameters α (1/cm) and n (dimensionless)	
	Saturated moisture content, θ_s, and residual moisture content, θ_r (percent)	
	Field capacity, moisture content at −0.33 bar (−336.6 cm) and −0.10 (−102 cm) (percent)	
	Permanent Wilting point, moisture content at −60 bar (−62,200 cm) (percent)	

DTN = data tracking number.

4.1.1 Definition of Soil Units for Use in Modeling of Net Infiltration

DTN: GS960408312212.005 [DIRS 146299] defines soil units of distinct soil characteristics that could affect infiltration of precipitation into the ground. This DTN is appropriate to use because it incorporates information obtained from the mapping of surficial map units in the infiltration model area, and it groups map units having like characteristics that could affect near-surface permeability and vegetation cover into a smaller number of units, for ease of modeling (Section 6.2). The map coverage of this DTN is comparable to the area that would be included in the simulation of net infiltration for Yucca Mountain.

The grouping of surficial map units into soil units to be used in an infiltration model is portrayed as GIS output in DTN: MO0608SPASDFIM.006 [DIRS 178082]. The use of this DTN file facilitates the calculation of the percentage of total area of the model regime for each soil unit, because the GIS software can report the number of cells for each unit, as well as the total number of grid cells for the entire area of the map.

4.1.2 Surface Soil Taxonomic Unit, Soil Sample Texture, and Fraction of Rock Fragments

Qualified data and sources for taxonomic unit, textural, and rock fragment content are DTNs: GS000383351030.001 [DIRS 148444], GS031208312211.001 [DIRS 171543], and MO0512SPASURFM.002 [DIRS 175955], which contain site-specific data for the soils in the Yucca Mountain area. In particular, DTNs: GS031208312211.001 [DIRS 171543] and MO0512SPASURFM.002 [DIRS 175955] contain grain-size distributions that were determined by laboratory analyses of samples collected to characterize Soil Units 1 through 5, 7, and 9 (Section 6.2), while grain-size data for the sand ramp sand in DTN: GS000383351030.001 [DIRS 148444] is representative of Soil Unit 6. The description of eolian deposits in DTN: GS940108315142.004 [DIRS 160344], p. 11 of 13, includes a discussion of the range of rock fragment content in Soil Unit 6 (Assumption 5.1).

4.1.3 Analogous Soil Hydraulic Parameter Values

A properties report by Khaleel and Freeman (1995 [DIRS 175734]) includes a database of soil hydraulic parameters based on laboratory testing of soil samples collected from Hanford Site, which is a DOE facility located in the arid Pasco Basin in eastern Washington. The properties report (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) uses grain-size distribution, moisture retention, and saturated hydraulic conductivity from the laboratory analysis of 183 soil samples to develop and provide the following hydraulic parameters values: residual saturation (θ_r), saturation (θ_s), saturated hydraulic conductivity (K_{sat}), and the moisture-retention curve-fitting parameters, α and n. The properties report also provides moisture-retention curves developed by fitting the curves to the data using *The RETC Code for Quantifying the Hydraulic Functions of Unsaturated Soils* (van Genuchten et al. 1991 [DIRS 108810]). These curves were used to estimate the field capacity (FC) and permanent wilting point (PWP). Field capacity is defined as the soil moisture content at −0.33 bar (−336.6 cm water) and at −0.10 bar (−102 cm water). Permanent wilting point is defined as the soil moisture content at −60 bar (−61,200 cm water).

Hydraulic properties are developed by matching the soil texture of Yucca Mountain soil samples to the soil texture of samples cataloged in the properties report (Khaleel and Freeman 1995 [DIRS 175734]). This is an accepted approach previously used in a DOE tank farm evaluation (JE 1999 [DIRS 176154]), Section B.1.1.2). A similar concept is incorporated into the ROSETTA program model (Schaap et al. 2001 [DIRS 176006], pp. 163 to 176) into which are input soil texture information, such as fraction of sand, silt, and clay. The program will match grain size information to a reference data set that includes hydraulic parameter values.

Corroboration of developed data (Khaleel and Freeman (1995 [DIRS 175734], Appendices A and B) is provided in Section 6.4.5.

The following factors are considered to evaluate developed data (Khaleel and Freeman (1995 [DIRS 175734], Appendices A and B) regarding their suitability for intended use in this Scientific Analysis (LP-SIII.2Q-BSC and SCI-PRO-001, attachments 3 and 4, Method 5: Technical Assessment):

- Extent to which the data demonstrate properties of interest
- Prior uses of the data.
- Reliability of the data source
- Qualification of personnel or organizations generating the data

The justification for use of Hanford site to provide analogous data for the Yucca Mountain site, based on the factors outlined above, is documented below (LP-SIII.9Q-BSC, section 5.2.1(m); SCI-PRO-005, Section 6.2.1 (M)).

Extent to which the data demonstrate the properties of interest: Data provided in the properties report (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) include saturated hydraulic conductivity, soil moisture at a range of matric potential, and moisture retention curve fitting parameters that would be used as input to several infiltration modeling approaches including the one developed for Yucca Mountain. These data are developed from soil and sediment samples collected at Hanford where soils have developed under arid climatic conditions similar to that of Yucca Mountain. The average annual precipitation at Hanford is about 17.3 cm/yr (DOE 2001 [DIRS 177079], Section 3.2) compared to about 12.5 cm/yr for Yucca Mountain (BSC 2004 [DIRS 169734], Section 3.4.2).

Hanford sediments have organic carbon content below 0.5 wt% (Truex et al. 2001 [DIRS 177078], Section 2.3.1.2). Organic carbon content in agricultural areas of Nye County range from about 0.006% to 0.70% (USDA 2006 [DIRS 176439]). Soil textural information provided in the properties report (Khaleel and Freeman 1995 [DIRS 175734], Appendix A) is directly comparable to soils information in DTNs: MO0512SPASURFM.002 [DIRS 175955], GS031208312211.001 [DIRS 171543], and GS000383351030.001 [DIRS 148444].

The soil depositional processes at Yucca Mountain compared to those at Hanford include some differences, which can contribute to differences in grain shape and soil structure. Large-scale fluvial processes dominate Hanford soil and sediments resulting in more-rounded particles and single-grain structure. Small-scale fluvial processes and eolian (Soil Unit 6) are the dominant processes at Yucca Mountain, resulting in less-rounded particles with more angular fragments. Soils of fluvial origin associated with Soil Units 1 through 4 (stream and alluvial fan material) cover over 40% of the infiltration model area. There is an eolian component that has accumulated on these surfaces through time, which is concentrated in the upper 0.5 to 1 m of the soil profile. Deposits representing eolian source material are mapped over only 4.8% of the area (Soil Unit 6). The dominant surficial deposit (54% of the model area; Soil Units 5, 7, and 9) is colluvium. The colluvium consists of rock fragments of parent material that have been separated from the underlying intact bedrock through weathering processes. Colluvium, however, by definition, does not remain in situ, but moves or has moved, or both, downslope through gravitational processes. The fine-grained component of colluvial soils is interpreted to be due to the influx of eolian material.

There are depositional mode differences between the YMP soils and Hanford soils and sediments; the differences in the associated hydraulic parameters, however, are not quantified because there are no site-specific hydraulic data for Yucca Mountain. Such differences contribute to an overall uncertainty, captured by the development of descriptive statistics for each hydraulic parameter that includes the parameter mean and standard deviations (Section 6.3).

Prior uses of the data: Similar applications of data (Khaleel and Freeman 1995 [DIRS 175734]) include the use of hydraulic parameter values extracted from data for the vadose zone flow and transport modeling by Kincaid et al. (1998 [DIRS 176155], Section 4.1.2.1.2 and Table 4.7). Kincaid et al. (1998 [DIRS 176155]) were prepared to provide an estimate of the cumulative radiological impacts of waste and disposal actions at Hanford. Soil hydraulic parameter data (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) were used as direct input into vadose zone flow and transport models that were integral to developing cumulative impacts (Kincaid et al. 1998 [DIRS 176155], Section 4.1.2.1.2 and Table 4.7).

The tank farm evaluation (JE 1999 [DIRS 176154]) was prepared by the DOE to develop methodologies and to identify data needs required for supporting tank waste retrieval and closure decisions. Underlying calculations used to develop the retrieval and closure methodologies include vadose zone flow and contaminant transport. A soil texture matching approach (JE 1999 [DIRS 176154]), Section B.1.1.2) combined with data presented in the properties report (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) were used to develop soil hydraulic parameters for direct input into vadose zone flow and contaminant transport models (JE 1999 [DIRS 176154], Table B.1.1).

Reliability of the data source: Hanford soil samples were tested in the Westinghouse Hanford Company Geotechnical Engineering Laboratory, a facility owned and operated by the DOE, and the properties report (Khaleel and Freeman 1995 [DIRS 175734]) was peer reviewed by Dr. Rien van Genuchten of the U.S. Salinity Laboratory at Riverside, CA, and by Mark Rockhold of the Pacific Northwest National Laboratory at Richland, WA. Dr. van Genuchten is a soil physicist and research leader at the George E. Brown, Jr., Salinity Laboratory of the USDA, Agricultural Research Service in Riverside, CA. He is also an adjunct full professor of soil physics in the Department of Environmental Sciences of the University of California, Riverside. Dr. van Genuchten's experience includes over 30 years of research since receiving his PhD in 1975 from New Mexico State University; his major professor was Dr. Peter Wierenga. Dr. van Genuchten has authored or coauthored approximately 300 research publications, including two books of which one is in Japanese, and five edited texts. Dr. Rockhold is a staff scientist with Pacific Northwest National Laboratory at Richland, WA. He is an experienced soil scientist with site-specific knowledge of the Hanford environment.

Qualification of personnel or organizations generating the data: Dr. Raziuddin Khaleel has over 30 years of experience in vadose zone and groundwater hydrology and numerical simulations of subsurface flow and transport. He was a key contributor to Hanford solid waste performance assessments and the immobilized low-activity waste performance assessment, particularly in the area of conceptual model development and direction of modeling. He also served as adjunct faculty for the Civil and Environmental Engineering Department of Washington State University Tri-Cities Campus in Richland, WA. He earned a BS in civil engineering from Bangladesh University of Engineering and Technology in 1966, an MS in water science and engineering from Asian University of Technology in Thailand in 1970, and a PhD in soil and water engineering from Texas A&M University in 1977. Eugene Freeman is the second author on the paper and is a qualified analyst. Mr. Freeman holds an MS in hydrology from University of Idaho (1995), a BS in geology from Montana State University (1986), and is a licensed professional geologist and hydrogeologist in Washington.

4.2 CRITERIA

An infiltration model is one component of the total system performance assessment of Yucca Mountain. General requirements to be satisfied by the total system performance assessment are stated in 10 CFR 63.114 [DIRS 176544]. Acceptance criteria used by the U.S. Nuclear Regulatory Commission to determine whether the technical requirements of 10 CFR 63.114(a) to (c) and (e) to (g) [DIRS 176544] have been met, with regard to the adequacy of an infiltration model, are listed in NUREG-1804 (NRC 2003 [DIRS 163274], Section 2.2.1.3.5.3).

Acceptance criteria relating to the climate and net infiltration model abstraction that are applicable to soil data input to the infiltration model are (NRC 2003 [DIRS 163274], Section 2.2.1.3.5.3):

- Acceptance Criterion 1: *System Description and Model Integration are Adequate*

  The aspects of geology, hydrology, geochemistry, physical phenomena, and couplings, that may affect climate and net infiltration, are adequately considered. Conditions and assumptions in the abstraction of climate and net infiltration are readily identified and consistent with the body of data presented in the description.

- Acceptance Criterion 2: Data are Sufficient for Model Justification

  Climatological and hydrological values used in the license application (e.g., time of onset of climate change, mean annual temperature, mean annual precipitation, mean annual net infiltration, etc.) are adequately justified. Adequate descriptions of how the data were used, interpreted, and appropriately synthesized into the parameters are provided.

  Estimates of present-day net infiltration using mathematical models at appropriate time and space scales are reasonably verified with site-specific climatic, surface, and subsurface information.

  The effects of fracture properties, fracture distributions, matrix properties, heterogeneities, time-varying boundary conditions, evapotranspiration, depth of soil cover, and surface-water runoff and run-on are considered, such that net infiltration is not underestimated.

Laboratory data provide a measure of K_{sat} for the Stage IV soils and, thus, also provide a bounding value for this parameter in soils having less well-developed carbonate soils. Measurement results of fracture-filling caliche are reported in DTN: GS950708312211.003 [DIRS 146873], Table S98356_004. Saturated hydraulic conductivity was measured on 15 subsamples from five samples of fracture-filling material. The caliche in the fractures is formed by precipitation of minerals from water on the fracture walls as it evaporates. As a result, it is vertically "layered" and measurements are reported for samples collected both parallel to and perpendicular to the layers. The eleven measurements that are in the perpendicular direction are considered representative of laminar Stage IV carbonate soil. These measurements have a geometric mean of 1.09E-06 cm/sec, which is approximately two orders of magnitude lower than the values derived for the soil units in Section 6.3. Saturated hydraulic conductivity values for soils exhibiting Stage I and Stage II carbonate soils would fall between the value allocated to Stage IV soils and those calculated for soils without considering carbonate content (Section 6.3), meaning that the values would be lower than the calculated values, but within two orders of magnitude.

Where used: This assumption is applied to the development of hydraulic parameters for the soil units of the infiltration model area (Section 6.3). The qualitative field observations of carbonate content are compared against laboratory measurements (Section 6.4.1) in assessing the contribution of this assumption to the uncertainty in results.

5.3 FIELD CAPACITY

Assumption: It is assumed that FC is the soil moisture content at which internal drainage ceases based on correlation to matric potentials of −0.33 bar and −0.10 bar.

Basis: Field capacity has been defined as the soil moisture content at which internal drainage ceases based on observations that the rate of flow and water-content changes decrease with time after a precipitation or irrigation event (Hillel 1980 [DIRS 100583], p. 67). This concept, however, was recognized as arbitrary and is not an intrinsic soil property independent of the way it is measured (Hillel 1980 [DIRS 100583], p. 68). This concept is most tenable on coarse-textured soils in which internal drainage is initially most rapid but soon slows down owing to the relatively steep decrease of hydraulic conductivity with increased matric suction (Hillel 1980 [DIRS 100583], p. 68). Although matric potentials of −0.33 bar or −0.10 bar have been used to correlate measurements of soil moisture storage in the field, these criteria do not apply universally to all soils and all conditions (Hillel 1980 [DIRS 100583], p. 70). An alternative approach from NUREG/CR-6565 (Meyer et al. 1997 [DIRS 176004], p. 6) using arguments by Hillel (1980 [DIRS 100583], pp. 67 to 72) defines FC as the drainage rate considered negligible, which is a function of the intended application. NUREG/CR-6565 (Meyer et al. 1997 [DIRS 176004], p. 6) suggests using an unsaturated hydraulic conductivity equal to 10^{-8} cm/sec. The weakness inherent with this approach is determining the definition of negligible flux.

The soil moisture content corresponding to −60 bar matric potential is more appropriate for the Yucca Mountain infiltration area because of the indigenous plant community. The −60 bar matric potential is consistent with the lower limits of soil moisture extraction determined for several Mojave Desert shrubs that can survive soil water potentials as low as −50 to −100 bar (Bamburg et al. 1975 [DIRS 127392], Figures 1 and 2; Hamerlynck et al. 2000 [DIRS 177022], Figure 3; Hamerlynck et al. 2002 [DIRS 177046], Figure 6; Odening et al. 1974 [DIRS 177026], pp. 1089 to 1090; Smith et al. 1997 [DIRS 103636], pp. 95, 110, 115, and 116).

Where used: This assumption is applied to the development of PWP and WHC for the soil units of the infiltration model area (Section 6.3).

Table 6-2. Soil Units Combined from Mapped Surficial Units

Soil Unit[a]	Surficial Map Unit[a]	Type of Deposit[b]	Soil Taxonomic Name[a]
1	0, 1[c], 1 to 3, 2[c], Tgp	Fluvial	Typic Argidurids
2	3[c], 3f, 3 to 4, 4[c], 4f, 4s, 4/1, 4s-5s, 3-5	Fluvial	Typic Haplocalcids
3	5[c], 5f, 5s, 5/1, 5 to 6, 5f to 6f, 6[c], 6f, 5[c] to 7[c]	Fluvial	Typic Haplocambids
4	7[c], 7f, 6 to 7, 6f to 7f	Fluvial	Typic Torriorthents
5	cu[c], cs	Colluvium	Lithic Haplocambids
6	e, eo, ey, 1/eo, 3/eo, 1/e, 3/e, cf/e	Eolian	Typic Torripsamments
7	rc[c]	Colluvium	Lithic Haplargids
8	r	Bedrock	Rock
9	cf[c]	Colluvium	Typic Calciargids
10	d	Disturbed	Disturbed Ground

[a] DTN: GS960408312212.005 [DIRS 146299], Data Summary Sheet.

[b] Surficial Map Unit 7 is the equivalent to unit Qa7 by Keefer et al.(2004 [DIRS 173899], Chapter 2); similarly, Surficial Map Unit 6 = Qa6, Surficial Map Unit 5 = Qa5, Surficial Map Unit 4 = Qa4, Surficial Map Unit 3 = Qa3, Surficial Map Unit 2 = Qa2, Surficial Map Unit 1 = Qa1, and Surficial Map Unit 0 = QT0.

[c] Surficial map units for which laboratory data are available.

Field mapping of surficial deposits uses the extent of soil development, geomorphic character, and topographic position of surficial deposits as primary criteria for defining map units, as these features provide relative ages of deposits. These field observations were summarized by Lundstrom et al. (1995 [DIRS 104657]). Individual map descriptions from DTNs: GS940108315142.004 [DIRS 160344], GS940108315142.005 [DIRS 160345], GS940708315142.008 [DIRS 160346], and GS950408315142.004 [DIRS 160347] were combined into one set of descriptions for mapped surficial deposits (Keefer et al. 2004 [DIRS 173899], Chapter 2; Swan et al. 2001 [DIRS 158784], pp. 8 to 21). Laboratory analyses of samples, representing the different surficial map units, were evaluated (Lundstrom et al. 1995 [DIRS 104657]) to further characterize and differentiate the units.

The primary use of the surficial deposits mapping for the YMP has been in the assessment of seismic risk from earthquake faults, where the geologic age of a deposit that is or is not offset by a fault is important. Laboratory analyses conducted on samples collected from the deposits of varying field-interpreted ages were used to further characterize the deposits and to support the age assignments. These empirical data represent the bulk of the information that was available for the analyses for developing hydraulic parameters (Section 6.3). The collection of these data focused on the fluvial deposits of Surficial Map Units 1 to 7 (Soil Units 1 to 4), as they are commonly comprised of stratigraphically distinct horizons useful for interpreting Quaternary faulting history.

6.2.2 Definition of Soil Units for Infiltration Modeling

The geographical extent of the 10 soil units (Table 6-2) is shown in Figure 6-1 (the large map; see inset for detailed soil distribution in the location where most of the data were collected), which is reproduced from DTN: MO0608SPASDFIM.006 [DIRS 178082]. The cumulative extent of each map unit was calculated using DTN: MO0608SPASDFIM.006 [DIRS 178082] and ARCINFO (Table 6-3).

Distinguishing characteristics of the surficial map units that lead to the grouping of these units into soil units for infiltration modeling are summarized in Table 6-4. Table 6-4 also provides the correlation of mapped surficial deposits to soil units in DTN: GS960408312212.005 [DIRS 146299]. Table 6-4 is organized by type of deposit (fluvial, eolian, or colluvial) and apparent age of the deposit, with Surficial Map Unit 7 being the youngest fluvial deposit and Surficial Map Unit 0 being the oldest fluvial deposit.

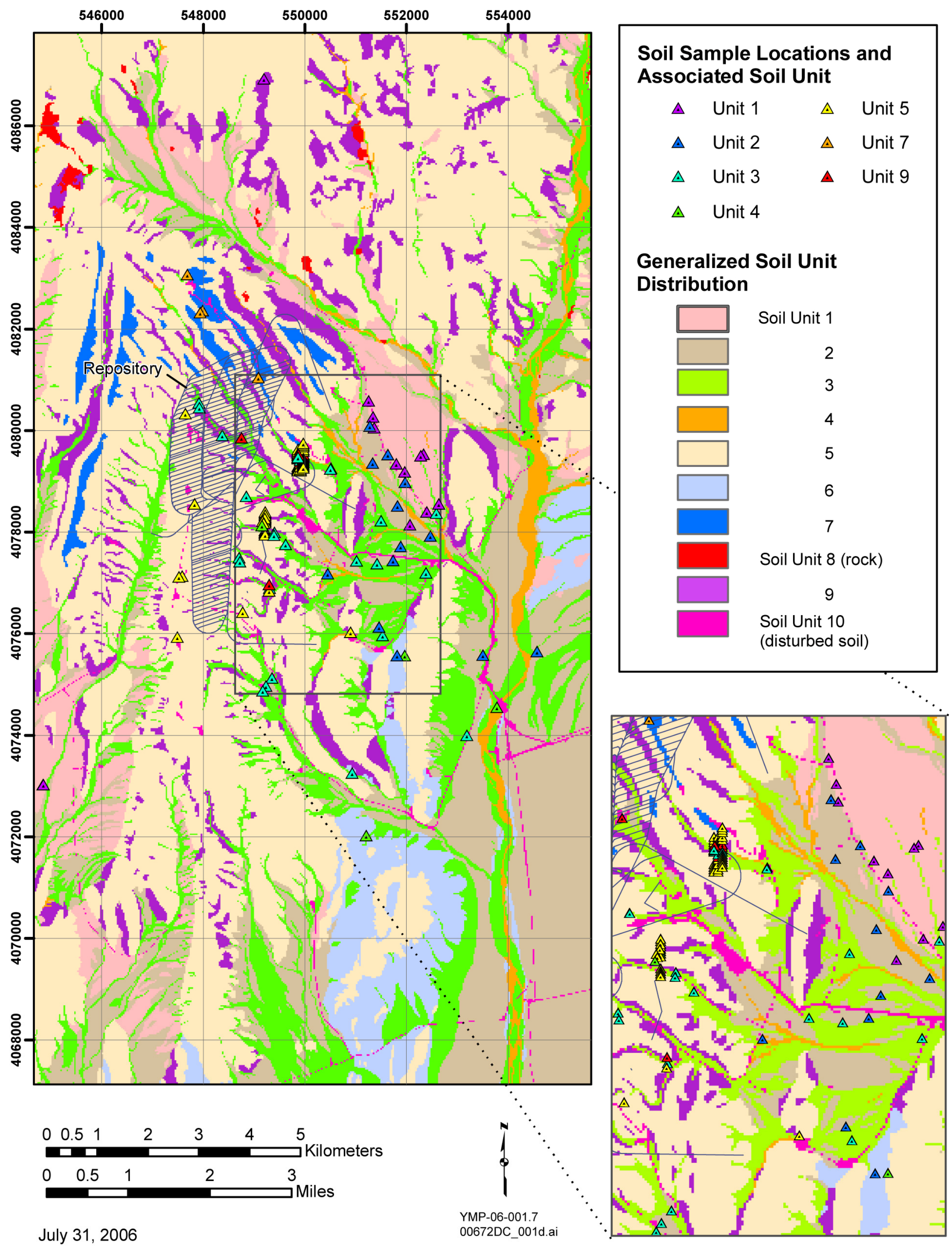
Table 6-3. Calculated Areas for Each Soil Unit

Soil Unit	Number of 30 × 30 m Cells	Calculated Area (%)
1	19,900	7.85
2	44,065	17.38
3	33,115	13.06
4	4,630	1.83
5	116,813	46.06
6	12,205	4.81
7	3,154	1.24
8	795	0.31
9	16,441	6.48
10	2,479	0.98

Source: DTN: MO0608SPASDFIM.006 [DIRS 178082].

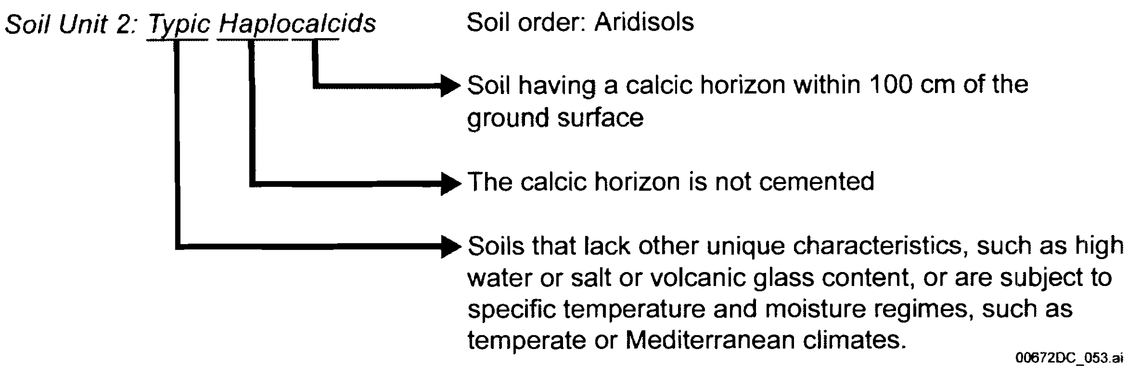
NOTES: Total number of cells and number of cells associated with each soil unit were extracted from DTN: MO0608SPASDFIM.006 [DIRS 178082] with ARCINFO [DIRS 157019].

Total number of cells in area of interest = 253,597.



NOTES: DTN: MO0608SPASDFIM.006 [DIRS 178082] was used for map distribution of soil units. ARCINFO and ArcGIS Desktop were used to process and display geospatial data associated with soil unit distributions from DTN: MO0608SPASDFIM.006 [DIRS 178082]. DTNs: GS000383351030.001 [DIRS 148444], GS031208312211.001 [DIRS 171543], and MO0512SPASURFM.002 [DIRS 175955] were used for locations of soil samples used in this analysis. (Enlarged inset shows most sampled area)

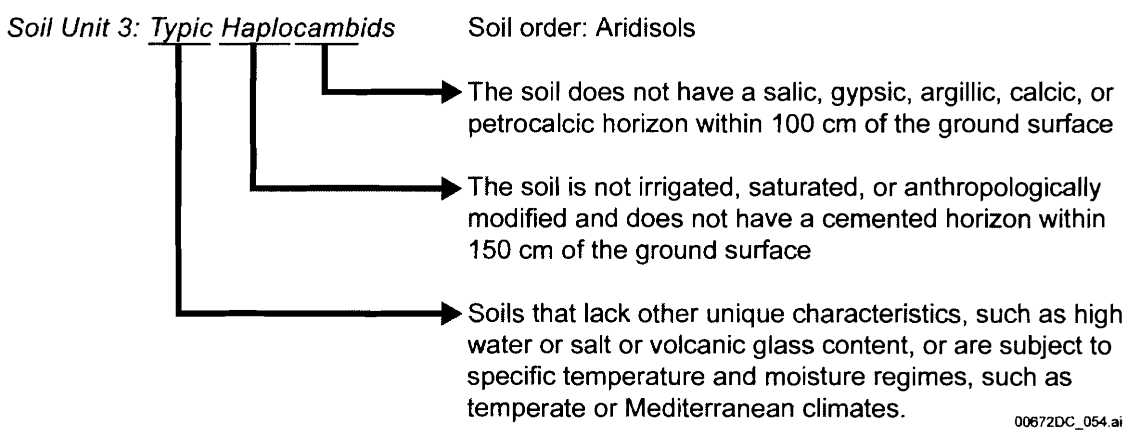
Figure 6-1. Distribution of Soil Units, Soil Sample Locations, and Soil Units Sampled



Sources: Keefer et al. 2004 [DIRS 173899], Chapter 2; Swan et al. 2001 [DIRS 158784], pp. 8 to 21.

Figure 6-3. Description of Soil Unit 2: Typic Haplocalcids

Soil Unit 2 consists of fluvial deposits of Surficial Map Units 3, 4, and 5, which exhibit some argillic (clay) accumulation, as well as noticeable carbonate accumulation (Table 6-4). Although the carbonate may be sufficient to almost encompass the horizon, it has not developed a cemented character. The desert pavement developed on the surface of these deposits is moderately-to-tightly packed. Eolian deposits, consisting of a sandy, silty material, have accumulated in the upper 0.5 m underneath the pavement and above the parent fluvial deposits. Soil Unit 2 comprises about 17% of the infiltration model area (Table 6-3) and includes Surficial Map Units 3, 4, and 5 (Table 6-2), and subunits thereof, which are considered to be of middle to late Pleistocene age (Keefer et al. 2004 [DIRS 173899], Table 2).



Sources: Keefer et al. 2004 [DIRS 173899], Chapter 2; Swan et al. 2001 [DIRS 158784], pp. 8 to 21.

Figure 6-4. Description of Soil Unit 3: Typic Haplocambids

Soil Unit 5 is the most extensive of the model units, covering 46% of the infiltration model area (Table 6-3), and is comprised of colluvial and debris flow deposits that mantle the hill slopes throughout the Yucca Mountain area (Table 6-4, Surficial Map Units cu and cs). This colluvial unit is typified by a thin mantle of angular rock rubble having lithologies of the underlying bedrock. The colluvium is generally less than 1 m in thickness. The clast-supported deposit lacks fine-grained material at the surface, but silt and sand of inferred eolian origin occur beneath the surface and increase with depth. The unit is poorly vegetated and occurs in various hill slope positions. Some deposits are estimated to be of early to mid-Pleistocene age, based on desert varnish development on rock clasts.

Soil Unit 6: Typic Torripsamments Soil order: Entisols

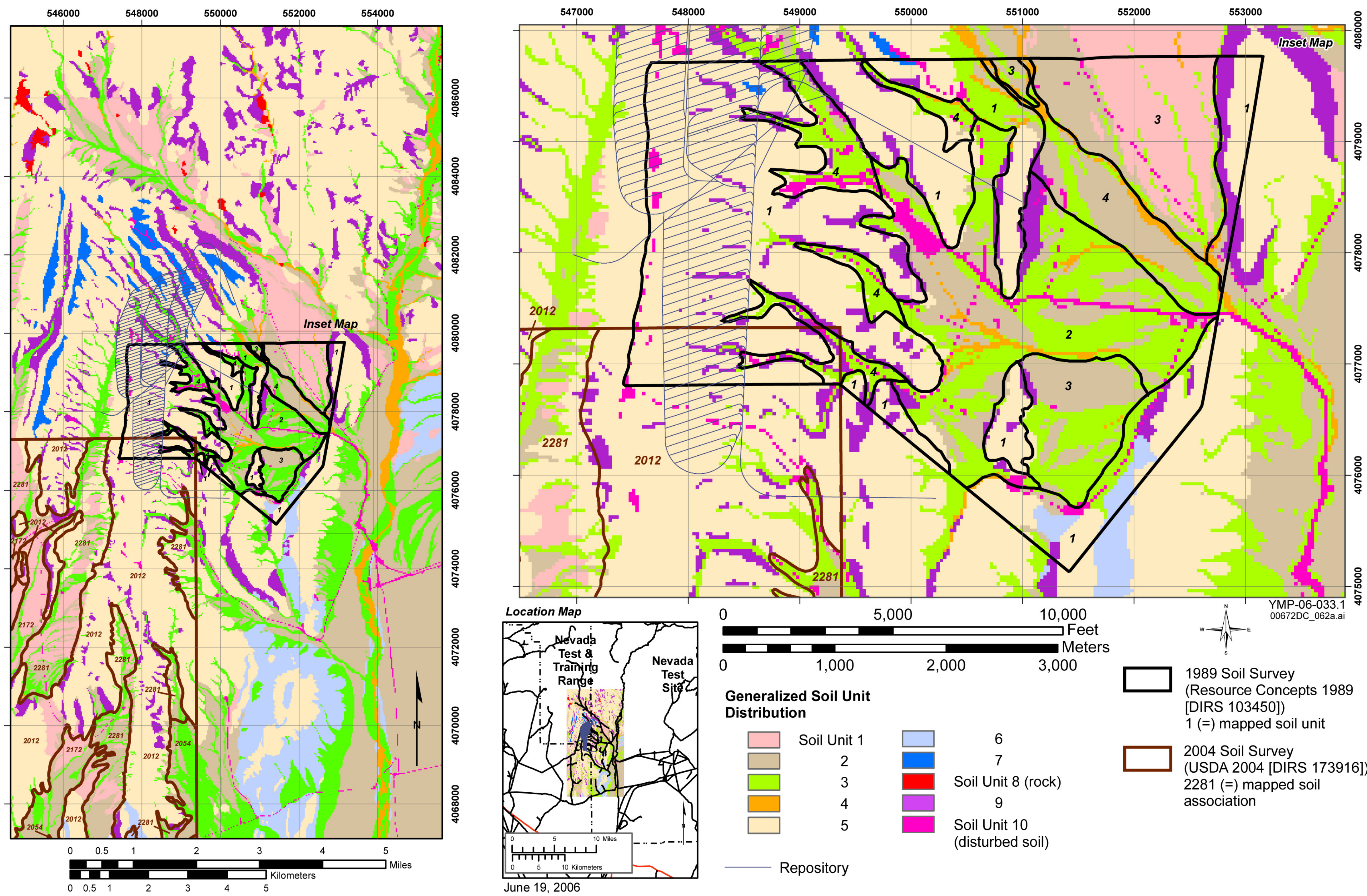
- psamments → The soil has less than 35%, by volume, rock fragments and a texture of loamy fine sand or coarser in all layers
- Torri → The soil is in an arid moisture regime
- Typic → Soils that lack other unique characteristics, such as high water or salt or volcanic glass content, or are subject to specific temperature and moisture regimes, such as temperate or Mediterranean climates.

00672DC_057.ai

Sources: Keefer et al. 2004 [DIRS 173899], Chapter 2; Swan et al. 2001 [DIRS 158784], pp. 8 to 21.

Figure 6-7. Description of Soil Unit 6: Typic Torripsamments

The mapped eolian deposits, e, eo, ey, 1/eo, 3/eo, 1/e, 3/e, and cf/e, are included in Soil Unit 6 (Table 6-2), which represents about 5% of the mapped area (Table 6-3). The most prominent units are the sand ramps that are preserved on the flanks of bedrock highs, such as Busted Butte. Some deposits are up to 22 m thick and exhibit multiple buried soil horizons, suggesting an episodic depositional history. The description of the sand ramps is from DTN: GS940108315142.004 [DIRS 160344], p. 11 of 13. The unit is primarily gravelly sand, with 5% to 50% gravel; soil development is evidenced by argillic and carbonate horizons. The angular gravel observed in exposures is interpreted to indicate substantial colluvial and possibly sheetwash processes during deposition.



Source: DTN: M0608SPASDFIM.006 [DIRS 178082].

NOTE: ARCINFO and ArcGIS Desktop were used to process and display geospatial data associated with soil unit distributions from DTN: M0608SPASDFIM.006 [DIRS 178082].

Figure 6-10. Generalized Soil Unit Distribution

Table 6-5. Comparison of Taxonomic Nomenclature for Soil Surveys

Source Designation	**Depth to Bedrock (cm)**	**Duripan within 100 cm**	**Argillic over Duripan**	**No Argillic or Salt Horizon over Duripan**	**Calcic Horizon**	**Argillic over Calcic Horizon**	**Argillic Horizon**	**Little Pedogenic Soil Development**	**Has Durinodes**
1989 Soil Survey[a]									
	<50		LDar	LDor			LH SU7	LT SU 5[c]	
	<100								
Soil Unit 1	<150					SU 9			
	<50								
	<100		Dar	TDor	SU 2[c]			SU 3[c]	
Soil Unit 2	<150					SU 9			
	<50		TDar	TDor					
	<100		SU 1[c]		SU 2			SU 3	
Soil Unit 3	<150								
	<50								
	<100				SU 2	THar		TT SU 3[c]	
Soil Unit 4	<150								
2004 Soil Survey[b]									
2012 Soil Association 309 = 3, 285 = G 336 = U	<50							LT SU 5[c]	
	<100	TH				SU 9			
	<150								
2054 Soil Association Y = 347 A = 259	<50								
	<100				SU 2[c]			TT SU 3[c]	
	<150								
2172 Soil Association S = 315 Y = 347	<50								
	<100		SU 1		SU 2[c]			TT	DT
	<150								
2281 Soil Association S = 322 Y = 347	<50								
	<100	TH	SU 1		SU 2[c]			TT SU 3	
	<150								

NOTES: DT = Duric Torriorthents; LDar, Lithic Durargids = Lithic Haplargids; LDor, Lithic Durothids = Lithic Haplodurids; LH, Lithic Haplargids; LT, Lithic Torriorthents; TDar, Typic Durargids = Typic Haplargids; TDor, Typic Durorthids = Typic Haplodurids; TH, Typic Haplodurids; THar, Typic Haplargids; TT, Typic Torriorthents.

SU 1 = Soil Unit 1, Typic Argidurids; SU 2 = Soil Unit 2, Typic Haplocalcids; SU 3 = Soil Unit 3, Typic Haplocambids; SU 4 = Soil Unit 4, Typic Torriorthents; SU 5 = Soil Unit 5, Lithic Haplocambids; SU 7 = Soil Unit 7, Lithic Haplargids; SU 9 = Soil Unit 9, Typic Calciargids.

[a] Resources Concepts 1989 [DIRS 103450], Table 1 and Figure 2.

[b] USDA 2004 [DIRS 173916], pp. v, vi, 259, 285, 315, 322, 336, 347, and 349.

[c] Primary soil units for geographic areas (Section 6.2.3.2) are from DTN: MO0608SPASDFIM.006 [DIRS 178082].

model area (Table 6-3). The closest occurrence of Soil Unit 6 is approximately 1.5 mi east of the lower extent of the projected repository footprint (Figure 6-1) and there are no occurrences of Soil Unit 6 over the projected repository footprint.

Soil Unit 8 is described as bedrock (Table 6-2), therefore, soil hydraulic parameters are not defined in Section 6.3. Soil Unit 10 consists of disturbed soils, which cover less than 1% of the infiltration model area (Table 6-3). There are no samples of disturbed soil, therefore, the hydraulic properties for Soil Unit 10 are assumed to be those of the adjacent soil.

The soil groups are further combined to assess the sensitivity on hydraulic property values on grouping. The first alternative grouping reduces the number of soil units to four, considering the characteristics of the soil units previously described and the number of Yucca Mountain samples in each of the base case soil units. The alternative grouping of four soil units is initially divided between fluvial and colluvial depositions.

Base case Soil Units 1 and 2 are fluvial deposits and each unit has a sufficient number of Yucca Mountain soil samples to be considered separately. Soil Unit 6 is the only soil classified as an eolian deposit (Table 6-4) and, as previously discussed, is similar to Soil Unit 2. Thus, Soil Unit 6 is grouped with Soil Unit 2 and is called Soil Unit 2-6. Soil Units 3 and 4 are also fluvial deposits and are combined into one group called Soil Unit 3-4 based on their apparent textural similarities. Soil Units 5, 7, and 9 are colluvial deposits and are combined into one group called Soil Unit 5-7-9, also based on their apparent textural similarities.

To further assess the sensitivity of hydraulic property values on grouping, a second alternative grouping, consisting of all Yucca Mountain soils in one group, is considered. This group consists of fluvial, colluvial, and eolian soil deposits.

In Section 6.3, soil hydraulic parameters and associated statistics are first developed and evaluated for the base case Soil Units 1 to 5, as well as 6 (assumed to have the same properties as Soil Unit 2), and 7 and 9. Statistics for two alternative soil groupings are then developed.

6.3 DEVELOPMENT OF SOIL HYDRAULIC PARAMETERS

The discussion of soil hydraulic parameters in Sections 6.3.1 through 6.3.3 applies equally to all soil groupings. The hydraulic parameter values developed as input to an infiltration model are:

- Saturated hydraulic conductivity, K_{sat}
- FC, which is defined as the moisture content at –0.33 bar and –0.10 bar
- PWP, which is defined as the moisture content at –60 bar
- Saturated moisture content, θ_s
- WHC, which is defined as difference between the FC and PWP (for alternate soil groups 1 and 2 only).

Statistics associated with these parameters are also developed to support stochastic analysis of infiltration. Statistics are developed for each soil group to assess the sensitivity of soil parameters to the grouping of soils (see Section 6.3.4). A pedotransfer function (PTF) approach is used to develop soil hydraulic parameters needed for infiltration modeling because site-specific soil texture data are available but

6.3.2 Matching Soil by Grain-Size Distribution

On the basis of soil texture, Yucca Mountain soil samples were matched to the analogous site sediment and soil samples. The Yucca Mountain soil sample texture information is provided as fraction of sand, silt, and clay in three input DTNs: GS000383351030.001 [DIRS 148444], GS031208312211.001 [DIRS 171543], and MO0512SPASURFM.002 [DIRS 175955]. These input DTNs also contain sample location, sample depth, and fraction of rock fragment content.

The analogous site database (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) contains percent sand, silt, and clay, which is the basis for matching samples. This database also contains percent rock and hydraulic parameters. In a few cases, exact texture matches have been identified. Generally, however, there is no exact match; for these cases, therefore, matches were selected based on those closely matching the percent of sand, silt, and clay and, secondarily, on those closely matching the sum of the silt and clay fractions.

The Euclidean distance (ED) is an indicator of how good the match is between any two samples, with the smaller ED values indicating better matches. An exact match has an ED of zero. The ED is applied to the sand, silt, and clay values by determining the difference between sand, silt, and clay fractions of any two soil samples. Because three parameters are considered, this application of ED represents the three-dimensional distance between the three parameters. The expression used to calculate ED between sand, silt, and clay for a pair of Yucca Mountain and analogous site samples is:

$$\mathrm{ED\ (3D)} = [(\mathrm{Sand}_{\mathrm{ymp}} - \mathrm{Sand}_{\mathrm{Hanford}})^2 + (\mathrm{Silt}_{\mathrm{ymp}} - \mathrm{Silt}_{\mathrm{Hanford}})^2 + (\mathrm{Clay}_{\mathrm{ymp}} - \mathrm{Clay}_{\mathrm{Hanford}})^2]^{1/2}$$

This expression of ED is appropriate for all of the soil units except Soil Unit 6. Soil Unit 6 was sampled once and divided into five fractions, upon which sand sieve analysis tests were performed. The results are reported as fraction sand and fraction silt plus clay. The average two-dimensional ED calculated for Soil Unit 6 is 0.024. The limited data, however, precludes calculating the three-dimensional ED or associated statistics for Soil Unit 6. Appendix A contains a tabulation of ED values for each sample match. Table 6-6 provides a summary of the match quality, as expressed by the ED, in terms of mean ED, standard deviation, minimum value, maximum value, and count of the number of matches.

The following example describes how hydraulic properties for Soil Unit 1 are developed. Yucca Mountain soil sample MWV11-3, from output DTN: MO0605SEPDEVSH.002, was matched to analogous site soil sample D13-08, because both samples had the same fraction of sand, silt, and clay. As a test for goodness of match, the ED is calculated for the matched soil samples; smaller ED values indicate better matches. The resulting ED for this match is zero as shown in output DTN: MO0605SEPDEVSH.002, worksheet 'MatchUncertainty'. Hydraulic parameter values, associated with the analogous database sample D13-08 (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B), are assigned to this Yucca Mountain sample and are tabulated in output DTN: MO0605SEPDEVSH.002, worksheet 'HanfordMatchSoil1'. The tabulation includes the gravel content of the analogous site sample, which, in this case, contained no measurable gravel. Section 6.3.3 explains in detail the calculation method used for rock-fragment correction.

The moisture content and K_{sat} data in the analogous site database (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) were developed from laboratory tests that had the > 2mm size fraction screened out of the sample. The moisture content and K_{sat} data in the database (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) were then corrected for gravel content. The moisture content and K_{sat} data (Khaleel and Freeman 1995 [DIRS 175734], Appendix A) must be adjusted back to values representative of zero rock content. They are then corrected for the specific Yucca Mountain soil rock fragment content.

Analogous site soil properties to be corrected include:

- Saturated hydraulic conductivity, K_{sat}
- Saturated moisture content, θ_s
- Field capacity, moisture content at −0.33 bar and −0.10 bar
- Wilting point, moisture content at −60 bar.

Corrections to K_{sat} were made in accordance with "Soil Containing Rock Fragments: Effects on Infiltration" (Brakensiek and Rawls 1994 [DIRS 175944], Equation 23). Corrections to moisture contents were made using the same procedure as that used in the properties report (Khaleel and Freeman 1995 [DIRS 175734], Equation 5).

The equation used to correct K_{sat} is (Brakensiek and Rawls 1994 [DIRS 175944], Equation 23):

$$\frac{K_b}{K_s} = 1 - m_g \qquad \text{(Eq. 6-1)}$$

where

K_b = Corrected saturated hydraulic conductivity

K_s = Saturated hydraulic conductivity of the fine fraction, 0% rock fragments

m_g = Weight fraction of the rock fragments.

The weight fraction of the rock fragments is from YMP data and is given in units of g/g (DTNs: GS031208312211.001 [DIRS 171543] and MO0512SPASURFM.002 [DIRS 175955]). Two other methods require the volume fraction of the rock fragments using the Peck and Watson equation (Brakensiek and Rawls 1994 [DIRS 175944], Equation 18), or the bulk void ratio and void ratio of the fine fraction using the Bouwer and Rice equation (Brakensiek and Rawls 1994 [DIRS 175944], Equation 19). An error analysis between the Bouwer and Rice equation and Equation 6-1 shows that the error between the two methods is not important for most practical applications (Brakensiek and Rawls 1994 [DIRS 175944], Figure 1). In this case, Equation 6-1 is applied using the weight fraction of the rock fragments, because of limitations of available data, allowing for the determination of bulk and fine void ratios.

The equation used to correct moisture contents (θ_r, θ_s, FC, and PWP) extracted from the analogous site database (Khaleel and Freeman 1995 [DIRS 175734], Equation 5) is:

$$\theta_b = \frac{w_f \dfrac{\rho_b}{\rho_w}}{1 + \dfrac{m_g}{m_f}} \qquad \text{(Eq. 6-2)}$$

where

θ_b = Corrected volumetric moisture content
w_f = Gravimetric moisture content
ρ_b = Bulk density of bulk soil; rock fragments and fines
ρ_w = Density of water
m_g = Weight fraction of the rock fragments
m_f = Weight fraction of fines.

Equation 6-2 was revised to directly use volumetric moisture content, θ, instead of the gravimetric moisture content, w_f, so that it could be used with available data. The revised equation is:

$$\theta_b = \frac{\theta_f}{1 + \dfrac{m_g}{m_f}} \qquad \text{(Eq. 6-3)}$$

where

θ_f = Uncorrected volumetric moisture content.

Although the majority of analogous site match samples have a rock fragment content of 0%, there are a few with rock fragment contents greater than 1%, a few as high as around 40%, but many ranging from 1% to 4%. A reverse rock fragment content correction was performed on the analogous site match samples to reset the hydraulic parameters to values representing samples with 0% rock fragment; 100% fines. After the reverse correction was performed on analogous site soil properties, the rock fragment correction was performed on the hydraulic parameters using the rock fragment contents from YMP data. Analogous site match samples with 0% rock fragment did not require this reverse rock fragment content correction.

Because the rock fragment content for Soil Unit 6 was not available in the textural analysis (DTN: GS000383351030.001 [DIRS 148444]), the rock fragment content was derived from a physical description (Section 6.2) of the material (DTN: GS940108315142.004 [DIRS 160344], p. 11 of 13). The rock fragment content is described as 5% to 50%. For the purpose of adding rock fragments to Soil Unit 6, the value of 27% rock fragments was chosen, which is the mid-point between 5% and 50% rounded down to the nearest whole number (Assumption 5.1).

Table 6-13. Percent of Total Samples for Each Soil Unit versus Percent Carbonate Measured in Sample, Compared with Field Observations of Pedogenic Carbonate Development (Continued)

% Measured $CaCO_3$ →		Stage I	Stage II		Stage III		Stage IV		
		0% to 2%	2% to 5%	5% to 10%	10% to 15%	15% to 25%	25% to 30%	30% to 50%	
Soil Unit	% Total Area								Field Estimate
									pavement
3	13.06	0.83	0.14	0.03	0.00	0.00	0.00	0.00	Stages I and II $CaCO_3$; pavement weakly developed or absent
4	1.83	0.89	0.04	0.04	0.04	0.00	0.00	0.00	No $CaCO_3$ or pavement development
5	46.06	0.84	0.06	0.10	0.00	0.00	0.00	0.00	Not described
6	4.81	–	–	–	–	–	–	–	Multiple buried $CaCO_3$ soils, poorly to moderately developed pavement
7	1.24	0.72	0.22	0.06	0.00	0.00	0.00	0.00	Not described $CaCO_3$ soils; poorly to well developed pavement
8	0.31	–	–	–	–	–	–	–	Not applicable
9	6.48	0.57	0.17	0.17	0.09	0.00	0.00	0.00	Not described
10	0.98	–	–	–	–	–	–	–	Not applicable

NOTES: Laboratory data are from DTNs: GS031208312211.001 [DIRS 171543], worksheet ‘ALL395’ and MO0512SPASURFM.002 [DIRS 175955], worksheets ‘ALL94’ and ‘ALL295’. Percent $CaCO_3$ per stage of pedogenic carbonate accumulation is from Machette (1985 [DIRS 104660], Section *Calcic soils of the southwestern United States*, Table 1). Field estimates of pedogenic carbonate stage and desert pavement development are from Table 6-4.

In overall consideration of the effect from pedogenic development on hydraulic parameters of soil units, for use in a replacement infiltration model, the pedogenic products of desert pavement, petrocalcic accumulations, and argillic horizons would slow the movement of infiltrating water through the soil. Therefore, the development of hydraulic properties, based on only particle size distributions, overestimates the rate of infiltration in soil units where these products are present.

6.4.2 Uncertainty Associated with Sampling Methods and Spatial Distribution of Samples

Methods used to collect and analyze samples from Yucca Mountain are outlined in USGS procedures that were in effect during the time that soil textural data were generated (DTNs: GS031208312211.001 [DIRS 171543] and MO0512SPASURFM.002 [DIRS 175955]). The procedures of interest for the purpose of this analysis are the same as those used in the sampling, which are NWM-USGS-GP-17, R1, *Describing and Sampling Soils in the Field*, and NWM-USGS-HP259 R0, R0-M1, R0-M2, *Determination of Bulk Density Using an Irregular Hole Bulk Density Sampler*, along with the procedures used in the determination of the percentages of sand, silt, clay, and rock fragments, which are NWM-USGS-HP-263 R0 and R0-M1, *Particle Size Analysis*.

Sample and analytical methods and procedures used to derive the analogous site database are described by Khaleel and Freeman (1995 [DIRS 175734], Section 2.0). The properties report (Khaleel and Freeman 1995 [DIRS 175734], Section 1) also provides a description of the sites sampled and the type of material found at each location. Samples were collected from boreholes sample hydraulic parameter values. The analogous site database (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) is complete with respect to grain-size distribution and gravel content, but does not include any of the other parameters useful for the development of PTFs, such as bulk density, porosity, organic content, or plasticity index. The soils and sediments identified in the analogous site database (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) were collected at Hanford, an arid region of eastern Washington. The soils at Hanford have developed under arid climatic conditions similar to those at Yucca Mountain. The average annual precipitation at Hanford is about 17.3 cm/yr (DOE 2001 [DIRS 177079], Section 3.2) compared to about 12.5 cm/yr for Yucca Mountain (BSC 2004 [DIRS 169734], Section 3.42). Hanford sediments have organic carbon content below 0.5 wt% (Truex et al. 2001 [DIRS 177078], Section 2.3.1.2). Organic carbon content in agricultural areas of Nye County range from about 0.006% to 0.70% (USDA 2006 [DIRS 176439]).

The soils at Hanford contain less organic material than soils developed under wetter conditions, which is also true of the soils at Yucca Mountain. The soil depositional processes at Yucca Mountain compared to those at Hanford include some differences that can contribute to differences in grain shape and soil structure. Large-scale fluvial processes dominate Hanford soil and sediments resulting in more-rounded particles and single-grain structure. Small-scale fluvial processes and eolian (Soil Unit 6) are the dominant processes at Yucca Mountain, resulting in less-rounded particles with more angular fragments (Section 6.2). Soils of fluvial origin associated with Soil Units 1 through 4 (stream and alluvial fan material) cover over 40% of the infiltration model area. There is an eolian component that has accumulated on these surfaces through time, which is concentrated in the upper 0.5 m of the soil profile (Table 6-4). Deposits representing eolian source material are mapped over only 4.8% of the area (Soil Unit 6).

The dominant surficial deposit (54% of the model area; Soil Units 5, 7, and 9) is colluvium. The colluvium consists of rock fragments of parent material that have been separated from the underlying intact bedrock through weathering processes. Colluvium, however, by definition, does not remain in situ, but moves or has moved, or both, downslope through gravitational processes. The fine-grained component of colluvial soils is interpreted to be due to the influx of eolian material. There are depositional mode differences between the YMP soils and Hanford soils and sediments; the differences in the associated hydraulic parameters, however, are not quantified because there are no site-specific hydraulic data for Yucca Mountain. Such differences contribute to an overall uncertainty, captured by the development of descriptive statistics for each hydraulic parameter, which include the parameter mean and standard deviations.

Overall, the literature review suggests that the matching approach, using the analogous site database (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B), would be less uncertain if additional data, such as bulk density, were available for Yucca Mountain and for Hanford.

6.4.5 Corroboration of Yucca Mountain Soil Parameters Derived from the Analogous Database with Two Alternate Pedotransfer Functions

An analysis was performed with the purpose of comparing the Yucca Mountain hydraulic soils properties generated with the Hanford data set against two other PTF methods (Appendix B). One of the PTF methods is outlined by Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) and later implemented by Carsel and Parrish (1988 [DIRS 147295]). The second method utilizes the ROSETTA program and database, a neural network-based model; a description of the algorithms and neural network methodology is provided by Schaap et al. (1998 [DIRS 177199] and 2001 [DIRS 176006]).

The purpose of this analysis is to provide a direct comparison between different PTF methods to show both a variation among hydraulic parameters generated by different PTF and that the method outlined in this analysis is reasonable when compared to other methods. The analysis was performed using the PTF methods to derive the hydraulic properties for each of the Yucca Mountain samples, similar to the method of matching the Yucca Mountain samples to the analogous site database and assigning a Yucca Mountain sample the same hydraulic properties as a matched Hanford sample (Section 6.3).

After deriving the hydraulic properties, using the two PTF methods, the hydraulic properties were organized into the same soil unit groups as was done with the analogous site data to include the soil units of Soil Unit 1, Soil Units 2 and 6, Soil Units 3 and 4, and Soil Units 5, 7, and 9. The descriptive statistics and standard errors were computed for these groups and compared to the descriptive statistics of the Hanford soil properties.

The method outlined by Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) is performed with a multiple regression model of the form:

$$\begin{aligned}\ln(K_{sat}), \theta_r, \ln(\alpha^{-1}), \ln(n-1) = [&c_0 + c_1S + c_2C + c_3\theta_s + c_{11}S^2 + c_{22}C^2 + c_{33}\theta_s^{\,2} + \\ &c_{12}SC + c_{13}S\theta_s + c_{23}C\theta_s + c_{112}S^2C + c_{223}C^2\theta_s + \\ &c_{113}S^2\theta_s + c_{122}SC^2 + c_{233}C\theta_s^{\,2} + c_{1133}S^2\theta_s^{\,2} + c_{2233}C^2\theta_s^{\,2}]\end{aligned}$$

where

S = percent sand ($5<S<70$)

C = percent clay ($5<C<60$)

θ_s = total saturated water content (cm^3/cm^3)

K_{sat} = saturated hydraulic conductivity (cm/hr)

θ_r = residual water content (cm^3/cm^3)

α = empirical van Genuchten et al. (1991 [DIRS 108810]) curve fitting constant (1/cm)

n = empirical van Genuchten et al. (1991 [DIRS 108810]) curve fitting constant (no units)

c = Coefficients

The coefficient, c, values (Table 6-14) were originally taken from Carsel and Parrish (1988 [DIRS 147295], Figure 1). Several errors were identified, however, associated with θ_r and ln(α-1) (Carsel and Parrish 1988 [DIRS 147295], Figure 1). Thus, the errors were replaced with correct coefficients from NUREG/CR-6565 (Meyer 1997 [DIRS 176004], p. 5). Soil parameters calculated using the Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) regression equation are limited to a percent sand range of 5% to 70%. Soil samples with sand ranges greater than 70% must be corrected using the method outlined by Cronican and Gribb (2004 [DIRS 177039]).

Following the derivation of soil properties (Rawls and Brakensiek 1985 [DIRS 177045]) and, as applicable, the correction by Cronican and Gribb (2004 [DIRS 177039]), soil properties were corrected for Yucca Mountain gravel content as was done with the analogous site data (Section 6.3.3). The mean, standard error, standard deviation, median, minimum, maximum, and number of values (count) were calculated (Appendix B and DTN: MO0608SPAPEDOT.000) for each of the hydraulic parameters (Table 6-15) for alternate soil group 2 (Section 6.3.4.3) and the soil units in alternate soil group 1 (Section 6.3.4.2).

The analysis using ROSETTA (Appendix B) was performed by entering Yucca Mountain soil textures and bulk densities, when available, into the software program through a text input file for each Yucca Mountain sample used in the base case analysis. Output from ROSETTA consisted of the saturated hydraulic conductivity (K_{sat}), van Genuchten parameters α and n, θ_r, and θ_s (van Genuchten et al. 1991 [DIRS 108810]). The gravel corrections were performed for K_{sat}, θ_r, and θ_s in the same manner as the analogous site data (Section 6.3.3). The mean, standard error, standard deviation, median, minimum, maximum, and number of values (count) were calculated (DTN: MO0608SPAPEDOT.000) for each of the hydraulic parameters (Table 6-16) for alternate soil group 2 (Section 6.3.4.3) and the soil units in alternate soil group 1 (Section 6.3.4.2).

The comparison analysis was performed for a group including all base case soil units, as well as the alternate groups, those being Soil Unit 1, Soil Units 2 and 6, Soil Units 3 and 4, and Soil Units 5, 7, and 9. Figures 6-12 to 6-19 show the comparison of the mean soil parameter values. The analysis files are available in DTN: MO0608SPAPEDOT.000.

Figures 6-12 and 6-13 show that FC moisture contents derived from the analogous site database method are larger than the other two methods. This increase in moisture content is also manifested in the WHC based on −0.10 and −0.33 bar (Figures 6-15 and 6-16) and θ_s. Moisture contents calculated with ROSETTA are generally lower than those calculated with the other two methods.

Soils from temperate and subtropical climates and agricultural soils generally have larger holding capacities compared to desert soils and it is likely that the PTFs of the Rawls and Brakensiek method (Rawls and Brakensiek 1985 [DIRS 177045]) and of ROSETTA are based on such soils. Thus, the greater WHC calculated using the analogous site database compared to WHC calculated with Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) and those of ROSETTA is unexpected.

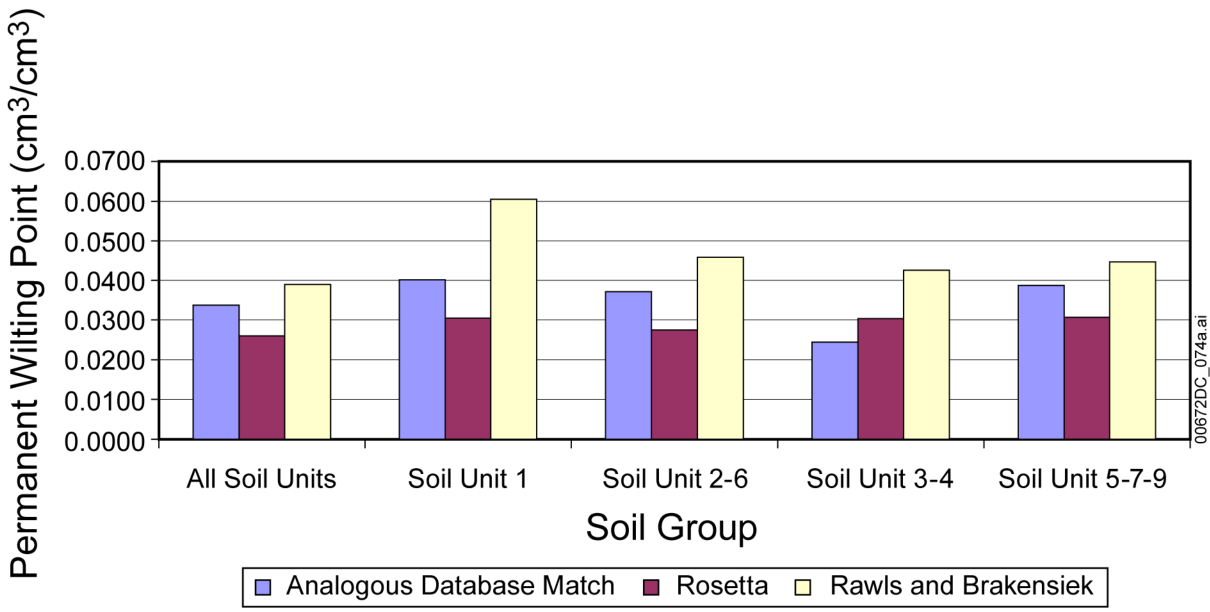
This result is consistent with a recharge study at the Glassboro Study Area, New Jersey, by the USGS in which it found that ROSETTA lead to unreasonably high recharge estimates, primarily due to the over-prediction of saturated hydraulic conductivity (USGS 2003 [DIRS 177192], p. 2). The study used data from six locations in southern New Jersey that appear to have steady-state flow conditions and five hydraulic property prediction and parameterization techniques were evaluated for recharge estimation. The unsaturated zone at the Glassboro Study Area, New Jersey, is mainly sand to sandy loam in texture. It is not clear why ROSETTA may be over-predicting $K_{sat;}$ the same study found that water retention was predicted relatively well by ROSETTA (USGS 2003 [DIRS 177192], p. 2). Figures 6-18 and 6-19 provide comparisons between the three methods based on arithmetic mean values and geometric mean values of K_{sat}, respectively. When comparing the results based on the arithmetic mean values, the large values dominate and the three methods appear to result in very similar K_{sat} values. Small K_{sat} values dominate with comparison of the geometric mean. This comparison reveals that the analogous site method and the Rawls and Brakensiek method (Rawls and Brakensiek 1985 [DIRS 177045]) have good agreement and, as previously noted, the ROSETTA results are consistently larger; the smaller the bar the larger the K_{sat} value.

Table 6-14. Rawls and Brakensiek Regression Constants

Term	Natural Log Saturated Hydraulic Conductivity (K_{sat}) Ln[cm/hr]	Residual Water Content (θr) [cm^3/cm^3]	Natural Log (1/α) Ln[cm]	Natural Log N −dimensionless
(Constant)	-8.96847E+00	-1.82482E-02	5.33967E+00	-7.84283E-01
S	0.00000E+00	8.72690E-04	0.00000E+00	1.77544E-02
C	-2.82120E-02	5.13488E-03	1.84504E-01	0.00000E+00
θs	1.95235E+01	2.93929E-02	-2.48395E+00	-1.06250E+00
S^2	1.81070E-04	0.00000E+00	0.00000E+00	-5.30000E-05
C^2	-9.41250E-03	-1.53950E-04	-2.13853E-03	-2.73493E-03
θ_s^2	-8.39522E+00	0.00000E+00	0.00000E+00	1.11135E+00
SC	0.00000E+00	0.00000E+00	0.00000E+00	0.00000E+00
$S\theta_s$	7.77180E-02	-1.08270E-03	-4.35649E-02	-3.08830E-02
$C\theta_s$	0.00000E+00	0.00000E+00	-6.17451E-01	0.00000E+00
S^2C	1.73000E-05	0.00000E+00	-1.28200E-05	-2.35000E-06
$C^2\theta_s$	2.73300E-02	3.07030E-04	8.95359E-03	7.98746E-03
$S^2\theta_s$	1.43400E-03	0.00000E+00	-7.24720E-04	0.00000E+00
SC^2	-3.50000E-06	0.00000E+00	5.40000E-06	0.00000E+00
$C\theta_s^2$	0.00000E+00	-2.35840E-03	5.00281E-01	-6.74491E-03
$S^2\theta_s^2$	-2.98000E-03	0.00000E+00	1.43598E-03	2.65870E-04
$C^2\theta_s^2$	-1.94920E-02	-1.82330E-04	-8.55375E-03	-6.10522E-03

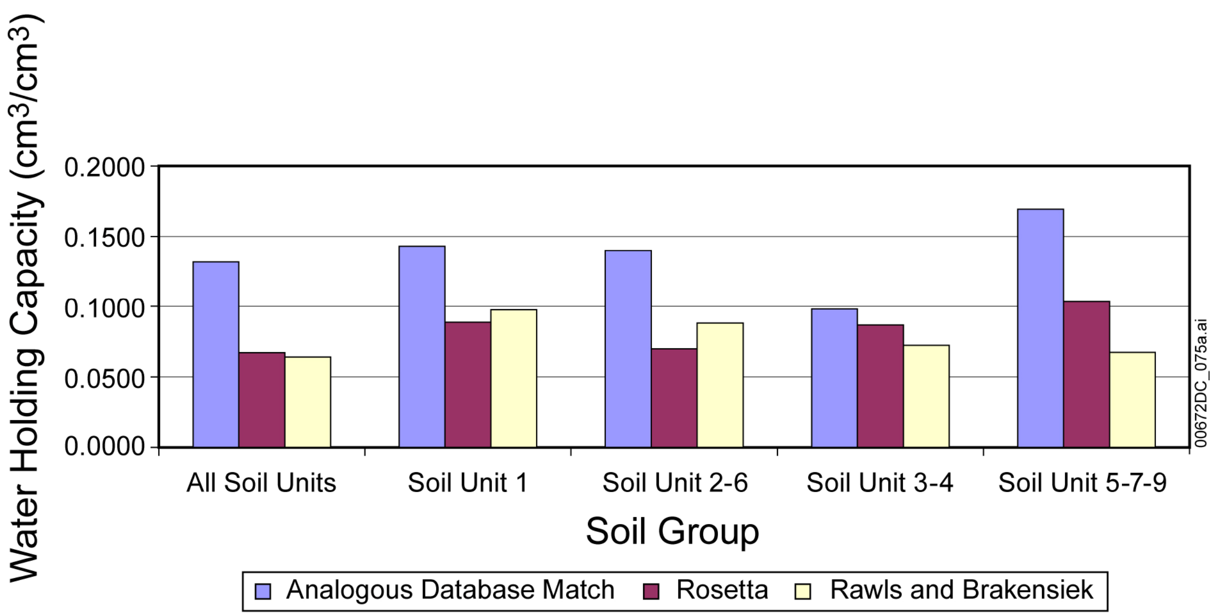
Source: Carsel and Parrish 1988 [DIRS 147295], Figure 1.

NOTE: 1) Corrected coefficients for θ_r and 1/α are from NUREG/CR-6565 (Meyer 1997[DIRS 176004], p. 5).
2) Values have been rounded to 6 significant digits.



Source: DTN: MO0608SPAPEDOT.000, *Summary_MethodCorroboration_ August31_2006.xls*, worksheet 'CompareMeans'.

Figure 6-14. Mean Permanent Wilting Point at –60 Bar (-61,200 cm) for Three Pedotransfer Function Methods Using Yucca Mountain Data



Source: DTN: MO0608SPAPEDOT.000, *Summary_MethodCorroboration_August31_2006.xls*, worksheet 'CompareMeans'.

Figure 6-15. Mean Water Holding Capacity at –0.10 Bar (–102 cm) Field Capacity for Three Pedotransfer Function Methods Using Yucca Mountain Data

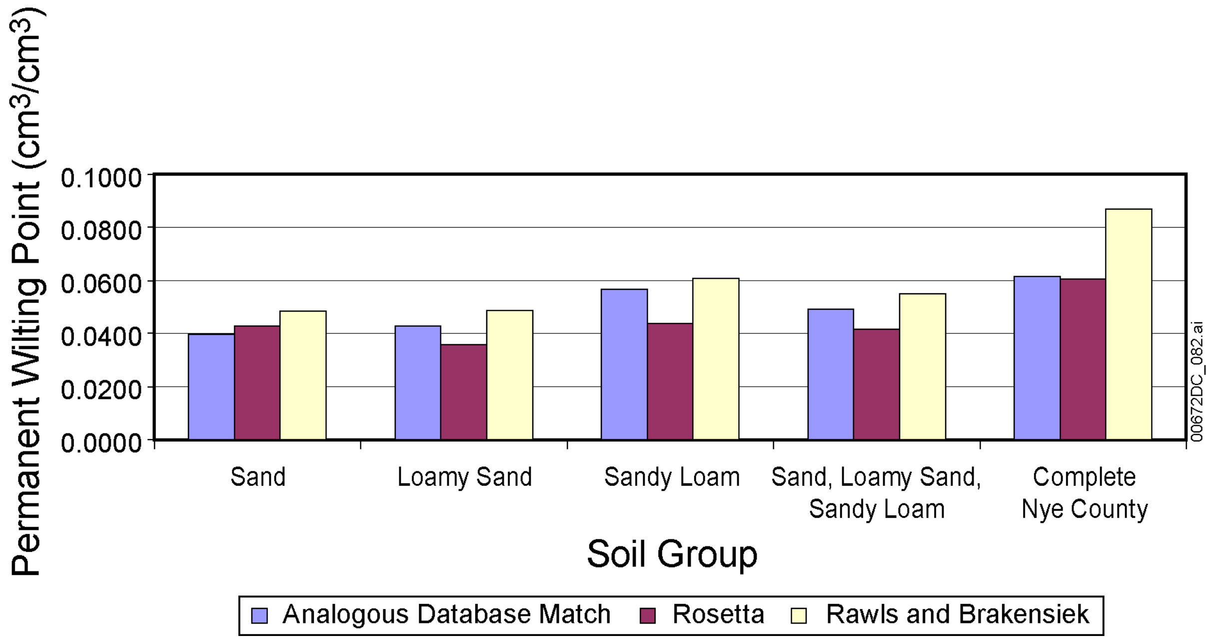
Table 6-17. Nye County Soils Selected for Comparison (Continued)

Nye County Layer (Sample) Identification	Soil Texture Class	Sand	Silt	Clay
92P03351	Sandy clay loam	69%	12%	20%
92P03352	Sandy loam	78%	8%	14%
92P03353	Loamy sand	84%	6%	10%

Sources: USDA 2006 [DIRS 176439]; USDA 1999 [DIRS 152585], Exhibit 618-8; DTN: MO0608SPANYECT.000, *NyeCountyInputData.txt*. (Note: Due to rounding errors, the sum of the sand, silt and clay percentages does not equal to 100 in some instances)

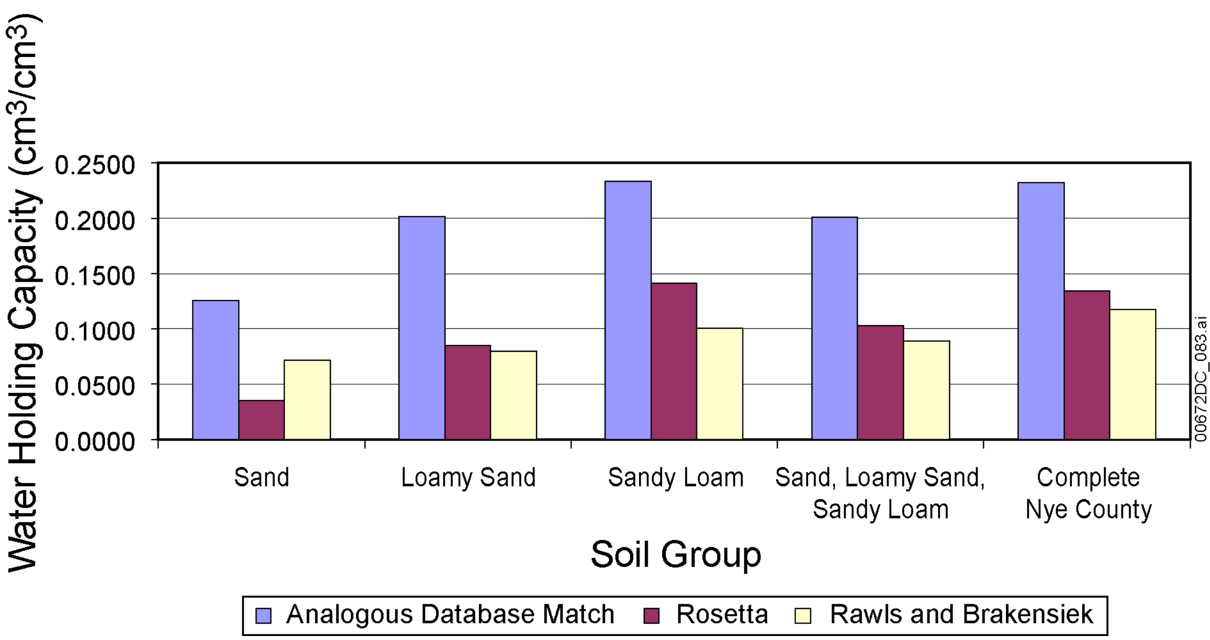
Table 6-18. Textural Match of Hanford Soil Samples to Nye County Soil Samples and Associated Hydraulic Parameter Values

Nye County Soil Sample ID	Hanford Site Soil Sample ID	Saturated Hydraulic Conductivity, K_{sat}, cm/sec	θ_r,	θ_s,	α	n
73C00274	3-0682	4.57E-05	0.05	0.43	0.013	2.086
73C00275	4-0973	1.27E-04	0.02	0.35	0.017	2.009
73C00276	5-0005	6.70E-05	0.04	0.39	0.007	2.243
73C00277	No Match	NA	NA	NA	NA	NA
73C00278	5A	5.73E-04	0.02	0.41	0.148	1.309
73C00279	241-AP-2	5.97E-04	0.10	0.52	0.031	3.087
73C00280	5A	5.73E-04	0.02	0.41	0.148	1.309
73C00284	4-0973	1.27E-04	0.02	0.35	0.017	2.009
73C00285	5-0005	6.70E-05	0.04	0.39	0.007	2.243
73C00286	No Match	NA	NA	NA	NA	NA
73C00287	4-1058	NA	0.10	0.57	0.003	1.527
73C00288	D09-01	1.20E-04	0.08	0.45	0.007	1.768
73C00289	No Match	NA	NA	NA	NA	NA
73C00290	241-AP-6	8.60E-05	0.07	0.40	0.005	1.948
73C00298	4-0973	1.27E-04	0.02	0.35	0.017	2.009
73C00299	D09-01	1.20E-04	0.08	0.45	0.007	1.768
73C00300	4-1058	NA	0.10	0.57	0.003	1.527
73C00301	D09-01	1.20E-04	0.08	0.45	0.007	1.768
73C00302	4-1058	NA	NA	NA	NA	NA
73C00306	4-1058	NA	NA	NA	NA	NA
73C00307	D09-01	1.20E-04	0.08	0.45	0.007	1.768
73C00308	No Match	NA	NA	NA	NA	NA
73C00309	5A	5.73E-04	0.02	0.41	0.148	1.309
73C00310	241-AP-6	8.60E-05	0.07	0.40	0.005	1.948
73C00311	5A	5.73E-04	0.02	0.41	0.148	1.309
73C00312	5A	5.73E-04	0.02	0.41	0.148	1.309
73C00313	241-AP-2	5.97E-04	0.10	0.52	0.031	3.087
73C00323	No Match	NA	NA	NA	NA	NA
73C00324	No Match	NA	NA	NA	NA	NA
73C00325	4-1058	NA	0.10	0.57	0.003	1.527
73C00326	4-1058	NA	0.10	0.57	0.003	1.527
73C00327	D09-01	1.20E-04	0.08	0.45	0.007	1.768
73C00328	No Match	1.20E-04	NA	NA	NA	NA



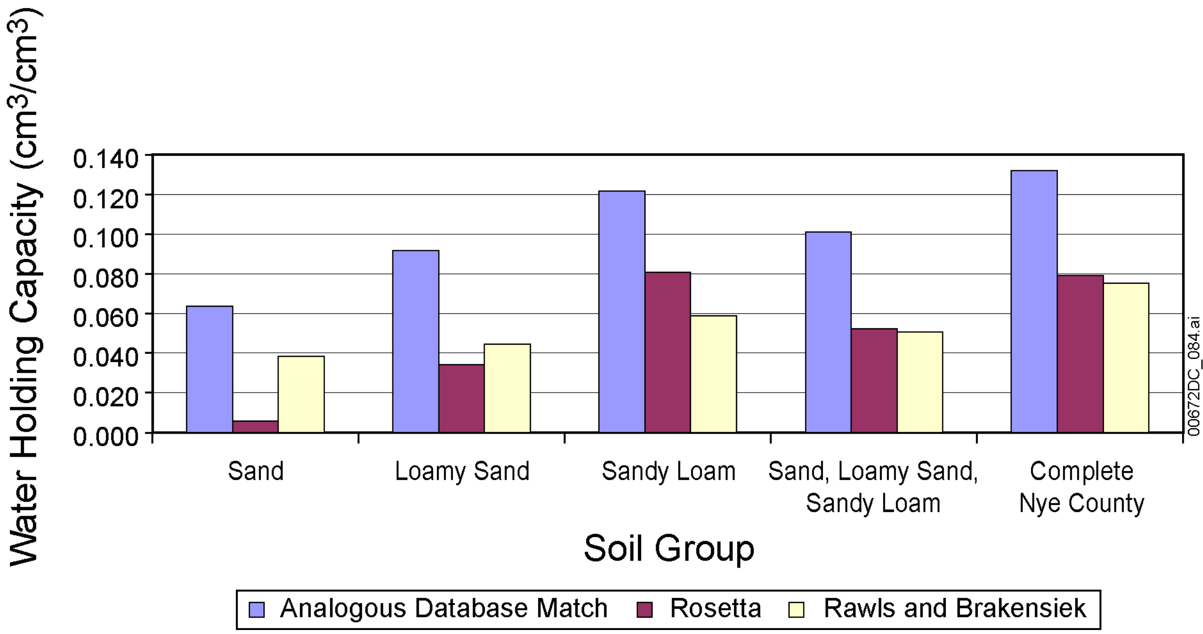
Source: DTN: MO0608SPANYECT.000, *NyeCounty_MethodCorroboration_ August1_2006.xls*, worksheet 'CompareMeans'.

Figure 6-22. Mean Permanent Wilting Point at −60 Bar (61,200 cm) for Three Pedotransfer Function Methods Using Nye County Data



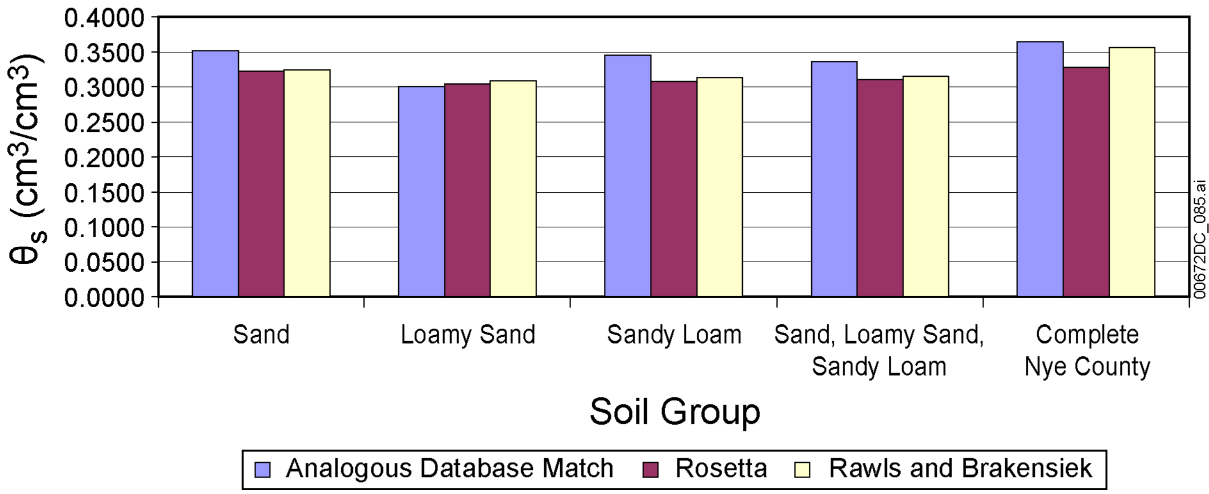
Source: DTN: MO0608SPANYECT.000, *NyeCounty_MethodCorroboration_ August1_2006.xls*, worksheet 'CompareMeans'.

Figure 6-23. Mean Water Holding Capacity at −0.10 Bar (−102 cm) Field Capacity for Three Pedotransfer Function Methods Using Nye County Data



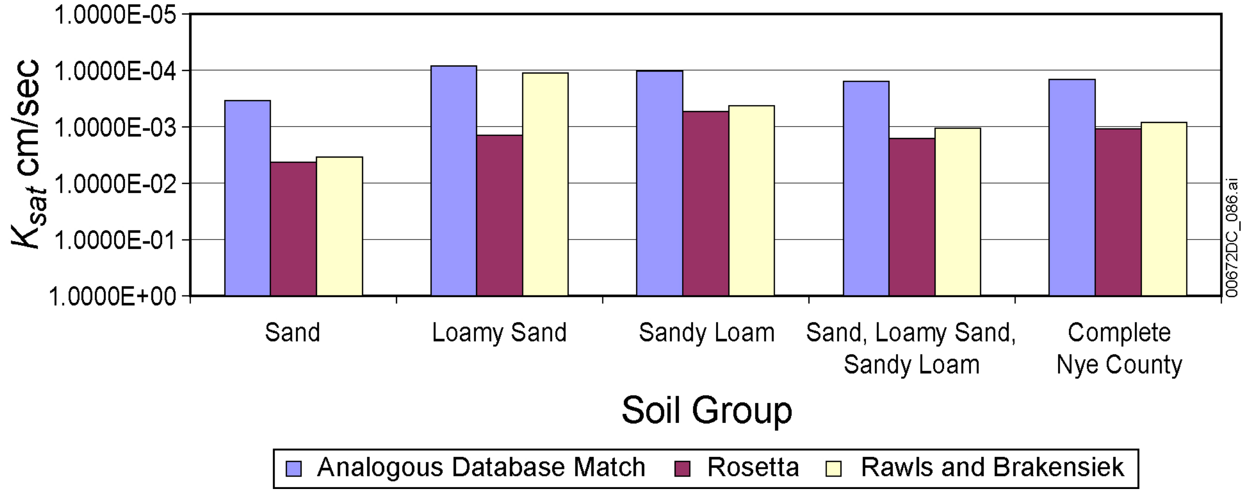
Source: DTN: MO0608SPANYECT.000, *NyeCounty_MethodCorroboration_ August1_2006.xls*, worksheet 'CompareMeans'.

Figure 6-24. Mean Water Holding Capacity at –0.33 Bar (–336.6 cm) Field Capacity for Three Pedotransfer Function Methods Using Nye County Data



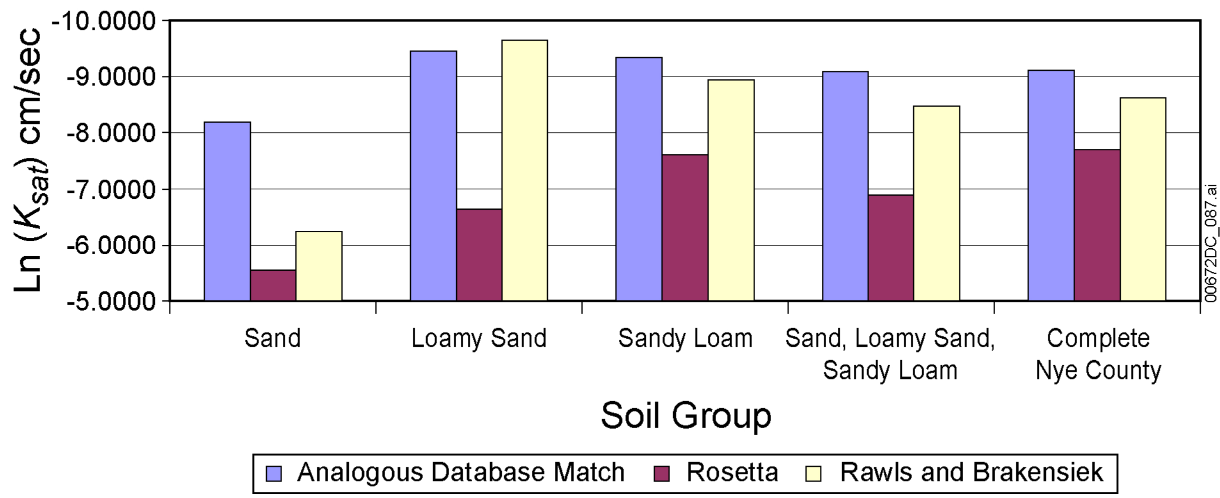
Source: DTN: MO0608SPANYECT.000, *NyeCounty_MethodCorroboration_ August1_2006.xls*, worksheet 'CompareMeans'.

Figure 6-25. Mean θ_S for Three Pedotransfer Function Methods Using Nye County Data



Source: DTN: MO0608SPANYECT.000, *NyeCounty_MethodCorroboration_ August1_2006.xls*, worksheet 'CompareMeans'.

Figure 6-26. Mean K_{sat} for Three Pedotransfer Function Methods Using Nye County Data



Source: DTN: MO0608SPANYECT.000, *NyeCounty_MethodCorroboration_ August1_2006.xls*, worksheet 'CompareMeans'.

Figure 6-27. Mean Ln (K_{sat}) for Three Pedotransfer Function Methods Using Nye County Data

Moisture retention curves plotted, using the Hanford values of θ_r, θ_s, α, and n (Table 6-18), with the van Genuchten equation with the Mualem model (m = 1 – 1/n) (van Genuchten 1980 [DIRS 100610]), are shown in Figures 6-28 to 6-30. The calculations are provided in DTN: MO0608SPANYECT.000. Nye County matric potential versus moisture content data (Table 6-18) are plotted on the curves corresponding to the appropriate Hanford match for comparison. The Nye County data used in the plots were organized by layers (samples) representing the USDA soil texture classifications sand, loamy sand, and sandy loam. Figures 6-28 to 6-30 show that the measured Nye County moisture contents are generally located on the "wetter" side of the plot compared to the corresponding Hanford data, especially for the Loamy Sand and the Sandy Loam.

These parameters were developed by matching textural data from Yucca Mountain soil samples collected at various locations within the model grid to textural data from the analogous site database (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B). Hydraulic parameters values associated with the sample matched to the analogous site database were then assigned to the Yucca Mountain sample. The next step was to develop the representative distribution of hydraulic parameter for each soil unit. For the base case soil grouping, a representative value for each parameter at each sample location is determined. For situations where only one soil sample was identified at a discrete coordinate, the corresponding set of hydraulic parameter values was assigned without any further adjustment and provided in output DTN: MO0605SPASOILS.005, worksheet 'SoilUnitXStatistics', where X represents a soil unit number. Where multiple YMP soil samples were identified at the same coordinate, the geometric mean of the K_{sat} values and the arithmetic mean of α, n, FC moisture content, PWP moisture content, θ_r, and θ_s were determined and provided in output DTN: MO0605SPASOILS.005, worksheet 'SoilUnitXStatistics'.

Thus, for the base case soil grouping, one set of representative hydraulic parameter values is developed for each discrete coordinate. The geometric mean of the K_{sat} values and the arithmetic mean of FC moisture content, PWP moisture content, and θ_s were determined for representative values at each sample location for each soil unit. For alternate soil groups 1 and 2, there was no attempt to develop representative samples at each sample location. The geometric mean of the K_{sat} values and the arithmetic mean of FC moisture content, PWP moisture content, WHC, and θ_s, were determined for each soil unit as a group. The geometric mean results in an intermediate K_{sat} value between the harmonic and arithmetic mean (Section 6.3.4) and provides the best representation for the infiltration model area given the potential for soil layering, small-scale and large-scale heterogeneities, occurrence of sloping surfaces, and soil textures that are encountered in the infiltration model area (Domenico and Schwartz 1990 [DIRS 100569], p. 67). The harmonic mean has application in layered systems where flow is vertical and could be appropriate for a lumped-parameter mass-balance bucket model, such as the infiltration model for Yucca Mountain (BSC 2006 [DIRS 177492]). The use of the harmonic mean, however, would result in lower average K_{sat} values which could underestimate infiltration, compared to those calculated using the recommended geometric mean.

A statistical analysis was performed on the resulting hydraulic properties. Descriptive statistics and estimated correlations for K_{sat}, FC moisture content, PWP moisture content, and θ_s are provided in Tables 6-7 and 6-9 for the base case soil grouping, respectively. Descriptive statistics were calculated using the standard Excel® DESCRIPTIVE STATISTICS function and are provided in output DTN: MO0605SPASOILS.005, worksheet 'SoilUnitXDescripStatistics', where X represents a soil unit number. For alternate soil groups 1 and 2, descriptive statistics for K_{sat}, FC, PWP, and WHC were developed and provided in output DTN: MO0605SEPALTRN.000 and summarized in Tables 6-11 and 6-12, respectively. Distribution type evaluation for alternate soil groups 1 and 2 is provided in Appendix D.

7.2 DATA TRACKING NUMBERS FOR DATA GENERATED IN THIS ANALYSIS

Table 7-1 summarizes the data generated in this analysis for use in a replacement infiltration model.

Table 7-1. Output Derived for Use in a Replacement Yucca Mountain Project Infiltration Model

Data Tracking Number	Title	Description	Location in Text
MO0605SEPALTRN.000	Alternative Soil Units, Hydraulic Parameters, and Associated Statistics for Infiltration Modeling at Yucca Mountain, NV	Provides the development of two alternative soil unit groupings, soil hydraulic parameters, and statistics	Tables 6-11 and 6-12
MO0605SEPDEVSH.002	Development of Soil Hydraulic Parameters for Infiltration Modeling at Yucca Mountain, NV	Provides the overall development used to derive the hydraulic parameters and the statistical evaluation for Yucca Mountain Soil Units 1 to 7, and 9. Development of soil hydraulic parameters was performed in Excel® worksheets and is organized Into eight separate workbooks - one for each soil unit. These data supersede data previously identified by DTN: MO0604SEPDEVSH.001.	Sections 6.3.4 and 6.3.4.1; Table 6-7
MO0605SEPFCSIM.000	Field Capacity of Soils at –1/10 Bar and Associated Statistics for Infiltration Modeling at Yucca Mountain, NV	Provides the development used to derive the field capacity at −1/10 bar and the statistical evaluation for Yucca Mountain Soil Units 1 to 5, along with 7 and 9. Development of the field capacity soil parameter was performed in Excel® worksheets and is organized into 21 separate workbooks - three for each of the seven soil units.	Table 6-7
MO0605SPASOILS.005	Soil Hydraulic Parameters and Associated Statistics for Infiltration Modeling at Yucca Mountain, NV	Provides soil units and associated hydraulic parameter values for the Yucca Mountain area infiltration model. This file supersedes data identified in DTN: MO0604SPASOILS.004.	Sections 6.3.4 and 6.3.4.1; Tables 6-7 to 6-9

7.3 UNCERTAINTIES AND LIMITATIONS

The following discussion summarizes uncertainties identified in Section 6.4 and an uncertainty associated with the definition of FC described in Section 5.3.

Pedogenic carbonates and clays reduce the hydraulic parameters of soil units and thus slow the movement of infiltrating water through the soil. Therefore, the development of hydraulic properties, based on only particle size distributions, would overestimate the rate of infiltration in soil units where pedogenic carbonates and clays are present. The sample collection methods and laboratory analysis procedures used for Yucca Mountain data and data in the analogous site database of Hanford soil hydraulic parameters were found to be well documented and reasonable for their intended use (Section 6.4). Because the Yucca Mountain sample locations are clustered in the center of the model area, rather than evenly or randomly distributed over the entire model area (Section 6.4.2), they are not necessarily representative of the values over the entire site. The data are, however, considered to be adequate for estimation of infiltration because 1) the bulk of the data are more-or-less over or immediately adjacent to the proposed repository, 2) water flow (percolation) within the unsaturated zone is predominantly vertical, with only a small lateral component.

The Nye County data (USDA 2006 [DIRS 176439]) were found to be useful in demonstrating reasonableness of the approach, but were not sufficient to use as an analogue for Yucca Mountain hydraulic parameters, because they lack required qualification and miss important hydraulic parameter or moisture-retention curve-related data (Section 6.4.3). The results of this analysis suggest that the matching approach using the analogous site database (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) would be less uncertain if additional data, such as bulk density, were available for Yucca Mountain and Hanford (Section 6.4.4). The matching approach (Section 6.4.5) was found to be reasonable, based on an evaluation of matching Nye County data (USDA 2006 [DIRS 176439]) to the analogous site database of Hanford soil hydraulic parameters (Khaleel and Freeman 1995 [DIRS 175734], Appendices A and B) and to two alternative PTFs.

Method corroboration was performed by (1) comparing the analogous site matching approach to two other PTFs (Rawls and Brakensiek 1985 [DIRS 177045]) and that of ROSETTA, (Schaap et al. 2001 [DIRS 176006], pp. 163 to 176) and (2) comparing the analogous site matching approach to Nye County data (Section 6.4.5 and 6.4.6). The FC moisture contents derived from the analogous site database method are slightly larger than the other two PTFs. This increase in moisture content is also manifested in the WHC based on –0.10 and –0.33 bar matric potential. The greater WHC calculated using the analogous site database compared to WHC calculated by Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) and by using ROSETTA is unexpected.

The development of the regression coefficients by Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) are likely, based on agricultural soils and soils from temperate to subtropical climates, including soils from the USDA UNSODA (unsaturated soil hydraulic properties) database, like the database used in ROSETTA. Soils from temperate and subtropical climates and agricultural soils generally have larger holding capacities compared to desert soils.

The K_{sat} values among the three methods agree well with one another. Uncertainty with respect to the moisture contents and holding capacities may be increased based on the results of the analysis, and uncertainty in K_{sat} may be reduced.

When the analogous site matching approach is compared to Nye County moisture data, a similar trend is observed. Nye County moisture data for FC at –0.10 bar matric potential show a good match to the analogous database-developed moisture data (Section 6.4.6). Likewise, moisture data developed by Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) and by using ROSETTA at –0.10 bar matric potential agree well with each other and are consistently lower than both the Nye County moisture data and the analogous database-developed moisture data. At –0.33 bar matric potential, the analogous database-developed moisture data more closely matches that developed by Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) and by using ROSETTA, while the Nye County moisture data are consistently higher than the other three PTFs (Section 6.4.6). The higher moisture contents observed in the Nye County data may be associated with the buildup of pedogenic carbonate in the soil, which can increase the WHC (Section 6.2.3.1). Neither the Nye County data nor the Yucca Mountain data are sufficient to quantify potential bias that could result from not considering the pedogenic carbonate. The suggested approach to sampling WHC (Section 6.3.4.2) for infiltration modeling

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IT-PRO-0011, *Software Management.*

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NWM-USGS-HP-263, R0. *Particle Size Analysis.* Denver, CO: U.S. Geological Survey. ACC: NNA.19930923.0031.

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175946 MO0509COV00029.000. Coverage Name: SURFDEPQS. Submittal date: 09/28/2005.

175955 MO0512SPASURFM.002. FY94 and FY95 Laboratory Measurements of Physical Properties of Surficial Materials at Yucca Mountain, Nevada (Part I). Submittal date: 12/08/2005.

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8.4 OUTPUT DATA, LISTED BY DATA TRACKING NUMBER

MO0605SEPALTRN.000. Alternative Soil Units, Hydraulic Parameters, And Associated Statistics For Infiltration Modeling At Yucca Mountain, NV. Submittal date: 5/31/06.

MO0605SEPDEVSH.002. Development of Soil Hydraulic Parameters for Infiltration Modeling at Yucca Mountain, NV. Submittal date: 5/2/06.

MO0605SEPFCSIM.000. Field Capacity of Soils at −1/10 Bar and Associated Statistics for Infiltration Modeling at Yucca Mountain, NV. Submittal date: 5/26/06.

MO0605SPASOILS.005. Soil Hydraulic Parameters And Associated Statistics For Infiltration Modeling At Yucca Mountain, NV. Submittal date: 5/2/2006.

MO0608SPANYECT.000. Corroboration of Method Using Alternative Pedotransfer Functions and Nye County Soils Data. Submittal Date: 8/31/2006.

MO0608SPAPEDOT.000. Corroboration of Method Using Alternative Pedotransfer Functions. Submittal date: 8/30/2006.

8.5 SOFTWARE CODES

176015 ArcGIS Desktop V.9.1. 2005. WINDOWS XP. STN: 11205-9.1-00.

157019 ARCINFO V.7.2.1. 2000. SGI, IRIX 6.5. STN: 10033-7.2.1-00.

171549 JMP 2002. *JMP, Version 5.* Multivolume set. Cary, North Carolina: SAS Institute. TIC: 256485.

BACKGROUND INFORMATION USED TO GENERATE DATA FOR YMP GROUP METHOD CORROBORATION

The method used to derive Yucca Mountain soil hydraulic properties is corroborated with two alternative pedotransfer functions (PTFs): Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) and ROSETTA (Schaap et al. 1998 [DIRS 177199] and 2001 [DIRS 176006]), a neural-network computer program developed at the United States USDA Salinity Laboratory. These calculations are documented in the non-Q DTN: MO0608SPAPEDOT.000 and the comparison between methods are discussed in Section 6.4.5.

DTN: MO0608SPAPEDOT.000 documents the calculations developed with the non-Q code ROSETTA (Schaap et al. 1998 [DIRS 177199]) that were prepared under the guidance of *Technical Work Plan For: Infiltration Model Assessment, Revision, and Analyses of Downstream Impacts* (BSC 2006 [DIRS 177492], Sections 1.1.6, 4.2, and 8.2) and under the requirements of *Augmented Quality Assurance Program* (DOE 2006 [DIRS 177173]). It also documents the calculations developed with the PTF from Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]). Table B-1 is reproduced from DTN: MO0608SPAPEDOT.000 and provides a summary of the data sources used in the analysis.

Table B-1. Summary of Inputs used in DTN: MO0608SPAPEDOT.000

Data Source:	Parameters:	File/Worksheet:
DTN: MO0605SEPALTRN.000 “Alternative Soil Units, Hydraulic Parameters, and Associated Statistics for Infiltration Modeling At Yucca Mountain, NV”	Permanent wilting point at −60 bar (cm^3/cm^3) Moisture content at −0.1 bar (cm^3/cm^3) Moisture content at −0.33 bar (cm^3/cm^3) Holding capacity at −0.1 bar (cm^3/cm^3) Holding capacity at −0.1 bar (cm^3/cm^3) Saturated hydraulic conductivity (cm/s) Saturated water content, theta S (cm^3/cm^3)	*AllSoilsFC1-10and1-3Bar_5-30-06.xls*/ ‘HydraulicPropandStatistics’
DTN: MO0512SPASURFM.002 “Fy94 and Fy95 Laboratory Measurements of Physical Properties of Surficial Materials at Yucca Mountain, Nevada (Part I)”	Soil texture (percent sand, silt, and clay) Rock fragment content Bead cone bulk density Total porosity	*YMPSoilProperties_PartI_ALL94andALL295.xls*/ ‘ALL94’/ ‘ALL295’
DTN: GS031208312211.001 “Fy95 Laboratory Measurements of Physical Properties of Surficial Material at Yucca Mountain, Part II”	Soil texture (percent sand, silt, and clay) Rock fragment content Bead cone bulk density Total porosity	*ALL395.xls*/’ALL395’

Source: DTN: MO0608SPAPEDOT.000.

In DTN: MO0608SPAPEDOT.000, calculations using the Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) regression equation are performed in the ‘AllSoilUnits Data’, ‘SoilUnit1 Data’, ‘SoilUnits2-6 Data’, ‘SoilUnits3-4 Data’ and ‘SoilUnits5-7-9 Data’, worksheets. The Rawls and Brakensiek regression coefficients are listed in the ‘COEF’ worksheet. The Cronican and Gribb (2004 [DIRS 177039]) regression equation is used for samples containing greater than 70% sand.

BACKGROUND INFORMATION USED TO GENERATE DATA FOR NYE COUNTY METHOD CORROBORATION

The method used to derive Yucca Mountain soil hydraulic properties is corroborated with Nye County soils data obtained from the United States Department of Agriculture (USDA) National Resource Conservation Service Soil Survey Laboratory Soil Characterization Database [DIRS 177088] and two alternative pedotransfer functions (PTFs): Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]) and ROSETTA (Schaap et al. 1998 [DIRS 177199] and 2001 [DIRS 176006]). The corroborative soil hydraulic parameter values were derived by matching soil textural data (i.e., percentages of silt, sand, and clay) and rock fragment content from the Nye County data to an analogous database that contains soil texture and hydraulic parameter values for soils similar to those at Yucca Mountain *Variability and Scaling of Hydraulic Properties for 200 Area Soils, Hanford Site* (Khaleel and Freeman 1995 [DIRS 175734], Appendix A and B).

The Nye County derived soil hydraulic properties were compared to soil hydraulic properties developed from two alternative pedotransfer functions (PTFs): one developed by Rawls and Brakensiek (Rawls and Brakensiek 1985) [DIRS 177045], and ROSETTA (Schaap et al. 2001 [DIRS 176006]), a neural-network computer program developed at the United States USDA Salinity Laboratory. Additionally, soil moisture retention data at −10 kPa (−0.10 bar) and −33 kPa (−0.33 bar) were available in the Nye County Data set, which were compared with the derived moisture contents at −0.10 and −0.33 bar.

DTN: MO0608SPANYECT.000 documents the calculations developed with the non-Q code ROSETTA (Schaap et al. 1998 [DIRS 177199]) that were prepared under the guidance of *Technical Work Plan For: Infiltration Model Assessment, Revision, and Analyses of Downstream Impacts* (BSC 2006 [DIRS 177492], Sections 1.1.6, 4.2, and 8.2) and under the requirements of *Augmented Quality Assurance Program* (DOE 2006 [DIRS 177173]). It also documents the calculations developed with the PTF from Rawls and Brakensiek (Rawls and Brakensiek 1985 [DIRS 177045]). Table C-1 is reproduced from DTN: MO0608SPANYECT.000 and provides a summary of the data sources used in the analysis.